BIOPHYSICAL DIVERSITY ON LANDSLIDES IN THE PEACE RIVER REGION OF BRITISH COLUMBIA

by

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ABSTRACT

The aim of this dissertation is to investigate and quantify biophysical diversity on landslides in the boreal forest of the Peace River Region of northern British Columbia (BC), sampling three landslides that occurred in the last 50 years. Landslides are increasing in the boreal forest, likely driven by climate changes such as increased precipitation and permafrost thaw, and as a derivative of large wildfires. An understanding of ecosystem recovery on landslides is important for conservation and management purposes. Several studies have been done in southern parts of the world to elucidate processes of landslide recovery. However, few studies have addressed landslide recovery in northern climates, and little is known about the biophysical diversity of landslides in this region. This research investigates whether landslides are more biophysically diverse than the surrounding relatively undisturbed terrain, and whether microsite variables or geomorphic diversity are predictors of plant community diversity. Using a series of field sampling campaigns and GIS (geographic information system) mapping exercises, I show that landslides are more biophysically diverse than the surrounding terrain in some respects, while the surrounding undisturbed terrain is more diverse in other aspects. The age and size of landslides also appear to influence diversity. Microsite diversity does not necessarily predict plant diversity. The research highlights the role of invasive plant species in slope stabilisation and plant community makeup. I also show that landslide ponds are disproportionately concentrated on rotational landslides, and that most ponds on landslides occur in the body and toe. I note post-slide modifications such as drainage of landslide ponds and lowering of landslide ridges, but many geomorphic features are expected to endure for decades to millennia. Overall, the research shows that vegetation recovery is complex and may take decades to fully manifest. This study contributes knowledge about plant community and site diversity on landslides by providing quantitative data and comparing those traits with those found

on surrounding terrain. These findings can be used as guidance when identifying conservation and management practices for ecological restoration of disturbed slopes.

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DEDICATION

I dedicate this PhD Dissertation to my Mom and Dad, who instilled in me a love of the natural world and the North, appreciation of simple things, a sense of humour regardless of life's situations, and perseverance in the face of adversity. God Bless.

~In loving memory of my father, Richard Kress, who left this world June 2, 2019~

Chapter 1. Introduction to landslide biophysical diversity research

1.1 Introduction

Throughout the world, landslides are known for their destructive impacts on ecosystems, infrastructure, and human life (Geertsema et al. 2009). However, relatively little has been studied regarding the contribution of landslides to ecosystem health and diversity over various scales. Following a disturbance such as a landslide, succession is initiated, and new plant communities begin to form. Many factors influence the pathways of succession, including dispersal processes, substrate availability, nutrient and moisture levels, and competition (Clements 1916; Gleason 1917; Gleason 1926; Connell and Slatyer 1977; Pickett and White 1985). Landslides are unusual disturbances in that primary succession and secondary succession occur simultaneously, due to the presence of biological legacies (Walker and Shiels 2013). Successional processes can also be reset if the landslide reactivates. Landslides are thus challenging to study.

This research aims to describe and compare biophysical diversity on landslides and in the surrounding relatively undisturbed terrain in the landslide-prone Peace River Region of northeastern British Columbia, Canada. The research is multidisciplinary, drawing on theories, applications, and literature of landslide ecology, geomorphology, plant ecology, remote sensing and spatial applications, ecosystem restoration and ecological engineering, and hydrology.

This chapter will present an introduction to the research by first discussing the background and context, followed by the research problem, the research aims, objectives and questions, and the significance of the research work. The chapter ends with an outline of the structure of the dissertation.

1.2 Background to the study

Globally, catastrophic landslides draw the attention of communities, governments, land managers, and researchers. Landslides can be large and destructive and often occur suddenly and rapidly (Cruden and Varnes 1996a). They can kill people and animals, destroy forests, and seriously damage buildings and transportation infrastructure. Landslides can also alter or obliterate habitat for fish and wildlife. The most common triggers of naturally occurring landslides are intense rainfall, rapid snowmelt, alterations in water level, volcanic eruptions, and earthquakes (Wieczorek 1996). Because of the impacts of landslides on nature and society, study of these events is ever-increasing.

Broadly, landslides can be divided into prehistoric and historic types. Prehistoric landslides are those that occurred in the period before recorded history and they can be thousands of years old. Study of prehistoric landslides can help explain how and why a landscape formed as it did and can help predict the nature and frequency of future landslides over space and time. Prehistoric landslide evolution is analysed using signatures or clues left behind in the landslide, such as organic material that can be radiocarbon dated. Historic landslides are those that have occurred in the time since history was written down. It is usually easier to determine the cause and triggers of these landslides, as they have not been subjected to significant weathering or reworking. Historic landslides can also help predict future events, although perhaps on shorter time scales.

The Peace River area features a unique combination of landforms due to various processes that created and changed the landscape over different scales of time. The valley and tributaries consist of thick layers of glaciolacustrine material from the former Glacial Lake Peace (Hickin et al. 2015). Over thousands of years, deep postglacial incision carved out the current valley, creating steep slopes along the major river systems. When present on steep slopes, the glaciolacustrine material is unstable. The area has a long history of natural disturbance caused by landslides, interspersed with periods of stability. Some of the landslides were one-time events, while others appear to have reactivated, burying previous slides to some extent. Some landslides are large, such as the Attachie landslide that blocked the Peace River in 1976. There is evidence of many other landslides that are quite small "slumps". Above the river valleys there are rolling hills and plateaus.

Landslide ecology

Landslide events are both erosional and depositional processes, removing existing natural features while at the same time creating new features on the landscape. These processes can result in a unique diversity of soil, vegetation, and microsite types across the landslide environment (Geertsema and Pojar 2007). Landslide ecology is a branch of landscape ecology that investigates how plant and animal communities respond and interact as a result of the changes caused by landslides. Some key components of study are nutrient cycling, soil development, plant adaptations, dispersal and colonisation, new mixes of native and non-native species, and successional trajectories. Studies address these relationships on multiple scales of space and time. Landslide ecology also involves the integration of these biological learnings into management practices for slope hydrology, soil erosion, and slope stability (Walker and Shiels 2013).

Geomorphology

Geomorphology is the study of the physical or morphological features or properties (landforms) of the Earth's outer crust in relation to geological features (Schaetzl and

Thompson 2015). Geomorphic or landform processes involve mechanical transport of organic and inorganic material (Swanson et al. 1988) and are strongly influenced by slope, pore water pressure, and soil cohesion. Landforms influence air and ground temperature, moisture availability, and nutrient availability at a site. They affect the flow of vegetative propagules, energy, organisms, and material through a landscape. Landforms also can affect the frequency and spatial distribution of other natural disturbances (e.g. fire) and control geomorphic processes that alter biotic features. Concepts of geomorphology are central to the present study, with its focus on geomorphic processes and recovery of landslides.

Plant ecology

Plant ecology is a subdiscipline of ecology that studies plant abundance and distribution, effects of environmental factors on plant abundance, and interactions among and between plants and other organisms (Keddy 2007). This discipline can be applied from the microsite to landscape scales, and from seasonal to millennial temporal scales. Plant ecology plays a central role in the present research, as the diversity of plant communities across the landslide is documented and compared to the surrounding area. The theories and principles of the discipline are incorporated as they relate to plant colonisation and abundance, successional trajectories, deterministic microsite features, and the influence of other organisms on plants.

Remote sensing and spatial applications

Remote sensing refers to any type of technology that captures an image from a distance. The most commonly used types of remote sensing are aerial photographs, satellite images, and more recently LiDAR (light detection and ranging). In this study a combination of LiDAR-constructed DEMs (digital elevation models), drone imagery, LANDSAT (land-use satellite) imagery, GIS (geographical information system) applications, and aerial photographs were used to identify, delineate, and analyse various components of biophysical diversity.

Ecosystem restoration and ecological engineering

Ecological or ecosystem restoration involves intentional activities by humans to start or accelerate recovery of an ecosystem to maintain or enhance ecosystem health. In many cases, the ecosystem has been damaged or destroyed by direct or indirect human activities. In other circumstances, the ecosystem has been degraded by a natural agent such as wildfire, flood, or landslide to the point where it is unable to recover to its historic successional trajectory. Restoration efforts attempt to regain this trajectory. The restored ecosystem will not necessarily recover its former state, developing instead along an altered trajectory (Burton 1991; SER Working Group 2004).

In many industries, native plants are being used to help restore ecosystems damaged by both human-caused and natural activities (Polster 1997; Stokes et al. 2009; Walker et al. 2009). The selected plants help stabilise soils and slopes, control water flow, and increase wildlife habitat, among many other services. This practice of applying engineering principles to natural earth materials is referred to as geological engineering. The present study draws heavily on the concepts, theories, and findings related to ecological restoration and geological engineering when providing conclusions and recommendations.

Hydrology

Hydrology studies the pathways, distribution and storage, and quality of water, and includes the hydrologic cycle (Schaetzl and Thompson 2015). Water is very important in landslide processes. It can both trigger a landslide and transport debris and sediments downslope and downstream. Soil strength properties are a function of soil water content (Meusburger and Alewell 2008), and landslide occurrence is closely linked to pore water pressure thresholds. Prolonged periods of rainfall often trigger landslides. The probability of slope failure is determined by the balance between precipitation and evapotranspiration by plants (Van Beek and Van Asch 2004), therefore vegetation plays a large role in this process. Mechanisms of landslide movement can significantly alter the hydrology of a slope, making it more unstable and changing soil development processes, which can also result in the formation of ponds and wetlands. Hydrological features such as gullies can limit the spatial extent of a slide (Geertsema et al. 2010). The present study incorporates hydrological principles and concepts when assessing landslide initiation and evolution. It similarly employs these theories to investigate persistence of water bodies formed by landslides.

1.3 The research problem

a) Current state of research

While the geological and geomorphological processes of landslides have been extensively studied throughout the world, much less research has focused on the ecological processes. In northern British Columbia, even the geological processes are not as well studied, and ecological processes have not been researched to any extent. This presents a challenge to landslide management, as it is important to understand the ecological processes of landslides to fully appreciate landslide evolution and recovery over multiple temporal and spatial scales.

Some work has been done on plant succession and ecosystem recovery on landslides (Francescato et al. 2001; Dale and Adams 2003), with several studies occurring in tropical climates (Shiels and Walker 2003; Shiels 2006; Shiels et al. 2006; Restrepo et al. 2009).

These studies have helped build knowledge on topics such as the role of organic materials and birds in landslide recovery. In recent years, landslide ecology research has focused on the application of knowledge about landslide recovery processes to restoration practices (Turner et al. 1998; Pickett et al. 2009; Walker and del Moral 2009; Walker et al. 2009). These findings have contributed greatly to the advancement of a more holistic approach to landslide management.

b) Literature gaps

Although there are increasingly more studies on landslide ecology and recovery, peer-reviewed literature quantifying biophysical diversity on landslides is lacking. Even less available is any research on landslide biophysical diversity in northern climates. In northern British Columbia (BC), there visually appears to be a wider diversity of plant communities and microtopography types on landslide surfaces as compared to the surrounding landscape (Geertsema and Pojar 2006). However, other than a coastal study (Smith 1986) there have not been efforts in the northern part of the province to quantify vegetative and environmental differences between landslides and surrounding terrain and analyse these differences to determine their significance. On a broader scale, studies incorporating this type of biophysical diversity analysis in other parts of the world do not appear to exist. The present study is the first known large-scale and comprehensive comparison of biophysical diversity on landslides and surrounding undisturbed terrain.

c) Problem

With changing climate, landslides in BC are projected to become more frequent and have greater magnitude, due to increased precipitation and degradation of permafrost (Geertsema

2006). It is expected there will be increased interest in prevention and mitigation of landslides, as well as restoration of ecosystems altered by a disturbance such as this. A lack of knowledge about succession, the plant assemblages that form, and the influence of biophysical factors may hinder the ability to manage landslides and carry out conservation measures. This research attempts to quantify these facets of landslide ecology to obtain a better understanding and provide lessons for restoration.

1.4 Research aims, objectives, and questions

This research aims to quantify, describe, and analyse components of biophysical diversity on landslides in the Peace River Region of northeastern British Columbia. The research further aims to compare this vegetation and site diversity with surrounding, relatively undisturbed terrain where possible, and provide some recommendations for restoration and land management on landslides.

Research objectives

There are five main objectives of the study:

(1) To quantify and analyse biophysical diversity on landslides and compare diversity with that found on the surrounding undisturbed terrain.

(2) To quantify, analyse and compare the distribution of site-level ecological classification on landslides and on the surrounding undisturbed terrain.

(3) To quantify, analyse and compare spatial turnover (beta diversity) of plant species and microsites on landslides and on the surrounding undisturbed terrain.

(4) To use the findings on biophysical diversity to assess whether geomorphic diversity is a predictor of vegetation diversity.

(5) To quantify and analyse the presence and distribution of landslide ponds on an area of the Peace River Region.

Research questions

There are five key research questions to be answered in this study:

(1) Are landslides demonstrably more biophysically diverse than undisturbed ecosystems?

(2) To what extent do landslides rearrange the relative abundance of site-level ecological classifications on a slope compared to adjacent undisturbed terrain?

(3) What is the extent of turnover of microsite and plant species diversity on landslides, and how does this compare to adjacent undisturbed terrain?

(4) Is vegetation diversity on landslides significantly related to geomorphological diversity?

(5) What is the distribution and abundance of landslide ponds at regional and local scales, and what are the ecological and management implications?

A large portion of the research centres around three landslides in the Peace River Region, presented in Figures 1-1 (Beatton River), 1-2 (Cecil Lake), and 1-3 (Hasler Flats). These landslides are described in detail in Chapter 2.

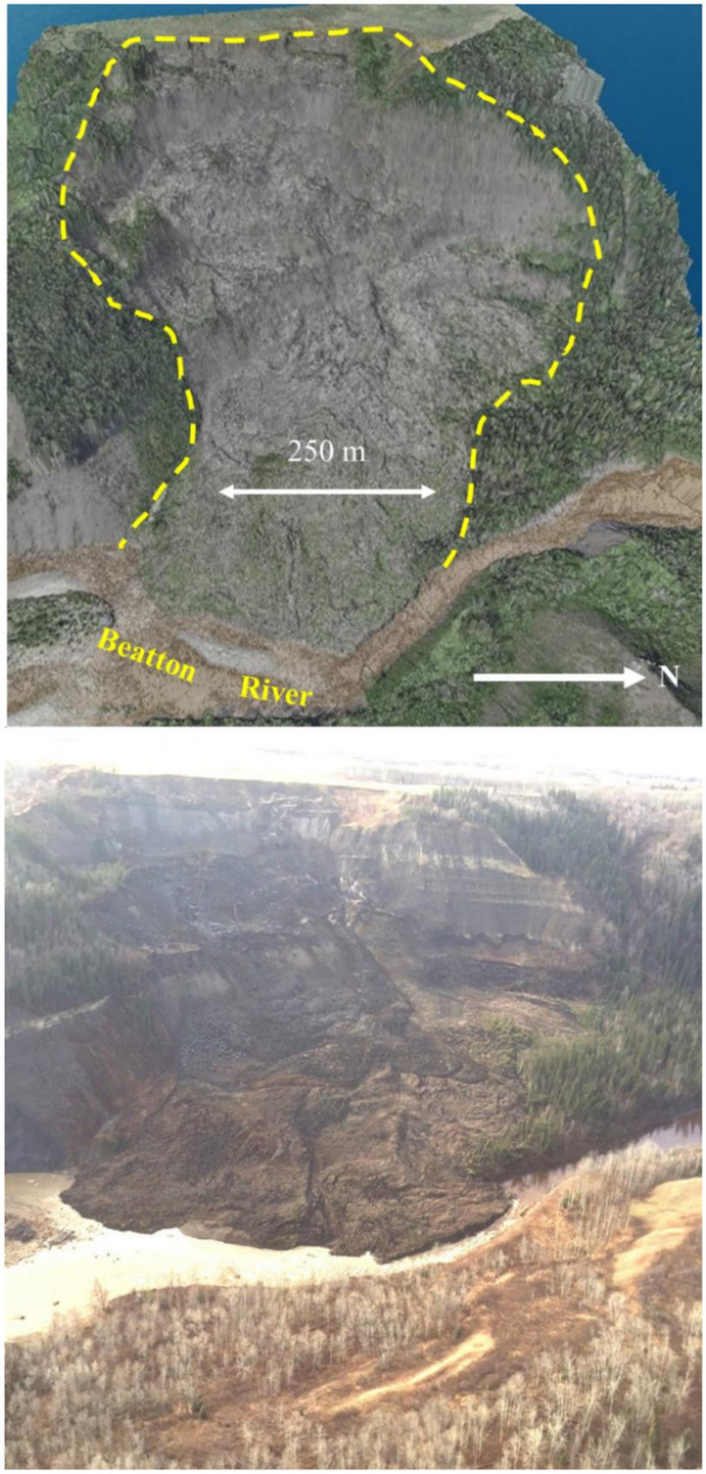

Figure 1-1. Beatton River landslide. Top image is an oblique 3D presentation of an ortho mosaic draped over drone imagery (flown in 2016), at vertical exaggeration 1X. Bottom image is an aerial view of the landslide, illustrating temporary partial blockage of the Beatton River. (Aerial photo was taken October 20, 2015, by M. Geertsema. Used with permission.)

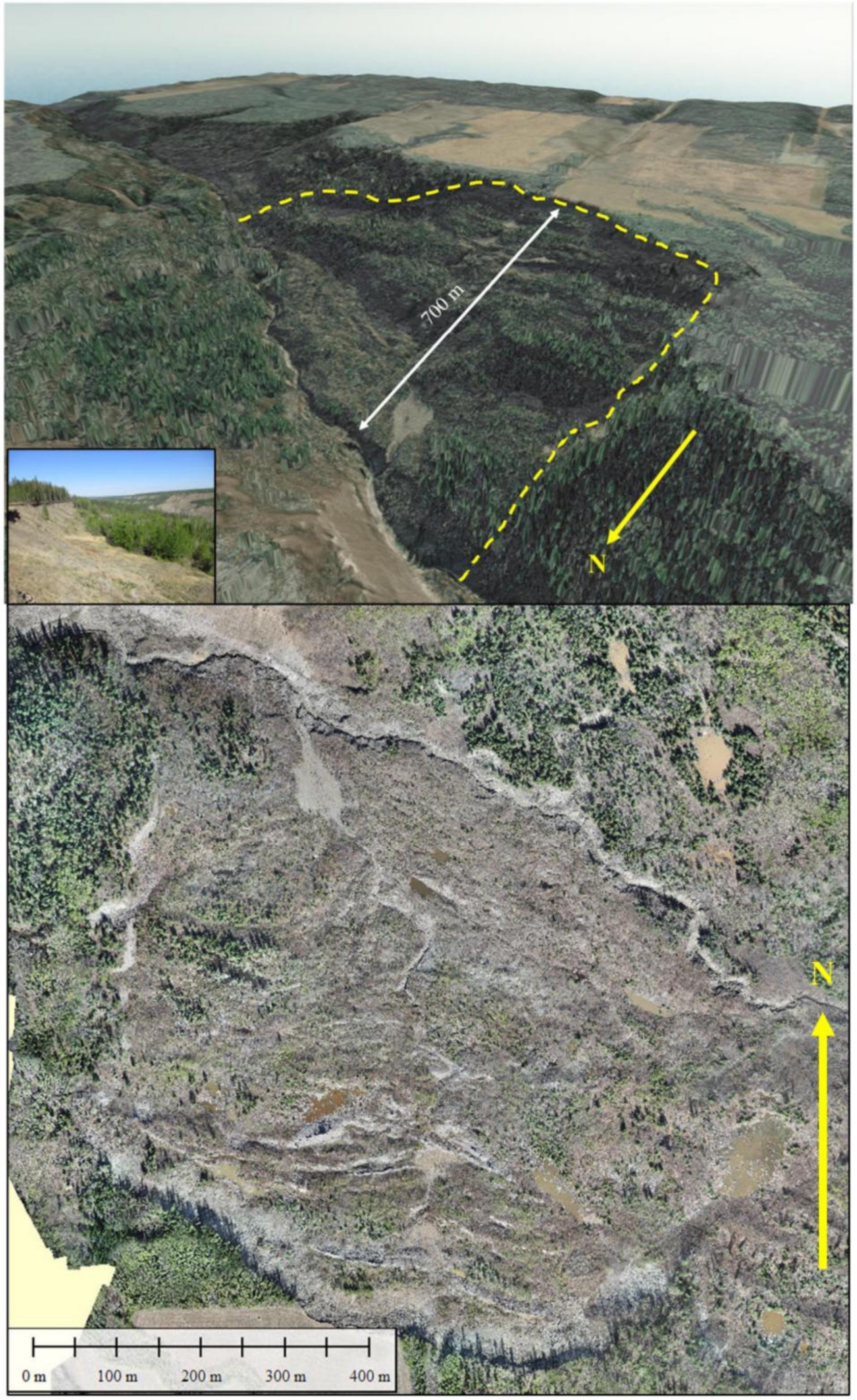

Figure 1-2. Cecil Lake landslide. Top image is an oblique 3D presentation of World Imagery layer draped over LiDAR imagery, vertical exaggeration 1X. Inset in top image is a photograph of the headscarp and part of the landslide, facing west. Inset photo was taken May 12, 2016. Bottom image is an ortho mosaic presentation of the landslide, showing variable topography and ponds.

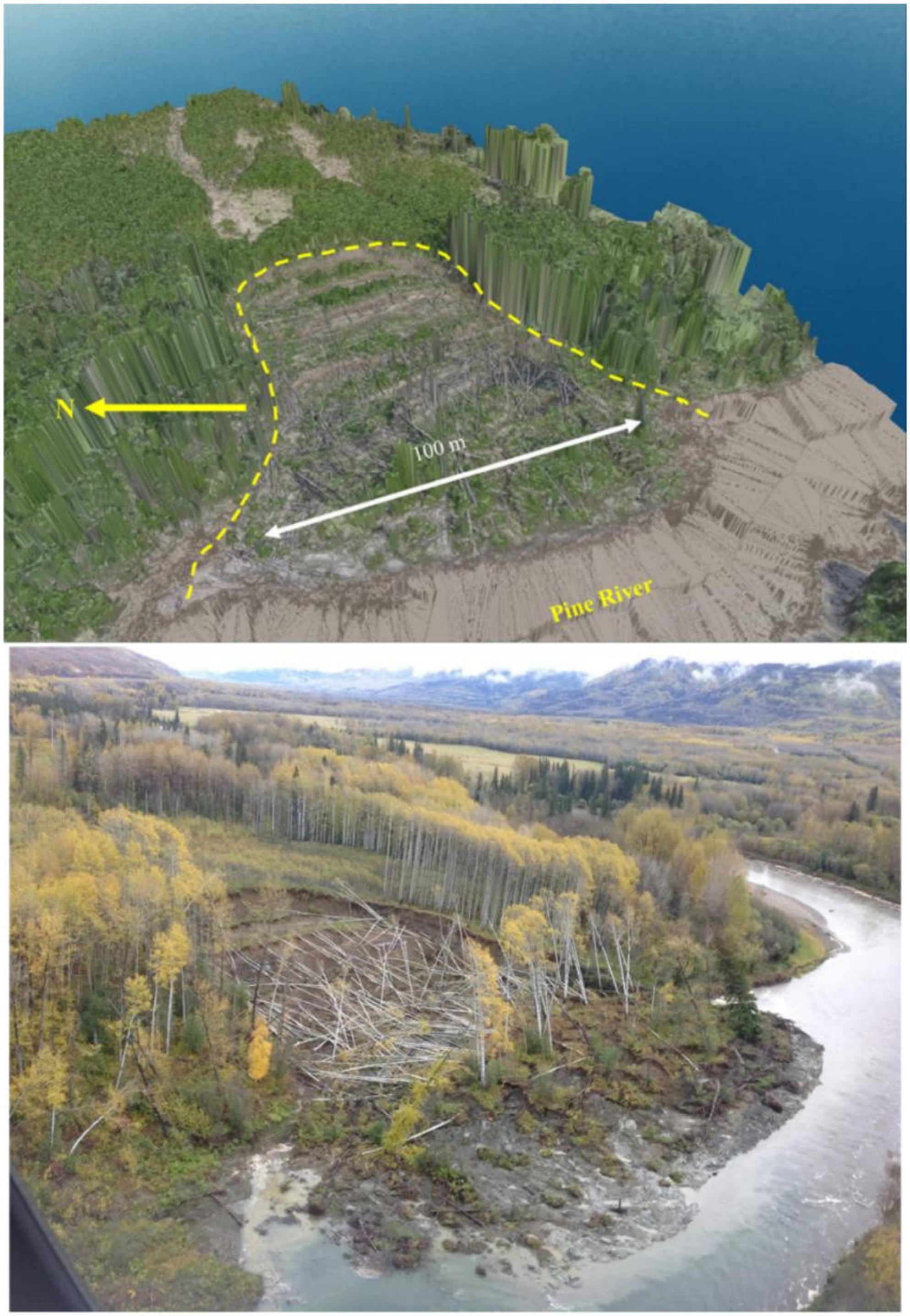

Figure 1-3. Hasler Flats landslide. Top image is an ortho mosaic draped over drone imagery, vertical exaggeration 1X. Bottom image is an aerial view of the landslide, facing south. (Aerial photo on bottom was taken September 30, 2013, by M. Geertsema. Used with permission.)

1.5 Significance

At a time when researchers are more frequently collaborating across disciplines or incorporating other disciplines into their research, the current study is truly a multidisciplinary endeavour. Overall, this research will contribute to the body of knowledge on disturbance ecology and restoration by describing and quantifying biophysical diversity of landslides in northeastern BC and providing recommendations for land management. Key contributions include measurement of alpha diversity and site-level ecological classification on landslides and comparison with nearby undisturbed areas, and quantification of geomorphological diversity on landslides with comparison to undisturbed terrain. An additional advance in knowledge is the quantification and analysis of spatial turnover (beta diversity) on landslides, which indicates the degree of differentiation among biological communities. Further contributions include quantification and description of surface water on landslides at a landscape level. All these learnings can enhance understanding of succession, recovery, and restoration of landslides and similar disturbances. The research findings may be especially useful in northeastern BC, where a new hydroelectric dam is under construction on the banks of the landslide-prone Peace River.

1.6 Structural outline of the dissertation

In Chapter 1, the context of the research has been introduced and framed within the wider realms of scientific endeavours. The research questions and objectives have been outlined, and an argument for the value of this research has been presented. Finally, a structural outline of the dissertation has been provided.

In Chapter 2, a detailed background on alpha diversity will be presented and methods will be laid out regarding data collection and diversity analysis for vegetation BEC (biogeoclimatic ecosystem classification) plots, relevés, site-level ecological classification mapping, geomorphic type mapping, microtopography variation, and the multivariate ordination of vegetation data. A detailed description of results from several lines of analysis will be presented. The results will be discussed in the context of existing research literature. Conclusions and recommendations on the findings will be provided, followed by a list of references.

In Chapter 3, background on beta diversity (i.e. turnover) will be provided, followed by a detailed presentation of the methods used for data collection and analysis for assessment of beta diversity on a series of field transects. Results will be presented, which will then be discussed in detail in the context of previous research and implications for management. Conclusions and recommendations on the findings will be provided, followed by a list of references.

In Chapter 4, background on landslide ponds will be presented and then detailed methods will be laid out regarding data collection and analysis of landslide ponds over the area covered by geographical mapsheet 94A (Charlie Lake). The results will be presented, followed by a discussion of key findings. Conclusions and recommendations will finish the chapter, closing out with references cited.

In Chapter 5, a summary of key findings and insights will be provided, followed by implications and recommendations for future applications.

Finally, appendices will provide additional information to supplement the various chapters.

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Chapter 2. Biophysical alpha diversity of landslides and comparison with surrounding undisturbed terrain

2.1 Introduction and Background

Landslides display a wide variety of sites, soils, and vegetation patterns compared to the surrounding undisturbed landscape (Geertsema et al. 2006) and they stand out visually from the adjacent terrain in terms of vegetation types and coverage, surface soils, and relief. Extremes in surface roughness, nutrients, and moisture are evident over very short distances on landslides.

Landslides are both erosional and depositional (Cruden and Varnes 1996). The erosional process can remove deep layers of soil that have developed over centuries, effectively setting the clock back for pedogenesis (Geertsema and Pojar 2007). Landslides mainly change soil properties by exposing parent material, creating a variety of stages of pedogenic development (Geertsema et al. 2009). Where once a Brunisol existed, there now may be an Orthic Regosol. As material moves downslope, it becomes jumbled and turbated, resulting in unique soil layers and buried organic material (Phillips and Lorz 2008). The depositional process may transport large amounts of organic material from the slopes above, depositing it in one place near the toe of the slide. These organic components contribute an influx of nutrients in the depositional toe zone (Walker and Shiels 2013), and result in a loss of nutrients from the erosional scarp zone. Tree uprooting on the landslide can affect soil morphology, distribution of rock fragments, and evolution of regolith, at the same time both creating and enhancing layering and vertical contrasts (Phillips and Lorz 2008). Ultimately, erosion and deposition cause increases in extremes of nutrient regimes, facilitating a variety of plant community development trajectories.

The processes of erosion and deposition may also create many distinct geomorphic formations on the landslide. At the headscarp, erosion can result in steep, dry cliffs. Material moving at a high speed can gain momentum and form ridges and pillars on the landslide body as it comes to a stop (Geertsema et al. 2006). Subsequent erosion may create deep gullies, and additional material can be deposited in flows. Weathering transforms ridges and pillars over time, reducing surface roughness. In a rotational slide, the backward tilting at times creates a depression where a sag pond can form (Takaoka 2015). Spreads produce horsts and grabens (raised and lowered blocks, respectively) as the material pulls apart between faults, and water may accumulate in the grabens. Small ponds may also form anywhere there is a depression in the landslide surface. Overall, the topography formed by landsliding can result in extremes of moisture. Very dry sites often abut very wet sites, and very rich sites often lie close to very poor sites.

In regions where much of the terrain is inherently unstable, landslide processes and the resulting variety of geomorphic landforms and site characteristics can create a very disturbed landscape in terms of vegetation processes, soil processes, hydrology, and habitat. Habitat diversity is strongly related to patterns of disturbance and recovery (Sousa 1984; Geertsema et al. 2009; Walker and Shiels 2013). If both site and soil change, the soil changes may persist much longer and have more profound ecological effects, such as the formation of wetlands or the infilling of valleys.

Observations across northern British Columbia (BC), Canada, indicate landslides in this part of the province are much more biophysically diverse than nearby undisturbed terrain (Geertsema and Pojar 2007). However, biophysical diversity on landslides in northeastern BC has not been measured or quantified in any substantial way. This chapter investigates whether landslides are demonstrably more biologically and physically diverse than adjacent undisturbed ecosystems. Four key questions were asked: 1) How does plant species abundance and distribution differ on landslides compared to adjacent undisturbed terrain? 2) To what extent do landslides rearrange the relative abundance of site-level ecological classifications on a slope compared to adjacent undisturbed terrain? 3) Is landslide geomorphology significantly more diverse than adjacent terrain, and 4) Is vegetation diversity on landslides significantly related to geomorphological diversity?

This chapter assesses alpha diversity of vegetation and environmental sites (i.e. biophysical diversity) within landslides in the study area and compares it with the surrounding undisturbed terrain where possible. The chapter also investigates the possibility of correlations between vegetation diversity and geomorphic diversity. Biophysical diversity in this study refers to the variety of vegetation and physical sites; for vegetation this variety can include both compositional and structural elements (Pitkanen 2000). It is hypothesised that there is higher vegetation diversity, site-level ecological classification diversity, and geomorphic diversity on landslides compared to the surrounding relatively undisturbed terrain, and that geomorphic diversity positively influences vegetation diversity.

Because of the complexities and many theoretical layers involved in the study of diversity, it is necessary to first examine the concept of biophysical diversity and its measurement to lay the groundwork for this research chapter.

Alpha diversity

In general, diversity in nature can be described in a series of scales forming a hierarchy. The three basic levels of diversity are alpha diversity, beta diversity, and gamma diversity

(Whittaker 1960). These three levels are related, and often, quantification of one level is required before calculation of another. Alpha diversity refers to within-site diversity, while gamma diversity is described at a regional level (resultant of alpha and beta diversities) and beta diversity is generally understood as change in diversity between sites. Alpha diversity addresses diversity at the stand or plot level and represents the range of species that may interact with each other (Noss 1990; Magurran 2004).

Biological diversity or biodiversity represents the variability among organisms from all sources and is essentially a comparative science (Magurran 2004). At different scales and contexts, the biodiversity of plants describes the range of alleles or genotypes in a population, the diversity of species or growth forms in a community, or the diversity of vegetation types across a landscape (Noss 1990; Burton et al. 1992). Diversity can be partitioned into two components: element richness and evenness (Simpson 1949). Species richness refers to the number of species in a unit of study (McIntosh 1967). Evenness is the variability in species abundances: the more equal the proportion of abundances between species, the higher the evenness, and the more diverse the community (Magurran 2004). Additionally, abundance is a surrogate measure of niche size, and statistical models assume that abundance is in some way related to a species' ecological importance (Magurran 2004). Alpha diversity describes richness and evenness of species of a particular stand or community or group of organisms. These concepts and measurements of diversity can be applied to various physical elements of ecosystems as well, including vegetation structure and substrates.

Measurement of diversity

The measurement of species diversity is based on three assumptions: 1) all species are equal, 2) all individuals are equal, and 3) species abundance has been recorded using appropriate and comparable units (Peet 1974). Diversity statistics are classified as either species richness measures (McIntosh 1967), or heterogeneity measures which combine richness and evenness components (Good 1953). Evenness measures assess the departure of the observed species abundance pattern from the expected pattern in a hypothetical assemblage (Lloyd and Ghelardi 1964).

Measurement of species richness

In its simplest form, species richness is the total number of species in a sampling area. Species richness can be estimated from samples through species-area curves, parametric methods, and nonparametric estimators (Magurran 2004). Species-area curves are a well-known measure and plot the cumulative number of species recorded as a function of sampling effort (Colwell and Coddington 1994). These curves can be extrapolated to give an estimate of total richness of the assemblage, and they illustrate the rate at which new species are found. Species richness can also be estimated using jack-knife statistics or bootstrapping, resampling methods that only require incidence data.

Differences in species richness between samples can be assessed in various ways. Richness estimates can be compared by using richness estimators such as Chao1 (non-parametric estimator that takes into account rare species) or ACE (i.e. abundance-based coverage estimator) to deduce overall minimum estimates (Chao 1984). A more accurate method of assessment of differences is rarefaction, which uses the information provided by all species collected to estimate the richness of a smaller sample. The two samples can then be compared directly. However, rarefaction is computationally taxing. It also assumes that individuals are randomly dispersed, which means that richness in clumped communities will be overestimated. Rarefaction curves converge at small sample sizes, so sampling size must be sufficient to characterise the community (Gotelli and Colwell 2001). Rarefaction did not appear suitable for the purposes of the present study due to the prevalence of clumped communities and relatively small sample size; therefore, it was not used.

Measurement of species abundance/evenness

Many different species abundance models have been devised to describe the relationship between the number of species and the number of individuals of each species. Models include the geometric series (Motomura 1932) and Fisher's logarithmic series (Fisher et al. 1943). Some models are better than others for showing species abundance distributions, but none are equally applicable to all assemblages due to local variations and the dependence on local influencing factors (Magurran 2004). However, distributions generated by models can still provide insight into processes determining biodiversity, because of the linkage of abundance of species with successful competition for limited resources.

One of the most common and useful methods of displaying abundance data is the rank/abundance plot. Species are plotted sequentially from most to least abundant on the horizontal (x) axis. Abundances are usually shown in $\log_{10}$ format on the y-axis to capture the full range of abundances of different species. Data sets can also be displayed as percentages or proportions to allow for comparison between samples (Whittaker 1965). The rank/abundance plot distinctly highlights contrasting patterns of species richness and differences in evenness among assemblages and can be very useful for showing changes following a disturbance (e.g. Bazzaz 1975). The shape of the rank/abundance plot can be used to infer which species abundance model best describes the data.

Diversity indices

In addition to the various measures of species richness and species abundance, there are also several diversity indices that have been developed. A diversity index is a single statistic that incorporates information on both richness and evenness components and is essentially a measure of heterogeneity (Good 1953; Hurlburt 1971). The weighting that is assigned to one component relative to the other can markedly affect the level of diversity calculated and the way sites or assemblages are ranked (Magurran 2004). Because each diversity index emphasises either the richness or evenness component of diversity, there is no single perfect index.

Species diversity indices can be used to compare communities, but different measures may produce different rankings of sites. There are both parametric and nonparametric measures of diversity. Parametric measures or indices depend on distribution of species abundances while nonparametric measures do not. One of the most well-known nonparametric diversity measures is the Shannon index or Shannon's diversity index, H' (Shannon 1948; Magurran 2004; Ortiz-Burgos 2016), which assumes that individuals are randomly sampled from an infinitely large community, and that all species are represented in the sample. The Shannon index estimates species diversity in a community by considering the number of species and their relative abundances (evenness). It represents the degree of uncertainty in predicting the species of a given individual selected at random from a community. The Shannon index H' usually ranges from 1.5 to 3.5 in temperate zones (Magurran 2004). The higher the H' value, the higher the diversity in a particular community. Some disadvantages of the Shannon index are that it is constrained and usually yields low numbers (Magurran 2004), and it can be difficult to interpret since it confounds richness and evenness.

Simpson's index, D (Simpson 1949) provides an alternative method of describing diversity. It calculates the probability that any two individuals drawn at random from an infinitely large community will belong to the same species (or some other category). As Simpson's index D decreases, diversity increases. Simpson's index is heavily weighted towards the most abundant species in the sample, so is less sensitive to species richness (Magurran 2004). It is one of the most meaningful and robust diversity measures, as it captures the variance of the species abundance distribution. Simpson's index is also much less sensitive to sample size than the Shannon index. A variation on Simpson's index D is Simpson's index of diversity, 1-D (used in this chapter), also known as the Gini-Simpson index, which represents the probability that two individuals randomly selected from a sample will belong to different species or categories. In this second formula, the greater the value of 1-D, the more diverse the sample. Both Simpson measures are on a scale of 0 to 1.

Pielou's evenness, J (Pielou 1966) measures the relative abundance of the different species making up the richness in an area (Magurran 2004). As evenness increases, so does diversity. A community where just a few species are dominant is less diverse than one where the abundances are more evenly distributed among several species. Evenness is reported on a scale of 0 to 1.

Hill (1973) devised a way of describing the relationship between indices by defining a diversity index as the reciprocal mean proportional abundances and classifying according to the weighting the indices give to rare species. Hill related this classification to the fact that diversity measures emphasise either species richness or dominance. The conclusion about whether one site is more diverse than another can thus depend on the choice of diversity measure.

Hill numbers (^{q}D) are a parametric class of true diversity measures that integrate species richness and species abundances and represent a hierarchy of diversity values. Essentially, Hill numbers are the 'effective number of species' or 'species equivalents' (MacArthur 1965, 1972), representing the number of equally abundant species that would be needed to give the same value of a diversity measure such as the Shannon index or Simpson's index. Hill numbers present a simplified interpretation of results, since the units always denote the effective number of species, regardless of position in the hierarchy (Morris et al. 2014). The parameter q determines the sensitivity of the measure to the relative abundances and quantifies how much the measure discounts rare species (Chiu and Chao 2014). The main Hill numbers (q) are $q = 0$, $q = 1$, $q = 2$, and $q = \infty$. Hill number $q = 0$ is simply richness and. Hill $q = 1$ is the exponential of the Shannon index and corresponds to the weighted harmonic mean of the species' proportional abundances. Hill $q = 2$ is the inverse of Simpson's concentration index and is associated with the weighted arithmetic mean of abundances. Hill $q = \infty$ represents infinity. As q nears infinity, the weighted generalised mean with exponent q-1 approaches the maximum proportional abundance of the most abundant species in the set of data. The formula for Hill number calculations is provided in Section 2.3.2.3 of this chapter.

In ecology, diversity measures are normally calculated on data for living organisms, but they can also be applied to any set of measurable categories of items, such as mapped units of landscape features (Nagendra 2002; Ricotta and Avena 2003). These calculations are generally less computationally intensive than for species, but the results still provide a robust measurement of diversity.

2.2 Study areas

The regional area of interest is the Peace River Region of northeastern BC, on landslides <100 years old in glaciolacustrine sediments. The area was subjected to advances of the Laurentide Ice Sheet on at least three separate occasions, with the most recent retreat occurring more than 27,400 years ago (Mathews 1978; Mathews 1980). Evidence of glacial events is presented in interglacial fluviatile gravel units. The study area is mostly within the Alberta Plateau of the Interior Plains Region subdivision of the Canadian physiographic classification system, and it is drained by the Peace River (Holland 1976). The Interior Plains are east of the Rocky Mountain Foothills and consist of plateaus, plains, prairies, and lowlands. The Plains are underlain by sedimentary rocks chiefly of Cretaceous age, primarily of the Fort St. John Group with thick series of shales and sandstones near the top. This area is also comprised of the Dunvegan Formation, which is hard cliff-forming sandstone, and the Smoky Group, which is interbedded shales and sandstones. A small portion of the study area is within the Rocky Mountain Foothills subdivision of the Eastern System of the Canadian Cordillera (Holland 1976). The Foothills are underlain completely by sedimentary rock, mainly from the Mesozoic age and consisting of a variety of limestones, siltstones, sandstones, and shales. The Foothills were covered by continental ice during the Pleistocene.

The regional study area is completely within the Boreal Forest region of Canada and the Boreal Plains ecoregion of BC (Demarchi 2011) and is also entirely within the Boreal White and Black Spruce moist warm (BWBSmw) biogeoclimatic unit, as defined using the Provincial BEC (Biogeoclimatic Ecosystem Classification) guidelines (DeLong et al. 2011). The climate of the area is continental, with low annual precipitation (Chilton 1981). Winters are cold and long, with frequent inputs of continental arctic air. Summers are warm and short but have long daylight hours that benefit agriculture. The most common soils in the area are Grey Luvisols, but Luvic Gleysols, Eutric Brunisols, Chernozems, Solods, Organic Soils, and Regosols are also present (Valentine 1978; Lord and Green 1986).

Following a series of field reconnaissance inspections, three landslides and their surrounding undisturbed terrain were selected as smaller study areas within the regional area of interest: these are known as the Beatton River, Cecil Lake, and Hasler Flats Landslides (Figure 2-1). Each of these study areas consisted of two paired study sites: the landslide itself and a delineated equivalent portion of the immediate surrounding undisturbed terrain. All three landslides occurred near tributaries of the Peace River. The Peace River and its tributaries have a long history of extensive and recurring slope instability. In addition to the above criteria, the landslide study areas were chosen based on local knowledge, safe and efficient access, and the presence of surrounding relatively undisturbed terrain at least equal in area to the landslide.

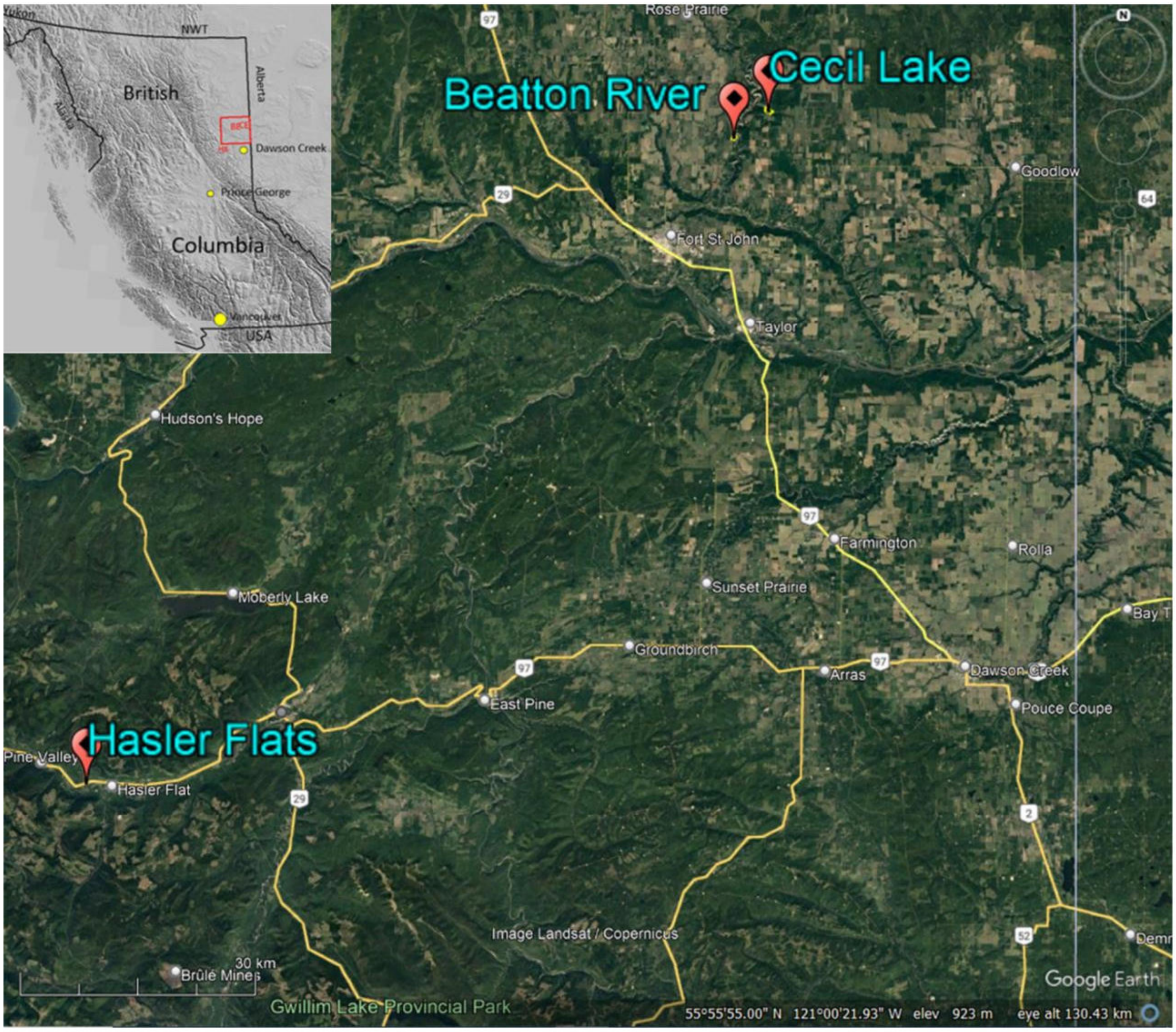

Figure 2-1. Study areas of Beatton River, Cecil Lake, and Hasler Flats landslides, shown in Google Earth Pro. The landslides are in the Peace River Region of northeastern British Columbia, Canada. Landslide locations are outlined in yellow and identified with red locator balloons. Inset map shows landslide locations at a provincial scale and in relation to Mapsheet 94A, which is outlined in red. BE = Beatton River landslide, CE = Cecil Lake landslide, and HA = Hasler Flats landslide.

The Beatton River landslide was the youngest disturbance, to a large degree a reactivation of older landslide deposits, with the most recent movement occurring in 2015. It is a rotational earth slide / earth flow and has somewhat more complex stratigraphy than the Cecil Lake or Hasler Flats slides, including exposed bedrock. The Beatton River landslide (56°21’57” N 120°42’26” W) is approximately 30 ha in size, with an elevation range of 655 m to 447 m (δ

208 m) and an average slope of ~17.2°. It is northeast facing, situated below (east of) a cultivated hay field and between mature forest stands to the north and a grassland/mature forest mix to the south. When the landslide occurred it temporarily blocked a portion of the channel of the Beatton River to the east.

The Hasler Flats landslide is the smallest slide at approximately 1.5 ha. It is a southwest-facing spread which occurred in 2013 and is situated in post-glacial lake sand (4 m in thickness) over silty clay. It is below a young, regenerated deciduous cutblock to the east and between mature deciduous stands to the north and south. The Hasler Flats landslide (55°36’39” N 122°0’45” W) has an elevation range of 615 m to 598 m (δ 17 m) and an average slope of ~6.3°. It is adjacent to the Pine River to the west, and the slide deposited debris into the river channel when it first occurred. This small landslide was chosen due to its distinctive horst-graben formation and small size, two features which could be studied and contrasted against the other two landslides. It is also conveniently located along the highway west of Chetwynd and had easy access.

The Cecil Lake landslide was both the oldest and the largest of the three selected landslides. It is a spread with a rupture surface in glacial lake sediments underlying glacial till and is largely comprised of silty clay. The Cecil Lake landslide (56°23’48” N 120°38’11” W) occurred in 1998 and is approximately 56 ha in size. It has an elevation range of 665 m to 556 m (δ 109 m) and an average slope of ~9.6°. It is a north-facing landslide less than a kilometre east of the Beatton River, and at its north boundary (i.e. toe) it contains a narrow but deeply incised unnamed creek that empties into the river. A small strip north of the creek was included in the landslide study site, as there was disturbance that appeared to be the same age as the rest of the landslide. The Cecil Lake landslide lies below a cultivated field and mature deciduous and mixedwood forests at its south end where the headscarp is. To the east is an older landslide, while to the west the Cecil Lake landslide abuts mature mixedwood forests. To the north above the creek is a steep south-facing mosaic of grasslands and mixedwood forests.

2.3 Methods and Analysis

2.3.1 Subjectively placed BEC plots

2.3.1.1 Field sampling of subjectively located BEC plots

In the first sampling season (2016), 91 subjectively placed 50 m^2 plots were established on the three landslide study sites (Beatton River, Cecil Lake, Hasler Flats) using the Provincial BEC (Biogeoclimatic Ecosystems Classification) field sampling methodology (BC Gov 2010, 2015), modified to accommodate smaller plots. In addition, one 400 m^2 (20 m x 20 m) benchmark mature forest plot each was established in the surrounding undisturbed terrain study site at Beatton River and Hasler Flats, along with one 50 m^2 benchmark grassland plot in the Beatton River undisturbed terrain study site. In 2017, an additional 21 50 m^2 plots on the Cecil Lake landslide and one 400 m^2 mature forest plot on the surrounding undisturbed terrain were sampled to complete coverage of the Cecil Lake study area, as seasonal limitations in 2016 ended the sampling prematurely. The objective of this sampling program was to assess and describe the variation in plant communities and site characteristics present on each landslide study site. The intent was to describe as much of the variability as possible through field reconnaissance across the landslide. In total 116 plots were sampled across the three study areas: 30 plots at Beatton River, 30 plots at Hasler Flats, and 56 plots at Cecil Lake.

Data were recorded on FS882 field cards normally used in British Columbia BEC field sampling (BC Gov 2010). Procedures followed the Describing Ecosystems field guide (BC Gov 2010, 2015) and provincial terrain classification guidelines (Howes and Kenk 1997). The Biogeoclimatic Ecosystem Classification (BEC) system is a hierarchical site-level ecological classification method developed in BC that combines climatic, vegetation, and site classifications (Pojar et al. 1987; Meidinger and Pojar 1991). The BEC system provides a framework for organising ecological information and ecosystem management learnings, creates common terminology among forest resource managers, and is used to prescribe and monitor treatments at the site level (DeLong et al. 2011). The biogeoclimatic subzone is the basic unit used in climatic classification and is a group of ecosystems that have developed under the influence of the same regional climate. Each subzone has a distinctive sequence of related ecosystems ranging from dry to wet sites, influenced not only by the regional climate, but also by local soil and topographic features. The site series is the basic unit of site classification and is defined by using late seral or climax vegetation. Site series represent site units with similar environmental properties and potential vegetation. An eight-class scale has been developed, based on relative soil moisture regime, relative soil nutrient regime, and various other environmental factors. The standard size of plot used in BEC sampling is 400 m^2, or 20 m x 20 m.

Sampling intensity and location of the subjective BEC plots was based on vegetative and geomorphic differences observed in the field, with plot locations determined while in the field traversing the study sites. Plots on the landslide were either circular or rectangular, depending on the extent and configuration of the geomorphic/vegetation type. Most plots were circular (i.e. 50 m^2 – 3.99 m radius). If plots needed to be rectangular to capture a microsite, they were configured to cover an area of 50 m^2. The smaller plot size of the subjective plots was chosen due to the broken-up and small-scale nature of many microsites on the landslide. Plots in the surrounding undisturbed terrain were generally larger, as more extensive areas of distinct plant communities were present. At each plot, vegetation, soil, and environment information was recorded and representative photographs were taken. Plant species were identified and recorded using BC's seven letter coding system (BC Forest Service 2016), and abundance was described in units of percent cover. Plant species identification was aided by consulting with specialists as well as several published and on-line resources (i.e. MacKinnon et al. 1992; Johnson et al. 1995; Kershaw et al. 1998; Douglas et al. 1998-2002; Klinkenberg 2021). For soils, information on geology, terrain, and organic and mineral horizons/layers was recorded. Environment information included microsite slope, microsite aspect, plant community structural stage, successional status, mesoslope position, surface substrate composition, topography, moisture regime, nutrient regime, and elevation. Soils were classified according to national standards (Soil Classification Working Group 1998).

An initial attempt was made to classify each sample to BEC site series using the appropriate guidebooks, recognising that some sites are a complex of multiple site series, as is also often noted when mapping post-logging site types. Forested ecosystems or precursors to these types of ecosystems were classified using the BWBS zone field guidebook (DeLong et al. 2011). Wetland and water features were classified using the Wetlands of British Columbia guide (MacKenzie and Moran 2004) and Technical Report 68, Biogeoclimatic Ecosystem Classification of Non-Forested Ecosystems in British Columbia (MacKenzie 2012). Grasslands were also classified using the MacKenzie (2012) guide. Rationale for classifications was supported by field photos and field notes, as well as analysis of and comparison with the digital imagery. For all classifications, it was recognised that landslide sites are seral or in a state of successional development as a precursor to supporting the mature plant community likely to develop on each site.

The 2016 data were entered into the VPro [VENUS (Vegetation and Environment NexUS) PROfessional] database program (MacKenzie and Klassen 2004), which is used primarily by BC research ecologists and contains data fields that mirror the FS882 cards. The program allows transfer of entered data to a spreadsheet and generation of various reports for analysis. Data can also be directly exported for statistical analysis in ecological multivariate analysis programs such as PC-ORD (PC-ORD 2015). The 2017 Cecil Lake plot data were entered in an Excel spreadsheet, due to some technical problems with VPro.

The subjectively located BEC 50 m^2 and 400 m^2 plots were originally intended to gather general baseline information about plant and site characteristics of the study sites but were ultimately central in some analysis components of the research. Although most of these plots were smaller than the random 20 m x 20 m relevé main plots and were established using different criteria, and thus could not be used for direct comparison in some parts of the study, the plot information was instrumental in analysing plant and site diversity and mapping out site series/types. The subjectively located plot information was used to assist in mapping out polygons to describe site series/types and terrain diversity. Other key analyses using these plots were a nonmetric multidimensional scaling (NMS) ordination of the vegetation and selected environmental data and calculation of microtopographic variability. The plots could eventually be registered in the Provincial BEC database (BECWeb 2023) if the smaller size and variable configuration are acceptable.

2.3.1.2 Nonmetric multidimensional scaling (NMS) ordination of BEC plot plant species and environmental variables

Nonmetric multidimensional scaling (NMS) ordination (Kruskal 1964; Mather 1976) was used to analyse vegetation and selected environmental data collected on the subjectively located BEC plots, to identify and describe any patterns in species composition in relation to environment. NMS is especially suited to heterogenous ecological datasets such as this one, because it does not require any specific design or model form, and so avoids parametric assumptions (Peck 2016). The multivariate analysis program PCORD v. 7 (McCune and Mefford 2016) was used to run the NMS ordination. Plant species and abundance data were loaded from a spreadsheet into the main matrix. Values for five select environmental variables were loaded into the secondary matrix. A random starting configuration was employed. The Gower distance measure was used, as some plots had no vegetation (as indicated by empty rows of data). The PC-ORD program user guide, citing previous works (Gower 1971; Legendre and Legendre 1998), notes that the Gower distance measure is a flexible, universal measure and is suitable for data sets containing empty rows, but not empty columns. Three runs with real data were carried out on the dataset. A Mantel test was performed to assess redundancy between each pair of runs. The dimensionality (i.e. appropriate number of axes) of the data was assessed by performing a stress test on autopilot mode at "thorough" setting and six axes, using 250 runs each of random and real data to determine the best solution. The stability of the final solution was assessed by checking to see if the stress leveled out and plateaued over time. The proportion of variance of each axis was calculated based on the r^2 (i.e. coefficient of determination) between distance in the ordination space and distance in the original species space.

The plant species most strongly associated with the environmental variables of interest were identified using Pearson correlations with the axes of the ordination. The five environmental variables assessed in the NMS ordination in the secondary matrix were soil moisture regime, mesoslope position, slope gradient, heat load index (HLI), and material origin. Heat load index and material origin variables were not specifically measured in the field but are derived variables, incorporating information from the field data.

Heat load index is a measure of heat on a site based on slope, aspect, and latitude (McCune and Keon 2002). The index is derived from direct incident radiation, which is the radiant solar energy that hits the earth's surface (Belessiotis and Delyannis 2011). To get a true representation of the heat potential for each plot, the aspect was "folded" about the northeast-southwest line using the formula ABS(180-ABS(Aspect -225)) provided in McCune and Keon (2002). The following formula (Equation 3 in the 2002 paper) was then used to calculate heat load index for each plot:

HLI = 0.339+0.808*COS(RADIANS(latitude))*COS(RADIANS(slope))-0.196*SIN(RADIANS(latitude))*SIN(RADIANS(slope))-0.482*COS(RADIANS(folded aspect))*SIN(RADIANS(slope))

where latitude is the site's location in degrees north of the equator, slope is in degrees, and folded aspect is calculated from aspect (in degrees azimuth from North) as shown above.

The material origin variable was created to categorise the level of soil development on each plot. Five classes were identified, based on information obtained from the field data and photos. Class 1 was the most stable level of soil material development, representing mature *in situ* material in the surrounding terrain. Class 2 represented intact mature material on the landslide that had been rafted from the surrounding terrain. Class 3 was material on the landslide body that had an intermediate level of soil development, with no A horizon and a weakly developed B horizon. Class 4 represented Orthic Regosols, having only a C horizon. Class 5 was ponds, with arrested development of soil, which in most cases was likely only a C horizon. Appendix 1 provides a more detailed description of each class.

2.3.2 Randomly located 400 m^2 relevés

2.3.2.1 Field sampling of randomly located 400 m^2 relevés

In the 2017 and 2018 sampling seasons, three randomly placed 400 m^2 (20 m x 20 m) square relevé plots were established on each landslide study site (Beatton River, Cecil Lake, Hasler Flats) to sample vegetation and environment components. Plot locations were determined beforehand using a grid system and random number generator. The same plot establishment and sampling procedures were followed for an equivalent area of the surrounding undisturbed landscape, for a total of six random relevés per study area, with three relevés on each of six paired study sites. In contrast to the subjectively located plots, the objective of this particular sampling program was to randomly sample vegetation and site conditions to compare and contrast mean diversity on the landslides and in the surrounding undisturbed terrain.

Data collection methods for these plots were very similar to those used on the subjectively located 50 m^2 and 400 m^2 plots, following the same BEC field manuals cited in Section 2.3.1.1. For the sake of clarity and simplicity, however, the random plots will be henceforth referred to as relevés and the subjectively located plots will be referred to as BEC plots for the remainder of this paper. At each 20 m x 20 m relevé, vegetation, soil, and environment details were recorded on FS882 field cards and representative photographs were taken. Environmental information was collected on slope, aspect, plant community structural stage, successional status, surface substrate composition, topography, mesoslope position, soil moisture regime, soil nutrient regime, and elevation. Vegetation cover was tallied by percent abundance and plant species were recorded using BC's seven letter coding system (BC Forest Service 2016, 2020). Plant species were identified using the same resources as in Section 2.3.1.1. Individual tree species, diameters and heights were also recorded. Information was collected on geology, terrain, and organic and mineral horizons, but with a reduced focus on soils. Field data were entered into Excel spreadsheets.

2.3.2.2 Rank abundance curves of plant species in relevés

Analysis of the relevé plot data was carried out in Excel. The mean relative abundance per species was calculated for the three relevés on each of the six study sites, and then the species were ordered from greatest to least percent cover. Mean rank abundance curves for the relevés were graphed for each study site, plotting the log base 10 of ranked plant cover abundance for each species. Individual curves were also plotted for each relevé. These rank abundance plots were examined and compared among study sites and between landslides and undisturbed terrain using the slope of a linear regression. The rank abundance method does not require a goodness of fit test, but rather equates diversity of the assemblage with the slope of the relationship, which reflects evenness of abundances. The steeper the slope, the lower the diversity of the sample, since the higher ranked species have much greater abundances than the lower ranked species. The richness of the sample is represented by the number of species on the horizontal axis.

2.3.2.3 Plant diversity indices and measures for relevés

To assess alpha diversity on the landslide and compare within-slide alpha diversity with undisturbed terrain, plant species richness and various abundance measures were calculated for the relevé plot data of each landslide (n=3) and compared to diversity values obtained from the three relevés on the surrounding terrain. Species richness (S = total number of species), the Shannon index [$H' = -\sum p_i * \ln(p_i)$, where p is the proportional abundance of each species], Simpson's index of diversity [1-D, or $1-\sum(n/N)^2$, where n is the total abundance of a particular species and N is the total abundance of all species], and Pielou's evenness value [$J = H'/\ln(S)$], were calculated.

To compare plant diversity between landslide and undisturbed sites for the relevés, two types of values were calculated. First, the overall diversity values were calculated by obtaining the mean cover value of each plant species over all three relevés for each study site. These means were then used to calculate richness, Shannon index of diversity, Pielou's evenness, and Simpson's index of diversity (1-D) for the study site. The second set of values was obtained by first calculating diversity values for each individual relevé in a study site, and then using these results to calculate the mean diversity values and the standard deviations for the study site.

In addition, true diversity Hill numbers q = 0, 1, 2, and ∞ were calculated for the plant species composition of the relevés on each study site, using a pre-formulated Excel spreadsheet obtained online (Goepel 2012). The formula for the different Hill q values is:

$$^{q}D = \left(\sum_{i=1}^{R} p_i^q \right)^{1/(1-q)}$$

Where:

R = Richness

q = Hill numbers order or effective number of species

pi = proportional abundance of the ith species

2.3.2.4 Plant growth form and species abundance in relevés

The composition and distribution of plant growth forms on a site can provide indicators of the environmental forces shaping an ecological community (Landau 2004). Abundances of individual plant species can also provide information about the influence of landslide disturbance on plant community development. To investigate a possible relationship between disturbance and growth form, each plant species in the three combined relevés on the landslide and the three relevés on the surrounding terrain for each landslide was classified and grouped by growth form in a table, along with each species' average percent cover (abundance). The standard provincial growth form categories of tree, shrub, forb, graminoid, fern and fern allies, bryophyte, and lichen were used (BC Gov. 2010, 2015). The mean plant species abundances by study site were subtotalled for each growth form category and their proportions of the total cover were then calculated and compared among study sites. Each individual plant species was also ranked in descending order by mean percent cover for each study site and a list of the ten most abundant species by cover was compiled for each study site. Plant species autecology guidance resources were consulted for interpretation of results (Haeussler et al. 1990; FEIS 2023).

2.3.2.5 Two-sample Kolmogorov-Smirnov test to compare plant assemblages in relevés

The two-way sample K-S test was used to test for significant differences between species abundance distributions of the two assemblages of relevés, for each of the three pairs of landslide-undisturbed terrain study sites. The two-sample Kolmogorov-Smirnov (K-S) test (Tokeshi 1993; Sokal and Rohlf 1995) is a nonparametric test of the equality of continuous or discontinuous one-dimensional probability distributions. It quantifies the distance between the empirical distribution functions of two samples and determines the likelihood of the two sets of samples occurring if they were drawn from the same (though unknown) probability distribution. The K-S test is considered one of the most useful nonparametric methods for comparing two samples, due to its sensitivity to differences in both location and shape of their empirical cumulative distribution functions. The maximum cumulative proportional difference (K-S test D statistic) of abundances between sites was calculated in Excel (Microsoft Corporation 2010) entering formulas by hand and compared with the critical value ($1.36/\sqrt{n}$), obtained from tables (Zaiontz 2017) based on a sample size >40 with a p-value of 0.05. If the maximum D-statistic was greater than the critical value, the null hypothesis of no difference between samples was rejected.

2.3.3 Mapping, classifying, and analysing site series/types using multiple types of plot data

2.3.3.1 Site types/series

The site type/series study incorporated the Beatton River, Cecil Lake, and Hasler Flats field data and photos from the BEC and relevé plots and a series of randomly located 30 m transects (described and analysed in Chapter 3) to type out vegetation and characterise patch diversity on the landslides and the surrounding undisturbed terrain. In British Columbia, the "site series" is the key unit of site-level ecosystem classification categories, based on distinctive plant associations and typical soil, parent material, or slope position characteristics (described in Section 2.3.1.1). In this paper, categories will be referred to interchangeably as either site types or site series. Prior to mapping the site series, the perimeter of the landslide was first digitised on mosaic transparent drone imagery, and then an equivalent area of adjacent surrounding relatively undisturbed terrain was also digitised. This analysis was a combination of site series classification using field manuals and GIS mapping exercises in Global Mapper (Global Mapper 2020) using high-resolution drone (UAV – unmanned aerial vehicle) imagery (i.e. mosaic transparent group TIF (tag image format) file) and an underlay of LiDAR (light detection and ranging) DSM (digital surface model). Pre-processed, government-purchased LiDAR data was used, which was collected at an average of 1.1 to 1.3 points per m^2. The data collection project was flown in 2006 at heights of 1200 to 1550 m using an Optech 3100 LiDAR system. In some areas the coverage was sparser, while in other places there was overlap and almost twice as many points per m^2. The configuration of the outer perimeter of the undisturbed terrain was constrained by the limited availability of the same high-resolution imagery that was available for the landslide site series mapping.

Prior to digitising site types/series polygons, an attempt was made to classify the site series of each relevé using the same manuals and guides as for the BEC plots (Section 2.3.1.1). When mapping the site types, plot data were employed to verify vegetation cover and serve as a means of ground-truthing. The digital drone imagery and field photos were used as cross-references to confirm plot classifications. Although some preliminary site series classification was done on the BEC plots during the first field season (2016), these plot classifications were reassessed based on a greater understanding of the local conditions following two more field seasons, as well as an assessment of the high-resolution digital imagery that subsequently became available. Classifications were revised where necessary.

Site types/series were initially delineated and digitised on the digital imagery in Global Mapper and assigned classifications based on vegetation and identifiable environmental indicators such as aspect and steepness of slope. Aerial interpretation methods were applied to assist in distinguishing different types of vegetation (Sayn-Wittgenstein 1960; Avery 1969; Sayn-Wittgenstein 1978). The GPS (global positioning system) plot locations for all subjectively and randomly located plots for each landslide were then transferred into Global Mapper, complete with their site series classifications.

Site series information determined from the plot data was used to verify the mapped types. Conversely, some plot site series classifications were modified after assessing the digital imagery and classification of other nearby plots. A plant indicator guide was consulted for site series that appeared transitional (Beaudry et al. 1999). The same steps for classification were followed for an equivalent area of the surrounding undisturbed terrain for each of the three study areas. Due to the transient and jumbled nature of vegetation, moisture, and soil material that is often characteristic of disturbed ecosystems such as landslides, not all plot sites fit into neat categories. As a result, some adjustments were made to the classifications. Additionally, some new site series/type categories were created to reflect site types influenced by human activities or types not described in the field guides, such as cultivated fields.

The areas of individual polygons of each site type were subtotalled, and proportions of each site series were calculated for the total area of each landslide and associated undisturbed area once the mapping was complete. The proportions of site series on and off the landslide were graphically compared in a two-way bar graph in order of moisture regime for each of the three study areas. Rank abundance curves were plotted for each study site, and Kolmogorov-Smirnov two-sample tests were done to compare landslide and undisturbed results and assess whether the two paired sites came from the same distribution or community. Finally, Shannon, Simpson's (1-D), and Pielou's diversity measures were calculated for the site types found at each study site and compared between landslide and undisturbed sites.

2.3.4 Mapping, classifying, and analysing biophysical features using multiple types of plot data

2.3.4.1 Geotyping

To describe and assess geophysical diversity, distinct individual geomorphic features were mapped out on each landslide study site (Beatton River, Cecil Lake, and Hasler Flats). Each feature was classified as a specific geomorphic type using Global Mapper to view the imagery and digitise polygon boundaries. These features were referred to as geotypes for the purposes of this study. The same digital imagery and digitised perimeter boundaries used in the site series work described in Section 2.3.3.1 were utilised.

The ultimate delineation for geotypes was based on terrain, although the presence of the "pond" geotype was at times first identified by the presence of cattail (*Typha* spp. – most likely *Typha latifolia*). The provincial terrain classification guidebook (Howes and Kenk 1998) was used as a baseline reference, and features were classified with one of the categories from the guidebook where possible. However, classification into pre-existing categories was not always possible due to the nature of some landslide features on slides adjacent to fields or cutblocks. Geotype classification was assisted by reference to the field card data, notes, and photographs from the BEC plots and relevés, as well as from random transects sampled for the beta diversity chapter (see Chapter 3).

The mapping was done on high-resolution drone photogrammetric imagery (mosaic transparent group TIF file), using Global Mapper. Digital elevation model (DEM) topographical imagery (DSM TIF file) was also used to assist in distinguishing geomorphic features. Once all features on each landslide were mapped and classified, the total areas of all the polygons for each geotype were added up. Summary statistics were then calculated. Further analysis of the geotyping results was carried out by calculating the Shannon and Simpson's diversity indices, as well as Pielou's evenness, for each landslide study site. Rank abundance curves were plotted for each of the six study sites to compare landslides and undisturbed terrain. Finally, a regression analysis was done to check for any relationship between relevé vegetation diversity and geotype diversity.

2.3.4.1 Microtopography/surface roughness of BEC plots

Microtopography refers to the amount of soil surface roughness at the local level, at a scale that can fundamentally influence nutrient and groundwater regimes, and thus plant establishment and reproduction and wetland processes. Data preparation for assessment of microtopography on the study areas involved clipping out the buffered BEC plots from LiDAR or drone cloud points in Global Mapper and running an analysis on the standardised elevation of the points for each plot. The surface roughness/microtopography of each plot on each study site was represented by the coefficient of variation (in %), calculated as the standard deviation of standardised point elevation values divided by the mean standardised elevation for each plot. Generally, the higher the coefficient of variation, the higher the spread of data relative to the mean standardised elevation, and thus the higher the micro-variability of the terrain within the plot. Although the standard deviation of elevation method of assessing surface roughness used in this study is not as computationally intensive as some other methods, it has been shown to perform equally as well as other more complex measures (Rozycka et al. 2016).

2.4 Results

2.4.1 Diversity of relevés

The landslide study areas exhibited a visually diverse array of plant communities and sites over short distances. Very dry, sparsely vegetated sites could be found juxtaposed with ponds and rafts, while level, heavily vegetated sites occurred next to steep, unvegetated scarps. An illustration of some of the diversity found in the study areas is presented in Figure 2-2.

Figure 2-2. Vegetation and site diversity on landslides in the study. From top left clockwise: horst and graben complex and mature rafts (Hasler Flats. Photo July 12, 2018); unvegetated weathered pillar next to heavy brush (Cecil Lake. Photo September 17, 2017); dewatered/revegetated pond site (Cecil Lake. Photo August 23, 2018); steep unvegetated scarps interspersed with relatively level swaths of abundant invasive vegetation and the occasional pond (Beatton River. Photo August 15, 2017).

Summaries of the ten overall most abundant plant species on landslide and undisturbed relevés at each study site are presented in Table 2-1. The species abundances are presented as mean percent cover of entire relevé area. A complete list of plant species and mean abundances for these plots is provided in Appendix 2.

Table 2-1. Ten most abundant plant species for relevés at all study sites, comparing landslide and undisturbed results. Values are mean percent cover of the entire relevé area +/- standard error of the mean.

Beatton River Landslide Releves

Species	Mean cover (%)
Melilotus officinalis	28.83 ± 44.31
Equisetum arvense	12.17 ± 19.78
Melilotus alba	6.00 ± 3.50
Sonchus arvensis	4.10 ± 2.46
Artemisia sp. 2	1.77 ± 0.87
Sonchus sp.	1.41 ± 1.42
Rubus idaeus	1.09 ± 1.87
Aster ciliolatus	0.70 ± 1.13
Solidago canadensis	0.65 ± 0.59
Taraxacum officinale	0.44 ± 0.50

Beatton River Undisturbed Releves

Species	Mean cover (%)
Amelanchier alnifolia	10.85 ± 16.60
Betula papyrifera	10.67 ± 18.48
Aralia nudicaulis	7.82 ± 2.30
Linnaea borealis	6.83 ± 6.14
Carex sp. 1	5.67 ± 9.82
Viburnum edule	5.55 ± 4.88
Rosa acicularis	4.93 ± 0.39
Picea glauca	4.73 ± 6.72
Carex sp. 3	4.00 ± 6.93
Aster conspicuus	3.85 ± 3.37

Cecil Lake Landslide Releves

Species	Mean cover (%)
Equisetum arvense	33.5 ± 12.17
Alnus viridis ssp. *sinuata*	24.09 ± 20.69
Petasites frigidus	6.73 ± 11.49
Salix sp.	5.63 ± 4.35
Populus balsamifera ssp. *balsamifera*	4.77 ± 6.28
Shepherdia canadensis	3.13 ± 0.33
Picea glauca	2.68 ± 2.07
Populus tremuloides	2.64 ± 2.46
Rosa acicularis	2.41 ± 0.39
Salix sp.	1.96 ± 2.90

Cecil Lake Undisturbed Releves

Species	Mean cover (%)
Picea glauca	22.89 ± 14.69
Populus tremuloides	9.11 ± 12.48
Rosa acicularis	6.91 ± 3.43
Viburnum edule	6.76 ± 3.77
Shepherdia canadensis	4.39 ± 4.02
Alnus viridis ssp. *sinuata*	4.02 ± 2.95
Betula papyrifera	3.62 ± 5.02
Cornus stolonifera	1.92 ± 1.74
Amelanchier alnifolia	0.97 ± 0.81
Rubus pubescens	0.78 ± 0.50

Hasler Flats Landslide Releves

Species	Mean cover (%)
Equisetum arvense	16.42 ± 1.04
Populus tremuloides	10.76 ± 5.33
Rosa acicularis	10.38 ± 2.21
Alnus viridis ssp. *sinuata*	6.31 ± 4.24
Rubus idaeus	5.60 ± 3.06
Cornus stolonifera	4.90 ± 3.78
Symphoricarpos albus	4.15 ± 2.43
Viburnum edule	2.42 ± 1.27
"Star moss"	2.42 ± 0.51
Lonicera dioica	2.35 ± 2.71

Hasler Flats Undisturbed Releves

Species	Mean cover (%)
Equisetum arvense	15.63 ± 6.95
Populus tremuloides	13.58 ± 5.07
Alnus viridis ssp. *sinuata*	9.86 ± 17.08
Cornus stolonifera	7.36 ± 4.38
Viburnum edule	6.98 ± 5.93
Aralia nudicaulis	6.86 ± 4.87
Symphoricarpos albus	5.38 ± 5.09
Rosa acicularis	5.28 ± 1.62
Populus balsamifera ssp. *balsamifera*	4.34 ± 6.32
Heracleum lanatum	3.84 ± 5.06

For the Beatton River landslide study site relevés, the forb yellow sweetclover (*Melilotus officinalis*) and the fern ally common horsetail (*Equisetum arvense*) were the leading species for percentage of total plant cover, at 28.8% and 12.2%, respectively. On the Beatton River undisturbed study site, the shrub saskatoon (*Amelanchier alnifolia*) and the tree paper birch (*Betula papyrifera*) were the leading species overall (10.8% and 10.7%, respectively), and wild sarsaparilla (*Aralia nudicaulis*) and twinflower (*Linnaea borealis*) were the leading forbs (7.8% and 6.8%, respectively). On the Cecil Lake landslide study site, the leading species overall was common horsetail at 33.5%. The leading shrubs on the Cecil Lake landslide study site were green alder (*Alnus viridus* ssp. *sinuata*) at 24%, followed by a willow (*Salix* sp.) at 5.6%. On the Cecil Lake undisturbed study site, the top two leading species were trees: white spruce (*Picea glauca*) at *22.9%* and trembling aspen (*Populus tremuloides*) at 9.1%. The next most abundant species were the shrubs prickly rose (*Rosa acicularis*) at 6.9% and highbush cranberry (*Viburnum edule*) at 6.8%. For both Hasler Flats study sites, the fern ally common horsetail was the overall leading species (16.4% landslide, 15.6% undisturbed), followed by trembling aspen (10.8% landslide, 13.6% undisturbed). On the Hasler Flats landslide study site, seven out of ten leadings species were shrubs, while on the surrounding undisturbed study site, five out of ten leading species were shrubs.

There was also a difference between landslides in the presence of undisturbed species that were also found on the landslide. For the Beatton River study area, none of the top ten undisturbed species were also found on the landslide. On the Cecil Lake landslide, four shrub species were shared between the undisturbed terrain and the landslide: *Populus tremuloides*, *Rosa acicularis*, *Shepherdia canadensis*, and *Alnus viridis* ssp. *sinuata*. Hasler Flats study area had six top species in common between the paired study sites: *Equisetum* *arvense*, *Populus tremuloides*, *Rosa acicularis, Alnus viridis* ssp. *sinuata*, *Cornus stolonifera*, and *Symphoricarpos albus*.

2.4.1.1 Plant growth form composition and species abundances for relevés

Plant growth form abundances varied significantly between relevé study sites. Table 2-2 provides a summary of mean vegetation covers by growth form as a percentage of mean total vegetation cover on the plots, as well as the subsequent proportions, for all six study sites. A complete list of abundances and proportions of all species by growth form in relation to mean total vegetation cover for each study site is provided in Appendix 3.

Table 2-2. Relevé mean growth form cover as a percentage of mean total vegetation cover, along with proportions, for all study sites. The table provides a comparison between landslide and undisturbed vegetation growth form cover.

Vegetation cover	Study site Beatton Landslide	Beatton Undisturbed	Cecil Landslide	Cecil Undisturbed	Hasler Landslide	Hasler Undisturbed
Mean total vegetation cover (%)	59.68	97.35	104.16	87.02	81.69	100.81
Trees						
Cover (%)	0.20	17.09	10.44	35.62	11.22	18.46
Proportion of mean total (%)	0.34	17.55	10.02	40.94	13.74	18.31
Shrubs (%)						
Cover (%)	1.74	37.27	43.83	27.57	41.53	46.04
Proportion of mean total (%)	2.92	38.29	42.08	31.68	50.84	45.67
Forbs (%)						
Cover (%)	45.27	26.38	13.82	13.08	6.86	20.08
Proportion of mean total (%)	75.86	27.09	13.26	15.03	8.40	19.91
Graminoids						
Cover (%)	0.13	15.97	1.67	2.75	2.97	0.39
Proportion of mean total (%)	0.21	16.40	1.60	3.16	3.63	0.39
Ferns & Fern allies						
Cover (%)	12.17	0.13	33.50	0.03	16.42	15.63
Proportion of mean total (%)	20.39	0.13	32.16	0.03	20.10	15.51
Bryophytes						
Cover (%)	0.17	0.43	0.90	7.93	2.69	0.21
Proportion of mean total (%)	0.28	0.44	0.86	9.11	3.30	0.21
Lichens (%)						
Cover (%)	N/A	0.08	0.02	0.05	N/A	N/A
Proportion of mean total (%)	N/A	0.08	0.02	0.06	N/A	N/A

For Beatton River, forbs dominated on the landslide (>75% of the total cover) while shrubs were leading on the undisturbed terrain (38.3% of total cover), followed by forbs (27.1%). For the Cecil Lake landslide study site, shrubs were dominant (43.8% of cover) followed by ferns and fern allies (33.5% of cover). On the Cecil Lake undisturbed terrain study site, trees dominated (41% of cover) followed closely by shrubs (>31% of cover). For the Hasler Flats landslide site, shrubs prevailed (>50% of cover) followed by ferns and fern allies (>20% of cover) and then trees (>13%). On the Hasler Flats undisturbed terrain, shrubs comprised

>45% of the total cover, followed by forbs (20% of cover) and then trees (>18% of cover). Fern and fern allies were close behind, at 15.5%.

2.4.1.2 Plant diversity indices and measures for relevés

The results for relevé plant diversity assessment using both the mean cover values and the individual relevé cover values show that in all comparisons, the Shannon index and Pielou's evenness were higher on the undisturbed terrain compared to the landslide (Table 2-3). However, all landslide study sites had more variation around the mean than their paired undisturbed study sites for the Shannon index.

Table 2-3. Combined* and mean (+/- standard error) vegetation diversity indices for relevés

Study site	Combined Shannon index (H')	Mean Shannon index (H') (n=3)	Combined Pielou's evenness (J)	Mean Pielou's evenness (J) (n=3)	Combined Simpson's index (1-D)	Mean Simpson's index (1-D)	Combined Richness (S)	Mean Richness (S) (n=3)
Beatton - Landslide	1.75	1.78 ± 0.26	0.47	0.55 ± 0.10	0.72	0.59 ± 0.22	41	25.33 ± 4.04
Beatton - Undisturbed	3.22	2.58 ± 0.17	0.71	0.66 ± 0.05	0.95	0.89 ± 0.03	91	52.33 ± 13.01
Cecil - Landslide	2.46	2.25 ± 0.36	0.53	0.55 ± 0.08	0.84	0.82 ± 0.06	106	61.00 ± 18.25
Cecil - Undisturbed	2.65	2.43 ± 0.30	0.64	0.65 ± 0.08	0.90	0.88 ± 0.05	65	43.33 ± 4.04
Hasler - Landslide	2.82	2.64 ± 0.33	0.63	0.63 ± 0.07	0.92	0.90 ± 0.03	90	65.33 ± 4.93
Hasler - Undisturbed	2.94	2.63 ± 0.12	0.66	0.65 ± 0.01	0.93	0.90 ± 0.01	84	57.00 ± 10.15

*where combined values are based on first averaging plant abundance data from the three relevés and then calculating the diversity indices.

Simpson's index of diversity was higher on the Beatton River and Cecil Lake undisturbed study sites compared to the landslide study sites, with an especially marked difference between the Beatton River landslide and undisturbed sites. However, the Beatton River landslide had a much higher standard deviation than the undisturbed study site. Simpson's index of diversity was slightly higher on the Hasler Flats undisturbed site compared to the landslide site using the mean cover metric, while the two values were the same for the individual cover metric. Richness was lower on the Beatton River landslide compared to the undisturbed terrain, while it was higher on the landslide for both Cecil Lake and Hasler Flats.

Hill numbers were calculated using the mean percent cover data of plant species of relevés for each study site, as shown in Table 2-4.

Table 2-4. Hill numbers for vegetation diversity on relevés.

Mean Hill Numbers -True Diversity ^{q}D:

Order q	Generalised Mean	Beatton - Landslide	Beatton - Undisturbed	Cecil - Landslide	Cecil - Undisturbed	Hasler - Landslide	Hasler - Undisturbed
0	harm	25.00	52.33	61.00	43.33	65.33	57.00
1	geom	6.04	13.36	9.84	11.74	14.54	13.94
2	avg	4.20	8.85	5.61	8.01	9.68	8.86
∞	inf	2.63	4.38	3.23	4.39	5.15	4.37

For the Cecil Lake and Hasler Flats study areas, mean Hill number 0 (species richness) was higher on the landslide study site than on the undisturbed terrain study site, while at the Beatton River study area, Hill number 0 was much higher on the undisturbed terrain. For the rest of the Hill numbers 1, 2, and infinity (∞), the values were higher on the undisturbed terrain than on the landslide for the Beatton River and Cecil Lake study areas, but higher on the landslide than the undisturbed terrain study site for Hasler Flats. The Beatton River study area exhibited the biggest difference between landslide and undisturbed terrain study sites, for all four Hill numbers. The Beatton River landslide study site had the lowest Hill numbers of all three landslides while the Hasler Flats landslide study site had the highest Hill numbers. Overall, the Hasler Flats study area had the smallest differences in Hill number values between landslide and undisturbed terrain study sites, while the Beatton River study area generally had the largest differences.

2.4.1.3 Rank abundance curves for plant species on relevés

Rank abundance curves provide a visual representation of the richness and evenness of a study site. The rank abundance curves for all relevé study sites are shown in Figure 2-3. Results indicate a higher evenness of the Cecil Lake and Hasler Flats undisturbed study sites compared to the landslide sites, as shown by the steeper gradient of the curves for the undisturbed sites. The opposite is apparent for the Beatton River study area, with the landslide study site having higher evenness than the undisturbed site.

The rank abundance curve for the Cecil Lake study site highlights the greater richness on the landslide compared to the surrounding undisturbed terrain. The Cecil Lake landslide site also had the highest species richness overall. The Beatton River landslide study site had a much lower richness than the surrounding undisturbed site, with less than half the number of species (41 compared to 91).

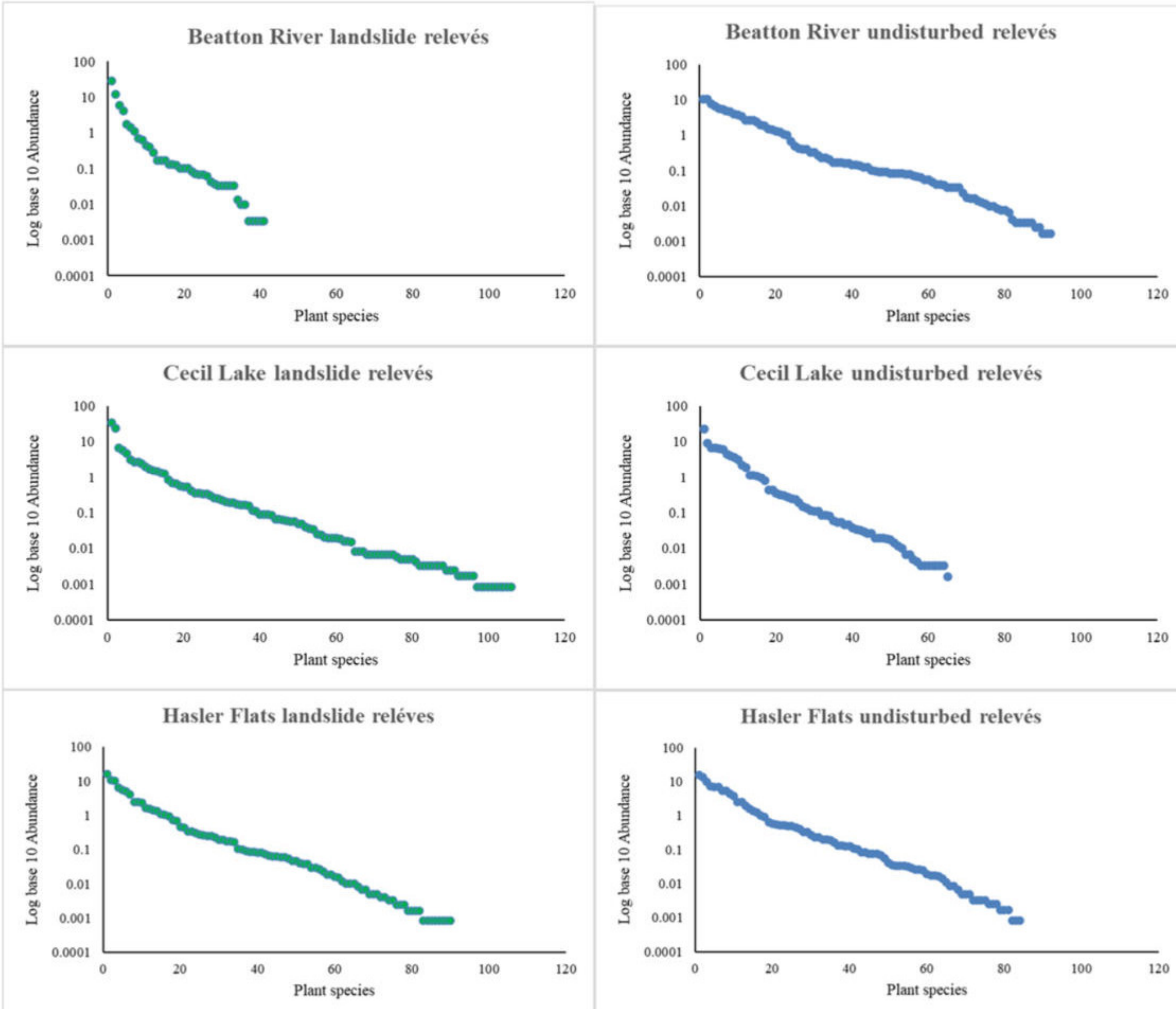

Figure 2-3. Comparison of rank abundance distributions for relevé plot plant species for all study sites. Abundance rank by species is on the x-axis.

2.4.1.4 Kolmogorov-Smirnov two sample comparison for relevés

The Kolmogorov-Smirnov two-sample test to compare the plant composition between the relevés on the paired study sites revealed that for the Beatton River and Cecil Lake study areas, the maximum proportional difference (D statistic) was greater than the critical value (Fig. 2-4). These results rejected the null hypothesis of no difference between the two samples, and indicated there was indeed a difference in plant community diversity structure between the landslide and undisturbed study sites. The opposite was true for the two Hasler Flats study sites, where the maximum D statistic was less than the critical value by half. The null hypothesis of no difference could not be rejected. Overall, the Beatton River study area K-S two sample test had the biggest difference between maximum D statistic and critical value.

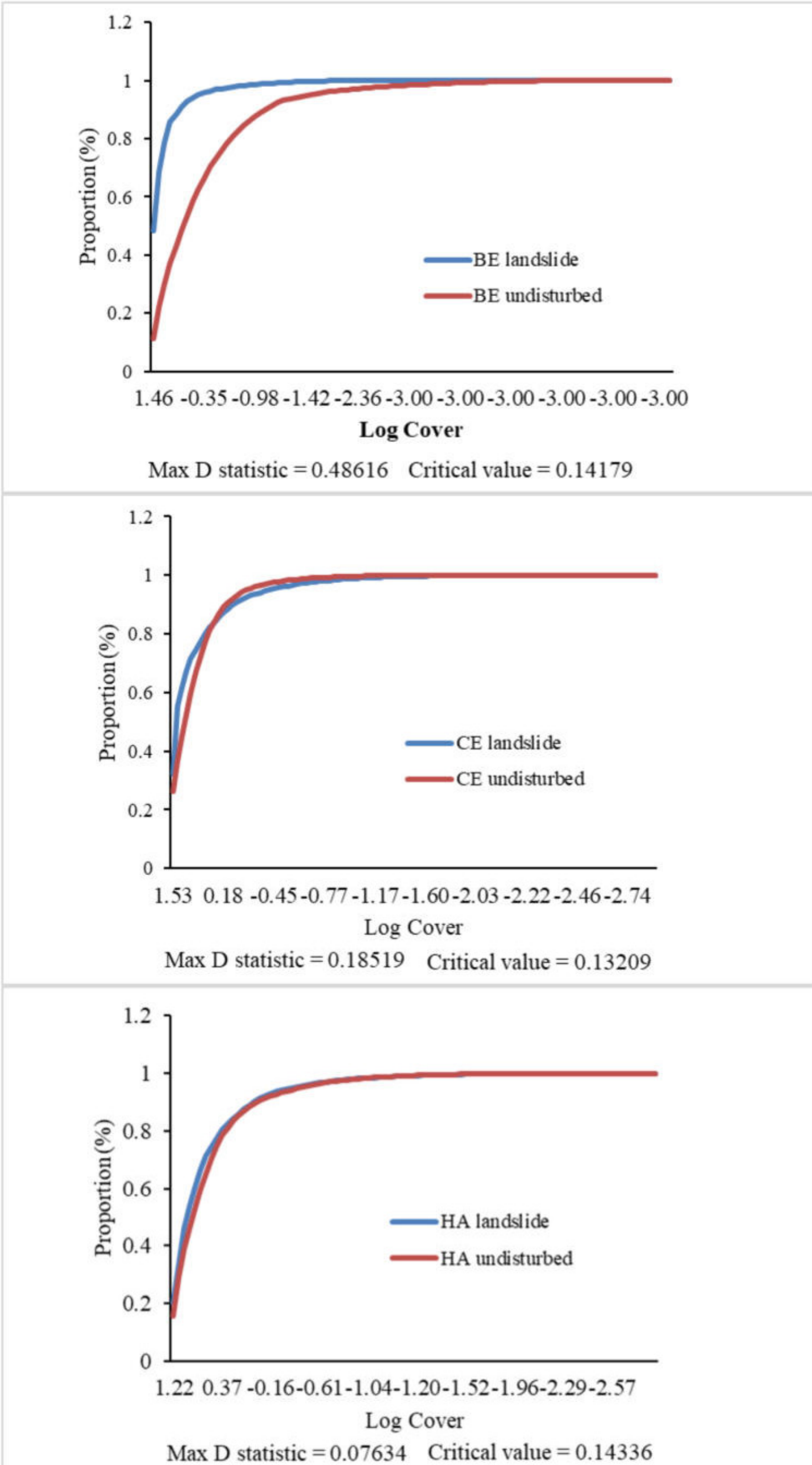

Figure 2-4. Kolmogorov-Smirnov two sample test for all relevés, comparing landslide and undisturbed plant abundance for Beatton River (BE), Cecil Lake (CE), and Hasler Flats (HA) study areas. Results where the maximum D statistic is greater than the critical value indicate a significant difference in plant community between two samples.

2.4.2 NMS ordination of BEC plot data: Assessing patterns and correlations of plant communities and environmental factors

2.4.2.1 Plant species and environment biplot of BEC plots

Nonmetric multidimensional scaling (NMS) ordination using PC-ORD was carried out on the vegetation and environment data for all BEC plots (landslide and undisturbed benchmark) to seek pattern within a matrix of multiple responses, in this case plant species. The Mantel test for redundancy for the six pairs of runs of real data yielded values of 93.84%, 88.37%, 88.92%, 90.62%, 90.46%, and 86.00%, indicating high redundancy. The final (best) solution from the stress test had three dimensions or axes, with stress (i.e. residual sum of squares) of 18.20. Stress directly measures the quality of an ordination. The Monte Carlo test result used 250 randomised runs, with the probability that a similar final stress could have been obtained by chance being 0.0040, or significantly low. The final solution had 138 iterations, with the stress levelling out and plateauing, indicating stability of the solution.

The resulting biplot (Figure 2-5) depicts all the plots in species space, paired with the environmental factors of interest. Axis 1 accounted for 50.7% of the variation in plant species composition, while Axis 2 accounted for 24.0% of the variation, totaling 74.7% of the plant community composition explained. Axis 3 is not shown, but accounted for 12.5% which, combined with Axis 1 and 2, explained a total of 87.2% of the variation in species composition among sites. The point distribution reflects the makeup of the plant community, with similar plots close together in the biplot.

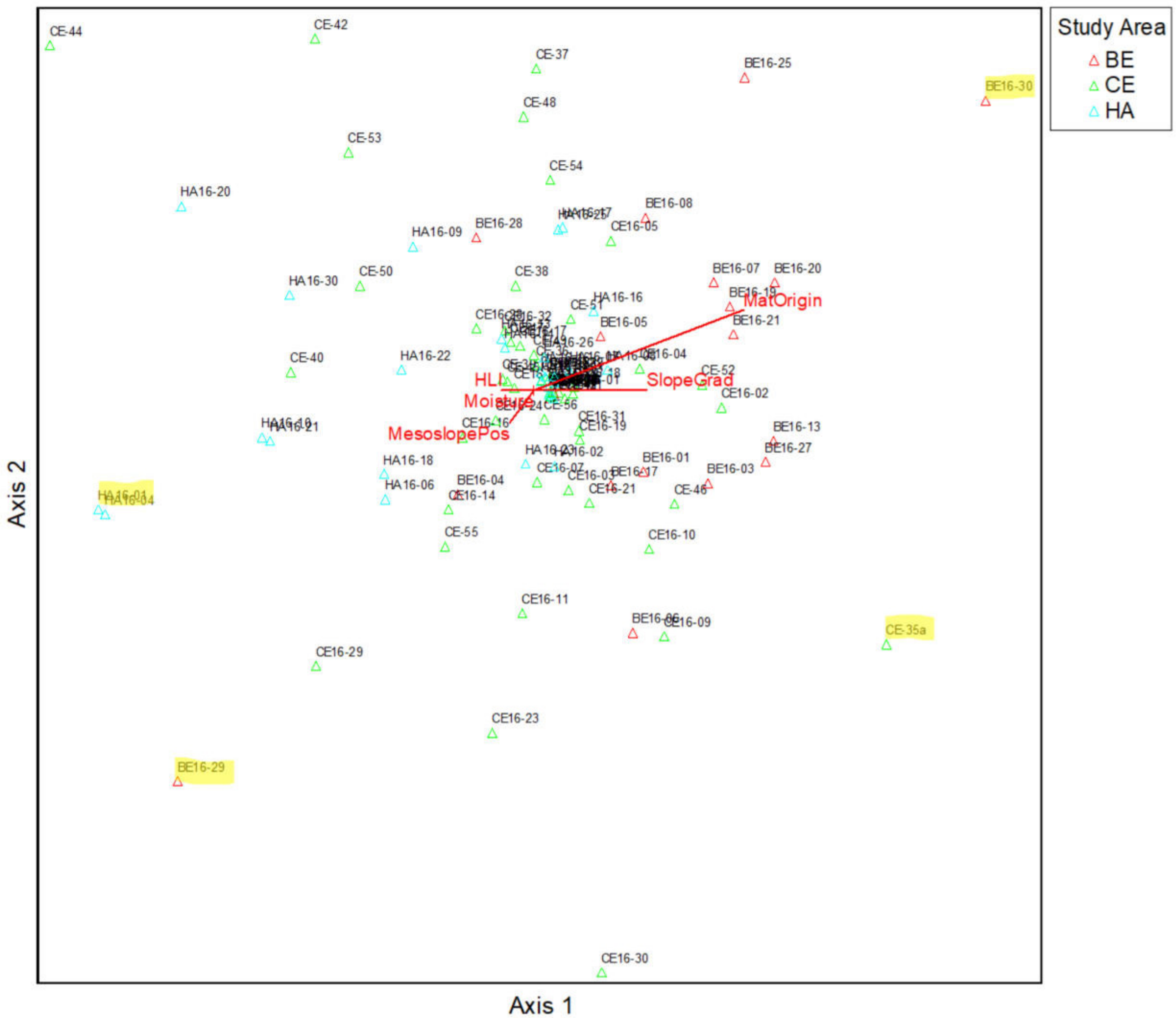

Figure 2-5. NMS (nonmetric multidimensional scaling) ordination biplot of 116 subjectively located averaged BEC (biogeoclimatic ecosystem classification) plots and 163 plant species sampled on three landslide study areas. The scale of the biplot has been increased to 700% due to the crowded distribution of the plots. Axis 1 explains 50% of the variation and represents an apparent gradient from forest community to open/grassland community, from left to right across the figure. Axis 2 explains 24% of the variation and represents an apparent soil moisture gradient from drier to wetter, moving from the upper to lower extent of the figure. Both axes are significant using the Monte Carlo test (p = 0.0040 and final stress = 18.20). Study areas are colour-coded, as shown in the legend. BE = Beatton River, CE = Cecil Lake, and HA = Hasler Flats. The environmental variables correlated with the ordination axes are: MesoslopePos (mesoslope position), Moisture (soil moisture regime), SlopeGrad (slope gradient in %), HLI (heat load index), and MatOrigin (material origin). Strength and nature of environmental variable relationships are represented by the length and direction of the red vectors. Undisturbed benchmark plots BE16-29, BE16-30, CE-35a, and HA16-01 are highlighted in yellow in the biplot.

The resulting statistically significant (randomisation p test = 0.0040) three-dimensional ordination solution shows the distribution of plots for all study areas (Beatton, Cecil, and

Hasler). Axis 1 and Axis 2 represent condensed gradients of differences in the composition of the data matrix. The environmental variables soil moisture regime, mesoslope position, heat load index, slope gradient, and material origin are represented as red vectors in the biplot, radiating out from the centroid.

Axis 1 appeared to represent a gradient from forest community to open/grassland community, moving from left to right. The benchmark plots on the undisturbed terrain (highlighted in Figure 2-5 as BE16-29, BE16-30, CE-35a, and HA16-01) appeared quite different in composition from the associated landslides, as they were much further away from most plots in ordination space. These plots were also different from each other, based on their location on the biplot. Interpretation of Axis 2 is less clear, but it appears to represent a moisture gradient, transitioning from drier to wetter when moving from the lower to upper extent of the axis in ordination space.

2.4.2.2 Plant species correlations with axes using Pearson's correlation coefficient r, for BEC plots

Using the NMS ordination results, Pearson's correlation r was calculated in PC-ORD for each plant species for Axis 1 and Axis 2. Plant species that were strongly correlated with Axis 1 either positively or negatively are shown in Table 2-5. The exotic forb yellow salsify (*Tragopogon dubius*) was most positively correlated with Axis 1, and the next four most positively correlated species were also grassland species. The forb creamy peavine (*Lathyrus ochroleucus*) was most negatively associated with Axis 1, followed by the shrub red honeysuckle (*Lonicera dioica*) and the tree trembling aspen (*Populus tremuloides*).

Table 2-5. Pearson correlations of BEC plot plant species abundance with NMS Axis 1. N = 116.

Positive correlation			**Negative correlation**		
Plant species	**Common name**	**r**	**Plant species**	**Common name**	**r**
Tragopogon dubius	Yellow salsify	0.328	*Lathyrus ochroleucus*	Creamy peavine	-0.625
Pascopyrum smithii	Western wheatgrass	0.316	*Lonicera dioica*	Red honeysuckle	-0.578
Lappula squarrosa	Bluebur	0.312	*Populus tremuloides*	Trembling aspen	-0.577
Koeleria macrantha	Prairie junegrass	0.303	*Viburnum edule*	Highbush-cranberry	-0.537
Achnatherum richardsonii	Richardson's needlegrass	0.299	*Vicia americana*	American vetch	-0.537

Plant species that were most strongly correlated with Axis 2 are shown in Table 2-6. The strongest positive correlation was the shrub species red swamp currant (*Ribes triste*), followed by the forb red clover (*Trifolium pratense*) and the fern ally field horsetail (*Equisetum arvense*), and then the tree balsam poplar (*Populus balsamifera* ssp. *balsamifera*). The plant species with the strongest negative correlation was the forb western meadowrue (*Thalictrum occidentale*), followed by the shrub Sitka alder (*Alnus viridis* ssp. *sinuata*) and then an unknown fern species. Also showing strong negative correlations with Axis 2 were the forb large-leaved avens (*Geum macrophyllum*) and the pixie cup lichen (*Cladonia pyxidata*).

Table 2-6. Pearson correlations of BEC plot plant species abundance with NMS Axis 2. N = 116.

Positive correlation			**Negative correlation**		
Plant species	**Common name**	**r**	**Plant species**	**Common name**	**r**
Ribes triste	Red swamp currant	0.366	*Thalictrum occidentale*	Western meadowrue	-0.483
Trifolium pratense	Red clover	0.351	*Alnus viridis ssp. sinuata*	Sitka alder	-0.400
Equisetum arvense	Field horsetail	0.281	*Unknown fern sp.*	Fern sp.	-0.400
Populus balsamifera ssp. balsamifera	Balsam poplar	0.270	*Geum macrophyllum*	Large-leaved avens	-0.392
Fragaria virginiana	Wild strawberry	0.264	*Cladonia pyxidata*	Pixie cup lichen	-0.356

None of the environmental variables tested exhibited overly strong associations with either of the axes (Table 2-7). However, material origin (MatOrigin) showed a somewhat strong correlation with Axis 2, the apparent moisture gradient, while slope gradient (SlopeGrad) had a weak correlation with Axis 1, the forest-grassland gradient. Mesoslope position

(MesoslopePos), heat load index (HLI), and soil moisture regime (Moisture) all had weak correlations with Axis 1. Of the three variables associated with the forest-grassland gradient, mesoslope position had the strongest association, followed by moisture regime.

Table 2-7. Pearson correlations of environment variables and Axis 1 and Axis 2 of the ordination space. N=116

Variable	Axis 1 (R^2= 50.7)	Axis 2 (R^2= 24.0)
MatOrigin	0.253	0.153
Moisture	-0.023	-0.020
SlopeGrad	0.185	0.024
MesoslopePos	-0.086	-0.101
HLI	-0.103	0.010

PCORD does not report p-values for correlations between variables and ordination axes, because sample sizes are typically large enough that even a very small correlation is "statistically significant". Therefore, usually the lowest r-value is more conservative than the one determined by the p-value (McCune and Grace 2002).

2.4.3 Mapping, classifying, and analysing site series/types using multiple types of plot data

2.4.3.1 Mapping, classifying, and analysing site types/series

The site series digitising exercise yielded a variety of configurations on each of the study sites, with some very small site type polygons next to very large polygons. In total, 20 different site types/site series were identified (Table 2-8).

Table 2-8. Site types/series found on all landslides and undisturbed terrain in the study.

"Site series"	Description*	Beatton landslide m²	Beatton undisturbed m²	Cecil landslide m²	Cecil undisturbed m²	Hasler landslide m²	Hasler undisturbed m²
101	Sw – Trailing raspberry – Step moss	31190	38200	161417	123924	0.0	0.0
102	Pl – Kinnikinnick – Lingonberry	977	0.0	0.0	0.0	0.0	0.0
103	SwPl – Soopolallie – Fuzzy-spiked wildrye	79743	35440	31387	0.0	134	0.0
110	Sw – Oak fern – Sarsaparilla	42487	17430	30929	6990	0.0	0.0
111	Sw – Currant - Horsetail	30142	57600	63888	18784	0.0	0.0
101$	At – Rose – Creamy peavine	82840	48945	134646	250756	6097	10130
103$	At – Rose – Fuzzy-spiked wildrye	0.0	13090	2257	626	1558	0.0
110$	At – Highbush-cranberry – Oak fern	8258	0.0	38737	0.0	628	807
111$6B.1	Acb – Dogwood – Highbush-cranberry	0.0	0.0	58348	0.0	1257	886
111$6B.2	At – Cow-parsnip – Meadowrue	0.0	0.0	0.0	0.0	1056	0.0
112 (Fm02)	AcbSw – Mountain alder – Dogwood	0.0	14460	0.0	0.0	2770	3142
C	Cultivated field	0.0	0.0	0.0	26670	0.0	0.0
Fl	Flood deposits - seasonal	0.0	0.0	6571	0.0	0.0	0.0
FL	Fluvial (creek/river)	0.0	0.0	5989	4600	0.0	0.0
Gb	Brushland	0.0	0.0	0.0	12550	0.0	0.0
Gb51	Saskatoon – Blue wildrye	0.0	46340	0.0	0.0	0.0	0.0
Gg	Grassland	2009	11740	0.0	62477	0.0	0.0
Gg51	Slender wheatgrass – Pasture sage	0.0	17927	0.0	0.0	0.0	0.0
Ro	Rock outcrop	242	0.0	0.0	0.0	0.0	0.0
Rt	Talus	23510	0.0	0.0	53537	0.0	0.0
W	Wetlands/ponds	818	1044	27563	1878	1482	24
	Totals	302216	302216	561732	562792	14982	14989

*Sw=White spruce (*Picea glauca*); Pl=Lodgepole pine (*Pinus contorta*); At=Trembling aspen (*Populus tremuloides*); Acb=Black cottonwood (*Populus balsamifera* ssp. *balsamifera*)

The majority of the site series in Table 2-8 are defined and described in the BWBS field guide (DeLong et al. 2011). As BWBS forests in the Peace River Region contain a notable component of mature deciduous trees, the field guide describes a number of deciduous site series, denoted by the dollar sign symbol $. There are four newly created or modified “site series” categories: cultivated field [C], flood deposits (seasonal) [Fl], fluvial (creek/river) [FL], and wetlands/ponds [W].

Figure 2-6 illustrates an example of site series mapping on the Beatton River landslide.

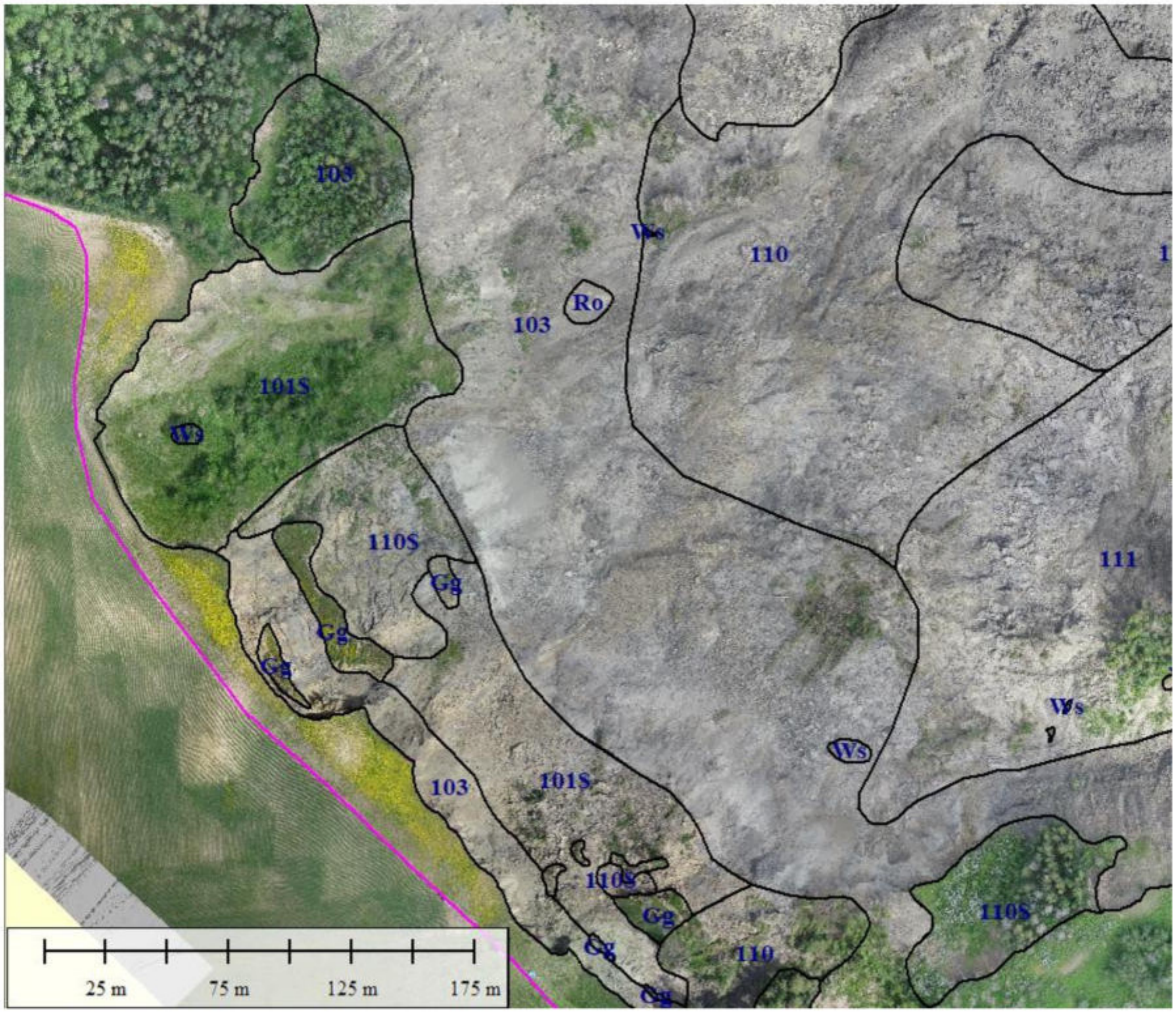

Figure 2-6. Site series/types mapping example for Beatton River landslide study site. Site series/types codes (shown in blue) are 101 = Sw – Trailing raspberry – Step moss, 101$ = At – Rose – Creamy peavine, 103 = SwPl – Soopolallie – Fuzzy-spiked wildrye, 110$ = At – Highbush-cranberry – Oak fern, 111 = Sw – Currant - Horsetail, Gg = Grassland, Ws = Wetland/pond (swamp). Black lines represent site series polygon boundaries. The pink line is the perimeter of the undisturbed terrain study site surrounding the landslide.

The results of the site series mapping and classification exercise showed a change in site series composition, area, and polygon count when comparing the landslide study site to the surrounding undisturbed terrain. The site series/types were graphed in order of moisture regime on paired bar charts, from driest to wettest, for each study area (Figure 2-7). For the

Beatton River landslide study site, the 101$ (i.e. mesic deciduous) site series occupied the highest proportion of the total study site area (27.4%), followed closely by 103, a somewhat drier site series, at 26.4 %. The next most abundant type on the Beatton River landslide was the moist site series 110 (14.1%), followed by the mesic coniferous 101 (10.3%) and then the very dry Rt site series (7.8%). The two mesic site series occupied 37.7% of the total landslide area. For the Beatton River undisturbed terrain study site, the leading site series was 111, a coniferous wet type (19.1%), followed closely by the deciduous mesic 101$ (16.2%) and the dry Gb51 (brushland) at 15.3%. The next highest abundance on the Beatton River undisturbed site was the coniferous mesic site series 101 (12.6%) and then the drier 103 (11.7%). Combined, the two mesic site series occupied 28.8% of the total undisturbed area.

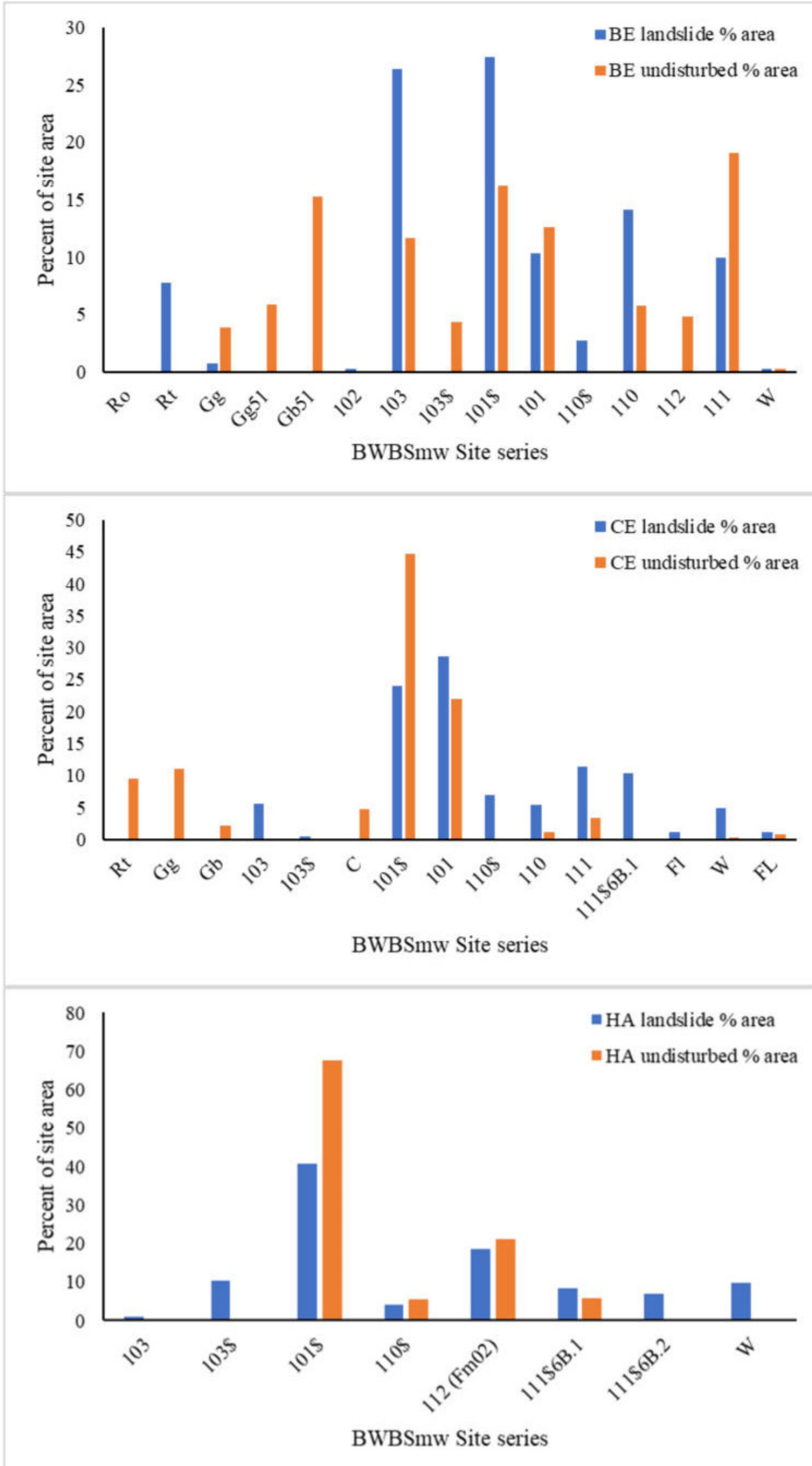

Figure 2-7. Site series percent area paired graphs for Beatton River, Cecil Lake, and Hasler Flats study areas, with categories ordered from low (left) to high (right) moisture regime.

Overall, there were more site series polygons on the Beatton River landslide study site (43) than the undisturbed study site (29). The landslide study site had a higher percentage of mesic site series area, as well as a higher ratio of deciduous to coniferous mesic site series area. There was a similar number of mesic polygons on the Beatton River landslide and on the undisturbed terrain, but the mean sizes and ranges were markedly different. The landslide had a higher proportion of dry site series area compared to the undisturbed terrain. Although the landslide contained five times more pond polygons than the undisturbed study site, the undisturbed ponds were on average six times larger.

For the Cecil Lake landslide study site, the mesic 101 site series per cent area was leading (28.7%) followed closely by its mesic deciduous equivalent 101$ (24.0%). The next two most abundant site series were 111 (11.4%) and 111$6B.1 (10.4%), which were wet types. For the Cecil Lake surrounding undisturbed terrain study site, the mesic deciduous 101$ site series area dominated (44.6%), followed by its coniferous equivalent 101 (22.0%). The next most abundant site series by per cent of total undisturbed area were grassland (Gg 11.1%) and talus (Rt 9.5%), which are dry types. Overall, mesic site series dominated on both the landslide and undisturbed terrain of the Cecil Lake study area, with coniferous 101 per cent area greater than deciduous 101$ on the landslide, and the opposite trend on the undisturbed terrain.

There were more than four times as many site series/types polygons on the Cecil Lake landslide compared to the undisturbed terrain (381 polygons vs. 86), but almost 75% of the landslide polygons were ponds. There were 71 times more pond polygons on the landslide study site than on the surrounding undisturbed terrain. However, the ponds on the Cecil Lake undisturbed terrain were an average of almost five times larger than the landslide ponds.

On the Hasler Flats landslide study site, the 101$ deciduous site series was leading (40.7% of the total area), followed by a much wetter site series, 112 (Fm02), which was 18.5 %. The pattern was similar for the undisturbed terrain study site, with 101$ at 67.6 % and 112 (Fm06) at 21.0 % of the total study site area. The third most abundant site series on the Hasler Flats landslide was a very dry type, 103$ (10.4 %), followed by ponds (W) at 9.9 %, and then two very wet site series, 111$6B.1 (8.4 %) and 111$6B.2 (7.0 %). On the Hasler Flats undisturbed study site, the third most abundant site type was 111$6B.1 (5.9 %) followed by the moist site 110$ (5.4 %). Ponds occupied only 0.2 % of the total undisturbed area.

Overall, the Hasler Flats landslide had more site series/types than the undisturbed terrain and there were significantly more individual polygons. The Hasler Flats landslide study site had eight site series, while the undisturbed terrain study site had five site series. The landslide had 47 polygons, while the undisturbed terrain had just seven polygons. The mean size of most polygons was smaller on the landslide. However, the pond polygons (W) on the landslide had a much larger mean size than those on the undisturbed study site, and there were also thirteen times more individual pond polygons on the landslide study site.

The diversity indices of the site series for the study sites for all three study areas (Table 2-9) indicate that the Beatton River undisturbed terrain was more diverse in site series/type composition than the landslide for Shannon diversity H’, Pielou’s evenness J, and Simpson’s index of diversity 1-D. In contrast, the Cecil Lake and Hasler Flats landslide study sites were more diverse in site series /type composition than the surrounding undisturbed terrain regarding Shannon diversity, Pielou’s evenness, and Simpson’s index of diversity. In terms of richness, the value was the same both on and off the slide for Beatton River and Cecil

Lake study areas. The Hasler Flats study area, however, had a higher richness of site series/types on the landslide study site compared to the surrounding undisturbed terrain (8 site series vs. 5). Of the three study areas, Hasler Flats also had the biggest difference between each pair of index values comparing landslide and undisturbed study sites.

Table 2-9. Diversity indices for site series polygons - all study sites. BE = Beatton River, CE = Cecil Lake, HA = Hasler Flats.

Site	Richness (S)	Shannon diversity index (H')	Pielou's evenness (J)	Simpson's index of diversity (1-D)
BE -Landslide	11	1.817	0.758	0.808
BE - Undisturbed	11	2.170	0.905	0.872
CE - Landslide	11	1.959	0.817	0.823
CE - Undisturbed	11	1.624	0.677	0.728
HA - Landslide	8	1.712	0.823	0.766
HA - Undisturbed	5	0.927	0.576	0.493

The Kolmogorov-Smirnov two sample test for all three study areas (Fig. 2-8) showed that there was no significant difference between landslide and undisturbed site series diversity. This finding is evidenced by the fact that the critical value is higher than the maximum D statistic in all three cases.

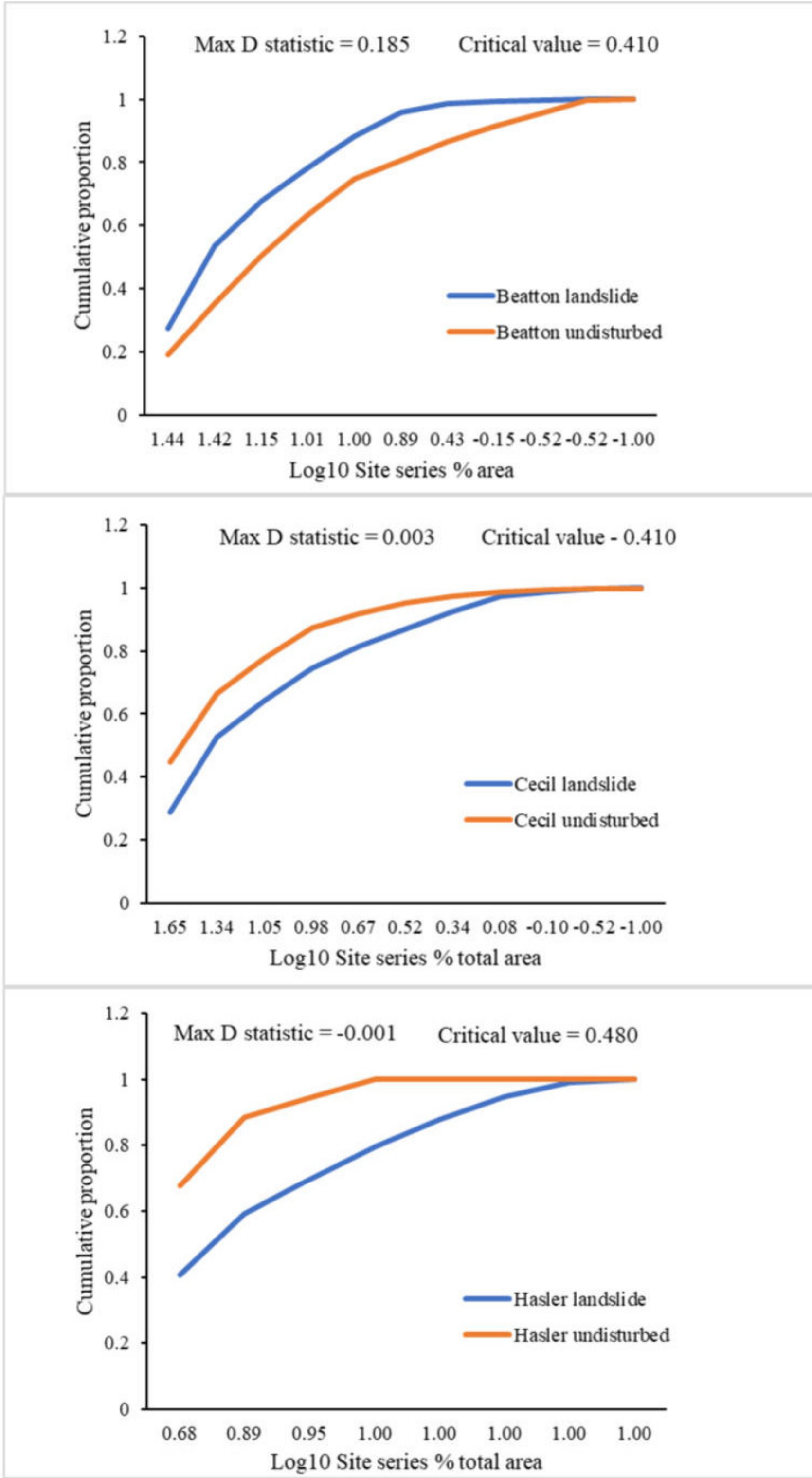

Figure 2-8. Site series Kolmogorov-Smirnov two sample tests for the paired study sites of each study area of Beatton River, Cecil Lake, Hasler Flats. For all three tests, the critical value is greater than the D statistic, indicating no significant difference.

2.4.4 Mapping, classifying, and analysing biophysical features using multiple types of plot data

2.4.4.1 Geotyping: Mapping, classifying, and analysing geomorphic features

Landslide Geotypes

In the geotyping exercise, 20 different geomorphic types were identified and digitised over the three landslide study sites. A glossary describing each classification is found in Appendix 4. Figure 2-9 shows an example of the digitised geotyping on the Cecil Lake landslide study site.

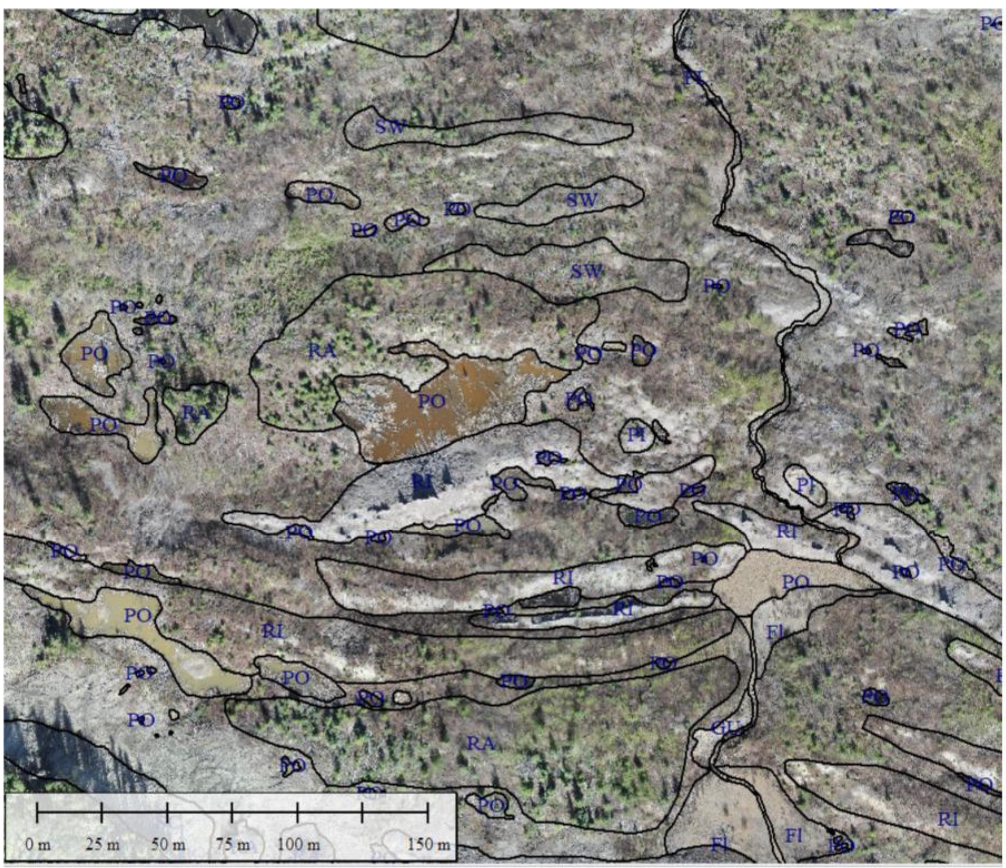

Figure 2-9. Example of digitised geotyping on the Cecil Lake landslide. Geotype codes (shown in blue) are PO = Pond/wet area, RI = Ridge, RA = Raft, PI = Pillar, Fl = Flood deposits -seasonal, SW = Swale, GU = Gully. The black lines are polygon boundaries.

The summaries of the resultant geotyped areas for each of the three landslides are presented in Table 2-10. Comprehensive tables listing each geotype polygon and its associated area for each landslide are provided in Appendix 5. For Beatton River and Cecil Lake, the slide matrix geotype occupied the largest percentage of the total area of the landslide study site. The slide matrix component was highest (almost 69%) on the Cecil Lake landslide and lowest (36.83%) on the Hasler Flats landslide. The leading geotype by percent area for Hasler Flats was rafts, at 45.72%. The second highest geotype percentage for both Beatton River and Cecil Lake was hummocks, at 14.25% and 10%, respectively, while for Hasler Flats the second highest geotype area was the landslide matrix (36.83%). The third and fourth highest geotype percentages were scarp (9.16%) and raft (8.54%) for Beatton River, raft (6.65%) and pond (4.91%) for Cecil Lake, and pond (9.89%) and scarp (6.03%) for Hasler Flats.

Table 2-10. Landslide geotype summary by area (m^2) and percentage.

		Beatton			Cecil			Hasler		
Geotype	Description	Count	Geotype Area (m^2)	% of Total Area	Count	Geotype Area (m^2)	% of Total Area	Count	Geotype Area (m^2)	% of Total Area
AP	Apron	1	9240	3.06	NA	NA	NA	NA	NA	NA
BA	Bank	NA	NA	NA	NA	NA	NA	NA	NA	NA
BE	Bench	NA	NA	NA	NA	NA	NA	NA	NA	NA
BL	Blocky site	4	19516	6.46	NA	NA	NA	NA	NA	NA
BS	Sandstone bedrock	1	802	0.27	NA	NA	NA	NA	NA	NA
CU	Cultivated field	2	225.2	0.07	NA	NA	NA	NA	NA	NA
DF	Debris flow	1	2996	0.99	NA	NA	NA	NA	NA	NA
DP	Depression	NA	NA	NA	NA	NA	NA	NA	NA	NA
EF	Earthflow	NA	NA	NA	1	240	0.04	NA	NA	NA
FL	Fluvial	1	165.6	0.05	3	5990	1.07	NA	NA	NA
FI	Flood deposits -seasonal	NA	NA	NA	4	6570	1.17	NA	NA	NA
FP	Floodplain	NA	NA	NA	NA	NA	NA	NA	NA	NA
GU	Gully	1	370.7	0.12	1	222.8	0.04	NA	NA	NA
HU	Hummocks	1	43060	14.25	3	56220	10	NA	NA	NA
PI	Pillar	NA	NA	NA	2	279.1	0.05	NA	NA	NA
PL	Plateau	NA	NA	NA	NA	NA	NA	NA	NA	NA
PO	Pond/wet area	15	818.1	0.27	284	27570	4.91	26	1482	9.89
RA	Raft	13	25804.6	8.54	11	37390	6.65	8	6850	45.72
RB	Rotational blocks	2	1055.6	0.35	NA	NA	NA	NA	NA	NA
RF	Rockfall/topple	4	10815	3.58	NA	NA	NA	NA	NA	NA
RI	Ridge	NA	NA	NA	12	25870	4.6	2	230.5	1.54
RU	Rubble	3	19694.8	6.52	NA	NA	NA	NA	NA	NA
SB	Sandbar	NA	NA	NA	NA	NA	NA	NA	NA	NA
SC	Scarp	6	27673.1	9.16	2	11710	2.08	2	903	6.03
SG	Steep grassy slope	NA	NA	NA	NA	NA	NA	NA	NA	NA
SM	Slide matrix	1	139863.3	46.3	1	387014.1	68.86	1	5517.5	36.83
ST	Steep treed slope	NA	NA	NA	NA	NA	NA	NA	NA	NA
SW	Swale/wrinkle	NA	NA	NA	3	2924	0.52	NA	NA	NA
TA	Talus/scree	NA	NA	NA	NA	NA	NA	NA	NA	NA
Total Area			302100			562000			14983	

The number and composition of geotype polygons differed markedly among landslide study sites. Beatton River landslide study site had 56 separate geotype polygons, Cecil Lake had 327 polygons, and Hasler Flats had 39 polygons. For all three landslides, ponds had the highest geotype polygon count. On the Cecil Lake landslide study site, ponds comprised almost 87% of the total number of polygons, but they only added up to 4.9% of the total area. Ridges had the second highest polygon count on the Cecil Lake landslide, followed closely by rafts. On the Beatton River and Hasler Flats landslides, rafts had the second highest polygon count. The third highest polygon count for the Beatton River landslide study site was represented by scarps, while for Hasler Flats scarps and ridges were tied for third place. The Beatton River study site had 15 different geotypes, Cecil Lake had 12 different geotypes, and Hasler Flats had five different geotypes.

The diversity indices for geotypes (Table 2-11) showed that the Beatton River landslide had the highest geotype richness, Shannon index, and Simpson's diversity of the three landslide study sites. The Beatton River landslide study site also had a higher Shannon diversity, Pielou's evenness, and Simpson's diversity than the oldest landslide, Cecil Lake. Hasler Flats had the lowest richness but the highest Pielou's evenness.

Table 2-11. Geotype diversity indices for landslide geotype polygons.

Site	Richness (S)	Shannon diversity index (H')	Pielou's evenness (J)	Simpson's index of diversity (1-D)
Beatton River	15	1.759	0.650	0.739
Cecil Lake	12	1.176	0.473	0.506
Hasler Flats	5	1.188	0.738	0.642

Undisturbed Geotypes

The results of the digitising of geotypes in the undisturbed terrain are presented in Table 2-12. Observations of the terrain in the field and on digital imagery showed a general trend of larger, more contiguous geotype polygons in the undisturbed areas for all three landslides. Digitising and summarising the polygons confirmed this, as all three undisturbed study sites had fewer types but larger, more extensive polygons. However, there appeared to be a greater diversity of geotypes on the landslides compared to the surrounding undisturbed terrain.

Table 2-12. Undisturbed geotype summary by area (m^2) and percentage.

Geotype	Description	Beatton River Undisturbed			Cecil Lake Undisturbed			Hasler Flats Undisturbed		
		Count	Geotype Area (m^2)	% of Total Area	Count	Geotype Area (m^2)	% of Total Area	Count	Geotype Area (m^2)	% of Total Area
AP	Apron	NA	NA	NA	NA	NA	NA	NA	NA	NA
BA	Bank	NA	NA	NA	1	19210	3.42	NA	NA	NA
BE	Bench	NA	NA	NA	NA	NA	NA	4	1911	12.75
BL	Blocky site	NA	NA	NA	NA	NA	NA	NA	NA	NA
BS	Sandstone bedrock	NA	NA	NA	NA	NA	NA	NA	NA	NA
CU	Cultivated field	1	11750	3.89	2	26670	4.74	NA	NA	NA
DF	Debris flow	NA	NA	NA	NA	NA	NA	NA	NA	NA
DP	Depression	1	9250	3.06	NA	NA	NA	2	927	6.19
EF	Earthflow	NA	NA	NA	NA	NA	NA	NA	NA	NA
FL	Fluvial	NA	NA	NA	3	4600	0.82	NA	NA	NA
Fl	Flood deposits -seasonal	NA	NA	NA	NA	NA	NA	NA	NA	NA
FP	Floodplain	1	65000	21.51	1	1014	0.18	2	3172	21.17
GU	Gully	NA	NA	NA	NA	NA	NA	NA	NA	NA
HU	Hummocks	NA	NA	NA	NA	NA	NA	NA	NA	NA
PI	Pillar	NA	NA	NA	NA	NA	NA	NA	NA	NA
PL	Plateau	NA	NA	NA	3	113100	20.12	1	6190	41.30
PO	Pond/wet area	3	1044	0.35	4	1878	0.33	2	23.5	0.16
RA	Raft	NA	NA	NA	NA	NA	NA	NA	NA	NA
RB	Rotational blocks	NA	NA	NA	NA	NA	NA	NA	NA	NA
RF	Rockfall/topple	NA	NA	NA	NA	NA	NA	NA	NA	NA
RI	Ridge	NA	NA	NA	NA	NA	NA	NA	NA	NA
RU	Rubble	1	11900	3.94	NA	NA	NA	NA	NA	NA
SB	Sandbar	1	9310	3.08	NA	NA	NA	NA	NA	NA
SC	Scarp	NA	NA	NA	NA	NA	NA	5	2763	18.44
SG	Steep grassy slope	1	99100	32.80	1	184300	32.79	NA	NA	NA
ST	Steep treed slope	2	94800	31.37	2	157800	28.07	NA	NA	NA
SM	Slide matrix	NA	NA	NA	NA	NA	NA	NA	NA	NA
SW	Swale/wrinkle	NA	NA	NA	NA	NA	NA	NA	NA	NA
TA	Talus/scree	NA	NA	NA	3	53500	9.52	NA	NA	NA

Diversity indices were calculated for the undisturbed geotypes (Table 2-13). Results show that the Cecil Lake study site had the highest richness, while Hasler Flats had the lowest richness. The Cecil Lake undisturbed terrain also had the highest Shannon index and Simpson’s index. The Hasler Flats undisturbed study site had the lowest Shannon and Simpson’s indices, but the highest Pielou’s evenness value.

Table 2-13. Geotype diversity indices for undisturbed geotype polygons.

Site	Richness (S)	Shannon diversity index (H')	Pielou's evenness (J)	Simpson's index of diversity (1-D)
Beatton River	8	1.547	0.744	0.743
Cecil Lake	9	1.599	0.728	0.761
Hasler Flats	6	1.450	0.810	0.731

Comparing landslide geotype diversity vs undisturbed geotype diversity

Rank abundance curves for geotype data were plotted for each of the six study sites (Fig. 2-10). The results show that the undisturbed sites had a lower evenness overall, illustrated by the steeper curve. However, the landslide sites had higher richness for Beatton River and Cecil Lake.

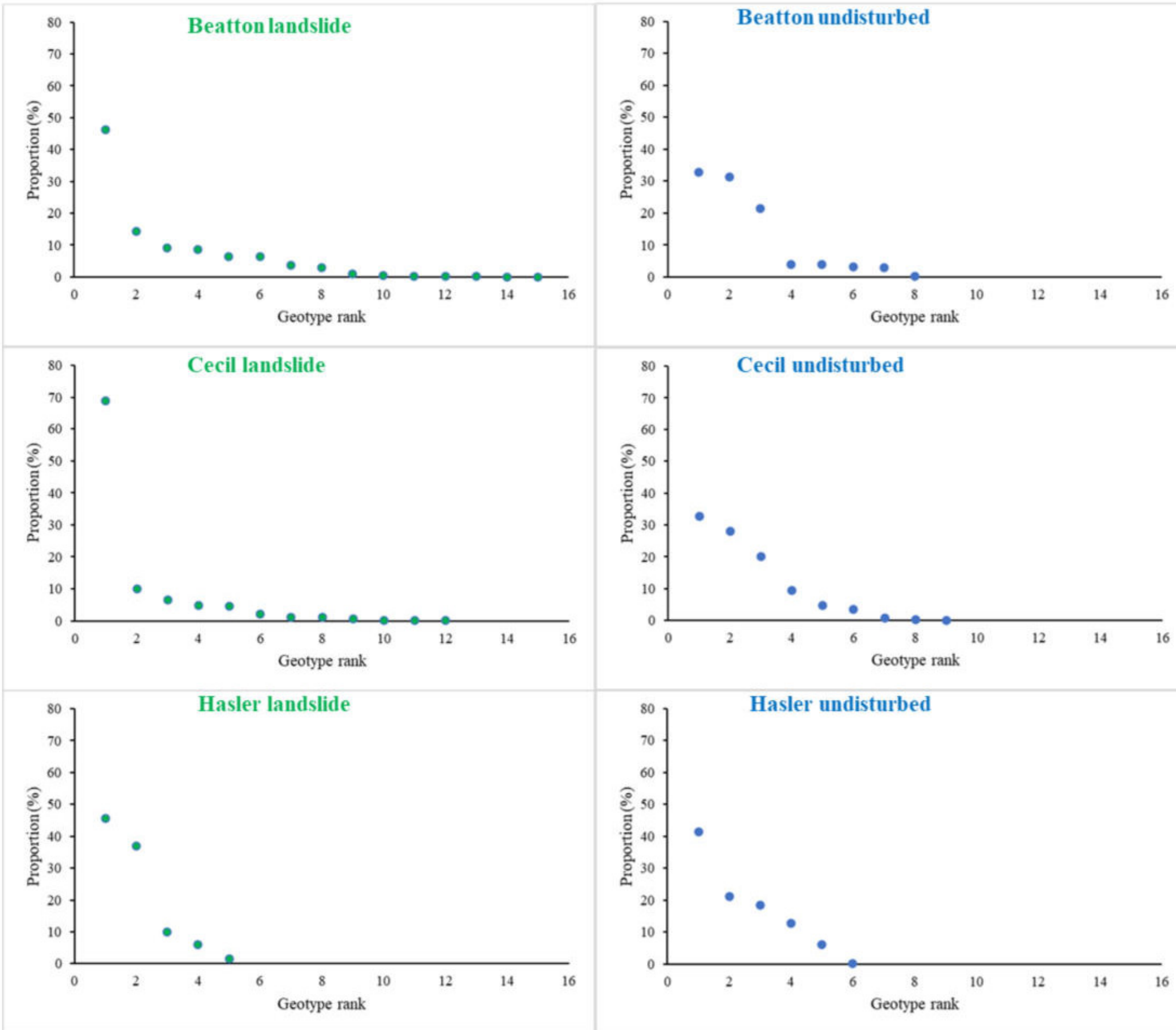

Figure 2-10. Rank abundance curves comparing geotype diversity on landslides and undisturbed terrain.

2.4.4.2 Surface roughness/microtopography of BEC plots

The results of the microtopography (surface roughness) exercise showed a range of coefficients of variation between the BEC plots for each landslide site, as shown in Table 2-10. The number of points for each buffered plot varied based on the quality of the LiDAR imagery and ranged from 48 to 120 points. A table summarising elevation point statistics for each buffered BEC plot is provided in Appendix 6.

Table 2-14. BEC 50m^2 plot LiDAR points: Elevation coefficient of variation (CV) summary statistics.

Landslide	Number of plots (n)	Mean CV (%)	Min CV (%)	Max CV (%)	Range of CV (%)
Beatton River	28	59.59	41.82	139.42	97.59
Cecil Lake	29	56.24	22.46	118.97	96.51
Hasler Flats	29	54.23	29.93	98.30	68.38

Beatton River, which was the most recent landslide, had the highest mean elevation CV, whereas the Hasler Flats landslide had the lowest mean CV. The same pattern existed for the range of CV, where Beatton River landslide had the highest range and Hasler Flats landslide had the lowest range. Cecil Lake and Hasler Flats landslides had a much smaller minimum CV overall (22.46% and 29.93%, respectively) than Beatton River (41.82%). Beatton River also had the highest maximum CV, at 139.42%. All three landslides contained at least one plot with an elevation CV greater than 100%.

Only a few plots were available for an assessment of the surface roughness on the surrounding undisturbed terrain for each study area, as the original plot sampling focused mainly on the landslide, with one plot in the undisturbed terrain for Cecil Lake and Hasler Flats and two plots in the undisturbed terrain for Beatton River. There were insufficient plots for a true comparison with the landslide plots. Additionally, the LiDAR point data used for analysing microtopography on the landslides study sites did not extend enough beyond the landslide area to provide adequate coverage of the adjacent undisturbed sites to calculate elevation CV for these areas. However, observations obtained from traversing the undisturbed terrain during subsequent sampling for this chapter showed that this terrain was generally smoother and less varied than the landslide body. This was also evidenced by the greatly reduced number of ponds on the undisturbed study sites for all study areas.

2.4.4.3 Assessing correlation between vegetation diversity and geotype diversity

Simple linear regression analyses were run to assess whether there was a significant association of vegetation diversity with geotype diversity in terms of richness, Shannon diversity, Pielou's evenness, and Simpson's diversity (Fig. 2-11).

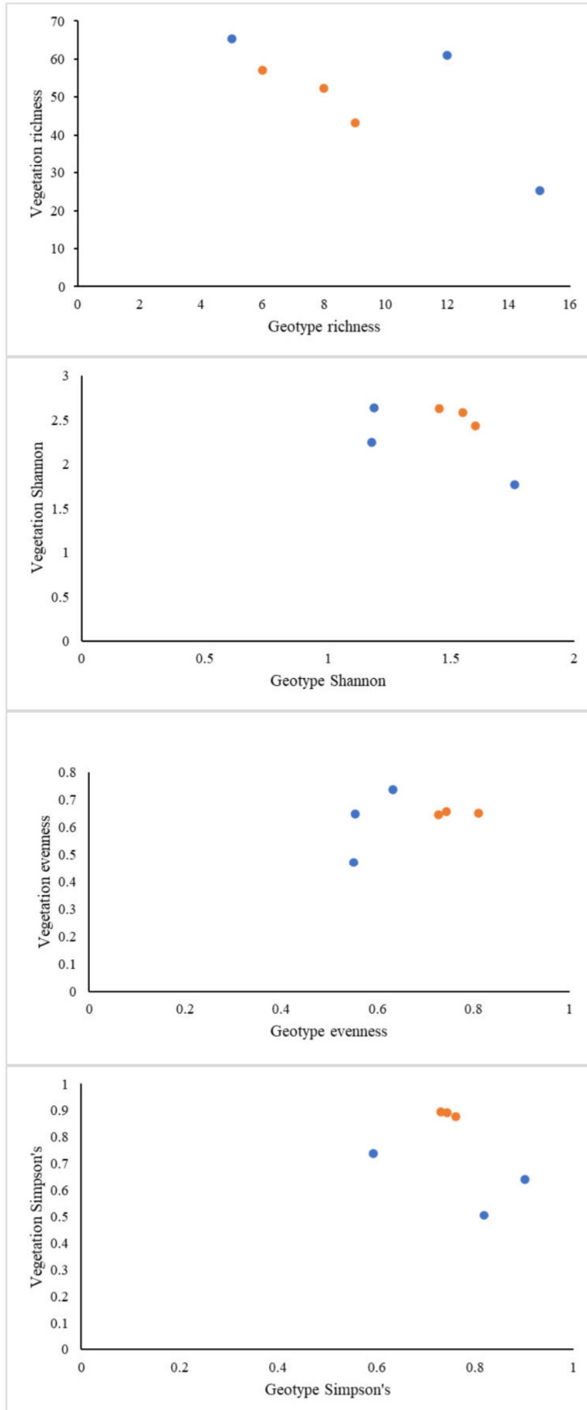

Figure 2-11. Relationships between relevé vegetation diversity and geotype diversity in terms of richness, Shannon diversity, Pielou's evenness, and Simpson's diversity for all three landslide study areas. Blue dots represent landslide sites and orange dots represent undisturbed sites for each study area. Regression lines are not shown, as no significant regression relationship was found for any of the comparisons.

Regression results were obtained for landslide richness ($R^2 = 0.632$, $F(1,1) = 1.718$, $p = 0.415$), landslide Shannon diversity ($R^2 = 0.778$, $F(1,1) = 3.495$, $p = 0.313$), landslide Pielou's evenness ($R^2 = 0.607$, $F(1,1) = 1.546$, $p = 0.431$), and landslide Simpson's diversity ($R^2 = 0.404$, $F(1,1) = 0.677$, $p = 0.562$). In addition, regression results were obtained for undisturbed richness ($R^2 = 0.868$, $F(1,1) = 6.601$, $p = 0.236$), undisturbed Shannon diversity ($R^2 = 0.798$, $F(1,1) = 3.944$, $p = 0.297$), undisturbed Pielou's evenness ($R^2 = 0.0376$, $F(1,1) = 0.0391$, $p = 0.876$), and undisturbed Simpson's diversity ($R^2 = 0.926$, $F(1,1) = 12.485$, $p = 0.176$). For all comparisons, and contrary to expectations, geomorphological diversity did not significantly predict vegetation diversity.

2.5 Discussion

This research chapter set out to answer some key questions related to the biophysical diversity of landslides in northeastern BC. The main hypothesis underpinning the research was that landslides are biophysically more diverse than nearby relatively undisturbed terrain, with a greater diversity of plant communities, species abundances, geomorphic types, and microsites. The methods employed to answer the questions consisted of a series of subjective and random vegetation sampling, as well as NMS ordination, species composition and abundance analyses, diversity index calculations, and classification and GIS mapping of biophysical features. The findings of this research point to a partial confirmation of the hypothesis that landslides are more diverse than the surrounding landscape, but this is not always the case. Results also indicate that landslide ecology is more complex than conventional succession theories would suggest.

1) How does plant species composition, abundance, and distribution differ on landslides compared to adjacent undisturbed terrain?

Plant diversity of relevés

Contrary to what was expected, the rank abundance curves and calculated evenness, Shannon, and Simpson diversity indices for the Beatton River and Cecil Lake study areas show the vegetation of the relevés on the undisturbed study sites is generally more diverse than on the landslides, while for the Hasler Flats study area there is no significant difference between disturbed and undisturbed relevés. The lower evenness on the landslides indicates a few species, especially exotics such as *Melilotus* spp. and *Sonchus* spp., are very abundant and there are many species with low relative abundances. These findings could be due to the surrounding terrain being much older than the landslide. As the landslides ranged between two and twenty years old at the time of sampling, not enough time had passed to allow the full spectrum of available plant species to establish. In addition, the headscarp was adjacent to an anthropogenically modified site for all three landslides: Beatton River and Cecil Lake landslides were both next to agricultural fields of forage crops, while Hasler Flats landslide was adjacent to a young deciduous cutblock. Anthropogenically developed or modified areas are usually relatively low in plant species diversity compared to the surrounding landscape. Further, the plants in cultivated agricultural fields are commonly grasses and other fast growing pioneer species which spread easily via wind and runoff.

The greater richness on the landslide compared to the undisturbed terrain for Cecil Lake and Hasler Flats landslides in contrast to Beatton River may be because the Beatton River landslide study site was the most recently disturbed slide and had a higher proportion of bare or sparsely vegetated areas. The Beatton landslide was largely a reactivation of a previous landslide. Thus, the randomly placed relevés were more likely to land on areas of low vegetation cover consisting of mainly exotic species. The Cecil Lake landslide study site had the highest species richness overall, likely because it was the oldest of the three slides and successional processes had allowed more species to establish. However, on the Cecil Lake landslide the leading species was still a fern ally (*Equisetum arvense*), while the second leading species was a shrub (*Alnus viridis* ssp. *sinuata*).

Evenness measures how evenly species abundances are distributed in a plant community, and as its value increases, so does diversity. Mean Pielou's evenness, J, was higher on the undisturbed terrain study sites compared to the landslide study sites for all three study areas, and all three undisturbed study sites had almost identical evenness values. In addition, the Beatton River and Cecil Lake study areas had identical evenness values on the landslide study sites, although Beatton River had slightly more variability. The paired Hasler Flats study sites had a much smaller difference between each other compared to Beatton River and Cecil Lake, and the Hasler Flats landslide had the highest evenness of the three landslide study sites. Overall, these findings suggest that the landslides are very similar in distribution of species abundances, despite the differences in sizes and ages. However, analysis of the top ten leading species on each study area revealed that although the three landslides all had high values of *Equisetum arvense*, *Rubus idaeus*, and *Populus tremuloides*, they each had a different array of leading species. The differences in species composition and abundances are most likely due to the propagule sources and amounts, as well as the available substrates on each landslide.

The Shannon index, H', and Simpson's index of diversity, 1-D, both indicated that vegetation was more diverse on the undisturbed terrain for Beatton River and Cecil Lake study areas but was very similar for the paired Hasler Flats study sites. Mean Shannon indices and mean Simpson's indices of diversity were higher on the undisturbed terrain than on the landslide for the Beatton River and Cecil Lake study areas, but slightly lower on the undisturbed terrain compared to the landslide for the Hasler Flats study area. The Beatton River study area had the biggest difference in both Shannon and Simpson's diversity between its paired study sites. The lower diversity on the Beatton River and Cecil Lake landslide study sites compared to the surrounding undisturbed terrain may be due to vegetation dynamics influenced by disturbance. Vegetation dynamics are driven by site availability, species availability, and species performance, and changes in any of these conditions can alter plant communities (Pickett et al. 2009). On the Beatton River landslide, *Melilotus* spp. and other exotics dominated on large portions of recently disturbed substrate, while on the Cecil Lake landslide, *Alnus* spp. and *Equisetum arvense* were widespread. Vegetation dynamics are intrinsically connected to landscape ecology, disturbance ecology, competition, invasion ecology, and community assembly. The process of recovery of landslide surfaces is complex due to the high spatial and temporal variability of soil stability and fertility (Walker et al. 2009). Surface soil erosion and patchiness of soil fertility can significantly hinder plant community development.

The minimal difference in Shannon and Simpson's diversity between the landslide and undisturbed terrain at Hasler Flats compared to the Beatton River and Cecil Lake study areas may be because the Hasler Flats landslide was much smaller, more gently sloped, and had a much high proportion of rafted material originating from the surrounding terrain, providing a mosaic of stable and fertile substrates and propagules for new vegetation. Further, the adjacent cutblock above the headscarp at Hasler was approximately 15 years old, with established shrubs and forbs in the understory. A greater diversity of plant species was available from this source compared to above the headscarps at the Beatton River or Cecil Lake study areas.

The biological legacies or residuals left after disturbance seem to be interacting with landslide size, age, and disturbance intensity in the study areas to influence vegetation dynamics, in agreement with other studies (Turner et al. 1998). Residual vegetation from vegetated rafts and chunks of intact soil can spread via seed banks, propagules, suckers, rhizomes, or serotinous cones. The life history traits of plants present at the time of disturbance interact with the disturbance intensity to influence the species composition of residuals. Succession occurs on a continuum of the role of residuals compared to new invaders, as well as a separate continuum of soil development (Franklin et al. 2000; Franklin and MacMahon 2000; Dale et al. 2005). Residuals are affected by the spatial variability and intensity of the disturbance, and thus larger disturbances such as the Cecil Lake landslide may present a greater degree of uncertainty and variability in successional pathways (Foster et al. 1998; Turner et al. 1998).

Hill numbers represent true diversity, or the effective number of equally abundant species required to achieve a specific diversity measure value. For the Cecil Lake and Hasler Flats study areas, the Hill number $q = 0$ (richness) was higher on the landslide study sites, whereas on the Beatton River study area, $q = 0$ was higher on the undisturbed study site. However, for all other Hill numbers ($q = 1, 2$, and ∞), the value was higher on the undisturbed terrain for Cecil Lake and Beatton River but higher on the landslide for Hasler Flats. These findings are consistent with the trends from the calculations of Shannon and Simpson's diversities. The Hasler Flats study area has the smallest Hill number differences between paired study sites, while the Beatton River study area shows the biggest differences between paired study sites. These findings indicate once again that the Beatton River study area has the biggest difference in diversity between landslide and undisturbed terrain, and the Hasler Flats study area has the smallest difference. The lower diversity on the Beatton River landslide study site compared to the undisturbed terrain is most likely attributable to the young age of the landslide and the fact it is still quite active. In addition, the proximity of the hay field just above the scarp, along with the steep slope and prevailing winds, could have contributed to abundant reseeding with exotic species such as sweetclover (*Melilotus* spp.) as well as noxious weeds such as thistles (*Sonchus* spp., *Cirsium* spp.).

As Hill numbers reached $q = \infty$, the differences on the undisturbed study sites became less different from each other, with values for all three sites being quite similar but all still higher than the landslide study sites. However, the landslide study sites maintained a distinct difference in value between each other, with the Hasler landslide study site having the highest Hill number value and the Beatton landslide study site having the lowest value. The maintenance of this difference indicates the sites are robustly different from each other in their diversities, and this difference appears to be influenced by spatial and temporal factors. Hasler Flats is the smallest landslide while Beatton River is the youngest landslide.

The distribution of growth forms on a disturbed site can change over time and is an indicator of successional status (Dale and Adams 2003). The plant growth form abundances for the relevés differed significantly between paired study sites (landslide vs. undisturbed) and also between landslide study areas. On the Beatton River landslide study site, most of the cover was forbs (>75% of total cover), followed by fern and fern allies (20% of total cover) and then distantly by shrubs (<3% of total cover). On the Beatton River undisturbed study site, shrubs were leading, followed by forbs and then trees and graminoids. The high dominance of forbs on the Beatton River landslide study site may be due to adjacency to a field of mixed forage species. In addition, the Beatton River landslide appears to be more active and is steeper than the other two slides, which could prevent more persistent woody species from establishing on the headscarp and large secondary scarps. The Beatton River landslide also had less pond cover and fewer wet areas in general, indicating a limited hydrological system.

Although a large proportion of the forb species on the Beatton River landslide was exotic invasives, the landslide surface could still eventually become populated with persistent native species, as introduced species may switch from competition to facilitation in their relationship with native species. In a study of revegetation on a landslide caused by the eruption of Mount St. Helens, vegetation plots populated with nonnative species had higher vegetation cover and more native species richness than those sites not invaded, indicating any type of invasion may facilitate primary succession (Dale and Adams 2003). Annual plant species were most common in the first two years after the eruption, likely the result of wind dispersal and the ability to grow in poor soil. In that study, the introduced species were more successful due to their ability to establish, spread, and fix nitrogen. On the Beatton River study area, the prevalence of shrubs and forbs over trees on the surrounding undisturbed terrain is reflected in the dominance of the first two growth forms on the landslide. Although the landslide was surrounded mostly by mature mixedwood and deciduous forests, a significant portion of the landscape was a grassland/shrubland complex.

For both Hasler Flats and Cecil Lake landslide relevés, shrubs dominated, followed by ferns and fern allies. The dominance of shrubs on both landslide sites may be due to propagule contributions from rafts, as well as the advanced age of the Cecil Lake landslide, which could have allowed time for shrubs to seed in via wind and animal dispersal. On the undisturbed terrain, the leading growth form for Hasler Flats was again shrubs, while on the Cecil Lake undisturbed site trees dominated. The presence of more shrubs on the Hasler Flats undisturbed site may be the result of the deciduous, somewhat open overstory, while the Cecil Lake undisturbed terrain overstory was mainly coniferous or mixedwood with a denser canopy. As deciduous stands shed their leaves in the autumn, more sunlight and nutrients reach the understory, stimulating growth of shrubs in the spring.

A comparison can be made of the autecology of the dominant species on the three different landslide surfaces. On the Beatton River landslide, the youngest slide, six out of the top ten most abundant species were exotics. Most of these exotics are perennials and can spread by both seeds and rhizomes. Wind and water are the primary modes of seed dispersal. The seeds were most likely transported downslope from the field above via prevailing winds and runoff. Most of the species are also seed-banking and have a longer range of seed viabilities or "shelf life" (FEIS 2023). The most abundant species on the Beatton River landslide, the exotic forb *Melilotus officinalis* (yellow sweetclover), dominated the toe of the landslide. It is an aggressive invader but is also a nitrogen-fixer, thus serving to improve the soil for future successional species. *Melilotus officinalis* is usually a biennial but is sometimes an annual or short-lived perennial and can have viable seed for up to 30 years (FEIS 2023). Thus, seed could be stored in the soil and reemerge following a future movement of the landslide. The four native species in the top ten most abundant list for the Beatton River landslide are the fern ally common horsetail (*Equisetum arvense*), the forb mugwort (*Artemisia* sp.), the shrub red raspberry (*Rubus idaeus*), and the forb Lindley's aster (*Aster ciliolatus*). All four species are perennials and can spread by both spores/seeds and rhizomes.

At Hasler Flats, the second oldest and the smallest landslide, seven of the ten most abundant plant species were shrubs, and there was one tree species, one fern ally species, and one moss species. The five most abundant species were the fern ally common horsetail (*Equisetum arvense*), followed by the tree species trembling aspen (*Populus tremuloides*), and the shrubs prickly rose (*Rosa acicularis*), green alder (*Alnus viridis* ssp. *sinuata*), and red raspberry (*Rubus idaeus*). None of the top ten species were exotic. This difference in species composition and abundances compared to Beatton River can be explained by the presence of ample native seed sources in the form of multiple rafts down the slope of the slide, in a series of horsts and grabens. These rafts often spanned much of the width of the slide, providing many potential seed sources to populate exposed soil. In addition, because the slide was so small (<2 ha) and was abutted by mature forests on both flanks, seeds and propagules could be readily dispersed from the adjacent forest.

On the Cecil Lake landslide, which was the oldest of the three slides and was 15 years older than the Hasler slide, five of the top ten most abundant species were shrubs, three species were trees, one species was a fern ally, and only one species was a forb. There were no exotic species in the list of the ten most abundant species. The five most abundant species were the fern ally *Equisetum arvense*, the shrub *Alnus viridis* ssp. *sinuata*, the forb palmate coltsfoot (*Petasites frigidus*), an unknown willow species (*Salix* sp.), and the tree balsam poplar (*Populus balsamifera* ssp. *balsamifera*). The common horsetail *Equisetum arvense* is a moisture indicator. It absorbs silicon from the soil, and then in turn can absorb excess moisture. *Equisetum arvense* has a perennial rhizomatous stem system which can extend into the soil up to 1.8 m (FEIS 2023), and it also reproduces via spores. *Alnus viridis* ssp. *sinuata* also prefers moist sites. It disperses seed over long distances by wind or water and can fix nitrogen and stabilise slopes (Haeussler 1990). *Petasites frigidus* grows on moist to wet sites. It is a perennial forb that expands via a creeping root. *Salix* spp. in general prefer moister sites and produce large amounts of seeds which are dispersed by wind and water and germinate best on exposed mineral soil. *Salix* spp. also reproduce by sprouts, which can grow very rapidly. *Populus balsamifera* ssp. *balsamifera* is an indicator of high moisture and nutrients. Seeds are easily dispersed long distances by wind. *Populus balsamifera* ssp. *balsamifera* can regenerate from root suckers, stump sprouts, and buried branch pieces. Suckering is most abundant where mineral soil is exposed.

The composition of the ten most abundant plant species on the Cecil Lake landslide is indicative of progression toward a more mature forested community. This makes sense, as the Cecil Lake landslide is the oldest of the three landslides. However, observations in the field showed large areas of the landslide at the north-facing headscarp that were still bare or sparsely vegetated. This delayed succession condition contrasts with a study of landslide recovery on a volcanic site (Saito et al. 2021), which found that grass vegetation recovery is quicker on shady slopes due to moisture and can recover within 12 years. It is likely the slower recovery of the north-facing headscarp at Cecil Lake is due to the colder climate of northeastern BC compared to Japan. In addition, there was evidence of reactivated mass movements along the Cecil Lake headscarp.

The two sample Kolmogorov-Smirnov (K-S) test showed the relevé communities of landslide vegetation were significantly different from the undisturbed plant communities for Beatton River and Cecil Lake study areas. These findings were consistent with the diversity values for the same relevés, which also indicated significant differences between the paired study sites for these two study areas. The K-S two-sample test also showed the two Beatton River study sites to be significantly more different from each other than the two Cecil Lake study sites were from each other. This pronounced difference on the Beatton River study area may be due to the younger age and active nature of the Beatton River landslide, in concert with the diversity of ecosystems (grassland, shrubland, mixedwood, mature aspen, mature conifer) in the surrounding undisturbed terrain. The K-S test did not show a significant difference in plant communities between the landslide and undisturbed study sites for Hasler Flats. This result also agreed with the diversity indices findings which showed that the plant communities were very similar on the landslide and on the undisturbed terrain.

NMS ordination of plant and environment data from BEC plots

In general, the NMS ordination of the plant and environment data from the BEC plots showed a combination clustered-scattered pattern, with few clear, strong associations. The concentration of more than half of each set of landslide plots in a central cluster surrounded by a somewhat uniformly scattered distribution of the remaining plots seems to indicate a significant degree of similarity among all three landslides. This redundancy may be due to the early successional stage of most of the plant communities, with different species still trying to establish and occupy a niche.

Although the ordination biplot did not reveal overly strong patterns, it did indicate an association of certain plant communities with landslide age. For the Beatton River landslide, the youngest slide, the plots that weren't clustered at the centre were largely associated to the open/grassland side of the gradient. In contrast, the scattered Hasler Flats plots were mainly distributed on the left side of the biplot, indicating forested communities. The plant communities of the oldest landslide, Cecil Lake, appear to be much more diverse than on the other landslides, as the plot locations on the biplot that weren't clustered at the centroid were scattered throughout much of the species space.

For all three study areas, the plant communities of the benchmark plots in the undisturbed terrain appear markedly different from the landslide plots, as they all occur as outliers on the biplot. This increased distance in species space confirms field observations that the plant communities of the surrounding undisturbed terrain were distinctly different from the landslide communities. The benchmark plots are also quite different from each other, as they are all far apart on the ordination biplot. The Beatton River and Hasler Flats benchmark tree plots in undisturbed terrain are closer to each other on the biplot and thus more like each other in composition than either of the plots is to the Cecil Lake tree plot. This similarity between the two study sites is consistent with the field data, as the Beatton River and Hasler Flats plots were in deciduous stands, while the Cecil Lake plot was in a mixedwood stand.

Of the environmental variables tested in the biplot, material origin and slope gradient appear to be bigger drivers of plant communities than mesoslope position, soil moisture regime, or heat load index. However, mesoslope position seems to have a greater influence on plant composition than soil moisture regime or heat load index. These findings are consistent with research on coastal BC comparing landslide revegetation with that of adjacent logged areas of the same age (Smith 1986), where the main factors influencing the rate and pattern of plant recovery on the bare surfaces were associated rock types and slope position. On the landslides, the development of vegetation and forest productivity were influenced by the post-disturbance soil materials, which were modified by mixing, surface erosion, and sloughing. Smith (1986) found the revegetation rate was slower on the steep upper and middle thirds of a landslide compared to the lower slopes, where revegetation was quite rapid. He identified a gradient of plant communities along the slope gradient of the landslides. Conifers dominated on the middle and upper slide zones, especially on coarse and acidic materials. Red alder (*Alnus rubra*) was predominant on the lower parts of the slides, particularly in fine-textured materials. Shrub and bryophyte covers were higher on the logged areas, while the forb cover was the same on the landslide and the logged area. Landslides had a much lower productivity, producing only a third as much wood volume as the harvested areas after 60 years.

In the Peace River Region study areas, field observations did not fully support the findings of Smith (1986) regarding the plant community gradient – slope gradient relationship. On the Hasler Flats landslide, shrubs and trees were interspersed down the length of the slope. On the Cecil Lake landslide, there were very few trees on the upper slope, scattered mixedwood rafts, young aspen (*Populus tremuloides*) patches and alder (*Alnus* spp.) swales on the middle slopes, and young (~10 years old) spruce (*Picea glauca*) and aspen scattered throughout the hummocky toe of the slide. The Beatton River landslide had very little tree cover overall, apart from some small rafts and a patch of *Picea glauca* seedlings in a rocky, rubbly portion of the slide. The main vegetation was the expanse of sweet clover (*Melilotus* spp.), thistle (*Sonchus* spp.), and other invaders occupying the hummocky toe of the slope. These differences may be due to the younger ages of the landslides in this study, as well as the very different climates between the two studies.

Positive Pearson's correlations associated with the apparent successional plant community gradient (Axis 1) are strongest for exotic and grassland species and negative correlations are strongest with trees and shrubs. For Axis 2, the apparent moisture gradient, the species most positively associated were the shrub *Ribes triste*, followed by the forb *Trifolium pratense*, and then the moisture indicators *Equisetum arvense* (fern ally) and *Populus balsamifera* ssp. *balsamifera* (tree).

2) To what extent do landslides rearrange relative abundance of site series/types on a slope compared to adjacent undisturbed terrain?

Site types/series

Landslides appear to rearrange relative abundances of site types to varying degrees compared to the adjacent terrain, and this variation seems to be driven by the age of the landslide at least to some extent. Overall, the general trend for all three study areas was more site series/types on the landslide than in the surrounding undisturbed terrain, or in situations where there was the same number of site series, they differed in classification between the two paired study sites. Another general trend was a greater number of individual polygons on the landslide for each site series, even when the proportion of the site series was similar between slide and undisturbed sites. In the Beatton River study area, the landslide study site had a higher percentage of mesic site series and a higher ratio of deciduous to coniferous mesic sites compared to the surrounding undisturbed terrain. On the Beatton River undisturbed terrain study site mesic sites also comprised the largest proportion of the total area. The Beatton River landslide and undisturbed study sites each contained a similar number of mesic polygons but the mean sizes and ranges were markedly different, and most mesic polygons were larger on the undisturbed terrain. The landslide also had a higher proportion of dry sites than the undisturbed terrain. Overall, there were more site series polygons on the Beatton River landslide compared to the undisturbed terrain. The slide had five times as many ponds, but the average pond on the undisturbed terrain was six times larger.

Although there were some similarities with the other two study areas, the Cecil Lake study area had the most notable differences in site type distribution between landslide and undisturbed terrain among the three landslides. On the Cecil Lake study area, for both study sites mesic types dominated with deciduous 101$ greater than coniferous 101. In contrast, the next two most abundant site series/types on the landslide were wet types (111$6B.1 and 111), while on the undisturbed terrain the next two most abundant site series/types were very dry types (Gg -grassland and Rt -talus). The main reason for the difference of moisture gradient on the undisturbed terrain appears to be the influence of the south-facing slopes across the creek, whereas the Cecil Lake landslide itself is north-facing and seems to be heavily influenced by groundwater. The Cecil Lake landslide had more than four times as many site type/series polygons as the undisturbed terrain, but almost 75% of these were ponds. The average size of the ponds on the undisturbed terrain was almost five times greater than those on the landslide. On the slide, the ponds appeared in clusters just below the scarp and on the toe of the slope, where the terrain was more uneven and marked with depressions. The ponds in the undisturbed terrain were more stable and vegetated. Overall, the age, size, geology, and aspect may all have contributed to the distinctness of site type distribution on the Cecil Lake landslide compared to Beatton River and Hasler Flats landslides.

The Hasler Flats study area yielded site type distributions most like what might be expected when comparing landslides and undisturbed terrain. On the Hasler Flats study area, for both study sites the mesic 101$ was leading, followed by the much wetter 112(Fm02). However, on the undisturbed terrain 101$ was a much higher proportion than on the landslide. Further, on the landslide the third most abundant site series was the very dry 103$, while on the undisturbed terrain the third most abundant site series was the very wet 111$6B.1. These results indicate that on this smaller, younger landslide, mesic sites are reduced overall and there is more diversity of dry and wet site types compared to the undisturbed terrain. The landslide also has many more polygons and a few more site series than the undisturbed terrain. The mean size of the pond (W) polygons was much greater on the landslide, and there were 13 times more pond polygons than on the undisturbed area. The findings regarding larger average pond size on the landslide are opposite of the Beatton River and Cecil Lake study areas, but the findings about the greater number of ponds on the landslide compared to the undisturbed terrain were the same as for Beatton River and Cecil Lake. The larger pond size on the Hasler Flats landslide is likely due to the series of horsts (ridges) and grabens (trenches or depressions), with water accumulating in the grabens. The surrounding terrain is much more uniform, with fewer depressions containing persistent water. Overall, the contrasts in the Hasler Flats study area site type distributions are due to the movement type and subsequent features (horsts/grabens), and these differences are more pronounced because of the small size of the landslide.

The pond distribution patterns on the three landslides are consistent with a study in Japan (Takaoka 2015), which found that ponds mainly occur in displaced masses downslope from ridges and in linear depressions along main ridges. This pattern was most pronounced on the Cecil Lake landslide, which also had numerous small ponds at the base of the headscarp. The Japanese study also found that 90% of the ponds on the landslide were <1000 m^2. This finding is consistent with the three landslides of the present study, where average pond size was 54.5 m^2 (Beatton River), 97.1 m^2 (Cecil Lake), and 56.9 m^2 (Hasler Flats). The characteristic of small landslide pond size is also confirmed at a regional scale in the pond mapping exercise in Chapter 4 of this study. Although ponds on landslides occupy small areas, they are a very important component of biodiversity. They provide connectivity, shelter, and a water source for larger animals such as ungulates and birds. Pond size influences species richness, as a series of smaller ponds have more species and higher conservation value than a single large pond of the same total area (Oertli et al. 2002).

Alpha diversity of site types on landslides appears to be influenced by the passage of time. Site series/type diversity was greater on the landslide than the undisturbed terrain for the Cecil Lake and Hasler Flats study areas in terms of Shannon diversity, Pielou's evenness, and Simpson's index of diversity. Richness was equal on the Cecil Lake paired study sites but higher on the Hasler Flats undisturbed terrain. Overall, the alpha diversity findings for Cecil Lake and Hasler Flats confirm observations in the field and indicate that site series are more diverse on older landslides compared to the surrounding undisturbed area. Conversely, site series diversity was greater on the undisturbed terrain for the Beatton River study area for all measures except richness, which was equal on the paired study sites. The findings for the Beatton River study area are consistent with observations in the field and indicate that site series diversity is reduced on more recent, steep landslides which are still in a state of heightened activity. The lower site series diversity indices on the Beatton River landslide study site compared to the surrounding terrain and the other landslides are likely due to the landslide having large areas of uniform terrain and fewer rafts. The Hasler Flats study area shows the largest positive difference in site series diversity indices between the landslide and the undisturbed terrain. This difference may be because not only does the Hasler Flats landslide contain rafts and remnants of the surrounding more developed plant communities, but it also has ridges and depressions where new species have established, and new combinations of soil moisture and soil nutrient regimes are created. The small size of the Hasler Flats landslide also increases the proportions of those site series found on rafts.

Overall, the differences in site series diversity and distributions between the Peace River Region study areas may be driven by both initial pre-slide vegetation and slope conditions and post-slide species interactions and geomorphic alterations over time. All three landslides in this study had evidence of past mass movements in the surrounding terrain, but the degree of diversity created by these past events differed between study areas. Vegetation may modify slope stability, thus influencing landslide size and severity, and at the landscape level vegetation may influence the spatial distribution of landslides through its interaction with the substrate (Restrepo et al. 2009). There may be both downslope and horizontal environmental gradients on a landslide, with conditions usually the mildest at landslide edges and harshest at the landslide centre. Over time, ecosystems on landslides can reorganise and embark on different successional trajectories, due to time lags caused by changing interactions, in addition to feedback between biota and substrate attributes. For example, differences in leaf litter chemical makeup and rate of decomposition between some early successional species may influence organic matter dynamics and nutrient cycling rates (Shiels 2006).

3) Are landslides significantly more geomorphically diverse than the surrounding undisturbed terrain?

Geotyping

Geodiversity indices have been increasingly used to try to quantify geophysical diversity on larger areas as a proxy for species diversity (Wallis et al. 2021). The geodiversity index is the sum of the spatial diversity of multiple environmental variables measured within each site and its surroundings, and comprises climate, habitat, and soil. The index quantifies the degree of variation across space. However, there is mixed evidence as to how effective geodiversity is at predicting biodiversity and ecosystem functions at the regional scale, and Wallis et al. (2021) found that climate variables are more important predictors than habitat and soil variables at the regional scale. Overall, the results in that study showed the geodiversity index only explained a small amount of the variation in plants and ecosystems, while environmental conditions and resources explained most of the variation.

While newer geodiversity indices may have limited utility, the geotype diversity work done in the present study with traditional diversity indices of Shannon and Simpson can be used for benchmark comparisons with plant and site series diversity. In general, the findings of the study highlight a relationship between geomorphic diversity and time, in view of the ages of the landslides. The geotyping analysis revealed that in terms of geomorphic diversity Cecil Lake, the oldest landslide, had the lowest Shannon diversity index, Pielou's evenness, and Simpson's index of diversity, while the Beatton River landslide yielded the highest richness, Shannon diversity index and Simpson's index of diversity. The Hasler Flats landslide registered the lowest richness but had higher Shannon diversity and Simpson's index of diversity than the Cecil Lake landslide. The overall higher geomorphic diversity indices on the Beatton River landslide compared to the other landslides was likely because the slide was very recent, and there was still large-scale movement occurring. In addition, the Beatton River landslide was situated in more complex stratigraphy than either Cecil Lake or Hasler Flats, with exposed bedrock and boulder fields resulting from rockfall. The Beatton River landslide had some much steeper slopes, which were susceptible to slumping. Many of the geotypes on the Beatton River landslide—such as aprons, scarps, rubble, and blocky areas—were sparsely vegetated due to either their steepness or the lack of organic material. Sparse vegetation may also result from greater distances from a dispersal source. Studies have found revegetation occurs inward toward the slide body from the landslide edges and outward from islands or rafts of vegetation (Francescato et al. 2001). Some of the most sparsely vegetated geotypes at Beatton River were in the centre of the slide.

The Cecil Lake landslide had the lowest geotype diversity indices of the three slides, except for richness. This seems contradictory at first, considering the variety of features observed in the field. However, features weather and become less distinct over time. The Cecil Lake landslide was very large, and some expansive areas were occupied by just one or two geotypes. Some examples of these geotypes include the long headscarp, as well as the large area of hummocks at the toe of the slide. The headscarp was quite sparsely vegetated, even though the landslide was twenty years old at time of sampling. The headscarp also still had mainly exotics and native grasses. This condition is likely due to the width and steepness of the slope, which can slow the rate of successful revegetation (Francescato et al. 2001).

Further, although most revegetation is initiated from the landslide edge, a significant length of the headscarp was bordered by a cultivated hay field. Therefore, the main source of plant propagules was likely from the field. Francescato et al. (2001) found that revegetation rate on landslides decreases over time, likely due to early saturation by easily established species. This situation may be occurring on the Cecil Lake landslide headscarp, due to the colonisation by agronomic species from the adjacent field.

Hasler Flats and Cecil Lake landslides both contained ridges, with those on Cecil Lake much more prominent and extensive. The larger ridges on the Cecil Lake landslide were likely because the disturbance area was much bigger and steeper than the Hasler Flats landslide, so the material gained more momentum as it moved downslope. In addition, the material on the Cecil Lake landslide was silty clay, while on Hasler Flats the material was fine sand for the first four metres of thickness. The clay ridges would likely persist longer, while the sand ridges would not be as pronounced from the start, and they would become subdued with weathering.

Although ponds did not occupy a notable amount of area on any of the slides, they were numerous and distributed throughout, especially on the Cecil Lake landslide. The trend of high numbers of small ponds was evident over a large area of the region, as described in Chapter 4. This abundance and widespread distribution of ponds indicated the presence of depressions throughout the slides, as well as the level of the groundwater. The ponds were in different stages of development depending on the slide and specific locations within the slide. Ponds provide habitat for many different types of wildlife. Evidence of wildlife use of the ponds was present, especially signs of beaver (*Castor canadensis*) activity such as felled trees, gnawed bark, and well-worn trails.

In all three study areas, vegetated rafts were a significant component of the landslide area. Rafts and other fragments of vegetative legacies are important for initiation of succession following disturbances. In one of only a few detailed quantitative studies of northern British Columbia landslides, Smith (1986) compared revegetation on landslides with surrounding logged areas as well as old growth areas on various islands of the northern coastal archipelago of Haida Gwaii. Initial revegetation on those landslides was shown to depend on the availability of stable microsites and islands of debris and other remnant organic material (Smith 1986).

Microtopography/surface roughness

It is assumed that over time, landslides will undergo smoothing of the surface due to slope degradation and local deposition of materials. The microtopography exercise in this study showed that all three landslides had a high degree of variability around the mean coefficient of variation (CV) of elevation on microsites and also a high mean CV overall, indicating variability of elevation is high both within sites and among sites. The most recent landslide, Beatton River, had the highest variability on average. This higher surface roughness could be due to the greater steepness of the slope in many places, as well as the presence of more rubbly areas and exposed bedrock and rockfall. It should be noted that only drone data were available for the Beatton River landslide for this exercise, so all elevation points were unclassified. Therefore, some of the points could be vegetation rather than ground points. However, there were only a few heavily vegetated plots, so the results are largely representative of ground surface elevations. The Beatton River landslide also had the highest range of elevational variability, which could be explained by somewhat equal proportions of steep, smooth slopes, rubbly moderate slopes, and hummocky gentle slopes at the toe.

The Cecil Lake landslide had the second highest elevational mean, maximum, and range of CV, even though it was older than the Hasler Flats landslide. This higher surface roughness could be mainly due to the steeper slope of the Cecil Lake landslide compared to the Hasler Flats landslide. Steeper slopes may increase the diversity of elevation variation as material falls and slides, creating rubbly piles at the same time as smooth scarps form.

When compared with field photographs taken at the microsite level, individual plot elevational CV results were not always representative of on-the-ground plot characteristics. For example, on the Beatton landslide one of the highest CVs (Plot 1 at 68.58%) was a flat grassy raft. The high CV calculation may be due to the vegetation present, as bare ground points were not filtered out. Overall, however, the elevation CVs appeared to accurately reflect the plot characteristics. The results were also consistent with other microtopography research (Rozycka et al. 2016).

4) Is vegetation diversity on landslides significantly related to geomorphological diversity?

One of the key premises of this study was that the diverse array of geomorphic features on landslides would positively influence the diversity of vegetation communities. Regression analyses were performed for each landslide to assess whether there were correlations between the relevé alpha diversity values of vegetation richness, Shannon index, evenness, and Simpson's index and the same measures for geomorphic diversity, using the geotyping results obtained for both on the landslide and in the undisturbed terrain. All four regressions showed that there was not a significant relationship for any of the diversity indices tested in any of the three study areas. This was somewhat surprising, considering how field observations suggested that vegetation and site diversity were closely related. There was not even a relatively stronger, but not significant, relationship on the landslides compared to the undisturbed terrain, as the R^2 and p-values were similar for both study site categories. A possible explanation could be that more successional time is required before true relationships have become established and are statistically discernible. Alternatively, it could be that the scale of the exercise masked any relationships, as the geotyping was done at the landscape level. It is possible the sample size of three relevés per study site was simply too small to obtain an accurate result. It is also possible a different analysis would be more appropriate. More study is required on this aspect of the research.

Limitations

One of the limitations of the study design was the fact that study areas were partly chosen based on access. This naturally resulted in selecting landslides with road access and increased the likelihood that the slides would be next to a field or other managed landscape. The presence of development in turn likely influenced the establishment of exotics from the adjacent field. A more random selection of study areas could result in some more remote landslides where revegetation is primarily influenced by native forest vegetation from the surrounding terrain. Alternatively, a deliberate selection of some more remote landslides would have allowed for a focused or comparative study of natural succession in contrast with succession influenced by exotic species. In addition, it would have been beneficial to study more landslides, to better assess correlations between vegetation and geomorphic diversity.

A further limitation was the small sample size of three landslides. Each landslide was unique in age, size, and slide type, which presented challenges when attempting to generalise findings. The differences among the landslides did provide a basis for identifying spatial and temporal trends, which is very useful as a baseline dataset. However, a series of landslides from different age classes, size classes, and landslide types would help to complete the picture. The sample size for this study was selected based on time and resource constraints, but future studies could expand on the work presented here.

An additional limitation of the study was the lack of sufficient LiDAR bare ground point data for assessing microtopography on undisturbed terrain. This deficit of imagery precluded a robust analysis of the undisturbed microtopography and did not allow a full comparison with the landslide study sites. The microtopography assessment component was added several years into the study and thus was not planned for, but for future landslide studies researchers should ensure adequate LiDAR is available before setting objectives and delineating study parameters where mapwork is planned. A related limitation was the limited availability of the LiDAR mosaic high-resolution imagery for the site series and geotype mapping on the undisturbed terrain for each study area. The outer perimeters were thus determined in part by the boundaries of the available high-resolution imagery.

The timing of the field data collection posed another possible limitation. Due to funding availability and other scheduling factors, vegetation plot sampling was done from early summer into the fall. During the late summer and fall sampling, there was less foliage and it was thus more difficult to identify species and estimate cover. However, extra effort was made to identify species and estimate cover based on stems, fallen leaves, and plant crown expanses. Therefore, it is believed that species identification and cover estimates were accurate within an acceptable margin of error. Regardless, it is still preferable to conduct sampling when plants are at their most robust and easily identifiable during the growing season.

A further limitation of the study design was the restriction of landslides to the Peace River Region. The Peace River Region is somewhat unusual in the province in that most slides occur in glaciolacustrine material. Therefore, the results are more specific to this area and less generalisable. However, basic elements of succession and site variability can still be applied to other parts of the province, country, or world to see if the results are comparable. In addition, the findings could apply to any part of the world that has been affected by glaciation.

Finally, a limitation of the data collection was the learning curve involved during some field sampling. This was especially the case when estimating plant species cover, particularly on the larger 400 m^2 plots. The implications of this are that some of the initial plots may have slightly inaccurate cover estimates. An alternative to this approach could be to have more than one person estimating the cover on the first few plots, and then compare notes and calibrate measurements before proceeding, or to take drone imagery of each plot and assess plant species cover by image analysis.

2.6 Conclusions and recommendations

Some general trends appear in the analysis of biophysical alpha diversity on landslides in the Peace River region of northeastern BC. Overall, plant communities vary depending on the age and size of the landslide and the slope and soil development of the various geotypes present. Exotic forb species are more dominant in the early stages of a landslide's successional development. Shrubs and trees become more established as the landslide stabilises. However, landslides can once again reactivate, setting plant succession back on some areas of the landslide.

The landslides in the study tend to have more diverse site series units compared to an equal area of the surrounding undisturbed terrain. In general, the landslides contain a larger proportion of mesic sites compared to surrounding undisturbed terrain, but they also have more pronounced extremes of site series at either end of the soil moisture regime gradient. The site series polygons are generally smaller on the landslide, compared to larger swaths of intact site series in the undisturbed areas.

The landslides in the study area are more geomorphically diverse than the surrounding undisturbed terrain. Geomorphic types tend to be more diverse on the landslides, due to mass movement, rearrangement of stratigraphy, and erosion of unstable substrates. Geomorphic diversity also varies inversely with the age of the landslide. Surface roughness also appears more diverse on landslides and tends to decline with landslide age. The most recent landslide had the highest surface roughness.

Ultimately, landslides in the study are generally less diverse than surrounding undisturbed terrain regarding plant diversity, but more diverse in abundance and distribution of site series and geomorphology. Although the landslides are lower in plant diversity due to rapid and wide-reaching establishment by invasive species and persistence of early successional species, the site series and geomorphological diversity present provide conditions for a greater variety of plant communities and wildlife habitats over time.

The findings of this study of alpha diversity on landslides in northeastern BC provide the groundwork for several recommendations regarding landslide restoration, management, and research. Landslides targeted for restoration should be prioritised and selected based on the risk of future instability to human safety and health, infrastructure, and ecosystems.

Remotely located landslides may be left to revegetate and restabilise unaided if future movements do not threaten to block waterways or cause heavy sedimentation. Restoration should first focus on landslides near communities and infrastructure, such as Old Fort and the Site C hydroelectric dam along the Peace River. Restoration should also focus on landslides near cultivated areas, as well as next to rivers, creeks, or other water bodies used for human drinking water or designated as sensitive wildlife habitat.

Restoration of landslides is essentially managed succession (Walker and del Moral 2008). Long-term research on primary succession on landslides provides information on temporal vegetation dynamics that serve as lessons for restoration practices. Applicable learnings include information on site amendments, development of community structure, nutrient dynamics, species life history traits, species interactions (competition), and modeling of transitions and trajectories. When considering restoration of landslides, it is important to realise that no plant community is ever static (Pickett et al. 2009). Successful restoration depends on accurate identification of where on the temporal gradient of succession a site is located, and appropriate intervention in disturbance, colonisation, and competition processes.

Landslides typically cause a loss of vertical vegetative structure, soil nutrients, and soil seed bank (Shiels and Walker 2003), as was observed on the three landslides studied. Restoration on landslides is particularly challenging due to the high spatial and temporal heterogeneity of soil stability and fertility (Walker et al. 2009). Surface soil erosion is a serious problem, as is patchiness of soil fertility. These conditions were especially evident on the Beatton River landslide but were also widespread along the headscarp of the Cecil Lake landslide. Persistent soil erosion is the first barrier to succession and restoration on landslides, and measures to reshape slopes are often unsuccessful because of subsequent erosion, compaction, and other problems (Walker et al. 2009).

Recovery of stable plant communities can be achieved by first stabilising the substrates with bioengineering techniques such as live stakes, brush layers, and wattle fences (Polster 2003; Singh 2010; Punetha et al. 2019), supplemented with establishment of early successional and mid-successional native plant cover and amendment of the soil with nutrients and organic matter. Successful growth of established plants on landslides may require different environmental conditions than colonising plants. The emphasis should be on assuring a diversity of functionally redundant species, so that if some plants do not survive, others with a similar life history can fill in the gaps (Walker et al. 2009). These species can stabilise and fertilise the surface and should have rapid growth and reproduction traits. On Peace River region landslides, native species to use in restoration plantings could include grasses such as blue wildrye (*Elymus glaucus*) and Canada bluejoint (*Calamagrostis canadensis*), forbs such as wild sarsaparilla (*Aralia nudicaulis*), palmate coltsfoot (*Petasites frigidus*), showy aster (*Aster conspicuus*) and false Solomon's seal (*Smilacina racemosa*) and shrubs such as prickly rose (*Rosa acicularis*), saskatoon (*Amelanchier alnifolia*), alder species (*Alnus* spp.), red-osier dogwood (*Cornus stolonifera*), and highbush cranberry (*Viburnum edule*). Because the deposition zone is generally more stable, restoration efforts in this part of the slide should focus on management of species interactions, such as reducing competition between native species and exotics such as *Melilotus officinalis*. Management of interactions should retain some exotics for nitrogen fixing and nutrient input, but exotic densities should be reduced around native species. Restoration in the headscarp and chute zones should prioritise proactive erosion control and enhanced seed dispersal, perhaps using hydroseeding. In addition, planting of native shrubs and tree seedlings could be done throughout the landslide wherever slopes are already stable, to diversify the species composition and increase the rate of succession.

Two strategies to accelerate succession on the large bare or sparse zones and the grass-dominated areas on the Beatton River and Cecil Lake landslides could be to increase natural dispersal by birds and amend the substrate surface with nutrients (Shiels and Walker 2001, 2003). The dispersal strategy with birds involves establishing perches in the open areas to encourage birds to fly closer to the centre of the landslide, where they may drop, regurgitate, or defecate seeds. The goal is to facilitate the establishment of native woody plants to shade out the graminoids and aggressive forbs. Success would depend on the bird species and the proximity of the perches from the forest edge. For seed deposition from birds to occur, there must be some vegetation on the slide (Shiels and Walker 2001). However, this poses a problem for restoration, because forest seed germination may be inhibited by competition with grasses, exotics, and other fast-growing pioneers. Forest seed germination may also be hindered on bare sites due to low organic matter and extreme microclimates. Commercial fertiliser and amendments with mature forest soil may help speed up plant colonisation. However, research has shown that organic matter input on landslides does not influence plant growth unless it is forest soil (Shiels et al. 2006). The type of organic substrate, frequency of organic deposition, and presence or absence of biota all directly influence soil nutrient patch dynamics, which ultimately affects plant development.

Overall, restoration on landslides in the Peace River Region should focus on ecosystem recovery and biodiversity, rather than plant species composition. It is important to consider long-term recovery trends and effects of nonnative species succession because restoration practices often incorporate nonnative species (Dale and Adams 2003). Further, the influence of invasive species and other disturbances needs to be fully integrated into successional theory.

Biogeomorphic systems such as landslides are viewed as open and path-dependent systems by many researchers (Stallins 2006). Plant communities change as the substrate changes, and the communities also actively change the substrate. The material impacts of organisms serving as ecosystem engineers may be just as important as the trophic links, since they stabilise substrates, enhance weathering, provide habitat, and promote facilitation. There are many developmentally connected feedbacks between geomorphic and ecological components, and multiple causes and recurrences should be considered when studying succession and planning restoration projects.

Further research on landslides in northern BC could enhance understanding of plant community development, geomorphic evolution, relationships between geomorphic diversity and vegetation diversity on landslides, and broader ecological processes on these disturbances. Resampling of vegetation plots on each of the three study areas after some years have passed could provide insights on whether species composition and site conditions are changing or becoming more diverse over time. Sampling on remote landslides away from the influence of cultivated fields or roadways would create a dataset for comparison of vegetation dynamics with solely native vegetation. In addition, a variety of landslides of different movement types, sizes, and ages could be sampled to provide a broader understanding of geomorphic, spatial, and temporal influences on alpha diversity. Experiments with bird perches, organic matter amendments, bioengineering, and hydroseeding on the bare slopes of the slides would present valuable lessons on the feasibility and effectiveness of management options. Finally, detailed studies on wildlife habitat, wildlife use of landslide features, and connectivity to the surrounding undisturbed terrain would provide a perspective of the ecological role of landslides at the landscape level. All these findings could be applied more generally to our understanding of landslide ecology (Walker and Shiels 2013), and the options for management, and restoration here and elsewhere in the world.

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Chapter 3. Beta diversity as a measure of biophysical turnover on landslides

3.1 Introduction and Background

Through marked alteration of vegetation and environment, landslides create diversity on a landscape. Diversity in nature can be described in a series of scales forming a hierarchy. As outlined in Chapter 2, the three basic levels of diversity are alpha diversity, beta diversity, and gamma diversity (Whittaker 1960). These three scales of diversity are related, and often quantification of one level is required before quantifying another. Alpha and gamma diversity refer to defined geographic units and are classified as inventory diversity (Whittaker 1972). Alpha diversity is within-site diversity, while gamma diversity is described at a regional level. These two diversities may be measured in similar ways, although they are not transferable (Tuomisto 2010a). Whittaker coined the concept of a third category of diversity, namely beta diversity. Beta diversity is generally understood as diversity between sites or communities. It refers to variation between samples and is classified as differentiation diversity. It requires a different set of techniques for measurement than inventory diversity. Essentially, beta diversity is assessed in relation to complementarity or relative similarity or dissimilarity between communities (Magurran 2004).

Beta diversity represents a key aspect of the spatial pattern of biodiversity. Whittaker (1960) described beta diversity in its simplest form as the change in species composition over an area, or the extent of change of community composition in relation to a gradient or pattern of environments. For this reason, it has also been referred to as spatial turnover. Generally, beta diversity increases as similarity in species composition decreases. A landscape with a certain number of species and little overlap in species composition over an area will be more diverse than an equivalent landscape with equally speciose assemblages but many shared species from site to site. Beta diversity has been found to be more effective than alpha diversity at detecting change in ecological communities (Seguin et al. 2013), and therefore is valuable in assessing the effects of disturbances over time as well as space.

3.1.1 Measurement of beta diversity

Unfortunately, many different definitions and concepts of beta diversity have arisen over the years, accompanied by an equally varying number of methods to describe and quantify it. This lack of standardisation has been the source of debate and discussion in recent years (Koleff et al. 2003; Moreno and Rodriguez 2010; Tuomisto 2010a; Tuomisto 2010b; Tuomisto 2010c; Anderson et al. 2011). Koleff et al. (2003) noted at least 24 measures of beta diversity for presence/absence data. All the variants of beta diversity measure some sort of differentiation or heterogeneity, but they each represent very different phenomena (Tuomisto 2010a). The many different measurements of these variants cannot be compared numerically. The debate over a lack of a unified concept and measure has led some to call beta diversity a key concept in ecology, while others deem it of no use (Jurasinski et al. 2009). In this current study, beta diversity refers to the change in species composition over space, or species turnover, and will focus on turnover as it relates to distance or area.

There are two main categories of beta diversity measures: species richness (coefficients that examine variation in richness across scales) and species composition (coefficients that examine variation in species composition between samples) (Jurasinski et al. 2009). Species richness measures assess the extent of difference between two or more areas of alpha diversity relative to gamma diversity, where gamma diversity is usually measured as total species richness. Species composition measures focus on the differences in species composition amongst areas of alpha diversity and were designed to measure complementarity or similarity/dissimilarity (Barwell et al. 2015; Chao and Chiu 2016). They employ similarity/dissimilarity coefficients, slope of distance-decay relationships, sum of squares species matrices, or gradient length in ordination space techniques. Species composition measures essentially assess the biotic distinctness of assemblages and include the Jaccard and Bray-Curtis coefficients. A third category of measures use the species-area relationship to measure turnover related to species accumulation with area.

Beta diversity indices

As with alpha diversity, various indices have been devised for beta diversity. Most indices use presence/absence data and so focus on the species richness component of diversity. One of the simplest and most effective measures is Whittaker's (1960) measure Bw, which is obtained by dividing total species recorded in the system by average sample diversity (species richness). Of six beta diversity measures tested by Wilson and Shmida (1984) for effectiveness in measuring community turnover, Whittaker's measure was found to fulfill most of the authors' criteria of number of community (assemblage) changes, additivity, independence from alpha diversity, and independence from excessive sampling, with fewest restrictions.

The more complementary two sites are, the higher their beta diversity. Complementarity describes the difference between sites in terms of the species they support. The beta diversity of pairs of sites can be described by using a similarity/dissimilarity coefficient. A matrix can be constructed using the Jaccard (1908) similarity index, which tallies species gained and species lost.

The Sorensen (1948) measure is another similarity measure that is popular and viewed as very effective. It uses presence/absence and is identical to the Bray-Curtis presence/absence coefficient. One disadvantage of this measure is that if samples differ markedly in species richness, the Sorensen measure will always be large (Lennon et al 2001). However, it can be modified to accommodate quantitative data (Bray and Curtis 1957).

A significant advantage of the beta diversity measures discussed is their ease of calculation and application. However, the coefficients do not take into consideration relative abundance of species. Dominant species have no more weight in a presence/absence beta diversity measure than a species represented by one individual. This has resulted in the development of similarity/dissimilarity measures based on quantitative data, such as the Bray-Curtis index (Bray and Curtis 1957).

3.1.2 Landslide beta diversity

Landslides create harsh environments that can act as ecological filters for plant community development (Furusawa et al. 2023). Because they are large-scale disturbances caused by stochastic events, landslides are difficult to study and generalise. The environment that results from a landslide often consists of a patchwork of rafted materials amid a variety of exposed and deposited substrates, which can lead to increased patchiness across the landscape. This greater patchiness presumably translates to increased beta diversity. Community assembly occurs by both stochastic/random (i.e. ecological drift) and deterministic (i.e. niche selection) processes. General patterns of community responses to landslides and environmental influences on community assemblages after a landslide are poorly understood. The extreme environment following a landslide is expected to favour niche-assembled communities comprised of specialist species, but little is known about this process.

Disturbances such as landslides can alter beta diversity by changing the relative importance of community assembly mechanisms that influence clustering of species across landscapes (Myers et al. 2015). Disturbance can increase clumping either through divergent selection of niches across environmental gradients or through reduced dispersal if species become rare after disturbance, or by a combination of the two processes. Disturbed landscapes may thus have a lower species richness and a lower overall alpha diversity than undisturbed landscapes, yet greater beta diversity.

In this chapter, I attempt to answer the question: To what extent does turnover or beta diversity in microsites and plant species occur on landslides? I also investigate whether vegetation beta diversity is correlated in any way with site beta diversity. For both lines of investigation, I also assess whether there is a difference between different sizes or ages of landslides and between landslide and undisturbed terrain study sites.

3.1.3 Study areas

The sampling transects for this study were established on the same three study areas described in Chapter 2, in the Peace River Region of northeastern BC on landslides < years old in glaciolacustrine material. The three landslides were Beatton River, Cecil Lake, and Hasler Flats. The Beatton River landslide most recently activated in 2015 and was approximately 30 ha. The Cecil Lake landslide occurred in 1998 and was about 56 ha. The much smaller Hasler Flats landslide occurred in 2013 and was only 1.5 ha in size. All three landslides initiated on plateaus and travelled downslope into rivers or streams. Detailed information on each landslide and its associated surrounding terrain can be found in Chapter 2 on alpha diversity, in Section 2.2.

3.2 Methods

3.2.1 Data collection

Sampling of vegetation cover and environment variables was carried out on paired landslide and undisturbed study sites in the Peace River Region of British Columbia on the three study areas: Beatton River, Cecil Lake, and Hasler Flats. On the Beatton River and Cecil Lake landslide study sites, seven randomly located transects were sampled, comprised of up to 30 m of a series of 1 x 1 m quadrats (plots). On the Hasler Flats landslide study site, just three transects were established, due to the much smaller size of the landslide (1.5 ha). In total, 17 landslide transects were sampled. On the associated undisturbed study sites surrounding each landslide, three transects were sampled for each of the three study areas, for a total of nine undisturbed transects. Transect commencement points for each transect were randomly located on a grid in the office prior to beginning field work, with point locations and transect directions determined using an online random number generator.

To further ensure randomness of data, field sampling was done to the right of the transect defined by a 30 m tape measure on even numbered transects and to the left of the transect on odd numbered transects. Individual quadrats were delineated using a 1 x 1 m square plot made of PVC (polyvinyl chloride) tubing (Figure 3-1). At each plot, plant species and associated percent covers were recorded, along with ground substrate percentages as per Land Management Handbook 25 (BC Gov 2010), as well as predominant slope and predominant aspect. Slope and aspect were measured at the microsite level (i.e. the 1 x 1 m quadrat plot). Aspect was eventually converted to folded aspect values along the north-south access to facilitate its analysis as a continuous variable (McCune and Keon 2002). Any vegetation or site type changes along the transect were recorded. Adjacent plots were added successively along the transect until two plots were sampled consecutively with no new species or the 30 m transect ended, whichever came first. If plots fell on a transition between two visibly different vegetation or substrate types, the plot was moved to the next metre marker where it was completely within the new type. Additionally, if there were no new species between two consecutive plots but there was a type change further along the 30 m of the transect, the next plot was established at the next metre marker fully within the new type. The number of quadrats per landslide transect ranged from 15-30 for Beatton River and 14-30 for Cecil Lake, while all transects for Hasler Flats had 30 quadrats. All undisturbed transects for Beatton River and Hasler Flats had 30 quadrats, while for Cecil Lake the number of quadrats per undisturbed transect ranged from 28-30. Sampling intensity for the landslide study sites was 0.23 transects/ha and 5.63 quadrats/ha for Beatton River, 0.12 transects/ha and 3.00 quadrats/ha for Cecil Lake, and 2.00 transects/ha and 60 quadrats/ha for Hasler Flats. Sampling intensity for the undisturbed study sites worked out to 0.1 transects/ha and 3.00 quadrats/ha for Beatton River, 0.05 transects/ha and 1.57 quadrats/ha for Cecil Lake, and 2.00 transects/ha and 60 quadrats/ha for Hasler Flats. For all transects, representative photographs were taken at various locations along the length.

Figure 3-1. Sampling transects with a series of 1 x 1 m quadrats along a measuring tape. Image on the left is Beatton River undisturbed transect BEtu1a. (Photo August 26, 2018) Image on the right is Beatton River landslide transect BEtl1a. (Photo July 18, 2017, by P. Burton. Used with permission.)

3.2.2 Data analysis

Vegetation data for each transect was entered into Excel spreadsheets, formatted, and then exported to the multivariate analysis program PC-ORD v. 7.10 (McCune and Mefford 2016; McCune and Mefford 2018) for analysis. For plots with no vegetation or 100 percent water, separate columns were created titled "NO_PLANTS" and "WATER". Two transects on the Beatton River landslide had no vegetation the entire length of the transect, and thus were eliminated from the PCORD analysis because it was discovered after field sampling that a beta diversity value could not be calculated in PCORD when empty rows were present. For each remaining transect on each landslide and in the associated surrounding undisturbed terrain, an initial value of Whittaker's measure of beta diversity (Bw) was calculated in PC-ORD, using the formula Bw = Gamma (overall) diversity/Alpha (local) diversity.

Environment data for each transect was entered into Excel spreadsheets and formatted for analysis in PC-ORD. Slope and folded aspect were inputted in separate columns. Folded aspect was calculated in Excel using the following formula:

ABS(180 - ABS(aspect -225°)

where ABS refers to the absolute value, and aspect was measured in degrees azimuth from true north. Folding aspect around the southwest slope-facing direction is considered representative of heat intensity on a site in the northern hemisphere (McCune and Keon 2002). Substrate values for organic matter, decaying wood, bedrock, rock (cobbles and stones), mineral soil, and water were inputted in separate columns. Once the environment data was formatted, each transect dataset was imported into PC-ORD and Whittaker's beta diversity Bw was calculated. Descriptive statistics were then calculated in Excel for the vegetation and environment beta diversity data for each study site.

To provide background information and a fuller picture of diversity on the sites, alpha diversity values for vegetation and environment variables were calculated for each transect by averaging the values of all quadrats/plots along the transect. Richness, evenness, Shannon index (H'), and Simpson's index (1-D) were all calculated for each transect in PC-ORD. The higher the evenness of a sample, the more similar the abundances are to each other in an area, and the higher the alpha diversity. The Shannon index incorporates richness and evenness to quantify the uncertainty in predicting the identity of an individual taken at random from a dataset. It is related to the weighted geometric mean of the proportional abundances (evenness). The higher the Shannon index, the greater the uncertainty. Simpson's index of diversity ranges between 0 and 1 and represents the probability that two individuals randomly selected from a sample will belong to different groupings. The higher the Simpson value, the greater the sample alpha diversity. Descriptive statistics were calculated in Excel for the vegetation and environment alpha diversity data for each study site, using the individual transect data generated in PC-ORD.

A scatter graph was created to display the relationship between the resultant vegetation beta diversity values and environment beta diversity values for all landslide transects, and for all undisturbed transects. Regression lines of vegetation beta diversity as a function of environment beta diversity and associated regression statistics were then calculated, displayed, and compared for the landslide and undisturbed transects.

3.3 Results

3.3.1 Transect vegetation beta diversity

3.3.1.1 Landslide transect vegetation beta diversity

The results for the landslide transect vegetation beta diversity calculations in PC-ORD revealed a range of values, both within and among study sites (Table 3-1).

Table 3-1. Landslide transect vegetation beta diversity (Bw) values.

Transect	Beta diversity (Bw)	Mean Bw	SD	CV %
Beatton River				
BEtl1a	2.7			
BEtl1	1.8			
BEtl4	0.8	2.42	1.15	47.69
BEtl5	3.0			
BEtl6	3.8			
Cecil Lake				
CEtl1	1.9			
CEtl2	2.3			
CEtl3c	5.5			
CEtl4	2.8	3.10	1.29	41.52
CEtl5	2.3			
CEtl6	4.2			
CEtl7	2.7			
Hasler Flats				
HAtl1a	2.9			
HAtl2	3.0	3.17	0.38	11.96
HAtl3	3.6			
Overall (all transects)		2.89	1.11	38.39

Cecil Lake transects showed the greatest range of landslide vegetation beta diversity (Bw) values, while Hasler Flats transects had the smallest range. Cecil Lake also yielded the single transect with the highest beta diversity value (CEtl3c at 5.5), whereas Beatton River had the transect with the lowest beta diversity value (BEtl4 at 0.8) of all the landslide transects.

Hasler Flats presented the highest mean landslide transect vegetation Bw (3.17) whereas Beatton River had the lowest mean Bw (2.42) of the three study sites. Cecil Lake showed the highest standard deviation (SD), Beatton River had the highest coefficient of variation (CV), and Hasler Flats exhibited the lowest SD and CV. Both Hasler Flats and Cecil Lake had a higher mean than the overall mean Bw value for all landslide vegetation transects in the study.

For background information, alpha diversity values for vegetation were calculated for each landslide transect study site (Table 3-2). Mean richness, evenness, Shannon index (H'), and Simpson's index (D) were all calculated in Excel from individual transect values generated in PC-ORD. Although these values were generally lower than those calculated for the landslide relevés in Chapter 2, the overall trend was the same for ranking the landslides.

Table 3-2. Landslide transect vegetation alpha diversity statistics.

	Beatton River			Cecil Lake			Hasler Flats			Overall - All landslide transects		
Diversity Measure	Mean	SD	CV %	Mean	SD	CV %	Mean	SD	CV%	Mean	SD	CV %
Beta diversity (Bw)	2.42	1.15	47.69	3.1	1.29	41.52	3.17	0.38	11.96	2.89	1.11	38.39
Richness (S)	6.64	2.61	39.32	11.4	2.99	26.26	12.3	1.57	12.78	9.99	3.51	35.08
Evenness (E)	0.58	0.09	15.41	0.67	0.05	6.73	0.63	0.11	18.28	0.63	0.08	13.06
Shannon (H')	0.96	0.37	38.54	1.55	0.39	25.05	1.47	0.22	15.05	1.34	0.43	32.41
Simpson (D)	0.46	0.15	32.54	0.66	0.15	22.55	0.64	0.07	11.22	0.59	0.16	27.07

Of the three landslides, Hasler Flats had the highest vegetation richness (12.3) while Beatton River had the lowest richness (6.64) but the highest CV (39.32%). Hasler Flats and Cecil Lake mean richness values were higher than the overall mean. Cecil Lake showed the highest evenness while Hasler Flats yielded the lowest evenness value. At the same time, Hasler Flats had the highest CV. The Shannon index was highest on the Cecil Lake landslide and lowest on the Beatton River landslide. Beatton River showed the highest CV for Shannon index. Cecil Lake and Hasler Flats both had a mean Shannon index that was higher than that of the mean overall value for all landslide transects. Cecil Lake also yielded the highest Simpson index while Beatton River was the lowest. Cecil Lake and Hasler Flats both had a higher mean Simpson index than the overall mean.

3.3.1.2 Undisturbed transect vegetation beta diversity

Table 3-3 shows the vegetation beta diversity values calculated in PC-ORD for each undisturbed transect.

Table 3-3. Undisturbed transect vegetation beta diversity (Bw) values.

Transect	Beta diversity (Bw)	Mean Bw	SD	CV %
Beatton River				
BEtu1a	3.3	2.50	0.75	30.20
BEtu2b	1.8			
BEtu3a	2.4			
Cecil Lake				
CEtu1	2.4	2.87	0.42	14.52
CEtu2	3.2			
CEtu3a	3.0			
Hasler Flats				
HAtu1a	2.3	2.03	0.55	27.09
HAtu2	1.4			
HAtu3	2.4			
Overall (all transects)		2.47	0.63	25.40

Of the three undisturbed study sites, Beatton River yielded the greatest range of transect vegetation Bw values while Cecil Lake showed the smallest range. Beatton River contained the undisturbed transect with the overall highest Bw value (BEtu1a at 3.3), while Hasler Flats had the transect with the lowest Bw value (HAtu2 at 1.4).

For the undisturbed transect vegetation, Hasler Flats yielded the lowest mean Bw, at 2.03. Cecil Lake presented the highest mean Bw, at 2.87. Cecil Lake also had the lowest SD and CV. Both Beatton River and Cecil Lake showed a mean Bw that was higher than the overall mean for all the undisturbed transects. Beatton River also had a higher SD and CV than these overall values for all undisturbed transects.

For background information, alpha diversity values for vegetation were calculated for each undisturbed transect study site (Table 3-4). Mean richness, evenness, Shannon index (H'), and Simpson's index (D) were all calculated in Excel from the individual transect values generated in PC-ORD. Although these alpha diversity values were for the most part lower than those calculated for the undisturbed relevés in Chapter 2, the results ranked the undisturbed study sites in the same order.

Table 3-4. Undisturbed transect vegetation alpha diversity statistics.

	Beatton River			Cecil Lake			Hasler Flats			Overall - All undisturbed transects		
Diversity Measure	**Mean**	**SD**	**CV %**	**Mean**	**SD**	**CV %**	**Mean**	**SD**	**CV %**	**Mean**	**SD**	**CV %**
Beta diversity (Bw)	2.50	0.75	30.20	2.87	0.42	14.52	2.03	0.55	27.09	2.47	0.63	25.40
Richness (S)	10.50	1.15	10.98	10.17	1.89	18.57	16.53	1.50	9.06	12.40	3.38	27.25
Evenness (E)	0.73	0.05	7.43	0.70	0.04	6.33	0.74	0.04	5.10	0.72	0.04	6.10
Shannon (H')	1.69	0.19	11.44	1.56	0.27	17.60	2.04	0.15	7.14	1.77	0.28	16.05
Simpson (D)	0.73	0.06	8.36	0.69	0.09	12.76	0.80	0.04	4.94	0.74	0.08	10.25

Hasler Flats showed the highest mean undisturbed transect vegetation richness value (16.53), while Cecil Lake had the lowest richness value (10.17). Only Hasler Flats exhibited a mean richness higher than the overall mean richness for all undisturbed study sites. Regarding evenness, all three undisturbed study sites were similar in mean value, but Beatton River yielded the highest CV while Hasler Flats had the lowest CV. The Shannon index was highest at Hasler Flats and lowest at Cecil Lake, but Cecil Lake had the highest SD and CV. Only Hasler Flats showed a higher Shannon index than the overall mean. Hasler Flats also had the highest Simpson index, while Cecil Lake yielded the lowest Simpson index. Additionally, Cecil Lake had the highest SD and CV for Simpson's index.

3.3.2 Transect environment beta diversity

The results for the environment beta diversity calculations in PC-ORD generally showed a smaller range of values as well as lower beta diversity values overall, compared to the vegetation beta diversity.

3.3.2.1 Landslide transect environment beta diversity

Table 3-5 presents the beta diversity values calculated in PC-ORD for landslide transect environment variables.

Table 3-5. Landslide transect environment beta diversity (Bw) values.

Transect	Beta diversity (Bw)	Mean Bw	SD	CV %
Beatton River				
BEtl1a	0.2	0.22	0.23	103.65
BEtl1	0.2			
BEtl4	0.0			
BEtl5	0.1			
BEtl6	0.6			
Cecil Lake				
CEtl1	0.2	0.43	0.33	75.87
CEtl2	0.2			
CEtl3c	0.9			
CEtl4	0.3			
CEtl5	0.2			
CEtl6	0.9			
CEtl7	0.3			
Hasler Flats				
HAtl1a	0.6	0.43	0.15	35.25
HAtl2	0.3			
HAtl3	0.4			
Overall (all transects)		0.36	0.27	75.56

The Cecil Lake study site showed the greatest range in landslide transect environment Bw values while Hasler Flats had the smallest range. Beatton River contained the transect with the overall lowest Bw (BEtl4, at 0.0), while Cecil Lake contained two transects with the highest Bw (CEtl3c and CEtl6, at 0.9).

Hasler Flats yielded the highest mean landslide transect environment Bw, at 0.43, while Beatton River had the lowest mean Bw, at 0.22. Hasler Flats showed the lowest SD and CV. Both Hasler Flats and Cecil Lake had mean Bw values that were higher than the overall mean environment Bw value for all landslide transects.

For background information, alpha diversity values for environment variables were calculated for each landslide transect study site (Table 3-6). Mean richness, evenness, Shannon index (H'), and Simpson's index (D) were all calculated in Excel using the individual transect values generated in PC-ORD. Alpha diversity values were generally lower than those calculated for landslide geotypes in Chapter 2, but the results overall ranked the landslide study sites in the same order.

Table 3-6. Landslide transect environment alpha diversity statistics.

	Beatton River			Cecil Lake			Hasler Flats			Overall -All landslide transects		
Diversity Measure	**Mean**	**SD**	**CV %**	**Mean**	**SD**	**CV %**	**Mean**	**SD**	**CV %**	**Mean**	**SD**	**CV %**
Beta diversity (Bw)	0.22	0.23	103.65	0.43	0.33	75.87	0.43	0.15	35.25	0.36	0.27	75.56
Richness (S)	4.42	0.30	6.86	3.87	0.17	4.40	4.20	0.50	11.90	4.12	0.37	9.04
Evenness (E)	0.67	0.05	6.79	0.69	0.08	11.03	0.63	0.04	7.13	0.67	0.06	9.36
Shannon (H')	1.00	0.11	11.28	0.92	0.12	13.23	0.90	0.14	15.13	0.94	0.12	12.79
Simpson (D)	0.55	0.05	8.60	0.52	0.07	14.05	0.48	0.06	11.90	0.52	0.06	12.11

Beatton River showed the highest landslide transect environment richness while Cecil Lake had the lowest richness. Hasler Flats yielded the highest CV, while Cecil Lake had the lowest CV. Both Beatton River and Hasler Flats showed a higher mean environment richness than the overall average for all landslide transects. Of the three study sites, Cecil Lake had the highest environment evenness, while Hasler Flats exhibited the lowest evenness. Cecil Lake also showed the highest CV. For landslide environment Shannon diversity, Beatton River had the highest value, while Hasler Flats yielded the lowest Shannon index. However, Hasler Flats also had the highest CV. Only Beatton River showed a higher mean Shannon than the overall mean Shannon value. For Simpson diversity, Beatton River had the highest value while Hasler Flats showed the lowest value. Beatton River was higher than the mean overall Simpson value, while Cecil Lake was tied with the overall mean.

3.3.2.2 Undisturbed transect environment beta diversity

Table 3-7 shows the environment beta diversity values for each undisturbed transect.

Table 3-7. Undisturbed transect environment beta diversity (Bw) values.

Transect	Beta diversity (Bw)	Mean Bw	SD	CV %
Beatton River				
BEtu1a	0.4	0.30	0.17	57.74
BEtu2b	0.4			
BEtu3a	0.1			
Cecil Lake				
CEtu1	0.1	0.13	0.06	43.30
CEtu2	0.1			
CEtu3a	0.2			
Hasler Flats				
HAtu1a	0.2	0.37	0.15	41.66
HAtu2	0.4			
HAtu3	0.5			
Overall (all transects)		0.27	0.16	59.29

Beatton River and Hasler Flats were tied for the highest range of undisturbed transect environment Bw values, while Cecil Lake had the lowest range of Bw values. Hasler Flats yielded the highest mean Bw value of the three undisturbed transect environment data sets, whereas Cecil Lake showed the lowest Bw. Beatton River had the highest CV, while Hasler Flats had the lowest CV. Of the three study sites, only Hasler Flats exhibited a higher mean environment Bw than the overall mean value for all undisturbed transects.

For background information, alpha diversity values for environment variables were calculated for each undisturbed transect study site (Table 3-8). Mean richness, evenness, Shannon index (H'), and Simpson's index (D) were all calculated in Excel using diversity values that were generated in PC-ORD for each transect. These alpha diversity values were overall lower than those calculated for undisturbed geotypes in Chapter 2, and for some indices the undisturbed study sites were ranked differently than in Chapter 2.

Table 3-8. Undisturbed transect environment alpha diversity statistics.

	Beatton River			Cecil Lake			Hasler Flats			Overall - All undisturbed transects		
Diversity Measure	**Mean**	**SD**	**CV %**	**Mean**	**SD**	**CV %**	**Mean**	**SD**	**CV %**	**Mean**	**SD**	**CV %**
Beta diversity (Bw)	0.30	0.17	57.74	0.13	0.06	43.30	0.37	0.15	41.66	0.27	0.16	59.29
Richness (S)	3.60	0.00	0.00	3.53	0.21	5.89	3.47	0.21	6.00	3.53	0.16	4.47
Evenness (S)	0.81	0.07	8.64	0.65	0.04	5.80	0.71	0.05	6.98	0.72	0.08	11.64
Shannon (H')	1.03	0.09	8.74	0.81	0.02	2.46	0.87	0.10	11.66	0.90	0.12	13.14
Simpson (D)	0.60	0.04	6.24	0.49	0.03	6.26	0.53	0.04	7.31	0.54	0.06	10.47

For the undisturbed transect environment alpha diversity data, Beatton River showed the highest environment richness whereas Hasler Flats had the lowest richness. Hasler Flats yielded the highest richness CV, while Beatton River had the lowest CV. The Beatton River richness value was also higher than the mean overall richness, while richness for Cecil Lake was tied with the overall mean. Beatton River showed the highest evenness, while Cecil Lake had the lowest evenness. Only Beatton River had a higher evenness than the overall average for all undisturbed transects. Beatton River also yielded the highest Shannon and Simpson diversities, while Cecil Lake had the lowest values. Beatton River was the only study site with environment Shannon and Simpson diversities higher than the overall average. Of the three undisturbed study sites, Hasler Flats had the highest CV for Simpson index.

3.3.3 Regression analysis: assessing the relationship between vegetation and environment beta diversity

Simple linear regression was used to test if environment Bw significantly predicted vegetation Bw both on the landslide and in the surrounding undisturbed terrain (Figure 3-2).

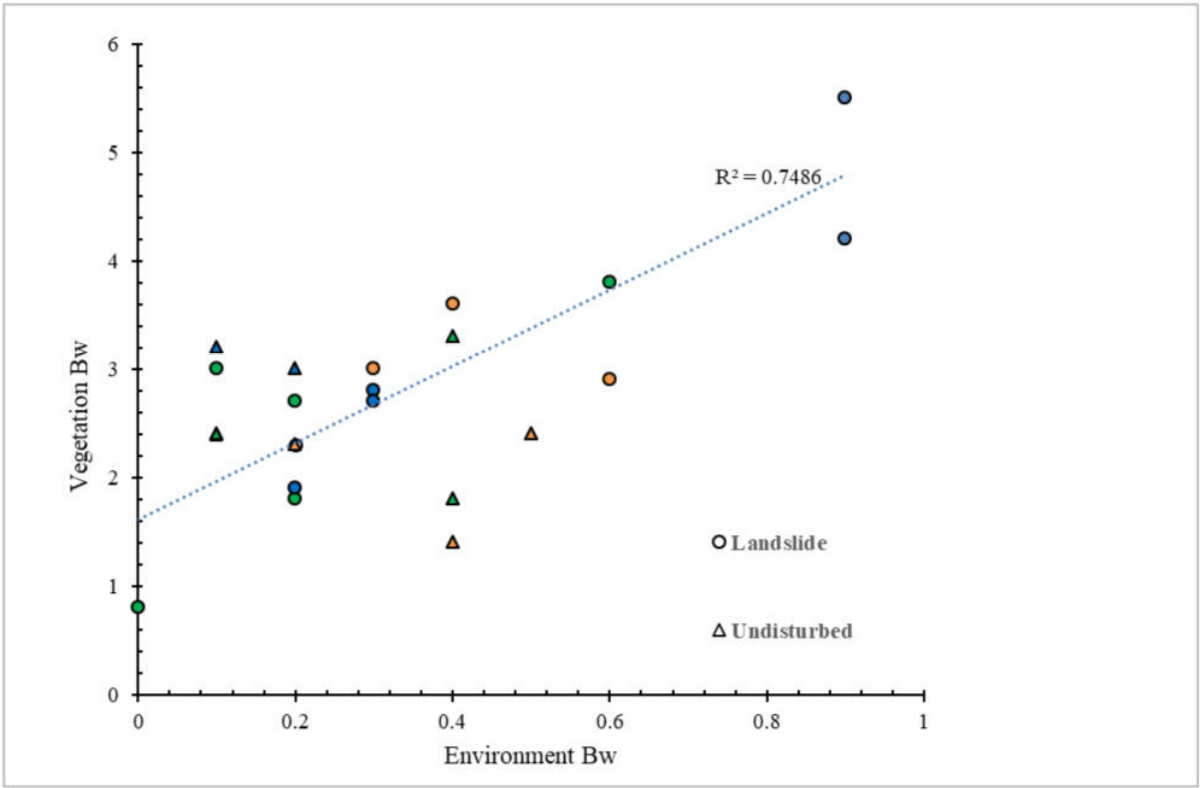

Figure 3-2. Landslide and undisturbed transect beta diversity (Bw) regression: vegetation vs environment. Blue symbols represent Cecil Lake transects, green symbols represent Beatton River transects, and orange symbols represent Hasler Flats transects. The blue dashed line is the regression line for landslide transect beta diversity (Bw). There was no significant regression for the undisturbed transects.

A regression line with the R^2 (coefficient of determination) value was drawn for the landslide transects, and a separate analysis was conducted for the undisturbed transects, to determine whether there was any relationship or correlation between vegetation beta diversity and environmental beta diversity. The fitted regression model was: Vegetation Bw = 1.617631918 + 3.525096525*(environment Bw). The regression for the landslide data was statistically significant ($R^2 = 0.75$, $F (1, 13) = 38.71$, $p = 0.000031$). The standard error of the slope coefficient was 0.5767 indicating the observed values for the landslide data fell an average of 0.58 units from the regression line. The low standard error suggested the model was precise enough to be used for predictions. Using the model, environment Bw significantly predicted vegetation Bw on landslides. The landslide transect vegetation beta diversity had a strong relationship with the beta diversity of the environmental variables. The R^2 value of 0.7486 indicated that almost 75% of the variation in vegetation Bw was explained by environment Bw. The undisturbed transects did not yield a significant relationship between vegetation beta diversity and environment beta diversity. When the landslide and undisturbed plots were combined in a single analysis (not reported), there was a significant, though somewhat weaker relationship than for just the landslide plots.

3.4 Discussion

The purpose of this research was to assess turnover of vegetation and site (environment) variables on landslides and to determine if there was any correlation between the two components. The research also investigated whether any correlations or relationships were influenced by size or age of the landslide disturbance, and whether there was a difference between landslide and undisturbed terrain areas.

In this study, vegetation and environment beta diversity were generally higher on landslides than on the surrounding undisturbed terrain. In addition, there were notable differences in diversity between the three study areas of Beatton River, Cecil Lake, and Hasler Flats. Average transect vegetation and environment beta diversity were both higher on the landslide than on the surrounding undisturbed terrain for the Cecil Lake and Hasler Flats study areas, but for Beatton River, vegetation and environment beta diversity were higher on the undisturbed terrain. The lower beta diversity on the Beatton River landslide was likely because the slide was newer and more active than the other two study sites, resulting in large areas of continuous bare ground. The Beatton River landslide also had the largest change in elevation from the top of the landslide to the bottom. In addition, this landslide was steeper and had more extreme exposures than the other two landslides, hindering the establishment of a variety of species across the disturbed area. The size of the three different study areas also likely affected the beta diversity values, as area influences both environmental gradients and the ecological mechanisms (such as species sorting) that drive spatial variation in species composition within a region unit (Heino et al. 2014).

The occurrences of lower alpha diversity but higher beta diversity on the landslide compared to the surrounding terrain for some of the study areas may be because while mature forest species were lost, the patchiness of the landslide habitats enabled more novel assemblages of species or life history strategies (Boinot and Alignier 2023). The structural complexity and heterogeneity of pre-existing and remaining habitats contributes to local and regional biotic successional processes and ultimately influences beta diversity (Abbasi et al. 2023). This impact is mainly seen through changes in both taxonomic and functional beta diversity. At the local level, biotic processes are determined by species-energy relationships and availability of resources.

Overall, vegetation beta diversity had a strong positive relationship with site or environment beta diversity on landslides in the study. As environment beta diversity increased, so did vegetation beta diversity. On the surrounding undisturbed terrain, however, there was no such relationship, either positive or negative.

3.4.1 Transect vegetation beta diversity

3.4.1.1 Vegetation beta diversity on the landslide

There were notable differences in vegetation beta diversity between the three landslide study sites of Beatton River, Cecil Lake, and Hasler Flats. Average transect vegetation beta diversity (Bw) was highest on the Hasler Flats landslide, but Cecil Lake had the greatest range or variability. The higher variation of the landslide vegetation beta diversity for the Cecil Lake transects was likely directly due to the larger size of the landslide, its age, and the adjacent landscape. The passage of time allowed more types of vegetation to encroach from the surrounding landscape and to propagate from rafts and seed banks. Overall, the surrounding landscape makeup may have strongly influenced the recovery rate of species diversity (Furusawa et al. 2023).

The higher among-site variability in plant species composition (beta diversity) on the Cecil Lake landslide suggests both a random, stochastic process of ecological drift and niche selection were critical for community assembly following the landslide disturbance. Field observations indicated the Cecil Lake landslide had a greater variety of site types in close proximity compared to Beatton River and Hasler Flats, allowing for the potential for higher turnover of plant species along any given transect distance. For example, the transect CEtl3c had the highest landslide vegetation beta diversity value (Bw = 5.5) and intersected a pond for ten metres of the transect length (Figure 3-3). This local site diversity likely contributed to the higher species turnover, as the pond and surrounding shorelines presented different habitats where new plants and unique communities could establish. Conversely, the Cecil Lake landslide transect with the lowest beta diversity, CEtl1 (for which Bw =1.9), had a uniform site type consisting of dense shrubs throughout the transect (Figure 3-4). This uniformity is expressed in the lower turnover denoted by a lower Bw value.

Figure 3-3. Cecil Lake landslide transect CEtl3c, showing high diversity of adjacent habitats as illustrated by *Alnus* spp. next to a pond, with sparsely vegetated south-facing slopes on the other side of the pond. (Photo August 25, 2018)

Figure 3-4. Cecil Lake landslide transect CEtl1, showing lower diversity of adjacent habitats as illustrated by expanse of level ground and relatively homogeneous vegetation. (Photo August 25, 2017)

The higher average beta diversity of the Hasler Flats landslide reflects the abundance of very different site types situated very close to each other, coupled with the much smaller area of the Hasler Flats landslide (Heino et al. 2014), compared to the Cecil Lake landslide. The Hasler Flats landslide consisted of a series of interlocking young aspen cutblock rafts from a 15 year old clearcut stand, exposed horsts (ridges of sand or clay) and grabens, and pond site types. Following the landslide disturbance, vegetation dispersal distances would have been shorter both from the surrounding landscape and within the landslide area. In addition, small samples in areas with high gamma diversity tend to have inflated beta diversity values, due to the dependence on sample size that interacts with gamma diversity (Cao et al. 2021). Despite its high site type diversity, Hasler Flats likely showed the smallest range of transect vegetation beta diversity values because of its smaller sample size. Hasler Flats had less than half the number of landslide transects of Cecil Lake, so this could have reduced the range just because there were fewer samples to begin with.

Although Hasler Flats had the highest mean vegetation beta diversity, it had the lowest CV. This lower CV indicates much less variation around the mean compared to Beatton River and Cecil Lake. This finding was in accord with field observations, as the Hasler Flats landslide overall appeared more consistent in diversity than Beatton River or Cecil Lake.

The lower average vegetation beta diversity of the Beatton River landslide compared to the other two landslide study sites was likely due to the large proportion of the slide that was sparsely vegetated because of recent movement and steep, unstable slopes. The Beatton River landslide also contained the transect with the lowest overall vegetation beta diversity, BEtl4 (Figure 3-5), for which Bw = 0.8. The transect BEtl4 was on a sparsely vegetated rubbly colluvial side slope and most of the vegetation was the invader exotic pioneers *Melilotus officinalis* and *Melilotus albus* (sweetclovers).

Figure 3-5. Sweetclover *(Melilotus* spp.) carpeting the toe of the Beatton River landslide. Transect is BEtl4. (Photo August 16, 2017)

Research has shown that sites with lower beta diversity may have higher alpha diversity, and the opposite can be true as well (Boinot and Alignier 2023). The background alpha diversity results of the present study showed variable outcomes. The Hasler Flats landslide had the highest richness (Figure 3-6), likely due to the many species rafted or otherwise dispersed from the adjacent aspen cutblock and the surrounding aspen (*Populus tremuloides*) and cottonwood (*P. balsamifera* ssp. *balsamifera*) stands with shrubby understories. The greater evenness, Shannon, and Simpson values at Cecil Lake may have resulted from the higher diversity of site types and the greater age and size of the landslide. Of the three landslides, Beatton River exhibited the lowest vegetation richness, evenness, Shannon, and Simpson measures. The lower alpha diversity values for Beatton River were likely due to the younger age of the landslide, as well as the fact that it was still quite active, so even when plants did establish, they could quickly die off or slide downslope and be buried or otherwise damaged. Depending on the severity of the disturbance, landslides can cause a shift from stochastic or random to more deterministic or predictable plant community assembly, with distinct responses in terms of beta diversity (Seguin et al. 2013). More frequent or severe landslides can lead to a homogenised species distribution or a high proportion of invasive species, as found on the Beatton River transect BEtl1 (Figure 3-7), while a lower disturbance frequency or severity can cause greater stochasticity.

Figure 3-6. Vegetation diversity on the Hasler Flats landslide, illustrated by dense layers of varied forbs, short shrubs, and tall shrubs. Transect is HAtl1a. (Photo July 28, 2018)

Figure 3-7. Invasive/exotic plants *Lactuca serriola* (prickly lettuce), *Sonchus* spp., *Melilotus* spp., and *Elymus repens* (quackgrass) on the Beatton River landslide. Transect shown is BEtl1. (Photo August 17, 2017)

3.4.1.2 Vegetation beta diversity in the surrounding undisturbed terrain

The variable levels of beta diversity in the undisturbed areas surrounding each landslide highlights the complexities of assessing beta diversity. The greater range of transect vegetation beta diversity values and the higher variability in the adjacent undisturbed terrain of the Beatton River site compared to Cecil Lake and Hasler Flats may have been due to the higher diversity of ecological habitats surrounding the Beatton River landslide. Habitats included mature conifer forest, mature aspen forest, mature cottonwood forest (Figure 3-8), shrublands, and grasslands.

Figure 3-8. Example of moist cottonwood (*Populus balsamifera* ssp. *balsamifera*) habitat in undisturbed terrain at Beatton River. Transect is BEtu1a. (Photo August 26, 2018)

Cecil Lake exhibited the lowest range of vegetation beta diversity values of the three undisturbed study sites but yielded the highest average undisturbed vegetation transect beta diversity. The Cecil Lake undisturbed study site also had the lowest CV, indicating less variation around the mean compared to Beatton River and Hasler Flats. The comparatively higher undisturbed transect vegetation beta diversity for Cecil Lake could have been due to the larger area, increasing the likelihood of transects falling on more heterogeneous terrain. Compared to the associated landslides, the mean vegetation beta diversity was lower in the surrounding undisturbed terrain for Cecil Lake and Hasler Flats, but higher in the undisturbed terrain than on the landslide at the Beatton River study area. Although there may be no significant differences in species diversity between an undisturbed and landslide community, much higher among-site variability may be found on landslides (Furusawa et al. 2023). The generally lower vegetation beta diversity on the undisturbed terrain for the three study areas was likely due to the presence of greater areas of homogeneous habitats, such as the adjacent cutblock next to Hasler Flats (Figure 3-9), as well as the passage of time that allowed certain successional species to outcompete pioneers and take over.

Figure 3-9. Relatively homogeneous vegetation (young aspen – *Populus tremuloides*) in undisturbed terrain at Hasler Flats. Transect is HAtu1a. (Photo August 10, 2018)

Overall, the assessment of vegetation alpha diversity in the undisturbed terrain among the three study areas revealed variability between study sites, with higher alpha diversity values for Beatton River and Hasler Flats and lower values for Cecil Lake in the undisturbed terrain compared to the landslide areas. The higher alpha diversity richness value of Hasler Flats compared to Cecil Lake may have been due to the greater array of shrub species in the terrain surrounding the Hasler Flats landslide. Hasler Flats also yielded the highest Shannon and Simpson values, further suggesting the surrounding undisturbed terrain vegetation had higher alpha diversity than the Beatton River and Cecil Lake study sites. Cecil Lake had the lowest Shannon and Simpson values, indicating the vegetation on the undisturbed terrain was less diverse. The similar evenness for all three undisturbed sites suggests the sites were similar in the proportional distribution of various species. It should be noted that "undisturbed" was a relative term, and for all three landslides there were signs of past disturbance in the surrounding terrain. There was evidence of older landslides, historical logging, cultivation of fields, and possibly other natural disturbances. All these factors undoubtedly contributed to a diversity of plant community growth forms and successional stages.

3.4.2 Transect environment beta diversity

3.4.2.1 Environment beta diversity on the landslide

Overall, the environment beta diversity values on the landslides were much lower than vegetation beta diversity and had smaller ranges, suggesting a lower turnover of site diversity compared to vegetation. Disturbance such as a landslide can either increase or decrease environmental heterogeneity, and likewise either increase or decrease beta diversity (Maab et al. 2014). The environment of an area can locally filter dispersing plant species, which may establish either through niche partitioning or dispersal (Maab et al. 2014). The variable environment beta diversity values among landslides in this study indicate different drivers influencing diversity for each landslide. Just as for vegetation beta diversity, the Cecil Lake landslide study site had the greatest range of environment beta diversity values, while Hasler Flats showed the smallest range. The higher range of beta diversity values at Cecil Lake could have been due to the greater diversity of site types observed on the landslide compared to Hasler Flats. The findings could also simply be explained by the fact that Cecil Lake landslide was almost 40 times larger and had more transects than Hasler Flats, increasing the potential for a random transect to fall on a diverse site. However, Hasler Flats had a much higher sampling intensity given its size, so the influence may not have been that great. Either way, the higher range indicates an increased variability in turnover of environment features on the Cecil Lake landslide. The Cecil Lake and Hasler Flats landslide study sites were tied for the highest environment beta diversity of the three landslide study sites, even though Cecil Lake landslide was more variable. Hasler Flats was a smaller and younger slide, and it appears these factors contributed to a higher beta diversity. The landslide was still in the process of weathering and becoming more subdued. The lower average environment beta diversity of Beatton River is consistent with field observations, as large parts of the landslide were uniform in slope, aspect, and substrate. However, Beatton River also had the highest CV (over 100%), indicating a large amount of variation among transects.

The variability in environment alpha diversity results for the three landslide study sites highlights the influence of space and time on environment heterogeneity (Maab et al. 2014). The higher landslide environment alpha diversity results for Beatton River contrasted with the lower beta diversity results. Higher alpha diversity could be explained by the site diversity present along some of the Beatton River transects. One of the transects, BEtl6, passed through rubbly boulders, across a pond, and then up a steep slope (Figure 3-10). Other transects on the landslide had patches with no vegetation. The lower environment richness of Cecil Lake compared to Beatton River and Hasler Flats could be due to the age of the landslide, as geomorphological features weather over time, becoming more uniform. The lower alpha diversity values for Hasler Flats may have been a result of the small size of the landslide and the more consistent configuration of the environment features.

Figure 3-10. Beatton River landslide transect BEtl6, showing microsite diversity of hummocks, depressions, ponds, and fissures. (Photo taken September 5, 2018)

3.4.2.2 Environment beta diversity in the surrounding undisturbed terrain

Overall, mean environment beta diversity values for the undisturbed transects were lower than for the landslide transects, but on an individual basis the Cecil Lake and Hasler Flats undisturbed study sites had lower average beta diversity while Beatton River had higher beta diversity compared to the associated landslides. Lower environment beta diversity in the undisturbed terrain could be due to the surfaces exhibiting a lower diversity of microsites over short distances compared to the landslides, as a result of minimal disturbance over time. The higher average beta diversity value for Hasler Flats and the lowest average beta diversity for Cecil Lake undisturbed samples could be explained by the fact that Hasler Flats samples were in more broken terrain (Figure 3-11) in the surrounding area, while Cecil Lake undisturbed samples fell in more uniform terrain (Figure 3-12). The similarity in beta diversity range for Beatton River and Hasler Flats is likely due to the similar undisturbed terrain of these two study sites.

Figure 3-11. Hasler Flats undisturbed transect HAtu3 showing broken terrain. Transect traverses uneven terrain and small fissures for the first 15 m (foreground), then ascends a steep slope for 8 m (visible in the distance), and finally levels out (evident in the photo where the sky shows through). (Photo August 3, 2018)

Figure 3-12. Cecil Lake undisturbed transect CEtu2 showing uniform, level terrain. (Photo August 17, 2018)

The variable environment alpha diversity of transects on undisturbed sites was reflective of the variation among landslide study areas. The higher environment alpha diversity values of richness, evenness, Shannon, and Simpson values for transects in the Beatton River undisturbed terrain could be explained by the fact that Beatton River had a variety of site types and ecosystems. Conversely, Hasler Flats exhibited the lowest richness, while Cecil Lake had the lowest evenness, Shannon, and Simpson values. The lower environment richness of the undisturbed Hasler Flats transects reflects more uniform terrain and may also be due to the smaller area over which transect locations were selected. The lower alpha diversity values for Cecil Lake may have been the result of a more subdued landscape overall, given the larger scale of the site as well as its advanced age.

3.4.3 Relationship between transect vegetation and environment beta diversity

Environmental factors shape both local and regional biotic processes, mainly through changes in functional and taxonomic beta diversity patterns (Abbasi et al. 2023) but also alpha diversity patterns (Boinot and Alignier 2023). The current study in the Peace River Region revealed a significant relationship between vegetation beta diversity and environment beta diversity on the landslide study sites, while there was no such relationship on the undisturbed sites. Generally, as environment beta diversity increased on the landslides, so did vegetation beta diversity, even though the environment beta diversity values were notably lower than those for vegetation beta diversity. The stronger association between vegetation and environment beta diversity on the Cecil Lake landslide study site compared to Beatton River and Hasler Flats could be explained by the greater age of this landslide, where plant communities have evolved with the changing microsites over time. It is also possible the plant communities altered the environment as time passed. The lack of a strong relationship between environment and vegetation beta diversity on the undisturbed areas is most likely due to the overall lower beta diversity for both environment and vegetation on these sites. The sites have stabilised, and thus more resilient plant species have tended to dominate.

Research has shown beta diversity is positively associated with local topographical heterogeneity as well as with community-level niche specialisation and niche marginality (Cao et al. 2021). Higher niche marginality, or ability to occupy the peripheries, indicates larger niche space, which may allow more species to use more variable resources, while higher niche specialisation enables species to specialise on narrower subsets of the resources present. Therefore, on a highly variable topography where niche specialisation or marginalisation are at work, a greater turnover of species can be found from one point to another across a given distance. Local processes of topographical heterogeneity and the resultant niche differentiation drive beta diversity at scales of 15-52 ha. Greater environmental variability on a site may ultimately lead to reduced evenness in communities (Furusawa et al. 2023).

Connectivity between habitats is important for driving the recovery of disturbed sites such as landslides. Connectivity is a product of the synergies between natural history, dispersal mechanisms, and the quantity, quality, and pattern of habitat patches, at the landscape level (Chiantore et al. 2018). Connectedness of habitats and the successional state of ecological communities together play an important role in understanding consequences of change in different ecosystems. Of the three landslides studied, Hasler Flats appeared to have the greatest connectivity, mainly due to its small size and the presence of many rafts. From the perspective of beta diversity as an indicator of ecological connectivity, recovery does not necessarily depend on the available species at the regional level. Instead, local ecological attributes affiliated with beta diversity and the creation of habitats by living organisms drive community assembly by way of species replacement (turnover) and habitat filtering in disturbed areas. Habitats and communities can become homogenised with an increased disturbance frequency or severity, exhibiting an accelerated homogenisation with increasing scale of disturbance. This condition appeared to be present on portions of the Beatton River landslide, where disturbance was still active and exotics dominated large portions of the landslide. Boinot and Alignier (2023) found alpha and beta diversity can be maintained with a variety of weed species and life strategies in highly disturbed sites, even if rare and more sensitive species are removed from the community. Homogeneous sites also recover faster, which results in diminished complexity and biodiversity over time (Chiantore et al. 2018).

3.4.4 Limitations

One of the limitations to the study was the fact that the number of samples and sampling intensity per hectare at each study site were not the same. The only study area with the same amount of transects on the landslide and in the surrounding undisturbed terrain was Hasler Flats. Another limitation was that not all transects were of equal length or had the same number of plots in a sample. For example, two transects could have both been 30 m long, but one might have only 20 plots because a portion of the transect was skipped once there were no new species. Plots were sampled again along the transect if there was a new type, but it is possible there were microsites in between that contained new species. Therefore, beta diversity could have been underestimated. Further, the landslides varied in age, type, and size, rendering the results more challenging to generalise. Overall, however, the methods used did provide a useful synopsis of beta diversity on landslides and in the surrounding terrain, and the study provided many insights into turnover on diverse disturbed sites.

3.5 Conclusions and Recommendations

Although there was some variability between transects on some landslides, overall, average vegetation and environment beta diversity (Bw) appears to be higher on landslides than on surrounding undisturbed terrain for sites in northeastern British Columbia. The trend is more pronounced for vegetation beta diversity. There is a strong relationship between vegetation beta diversity and environment beta diversity on the landslides, even though the environment beta diversity values are much smaller. This finding suggests that environment beta diversity does not need to be very high to produce increased vegetation beta diversity.

The differences in vegetation and environment beta diversity values between landslides of differing sizes and ages indicates that spatial and temporal factors may influence the level of turnover on a given landslide. The smallest landslide (Hasler Flats) had the highest beta diversity, and it was the second oldest of three landslides. The newest and most active landslide (Beatton River) had the lowest beta diversity.

The findings of this study of beta diversity on landslides can help inform restoration planning for other landslides in the Peace River Region, as well as for low-gradient, deep-seated landslides throughout the circumboreal zone which occur on glaciolacustrine unconsolidated material. Beta diversity is a primary signal of the health of a community and the proper functioning of ecosystems. It can provide important information about ecosystem mechanisms for the purposes of restoration. However, patterns of beta diversity on their own should not be used as a benchmark for restoration, since observed change in beta diversity in disturbed areas such as landslides is chiefly due to random sampling effects influenced by changes in local community size (Myers et al. 2015). Sites with very similar habitat might have quite different makeup of species because of the order that species arrive on the landslide. This phenomenon can produce multiple stable equilibria.

Knowledge about the connections between ecosystem disturbance and taxonomic, functional, and beta diversity of landslides may provide crucial information for natural resources management (De et al. 2023) as well as restoration. Beta diversity presents important potential for management of environmental monitoring and conservation since diverse processes can result in the same beta diversity pattern (Maab et al. 2014). The present study of landslides has shown that when only a few plant species prevail because of accelerated habitat disruption, the species composition becomes more uniform and the diversity of the community decreases, as evident on the Beatton River landslide. High alpha diversity may obscure deleterious effects of habitat disturbances on plant species diversity (Dehling and Dehling 2023). Just as for beta diversity, alpha diversity alone should not be viewed as a representative indicator of disturbance impacts since it does not consider possible local or regional changes in species composition or turnover. Habitat alterations resulting from disturbances such as landslides can eliminate vital functional roles, reducing an ecologically complex system to one that is simpler. In this situation, unique native species disappear, and more common and often invasive species take over, creating homogenised communities that diminish regional diversity. Alpha and beta diversity can be maintained with a variety of weed species and life history strategies in simple, severely disturbed areas, even when uncommon and more disturbance-sensitive species are eliminated (Boinot and Alignier 2023). However, this type of diversity is not a good indicator for conservation or healthy functioning of ecosystems, because the original natural community system has been modified. As there are different drivers for alpha and beta diversity, both types of diversity can be advanced by implementing different arrays of management practices (Boinot and Alignier 2023). Any attempts at restoration of landslides should retain patchiness and maintain beta diversity. As climates change in an unpredictable way in coming years, beta diversity may provide important wildlife habitat at various scales and enhance resilience of populations in uncertain times.

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Chapter 4. Landslide-generated ponds in the Fort St. John area, British Columbia: Characteristics, distribution, and ecological implications

4.1. Introduction

Traditionally, landslides have been viewed as destructive to the habitats and ecology of a landscape, in that they remove vegetation, bury other vegetation, disintegrate soil profiles, fill in water bodies, and alter hydrology. However, the same processes that are seen as destructive can serve to enhance ecological diversity by creating new geomorphic and hydrological features. In addition to depositing sediment nutrients and habitat debris into river systems and changing stream morphology, landslides often produce a diverse array of topographies on the landslide surface, with many pond depressions that contain water ephemerally, seasonally, or year-round. The size, number, and distribution of such water bodies is variable and may depend on the material of the landslide as well as the landslide type. The focus of the research reported here is the ecological contribution of these landslide ponds to diversity and implications for management.

Water bodies on landslides form important habitats that contribute to biodiversity in many different environments (Geertsema and Pojar 2007; Shapley et al. 2019). At the landscape level, these aquatic habitats can create a network of reproductive and dispersal routes for pond-dependent fauna such as invertebrates, amphibians, and reptiles; this network of various sizes of ponds provides more value than one large lake (Pop and Chitu 2013). While landslides themselves create ponds, they also can provide ideal habitat for beavers (*Castor canadensis*) (Krueger and Johnson 2016), and beavers can then further modify the geomorphology and hydrology of the landslide (Butler and Malanson, 1995; Westbrook et al. 2017) and increase the ecological diversity of ponds (Nummi et al. 2019).

Although few detailed studies of landslide ponds have been reported, existing research has revealed interesting characteristics. Sasaki and Sugai (2015) found that landslide ponds in the mountains of Japan chiefly occur on bigger landslides, in large or deep depressions along scarps, or in small depressions at pressure ridges, and are mainly fed by groundwater. The authors of the study also found that pond size is constrained by the topography of the landslide, and ponds at different stages of development can be present concurrently due to new activity on an existing landslide. Ponds can persist and expand over time (Cruden et al. 1997). Surface water infiltration through boulder debris and fractures on an existing slide can saturate the substrate and facilitate further slide activity (Coe et al. 2003), which then forms new depressions that develop into ponds. On larger slides, different temperature and water regimes may exist among head, body, and toe positions of the landslide due to differences in elevation, which can influence infiltration and pond persistence (Coe et al. 2003). Coe et al. (2009) found that pond location and persistence may be controlled by basal topography, in that the landslide ponds may persist in one location for over 100 years even while the landslide material moves around, below, and through the pond.

The studies discussed above have helped to explain pond distribution and development on landslides in other parts of the world. The key purposes of the research reported here are to compile an inventory of landslide ponds in a designated study area of the Peace River Region of northeastern British Columbia, Canada using GIS applications, to describe characteristics of size and distribution of these ponds within landslides and between landslide types, to identify ecological importance, and to provide recommendations for management.

The study of landslides in the Charlie Lake 1:250,000 mapsheet area and in the Peace River Region in general is of interest to various government and industrial entities because of the potential and existing impacts of mass movement events on industrial development and public safety. Some of the earliest geomorphology studies were carried out in anticipation of a proposed hydroelectric dam, Site C (now under construction), near the town of Taylor (Mathews 1978; Catto 1991). These investigations focused on the geological setting of historic landslides and attempted to determine slide mechanics. Since then, major work has been done to describe the geological history and stratigraphic makeup of the mapsheet area (Mathews 1978, 1980; Bobrowsky et al. 1990; Bobrowsky and Rutter 1992; Catto et al. 1996; Hartman 2005). In recent years, more detailed assessments of movement mechanisms have been performed on specific landslides, such as the Cache Creek slide (Van Esch 2012), the Attachie slide (Fletcher et al. 2002; Van Esch 2012), and the Beatton River slide (Dandurand 2018).

An inventory of all landslides in the Charlie Lake mapsheet area was compiled by Severin (2004), with each mapped landslide categorised according to factors such as movement type and activity level. Severin (2004) found that the majority of identified landslides occurred in the Peace River and Beatton River Valleys within the pre-glacial valley limits, where valley fill and rebound features in the shale bedrock are more prominent. In the current research, the aim is to investigate landslides in the Peace River Region with a focus on landslide ponds and their potential ecological value, using the same study area as Severin (2004).

The objectives of the landslide pond research were to: 1) Obtain a snapshot in time of pond locations on landslides in the study area; 2) Enumerate and graphically illustrate pond area and distribution in relation to landslide type and geomorphic location; and 3) Investigate potential ecological and management implications of the findings.

What follows is a synthesis of the research and findings of the landslide pond study. First, the study area is described, followed by a detailed description of the methods that were employed to address the research question regarding the nature of landslide pond presence, abundance, distribution, and possible ecological roles in a specified area of the Peace River Region. The results are presented, including some representative pond photographs from a few pond-bearing landslides in the area. Presentation of the results is followed by a discussion of key findings regarding ponds on landslides and possible ecological implications. The discussion includes a section on the influence of beavers, which often play a role of keystone species at the landscape level. Finally, the chapter concludes with some recommendations for further research and land management considerations. The work reported here is the first known large-scale detailed regional inventory and description of ponds on landslides.

4.2. Study area

The study area covers the entire NTS (National Topographic System) mapsheet 94A (Charlie Lake mapsheet, 1:250,000), an area of approximately 16,000 km^2 (1,600,000 ha) that includes the communities of Fort St. John, Hudson's Hope, and Taylor in the Peace River Region of British Columbia (Figure 4-1). The Beatton River and Cecil Lake Landslide study sites described in Chapters 2 and 3 are located within this mapsheet. The area is represented by the Boreal White and Black Spruce (BWBS) biogeoclimatic zone (Meidinger and Pojar 1991) and is completely within the boreal forest biome. The climate is temperate, with warm, wet summers and cold winters (Meidinger and Pojar 1991). Much of the precipitation falls in the summer months. Vegetation consists of pure and mixed conifer and aspen forests on the uplands, transitional aspen parkland, and grasslands along the river slopes.

Historically, the main forms of land use in the area were farming, forestry, and fur trapping. However, in recent decades, oil and gas activity has expanded exponentially, greatly increasing the industrial footprint on the land through exploration, extraction, and infrastructure.

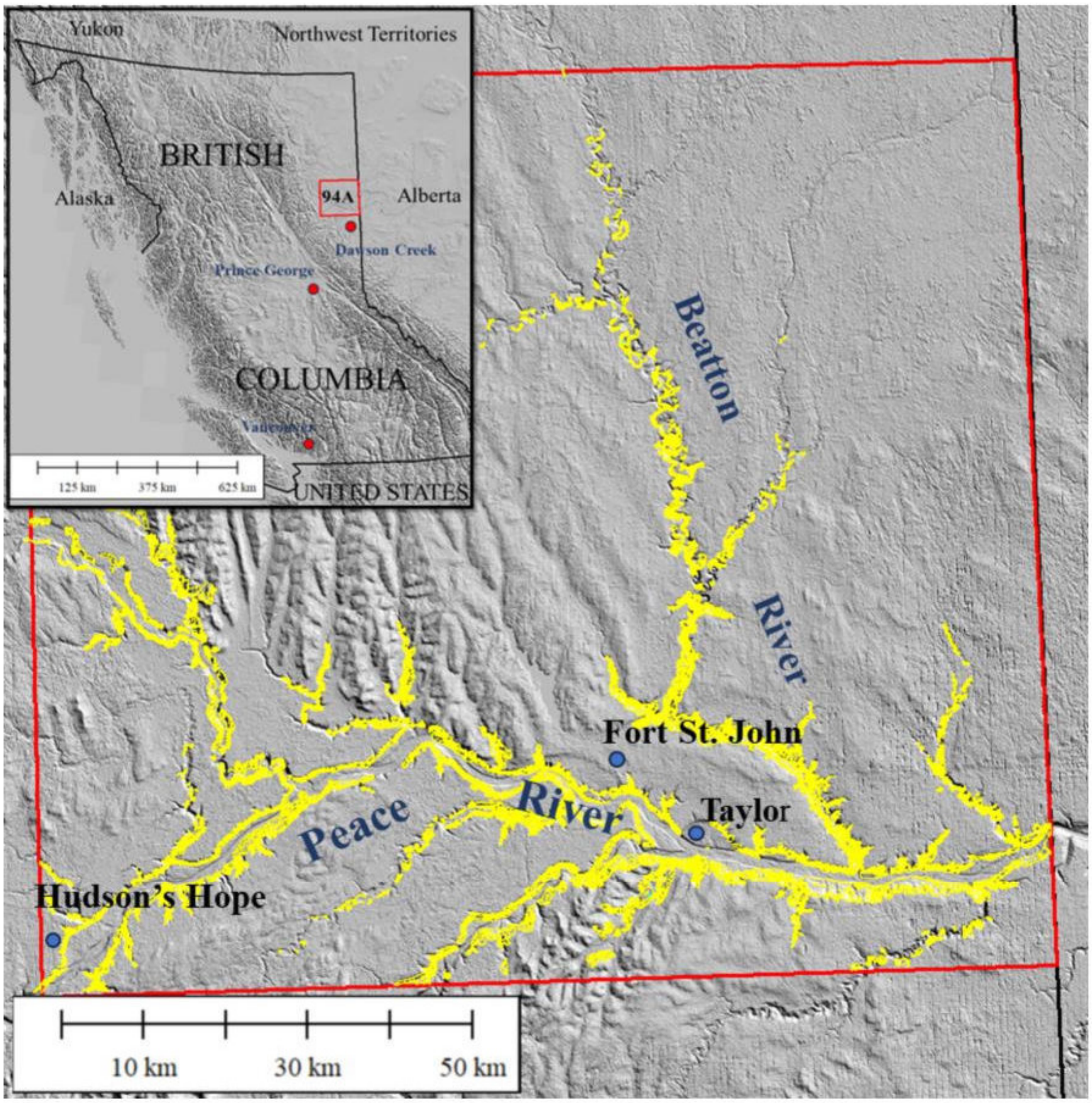

Figure 4-1. Landslide ponds study area – Mapsheet 94A (1:250,000) Peace River Region of northeastern British Columbia, Canada. The yellow areas indicate history of landslides along the Peace River and its tributaries, based on shape file linework by Severin (2004). Shape file linework imagery reproduced with permission.

The geology of the area consists of Quaternary stratigraphy from the historical episodes of Glacial Lake Mathews and Glacial Lake Peace (Mathews 1978, 1980) formed by successive advances and retreats of Cordilleran and Laurentide ice sheets. Many of the sediments are fine clay and silt overlaying shale bedrock (Catto 1991). The Shaftesbury (marine shale) and Dunvegan (marine and deltaic sandstone with shale interbeds) formations prevail in this area (Mathews 1978), and most existing landslides occurred within the Lower Cretaceous Shaftesbury Formation (Severin 2004). Many tributaries of the Peace River were formed by the rapid carving of valleys following isostatic rebound as the glaciers retreated and the land masses rose (Mathews 1978; Catto 1991; Hartman and Clague 2008). Prehistoric and contemporary landslides are abundant along the Peace River and its tributaries.

4.3. Methods

This study used computerised geographic information system (GIS) techniques and large Excel spreadsheets to compile and analyse the distribution and spatial characteristics of pond-bearing landslides and their associated water bodies within the area of interest. It also incorporated some field observations obtained during data collection for Chapters 2 and 3 to enhance the discussion on pond description and development.

To limit scope for the time-intensive digitising and data entry work, the study was restricted to a specific 1:250,000 mapsheet of the Peace River Region, mapsheet 94A, and only ponds on landslides were inventoried and described on this 16,000 km^2 area. Ponds were digitised by hand rather than using digital image processing (i.e. supervised image analysis), as many of the ponds were smaller than what could be captured in processing, and the aim was to map all ponds visually discernible on the imagery.

To begin the mapping of landslide ponds, Mapsheet 94A (NTS 2021) was loaded from the World Imagery layer (World Imagery 2021) into the Global Mapper GIS application (Global Mapper 2021). Google Earth Pro imagery (Google Earth Pro 2021) was loaded on a separate computer monitor. World Imagery and Google Earth Pro are platforms that synthesise aerial photographs, and it was these photographs that were analysed. The resolution of both sets of imagery was intermediate, with World Imagery having a slightly better resolution. The two sets of imagery were used as cross-references to each other, to verify whether the features identified were indeed landslides and ponds, or something else. While the World Imagery had clearer features, Google Earth Pro had the advantage of providing a 3D view as well as rapid zooming capabilities. The vintage for both types of imagery varied and covered a range of years, typically 2006 to 2018.

Using the World Imagery map layer and a map tile grid in Global Mapper, and Google Earth Pro as a cross-reference, the entire mapsheet was systematically assessed visually for the presence of ponds, and all ponds located on landslides were digitised working at a scale of approximately 1:500 (Figure 4-2). The ponds were then labelled with numbers and classified as either ponds, dried out ponds, or wetlands. Each pond was assigned a unique number. Although some ponds were partially or completely dried out, all were counted, since the drying appeared to be seasonal. Early spring imagery was not always available to confirm the extent of water pooling, but other indicators such as variations in vegetation were used to verify. The occurrence and extent of dried ponds was evidenced by aquatic or wetland vegetation still present, mainly recognisable as cattail (*Typha* spp. – most likely *Typha latifolia*), which contrasted in texture and colour against the surrounding terrain. Because wetlands in general are essentially a type of pond, they were combined with the ponds when compiling and analysing the data.

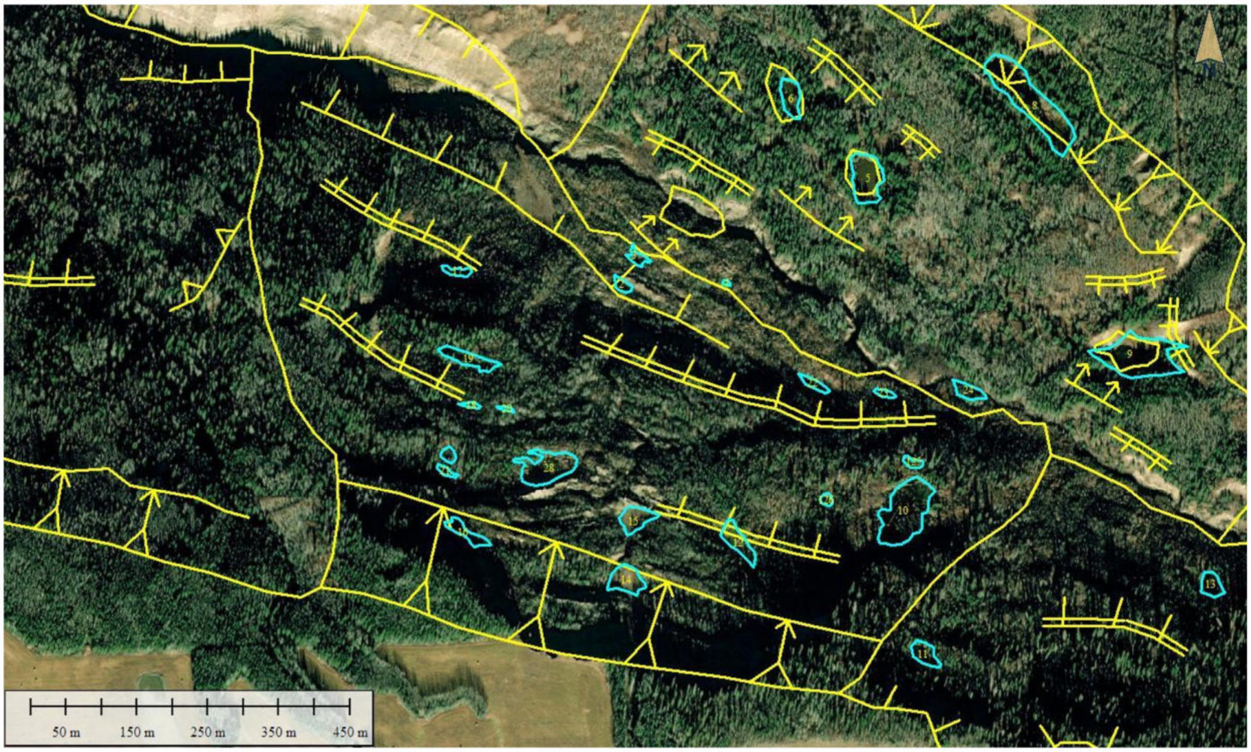

Figure 4-2. Sample of landslide pond mapping. Location is Cecil Lake. Ponds are outlined in blue. Yellow lines indicate landslide features that had been previously mapped by Severin (2004). Severin landslide shape file lines used with permission.

Once the ponds were mapped, Severin's (2004) landslide shape file was loaded into Global Mapper as an overlay on the pond polygons. Severin's digital GIS rendering of landslides (2004) was in the format of linework rather than enclosed area polygons (see Figure 4-2), and thus individual areas of these landslides were not obtainable in the GIS dataset. Therefore, the table from the inventory created by Severin and the landslide areas provided in Appendix IV of his thesis were used to obtain the initial total area of landslides. In the present study, a small number of additional landslides that were not included in the 2004 study were identified and digitised, as well as portions of other landslides where new movement had occurred since the 2004 work done by Severin. The new area was added to the total landslide area prior to analysis of landslide ponds. No minimum or maximum size limit was assigned for either ponds or landslides; anything that could be discerned by zooming in on the imagery was mapped.

A large Excel spreadsheet was created to record various data related to the ponds and associated landslides (Appendix 7). In the spreadsheet, a unique number was assigned to each pond-bearing landslide, in numerical order starting from the first landslide with ponds encountered in the pond digitising exercise. The landslides were not numerically labelled in Global Mapper, as several landslides were either eliminated or renumbered in the final spreadsheet list. However, the geographical location (UTMs – Universal Transverse Mercator) of the centre of each pond-bearing landslide was recorded in the spreadsheet.

Once pond and landslide numbers were assigned, the general location of each pond on the landslide was recorded in the spreadsheet, for example if it was above or below a scarp or on a debris apron. The geomorphic location of each pond was also recorded and classified as to whether it was on the head, body, or toe of the landslide, using a simplified version of Cruden and Varne's (1996) rendering of landslide anatomy (Figure 4-3). In some situations, ponds appeared to be on the borderline between geomorphic locations. If a pond seemed borderline between the head and the body, the pond was classified as being on the head if it was at the base of the main scarp before the slope changed by more than approximately 5 degrees. If the pond was located after a change in slope, it was classified as being on the body. A similar method was applied to ponds that appeared borderline between the body and the toe, in that ponds located at the base of the body before the slope changed significantly were classified as being on the body, and those occurring after a slope change were classified as being on the toe. The Global Mapper Profile tool applied on an Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (DEM) image of 1 arc-second resolution (ASTER GDEM v2 2021) was used to assist in determining slope. Geomorphic location classifications were assigned initially by incorporating information on landslides found in Cruden and Varnes (1996) and Highland and Bobrowsky (2008) but decisions were ultimately subjective based on the characteristics of each individual location.

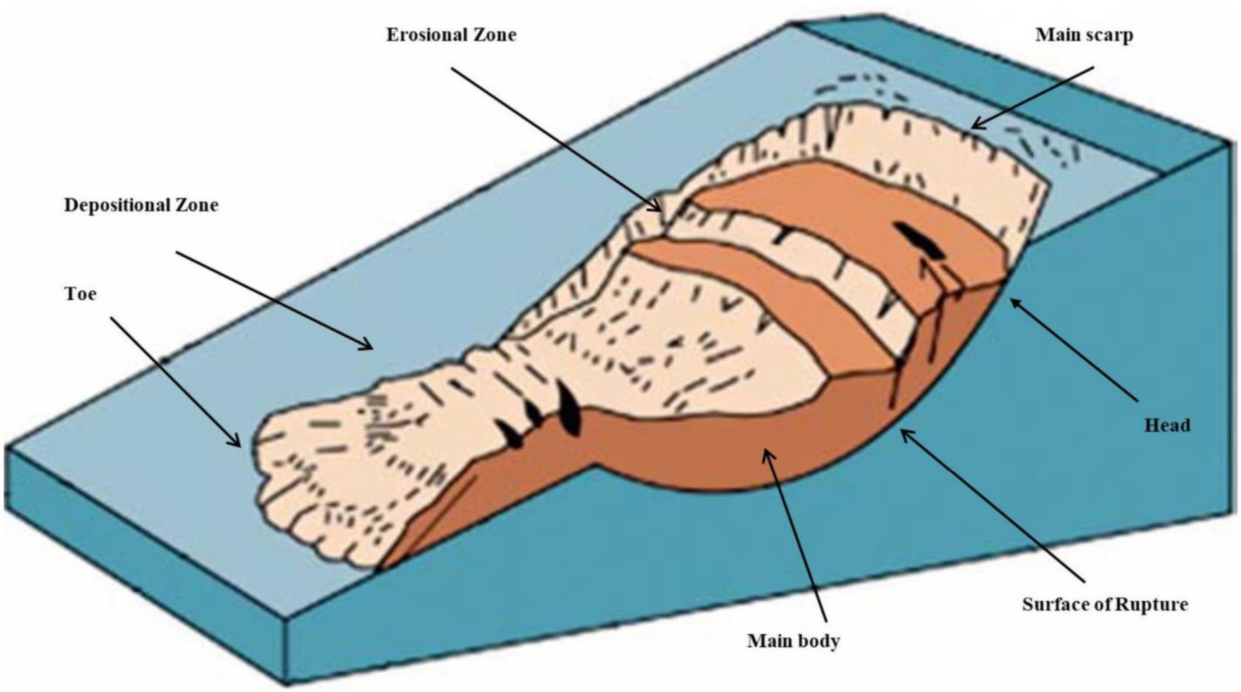

Figure 4-3. Simplified anatomy of a landslide showing head, body, and toe. Adapted from Cruden and Varnes 1996. Credit: Transportation Research Board. 1996. *Landslides: Investigations and Mitigation. Special Report 247*. https://doi.org/10.17226/11057. Reproduced with permission from the National Academy of Sciences, Courtesy of the National Academies Press, Washington, D.C.

For each pond, the size in km^2 was recorded as calculated in Global Mapper, and values were then converted to hectares (ha) for the purposes of the study. The movement type of each pond-bearing landslide was classified according to the relevant descriptions and diagrams laid out in Severin's (2004) thesis. In the study area, six pond-bearing landslide types were identified: compound failure, mobile flow, multi-level rotational failure, retrogressive rotational failure, rotational failure, and shallow retrogressive rotational failure. The definitions of these types are outlined in Severin (2004) and are based on key landslide classification works (Varnes 1978; Hutchinson 1988; Cruden and Varnes 1996). However, Severin modified some classifications to reflect the unique characteristics of landslides in the Peace River Region. *Compound failures* occur on pre-sheared surfaces in bentonitic-rich layers of Shaftesbury shale and generally have a low angle. As the slope range parameter of compound failures was not specified in Severin (2004), a subjective judgment was made in the present study to classify as a compound failure any slide with a relatively long, straight profile and an average slope of approximately 20% or less. This classification method relied heavily on the Global Mapper Profile feature to assess slope profile characteristics. *Mobile flows* usually occur in gullies along the river and fan out at the bottom of the gully. They are shallow and are triggered during heavy rainfall and snowmelt seasons. *Rotational failures* develop along pre-sheared surfaces mainly in pre-glacial sediments, mostly on south-facing slopes. The debris is often broken up across the slope, rather than appearing as a classic slumped block. *Multi-level rotational failures* take place along several weak shear planes at different levels. The failures can occur either separately or simultaneously. *Retrogressive rotational failures* develop when rupture surfaces lengthen along a weak layer in the slope and there is progression of a single rotational slip upslope, ending at a curved back scarp. The initial small failure destabilises the toe, causing further slumping, and there are often back-tilted blocks of debris present. *Shallow retrogressive rotational failures* are similar to retrogressive rotational failures, but only occur in Glacial Lake Peace clay. The till below acts as a base that the failure plane cannot penetrate. The basal shear plane normally coincides with the surface of the Wisconsinan till. The sediment remobilises and flows over a stable bench and quickly disintegrates at a slope angle of 3.5 degrees.

Although the original landslide inventory (Severin 2004) categorised each landslide by movement type and assigned it a reference number, no digital or hard copy geographical reference database or information in the GIS shape files was available to determine the reference number or landslide type designation of any specific landslide within the mapsheet study area. Therefore, classification of landslide types in the current study mostly relied on Severin's geomorphological symbols in the map file and descriptions in the thesis text, combined with the Profile feature in Global Mapper applied on a Digital Elevation Model (DEM) image and my understanding of geomorphological features.

The activity level of each slide was classified using Severin's (2004) activity classifications, as that information was present in the shape files themselves. Severin's classifications for activity level included Very Active, Active, Low Activity – Dormant, Low Activity – Abandoned, and Modified. Low Activity – Dormant landslides refer to those landslides that are probably older than 50 years, but still have active erosion near the toe, while Low Activity – Abandoned landslides are older than 50 years and do not currently have active erosion at the toe. Landslides were classified as Active that were originally Dormant if there was any new activity on them, as Active slides are defined as those with activity in the last 50 years (Severin 2004). Modified landslides were those that had been stabilised with artificial earth works following failure.

The last column in the spreadsheet was a comments section, where pertinent information about the ponds or landslides was recorded. After the initial inventory was completed, each map tile of the mapsheet was methodically re-checked to verify classifications and record any missed features. Some pond polygons were deleted from the final list due to not falling on an actual landslide, while other pond polygons were deleted because they were not actually ponds, but instead were shadows. The ponds that remained in the data set retained their original number designations. Therefore, there were some gaps in the final numbering. For the final spreadsheet, comments were modified or deleted as issues were addressed.

This spreadsheet was then used as a baseline for various calculations and graphs. The overall total number and area of ponds and the total number and area of landslides for the mapsheet were summarised. A frequency distribution of landslide ponds by size class was calculated and graphed. The total number of landslides for each landslide type and the total number of pond-bearing landslides for each landslide type were then calculated and compared in a paired graph. Mean pond size overall, mean pond size per landslide type, and mean pond size per geomorphic location within landslides were then calculated and graphed. Minimum, maximum, and median pond sizes were also determined for each of the preceding categories. Due to time constraints, no attempt was made to map and analyse ponds on undisturbed terrain.

4.4. Results

4.4.1 Pond characteristics in overall study area

Of the total 1,638 landslides identified in the study area, 223 landslides with ponds were identified, and 755 ponds were recorded on these pond-bearing landslides (Table 4-1). There appeared to be a clustering pattern, with some large landslides containing many small ponds. Other smaller landslides only had a few ponds. Many of the ponds appeared to be persistent, with signs of cattails (*Typha* spp. – most likely *Typha latifolia*) and development into wetland ecosystems.

Ponds occupied only a small fraction of the total landslide area. The total area of landslides in the study area was 768.25 km^2 (76,825 ha), including some added area not digitised in Severin's work. The total area of ponds on these landslides was 111.647 ha. Therefore, landslide ponds only occupied 0.14% of the total landslide area. The minimum landslide pond size was 0.0009 ha while the maximum pond size was 5.890 ha, showing a wide range of sizes. However, most ponds were in the <1.00 ha size class (Figure 4-4). The mean pond size was 0.15 ha, and the median pond size was 0.05 ha. Because the landslides in Severin's (2004) work were not digitised as enclosed polygons with a fixed area, it was not possible to calculate the area of pond-bearing landslides separately for the present study. Therefore, calculation of the proportion of total area occupied by ponds on just pond-bearing landslides was not possible. Re-digitising 1,600 landslides would have added significantly to the workload for this study and was not feasible with the time constraints and scope of the project.

Table 4-1. Summary information on ponds and landslides in the 768.25 km^2 (76,825 ha) study area.

Total number of landslides mapped	1,638
Total number of landslides with ponds	223
Percent (%) of total landslides that contain ponds	13.61
Total number of ponds on landslides	755
Mean number of ponds/pond-bearing landslide	3.386
Minimum number of ponds/pond-bearing landslide	1
Maximum number of ponds/pond-bearing landslide	29
Total pond area (ha) on landslides	111.647
Minimum landslide pond size (ha)	0.0009
Maximum landslide pond size (ha)	5.890
Mean landslide pond size (ha)	0.148
Total landslide area (ha)	76,918.527
Percentage of total landslide area covered by ponds	0.14

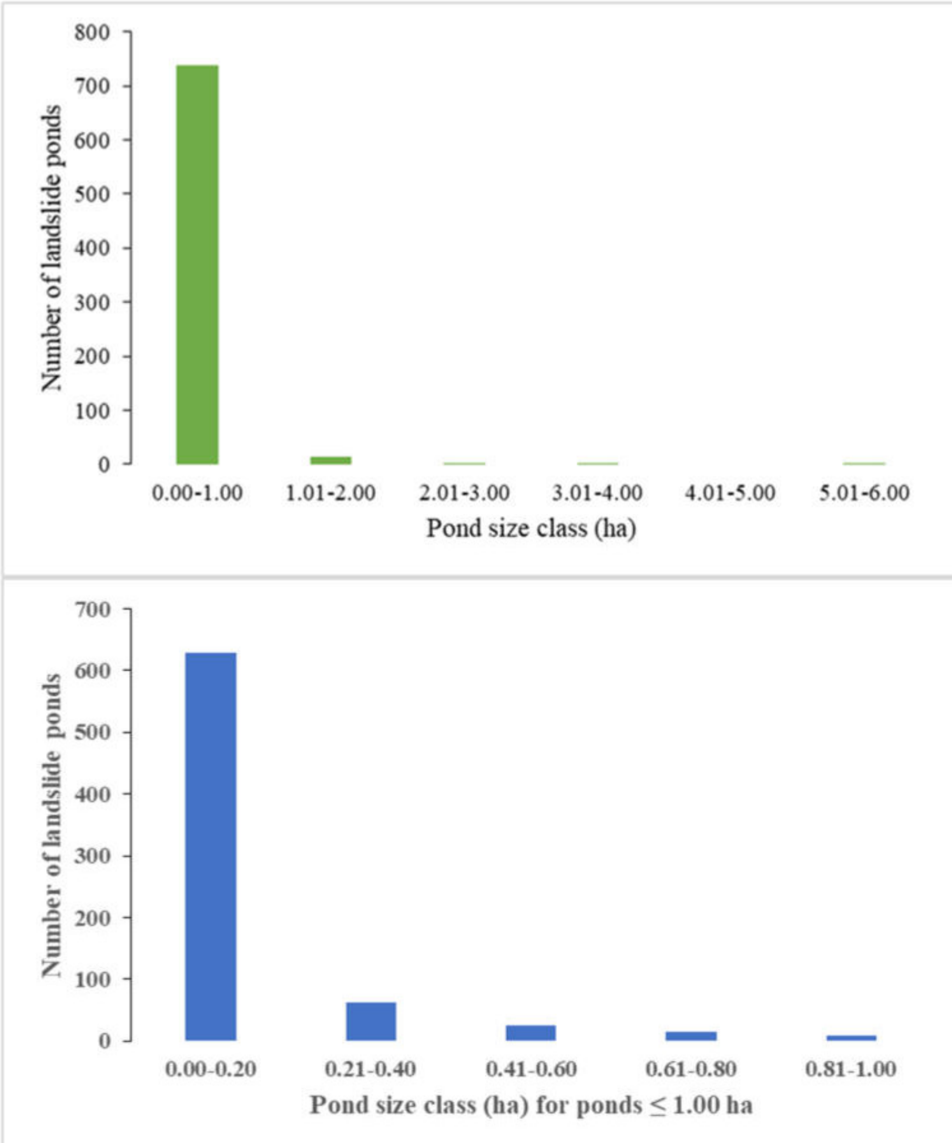

Figure 4-4. Frequency distribution graphs showing landslide pond size distribution in hectares (ha). The upper graph shows all landslide-generated ponds in Mapsheet 94A, while the lower graph shows the size distribution for landslide ponds ≤ 1.00 ha.

4.4.1.1 Pond number and total area by geomorphic location

Over the study area, the majority of the 755 ponds were located on the body of landslides (370 ponds, 49%), followed by the toe (236 ponds, 31%) and then the head (149 ponds, 20%). (Figure 4-5).

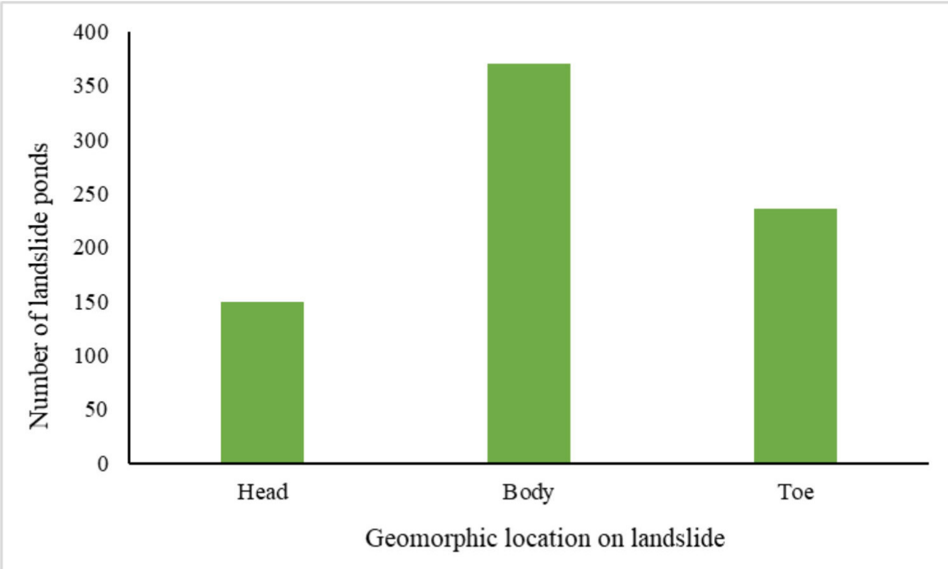

Figure 4-5. Total number of landslide ponds per geomorphic location.

Ponds on the body of the slides also comprised the highest total area (53.252 ha), which represented almost 48% of the total pond area (Figure 4-6). This was followed by pond area on the toe (27%) and pond area on the head (25%).

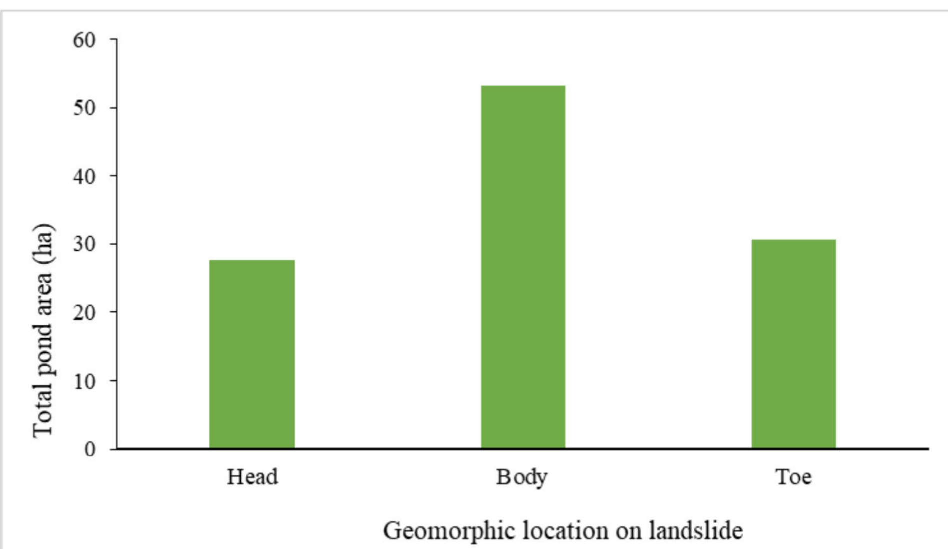

Figure 4-6. Total landslide pond area (ha) by geomorphic location.

4.4.1.2 Pond size by geomorphic location

Pond size was quite variable both within and among different geomorphic location types. Ponds on the head had the largest average size at 0.186 ha, while ponds on the toe were the smallest average size at 0.130 ha (Figure 4-7). The average size of ponds on the body was 0.144 ha. Overall, a location on the body contained a pond with the smallest size (0.0009 ha) and a location on the body also contained the largest pond size (5.890 ha). The head had the largest range of pond sizes (1.569 ha), while the body had the smallest range (0.059 ha). The range of pond sizes on the toe was (0.356 ha).

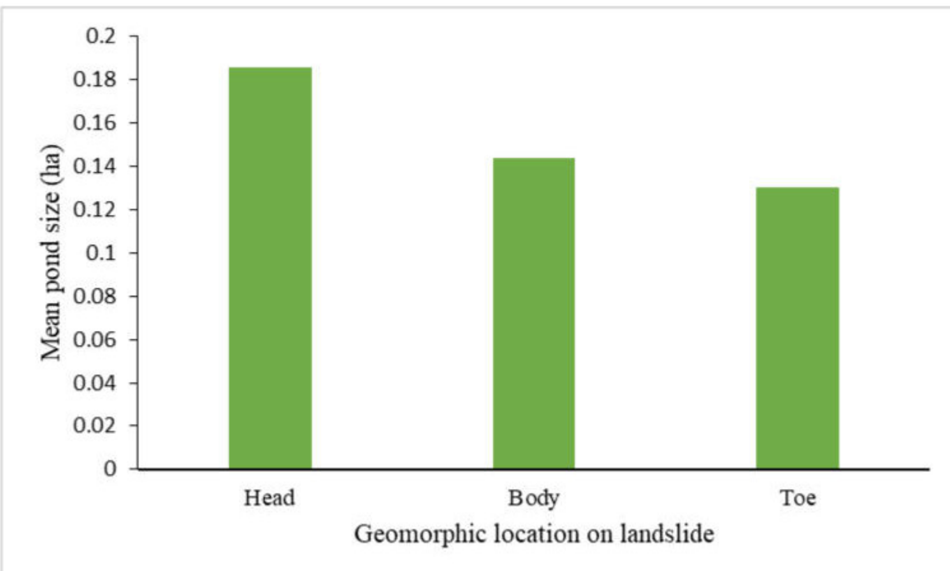

Figure 4-7. Mean pond size (ha) by geomorphic location on landslide.

4.4.1.3 Landslide types for slides containing ponds

Landslide ponds occurred more frequently on certain landslide types (Figure 4-8). The highest number of pond-bearing slides were retrogressive rotational failures, followed by rotational failures and then compound failures. Proportionally, retrogressive rotational failures comprised approximately 39.5% of the total landslides with ponds, followed by rotational failures at 32.7%, and then compound failures (14.8%).

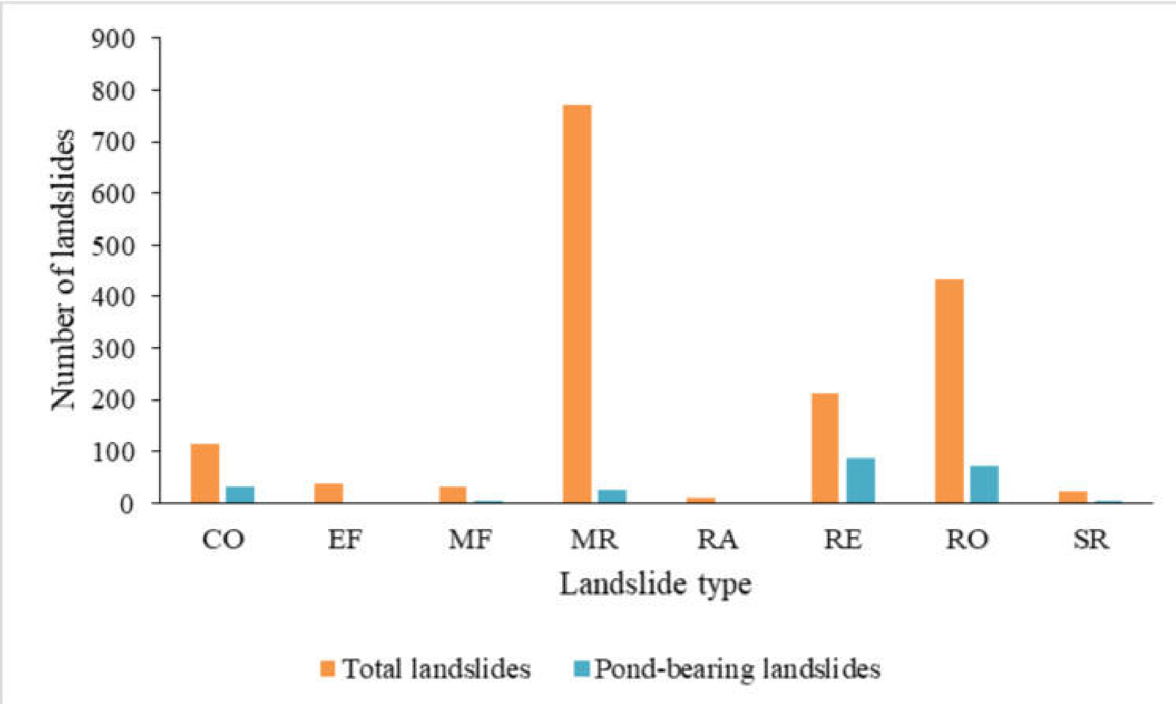

Figure 4-8. Paired graph showing overall number of landslides per landslide type compared to number of pond-bearing landslides per landslide type. Landslide type names have been abbreviated to accommodate graph. Type abbreviations: CO = Compound; EF = Earth flow; MF = Mobile flow; MR = Multi-level rotational; RA = Ravelling; RE = Retrogressive rotational; RO = Rotational; SR = Shallow retrogressive. Note: No ponds were found on Ravelling (RA) or Earth flow (EF) landslide types.

4.4.2 Ponds and landslide type

4.4.2.1 Number of ponds per landslide type

Pond numbers ranged widely across landslide types (Figure 4-9). Retrogressive rotational failures contained by far the greatest overall number and proportion of the total 755 ponds (394 ponds, approximately 52%). The next highest proportion of ponds was on rotational failures (20%, 151 ponds), followed by compound failures (14%, 107 ponds). Shallow retrogressive failures had the lowest proportion of total ponds (approximately 2%, 13 ponds).

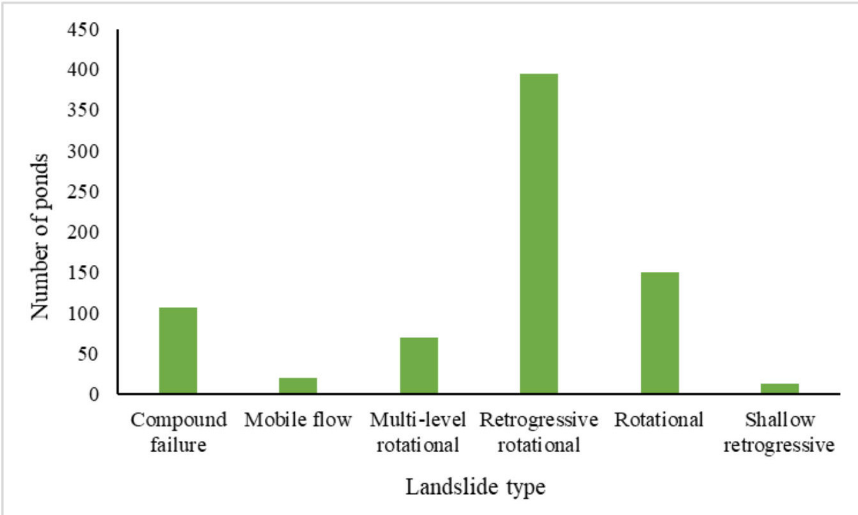

Figure 4-9. Number of ponds per landslide type.

4.4.2.2 Pond area per landslide type

Within the study area, the planimetric surface area occupied by landslide ponds primarily occurred in one landslide type (Figure 4-10). By far, retrogressive rotational failures contained the highest total area (77.696 ha, 69.59 %), followed distantly by rotational failures (18.877 ha, 16.91 %) and then compound failures (5.737 ha, 5.14 %).

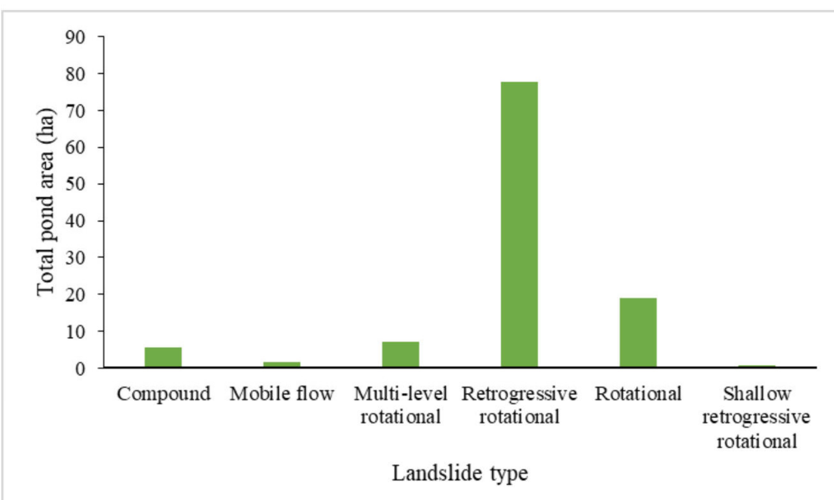

Figure 4-10. Pond area (ha) in each pond-bearing landslide type.

4.4.2.3 Mean pond size per landslide type

Pond size varied widely between landslide types in the study area (Figure 4-11 and Appendix 8). Retrogressive rotational failures had the largest average pond size (0.197 ha), followed by rotational failures (0.125 ha), and then multi-level rotational failures (0.102 ha). Shallow retrogressive slides had the smallest average pond size (0.051 ha). There was quite a range of pond sizes both among and within slide types, with large standard deviations. Retrogressive rotational failures had the smallest minimum pond size (0.0009 ha), as well as the largest maximum pond size (5.890 ha). Mobile flows had the largest minimum pond size (0.005 ha). Shallow retrogressive failures had the smallest maximum pond size (0.287 ha). Within slide types, retrogressive rotational failures had the greatest pond size range (5.889 ha), followed by rotational failures (1.651 ha). Shallow retrogressive rotational failures had the smallest pond size range (0.285 ha). However, it should be noted that there were only a few shallow retrogressive rotational failures in the data set. The next smallest pond size range was within compound failures, at 0.290 ha.

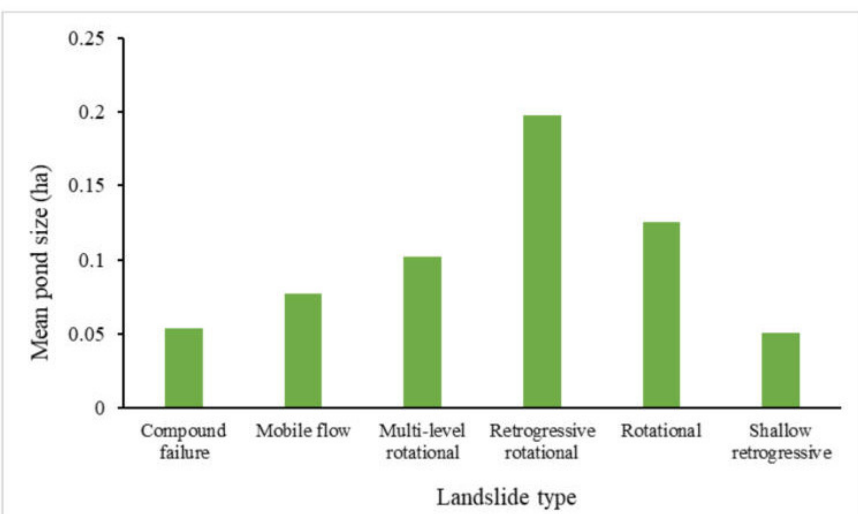

Figure 4-11. Mean pond size (ha) per landslide type.

4.4.3 Geomorphic location of ponds and landslide type

This section presents the results of compilation and analysis of pond area and size for various combinations of pond geomorphic locations and landslide types. In all cases for the results regarding pond size, the standard deviations were quite large, often much larger than the average size (see Appendix 9).

4.4.3.1 Head and landslide type

4.4.3.1a Number and proportion of ponds on head per landslide type

Ponds on the head of landslides occurred much more frequently on some landslide types than on others (Figure 4-12). The highest number and proportion of ponds on the head were on retrogressive rotational failures (80 ponds, 54%). Rotational failures had the next highest number and proportion of ponds (29 ponds, 19%), followed by multi-level rotational failures. The smallest number and proportion of ponds on the head occurred on the single mobile flow on which landslide ponds were detected.

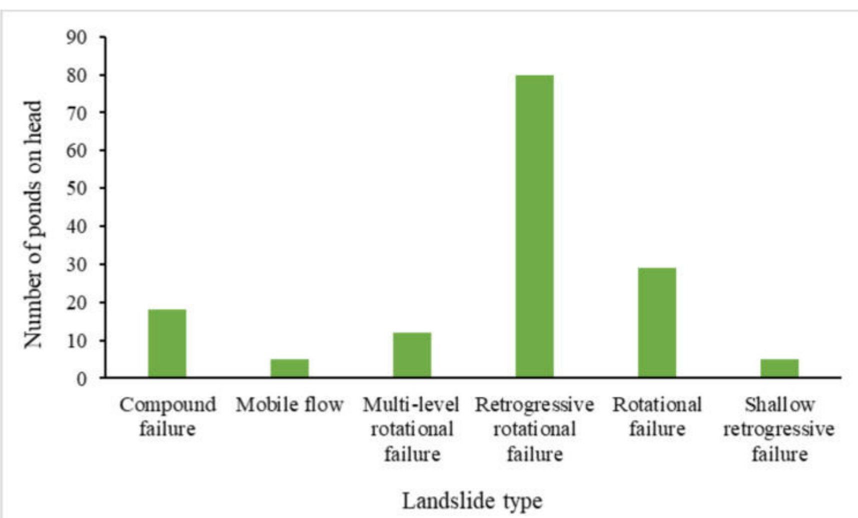

Figure 4-12. Number of ponds on head per landslide type.

4.4.3.1b Pond area on head per landslide type

The area occupied by ponds on the head of slides varied strongly by landslide type (Figure 4-13). Most of the total area of ponds on the head of slides was represented by retrogressive rotational failures, comprising 22.493 ha (81.21 %). The second highest area was on rotational failures, with a much smaller value of 2.377 ha (8.58 %), followed by compound failures (1.302 ha, 4.70 %).

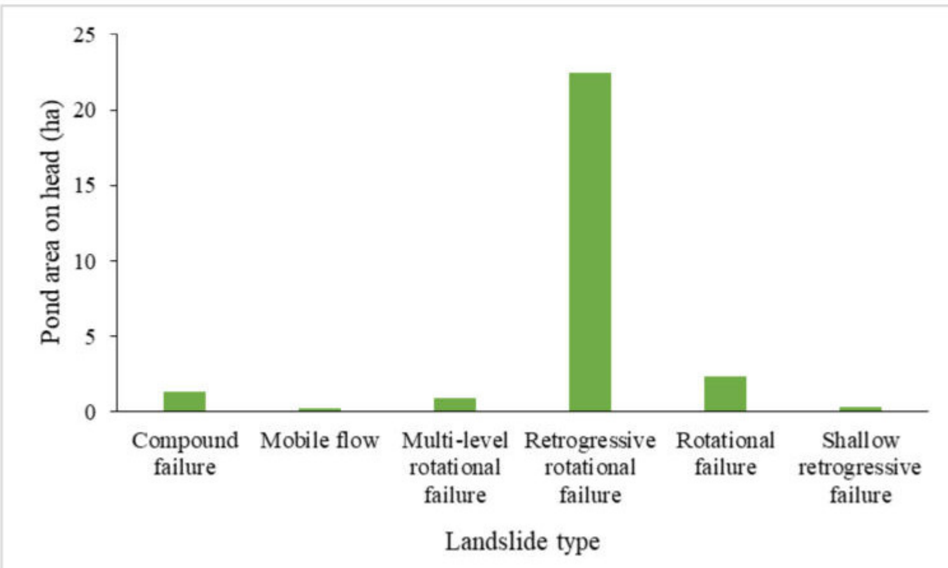

Figure 4-13. Pond area (ha) on head per landslide type.

4.4.3.2 Body and landslide type

4.4.3.2a Number and proportion of ponds on body per landslide type

Occurrence of ponds on the body of landslides varied but showed a tendency towards certain landslide types (Figure 4-14). With a similar trend as for ponds on the head, the highest number and proportion of ponds on the body occurred on retrogressive rotational failures (192 ponds, 50.26%). Rotational failures had the second highest number and proportion of ponds (81 ponds, 21.2 %). Shallow retrogressive failures represented the smallest number and proportion of ponds on the body (5 ponds, 1.31%).

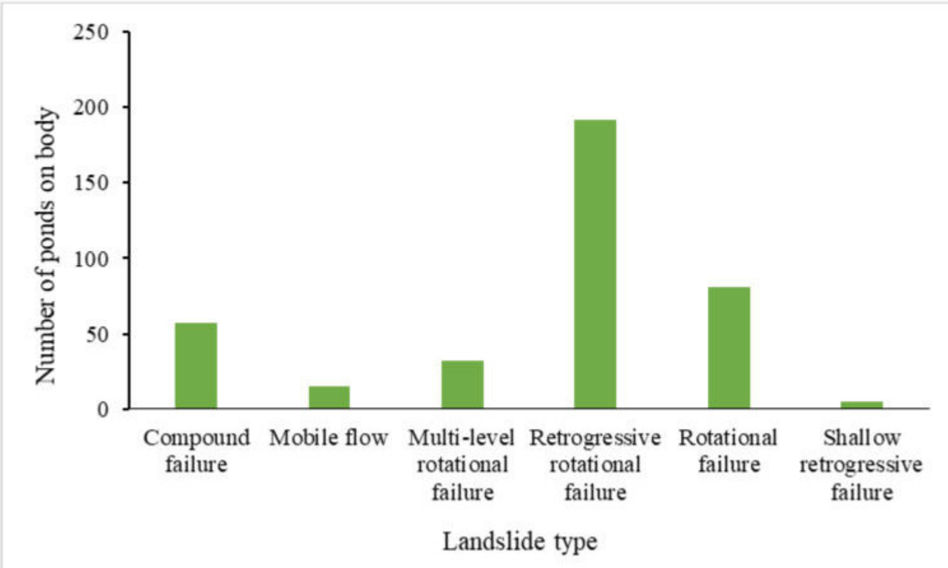

Figure 4-14. Number of ponds on body per landslide type.

4.4.3.2b Pond area on body per slide type

The area occupied by ponds on the body of slides showed a strong tendency toward just one or two landslide types in the study area (Figure 4-15). Retrogressive rotational failures contained the highest overall area of ponds on the body, at 36.946 ha (69.38 %). Rotational failures were a distant second at 9.983 ha (18.75 %), followed by compound failures (2.849 ha, 5.35 %).

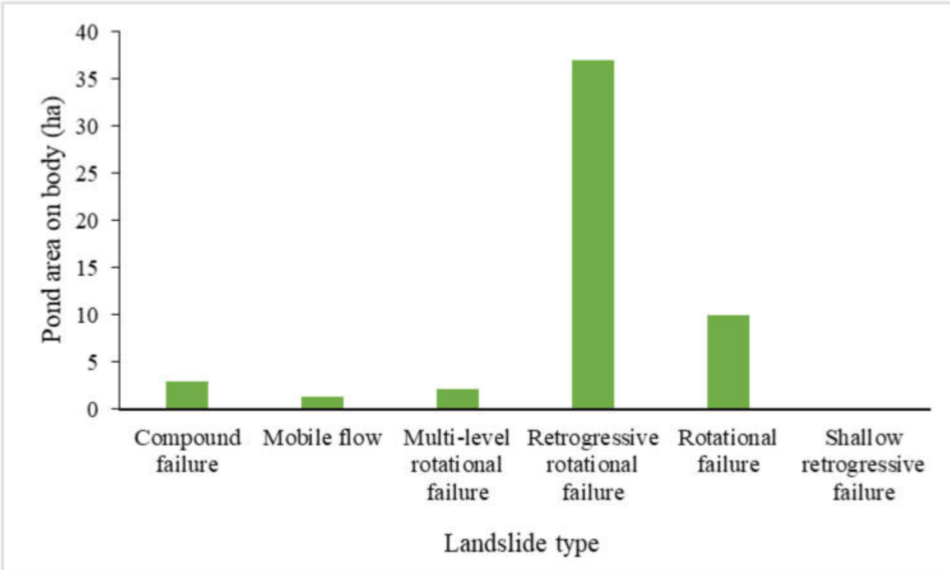

Figure 4-15. Total pond area (ha) on body per landslide type.

4.4.3.3 Toe and landslide type

4.4.3.3a Number and proportion of ponds on toe per landslide type

The occurrence of ponds on the toe of a landslide was variable, but more evenly distributed among landslide types than that of ponds on the body (Figure 4-16). More than half of ponds on the slide toe occurred on retrogressive rotational failures (122 ponds, 51.69%). The next highest number of ponds on the toe was represented by rotational failures (41 ponds,17.37%), similar to the trend for ponds on the head and body. No ponds on the toe were located on mobile flows, and the next lowest pond number on the toe was found on shallow retrogressive failures (3 ponds, 1.27%).

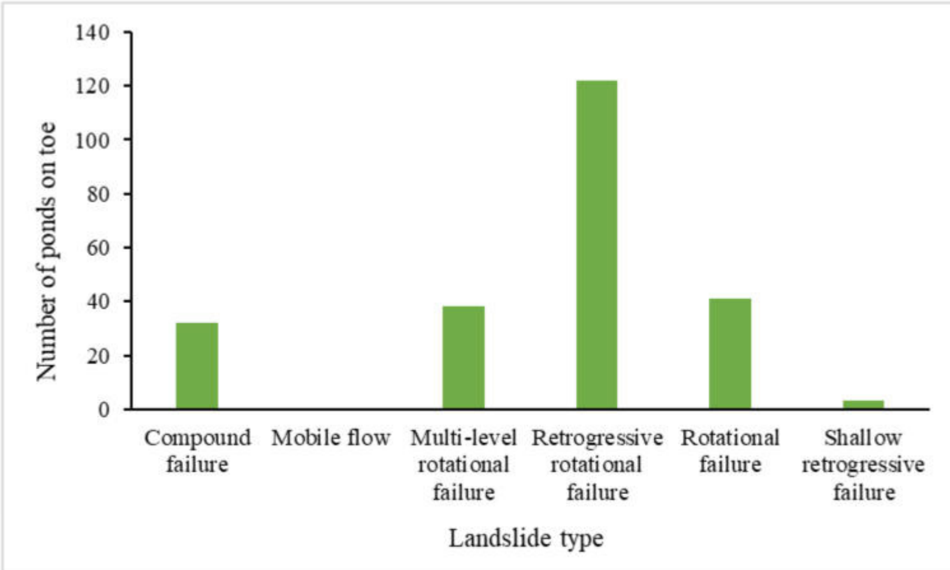

Figure 4-16. Number of ponds on toe per landslide type.

4.4.3.3b Pond area on toe per landslide type

Total area of ponds on the toe of landslides was somewhat variable between landslide types (Figure 4-17). The pond area on the toe was highest on retrogressive rotational failures, at 18.257 ha (59.47 %), and this slide type also had the greatest overall pond area in the study (see Figures 4-13 and 4-14). The second highest area of ponds on the toe was on rotational failures (6.517 ha, 21.23 %), followed by multi-level rotational failures (4.124 ha, 13.43 %).

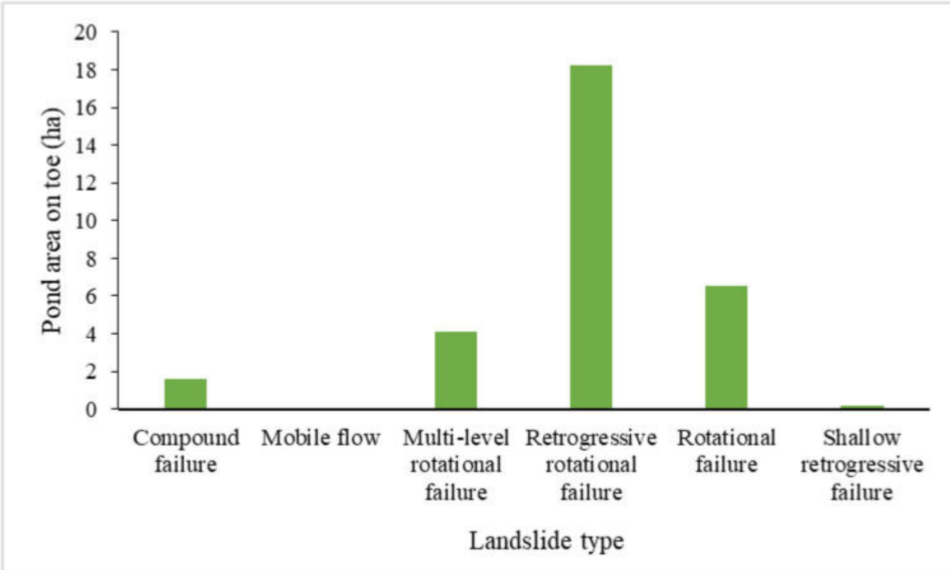

Figure 4-17. Pond area (ha) on toe per landslide type.

4.4.4 Landslide pond development

The landslide-generated ponds in the study area exhibited varying stages of development, both between and within individual landslides. Because of the seasonal nature of pond water levels and vegetation, it would not have been accurate to attempt to categorise the ponds in the study according to development stage. However, some representative photographs illustrate the diversity of vegetation development present on landslide-bearing ponds in the mapsheet study area. These photographs were taken during fieldwork for Chapters 2 and 3 in the same area. Figure 4-18 shows a pond recently formed in fresh unvegetated soil.

Figure 4-19 shows a pond with a more stable bank, with vegetation growing around the perimeter of the pond. Figure 4-20 shows a pond with an obviously stable bank, surrounded by vegetation, and containing aquatic vegetation including cattail (*Typha* spp. – most likely *Typha latifolia*).

Figure 4-18. Very new pond on landslide (Beatton River Landslide). The most recent major movement on the landslide occurred in 2015, so the pond was approximately three years old at time of photograph. (Photo June 19, 2018)

Figure 4-19. Newer pond on landslide (Beatton River Landslide). Pond is on an older part of the landslide near the toe. (Photo August 9, 2017)

Figure 4-20. Persistent pond on landslide (Cecil Lake Landslide). Landslide occurred in 1998, thus the pond was approximately 20 years old at time of photograph. (Photo June 23, 2017)

4.5. Discussion

This study set out to compile an inventory of landslide ponds on NTS Mapsheet 94A and describe area, size, and distribution of the ponds in relation to overall number and area of landslides, geomorphic locations on the landslide, and occurrence on landslide types. The overarching purpose was to employ this information to identify potential ecological implications of pond occurrence and distribution and provide recommendations for management.

4.5.1 Landslide pond characteristics and distribution

The results showed a wide range of pond sizes, with the average size of ponds for each landslide type falling within an intermediate range. Research has shown that intermediate sized ponds (ranging in size from 200 to 4000 m^2, or 0.02 to 0.4 ha) contain the highest density, richness, and diversity of pond-breeding amphibians (Semlitsch et al. 2015). In the present study, 497 ponds (over 65%) fell within the intermediate size range. This could be significant for maintenance of amphibian diversity in the study area. Although no amphibians or aquatic insects were observed in the ponds encountered on the Cecil Lake, Beatton River, and Hasler Flats landslides (Chapters 2 and 3), waterfowl were seen on some of the ponds. The ponds in the study area also exhibited a range of stages of evolution. This diversity of developmental stages could allow for a variety of different macroinvertebrate communities to develop, each taking advantage of the particular hydrologic, sedimentary, and vegetative conditions present (Jeffries 2011).

The characteristics of each geomorphic location on the landslide may influence the distribution of ponds. Generally, each part of a landslide has different kinds and orientations of geomorphic structures (Parise 2003). In the present study, ponds were most prevalent on the body of landslides, followed by the toe. Ponds on the body represented the highest total number, as well as the highest total area. Greater pond presence on the landslide body may be due to the diversity in topography that results as the slide material is moved, creating depressions and cutting off drainage. As the landslide stabilises, vegetation starts to encroach, further stabilising ponds. The conditions are generally better for plants to persist on the body compared to the steeper nature of the head, which prevents soil from building up and hinders plant root establishment and persistence (Walker and Shiels 2013).

As discussed in the Introduction, a network of varying sizes of ponds can provide value for dispersal of water-dependent organisms (Pop and Chitu 2013). Ponds on the toe represented the second highest number and total area of all the mapped ponds but had the smallest average size. These toe ponds had a size range that was less than the head and greater than the body, and thus had greater size diversity than ponds on the body. This size variation could be due to the broken up and uneven nature of the terrain often present on the toe, where large amounts of material are deposited, often rapidly.

Although ponds were more prevalent on the landslide body, the head had the largest maximum pond size and the greatest size range. Most ponds on the head of the landslide were at or near the transition zone with the body. Deep, long depressions were more likely to be present at this sharp transition in slope from positive to negative, forming the larger ponds. The smaller ponds on the head tended to be in small depressions. These findings suggest that the head of a landslide may provide more diverse habitats for some aquatic organisms, as well as for larger animals seeking water or shade.

The apparent relationship between landslide type and number of ponds in the study area may be a function of the underlying material and the topographical characteristics of the landslide. Most of the ponds in the data set were located on either retrogressive rotational slides or rotational slides, followed by compound slides. By far, most ponds were found on retrogressive rotational slides. The persistence of ponds on this landslide type may be due to pre-existing fault planes that form depressions and restrict drainage following movement of slide material. Retrogressive rotational slides have multiple weak layers and fractures (Severin 2004), creating many potential sites for ponds. Ponds on retrogressive rotational slides also had the greatest mean size and the greatest range of sizes, followed by ponds on rotational slides. Retrogressive rotational slides tend to produce a series of geomorphic features as the land mass slumps and shifts. This process may result in a great variation of depressions and cracks where ponds can form. Rotational failures have a similar configuration, but with fewer fracture planes (Cruden and Varnes 1996; Severin 2004). The compound failures possibly have a relatively high proportion of ponds in the study because the overall slope on this type of landslide is gentler, enhancing the ability of the material to retain water. The fewest number of ponds were on shallow retrogressive failures. It is possible the fracture planes of this landslide type were not severe enough to create persistent depressions for water retention.

Geomorphic location of ponds on the landslide varied somewhat with landslide type. For ponds on the head, by far the highest number and total area were on retrogressive rotational failures, followed by rotational failures and then compound failures. This prevalence on retrogressive rotational failures could be due to the relatively steep headscarp of these types of landslides and the associated deep and wide fissures at the transition zone with the body. Regarding ponds on the body, the highest number and area of ponds was again on retrogressive rotational failures, followed by rotational failures and then shallow retrogressive failures. Total pond area on the body was higher than for ponds on the head for most landslide types noted. For ponds on the toe, the trend was the same, with the highest number and area of toe ponds occurring on retrogressive rotational failures and rotational failures. Retrogressive rotational failures have multiple shear zones (Cruden and Varnes 1996), which can produce depressions and fissures at all geomorphic locations of the landslide. Overall, the results suggest that retrogressive rotational failures are more ecologically diverse than the other landslides sampled regarding pond size, area, distribution, and persistence.

4.5.2 Landslide pond dynamics

Although ponds on landslides can persist for many decades, they evolve and change over this time. The ponds in the study area showed a diversity of stages of evolution. Initially, when most ponds form after a landslide event, they are in fresh unvegetated soil (see Figure 4-18). Over time, the vegetation starts to grow in around the pond from propagules either within the soil or from surrounding rafts of vegetation or from seeds dispersed from adjacent forest vegetation (see Figure 4-19). This vegetation can serve to stabilise the pond, and it also can influence the ecology of the site. Eventually, the area surrounding the pond may become fully vegetated and the pond may persist for years (see Figure 4-20).

As habitat and water persistence change, so do the populations and compositions of plants and animals. For example, macroinvertebrate communities develop and change in response to pond persistence and hydrological cycles, and at times there is a fine threshold between different community compositions (Jeffries 2011). The gradual revegetation of the pond site can also influence the size and persistence of the pond. Surrounding vegetation as well as aquatic vegetation can shrink the pond either seasonally or over years, as established vegetation takes up the water through transpiration, eventually lowering the overall reserves.

4.5.3 Beaver influence on landslide ponds

Evidence on the study sites visited for field sampling in Chapters 2 and 3 suggested that beavers can play a part in forming or altering ponds on landslides. The North American beaver (*Castor canadensis*) is common in the study area and throughout northeastern British

Columbia and can significantly impact landscapes that have water present. Beavers can alter hydrogeomorphic and ecological processes through dam building and the associated felling of trees, and excavation and transport of large amounts of sediments, resulting in the flooding of various terrains (Butler and Malanson 1995; Westbrook et al. 2017). Beaver-modified landscape patches produce distinct habitats that can increase richness and abundance of terrestrial and semi-aquatic mammals (Nummi et al. 2019). Although it was difficult to identify beaver ponds in the imagery used, in the field there was evidence of beaver activity on the Cecil Lake landslide study site (Figures 4-21, 4-22, and 4-23), as well as the Hasler Flats landslide study site (Figure 4-24) sampled in work for Chapters 2 and 3. The beavers appear to have significantly influenced the configuration and size of the bigger ponds on site at the Cecil Lake landslide (Figure 4-22). Field evidence of old weathered, advanced-decay gnawed logs and stumps (Figure 4-23) indicate beavers have maintained a presence for many years and operated in cycles on different parts of the landslide. In many areas on the Cecil Lake landslide there were small beaver-browsed sapling stumps and beaver trails throughout the woods leading to ponds. On the Hasler Flats landslide, there was evidence of very recent felling of large aspen trees in addition to well-worn trails leading from the sidescarp to the landslide ponds (Figure 4-24).

Figure 4-21. Recent beaver gnawing activity on young sapling near pond (Cecil Lake Landslide). (Photo September 7, 2017)

Figure 4-22. Beaver pond on the Cecil Lake Landslide. (Photo June 22, 2017)

Figure 4-23. Older beaver gnawing activity on the Cecil Lake Landslide. (Photo September 10, 2017)

Figure 4-24. Recent beaver activity at the Hasler Flats landslide. Top image shows well-used beaver path (bottom centre of photo) leading from the sidescarp to a landslide pond. Lower image shows very recent felling of large aspen trees (*Populus tremuloides*) by beavers just above the sidescarp. (Photos August 14, 2018)

4.5.4 Limitations of the study

A limitation to the landslide ponds study was the intermediate and variable resolution of the imagery used when determining and mapping landslide ponds. Some ponds may have been missed if they were too small, or if the available imagery in the area was of a poorer resolution. However, the vast majority of ponds present were most likely identified and digitised, and any missed ponds probably did not affect the overall results.

Another limitation of the study was the fact that the pre-existing digitised landslides did not have individual areas assigned to them in a format that could be georeferenced. Thus, calculation of proportions of total area of pond-bearing landslides occupied by ponds was not possible. This information would have been a useful metric to have for comparison and consideration. However, the landslide area summary information that was available provided an initial baseline for calculating the proportion of total landslide area occupied by ponds.

The georeferenced and numbered landslide type designations that Severin (2004) assigned to each landslide were also unavailable, so in this study I assigned my own classifications for each individual pond-bearing landslide based on Severin's definitions. Landslide types were classified mainly using Severin's geomorphic symbols and the DEM imagery. My designations may not have been completely accurate, as I did not have access to high resolution aerial photographs as stereo pairs and am not a trained geomorphologist. Nevertheless, the classifications were likely accurate enough for distinguishing between obviously different landslide types and describing pond distribution.

An additional limitation to the study was the lack of previous research on landslide ponds, for comparison. There have not been many studies to inventory landslide ponds, let alone to describe ecological elements. This study is thus a baseline for future research.

4.5. Conclusions and recommendations

In this study I provided an initial inventory of ponds on landslides in an area of northeastern British Columbia that is particularly susceptible to landslides. I also presented details on the number, size, and distribution of ponds on different geomorphic locations within landslides and among different landslide types. Although they only occupy a small proportion of the total landslide area in the mapsheet study area, landslide ponds may provide important ecological roles for amphibians, ungulates, birds, and other wildlife both at the local and landscape scales in the Peace River Region. These ponds serve many purposes, including nesting, feeding, shelter, water, protection, connectivity, and biodiversity.

Pond size and distribution impact wildlife species richness and overall diversity, as an array of smaller ponds yields a greater number of species and higher conservation value than a large pond of the same total area (Oertli et al. 2002).

This study provides the first detailed baseline information on landslide pond distribution in the Peace River Region and adds a valuable component to the knowledge base on water bodies in the area. The findings present a benchmark for conservation considerations in the Region. As landslide ponds do not occur in great numbers on the landscape here and yet are potentially high in ecological value, efforts should be made to conserve them. Conservation would allow for preservation of breeding, nesting, feeding, and shelter habitats for various species, as well as connectivity for migrating species. Knowledge about the specific ecological value of these landslide ponds is significantly lacking and requires further investigation. To better understand how these ponds are used by wildlife, a subset of the pond-bearing landslides should be selected to sample in the field. Ecological information such as pond plant species composition, aquatic invertebrates, and signs of wildlife use should be recorded in detail for each pond in the subset. Ideally, such a study would be carried out over multiple seasons and years to capture the full breadth of use of the pond, as well as any changes to the pond. It would also be informative to carry out similar research in landscapes dominated by other landslide types such as rock falls.

Although the ecological value of landslide ponds is recognised, geohazard assessment considers the presence of pooled water on unstable slopes a dangerous situation to be avoided. In fact, some management measures recommend draining ponds on landslides (Kansas Geological Survey 1999). Therefore, a balance must be sought between conserving important habitat and preventing catastrophic reactivation of landslides. Landslide ponds may serve an important role as an indicator for land management decisions concerning infrastructure, resource development, home building, and other activities on the land base. Persistent ponds signify a high water table and soil saturation, conditions which can indicate the potential for slope instability and increased possibility of flooding. Care should be taken to develop away from areas where landslide ponds are present. If landslides with ponds already exist near developed areas or sensitive fisheries habitat, they should be monitored on a regular basis and assessed for reactivation. It is possible some ponds should be drained if there are signs of imminent danger of slope movement. For landslides in remote areas, however, the ponds should be left intact to provide connectivity, habitat, and other ecological roles.

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Chapter 5. Conclusions and Recommendations for Landslide Recovery and Management

5.1 Conclusions

This research set out to describe and quantify various aspects of biophysical diversity on landslides in the landslide-prone Peace River Region of northeastern British Columbia and present ecological implications and management recommendations based on the findings. The central research questions for this research were:

(1) Are landslides demonstrably more biophysically diverse than undisturbed ecosystems?

(2) To what extent do landslides rearrange the relative abundance of site series/types on a slope compared to adjacent undisturbed terrain?

(3) What is the extent turnover in microsite and plant species diversity on landslides, and how does this compare to adjacent undisturbed terrain?

(4) Is vegetation diversity on landslides significantly related to geomorphological diversity?

(5) What is the distribution and abundance of landslide ponds at a regional and local scale, and what are the ecological and management implications?

The overarching purpose of the work was to compare biophysical diversity within and among landslides, and between landslides and surrounding undisturbed terrain. An additional objective was to investigate possible correlations between vegetation diversity and site diversity. Vegetation and site characteristics on three different landslides were measured and analysed for alpha diversity and beta diversity values (Chapter 2 and Chapter 3, respectively), and characteristics of ponds on landslides within a larger area in the region were also assessed, described, and analysed (Chapter 4). The findings of this study revealed that quantification and prediction of biophysical diversity on a severe disturbance such as a landslide is complex and highly dependent on individual study site characteristics. Despite these challenges, it is still possible to analyse the results and draw learnings for application in management, ecology, and rehabilitation on landslides in the Peace River Region and for landslides at the broader scale.

This work showed that following a mass movement in the Peace River Region, plant community composition on landslides varies depending on the age and size of the landslide and the slope and soil development of the various geomorphological features present. Exotic forb species tend to dominate in early stages of landslide revegetation and can persist if the disturbance periodically reactivates, effectively preventing the establishment of shrubs and trees.

The landslides in the study were overall less diverse in alpha diversity of plant communities than the surrounding undisturbed terrain, a finding which diverged from initial expectations. However, the landslides were more diverse in abundance and distribution of site types/series and geomorphic features than the undisturbed terrain. Although there was a greater proportion of mesic sites on landslides, there were also more extreme site series on a scale of moisture regime. Geomorphic types were overall more diverse on the landslides due to mass movement and substrate rearrangement, and type diversity and surface roughness both tended to decrease with age of the landslide. Therefore, although the landslides were lower in plant alpha diversity, the site series and geomorphic diversity present provide conditions for a greater variety of plant communities and wildlife habitats over time.

Beta diversity often reflects the health and proper functioning of an ecosystem. Beta diversity or turnover of both vegetation and environment variables was generally higher on landslides than the surrounding undisturbed terrain, with a strong relationship between the vegetation and environment beta diversities. Beta diversity was also affected by spatial and temporal characteristics of the study area. The largest and oldest landslide, Cecil Lake, showed the highest mean vegetation beta diversity and also the most variable vegetation beta diversity. This suggests that processes affecting turnover of plant communities may be at work to varying degrees on different parts of a landslide within a given time period. The vegetation beta diversity on the surrounding terrain was both lower and much less variable, suggesting a state of relative stability. The smallest landslide, Hasler Flats, had the highest beta diversity but also had much less variability. This suggests size can inversely influence beta diversity, with smaller areas facilitating greater relative patchiness. Overall, environment beta diversity was much lower than vegetation beta diversity for all study sites, and it was also lower on undisturbed areas compared to the landslides. Cecil Lake and Hasler Flats landslides both had environment beta diversity values that were nearly twice as much as the youngest landslide, Beatton River, but Cecil Lake had more than twice the variability as Hasler Flats. Beatton River had a markedly higher variability. Interestingly, Beatton River had some higher vegetation and environment alpha diversity values than the oldest landslide, Cecil Lake. The above findings highlight the variability of the effects of patchiness on biophysical diversity in general.

This study of landslides in the Peace River Region uncovered variable relationships between vegetation and site or environment diversity, depending on the spatial and temporal scale of the samples. The NMS ordination analysis on the BEC vegetation plots showed some weak relationships between plant community development and slope gradient, and to a lesser degree mesoslope position, heat load index, and moisture. Contrary to expectations, a significant relationship was not found between vegetation alpha diversity and environment (geomorphic) alpha diversity on any of the three landslides studied (Chapter 2). However, there was a significant positive relationship between vegetation beta diversity and environment beta diversity on the transects sampled in Chapter 3. These findings suggest that while within-plot vegetation diversity seems to be independent of within-plot environmental diversity, vegetation turnover over space is distinctly linked to microsite condition turnover. The complex nature of these relationships between vegetation and environment indicates a scale-dependency that is not yet clear and requires further investigation. In general, it appears that during the first 20 or more years following landslide occurrence, plant community succession is still sorting out, at the same time as the terrain is weathering and evolving.

Although both prehistoric and historic landslides are abundant along the Peace River and its tributaries, the research in Chapter 4 found only a small proportion of these landslides contained persistent ponds. The results showed trends in landslide pond size, geomorphic location on the landslide, and association with certain landslide types. Most ponds were under one hectare in surface area, with most being less than one-tenth that size. Further, these ponds tended to occur more frequently and in greater numbers on certain types of landslides, namely retrogressive rotational, rotational, and multi-level rotational landslides. In addition, ponds occurred in greater concentrations on the body of the landslide, followed by the toe and then least frequently on the head. However, ponds on average tended to be larger on the head of landslides. This is likely due to the presence of the rupture zone below the headscarp, where movement of material away from the zone followed by stabilisation can cause large depressions, restricting drainage. Landslide ponds encountered during fieldwork for Chapter 2 and Chapter 3 had evidence of beaver activity and alteration, as well as use by waterfowl and other animals.

5.2 Recommendations

The findings of this research provide a foundation to begin managing landslides in the Peace River Region from an ecological perspective, considering succession and the influence of spatial and temporal scales. Landslides close to communities, infrastructure, or other important developments or ecosystems should be the priority for management and restoration. Landslides abutting large rivers used for drinking water or important fish-bearing streams should be given special attention, as sediment input can be substantial. The type of landslide and its geomorphological characteristics may also provide guidance for prioritising management. Rotational landslides tend to be more susceptible to reactivation, especially those with steeper slopes of perhaps 20 degrees or more. The presence of moving water within the landslide also tends to reactivate portions of the slide. The Beatton River landslide had some areas of seepage and debris flow, while the Cecil Lake landslide was influenced by a creek running through it from the south, creating an active gully. When landslides first occur, they should be assessed in the field to determine potential risks for reactivation.

Once a landslide has been assessed and is determined safe to work on, initial measures should focus on revegetating and stabilising the terrain to enhance the rate of ecological succession. Invasive, exotic plant species such as *Melilotus* spp. and *Sonchus* spp. are obviously very effective at colonising, stabilising, and enriching freshly disturbed terrain.

However, these species pose the problem of creating reduced plant community diversity and structure over time. To alleviate this, land managers should also plant a variety of competitive, rapidly growing native pioneer grass seed mixes such as blue wildrye (*Elymus glaucus*) and Canada bluejoint (*Calamagrostis canadensis*), forbs including wild sarsaparilla (*Aralia nudicaulis*), palmate coltsfoot (*Petasites frigidus*), showy aster (*Aster conspicuus*) and false Solomon's seal (*Smilacina racemosa*), and common shrubs prickly rose (*Rosa acicularis*), saskatoon (*Amelanchier alnifolia*), alder species (*Alnus* spp.), red-osier dogwood (*Cornus stolonifera*), and highbush cranberry (*Viburnum edule*), as found most abundantly on the landslides in this study. In addition, ecologically suitable deep-rooted or high evapotranspiration trees such as trembling aspen (*Populus tremuloides*), white spruce (*Picea glauca*) and cottonwood (*Populus balsamifera*) should be planted where possible and safe to do so to help stabilise the soil and take up extra moisture. Decisions on species selection should incorporate local and regional goals for landscape ecosystem health and measures around climate change adaptation. Organic amendments and bird perches in open areas may also be necessary to ensure adequate substrate conditions, plant dispersal and establishment. Further, these sites should be monitored over time, and managers should be prepared to re-plant or stabilise the slope if steep portions of the landslide are reactivated. It is also important to note that there are often other disturbances interacting with landslides, such as floods and fires. These disturbances should also be taken into consideration when planning and monitoring restoration.

Because of the complexities of landslide succession and the potential for reactivation, restoration on landslides should focus on ecosystem recovery and biodiversity, rather than species composition. Ecosystem recovery is not intended to return the disturbed system to its historic condition, but rather to its historic trajectory. Work should involve stabilising the soil through planting and bioengineering measures, rehabilitating water courses, and creating a diverse multi-level vegetation cover of mostly native species. The measures described above could be applicable to deep-seated, moderate to steep landslides occurring on glaciated sites in unconsolidated glaciolacustrine material elsewhere in British Columbia and in other parts of the world.

Much remains to be learned about landslide recovery and ecology in the Peace River Region, and the Beatton River landslide could provide an outdoor laboratory for restoration experimentation and trials. Because the landslide is so young and much of the surface is steep and unstable, there are many opportunities to try different slope stabilisation and revegetation measures. The trials could be easily monitored, as access to the landslide is good.

Further research should focus on a variety of landslide types, sizes, and ages in the region, and these methods could also be extended to other regions. Similar vegetation and microsite sampling for both the landslide and the surrounding terrain should be employed, preferably with an increased sample size for the relevés and transects and greater utilisation of remote-sensed imagery. To better understand the dynamics of colonisation by native plant species, an attempt should be made to locate remote landslides free from the influence of invasive exotic species.

Although relatively sparse at the regional scale and generally small in size, landslide ponds may have important implications for landslide stability and ecosystem health. The presence of ponds indicates saturation, therefore pond-bearing landslides near priority management areas should be monitored so that they can be stabilised quickly if they reactivate. These ponds should also be conserved for their ecological value for amphibians and invertebrates, as well as for habitat and a feeding and drinking source for waterfowl and fur-bearing mammals. Further research is needed to investigate the ecological significance of these features.

5.3 Final thoughts

The research that formed the basis of this dissertation was initiated to address the gap in knowledge about biophysical diversity and recovery on landslides in northeastern British Columbia's Peace River Region, a glaciated area highly susceptible to landslide activity. The work is the first of its kind in the region, as there were no previous published diversity studies that collected and analysed detailed field data on landslide vegetation species or ponds, let alone at such a large scale of study.

This research provided quantitative confirmation of the increased diversity of some biophysical aspects of landslides compared to undisturbed terrain in northeastern British Columbia and demonstrated that both vegetation and environmental diversity vary with age and size of landslides. The results suggest landslide diversity and recovery evolve over time and may take decades to settle out, and both invasion by exotic vegetation and reactivation of the slide can hinder ecological succession. The findings obtained from the vegetation surveys in this study were used to present recommendations on native plant species to use for restoration of landslides in the Peace River Region and other similar areas. This study also provided valuable baseline information about ponds on landslides, a topic that warrants further investigation given the ecological value of networks of small ponds. Overall, this research has significantly enhanced understanding of landslide diversity and recovery in the

Peace River Region and provided timely recommendations for restoration and management of landslides both locally and for similar glaciolacustrine sites around the world.

APPENDICES

Appendix 1 Material Origin classes

The Material Origin variable for the BEC 50m^2 plots is a new variable created from components of the soil and site description data collected during BEC sampling. It is intended to describe the primary level of soil development present on each plot site.

The coding separates out those plots which have intermediate soil development, as well as those plots which are ponds. Coding is as follows:

1. Mature *in situ* (benchmark plot in surrounding terrain)

Category 1 consists of intact material with a well-developed soil profile, situated in the surrounding terrain. Soils have at least a B horizon, and an A horizon may also be present. In Dystric Brunisols, the A horizon is commonly absent.

2. Mature raft

Category 2 consists of mature intact material transported from the surrounding terrain onto the landslide through slope movement processes. The soil is well-developed and has at least a B horizon. An A horizon may also be present.

3. Intermediate development

Category 3 consists of partially-developed landslide body soils with an immature B horizon and no A horizon. The B horizon is thin, usually less than 10 cm in thickness.

4. Orthic Regosol

Category 4 consists of material on the landslide body which has only a C horizon exposed. The A/B horizons have either been buried, stripped away by movement of material downslope, or eroded away by weathering.

5. Pond

Category 5 consists of soils that are inundated under various ponds on the landslide body. Soil development at present is mostly arrested, with soils likely comprised of just a C horizon at the time of flooding.

Appendix 2 Vegetation summary tables - Mean species cover (% of total relevé area)

Beatton River Landslide Relevés BErl1, BErl2, BErl3

Species	Common name(s)	Mean cover (%)	SD (+/-)
Melilotus officinalis	Yellow sweet-clover	28.833	44.312
Equisetum arvense	Common horsetail	12.167	19.776
Melilotus alba	White sweet-clover	6.000	3.500
Sonchus arvensis	Perennial sow-thistle	4.100	2.456
Artemisia sp. 2	Sage sp.	1.767	0.874
Lactuca serriola	Prickly lettuce	1.410	1.417
Rubus idaeus	Red raspberry	1.087	1.874
Aster ciliolatus	Fringed aster	0.700	1.127
Solidago canadensis	Canada goldenrod	0.650	0.589
Taraxacum officinale	Common dandelion	0.443	0.501
Fragaria virginiana	Wild strawberry	0.400	0.529
Cornus stolonifera	Red-osier dogwood	0.283	0.407
Unknown forb (white)	Forb sp.	0.167	0.289
Brachythecium sp.	Ragged moss sp.	0.167	0.289
Populus balsamifera ssp. *balsamifera*	Black cottonwood	0.167	0.208
Chenopodium album	Lamb's-quarters	0.133	0.115
Rosa acicularis	Prickly rose	0.133	0.153
Achillea millefolium	Yarrow	0.123	0.155
Tragopogon dubius	Goat's-beard, Yellow salsify	0.103	0.095
Hieracium triste	Wooly hawkweed	0.100	0.100
Elymus repens (aka *Agropyron repens*)	Quackgrass, couch grass	0.100	0.173
Aster sp.	Aster sp.	0.083	0.144
Vicia americana	American vetch	0.073	0.110
Ranunculus sp.	Buttercup sp.	0.067	0.115
Salix sp. 2	Willow sp. 2	0.067	0.115
Salix sp.	Willow sp.	0.060	0.053
Shepherdia canadensis	Soopolallie	0.043	0.051
Epilobium angustifolium	Fireweed	0.037	0.055
Lathyrus ochroleucus	Creamy peavine	0.033	0.058
Medicago sativa	Alfalfa	0.033	0.058
Elaeagnus commutata	Wolf-willow	0.033	0.058
Salix sp. 1	Willow sp. 1	0.033	0.058
Picea glauca	White spruce	0.033	0.058
Cirsium arvense	Canada thistle	0.013	0.006

Beatton River Landslide Relevés BErl1, BErl2, BErl3 -cont'd

Species	**Common name(s)**	**Mean cover (%)**	**SD (+/-)**
Elymus glaucus	Blue wildrye	0.010	0.017
Elymus lanceolatus ssp. *lanceolatus*	Thickspike wheatgrass	0.010	0.017
Lily sp.	Lily sp.	0.003	0.006
Trifolium hybridum	Alsike clover	0.003	0.006
Bromus inermis ssp. *inermis*	Smooth brome	0.003	0.006
Elymus trachycaulus ssp. *trachycaulus*	Slender wheatgrass	0.003	0.006
Ribes lacustre	Black gooseberry	0.003	0.006

Beatton River Undisturbed Relevés BEru1, BEru2d, BEru3

Species	Common name(s)	Mean cover (%)	SD (+/-)
Amelanchier alnifolia	Saskatoon	10.846	16.598
Betula papyrifera	Paper birch	10.667	18.475
Aralia nudicaulis	Wild sarsaparilla	7.824	2.299
Linnaea borealis	Twinflower	6.832	6.135
Carex sp. 1	Sedge sp. 1	5.667	9.815
Viburnum edule	Highbush-cranberry	5.550	4.877
Rosa acicularis	Prickly rose	4.925	0.393
Picea glauca	White spruce	4.727	6.724
Carex sp. 3	Sedge sp. 3	4.000	6.928
Aster conspicuus	Showy aster	3.852	3.372
Alnus viridis ssp. *sinuata*	Sitka alder	3.500	6.062
Cornus stolonifera	Red-osier dogwood	2.683	2.675
Leymus innovatus	Fuzzy-spiked wildrye	2.625	2.770
Calamagrostis canadensis	Bluejoint	2.614	3.105
Shepherdia canadensis	Soopolallie	2.407	3.049
Symphoricarpos albus	Common snowberry	2.003	3.038
Apocynum androsaemifolium	Spreading dogbane	1.833	3.175
Salix sp. 2	Willow sp. 2	1.510	2.615
Artemisia sp. 1	Sage sp. 1	1.417	2.454
Populus tremuloides	Trembling aspen	1.297	1.101
Rubus pubescens	Trailing raspberry	1.268	1.874
Elaeagnus commutata	Wolf-willow	1.083	1.876
Tragopogon dubius	Goat's-beard, yellow salsify	1.000	1.732
Hesperostipa curtiseta	Needle-and-thread grass	0.667	1.155
Pyrola asarifolia	Pink wintergreen	0.500	0.621
Prunus virginiana	Choke cherry	0.422	0.298
Lonicera dioica	Red honeysuckle	0.396	0.487
Populus balsamifera ssp. *balsamifera*	Black cottonwood	0.396	0.351
Spiraea betulifolia	Birch-leaved spirea	0.333	0.577
Lathyrus ochroleucus	Creamy peavine	0.329	0.333
Cornus canadensis	Bunchberry	0.277	0.392
Platydictya jungermannioides	False willow moss, Spruce's leskea	0.233	0.400
Vicia americana	American vetch	0.233	0.354

Beatton River Undisturbed Relevés BEru1, BEru2d, BEru3 - cont'd

Species	Common name(s)	Mean cover (%)	SD (+/-)
Galium boreale	Northern bedstraw	0.213	0.191
Mitella nuda	Common mitrewort	0.169	0.291
Maianthemum canadense	Wild lily-of-the-valley	0.168	0.148
"Silver grass"	Grass sp.	0.167	0.289
Fragaria vesca	Wood strawberry	0.165	0.188
Salix sp. 3	Willow sp. 3	0.162	0.193
Disporum trachycarpum	Rough-fruited fairybells	0.149	0.157
Ribes lacustre	Black gooseberry	0.148	0.129
Mertensia paniculata	Tall bluebell	0.143	0.128
Equisetum arvense	Common horsetail	0.127	0.217
Ribes triste	Red swamp currant	0.125	0.110
Actaea rubra	Baneberry	0.100	0.163
Orthilia secunda	One-sided wintergreen	0.095	0.095
Fragaria virginiana	Wild strawberry	0.094	0.126
Epilobium angustifolium	Fireweed	0.093	0.089
Comandra umbellata	Bastard toadflax	0.093	0.162
Aster ciliolatus	Fringed aster	0.083	0.018
Achnatherum nelsonii	Columbia needlegrass	0.083	0.144
Hesperostipa spartea (aka *Stipa spartea)*	Porcupinegrass	0.083	0.144
Peltigera sp.	Pelt lichen sp.	0.080	0.122
Rubus idaeus	Red raspberry	0.079	0.097
Lonicera involucrata	Black twinberry	0.073	0.082
Osmorhiza chilensis	Mountain sweet-cicely	0.068	0.117
Hylocomium splendens	Step moss	0.066	0.095
Plagiomnium cuspidatum	Baby tooth moss, woodsy thyme-moss	0.056	0.048
Maianthemum canadense	Violet sp.	0.055	0.048
Ribes oxyacanthoides	Northern gooseberry	0.048	0.048
Eurynchiastrum pulchellum	Elegant feather-moss	0.040	0.037
Galium triflorum	Sweet-scented bedstraw	0.040	0.038
Achillea millefolium	Yarrow	0.039	0.053
Geocaulon lividum	False toadflax, northern comandra	0.033	0.058
Sonchus sp.	Sow-thistle sp.	0.033	0.058
Androsace septentrionalis	Pygmyflower rockjasmine	0.033	0.058

Beatton River Undisturbed Relevés BEru1, BEru2d, BEru3 - cont'd

Species	Common name(s)	Mean cover (%)	SD (+/-)
Ribes sp.	Gooseberry/currant sp.	0.033	0.058
Smilacina stellata	Star-flowered false Solomon's seal	0.023	0.030
Taraxacum officinale	Common dandelion	0.018	0.018
Erigeron glabellus	Smooth fleabane	0.017	0.029
Koelaria macrantha	Junegrass	0.017	0.029
Pleurozium schreberi	Red-stemmed feathermoss	0.014	0.017
Pohlia nutans	Nodding thread-moss	0.013	0.022
Pyrola sp.	Wintergreen sp.	0.012	0.014
Erigeron acris	Bitter fleabane	0.010	0.017
Agropyron sp.	Slender wheatgrass	0.010	0.017
Syntrichia ruralis	Twisted moss	0.008	0.013
Solidago canadensis	Canada goldenrod	0.008	0.014
Salix sp. 1	Willow sp. 1	0.008	0.013
Trifolium pratense	Clover sp.	0.007	0.012
Petasites frigidus	Sweet coltsfoot	0.004	0.007
Dicranum polysetum	Broom moss, wavyleaf moss	0.003	0.004
Gymnocarpium dryopteris	Oak fern	0.003	0.004
Delphinium sp.	Larkspur sp.	0.003	0.006
Dryas drummondii	Yellow mountain avens	0.003	0.006
Maianthemum stellatum	Starry false lily of the valley	0.003	0.006
Rhinanthus minor	Yellow rattle	0.003	0.006
Glyceria sp.	Manna grass sp.	0.003	0.006
Platanthera dilitata	White northern bog-orchid	0.002	0.003
Cladonia sp.	Pixie cup sp.	0.002	0.003
Juniperus communis	Common juniper	0.002	0.003

Cecil Lake Landslide Relevés CErl1, CErl2, CErl3

Species	Common name(s)	Mean cover (%)	SD (+/-)
Equisetum arvense	Common horsetail	33.500	12.173
Alnus viridis ssp. *sinuata*	Sitka alder	24.092	20.687
Petasites frigidus	Sweet coltsfoot	6.733	11.490
Salix sp. 1	Willow sp. 1	5.630	4.352
Populus balsamifera ssp. *balsamifera*	Black cottonwood	4.767	6.280
Shepherdia canadensis	Soopolallie	3.128	0.327
Picea glauca	White spruce	2.679	2.065
Populus tremuloides	Trembling aspen	2.642	2.455
Rosa acicularis	Prickly rose	2.412	0.390
Salix sp. 2	Willow sp. 2	1.958	2.895
Trifolium hybridum	Alsike clover	1.664	2.516
Salix sp. 3	Willow sp. 3	1.518	1.885
Viburnum edule	Highbush-cranberry	1.492	1.784
Cornus stolonifera	Red-osier dogwood	1.325	0.282
Calamagrostis canadensis	Bluejoint	1.258	1.906
Taraxacum officinale	Common dandelion	0.833	0.441
Typha sp.	Cattail sp.	0.675	0.622
Salix sp. 6	Willow sp. 6	0.667	1.155
Eurynchiastrum pulchellum	Elegant feather-moss	0.567	0.787
Rubus idaeus	Red raspberry	0.523	0.285
Aster ciliolatus	Fringed aster	0.518	0.729
Epilobium angustifolium	Fireweed	0.415	0.388
Betula papyrifera	Paper birch	0.350	0.563
Cirsium arvense	Canada thistle	0.348	0.410
Linnaea borealis	Twinflower	0.332	0.282
Fragaria virginiana	Wild strawberry	0.329	0.170
Sonchus arvensis	Perennial sow-thistle	0.298	0.495
Rubus pubescens	Trailing raspberry	0.265	0.190
Vicia americana	American vetch	0.253	0.137
Salix sp. 4	Willow sp. 4	0.225	0.390
Lathyrus ochroleucus	Creamy peavine	0.203	0.086
Aralia nudicaulis	Wild sarsaparilla	0.197	0.341
Pyrola asarifolia	Pink wintergreen	0.194	0.319

Cecil Lake Landslide Relevés CErl1, CErl2, CErl3 - cont'd

Species	Common name(s)	Mean cover (%)	SD (+/-)
Aster conspicuus	Showy aster	0.170	0.255
Brachythecium sp. 2	Ragged moss sp.	0.167	0.289
Salix sp. 5	Willow sp. 5	0.167	0.289
Solidago canadensis	Canada goldenrod	0.161	0.177
Amelanchier alnifolia	Saskatoon	0.117	0.126
Mertensia paniculata	Tall bluebell	0.108	0.091
Ribes oxyacanthoides	Northern gooseberry	0.092	0.103
Cornus canadensis	Bunchberry	0.091	0.077
Phleum pratense	Timothy	0.090	0.087
Elymus trachycaulus	Slender wheat grass	0.084	0.146
Brachythecium sp. 1	Moss sp.	0.067	0.115
Salix exigua	Sandbar willow	0.067	0.115
Hordeum jubatum	Foxtail barley	0.064	0.051
Symphoricarpos albus	Common snowberry	0.060	0.100
Delphinium glaucum	Tall larkspur	0.057	0.098
Lonicera involucrata	Black twinberry	0.057	0.068
Goodyera repens	Dwarf rattlesnake-plantain	0.050	0.087
"Hairy grass"	"Hairy" grass sp.	0.049	0.085
Brachythecium sp. 3	Moss sp.	0.039	0.068
Pohlia nutans	Nodding thread-moss	0.037	0.064
Cinna latifolia	Nodding wood-reed	0.033	0.058
Galium triflorum	Sweet-scented bedstraw	0.026	0.017
Fragaria vesca	Wood strawberry	0.024	0.042
Glyceria sp.	Manna grass sp. 1	0.021	0.034
Achillea sibirica	Siberian yarrow	0.020	0.026
Melilotus officinalis	Yellow sweet-clover	0.019	0.033
Bromus inermis ssp. *inermis*	Smooth brome	0.019	0.033
"Tallwheat grass" sp.	"Tallwheat" grass sp.	0.018	0.032
Achillea millefolium	Common yarrow	0.016	0.018
Ribes sp.	Gooseberry/currant sp.	0.016	0.027
Geum macrophyllum	Large-leaved avens	0.015	0.022
Galium boreale	Northern bedstraw	0.008	0.010
Matricaria perforata	Scentless chamomile	0.008	0.014

Cecil Lake Landslide Relevés CErl1, CErl2, CErl3 - cont'd

Species	Common name(s)	Mean cover (%)	SD (+/-)
Ribes triste	Red swamp currant	0.008	0.014
Dicranum sp.	Broom moss sp.	0.007	0.012
Funaria sp.	Rope moss sp.	0.007	0.012
Epilobium ciliatum	Purple-leaved willowherb	0.007	0.012
Mitella nuda	Common mitrewort	0.007	0.012
Spiraea sp.	Hardhack sp.	0.007	0.012
Agrostis stolonifera	Redtop	0.007	0.012
Cladonia sp.	Pixie cup sp.	0.007	0.012
Nephroma sp.	Kidney lichen sp.	0.007	0.012
Lonicera dioica	Red honeysuckle	0.006	0.010
Bromus ciliatus	Fringed brome	0.005	0.009
Poa nemoralis ssp. *interior*	Inland blue grass	0.005	0.009
Elymus lanceolatus ssp. *lanceolatus*	Thickspike wheatgrass	0.005	0.009
Peltigera sp.	Pelt lichen sp.	0.005	0.009
Actaea rubra	Baneberry	0.004	0.007
Hylocomium splendens	Step moss	0.003	0.006
Achillea sp.	Yarrow sp.	0.003	0.006
Chenopodium sp.	Goosefoot sp.	0.003	0.006
Crepis tectorum	Annual hawksbeard	0.003	0.006
Leucantheum sp.	Daisy sp.	0.003	0.006
Sanicula marilandica	Maryland black snakeroot	0.003	0.004
Koelaria macrantha	Junegrass	0.003	0.006
Rush sp.	Rush sp.	0.003	0.004
Ribes sp. 2	Gooseberry/currant sp. 2	0.003	0.006
Ribes lacustre	Black gooseberry	0.003	0.004
Rumex crispus	Curly dock	0.002	0.003
Platanthera dilitata	White northern bog-orchid	0.002	0.003
Viola sp.	Violet sp.	0.002	0.001
Poa pratensis	Kentucky bluegrass	0.002	0.003
Ribes laxiflorum	Trailing black currant	0.002	0.003
Marchantia sp.	Liverwort sp.	0.001	0.001
"Bottlebrush moss" sp.	"Bottlebrush" moss sp.	0.001	0.001
Pleurozium schreberi	Red-stemmed feathermoss	0.001	0.001

Cecil Lake Landslide Relevés CErl1, CErl2, CErl3 - cont'd

Species	Common name(s)	Mean cover (%)	SD (+/-)
Hieracium triste	Wooly hawkweed	0.001	0.001
Senecio eremophilus	Cutleaf groundsel	0.001	0.001
Sonchus arvensis	Perennial sow thistle	0.001	0.001
Gentianella amarella	Autumn gentian	0.001	0.001
"Bigwheat grass" sp.	"Bigwheat" grass sp.	0.001	0.001
Glyceria sp. 2	Manna grass sp. 2	0.001	0.001
Beckmannia syzigachne	American sloughgrass	0.001	0.001

Cecil Lake Undisturbed Relevés CEru1, CEru2a, CEru3

Species	Common name(s)	Mean cover (%)	SD (+/-)
Picea glauca	White spruce	22.893	14.687
Populus tremuloides	Trembling aspen	9.107	12.483
Rosa acicularis	Prickly rose	6.908	3.425
Viburnum edule	Highbush-cranberry	6.762	3.772
Aralia nudicaulis	Wild sarsaparilla	6.460	1.935
Hylocomium splendens	Step moss	6.210	5.743
Shepherdia canadensis	Soopolallie	4.388	4.020
Alnus viridis ssp. *sinuata*	Sitka alder	4.015	2.953
Betula papyrifera	Paper birch	3.624	5.017
Linnaea borealis	Twinflower	3.137	3.102
"Fuzzy grass" sp.	"Fuzzy" grass sp.	2.253	3.894
Cornus stolonifera	Red-osier dogwood	1.922	1.738
Pleurozium schreberi	Red-stemmed feathermoss	1.118	1.779
Aster conspicuus	Showy aster	1.118	0.986
Cornus canadensis	Bunchberry	1.058	0.820
Amelanchier alnifolia	Saskatoon	0.971	0.806
Rubus pubescens	Trailing raspberry	0.782	0.500
Ribes triste	Red swamp currant	0.445	0.404
Symphoricarpos albus	Common snowberry	0.426	0.224
Mertensia paniculata	Tall bluebell	0.349	0.327
Ptilium crista-castrensis	Knight's plume	0.323	0.543
Ribes lacustre	Black gooseberry	0.297	0.285
Lonicera dioica	Red honeysuckle	0.279	0.106
"Thin grass" sp.	"Thin" grass sp.	0.253	0.439
Calamagrostis canadensis	Bluejoint	0.240	0.235
Salix sp.	Willow sp.	0.190	0.329
Lathyrus ochroleucus	Creamy peavine	0.146	0.156
Clematis sp.	Clematis sp.	0.133	0.231
Lonicera involucrata	Black twinberry	0.115	0.133
Rhytidiadelphus triquetrus	Electrified cat's-tail moss	0.110	0.191
Mitella nuda	Common mitrewort	0.108	0.166
Eurynchiastrum pulcellum	Elegant beaked moss	0.087	0.150
Disporum trachycarpum	Rough-fruited fairybells	0.086	0.012

Cecil Lake Undisturbed Relevés CEru1, CEru2a, CEru3 - cont'd

Species	Common name(s)	Mean cover (%)	SD (+/-)
Orthilia secunda	One-sided wintergreen	0.081	0.059
Geocaulon lividum	Bastard toad-flax	0.060	0.060
Aster ciliolatus	Fringed aster	0.053	0.084
Galium boreale	Northern bedstraw	0.053	0.051
Pyrola chlorantha	Green wintergreen	0.047	0.072
Peltigera polydactylon	Pioneer pelt	0.047	0.045
Pyrola asarifolia	Pink wintergreen	0.038	0.013
Ribes oxyacanthoides	Northern gooseberry	0.035	0.061
Fragaria virginiana	Wild strawberry	0.033	0.058
Rubus idaeus	Red raspberry	0.029	0.026
Brachythecium sp.	Ragged moss sp.	0.027	0.046
Fragaria vesca	Wood strawberry	0.027	0.025
Moss sp.	Moss sp.	0.020	0.035
Fern sp.	Fern sp.	0.020	0.035
Epilobium angustifolium	Fireweed	0.020	0.035
Actaea rubra	Baneberry	0.018	0.011
Osmorhiza chilensis	Mountain sweet-cicely	0.018	0.028
Dicranum polysetum	Wavy leaf moss, broom moss	0.014	0.025
Galium triflorum	Sweet-scented bedstraw	0.012	0.013
Dicranum scoparium	Broom forkmoss	0.010	0.017
Plagiomnium cuspidatum	Baby tooth moss, woodsy thyme moss	0.007	0.012
Viola sp.	Violet sp.	0.007	0.012
Vicia americana	American vetch	0.005	0.005
Delphinium glaucum	Tall larkspur	0.004	0.007
Equisetum arvense	Common horsetail	0.003	0.006
Goodyera oblongifolia	Rattlesnake-plantain	0.003	0.006
Listera sp. (aka *Neottia* sp.)	Twayblade sp.	0.003	0.006
Maianthemum canadense	Wild lily-of-the-valley	0.003	0.006
Taraxacum officinale	Common dandelion	0.003	0.006
Cladonia sp.	Pixie cup sp.	0.003	0.006
Prunus virginiana	Choke cherry	0.003	0.006
Gymnocarpium dryopteris	Oak fern	0.002	0.003

Hasler Flats Landslide Relevés HArl1b, HArl2b, HArl3a

Species	Common name(s)	Mean cover (%)	SD (+/-)
Equisetum arvense	Common horsetail	16.417	1.041
Populus tremuloides	Trembling aspen	10.758	5.329
Rosa acicularis	Prickly rose	10.375	2.211
Alnus viridis ssp. *sinuata*	Sitka alder	6.308	4.242
Rubus idaeus	Red raspberry	5.595	3.055
Cornus stolonifera	Red-osier dogwood	4.900	3.776
Symphoricarpos albus	Common snowberry	4.145	2.427
Pohlia nutans	Nodding thread-moss	2.423	0.505
Viburnum edule	Highbush-cranberry	2.423	1.273
Lonicera dioica	Red honeysuckle	2.348	2.706
Smilacina racemosa	False Solomon's-seal	1.623	2.537
Amelanchier alnifolia	Saskatoon	1.528	1.671
Aralia nudicaulis	Wild sarsaparilla	1.403	2.147
Prunus virginiana	Choke cherry	1.320	0.437
Calamagrostis canadensis	Bluejoint	1.088	0.934
Bromus inermis	Smooth brome	1.051	1.818
Aster conspicuus	Showy aster	0.925	0.839
Lonicera involucrata	Black twinberry	0.716	0.584
Elymus glaucus ssp. *glaucus*	Blue wildrye	0.696	0.654
Ribes oxyacanthoides	Northern gooseberry	0.461	0.491
Salix sp. 2	Willow sp. 2	0.434	0.475
Rubus pubescens	Trailing raspberry	0.348	0.378
Ribes triste	Red swamp currant	0.335	0.273
Populus balsamifera ssp. *balsamifera*	Black cottonwood	0.300	0.173
Mertensia paniculata	Tall bluebell	0.281	0.110
Salix sp. 1	Willow sp. 1	0.266	0.142
Petasites frigidus	Sweet coltsfoot	0.248	0.161
Vicia americana	American vetch	0.247	0.178
Streptopus amplexifolius	Clasping twistedstalk	0.232	0.401
Viola sp.	Violet sp.	0.199	0.313
Marchantia polymorpha	Common liverwort	0.198	0.208
Aster ciliolatus	Fringed aster	0.176	0.172
Lathyrus ochroleucus	Creamy peavine	0.176	0.204

Hasler Flats Landslide Relevés HArl1b, HArl2b, HArl3a - cont'd

Species	Common name(s)	Mean cover (%)	SD (+/-)
Galium boreale	Northern bedstraw	0.163	0.142
Betula papyrifera	Paper birch	0.103	0.003
Heracleum lanatum	Cow-parsnip	0.098	0.100
Actaea rubra	Baneberry	0.090	0.089
Smilacina stellata	Star-flowered false Solomon's-seal	0.088	0.153
Taraxacum officinale	Common dandelion	0.088	0.052
Fragaria vesca	Wood strawberry	0.084	0.135
Epilobium angustifolium	Fireweed	0.082	0.085
Cornus canadensis	Bunchberry	0.074	0.004
Mitella nuda	Common mitrewort	0.068	0.089
Galium triflorum	Sweet-scented bedstraw	0.065	0.061
Picea glauca	White spruce	0.063	0.097
Dicranum polysetum	Wavy leaf moss, broom moss	0.062	0.107
Pyrola asarifolia	Pink wintergreen	0.061	0.093
Thalictrum occidentale	Western meadowrue	0.054	0.019
Fragaria virginiana	Wild strawberry	0.047	0.081
Cirsium arvense	Canada thistle	0.046	0.058
Spiraea betulifolia	Birch-leaved spirea	0.040	0.034
Maianthemum canadense	Wild lily-of-the-valley	0.039	0.046
Poa palustris	Fowl blue grass	0.038	0.026
Sonchus arvensis	Perennial sow-thistle	0.030	0.014
Epilobium ciliatum	Purple-leaved willowherb	0.029	0.020
Linnaea borealis	Twinflower	0.027	0.031
Veratrum viride	Indian hellebore	0.023	0.040
"Oat grass" sp.	"Oat grass" grass sp.	0.019	0.033
Rubus parviflorus	Thimbleberry	0.019	0.019
Bromus ciliatus	Fringed brome	0.016	0.027
Typha sp.	Cattail sp.	0.015	0.020
Leymus innovatus	Fuzzy-spiked wildrye	0.012	0.020
Veronica beccabunga	European speedwell, brooklime	0.010	0.017
Elymus trachycaulus ssp. *trachycaulus*	Slender wheatgrass	0.010	0.011
Carex sp.	Sedge sp.	0.010	0.017
Carex rostrata	Beaked sedge	0.008	0.009

Hasler Flats Landslide Relevés HArl1b, HArl2b, HArl3a - cont'd

Species	Common name(s)	Mean cover (%)	SD (+/-)
Cirsium vulgare	Bull thistle	0.007	0.012
Festuca sp.	Fescue sp.	0.007	0.012
Achillea millefolium	Yarrow	0.005	0.005
Trisetum cernuum	Nodding trisetum	0.005	0.009
"Limp grass" sp.	"Limp grass" grass sp.	0.005	0.009
Syntrichia ruralis	Twisted moss	0.004	0.007
Plagiomnium cuspidatum	Baby tooth moss, woodsy thyme-moss	0.004	0.007
Cyclamen hederifolium	Hardy cyclamen, ivy leaved cyclamen	0.003	0.006
Hieracium sabaudum	European hawkweed, Savoy hawkweed	0.003	0.006
Orthilia secunda	One-sided wintergreen	0.003	0.004
"Frothy grass" sp.	"Frothy grass" grass sp.	0.003	0.004
Shepherdia canadensis	Soopolallie	0.003	0.004
Leptobryum pyriforme	Golden thread-moss	0.002	0.003
Fern sp.	Fern sp.	0.002	0.003
Equisetum variegatum	Variegated scouring-rush	0.002	0.003
Geum macrophyllum	Large-leaved avens	0.002	0.003
Chenopodium capitatum	Strawberry-blite	0.001	0.001
Boechera stricta	Canada rockcress	0.001	0.001
Plantago major	Broadleaf plantain	0.001	0.001
"Pondweed" sp.	Pondweed sp.	0.001	0.001
Trifolium hybridum	Alsike clover	0.001	0.001
Phleum pratense	Timothy	0.001	0.001
Ribes hudsonianum	Northern black currant	0.001	0.001
Ribes laxiflorum	Trailing black currant	0.001	0.001

Hasler Flats Undisturbed Relevés HAru1, HAru2a, HAru3a

Species	Common name(s)	Mean cover (%)	SD (+/-)
Equisetum arvense	Common horsetail	15.625	6.945
Populus tremuloides	Trembling aspen	13.580	5.074
Alnus viridis ssp. *sinuata*	Sitka alder	9.863	17.084
Cornus stolonifera	Red-osier dogwood	7.358	4.376
Viburnum edule	Highbush-cranberry	6.983	5.925
Aralia nudicaulis	Wild sarsaparilla	6.856	4.865
Symphoricarpos albus	Common snowberry	5.378	5.090
Rosa acicularis	Prickly rose	5.283	1.617
Populus balsamifera ssp. *balsamifera*	Black cottonwood	4.335	6.321
Heracleum lanatum	Cow-parsnip	3.844	5.059
Aster conspicuus	Showy aster	2.556	2.311
Amelanchier alnifolia	Saskatoon	2.503	1.616
Lonicera dioica	Red honeysuckle	1.976	2.900
Prunus virginiana	Choke cherry	1.609	1.262
Mitella nuda	Common mitrewort	1.397	1.984
Rubus idaeus	Red raspberry	1.236	1.720
Salix sp. 2	Willow sp. 2	1.026	0.876
Ribes oxyacanthoides	Northern gooseberry	0.904	1.521
Smilacina racemosa	False Solomon's-seal	0.653	0.481
Actaea rubra	Baneberry	0.580	0.544
Rubus pubescens	Trailing raspberry	0.551	0.240
Thalictrum occidentale	Western meadowrue	0.516	0.532
Picea glauca	White spruce	0.510	0.515
Smilacina stellata	Star-flowered false Solomon's-seal	0.488	0.420
Ribes triste	Red swamp currant	0.487	0.318
Lonicera involucrata	Black twinberry	0.438	0.193
Viola sp.	Violet sp.	0.415	0.595
Lathyrus ochroleucus	Creamy peavine	0.328	0.285
Maianthemum canadense	Wild lily-of-the-valley	0.327	0.375
Streptopus amplexifolius	Clasping twistedstalk	0.276	0.386
Vicia americana	American vetch	0.235	0.147
Petasites frigidus	Sweet coltsfoot	0.231	0.138
Angelica lucida	Seacoast angelica, sea-watch	0.199	0.179

Hasler Flats Undisturbed Relevés HAru1, HAru2a, HAru3a - cont'd

Species	Common name(s)	Mean cover (%)	SD (+/-)
Salix sp. 1	Willow sp. 1	0.195	0.287
Calamagrostis canadensis	Bluejoint	0.185	0.215
Pyrola asarifolia	Pink wintergreen	0.163	0.249
Aster foliaceus	Leafy-bracted aster	0.131	0.218
Ribes hudsonianum	Northern black currant	0.130	0.225
Mertensia paniculata	Tall bluebell	0.124	0.027
Cirsium arvense	Creeping thistle	0.123	0.214
Aster ciliolatus	Fringed aster	0.110	0.132
Dicranum polysetum	Wavy leaf moss, broom moss	0.105	0.173
Galium boreale	Northern bedstraw	0.085	0.071
Shepherdia canadensis	Soopolallie	0.083	0.144
Galium triflorum	Sweet-scented bedstraw	0.077	0.028
"Mystery grass 2" sp.	Mystery grass sp. 2	0.077	0.133
Disporum trachycarpum	Rough-fruited fairybells	0.074	0.128
Plagiomnium cuspidatum	Baby tooth moss, woodsy thyme-moss	0.068	0.118
Fragaria vesca	Wood strawberry	0.056	0.097
Plagiomnium ellipticum	Marsh thyme-moss	0.041	0.056
Osmorhiza chilensis	Mountain sweet-cicely	0.035	0.044
Cornus canadensis	Bunchberry	0.034	0.049
Salix sp. 3	Willow sp. 3	0.033	0.058
Acer glabrum	Douglas maple	0.033	0.058
Orthilia secunda	One-sided wintergreen	0.032	0.051
Bromus inermis ssp. *inermis*	Smooth brome	0.028	0.018
Fragaria virginiana	Wild strawberry	0.027	0.031
Taraxacum officinale	Common dandelion	0.026	0.030
"Hairy grass"	"Hairy grass" grass sp.	0.024	0.042
Epilobium ciliatum	Purple-leaved willowherb	0.019	0.033
Veronica beccabunga	European speedwell, brooklime	0.018	0.030
Carex disperma	Soft-leaf sedge, two-seed sedge	0.018	0.016
"Mystery grass" sp. 1	"Mystery grass" grass sp. 1	0.017	0.027
Veratrum viride	Indian hellebore	0.014	0.025
Linnaea borealis	Twinflower	0.011	0.019
Bromus ciliatus	Fringed brome	0.008	0.014

Hasler Flats Undisturbed Relevés HAru1, HAru2a, HAru3a - cont'd

Species	Common name(s)	Mean cover (%)	SD (+/-)
Poa pratensis	Kentucky bluegrass	0.008	0.014
Equisetum pratense	Meadow horsetail, shade horsetail	0.007	0.006
Spiraea betulifolia	Birch-leaved spirea	0.005	0.009
Leymus innovatus	Fuzzy-spiked wildrye	0.005	0.009
Elymus lanceolatus ssp. *lanceolatus*	Thickspike wheatgrass	0.005	0.004
Epilobium angustifolium	Fireweed	0.003	0.003
Geum rivale	Water avens, purple avens	0.003	0.006
Phleum pratense	Timothy	0.003	0.004
"Soft grass" sp	"Soft grass" grass sp.	0.003	0.004
Grass sp.	Unknown grass sp.	0.003	0.006
Carex sp.	Sedge sp.	0.003	0.006
Rubus parviflorus	Thimbleberry	0.003	0.004
Botrychium virginianum	Rattlesnake fern	0.002	0.003
Cyclamen hederifolium	Hardy cyclamen, ivy leaved cyclamen	0.002	0.003
Glyceria sp.	Manna grass sp.	0.002	0.003
Achillea millefolium	Yarrow	0.001	0.001
Monotropa uniflora	Ghost pipe, Indian-pipe	0.001	0.001
Ribes lacustre	Black gooseberry	0.001	0.001

Appendix 3 Vegetation cover by growth form

Beatton River Landslide Relevés - Total mean vegetation cover = 59.68%

Species	Mean cover (%)
Trees	
Populus balsamifera ssp. *balsamifera*	0.167
Picea glauca	0.033
Total	**0.200**
Proportion of all cover	**0.335**
Shrubs	
Rubus idaeus	1.087
Cornus stolonifera	0.283
Rosa acicularis	0.133
Salix sp. 2	0.067
Salix sp.	0.060
Shepherdia canadensis	0.043
Elaeagnus commutata	0.033
Salix sp. 1	0.033
Ribes lacustre	0.003
Total	**1.742**
Proportion of all cover	**2.919**
Forbs	
Melilotus officinalis	28.833
Melilotus alba	6.000
Sonchus arvensis	4.100
Artemisia sp. 2	1.767
Lactuca serriola	1.410
Aster ciliolatus	0.700
Solidago canadensis	0.650
Taraxacum officinale	0.443
Fragaria virginiana	0.400
Unknown forb (white)	0.167
Chenopodium album	0.133
Achillea millefolium	0.123
Tragopogon dubius	0.103
Hieracium triste	0.100
Aster sp.	0.083
Vicia americana	0.073
Ranunculus sp.	0.067

Beatton River Landslide Relevés - cont'd

Forbs -cont'd	
Epilobium angustifolium	0.037
Lathyrus ochroleucus	0.033
Medicago sativa	0.033
Cirsium arvense	0.013
Lily sp.	0.003
Trifolium hybridum	0.003
Total	**45.274**
Proportion of all cover	**75.861**
Graminoids	
Elymus repens (aka *Agropyron repens*)	0.100
Elymus glaucus	0.010
Elymus lanceolatus ssp. *lanceolatus*	0.010
Bromus inermis ssp. *inermis*	0.003
Elymus trachycaulus ssp. *trachycaulus*	0.003
Total	**0.126**
Proportion of all cover	**0.211**
Ferns & Fern allies	
Equisetum arvense	12.167
Total	**12.167**
Proportion of all cover	**20.387**
Bryophytes	
Brachythecium sp.	0.167
Total	**0.167**
Proportion of all cover	**0.280**

Beatton River Undisturbed Relevés - Total mean vegetation cover = 97.348%

Species	Mean cover (%)
<u>Trees</u>	
Betula papyrifera	10.667
Picea glauca	4.727
Populus tremuloides	1.297
Populus balsamifera ssp. *balsamifera*	0.396
Total	**17.087**
Proportion of all cover	**17.552**
<u>Shrubs</u>	
Amelanchier alnifolia	10.846
Viburnum edule	5.550
Rosa acicularis	4.925
Alnus viridis ssp. *sinuata*	3.500
Cornus stolonifera	2.683
Shepherdia canadensis	2.407
Symphoricarpos albus	2.003
Salix sp. 2	1.510
Rubus pubescens	1.268
Elaeagnus commutata	1.083
Prunus virginiana	0.422
Lonicera dioica	0.396
Salix sp.	0.162
Ribes lacustre	0.148
Ribes triste	0.125
Rubus idaeus	0.079
Lonicera involucrata	0.073
Ribes oxyacanthoides	0.048
Ribes sp.	0.033
Salix sp. 1	0.008
Juniperus communis	0.002
Total	**37.271**
Proportion of all cover	**38.286**
<u>Forbs</u>	
Aralia nudicaulis	7.824
Linnaea borealis	6.832
Aster conspicuus	3.852

Beatton River Undisturbed Relevés - cont'd

Species	Mean cover (%)
Forbs - cont'd	
Apocynum androsaemifolium	1.833
Artemisia sp. 1	1.417
Tragopogon dubius	1.000
Pyrola asarifolia	0.500
Spiraea betulifolia	0.333
Lathyrus ochroleucus	0.329
Cornus canadensis	0.277
Vicia americana	0.233
Galium boreale	0.213
Mitella nuda	0.169
Maianthemum canadense	0.168
Fragaria vesca	0.165
Disporum trachycarpum (aka *Prosartes trachycarpa*)	0.149
Mertensia paniculata	0.143
Actaea rubra	0.100
Orthilia secunda	0.095
Fragaria virginiana	0.094
Epilobium angustifolium	0.093
Comandra umbellata	0.093
Aster ciliolatus	0.083
Osmorhiza chilensis	0.068
Maianthemum canadense	0.055
Galium triflorum	0.040
Achillea millefolium	0.039
Geocaulon lividum	0.033
Sonchus sp.	0.033
Smilacina stellata	0.023
Taraxacum officinale	0.018
Erigeron glabellus	0.017
Pyrola sp.	0.012
Erigeron acris	0.010
Solidago canadensis	0.008
Trifolium pratense	0.007
Petasites frigidus	0.004
Delphinium sp.	0.003

Beatton River Undisturbed Relevés - cont'd

Species	Mean cover (%)
Forbs - cont'd	
Dryas drummondii	0.003
Maianthemum stellatum	0.003
Rhinanthus minor	0.003
Platanthera dilitata	0.002
Total	**26.376**
Proportion of all cover	**27.095**
Graminoids	
Carex sp. 1	5.667
Carex sp. 3	4.000
Leymus innovatus	2.625
Calamagrostis canadensis	2.614
Hesperostipa curtiseta	0.667
"Silver grass"	0.167
Achnatherum nelsonii	0.083
Hesperostipa spartea (aka *Stipa spartea*)	0.083
Androsace septentrionalis	0.033
Koelaria macrantha	0.017
Elymus trachycaulus ssp. *trachycaulus*	0.010
Glyceria sp.	0.003
Total	**15.969**
Proportion of all cover	**16.404**
Ferns & Fern allies	
Equisetum arvense	0.127
Gymnocarpium dryopteris	0.003
Total	**0.130**
Proportion of all cover	**0.134**
Bryophytes	
Platydictya jungermannioides	0.233
Hylocomium splendens	0.066
Plagiomnium cuspidatum	0.056
Eurynchiastrum pulchellum	0.040
Pleurozium schreberi	0.014

Beatton River Undisturbed Relevés - cont'd

Species	Mean cover (%)
Bryophytes - cont'd	
Pohlia nutans	0.013
Syntrichia ruralis	0.008
Dicranum polysetum	0.003
Total	**0.433**
Proportion of all cover	**0.445**
Lichens	
Peltigera sp.	0.080
Cladonia sp.	0.002
Total	**0.082**
Proportion of all cover	**0.084**

Cecil Lake Landslide Relevés - Total mean vegetation cover = 104.160%

Species	Mean cover (%)
Trees	
Populus balsamifera ssp. *balsamifera*	4.767
Picea glauca	2.679
Populus tremuloides	2.642
Betula papyrifera	0.350
Total	**10.438**
Proportion of all cover	**10.021**
Shrubs	
Alnus viridis ssp. *sinuata*	24.092
Salix sp. *1*	5.630
Shepherdia canadensis	3.128
Rosa acicularis	2.412
Salix sp. 2	1.958
Salix sp. *3*	1.518
Viburnum edule	1.492
Cornus stolonifera	1.325
Salix sp. *6*	0.667
Rubus idaeus	0.523
Rubus pubescens	0.265
Salix sp. *4*	0.225
Salix sp. *5*	0.167
Amelanchier alnifolia	0.117
Ribes oxyacanthoides	0.092
Salix exigua	0.067
Symphoricarpos albus	0.060
Lonicera involucrata	0.057
Ribes sp.	0.016
Ribes triste	0.008
Lonicera dioica	0.006
Ribes sp. 2	0.003
Ribes lacustre	0.003
Ribes laxiflorum	0.002
Total	**43.833**
Proportion of all cover	**42.082**

Cecil Lake Landslide Relevés - cont'd

Species	Mean cover (%)
Forbs	
Petasites frigidus	6.733
Trifolium hybridum	1.664
Taraxacum officinale	0.833
Typha sp.	0.675
Aster ciliolatus	0.518
Epilobium angustifolium	0.415
Cirsium arvense	0.348
Linnaea borealis	0.332
Fragaria virginiana	0.329
Sonchus arvensis	0.298
Vicia americana	0.253
Lathyrus ochroleucus	0.203
Aralia nudicaulis	0.197
Pyrola asarifolia	0.194
Aster conspicuus	0.170
Solidago canadensis	0.161
Mertensia paniculata	0.108
Cornus canadensis	0.091
Delphinium glaucum	0.057
Goodyera repens	0.050
Galium triflorum	0.026
Fragaria vesca	0.024
Achillea sibirica	0.020
Melilotus officinalis	0.019
Achillea millefolium	0.016
Geum macrophyllum	0.015
Galium boreale	0.008
Matricaria perforata (aka *Tripleurospermum inodorum*)	0.008
Epilobium ciliatum	0.007
Mitella nuda	0.007
Spiraea sp.	0.007
Actaea rubra	0.004
Achillea sp.	0.003
Chenopodium sp.	0.003

Cecil Lake Landslide Relevés - cont'd

Species	Mean cover (%)
Forbs - cont'd	
Crepis tectorum	0.003
Leucantheum sp.	0.003
Sanicula marilandica	0.003
Rumex crispus	0.002
Platanthera dilitata	0.002
Viola sp.	0.002
Hieracium triste	0.001
Senecio eremophilus	0.001
Sonchus arvensis	0.001
Gentianella amarella	0.001
Total	**13.815**
Proportion of all cover	**13.263**
Graminoids	
Calamagrostis canadensis	1.258
Phleum pratense	0.090
Elymus trachycaulus	0.084
Hordeum jubatum	0.064
"Hairy grass"	0.049
Cinna latifolia	0.033
Glyceria sp.	0.021
Bromus inermis ssp. *inermis*	0.019
"Tallwheat grass"	0.018
Agrostis stolonifera	0.007
Bromus ciliatus	0.005
Poa nemoralis ssp. *interior*	0.005
Elymus lanceolatus ssp. lanceolatus	0.005
Koelaria macrantha	0.003
Rush sp.	0.003
Poa pratensis	0.002
"Bigwheat grass"	0.001
Glyceria sp. 2	0.001
Beckmannia syzigachne	0.001
Total	**1.669**
Proportion of all cover	**1.602**

Cecil Lake Landslide Relevés - cont'd

Species	Mean cover (%)
Ferns & Fern allies	
Equisetum arvense	33.500
Total	**33.500**
Proportion of all cover	**32.162**
Bryophytes	
Eurynchiastrum pulchellum	0.567
Brachythecium sp.	0.167
Brachythecium sp. 1	0.067
Brachythecium sp.	0.039
Pohlia nutans	0.037
Dicranum sp.	0.007
Funaria sp.	0.007
Hylocomium splendens	0.003
Marchantia sp.	0.001
"Bottlebrush moss"	0.001
Pleurozium schreberi	0.001
Total	**0.897**
Proportion of all cover	**0.861**
Lichens	
Cladonia sp.	0.007
Nephroma sp.	0.007
Peltigera sp.	0.005
Total	**0.019**
Proportion of all cover	**0.018**

Cecil Lake Undisturbed Relevés - Total mean vegetation cover = 87.022%

Species	Mean cover (%)
<u>Trees</u>	
Picea glauca	22.893
Populus tremuloides	9.107
Betula papyrifera	3.624
Total	**35.624**
Proportion of all cover	**40.937**
<u>Shrubs</u>	
Rosa acicularis	6.908
Viburnum edule	6.762
Shepherdia canadensis	4.388
Alnus viridis ssp. *sinuata*	4.015
Cornus stolonifera	1.922
Amelanchier alnifolia	0.971
Rubus pubescens	0.782
Ribes triste	0.445
Symphoricarpos albus	0.426
Ribes lacustre	0.297
Lonicera dioica	0.279
Salix sp.	0.190
Lonicera involucrata	0.115
Ribes oxyacanthoides	0.035
Rubus idaeus	0.029
Prunus virginiana	0.003
Total	**27.567**
Proportion of all cover	**31.678**
<u>Forbs</u>	
Aralia nudicaulis	6.460
Linnaea borealis	3.137
Aster conspicuus	1.118
Cornus canadensis	1.058
Mertensia paniculata	0.349
Lathyrus ochroleucus	0.146
Clematis sp.	0.133
Mitella nuda	0.108
Disporum trachycarpum (aka *Prosartes trachycarpa*)	0.086

Cecil Lake Undisturbed Relevés - cont'd

Species	Mean cover (%)
Forbs - cont'd	
Orthilia secunda	0.081
Geocaulon lividum	0.060
Aster ciliolatus	0.053
Galium boreale	0.053
Pyrola chlorantha	0.047
Pyrola asarifolia	0.038
Fragaria virginiana	0.033
Fragaria vesca	0.027
Epilobium angustifolium	0.020
Actaea rubra	0.018
Osmorhiza chilensis	0.018
Galium triflorum	0.012
Viola sp.	0.007
Vicia americana	0.005
Delphinium glaucum	0.004
Goodyera oblongifolia	0.003
Listera s p. (aka *Neottia* sp.)	0.003
Maianthemum canadense	0.003
Taraxacum officinale	0.003
Total	**13.083**
Proportion of all cover	**15.034**
Graminoids	
"Fuzzy grass"	2.253
"Thin grass"	0.253
Calamagrostis canadensis	0.240
Total	**2.746**
Proportion of all cover	**3.156**
Ferns & Fern Allies	
Fern sp.	0.020
Equisetum arvense	0.003
Gymnocarpium dryopteris	0.002
Total	**0.025**
Proportion of all cover	**0.029**

Cecil Lake Undisturbed Relevés - cont'd

Species	Mean cover (%)
Bryophytes	
Hylocomium splendens	6.210
Pleurozium schreberi	1.118
Ptilium crista-castrensis	0.323
Rhytidiadelphus triquetrus	0.110
Eurynchiastrum pulcellum	0.087
Brachythecium sp.	0.027
Moss sp.	0.020
Dicranum polysetum	0.014
Dicranum scoparium	0.010
Plagiomnium cuspidatum	0.007
Total	**7.926**
Proportion of all cover	**9.108**
Lichens	
Peltigera polydactylon	0.047
Cladonia sp.	0.003
Total	**0.050**
Proportion of all cover	**0.057**

Hasler Flats Landslide Relevés - Total mean vegetation cover = 81.687%

Species	Mean cover (%)
Trees	
Populus tremuloides	10.758
Populus balsamifera ssp. *balsamifera*	0.300
Betula papyrifera	0.103
Picea glauca	0.063
Total	**11.224**
Proportion of all cover	**13.740**
Shrubs	
Rosa acicularis	10.375
Alnus viridis ssp. *sinuata*	6.308
Rubus idaeus	5.595
Cornus stolonifera	4.900
Symphoricarpos albus	4.145
Viburnum edule	2.423
Lonicera dioica	2.348
Amelanchier alnifolia	1.528
Prunus virginiana	1.320
Lonicera involucrata	0.716
Ribes oxyacanthoides	0.461
Salix sp.	0.434
Rubus pubescens	0.348
Ribes triste	0.335
Salix sp.	0.266
Rubus parviflorus	0.019
Shepherdia canadensis	0.003
Ribes hudsonianum	0.001
Ribes laxiflorum	0.001
Total	**41.526**
Proportion of all cover	**50.836**
Forbs	
Smilacina racemosa	1.623
Aralia nudicaulis	1.403
Aster conspicuus	0.925
Mertensia paniculata	0.281
Petasites frigidus	0.248

Hasler Flats Landslide Relevés - cont'd

Species	Mean cover (%)
Forbs - cont'd	
Vicia americana	0.247
Streptopus amplexifolius	0.232
Viola sp.	0.199
Aster ciliolatus	0.176
Lathyrus ochroleucus	0.176
Galium boreale	0.163
Heracleum lanatum	0.098
Actaea rubra	0.090
Smilacina stellata	0.088
Taraxacum officinale	0.088
Fragaria vesca	0.084
Epilobium angustifolium	0.082
Cornus canadensis	0.074
Mitella nuda	0.068
Galium triflorum	0.065
Pyrola asarifolia	0.061
Thalictrum occidentale	0.054
Fragaria virginiana	0.047
Cirsium arvense	0.046
Spiraea betulifolia	0.040
Maianthemum canadense	0.039
Sonchus arvensis	0.030
Epilobium ciliatum	0.029
Linnaea borealis	0.027
Veratrum viride	0.023
Typha sp.	0.015
Veronica beccabunga	0.010
Cirsium vulgare	0.007
Achillea millefolium	0.005
Cyclamen hederifolium	0.003
Hieracium sabaudum	0.003
Orthilia secunda	0.003
Geum macrophyllum	0.002
Chenopodium capitatum	0.001

Hasler Flats Landslide Relevés - cont'd

Species	Mean cover (%)
Forbs - cont'd	
Boechera stricta	0.001
Plantago major	0.001
"Pondweed"	0.001
Trifolium hybridum	0.001
Total	**6.859**
Proportion of all cover	**8.397**
Graminoids	
Calamagrostis canadensis	1.088
Bromus inermis	1.051
Elymus glaucus ssp. *glaucus*	0.696
Poa palustris	0.038
"Oat grass"	0.019
Bromus ciliatus	0.016
Leymus innovatus	0.012
Elymus trachycaulus ssp. *trachycaulus*	0.010
Carex sp.	0.010
Carex rostrata	0.008
Festuca sp.	0.007
Trisetum cernuum	0.005
"Limp grass"	0.005
"Frothy grass"	0.003
Phleum pratense	0.001
Total	**2.969**
Proportion of all cover	**3.635**
Ferns & Fern allies	
Equisetum arvense	16.417
Equisetum variegatum	0.002
Fern sp.	0.002
Total	**16.421**
Proportion of all cover	**20.102**

Hasler Flats Landslide Relevés - cont'd

Species	Mean cover (%)
Bryophytes	
Pohlia nutans	2.423
Marchantia polymorpha	0.198
Dicranum polysetum	0.062
Syntrichia ruralis	0.004
Plagiomnium cuspidatum	0.004
Leptobryum pyriforme	0.002
Total	**2.693**
Proportion of all cover	**3.297**

Hasler Flats Undisturbed Relevés - Total mean vegetation cover = 100.807%

Species	Mean cover (%)
Trees	
Populus tremuloides	13.580
Populus balsamifera ssp. *balsamifera*	4.335
Picea glauca	0.510
Acer glabrum	0.033
Total	**18.458**
Proportion of all cover	**18.310**
Shrubs	
Alnus viridis ssp. *sinuata*	9.863
Cornus stolonifera	7.358
Viburnum edule	6.983
Symphoricarpos albus	5.378
Rosa acicularis	5.283
Amelanchier alnifolia	2.503
Lonicera dioica	1.976
Prunus virginiana	1.609
Rubus idaeus	1.236
Salix sp. 2	1.026
Ribes oxyacanthoides	0.904
Rubus pubescens	0.551
Ribes triste	0.487
Lonicera involucrata	0.438
Salix sp. 1	0.195
Ribes hudsonianum	0.130
Shepherdia canadensis	0.083
Salix sp. 3	0.033
Rubus parviflorus	0.003
Ribes lacustre	0.001
Total	**46.040**
Proportion of all cover	**45.671**
Forbs	
Aralia nudicaulis	6.856
Heracleum lanatum	3.844
Aster conspicuus	2.556
Mitella nuda	1.397

Hasler Flats Undisturbed Relevés - cont'd

Species	Mean cover (%)
<u>Forbs</u> - cont'd	
Smilacina racemosa	0.653
Actaea rubra	0.580
Thalictrum occidentale	0.516
Smilacina stellata	0.488
Viola sp.	0.415
Lathyrus ochroleucus	0.328
Maianthemum canadense	0.327
Streptopus amplexifolius	0.276
Vicia americana	0.235
Petasites frigidus	0.231
Angelica lucida	0.199
Pyrola asarifolia	0.163
Aster foliaceus	0.131
Mertensia paniculata	0.124
Cirsium arvense	0.123
Aster ciliolatus	0.110
Galium boreale	0.085
Galium triflorum	0.077
Disporum trachycarpum (aka *Prosartes trachycarpa*)	0.074
Fragaria vesca	0.056
Osmorhiza chilensis	0.035
Cornus canadensis	0.034
Orthilia secunda	0.032
Fragaria virginiana	0.027
Taraxacum officinale	0.026
Epilobium ciliatum	0.019
Veronica beccabunga	0.018
Veratrum viride	0.014
Linnaea borealis	0.011
Spiraea betulifolia	0.005
Epilobium angustifolium	0.003
Geum macrophyllum	0.003

Hasler Flats Undisturbed Relevés - cont'd

Species	Mean cover (%)
Forbs - cont'd	
Cyclamen hederifolium	0.002
Achillea millefolium	0.001
Monotropa uniflora	0.001
Total	**20.075**
Proportion of all cover	**19.914**
Graminoids	
Calamagrostis canadensis	0.185
"Mystery grass 2"	0.077
Bromus inermis ssp. *inermis*	0.028
"Hairy grass"	0.024
Carex disperma	0.018
"Mystery grass"	0.017
Bromus ciliatus	0.008
Poa pratensis	0.008
Leymus innovatus	0.005
Elymus lanceolatus ssp. *lanceolatus*	0.005
Phleum pratense	0.003
"Soft grass"	0.003
Unknown grass sp.	0.003
Carex sp.	0.003
Glyceria sp.	0.002
Total	**0.389**
Proportion of all cover	**0.386**
Ferns & Fern allies	
Equisetum arvense	15.625
Equisetum pratense	0.007
Botrychium virginianum	0.002
Total	**15.634**
Proportion of all cover	**15.509**
Bryophytes	
Dicranum polysetum	0.105
Plagiomnium cuspidatum	0.068
Plagiomnium ellipticum	0.041
Total	**0.214**
Proportion of all cover	**0.212**

Appendix 4 Landslide geotypes glossary

The geotype concept was developed in this study to delineate and classify geomorphic diversity as it relates to potential microsite and ecosystem diversity. No explicit guidelines existed for this work; therefore, a novel classification system was designed, using various sources for reference. The geotype definitions draw from several disciplines, including geography, geology, geomorphology, and hydrology. The main feature of the geotype classifications is that they describe identification of features on digital LiDAR imagery (rather than in the field), with the assistance of a digital elevation model.

AP – Apron

A relatively gentle, fanned out slope at the foot of a steeper slope, which is formed by materials from the steeper, upper slope.

BA – Bank

The sides of the channel of a river or creek, as well as the level land adjacent.

BE – Bench

A long, relatively narrow strip of level or gently sloped land with distinctly steeper slopes above and below it.

BL – Blocky site

An accumulation of large (>25 cm) chunks of consolidated, mostly unvegetated substrate.

BS – Sandstone bedrock

Exposed sedimentary rock, identified as sandstone based on background knowledge of local stratigraphy.

CU – Cultivated field

Raft of material broken off and transported from adjacent agricultural field.

DF – Debris flow

A mass of loose mud, sand, soil, rocks, vegetation, and air progressing down a slope. Seepage is present, and a water source is evident.

DP – Depression

A low spot, identified by a darker circle compared to surrounding terrain.

EF – Earthflow

A moving mass of saturated fine-grained materials (eg. clay, fine sand, silt) progressing downslope. Visually distinguished from debris flows by the lack of large materials in the matrix.

FL – Fluvial

A river or creek channel with flowing water evident.

Fl – Flood deposits – seasonal

Fine blanket of material deposited by high water events. Identified by paler colour and flat appearance compared to surrounding terrain.

FP – Floodplain

A relatively flat, extensive area next to a river or creek, where water seasonally rises and covers the terrain. Identified by pools of standing water and shorter, saturation-tolerant vegetation.

GU – Gully

Sharp erosions of soil due to running water, usually on a hill side. Can be tens of metres wide and deep.

HU – Hummocks

Clusters of small knolls or mounds, usually <15 m tall.

PI – Pillar

A tall vertical column of slide material that remains after surrounding material has wasted away.

PL – Plateau

A flat, elevated landform rising distinctly above the surrounding terrain on at least one side.

PO – Pond/wet area

Any depression that contains standing water for any period of time, as visible on drone imagery. There is no lower size or depth limit. Identified in imagery by much darker colour than surrounding terrain and/or presence of cattail (*Typha* spp.).

RA – Raft

Intact pieces of vegetated terrain that have been transported down the landslide. Can consist of surrounding mature forest, grassland, or cultivated field.

RB – Rotational blocks

Blocks of slide material that are tilted due to rotational movement.

RF – Rockfall/topple

A concentrated accumulation of rock that has fallen freely from a cliff face and moved downslope.

RI – Ridge

A chain of eroded hills that form a continuous elevated crest for some distance.

RU – Rubble

A blanket of irregular broken stone fragments on gentle or flat terrain.

SB – Sandbar

A ridge or island of sand in a river or creek channel.

SC – Scarp

A steep, often sparsely vegetated surface at the upper edge or within the landslide, caused by movement of displaced material away from stable material.

SG – Steep grassy slope

A stable slope generally > 35% gradient, covered in grasses and some short shrubs.

SM – Slide matrix

The main portion of the slide material within which other geomorphic features are found. Usually sparsely vegetated regosol.

ST – Steep treed slope

A stable slope generally > 35% gradient, covered in mature trees.

SW – Swale/wrinkle

Gently rolling lateral extensions of material populated by thick shrub growth.

TA – Talus/scree

A sheet of loose rock fragments over a slope.

Appendix 5 Geotype polygons

Beatton River Landslide Geotype polygons

Geotype code	Description	Area (m^2)	Index in Layer
AP	Apron - colluvial	9240	39
BL	Blocky	1447	26
BL	Blocky	4889	0
BL	Blocky	5550	22
BL	Blocky	7630	27
CU	Cultivated field	27.9	15
CU	Cultivated field	197.3	12
DF	Debris flow	2996	11
FL	Fluvial deposit	165.6	18
GU	Gully	370.7	36
HU	Hummocks	43060	34
PO	Pond/wet area	8	54
PO	Pond/wet area	8.8	46
PO	Pond/wet area	9.8	52
PO	Pond/wet area	9.9	47
PO	Pond/wet area	13.4	48
PO	Pond/wet area	21.9	49
PO	Pond/wet area	32.4	53
PO	Pond/wet area	35.7	43
PO	Pond/wet area	60.4	51
PO	Pond/wet area	72.4	42
PO	Pond/wet area	77.2	50
PO	Pond/wet area	91.6	41
PO	Pond/wet area	114.4	45
PO	Pond/wet area	129.9	44
PO	Pond/wet area	132.3	40
RA	Raft	67.7	6
RA	Raft	197.9	30
RA	Raft	518	19
RA	Raft	610	32
RA	Raft	670	16
RA	Raft	718	14
RA	Raft	938	29
RA	Raft	1492	2

Beatton River Landslide Geotype polygons - continued

RA	Raft	2110	13
RA	Raft	2899	17
RA	Raft	3014	28
RA	Raft	3560	23
RA	Raft	9010	7
RB	Rotational block	211.6	9
RB	Rotational block	844	1
RF	Rockfall/topple	859	4
RF	Rockfall/topple	2335	3
RF	Rockfall/topple	3102	31
RF	Rockfall/topple	4519	5
RU	Rubble	364.8	35
RU	Rubble	7440	37
RU	Rubble	11890	21
SB	Sandstone bedrock	802	10
SC	Scarp	439.1	24
SC	Scarp	591	33
SC	Scarp	2312	8
SC	Scarp	3011	20
SC	Scarp	5360	38
SC	Scarp	15960	25

Beatton River Undisturbed Geotype polygons

Geotype code	Description	Area (m^2)	Index in Layer
CU	Cultivated field	11750	0
DP	Depression	9250	3
FP	Floodplain	65000	10
PO	Pond/wet area	606	6
PO	Pond/wet area	340.5	7
PO	Pond/wet area	97.5	8
RU	Rubble	11900	2
SB	Sandbar	9310	1
SG	Steep grassy slope	99100	4
ST	Steep treed slope	30250	5
ST	Steep treed slope	64600	9

Cecil Lake Landslide Geotype polygons

Geotype code	Description	Area (m^2)	Index in Layer
EF	Earth flow	240	13
FL	Fluvial	500	312
FL	Fluvial	1135	319
FL	Fluvial	4354	311
Fl	Flood deposits -seasonal	543	315
Fl	Flood deposits -seasonal	868	314
Fl	Flood deposits -seasonal	1108	313
Fl	Flood deposits -seasonal	4052	19
GU	Gully	222.8	12
HU	Hummocks	2520	0
HU	Hummocks	7790	1
PI	Pillar	135.2	17
PI	Pillar	143.9	18
PO	Pond/wet area	0.7	55
PO	Pond/wet area	0.7	222
PO	Pond/wet area	0.8	58
PO	Pond/wet area	0.8	200
PO	Pond/wet area	0.8	219
PO	Pond/wet area	0.9	50
PO	Pond/wet area	0.9	57
PO	Pond/wet area	0.9	210
PO	Pond/wet area	1	94
PO	Pond/wet area	1	180
PO	Pond/wet area	1	192
PO	Pond/wet area	1	198
PO	Pond/wet area	1	216
PO	Pond/wet area	1	224
PO	Pond/wet area	1.1	166
PO	Pond/wet area	1.1	217
PO	Pond/wet area	1.3	201
PO	Pond/wet area	1.4	177
PO	Pond/wet area	1.6	56
PO	Pond/wet area	1.6	197
PO	Pond/wet area	1.8	129

Cecil Lake Landslide Geotype polygons - continued

Geotype code	Description	Area (m^2)	Index in Layer
PO	Pond/wet area	1.8	227
PO	Pond/wet area	1.9	43
PO	Pond/wet area	2	178
PO	Pond/wet area	2.1	148
PO	Pond/wet area	2.1	175
PO	Pond/wet area	2.2	54
PO	Pond/wet area	2.2	236
PO	Pond/wet area	2.3	52
PO	Pond/wet area	2.4	157
PO	Pond/wet area	2.5	37
PO	Pond/wet area	2.5	220
PO	Pond/wet area	2.5	225
PO	Pond/wet area	2.7	51
PO	Pond/wet area	2.7	114
PO	Pond/wet area	2.7	174
PO	Pond/wet area	2.7	179
PO	Pond/wet area	2.7	223
PO	Pond/wet area	2.8	61
PO	Pond/wet area	2.8	221
PO	Pond/wet area	2.9	205
PO	Pond/wet area	3.1	199
PO	Pond/wet area	3.2	228
PO	Pond/wet area	3.3	38
PO	Pond/wet area	3.4	49
PO	Pond/wet area	3.4	102
PO	Pond/wet area	3.5	30
PO	Pond/wet area	3.5	122
PO	Pond/wet area	3.6	209
PO	Pond/wet area	3.7	176
PO	Pond/wet area	3.9	86
PO	Pond/wet area	3.9	111
PO	Pond/wet area	3.9	133
PO	Pond/wet area	3.9	230
PO	Pond/wet area	4	35

Cecil Lake Landslide Geotype polygons - continued

Geotype code	Description	Area (m^2)	Index in Layer
PO	Pond/wet area	4	208
PO	Pond/wet area	4.1	118
PO	Pond/wet area	4.3	202
PO	Pond/wet area	4.4	110
PO	Pond/wet area	4.4	207
PO	Pond/wet area	4.5	146
PO	Pond/wet area	4.5	161
PO	Pond/wet area	4.6	135
PO	Pond/wet area	4.6	215
PO	Pond/wet area	4.6	218
PO	Pond/wet area	4.7	112
PO	Pond/wet area	4.7	116
PO	Pond/wet area	4.7	181
PO	Pond/wet area	4.8	66
PO	Pond/wet area	4.8	137
PO	Pond/wet area	4.9	143
PO	Pond/wet area	5	41
PO	Pond/wet area	5.1	65
PO	Pond/wet area	5.1	206
PO	Pond/wet area	5.2	36
PO	Pond/wet area	5.2	132
PO	Pond/wet area	5.3	79
PO	Pond/wet area	5.5	282
PO	Pond/wet area	5.6	144
PO	Pond/wet area	5.6	167
PO	Pond/wet area	5.6	170
PO	Pond/wet area	5.7	93
PO	Pond/wet area	5.9	60
PO	Pond/wet area	6	46
PO	Pond/wet area	6	117
PO	Pond/wet area	6	125
PO	Pond/wet area	6.1	140
PO	Pond/wet area	6.2	194
PO	Pond/wet area	6.3	78

Cecil Lake Landslide Geotype polygons - continued

Geotype code	Description	Area (m^2)	Index in Layer
PO	Pond/wet area	6.3	81
PO	Pond/wet area	6.3	171
PO	Pond/wet area	6.5	168
PO	Pond/wet area	6.5	226
PO	Pond/wet area	6.6	203
PO	Pond/wet area	6.6	212
PO	Pond/wet area	6.7	238
PO	Pond/wet area	6.8	136
PO	Pond/wet area	6.9	47
PO	Pond/wet area	7.1	34
PO	Pond/wet area	7.1	204
PO	Pond/wet area	7.2	237
PO	Pond/wet area	7.7	113
PO	Pond/wet area	7.9	53
PO	Pond/wet area	8	97
PO	Pond/wet area	8.1	59
PO	Pond/wet area	8.2	45
PO	Pond/wet area	8.3	300
PO	Pond/wet area	8.5	40
PO	Pond/wet area	8.5	100
PO	Pond/wet area	8.6	274
PO	Pond/wet area	8.7	147
PO	Pond/wet area	8.8	101
PO	Pond/wet area	8.9	134
PO	Pond/wet area	9	44
PO	Pond/wet area	9.1	138
PO	Pond/wet area	9.7	156
PO	Pond/wet area	10.1	301
PO	Pond/wet area	10.4	164
PO	Pond/wet area	10.6	191
PO	Pond/wet area	10.9	235
PO	Pond/wet area	11	119
PO	Pond/wet area	11.2	42
PO	Pond/wet area	11.4	92

Cecil Lake Landslide Geotype polygons - continued

Geotype code	Description	Area (m^2)	Index in Layer
PO	Pond/wet area	11.4	95
PO	Pond/wet area	11.5	303
PO	Pond/wet area	11.6	173
PO	Pond/wet area	11.8	32
PO	Pond/wet area	12	169
PO	Pond/wet area	12.2	77
PO	Pond/wet area	12.3	149
PO	Pond/wet area	12.4	145
PO	Pond/wet area	12.5	29
PO	Pond/wet area	13	162
PO	Pond/wet area	13.5	232
PO	Pond/wet area	13.8	39
PO	Pond/wet area	13.9	172
PO	Pond/wet area	14	70
PO	Pond/wet area	14.6	121
PO	Pond/wet area	14.7	229
PO	Pond/wet area	15.1	165
PO	Pond/wet area	15.2	245
PO	Pond/wet area	15.5	275
PO	Pond/wet area	16	128
PO	Pond/wet area	16.3	67
PO	Pond/wet area	16.8	76
PO	Pond/wet area	16.8	98
PO	Pond/wet area	16.8	182
PO	Pond/wet area	17.2	297
PO	Pond/wet area	17.2	48
PO	Pond/wet area	17.2	163
PO	Pond/wet area	17.4	160
PO	Pond/wet area	17.5	63
PO	Pond/wet area	17.8	159
PO	Pond/wet area	17.9	142
PO	Pond/wet area	17.9	270
PO	Pond/wet area	18.3	83
PO	Pond/wet area	18.5	73

Cecil Lake Landslide Geotype polygons - continued

Geotype code	Description	Area (m^2)	Index in Layer
PO	Pond/wet area	18.9	273
PO	Pond/wet area	19.3	33
PO	Pond/wet area	20.2	247
PO	Pond/wet area	20.4	62
PO	Pond/wet area	20.9	272
PO	Pond/wet area	21.3	103
PO	Pond/wet area	21.5	75
PO	Pond/wet area	22	213
PO	Pond/wet area	22.1	261
PO	Pond/wet area	22.7	260
PO	Pond/wet area	22.8	120
PO	Pond/wet area	23.6	151
PO	Pond/wet area	24.5	107
PO	Pond/wet area	24.6	195
PO	Pond/wet area	24.8	126
PO	Pond/wet area	25.4	87
PO	Pond/wet area	25.6	211
PO	Pond/wet area	26.4	187
PO	Pond/wet area	27.4	233
PO	Pond/wet area	28	105
PO	Pond/wet area	28.7	280
PO	Pond/wet area	29.1	302
PO	Pond/wet area	29.1	234
PO	Pond/wet area	29.3	306
PO	Pond/wet area	29.4	82
PO	Pond/wet area	30.4	256
PO	Pond/wet area	30.7	186
PO	Pond/wet area	31	27
PO	Pond/wet area	31.1	296
PO	Pond/wet area	31.2	71
PO	Pond/wet area	31.2	269
PO	Pond/wet area	32.1	64
PO	Pond/wet area	32.1	255
PO	Pond/wet area	32.4	271

Cecil Lake Landslide Geotype polygons - continued

Geotype code	Description	Area (m^2)	Index in Layer
PO	Pond/wet area	32.7	72
PO	Pond/wet area	32.8	295
PO	Pond/wet area	33.4	239
PO	Pond/wet area	34.5	246
PO	Pond/wet area	34.9	74
PO	Pond/wet area	34.9	281
PO	Pond/wet area	35.5	307
PO	Pond/wet area	35.7	141
PO	Pond/wet area	35.7	183
PO	Pond/wet area	36.1	189
PO	Pond/wet area	36.7	289
PO	Pond/wet area	38.8	299
PO	Pond/wet area	40.4	304
PO	Pond/wet area	40.5	254
PO	Pond/wet area	41.5	80
PO	Pond/wet area	41.9	264
PO	Pond/wet area	42.2	158
PO	Pond/wet area	44.4	104
PO	Pond/wet area	45	109
PO	Pond/wet area	45.6	90
PO	Pond/wet area	46.4	190
PO	Pond/wet area	46.7	196
PO	Pond/wet area	46.8	139
PO	Pond/wet area	47.3	88
PO	Pond/wet area	47.3	294
PO	Pond/wet area	47.6	130
PO	Pond/wet area	48.2	106
PO	Pond/wet area	49.2	279
PO	Pond/wet area	51.8	193
PO	Pond/wet area	52.1	89
PO	Pond/wet area	57.5	131
PO	Pond/wet area	58.4	309
PO	Pond/wet area	61.3	276
PO	Pond/wet area	64.2	286

Cecil Lake Landslide Geotype polygons - continued

Geotype code	Description	Area (m^2)	Index in Layer
PO	Pond/wet area	66.5	278
PO	Pond/wet area	67	115
PO	Pond/wet area	67.2	85
PO	Pond/wet area	67.4	127
PO	Pond/wet area	68.4	99
PO	Pond/wet area	68.6	108
PO	Pond/wet area	69.8	310
PO	Pond/wet area	71.8	288
PO	Pond/wet area	75.9	259
PO	Pond/wet area	77.9	184
PO	Pond/wet area	79.2	305
PO	Pond/wet area	82.6	152
PO	Pond/wet area	88.2	284
PO	Pond/wet area	91.3	185
PO	Pond/wet area	92	231
PO	Pond/wet area	97.1	285
PO	Pond/wet area	98.8	84
PO	Pond/wet area	100.8	96
PO	Pond/wet area	102	287
PO	Pond/wet area	109.8	124
PO	Pond/wet area	110.1	253
PO	Pond/wet area	114.3	68
PO	Pond/wet area	114.3	123
PO	Pond/wet area	115	28
PO	Pond/wet area	117	91
PO	Pond/wet area	118.8	188
PO	Pond/wet area	126.3	250
PO	Pond/wet area	128.9	290
PO	Pond/wet area	129	248
PO	Pond/wet area	129.2	263
PO	Pond/wet area	138.2	298
PO	Pond/wet area	138.7	214
PO	Pond/wet area	142	244
PO	Pond/wet area	147.9	150

Cecil Lake Landslide Geotype polygons - continued

Geotype code	Description	Area (m^2)	Index in Layer
PO	Pond/wet area	179.5	31
PO	Pond/wet area	184.5	243
PO	Pond/wet area	185.8	262
PO	Pond/wet area	189.6	277
PO	Pond/wet area	216.9	293
PO	Pond/wet area	218.4	308
PO	Pond/wet area	219.8	292
PO	Pond/wet area	262.9	155
PO	Pond/wet area	283.4	153
PO	Pond/wet area	287.7	69
PO	Pond/wet area	306.3	283
PO	Pond/wet area	317.7	268
PO	Pond/wet area	318.8	251
PO	Pond/wet area	362.6	154
PO	Pond/wet area	499.9	258
PO	Pond/wet area	539	257
PO	Pond/wet area	636	267
PO	Pond/wet area	695	291
PO	Pond/wet area	797	241
PO	Pond/wet area	1115	252
PO	Pond/wet area	1141	266
PO	Pond/wet area	1424	249
PO	Pond/wet area	2231	240
PO	Pond/wet area	2281	242
PO	Pond/wet area	5790	265
RA	Raft	221.6	21
RA	Raft	390.5	3
RA	Raft	429	22
RA	Raft	1009	2
RA	Raft	1211	14
RA	Raft	1277	5
RA	Raft	1387	7
RA	Raft	2827	322
RA	Raft	4466	8

Cecil Lake Landslide Geotype polygons - continued

Geotype code	Description	Area (m^2)	Index in Layer
RA	Raft	6840	6
RA	Raft	17320	4
RI	Ridge	408.5	317
RI	Ridge	586	15
RI	Ridge	607	323
RI	Ridge	645	25
RI	Ridge	965	24
RI	Ridge	1667	324
RI	Ridge	2117	16
RI	Ridge	2244	23
RI	Ridge	2719	316
RI	Ridge	2786	20
RI	Ridge	5330	26
RI	Ridge	5790	318
SC	Scarp	2218	321
SC	Scarp	9490	320
SW	Swale/wrinkle	617	10
SW	Swale/wrinkle	902	11
SW	Swale/wrinkle	1404	9

Cecil Lake Undisturbed Geotype polygons

Geotype code	Description	Area (m^2)	Index in Layer
BA	Bank	19210	17
CU	Cultivated field	10290	0
CU	Cultivated field	16380	1
FL	Fluvial	177.8	7
FL	Fluvial	314.1	4
FL	Fluvial	4108	2
FP	Floodplain	1014	19
PL	Plateau	29450	12
PL	Plateau	32980	14
PL	Plateau	50700	16
PO	Pond/wet area	28.1	11
PO	Pond/wet area	437.9	10
PO	Pond/wet area	570	8
PO	Pond/wet area	842	9
SG	Steep grassy slope	184300	15
ST	Steep treed slope	13660	13
ST	Steep treed slope	144200	18
TA	Talus/scree	957	6
TA	Talus/scree	17440	3
TA	Talus/scree	35140	5

Hasler Flats Landslide Geotype polygons

Geotype code	Description	Area (m^2)	Index in Layer
PO	Pond/wet area	4.6	36
PO	Pond/wet area	5.2	17
PO	Pond/wet area	6.3	24
PO	Pond/wet area	7.2	33
PO	Pond/wet area	7.6	12
PO	Pond/wet area	9.4	34
PO	Pond/wet area	10.3	23
PO	Pond/wet area	10.4	16
PO	Pond/wet area	10.8	30
PO	Pond/wet area	12.4	28
PO	Pond/wet area	15.1	11
PO	Pond/wet area	17.5	13
PO	Pond/wet area	22.6	22
PO	Pond/wet area	26	15
PO	Pond/wet area	38	21
PO	Pond/wet area	38.1	26
PO	Pond/wet area	39.9	27
PO	Pond/wet area	53.3	14
PO	Pond/wet area	55.5	25
PO	Pond/wet area	58.2	35
PO	Pond/wet area	87.6	29
PO	Pond/wet area	104.3	31
PO	Pond/wet area	105	32
PO	Pond/wet area	111.6	19
PO	Pond/wet area	134.5	18
PO	Pond/wet area	490.3	20
RA	Raft	121	0
RA	Raft	132.9	2
RA	Raft	287.6	1
RA	Raft	366	5
RA	Raft	383.4	4
RA	Raft	486.1	6
RA	Raft	616	3
RA	Raft	4456	38
RI	Ridge	88.5	10
RI	Ridge	142	8
SC	Scarp	173.5	37
SC	Scarp	730	9

Hasler Flats Undisturbed Geotype polygons

Geotype code	Description	Area (m^2)	Index in Layer
BE	Bench	440.2	4
BE	Bench	385.4	9
BE	Bench	335.5	11
BE	Bench	750	14
DP	Depression	428.8	7
DP	Depression	497.9	13
FP	Floodplain	1411	2
FP	Floodplain	1760	3
PL	Plateau	6190	5
PO	Pond/wet area	16	0
PO	Pond/wet area	7.5	1
SC	Scarp	340.3	6
SC	Scarp	661	8
SC	Scarp	363.2	10
SC	Scarp	352.1	12
SC	Scarp	1046	15

Appendix 6 Microtopography elevation summary tables - BEC plots

Beatton River BEC plot elevation summary (n = 28 plots)

Plot	No. of points	Mean elev (m)	Min elev (m)	Mean microsite elev (m)	Min microsite elev (m)	Max microsite elev (m)	Standardised SD (+/-m)	Standardised CV (%)
BE1	49	644.81	643.56	1.25	0	4.88	0.87	69.41
BE2	50	648.03	645.57	2.46	0	4.34	1.21	49.38
BE3	49	640.05	639.29	0.76	0	1.39	0.38	50.09
BE4	49	645.42	642.10	3.33	0	7.97	1.86	55.90
BE5	49	643.06	640.92	2.14	0	6.17	1.14	53.38
BE6	50	644.54	638.61	5.93	0	11.30	3.33	56.20
BE7	50	642.77	641.81	0.95	0	4.47	0.84	88.29
BE8	51	629.00	627.26	1.75	0	3.72	1.04	59.34
BE9	49	594.54	593.78	0.77	0	2.33	0.54	70.87
BE10	47	591.38	591.05	0.33	0	1.88	0.46	139.42
BE11	48	594.38	593.30	1.08	0	2.21	0.60	55.69
BE12	45	591.42	590.68	0.74	0	1.37	0.36	49.12
BE13	48	575.60	575.01	0.58	0	1.81	0.47	80.36
BE14	47	558.80	556.37	2.43	0	5.02	1.34	55.20
BE15	48	577.12	574.13	2.99	0	6.14	1.66	55.73
BE16	47	513.62	512.43	1.19	0	2.09	0.55	46.17
BE17	49	511.33	510.04	1.28	0	4.28	0.92	71.57
BE18	50	489.28	488.87	0.42	0	1.09	0.28	67.53
BE19	49	491.24	490.39	0.85	0	2.33	0.51	60.20
BE20	48	480.94	480.24	0.70	0	1.33	0.32	45.71
BE21	46	475.02	474.59	0.43	0	0.91	0.21	48.15
BE22	50	473.63	473.31	0.32	0	1.02	0.21	64.33
BE23	48	484.04	482.30	1.74	0	3.03	0.73	41.82
BE24	47	546.41	545.57	0.84	0	1.56	0.39	45.74
BE25	49	644.69	643.36	1.34	0	2.90	0.92	69.12
BE26	51	649.54	645.96	3.58	0	7.25	2.04	56.98
BE27	50	645.65	645.17	0.48	0	0.99	0.24	49.85
BE28	49	640.08	636.22	3.86	0	7.58	2.02	52.19

Cecil Lake BEC plot elevation summary (n = 55 plots)

Plot	No. of points	Mean elev (m)	Min elev (m)	Mean microsite elev (m)	Min microsite elev (m)	Max microsite elev (m)	Standardised SD (+/-m)	Standardised CV (%)
CE1	49	670.75	669.25	1.50	0	3.54	0.93	62.48
CE2	46	661.89	660.42	1.47	0	2.44	0.68	46.45
CE3	48	646.31	646.08	0.23	0	0.84	0.19	79.53
CE4	48	647.64	646.23	1.41	0	2.91	0.89	63.39
CE5	46	647.60	645.41	2.19	0	3.63	1.11	50.66
CE6	49	633.92	631.44	2.48	0	4.77	1.38	55.63
CE7	49	629.59	629.17	0.42	0	0.78	0.22	52.74
CE8	50	663.58	661.83	1.75	0	3.04	0.83	47.07
CE9	48	658.92	657.26	1.66	0	2.66	0.73	44.05
CE10	48	663.48	662.53	0.95	0	1.89	0.50	53.23
CE11	46	658.25	656.34	1.91	0	3.76	1.17	61.18
CE12	48	647.26	645.07	2.19	0	4.71	1.27	58.05
CE13	49	655.66	653.88	1.78	0	2.76	0.78	43.95
CE14	48	646.35	645.84	0.51	0	0.73	0.15	29.17
CE15	51	641.23	640.83	0.40	0	0.72	0.18	46.01
CE16	50	642.02	641.23	0.79	0	1.40	0.29	37.31
CE17	46	632.64	631.10	1.54	0	3.39	1.01	65.54
CE18	49	629.66	628.45	1.21	0	1.80	0.47	38.93
CE19	50	626.75	626.00	0.75	0	1.25	0.28	37.60
CE20	51	614.60	614.45	0.15	0	0.54	0.12	74.66
CE21	47	621.29	620.42	0.87	0	1.80	0.45	51.40
CE22	49	652.20	650.59	1.61	0	2.59	0.74	45.71
CE23	50	644.48	643.92	0.56	0	0.88	0.23	41.73
CE24	46	638.38	637.38	1.00	0	1.88	0.54	54.41
CE25	49	636.20	635.57	0.63	0	1.42	0.37	59.57
CE26	50	634.52	634.35	0.17	0	0.87	0.19	112.80
CE27	51	627.78	627.42	0.36	0	1.03	0.25	69.62
CE28	48	616.41	615.01	1.40	0	2.60	0.76	54.15
CE29	48	600.86	600.26	0.60	0	1.64	0.39	65.89
CE30	46	579.89	578.68	1.21	0	2.23	0.57	46.81

Cecil Lake BEC plot elevation summary - cont'd

Plot	No. of points	Mean elev (m)	Min elev (m)	Mean microsite elev (m)	Min microsite elev (m)	Max microsite elev (m)	Standardised SD (+/-m)	Standardised CV (%)
CE31	50	564.17	564.08	0.09	0	0.21	0.04	43.51
CE32	50	568.46	567.72	0.74	0	1.36	0.38	52.25
CE33	50	578.46	577.21	1.25	0	2.55	0.79	63.03
CE34	48	574.87	574.77	0.10	0	0.14	0.02	22.46
CE36	50	640.36	640.28	0.08	0	0.15	0.03	40.87
CE37	48	645.77	644.88	0.89	0	1.88	0.56	62.80
CE38	49	646.10	644.99	1.11	0	1.93	0.54	49.08
CE39	50	641.34	640.08	1.26	0	2.19	0.57	45.74
CE40	48	639.52	638.94	0.58	0	0.88	0.18	30.82
CE41	52	626.70	626.57	0.13	0	0.47	0.09	72.30
CE42	49	611.79	611.35	0.44	0	1.10	0.32	72.94
CE43	50	610.97	610.76	0.21	0	1.23	0.25	118.97
CE44	50	626.78	625.46	1.32	0	2.60	0.84	63.42
CE45	47	588.08	586.01	2.07	0	4.05	1.08	52.10
CE46	52	633.83	633.03	0.80	0	1.45	0.37	45.97
CE47	48	632.16	631.60	0.56	0	1.47	0.43	77.63
CE48	48	616.63	616.02	0.61	0	1.53	0.36	59.16
CE49	47	588.08	586.01	2.07	0	4.05	1.08	52.10
CE50	51	580.27	579.31	0.96	0	1.96	0.62	65.05
CE51	49	578.59	575.91	2.68	0	4.32	1.24	46.13
CE52	49	572.10	571.97	0.13	0	0.54	0.10	72.33
CE53	48	572.15	571.18	0.97	0	1.48	0.34	34.63
CE54	49	570.99	570.47	0.52	0	1.10	0.29	55.65
CE55	49	582.11	581.57	0.54	0	1.14	0.30	55.37
CE56	49	581.21	580.97	0.24	0	0.91	0.21	88.92

Hasler Flats BEC plot elevation summary (n = 29)

Plot	No. of points	Mean elev (m)	Min elev (m)	Mean microsite elev (m)	Min microsite elev (m)	Max microsite elev (m)	Standardised SD (+/-m)	Standardised CV (%)
HA2	41	598.72	598.24	0.48	0	1.24	0.26	54.05
HA3	51	599.56	598.74	0.82	0	1.74	0.47	57.18
HA4	52	601.95	601.33	0.62	0	1.51	0.40	64.81
HA5	62	599.19	598.17	1.01	0	2.55	0.73	71.48
HA6	65	601.10	600.41	0.69	0	1.38	0.29	41.77
HA7	99	609.13	607.97	1.16	0	2.82	0.78	67.24
HA8	74	608.47	606.90	1.57	0	2.48	0.68	43.32
HA9	66	606.40	605.33	1.07	0	1.93	0.56	52.16
HA10	43	606.87	606.50	0.37	0	0.82	0.18	48.51
HA11	48	604.89	604.59	0.30	0	0.55	0.13	42.29
HA12	36	603.79	603.38	0.41	0	1.81	0.38	91.17
HA13	58	604.59	603.77	0.82	0	1.86	0.50	60.75
HA14	74	603.80	603.17	0.63	0	1.03	0.21	34.09
HA15	90	604.29	602.92	1.37	0	3.18	0.84	61.53
HA16	102	601.01	600.00	1.01	0	1.64	0.46	45.51
HA17	79	601.15	599.94	1.21	0	1.81	0.53	44.20
HA18	92	601.81	600.75	1.06	0	1.57	0.34	31.77
HA19	70	599.28	598.76	0.52	0	1.09	0.25	48.00
HA20	69	600.72	600.20	0.52	0	1.09	0.28	53.71
HA21	23	600.69	599.93	0.76	0	1.04	0.23	29.93
HA22	36	598.98	598.74	0.24	0	0.67	0.16	64.27
HA23	29	597.25	597.13	0.12	0	0.22	0.06	51.50
HA24	60	599.87	599.09	0.78	0	1.43	0.33	41.90
HA25	52	600.39	599.83	0.56	0	1.05	0.33	60.08
HA26	42	602.12	600.58	1.54	0	2.34	0.54	35.14
HA27	81	603.00	602.00	1.00	0	1.96	0.54	53.84
HA28	58	607.83	606.65	1.18	0	4.23	1.16	98.30
HA29	112	602.58	601.63	0.95	0	1.90	0.59	62.31
HA30	78	601.15	600.87	0.28	0	0.66	0.17	61.94

Appendix 7 Landslide pond descriptions - Mapsheet 94A

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.0009	**515**	141	10U 635411 6231647	Retrogressive rotational failure	Dormant	Flat area midway down slide	Body
0.002	**154**	61	10U 648617 6262829	Retrogressive rotational failure	Active	In fresh material	Toe
0.0023	**517**	141	10U 635411 6231647	Retrogressive rotational failure	Dormant	Flat area midway down slide	Toe
0.0026	**680**	196	10U 658130 6232188	Retrogressive rotational failure	Dormant	Right next to creek	Toe
0.0026	**52**	71	10U 660889 6229983	Shallow retrogressive failure	Dormant	Just below headscarp (small, intact)	Head
0.0028	**96**	45	10U 645103 6237317	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.003	**51**	71	10U 660889 6229983	Shallow retrogressive failure	Dormant	Below headscarp (small, intact)	Body
0.0032	**616**	173	10U 647595 6263055	Compound failure	Active	Just below new part of headscarp (small, intact)	Head
0.0032	**153**	61	10U 648617 6262829	Retrogressive rotational failure	Active	In fresh material	Toe
0.0034	**497**	136	10U 627698 6232647	Rotational failure	Dormant	Above small scarp (intact), near river	Body
0.0034	**587**	47	10U 640425 6241038	Retrogressive rotational failure	Dormant	Above small scarp (in debris)	Toe
0.0036	**88**	40	10U 648407 6238441	Multi-level rotational failure	Active	Debris apron	Toe
0.0036	**344**	94	10U 586742 6231586	Rotational failure	Dormant	Debris apron	Body
0.004	**280**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Toe	Toe
0.0043	**424**	113	10U 607910 6245770	Rotational failure	Dormant	Below small scarp (in debris)	Head
0.0043	**378**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron near river	Toe
0.0045	**48**	71	10U 660889 6229983	Shallow retrogressive failure	Dormant	Just below headscarp (small, intact)	Head
0.0046	**679**	196	10U 658130 6232188	Retrogressive rotational failure	Dormant	Next to creek	Toe
0.0047	**283**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	At bottom of slide	Toe
0.0049	**82**	40	10U 648407 6238441	Multi-level rotational failure	Active	Debris apron below large scarp (intact)	Toe
0.005	**37**	27	10U 661452 6225535	Compound failure	Dormant	Toe	Toe
0.005	**367**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron near river	Toe
0.0051	**476**	126	10U 631665 6307193	Rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.0054	**456**	122	10U 619929 6209531	Mobile flow	Active	Near top of slide	Body
0.0054	**345**	94	10U 586742 6231586	Rotational failure	Dormant	Debris apron	Body
0.0054	**519**	141	10U 635411 6231647	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Toe
0.0055	**520**	141	10U 635411 6231647	Retrogressive rotational failure	Dormant	Base of slide, next to creek	Toe
0.0056	**87**	41	10U 647664 6238258	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.0056	**522**	140	10U 634447 6231204	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.0059	**514**	141	10U 635411 6231647	Retrogressive rotational failure	Dormant	Flat area midway down slide	Body
0.006	**342**	94	10U 586742 6231586	Rotational failure	Dormant	Debris apron	Body
0.006	**521**	141	10U 635411 6231647	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.006	**678**	196	10U 658130 6232188	Retrogressive rotational failure	Dormant	Next to creek	Toe
0.0061	**457**	122	10U 619929 6209531	Mobile flow	Active	Near top of slide	Body
0.0063	**36**	27	10U 661452 6225535	Compound failure	Dormant	Toe	Toe
0.0064	**90**	43	10U 646755 6238196	Retrogressive rotational failure	Active	Just above small scarp (intact)	Toe
0.0064	**317**	89	10U 583121 6249823	Multi-level rotational failure	Dormant	Debris apron, right at base of large scarp (intact)	Toe
0.0064	**381**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron near river	Toe
0.0066	**100**	46	10U 640572 6238860	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0066	**637**	182	10U 653926 6268718	Retrogressive rotational failure	Dormant	Below/within small scarp (intact), near river	Toe
0.0067	**459**	122	10U 619929 6209531	Mobile flow	Active	Near top of slide (midway across)	Body
0.0068	**506**	139	10U 633271 6230890	Compound failure	Dormant	On hillside in small depression	Body
0.0068	**25**	60	10U 647207 6252566	Rotational failure	Dormant	Debris apron	Toe
0.0068	**4**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Below small scarp (intact)	Toe
0.0068	**50**	71	10U 660889 6229983	Shallow retrogressive failure	Dormant	Just below headscarp (small, intact)	Body
0.0069	**335**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Just above small retrogressive scarp (intact)	Body
0.0069	**767**	226	10U 673115 6239339	Multi-level rotational failure	Dormant	Above small scarp (intact)	Body
0.0069	**393**	104	10U 607196 6251797	Compound failure	Dormant	Debris apron	Body
0.007	**49**	71	10U 660889 6229983	Shallow retrogressive failure	Dormant	Just below headscarp (small, intact)	Body
0.0071	**484**	130	10U 633609 6300494	Compound failure	Dormant	Base of headscarp (small, intact)	Head
0.0072	**379**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron	Body
0.0072	**615**	173	10U 647595 6263055	Compound failure	Active	Just below new part of headscarp (small, intact)	Head
0.0073	**592**	162	10U 639763 6241926	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Head
0.0074	**542**	3	10U 635265 6222327	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0075	**77**	44	10U 646758 6237400	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0075	**369**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron near river	Toe
0.0077	**38**	27	10U 661452 6225535	Compound failure	Dormant	Toe	Toe
0.0077	**377**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron near river	Toe
0.0079	**639**	184	10U 657390 6240045	Rotational failure	Dormant	Debris apron near creek	Toe
0.0079	**584**	161	10U 639518 6240605	Retrogressive rotational failure	Dormant	Below small scarp (intact), near river	Toe
0.0081	**423**	113	10U 607910 6245770	Rotational failure	Dormant	Base of headscarp (large, intact)	Head
0.0081	**530**	144	10U 626024 6221319	Rotational failure	Dormant	Below small scarp (intact)	Body
0.0081	**635**	182	10U 653926 6268718	Retrogressive rotational failure	Dormant	Above small scarp (intact), near river	Toe
0.0081	**410**	108	10U 607734 6248896	Rotational failure	Dormant	Above small scarp (intact)	Body

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.0083	**417**	111	10U 608499 6247479	Compound failure	Dormant	Above small scarp (in debris)	Body
0.0083	**660**	189	10U 654871 6235759	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.0084	**373**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron near river	Toe
0.0086	**737**	15	10U 655647 6215120	Retrogressive rotational failure	Dormant	Next to South side scarp	Body
0.0087	**402**	105	10U 607741 6250210	Compound failure	Dormant	Within small scarp (in debris) below headscarp (small, intact)	Body
0.0087	**16**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Just below headscarp (large, intact)	Head
0.0088	**472**	126	10U 631665 6307193	Rotational failure	Dormant	Below headscarp (small, intact)	Head
0.0089	**659**	189	10U 654871 6235759	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.0089	**341**	94	10U 586742 6231586	Rotational failure	Dormant	Debris apron	Body
0.0089	**430**	114	10U 607383 6243249	Retrogressive rotational failure	Dormant	Near creek/river	Toe
0.009	**421**	112	10U 608153 6247351	Rotational failure	Dormant	Below small scarp (intact)	Toe
0.009	**607**	53	10U 641413 6249461	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Body
0.009	**617**	173	10U 647595 6263055	Compound failure	Active	Below new part of headscarp (small, intact)	Head
0.0091	**498**	136	10U 627698 6232647	Rotational failure	Dormant	Above small scarp (intact), near river	Body
0.0093	**316**	89	10U 583121 6249823	Multi-level rotational failure	Dormant	Debris apron below large scarp (intact)	Toe
0.0093	**586**	47	10U 640425 6241038	Retrogressive rotational failure	Dormant	Next to small scarp (in debris)	Toe
0.0094	**548**	145	10U 634428 6225821	Multi-level rotational failure	Dormant	Debris apron	Toe
0.0095	**47**	71	10U 660889 6229983	Shallow retrogressive failure	Dormant	Just below headscarp (small, intact)	Head
0.0097	**231**	4	10U 637998 6220826	Multi-level rotational failure	Dormant	Debris apron - near creek	Toe
0.0097	**730**	14	10U 655144 6217752	Compound failure	Dormant	Within small scarp (in debris)	Head
0.0098	**346**	94	10U 586742 6231586	Rotational failure	Dormant	Debris apron	Body
0.01	**57**	33	10U 657471 6230119	Compound failure	Dormant	Below small scarp (intact)	Body
0.01	**408**	107	10U 607530 6250024	Compound failure	Dormant	Within headscarp (small, intact) by south sidescarp	Head
0.01	**609**	169	10U 642693 6252730	Retrogressive rotational failure	Dormant	Below headscarp (small, intact)	Head
0.01	**766**	225	10U 672724 6237484	Retrogressive rotational failure	Dormant	Next to small scarp (intact)	Body
0.0101	**20**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Near small scarp (in debris)	Body
0.0101	**471**	126	10U 631665 6307193	Rotational failure	Dormant	Below headscarp (small, intact)	Body
0.0102	**588**	47	10U 640425 6241038	Retrogressive rotational failure	Dormant	Below small scarp (in debris), near river	Toe
0.0102	**254**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Above backtilt	Body
0.0103	**418**	111	10U 608499 6247479	Compound failure	Dormant	Below headscarp (large, intact)	Head
0.0104	**163**	22	10U 668246 6222087	Compound failure	Dormant	Below small scarp (intact)	Body
0.0106	**286**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	At bottom of slide	Toe

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.0106	**602**	165	10U 641712 6246986	Rotational failure	Dormant	Base of headscarp (large, intact)	Body
0.0106	**558**	148	10U 635615 6217619	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Toe
0.0106	**372**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron right by river	Toe
0.0106	**31**	24	10U 662143 6223550	Rotational failure	Dormant	Above small scarp (in debris)	Body
0.011	**404**	105	10U 607741 6250210	Compound failure	Dormant	Above small scarp (in debris)	Body
0.0111	**668**	38	10U 652244 6236095	Retrogressive rotational failure	Dormant	Next to river at bottom of slide	Toe
0.0112	**502**	137	10U 628079 6232225	Multi-level rotational failure	Dormant	Just above small scarp (intact), near river	Body
0.0112	**550**	145	10U 634428 6225821	Multi-level rotational failure	Dormant	Debris apron	Toe
0.0113	**309**	87	10U 580867 6250762	Compound failure	Dormant	Debris apron - below headscarp (small, intact), above large scarp (intact)	Body
0.0114	**399**	105	10U 607741 6250210	Compound failure	Dormant	Within small scarp (in debris) below headscarp (small, intact)	Body
0.0118	**368**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron near river	Toe
0.0118	**677**	196	10U 658130 6232188	Retrogressive rotational failure	Dormant	Below small scarp (in debris), near creek	Toe
0.0118	**749**	214	10U 664400 6210645	Multi-level rotational failure	Dormant	Below headscarp (small, intact)	Head
0.0122	**376**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron	Body
0.0122	**308**	87	10U 580867 6250762	Compound failure	Dormant	Just below headscarp (small, intact), above large scarp (intact)	Body
0.0123	**219**	4	10U 637998 6220826	Multi-level rotational failure	Dormant	Next to small scarp (intact)	Body
0.0124	**478**	127	10U 632593 6304450	Rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.0125	**518**	141	10U 635411 6231647	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Toe
0.0125	**422**	112	10U 608153 6247351	Rotational failure	Dormant	Above small scarp (intact)	Body
0.0127	**429**	114	10U 607383 6243249	Retrogressive rotational failure	Dormant	Near creek/river	Toe
0.0127	**638**	183	10U 652608 6268058	Retrogressive rotational failure	Dormant	Below/within small scarp (intact)	Toe
0.0128	**400**	105	10U 607741 6250210	Compound failure	Dormant	Below small scarp (in debris)	Body
0.0128	**489**	132	10U 633416 6298822	Rotational failure	Dormant	Below small scarp (in debris), near river	Toe
0.0129	**724**	207	10U 655366 6218822	Retrogressive rotational failure	Dormant	Within large scarp (intact)	Toe
0.0129	**289**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	At bottom of slide	Toe
0.0129	**425**	113	10U 607910 6245770	Rotational failure	Dormant	Below small scarp (in debris)	Head
0.0129	**535**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.013	**371**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron near river	Toe
0.013	**509**	140	10U 634447 6231204	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.0134	**403**	105	10U 607741 6250210	Compound failure	Dormant	Below small scarp (in debris)	Body
0.0134	**512**	141	10U 635411 6231647	Retrogressive rotational failure	Dormant	Flat area midway down slide	Body
0.0134	**582**	161	10U 639518 6240605	Retrogressive rotational failure	Dormant	Below small scarp (intact), near river	Toe

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.0135	**99**	46	10U 640572 6238860	Retrogressive rotational failure	Dormant	Just below small scarp (in debris)	Body
0.0136	**566**	153	10U 637499 6223113	Rotational failure	Active	Within small scarp (in debris)	Body
0.0138	**781**	233	10U 682783 6224622	Rotational failure	Dormant	Debris apron below headscarp (large, intact)	Toe
0.014	**723**	207	10U 655366 6218822	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.0141	**80**	40	10U 648407 6238441	Multi-level rotational failure	Active	Debris apron below large scarp (intact)	Toe
0.0141	**18**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Next to small scarp (in debris)	Body
0.0142	**470**	125	10U 622324 6288717	Rotational failure	Dormant	Below headscarp (small, intact)	Body
0.0144	**44**	71	10U 660889 6229983	Shallow retrogressive failure	Dormant	Just below headscarp (small, intact)	Head
0.0144	**445**	121	10U 608754 6224408	Rotational failure	Dormant	Debris apron near river	Toe
0.0144	**191**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.0144	**419**	111	10U 608499 6247479	Compound failure	Dormant	Below headscarp (large, intact)	Head
0.0145	**415**	111	10U 608499 6247479	Compound failure	Dormant	Below small scarp (in debris)	Toe
0.0145	**681**	196	10U 658130 6232188	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Body
0.0145	**613**	172	10U 641260 6254208	Rotational failure	Active	Debris apron below headscarp (large, intact)	Body
0.0147	**365**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron near river	Toe
0.0147	**416**	111	10U 608499 6247479	Compound failure	Dormant	Above small scarp (in debris)	Body
0.0147	**655**	189	10U 654871 6235759	Retrogressive rotational failure	Dormant	Beside creek	Toe
0.0148	**511**	141	10U 635411 6231647	Retrogressive rotational failure	Dormant	Flat area below small scarp (in debris)	Toe
0.0149	**374**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron	Body
0.015	**774**	229	10U 674428 6241207	Retrogressive rotational failure	Dormant	Within headscarp (small, intact)	Head
0.0151	**527**	143	10U 624881 6220596	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.0152	**86**	41	10U 647664 6238258	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.0154	**294**	84	10U 612699 6237705	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Toe
0.0154	**763**	224	10U 673168 6235959	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.0155	**630**	180	10U 634582 6300315	Retrogressive rotational failure	Dormant	Base of small scarp (intact)	Body
0.0157	**329**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Just below small retrogressive scarp (intact)	Body
0.0157	**732**	14	10U 655144 6217752	Compound failure	Dormant	Below small scarp (in debris)	Body
0.0158	**98**	45	10U 645103 6237317	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0159	**631**	180	10U 634582 6300315	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.0162	**526**	143	10U 624881 6220596	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.0163	**204**	14	10U 655144 6217752	Compound failure	Dormant	Below small scarp (in debris)	Body
0.0163	**485**	130	10U 633609 6300494	Compound failure	Dormant	Below small scarp (intact)	Body

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.0166	**557**	148	10U 635615 6217619	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Toe
0.0168	**420**	111	10U 608499 6247479	Compound failure	Dormant	Below small scarp (in debris)	Toe
0.0169	**683**	197	10U 659267 6231807	Rotational failure	Dormant	Debris apron at base of headscarp (large, intact)	Body
0.0169	**682**	196	10U 658130 6232188	Retrogressive rotational failure	Dormant	Just above small scarp (in debris)	Body
0.017	**460**	122	10U 619929 6209531	Mobile flow	Active	Near top of slide (midway across)	Body
0.017	**363**	99	10U 598103 6246815	Rotational failure	Dormant	Within small scarp (in debris)	Body
0.0173	**414**	110	10U 608193 6247991	Compound failure	Dormant	Below headscarp (small, intact)	Body
0.0173	**411**	109	10U 608185 6248414	Compound failure	Dormant	Debris apron near river/creek	Toe
0.0173	**667**	38	10U 652244 6236095	Retrogressive rotational failure	Dormant	Next to river at bottom of slide	Toe
0.0173	**505**	138	10U 632037 6230791	Rotational failure	Dormant	Debris apron	Toe
0.0174	**282**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	At bottom of slide	Toe
0.0174	**664**	191	10U 649843 6238652	Rotational failure	Dormant	Within headscarp (large, intact)	Head
0.0174	**326**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Above small retrogressive scarp (intact)	Body
0.0174	**375**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron right by river	Toe
0.0175	**562**	151	10U 637222 6220172	Compound failure	Dormant	Middle of slide	Body
0.0176	**362**	99	10U 598103 6246815	Rotational failure	Dormant	Within small scarp (in debris)	Body
0.0177	**718**	204	10U 654675 6219635	Retrogressive rotational failure	Dormant	Below headscarp (small, intact)	Head
0.0181	**742**	212	10U 656103 6216700	Retrogressive rotational failure	Dormant	Bottom of slide, near creek	Toe
0.0182	**30**	24	10U 662143 6223550	Rotational failure	Dormant	Above small scarp (intact)	Body
0.0184	**328**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Within small retrogressive scarp (intact)	Body
0.0187	**382**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron near river	Toe
0.0187	**641**	185	10U 656213 6239712	Rotational failure	Dormant	Base of headscarp (large, intact)	Body
0.0188	**176**	20	10U 679534 6219946	Rotational failure	Dormant	Below headscarp (large, intact)	Body
0.0189	**392**	103	10U 589643 6282999	Rotational failure	Dormant	Debris apron	Body
0.019	**474**	126	10U 631665 6307193	Rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.0191	**531**	144	10U 626024 6221319	Rotational failure	Dormant	Above small scarp (intact)	Body
0.0191	**263**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Below headscarp (large, intact), near west sidescarp	Body
0.0194	**748**	214	10U 664400 6210645	Multi-level rotational failure	Dormant	Above small scarp (in debris)	Body
0.0194	**440**	116	10U 606417 6242052	Rotational failure	Dormant	Debris apron	Toe
0.0194	**302**	85	10U 612971 6237140	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Toe
0.0195	**315**	89	10U 583121 6249823	Multi-level rotational failure	Dormant	Debris apron below large scarp (intact)	Toe
0.0196	**469**	125	10U 622324 6288717	Rotational failure	Dormant	Halfway down slide	Body

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.0198	**213**	9	10U 639115 6218246	Rotational failure	Dormant	Below small scarp (intact)	Toe
0.02	**634**	182	10U 653926 6268718	Retrogressive rotational failure	Dormant	Above small scarp (intact), near river	Toe
0.0201	**725**	207	10U 655366 6218822	Retrogressive rotational failure	Dormant	Within large scarp (intact)	Toe
0.0201	**481**	127	10U 632593 6304450	Rotational failure	Dormant	Below headscarp (small, intact)	Body
0.0204	**686**	198	10U 660187 6227739	Retrogressive rotational failure	Dormant	Below small scarp (intact), right by river	Toe
0.0204	**398**	105	10U 607741 6250210	Compound failure	Dormant	At base of headscarp (large, intact)	Head
0.0204	**327**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Above small retrogressive scarp (intact)	Body
0.0206	**447**	122	10U 619929 6209531	Mobile flow	Active	Near base of slide	Body
0.0208	**473**	126	10U 631665 6307193	Rotational failure	Dormant	Below headscarp (small, intact)	Head
0.0208	**370**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron near river	Toe
0.021	**644**	186	10U 655856 6238250	Retrogressive rotational failure	Dormant	Below large headscarp (intact)	Head
0.021	**483**	129	10U 633999 6301639	Rotational failure	Dormant	Just below headscarp (small) and above small scarp (both intact)	Body
0.0212	**722**	207	10U 655366 6218822	Retrogressive rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.0212	**250**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Above backtilt	Body
0.0215	**360**	97	10U 597665 6245826	Rotational failure	Dormant	On level portion of headscarp (large, intact)	Head
0.0216	**409**	108	10U 607734 6248896	Rotational failure	Dormant	Next to small scarp (intact)	Body
0.0221	**490**	132	10U 633416 6298822	Rotational failure	Dormant	Below small scarp (in debris), near river	Toe
0.0222	**126**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Below small scarp (in debris)	Body
0.0223	**23**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Below small scarp (in debris)	Toe
0.0224	**606**	53	10U 641413 6249461	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Body
0.0224	**338**	93	10U 585645 6232574	Rotational failure	Active	Bottom of slide, by river	Toe
0.0225	**593**	74	10U 636436 6241818	Compound failure	Dormant	Below headscarp (large, intact)	Body
0.0226	**649**	187	10U 655524 6236858	Multi-level rotational failure	Dormant	Halfway down slide, by south sidescarp	Body
0.0226	**661**	190	10U 653976 6235516	Retrogressive rotational failure	Dormant	Apron at top of slide below headscarp (large, intact)	Head
0.0226	**278**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Toe	Toe
0.0233	**21**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Below headscarp (large, intact)	Body
0.0235	**500**	136	10U 627698 6232647	Rotational failure	Dormant	Above small scarp (intact), near river	Body
0.0235	**687**	199	10U 659140 6227440	Multi-level rotational failure	Dormant	Below small scarp (in debris)	Toe
0.0237	**380**	100	10U 598414 6248139	Compound failure	Dormant	Debris apron	Body
0.024	**395**	105	10U 607741 6250210	Compound failure	Dormant	Base of headscarp (small, intact)	Head
0.024	**84**	41	10U 647664 6238258	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.0241	**160**	63	10U 656420 6272207	Rotational failure	Dormant	Just below small scarp (in debris)	Body

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.0241	**696**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Above small scarp (in debris)	Head
0.0242	**701**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Above small scarp (in debris)	Body
0.0243	**764**	224	10U 673168 6235959	Retrogressive rotational failure	Dormant	Within/below headscarp (small, intact)	Head
0.0246	**394**	105	10U 607741 6250210	Compound failure	Dormant	Small scarp (in debris)	Body
0.0246	**464**	122	10U 619929 6209531	Mobile flow	Active	Top of slide along west sidescarp	Head
0.0251	**325**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Above small retrogressive scarp (intact)	Body
0.0253	**790**	20	10U 679534 6219946	Rotational failure	Dormant	Base of headscarp (large, intact)	Body
0.0254	**614**	172	10U 641260 6254208	Rotational failure	Active	Debris apron at base of new headscarp (large, intact)	Head
0.0254	**340**	94	10U 586742 6231586	Rotational failure	Dormant	Debris apron	Body
0.0255	**300**	85	10U 612971 6237140	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Toe
0.0255	**32**	25	10U 661743 6223747	Compound failure	Dormant	Below small scarp (intact)	Body
0.0257	**386**	103	10U 589643 6282999	Rotational failure	Dormant	Debris apron	Body
0.0258	**264**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0259	**758**	219	10U 672065 6223288	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.0264	**773**	228	10U 676317 6244415	Retrogressive rotational failure	Dormant	Within headscarp (small, intact)	Head
0.0265	**529**	144	10U 626024 6221319	Rotational failure	Dormant	Just above small scarp (intact)	Toe
0.0266	**260**	3	10U 635265 6222327	Retrogressive rotational failure	Abandoned	Above small scarp, below headscarp (large, intact)	Head
0.0267	**523**	140	10U 634447 6231204	Retrogressive rotational failure	Dormant	Right above small scarp (intact)	Body
0.0268	**40**	29	10U 659264 6228605	Rotational failure	Abandoned	Debris apron	Toe
0.0271	**656**	189	10U 654871 6235759	Retrogressive rotational failure	Dormant	Beside creek	Toe
0.0273	**675**	195	10U 655685 6231888	Rotational failure	Dormant	Above small scarp (intact)	Body
0.0274	**303**	85	10U 612971 6237140	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Toe
0.0276	**706**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Next to small scarp (in debris)	Body
0.0276	**102**	41	10U 647664 6238258	Retrogressive rotational failure	Dormant	Just below large scarp (intact)	Toe
0.0277	**274**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	At base of large scarp (intact)	Body
0.0279	**56**	33	10U 657471 6230119	Compound failure	Dormant	Below large scarp (intact)	Toe
0.0281	**689**	200	10U 658361 6228323	Multi-level rotational failure	Dormant	Below small scarp (in debris)	Toe
0.0283	**544**	3	10U 635265 6222327	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0285	**662**	190	10U 653976 6235516	Retrogressive rotational failure	Dormant	Apron at top of slide below headscarp (large, intact)	Head
0.0285	**780**	232	10U 681946 6227934	Retrogressive rotational failure	Dormant	Base of slide next to creek	Toe
0.0286	**756**	217	10U 662941 6224282	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.0287	**413**	110	10U 608193 6247991	Compound failure	Dormant	Below small scarp (in debris)	Body

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.0288	**589**	47	10U 640425 6241038	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0288	**784**	235	10U 685591 6226178	Multi-level rotational failure	Dormant	Base of large scarp (intact), in debris apron	Toe
0.0288	**389**	103	10U 589643 6282999	Rotational failure	Dormant	Debris apron near river	Toe
0.0289	**396**	105	10U 607741 6250210	Compound failure	Dormant	Within small scarp (in debris)	Body
0.0289	**125**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Above small scarp (in debris)	Body
0.0291	**230**	4	10U 637998 6220826	Multi-level rotational failure	Dormant	Debris apron - near creek	Toe
0.0296	**426**	114	10U 607383 6243249	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Head
0.0296	**757**	218	10U 663556 6223926	Retrogressive rotational failure	Dormant	Below headscarp (large, intact), above small scarp (intact)	Body
0.0299	**597**	163	10U 640344 6243435	Multi-level rotational failure	Dormant	Below headscarp (large, intact)	Head
0.0302	**571**	152	10U 637789 6222601	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.0304	**524**	142	10U 630879 6227122	Retrogressive rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.0307	**229**	4	10U 637998 6220826	Multi-level rotational failure	Dormant	Debris apron	Toe
0.0307	**716**	204	10U 654675 6219635	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.0307	**58**	33	10U 657471 6230119	Compound failure	Dormant	Above small scarp (intact)	Body
0.0309	**705**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0309	**772**	227	10U 673362 6239998	Retrogressive rotational failure	Dormant	Within headscarp (small, intact)	Head
0.031	**499**	136	10U 627698 6232647	Rotational failure	Dormant	Above small scarp (intact), near river	Body
0.0316	**646**	186	10U 655856 6238250	Retrogressive rotational failure	Dormant	Base of small scarp (in debris), by creek	Toe
0.0318	**698**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0319	**359**	97	10U 597665 6245826	Rotational failure	Dormant	Within small scarp (in debris)	Body
0.0321	**625**	178	10U 637541 6284374	Retrogressive rotational failure	Dormant	Above small scarp (in debris)	Body
0.0321	**727**	208	10U 655089 6218426	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.0321	**322**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Just above small retrogressive scarp (intact)	Body
0.0322	**603**	166	10U 641866 6247606	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.0327	**491**	133	10U 633983 6299243	Rotational failure	Dormant	Debris apron	Toe
0.033	**777**	230	10U 673848 6240822	Rotational failure	Dormant	Below headscarp (small, intact)	Body
0.0331	**2**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Below small scarp (intact)	Toe
0.0334	**406**	107	10U 607530 6250024	Compound failure	Dormant	Below headscarp (small, intact)	Body
0.0334	**401**	105	10U 607741 6250210	Compound failure	Dormant	Within small scarp (in debris)	Body
0.0335	**465**	122	10U 619929 6209531	Mobile flow	Active	Top of slide along west sidescarp	Head
0.0338	**124**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Below headscarp (large, intact)	Body
0.0338	**719**	205	10U 653493 6218800	Multi-level rotational failure	Dormant	Base of headscarp (small, intact)	Head

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.034	**190**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.0343	**292**	84	10U 612699 6237705	Retrogressive rotational failure	Dormant	Just below small scarp (intact)	Body
0.0346	**731**	14	10U 655144 6217752	Compound failure	Dormant	Below small scarp (in debris)	Body
0.0347	**436**	115	10U 606706 6242217	Rotational failure	Dormant	Near creek/river	Toe
0.035	**275**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	At base of large scarp (intact)	Body
0.0351	**525**	142	10U 630879 6227122	Retrogressive rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.0354	**741**	212	10U 656103 6216700	Retrogressive rotational failure	Dormant	Bottom of slide, by creek	Toe
0.0356	**227**	4	10U 637998 6220826	Multi-level rotational failure	Dormant	Debris apron	Toe
0.0356	**455**	122	10U 619929 6209531	Mobile flow	Active	Near top of slide	Body
0.0357	**754**	215	10U 664950 6210554	Multi-level rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.0357	**17**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Just above small scarp (in debris)	Body
0.0361	**738**	15	10U 655647 6215120	Retrogressive rotational failure	Dormant	Above/within small scarp (in debris)	Body
0.0363	**692**	201	10U 655452 6222977	Retrogressive rotational failure	Dormant	Bottom of slide	Toe
0.0365	**279**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Toe	Toe
0.0367	**513**	141	10U 635411 6231647	Retrogressive rotational failure	Dormant	Flat area midway down slide	Toe
0.0375	**510**	140	10U 634447 6231204	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0375	**676**	195	10U 655685 6231888	Rotational failure	Dormant	Below headscarp (small, intact)	Body
0.0379	**621**	176	10U 638057 6276259	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Head
0.0382	**707**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0384	**488**	132	10U 633416 6298822	Rotational failure	Dormant	Below large scarp (intact), near river	Toe
0.0384	**541**	3	10U 635265 6222327	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0385	**313**	89	10U 583121 6249823	Multi-level rotational failure	Dormant	Debris apron next to river	Toe
0.0385	**46**	71	10U 660889 6229983	Shallow retrogressive failure	Dormant	Below headscarp (small, intact)	Body
0.0387	**181**	17	10U 672017 6212944	Rotational failure	Dormant	Below small scarp (intact)	Body
0.0389	**549**	145	10U 634428 6225821	Multi-level rotational failure	Dormant	Debris apron	Toe
0.0389	**717**	204	10U 654675 6219635	Retrogressive rotational failure	Dormant	Above small scarp (intact), below headscarp (small, intact)	Head
0.0397	**650**	188	10U 655498 6235114	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Head
0.0398	**585**	47	10U 640425 6241038	Retrogressive rotational failure	Dormant	Halfway down slide	Body
0.04	**583**	161	10U 639518 6240605	Retrogressive rotational failure	Dormant	Below small scarp (intact), near river	Toe
0.0402	**605**	53	10U 641413 6249461	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Body
0.0405	**3**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Below small scarp (intact)	Toe
0.0405	**441**	117	10U 605801 6243804	Rotational failure	Dormant	Below headscarp (large, intact), above small scarp (in debris)	Body

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.0406	**307**	87	10U 580867 6250762	Compound failure	Dormant	Just below headscarp (small, intact)	Head
0.0406	**201**	13	10U 656024 6217434	Compound failure	Dormant	Below small scarp (in debris)	Body
0.0409	**736**	210	10U 655750 6214657	Rotational failure	Dormant	Below headscarp (small, intact), next to north sidescarp	Head
0.0414	**60**	36	10U 658291 6231793	Retrogressive rotational failure	Dormant	Toe	Toe
0.0414	**22**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Below small scarp (in debris)	Toe
0.0415	**129**	64	10U 641133 6264748	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Head
0.0417	**688**	200	10U 658361 6228323	Multi-level rotational failure	Dormant	Above small scarp (intact)	Body
0.0418	**598**	164	10U 640997 6242676	Rotational failure	Dormant	Above small scarp (in debris)	Body
0.0419	**284**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	At bottom of slide	Toe
0.0419	**570**	152	10U 637789 6222601	Retrogressive rotational failure	Dormant	Base of small scarp (intact)	Body
0.0421	**336**	92	10U 584580 6235119	Rotational failure	Dormant	Within small scarp (in debris)	Body
0.0422	**788**	236	10U 675638 6221766	Multi-level rotational failure	Dormant	Debris apron at base of slide	Toe
0.0425	**101**	45	10U 645103 6237317	Retrogressive rotational failure	Dormant	Just above small scarp (intact)	Body
0.0427	**504**	137	10U 628079 6232225	Multi-level rotational failure	Dormant	Above small scarp (intact), near east sidescarp	Body
0.0428	**199**	12	10U 656272 6218290	Rotational failure	Dormant	Above small scarp (in debris)	Body
0.0429	**306**	87	10U 580867 6250762	Compound failure	Dormant	Just below headscarp (small, intact)	Head
0.0435	**81**	40	10U 648407 6238441	Multi-level rotational failure	Active	Debris apron below large scarp (intact)	Toe
0.0435	**568**	154	10U 636856 6222710	Compound failure	Dormant	Above small scarp (intact), near east sidescarp	Body
0.0436	**387**	103	10U 589643 6282999	Rotational failure	Dormant	Debris apron right by river	Toe
0.0437	**141**	74	10U 636436 6241818	Compound failure	Dormant	Below headscarp (large, intact)	Body
0.0438	**626**	178	10U 637541 6284374	Retrogressive rotational failure	Dormant	Below small scarp (intact), near east sidescarp	Toe
0.0439	**39**	28	10U 660309 6228226	Compound failure	Dormant	Toe	Toe
0.044	**543**	3	10U 635265 6222327	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0442	**35**	27	10U 661452 6225535	Compound failure	Dormant	Body	Body
0.0443	**85**	41	10U 647664 6238258	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.0446	**785**	235	10U 685591 6226178	Multi-level rotational failure	Dormant	Base of large scarp (intact), in debris apron	Toe
0.0447	**791**	238	10U 679053 6219617	Rotational failure	Dormant	Debris apron	Body
0.0451	**492**	133	10U 633983 6299243	Rotational failure	Dormant	Debris apron	Toe
0.0452	**397**	105	10U 607741 6250210	Compound failure	Dormant	Debris apron near river	Toe
0.0452	**712**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Next to small scarp (in debris)	Head
0.0456	**461**	122	10U 619929 6209531	Mobile flow	Active	Top of slide along west sidescarp	Head
0.0456	**182**	17	10U 672017 6212944	Rotational failure	Dormant	Below small scarp (intact)	Body

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.0457	**721**	207	10U 655366 6218822	Retrogressive rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.0458	**159**	63	10U 656420 6272207	Rotational failure	Dormant	Below small scarp (in debris)	Toe
0.0462	**740**	211	10U 655836 6216390	Retrogressive rotational failure	Dormant	Bottom of slide, near west sidescarp	Toe
0.0462	**708**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0463	**192**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.0465	**453**	122	10U 619929 6209531	Mobile flow	Active	Near base of slide	Body
0.0466	**312**	88	10U 582374 6251325	Rotational failure	Dormant	Within debris of small scarp (in debris)	Toe
0.047	**281**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Toe	Toe
0.0472	**223**	5	10U 637848 6220421	Retrogressive rotational failure	Active	Just above small scarp (in debris)	Body
0.0473	**162**	22	10U 668246 6222087	Compound failure	Dormant	Above small scarp (intact)	Body
0.0473	**768**	227	10U 673362 6239998	Retrogressive rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.0473	**390**	103	10U 589643 6282999	Rotational failure	Dormant	Debris apron near river	Toe
0.0474	**700**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0474	**152**	61	10U 648617 6262829	Retrogressive rotational failure	Active	In fresh material below small scarp (in debris)	Toe
0.0474	**553**	146	10U 635074 6225748	Multi-level rotational failure	Dormant	Above small scarp (in debris)	Head
0.0476	**792**	89	10U 583121 6249823	Multi-level rotational failure	Dormant	Debris apron next to river	Toe
0.0478	**252**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Above backtilt	Body
0.048	**622**	176	10U 638057 6276259	Retrogressive rotational failure	Dormant	Within small scarp (intact)	Body
0.0485	**188**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.0488	**442**	118	10U 605649 6243226	Rotational failure	Dormant	Just above small scarp (intact)	Body
0.0491	**388**	103	10U 589643 6282999	Rotational failure	Dormant	Debris apron	Body
0.0494	**268**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Above large scarp (intact), below small scarp (in debris)	Body
0.0498	**486**	130	10U 633609 6300494	Compound failure	Dormant	Within small scarp (intact)	Body
0.0498	**225**	5	10U 637848 6220421	Retrogressive rotational failure	Active	Below headscarp (small, intact)	Head
0.0498	**534**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0499	**711**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below headscarp (small, intact)	Head
0.0499	**454**	122	10U 619929 6209531	Mobile flow	Active	Near centre of slide	Body
0.05	**26**	60	10U 647207 6252566	Rotational failure	Dormant	Debris apron	Toe
0.0501	**120**	54	10U 642211 6250812	Rotational failure	Dormant	In debris apron at base of headscarp (large, intact)	Body
0.0506	**651**	188	10U 655498 6235114	Retrogressive rotational failure	Dormant	Near creek	Toe
0.0507	**195**	11	10U 656217 6219302	Retrogressive rotational failure	Active	Just below small scarp (in debris)	Body
0.0508	**361**	98	10U 598431 6246464	Compound failure	Dormant	Just below headscarp (small, intact)	Head

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.0508	**673**	194	10U 656093 6232341	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Body
0.0512	**431**	114	10U 607383 6243249	Retrogressive rotational failure	Dormant	Below large scarp (intact)	Body
0.0513	**265**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Above large scarp (intact)	Body
0.0516	**769**	227	10U 673362 6239998	Retrogressive rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.0522	**205**	14	10U 655144 6217752	Compound failure	Dormant	Above small scarp (in debris)	Body
0.0525	**726**	208	10U 655089 6218426	Retrogressive rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.0528	**149**	76	10U 633480 6244644	Retrogressive rotational failure	Dormant	Just above small scarp (in debris)	Body
0.0528	**775**	230	10U 673848 6240822	Rotational failure	Dormant	Within headscarp (small, intact)	Head
0.0529	**729**	14	10U 655144 6217752	Compound failure	Dormant	Above small scarp (in debris)	Body
0.053	**564**	4	10U 637998 6220826	Multi-level rotational failure	Dormant	Base of small scarp (intact)	Body
0.0531	**135**	70	10U 631913 6311160	Retrogressive rotational failure	Dormant	Below headscarp (small, intact)	Body
0.0533	**269**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	At base of headscarp (large, intact)	Body
0.0535	**89**	43	10U 646755 6238196	Retrogressive rotational failure	Active	Just below small scarp (intact)	Body
0.0539	**463**	122	10U 619929 6209531	Mobile flow	Active	Top of slide near west sidescarp	Head
0.0539	**507**	139	10U 633271 6230890	Compound failure	Dormant	Above small scarp (in debris)	Body
0.054	**528**	143	10U 624881 6220596	Retrogressive rotational failure	Dormant	Below small scarp (intact), near north sidescarp	Toe
0.0547	**118**	53	10U 641413 6249461	Retrogressive rotational failure	Dormant	Just below headscarp (large, intact)	Body
0.0547	**285**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	At bottom of slide	Toe
0.0548	**83**	40	10U 648407 6238441	Multi-level rotational failure	Active	Just below large scarp (intact)	Body
0.0551	**540**	3	10U 635265 6222327	Retrogressive rotational failure	Dormant	Above small scarp (in debris)	Body
0.0551	**443**	119	10U 599356 6238157	Multi-level rotational failure	Dormant	Base of large scarp (intact)	Body
0.0552	**439**	116	10U 606417 6242052	Rotational failure	Dormant	Debris apron	Toe
0.056	**508**	140	10U 634447 6231204	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.0563	**311**	88	10U 582374 6251325	Rotational failure	Dormant	Just below small scarp (in debris)	Toe
0.0565	**642**	186	10U 655856 6238250	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Head
0.0565	**734**	210	10U 655750 6214657	Rotational failure	Dormant	Just above small scarp (in debris)	Body
0.0567	**697**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Above small scarp (in debris)	Head
0.0569	**458**	122	10U 619929 6209531	Mobile flow	Active	Near top of slide	Body
0.0571	**314**	89	10U 583121 6249823	Multi-level rotational failure	Dormant	Debris apron next to river	Toe
0.0576	**364**	99	10U 598103 6246815	Rotational failure	Dormant	At base of headscarp (large, intact), by sidescarp	Head
0.0578	**293**	84	10U 612699 6237705	Retrogressive rotational failure	Dormant	Within small scarp (in debris)	Body
0.0579	**95**	45	10U 645103 6237317	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.0587	**674**	194	10U 656093 6232341	Retrogressive rotational failure	Dormant	Just below small scarp (in debris)	Body
0.0588	**451**	122	10U 619929 6209531	Mobile flow	Active	Centre of slide	Body
0.0589	**645**	186	10U 655856 6238250	Retrogressive rotational failure	Dormant	Below large headscarp (intact)	Head
0.0593	**337**	92	10U 584580 6235119	Rotational failure	Dormant	Just below headscarp (large, intact)	Body
0.0594	**53**	71	10U 660889 6229983	Shallow retrogressive failure	Dormant	Just below small scarp (intact)	Toe
0.0598	**733**	209	10U 655227 6215278	Retrogressive rotational failure	Dormant	Base of small scarp (in debris)	Body
0.06	**220**	4	10U 637998 6220826	Multi-level rotational failure	Dormant	Below small scarp (intact)	Body
0.0603	**632**	181	10U 654030 6269428	Rotational failure	Dormant	Bottom of slide	Toe
0.0608	**298**	85	10U 612971 6237140	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Toe
0.061	**41**	31	10U 657777 6229034	Compound failure	Dormant	Below small scarp (intact)	Toe
0.0611	**143**	75	10U 633471 6243680	Retrogressive rotational failure	Active	Just below small scarp (intact)	Body
0.0621	**466**	85	10U 612971 6237140	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0622	**79**	40	10U 648407 6238441	Multi-level rotational failure	Active	Debris apron	Toe
0.0628	**702**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Above small scarp (in debris)	Body
0.0629	**782**	234	10U 684625 6226289	Retrogressive rotational failure	Dormant	Below/within small scarp (intact)	Body
0.0633	**448**	122	10U 619929 6209531	Mobile flow	Active	Near base of slide by west sidescarp	Body
0.0644	**55**	72	10U 659938 6229825	Retrogressive rotational failure	Dormant	Near base of headscarp (large), above small scarp (in debris)	Body
0.065	**339**	94	10U 586742 6231586	Rotational failure	Dormant	At base of headscarp (large, intact)	Head
0.0651	**728**	14	10U 655144 6217752	Compound failure	Dormant	Bottom of slide, near north sidescarp	Toe
0.0651	**759**	220	10U 673724 6221673	Multi-level rotational failure	Dormant	Above small scarp (intact)	Body
0.0656	**434**	114	10U 607383 6243249	Retrogressive rotational failure	Dormant	Next to south sidescarp	Body
0.0658	**383**	101	10U 598608 6247865	Compound failure	Dormant	Debris apron below headscarp (small, intact)	Body
0.066	**624**	177	10U 638157 6284497	Rotational failure	Dormant	Base of small scarp (intact)	Toe
0.0662	**575**	157	10U 643272 6221186	Retrogressive rotational failure	Dormant	Below large scarp (intact)	Head
0.0665	**310**	87	10U 580867 6250762	Compound failure	Dormant	Debris apron, just above large scarp (small, intact)	Body
0.0667	**119**	53	10U 641413 6249461	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Body
0.0669	**765**	222	10U 672726 6234762	Retrogressive rotational failure	Dormant	Next to creek	Toe
0.0673	**34**	27	10U 661452 6225535	Compound failure	Dormant	Body	Body
0.0679	**45**	71	10U 660889 6229983	Shallow retrogressive failure	Dormant	Below headscarp (small, intact)	Body
0.068	**217**	4	10U 637998 6220826	Multi-level rotational failure	Dormant	Below headscarp (large, intact)	Head
0.0686	**384**	102	10U 596707 6242884	Rotational failure	Dormant	Above small scarp (in debris)	Body
0.069	**222**	5	10U 637848 6220421	Retrogressive rotational failure	Active	Below headscarp (small, intact)	Head

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.0691	**24**	59	10U 646337 6252998	Retrogressive rotational failure	Dormant	Toe	Toe
0.0702	**196**	11	10U 656217 6219302	Retrogressive rotational failure	Active	Just below small scarp (in debris)	Body
0.0705	**743**	212	10U 656103 6216700	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.0707	**301**	85	10U 612971 6237140	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Toe
0.0709	**559**	149	10U 635558 6216354	Rotational failure	Dormant	Within small scarp (in debris)	Body
0.0711	**180**	17	10U 672017 6212944	Rotational failure	Dormant	Within headscarp (small, intact)	Head
0.0721	**324**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Just above small retrogressive scarp (intact)	Body
0.0723	**569**	152	10U 637789 6222601	Retrogressive rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.0726	**435**	115	10U 606706 6242217	Rotational failure	Dormant	Above small scarp (intact)	Body
0.0732	**27**	60	10U 647207 6252566	Rotational failure	Dormant	Debris apron	Toe
0.0733	**714**	202	10U 654150 6220760	Retrogressive rotational failure	Dormant	Within small scarp (intact)	Toe
0.0739	**108**	48	10U 641990 6244350	Rotational failure	Dormant	At base of headscarp (large, intact)	Head
0.0747	**33**	26	10U 661704 6225287	Shallow retrogressive failure	Dormant	In debris apron	Toe
0.075	**693**	201	10U 655452 6222977	Retrogressive rotational failure	Dormant	Within small scarp (in debris)	Toe
0.0751	**793**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Just above small retrogressive scarp (intact)	Body
0.0754	**405**	106	10U 607981 6249961	Rotational failure	Dormant	Debris apron near river	Body
0.0755	**685**	33	10U 657471 6230119	Compound failure	Dormant	Above large scarp (intact), near river	Body
0.0767	**670**	194	10U 656093 6232341	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Head
0.0771	**93**	45	10U 645103 6237317	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.0777	**643**	186	10U 655856 6238250	Retrogressive rotational failure	Dormant	Base of headscarp (large, intact)	Head
0.0779	**710**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below headscarp (small, intact)	Head
0.0782	**433**	114	10U 607383 6243249	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.079	**140**	74	10U 636436 6241818	Compound failure	Dormant	At base of headscarp (large, intact)	Body
0.0793	**91**	43	10U 646755 6238196	Retrogressive rotational failure	Active	Just below small scarp (intact)	Toe
0.0798	**636**	182	10U 653926 6268718	Retrogressive rotational failure	Dormant	Just above small scarp (intact), near river	Toe
0.0809	**54**	71	10U 660889 6229983	Shallow retrogressive failure	Dormant	Just above small scarp (intact)	Toe
0.0816	**13**	58	10U 646995 6252365	Compound failure	Dormant	Below small scarp (in debris)	Toe
0.0816	**438**	115	10U 606706 6242217	Rotational failure	Dormant	Near west sidescarp	Body
0.0817	**663**	39	10U 651511 6236995	Rotational failure	Dormant	Debris apron	Toe
0.0821	**437**	115	10U 606706 6242217	Rotational failure	Dormant	Below headscarp (large, intact)	Body
0.0823	**699**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0836	**355**	96	10U 597364 6244753	Compound failure	Dormant	Just below small scarp (in debris)	Body

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.0837	**288**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	At bottom of slide	Toe
0.086	**444**	120	10U 603024 6239487	Rotational failure	Dormant	Just below headscarp (large, intact)	Head
0.0863	**601**	50	10U 641564 6246268	Compound failure	Dormant	Within small scarp (in debris)	Body
0.0868	**151**	78	10U 637889 6241550	Rotational failure	Dormant	Just below headscarp (small)	Head
0.0874	**75**	44	10U 646758 6237400	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0874	**760**	221	10U 670755 6236278	Rotational failure	Dormant	Base of headscarp (large, intact)	Head
0.0876	**783**	234	10U 684625 6226289	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.0877	**385**	103	10U 589643 6282999	Rotational failure	Dormant	At base of headscarp (small, intact)	Head
0.0881	**407**	107	10U 607530 6250024	Compound failure	Dormant	Below headscarp (small, intact) near south sidescarp	Body
0.089	**343**	94	10U 586742 6231586	Rotational failure	Dormant	Debris apron	Body
0.0915	**123**	55	10U 641685 6251522	Multi-level rotational failure	Abandoned	Debris apron	Toe
0.0923	**779**	231	10U 680412 6226004	Multi-level rotational failure	Dormant	Debris apron at base of large scarp (intact)	Toe
0.0927	**391**	103	10U 589643 6282999	Rotational failure	Dormant	Debris apron near river	Toe
0.0928	**287**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	At bottom of slide	Toe
0.093	**161**	22	10U 668246 6222087	Compound failure	Dormant	Below small scarp (intact)	Body
0.0931	**11**	58	10U 646995 6252365	Compound failure	Dormant	Below headscarp (small, intact)	Head
0.0942	**753**	215	10U 664950 6210554	Multi-level rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.0944	**709**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.0947	**539**	3	10U 635265 6222327	Retrogressive rotational failure	Dormant	Just below small scarp (intact)	Body
0.095	**321**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Just above small retrogressive scarp (intact)	Body
0.0958	**273**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Below large scarp (intact)	Body
0.0976	**187**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.0995	**200**	13	10U 656024 6217434	Compound failure	Dormant	Above small scarp (in debris), just below headscarp (small, intact)	Head
0.0996	**29**	23	10U 662280 6223095	Rotational failure	Active	Above debris apron	Body
0.1017	**144**	75	10U 633471 6243680	Retrogressive rotational failure	Active	Below small scarp (intact), next to small scarp (in debris)	Body
0.1019	**563**	4	10U 637998 6220826	Multi-level rotational failure	Dormant	Below small scarp (intact)	Body
0.1028	**745**	212	10U 656103 6216700	Retrogressive rotational railure	Dormant	Below headscarp (large, intact)	Body
0.1031	**690**	30	10U 658107 6228756	Compound failure	Dormant	Below small scarp (in debris)	Toe
0.1033	**197**	12	10U 656272 6218290	Rotational failure	Dormant	Above small scarp (in debris)	Body
0.1035	**672**	194	10U 656093 6232341	Retrogressive rotational failure	Dormant	Just below small scarp (in debris)	Body
0.1045	**122**	55	10U 641685 6251522	Multi-level rotational failure	Abandoned	Debris apron	Toe
0.1045	**595**	162	10U 639763 6241926	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.1049	**794**	97	10U 597665 6245826	Rotational failure	Dormant	At base of headscarp (large, intact)	Head
0.1055	**648**	187	10U 655524 6236858	Multi-level rotational failure	Dormant	Below headscarp (large, intact)	Head
0.1057	**215**	86	10U 639774 6220198	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Head
0.1074	**581**	161	10U 639518 6240605	Retrogressive rotational failure	Dormant	Below small scarp (in debris), near river	Toe
0.1086	**612**	172	10U 641260 6254208	Rotational failure	Active	Debris apron beside creek	Toe
0.1091	**462**	122	10U 619929 6209531	Mobile flow	Active	Top of slide near west sidescarp	Head
0.1094	**786**	235	10U 685591 6226178	Multi-level rotational failure	Dormant	Base of large scarp (intact), in debris apron	Toe
0.1096	**482**	128	10U 632934 6302871	Rotational failure	Dormant	Base of headscarp (large, intact)	Body
0.1101	**216**	4	10U 637998 6220826	Multi-level rotational failure	Dormant	Below headscarp (large, intact), above small scarp (intact)	Head
0.1103	**226**	4	10U 637998 6220826	Multi-level rotational failure	Dormant	Debris apron	Toe
0.1106	**654**	189	10U 654871 6235759	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Body
0.1112	**752**	215	10U 664950 6210554	Multi-level rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.1116	**778**	227	10U 673362 6239998	Retrogressive rotational failure	Dormant	Base of slide, near creek	Toe
0.1121	**750**	214	10U 664400 6210645	Multi-level rotational failure	Dormant	Below headscarp (small, intact)	Head
0.1121	**776**	230	10U 673848 6240822	Rotational failure	Dormant	Within headscarp (small, intact)	Head
0.1129	**565**	152	10U 637789 6222601	Retrogressive rotational failure	Dormant	Above small scarp (intact), next to east sidescarp	Body
0.1136	**6**	59	10U 646337 6252998	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.1139	**577**	158	10U 643429 6220210	Rotational failure	Dormant	Below small scarp (in debris), by north sidescarp	Toe
0.1152	**720**	206	10U 655413 6219392	Retrogressive rotational failure	Dormant	Below headscarp (small, intact)	Head
0.1161	**323**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Toe
0.117	**762**	81	10U 673096 6235267	Retrogressive rotational failure	Dormant	Above small scarp (intact), near creek	Body
0.1173	**590**	47	10U 640425 6241038	Retrogressive rotational failure	Dormant	Halfway down slide	Body
0.1194	**15**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Just above small scarp (in debris)	Body
0.1195	**449**	122	10U 619929 6209531	Mobile flow	Active	Near base of slide by west sidescarp	Body
0.1205	**92**	45	10U 645103 6237317	Retrogressive rotational failure	Dormant	Within large scarp (intact), below headscarp (small, intact)	Head
0.1218	**145**	75	10U 633471 6243680	Retrogressive rotational failure	Active	Just below small scarp (intact)	Body
0.1223	**19**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Below small scarp (in debris)	Body
0.1229	**256**	2	10U 633364 6222821	Compound failure	Abandoned	Below small scarp (in debris)	Toe
0.1233	**142**	74	10U 636436 6241818	Compound failure	Dormant	Below small scarp (intact)	Body
0.1233	**432**	114	10U 607383 6243249	Retrogressive rotational failure	Dormant	Below large scarp (intact)	Body
0.1235	**331**	91	10U 585686 6240356	Compound failure	Dormant	Just below small scarp (intact)	Body
0.1238	**12**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Just above small scarp (in debris)	Body

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.1244	**467**	123	10U 615696 6235258	Multi-level rotational failure	Dormant	Debris apron near river	Toe
0.1269	**573**	156	10U 643924 6221112	Rotational failure	Dormant	Within small scarp (in debris)	Body
0.1275	**479**	127	10U 632593 6304450	Rotational failure	Dormant	Within small scarp (intact)	Body
0.1281	**354**	96	10U 597364 6244753	Compound failure	Dormant	Within small scarp (in debris)	Body
0.1284	**412**	109	10U 608185 6248414	Compound failure	Dormant	Debris apron near river/creek	Toe
0.131	**107**	48	10U 641990 6244350	Rotational failure	Dormant	At base of headscarp (large, intact)	Head
0.131	**127**	56	10U 644848 6253033	Retrogressive rotational failure	Dormant	Below small scarp	Toe
0.1311	**671**	194	10U 656093 6232341	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.1317	**658**	189	10U 654871 6235759	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.1324	**212**	9	10U 639115 6218246	Rotational failure	Dormant	Below small scarp (intact)	Toe
0.1338	**501**	137	10U 628079 6232225	Multi-level rotational failure	Dormant	Below small scarp (intact), by southwest sidescarp	Body
0.137	**139**	73	10U 634577 6242061	Compound failure	Dormant	Below small scarp (in debris)	Body
0.1383	**537**	3	10U 635265 6222327	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.1396	**358**	97	10U 597665 6245826	Rotational failure	Dormant	At base of headscarp (large, intact)	Head
0.1409	**666**	38	10U 652244 6236095	Retrogressive rotational failure	Dormant	Next to river at bottom of slide	Toe
0.1415	**771**	227	10U 673362 6239998	Retrogressive rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.1417	**761**	222	10U 672726 6234762	Retrogressive rotational failure	Dormant	Above small scarp (in debris), near creek	Toe
0.1418	**255**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.1419	**228**	4	10U 637998 6220826	Multi-level rotational failure	Dormant	Debris apron	Toe
0.1423	**665**	192	10U 649524 6238522	Rotational failure	Dormant	Below headscarp (small, intact)	Body
0.1425	**277**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.1431	**224**	5	10U 637848 6220421	Retrogressive rotational failure	Active	Between 2 small scarps (in debris)	Body
0.1437	**604**	167	10U 642365 6247706	Rotational failure	Dormant	Bottom of slide, next to creek	Toe
0.1439	**578**	159	10U 649510 6220866	Rotational failure	Dormant	Next to west side scarp, near base of slide	Toe
0.1441	**14**	57	10U 645882 6252696	Retrogressive rotational failure	Active	At base of headscarp (large, intact)	Head
0.1441	**580**	160	10U 648168 6224229	Compound failure	Dormant	Above small scarp (in debris)	Body
0.1442	**116**	53	10U 641413 6249461	Retrogressive rotational failure	Dormant	At base of headscarp (large, intact)	Body
0.1448	**179**	19	10U 675077 6219231	Rotational failure	Dormant	Debris apron	Body
0.1452	**450**	122	10U 619929 6209531	Mobile flow	Active	Centre of slide	Body
0.1457	**591**	47	10U 640425 6241038	Retrogressive rotational failure	Dormant	Below, to the right of small scarp (in debris)	Body
0.1467	**7**	59	10U 646337 6252998	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Body
0.1476	**715**	203	10U 654136 6220177	Retrogressive rotational failure	Dormant	Above small scarp (in debris), near south sidescarp	Toe
0.1481	**703**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.1507	**620**	176	10U 638057 6276259	Retrogressive rotational failure	Dormant	Base of headscarp (large, intact)	Head
0.1518	**94**	45	10U 645103 6237317	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.1518	**97**	45	10U 645103 6237317	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.1534	**189**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.1542	**547**	145	10U 634428 6225821	Multi-level rotational failure	Dormant	Debris apron	Toe
0.1546	**221**	4	10U 637998 6220826	Multi-level rotational failure	Dormant	Below small scarp (intact)	Body
0.1546	**198**	12	10U 656272 6218290	Rotational failure	Dormant	Just below headscarp (small, intact)	Head
0.1557	**290**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	At bottom of slide	Toe
0.1561	**138**	73	10U 634577 6242061	Compound failure	Dormant	Next to small scarp (intact)	Toe
0.1578	**356**	96	10U 597364 6244753	Compound failure	Dormant	Next to north sidescarp	Body
0.1591	**291**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	At bottom of slide	Toe
0.1597	**247**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Backtilt below small scarp (intact)	Body
0.1607	**551**	145	10U 634428 6225821	Multi-level rotational failure	Dormant	Debris apron	Toe
0.1614	**735**	15	10U 655647 6215120	Retrogressive rotational failure	Dormant	Below headscarp (small, intact), along south sidescarp	Head
0.1616	**579**	159	10U 649510 6220866	Rotational failure	Dormant	Above small scarp (intact)	Body
0.1622	**744**	212	10U 656103 6216700	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Head
0.1634	**684**	33	10U 657471 6230119	Compound failure	Dormant	Below large scarp (intact), near river	Toe
0.1639	**572**	155	10U 644195 6222091	Multi-level rotational failure	Dormant	Below small scarp (intact)	Body
0.1664	**496**	75	10U 633471 6243680	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.1668	**746**	213	10U 659241 6219068	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.1673	**567**	154	10U 636856 6222710	Compound failure	Dormant	Below small scarp (intact), near east sidescarp	Body
0.1674	**755**	216	10U 663258 6218654	Multi-level rotational failure	Dormant	Above small scarp (intact), near river	Toe
0.1689	**1**	15	10U 655647 6215120	Retrogressive rotational failure	Dormant	Just below headscarp (small, intact)	Head
0.1718	**42**	30	10U 658107 6228756	Compound failure	Abandoned	Next to small scarp (in debris)	Toe
0.1726	**242**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.1729	**259**	3	10U 635265 6222327	Retrogressive rotational failure	Abandoned	Above small scarp, below headscarp (large, intact)	Head
0.1733	**249**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Next to small scarp (in debris)	Body
0.1735	**669**	193	10U 657047 6232296	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Head
0.1761	**206**	16	10U 655340 6214299	Rotational failure	Dormant	On headscarp (small, intact)	Head
0.1761	**276**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.1765	**546**	145	10U 634428 6225821	Multi-level rotational failure	Dormant	Debris apron	Toe
0.1811	**751**	214	10U 664400 6210645	Multi-level rotational failure	Dormant	Within headscarp (small, intact)	Head

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.1825	**657**	189	10U 654871 6235759	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Head
0.1828	**121**	55	10U 641685 6251522	Multi-level rotational failure	Abandoned	Debris apron	Toe
0.1841	**76**	44	10U 646758 6237400	Retrogressive rotational failure	Dormant	Next to small scarp (in debris)	Body
0.1863	**117**	53	10U 641413 6249461	Retrogressive rotational failure	Dormant	At base of headscarp (large, intact)	Body
0.1874	**596**	163	10U 640344 6243435	Multi-level rotational failure	Dormant	Below large scarp (intact)	Body
0.189	**243**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.1897	**704**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.1905	**261**	3	10U 635265 6222327	Retrogressive rotational failure	Abandoned	Just below small scarp near headscarp (large, intact)	Head
0.191	**175**	20	10U 679534 6219946	Rotational failure	Dormant	Below headscarp (large, intact)	Body
0.1911	**713**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.1937	**113**	50	10U 641564 6246268	Compound failure	Dormant	Below small scarp (intact)	Body
0.197	**158**	63	10U 656420 6272207	Rotational failure	Dormant	Just above small scarp (in debris)	Body
0.1975	**115**	52	10U 641810 6248528	Rotational failure	Dormant	In debris apron below headscarp (large, intact)	Body
0.1978	**251**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Next to small scarp (intact) and backtilt	Body
0.2006	**747**	213	10U 659241 6219068	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.2009	**640**	185	10U 656213 6239712	Rotational failure	Dormant	Base of headscarp (large, intact)	Body
0.2012	**137**	73	10U 634577 6242061	Compound failure	Dormant	Bottom of slide	Toe
0.2022	**241**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.2033	**789**	237	10U 680337 6220929	Retrogressive rotational failure	Dormant	Just above large scarp (intact), near river	Toe
0.209	**299**	85	10U 612971 6237140	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Toe
0.2105	**599**	48	10U 641990 6244350	Rotational failure	Dormant	Base of headscarp (large, intact), next to small scarp (in debris)	Body
0.2115	**258**	3	10U 635265 6222327	Retrogressive rotational failure	Abandoned	Above small scarp, below headscarp (large, intact)	Head
0.2182	**594**	162	10U 639763 6241926	Retrogressive otational failure	Dormant	Below headscarp (large, intact)	Body
0.222	**574**	157	10U 643272 6221186	Retrogressive rotational failure	Dormant	Above small scarp (in debris)	Toe
0.2223	**428**	114	10U 607383 6243249	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.2225	**516**	141	10U 635411 6231647	Retrogressive rotational failure	Dormant	Flat area midway down slide	Toe
0.2228	**533**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Between 2 small scarps (intact), by river	Toe
0.2237	**576**	157	10U 643272 6221186	Retrogressive rotational failure	Dormant	Above small scarp (in debris)	Body
0.2251	**618**	174	10U 642740 6258340	Retrogressive rotational failure	Dormant	Base of headscarp (large, intact), above small scarp (intact)	Body
0.2332	**240**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
0.234	**136**	70	10U 631913 6311160	Retrogressive rotational failure	Dormant	Body	Body
0.2342	**610**	170	10U 642859 6253490	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.236	**545**	3	10U 635265 6222327	Retrogressive rotational failure	Dormant	Below, to east of small scarp (in debris)	Body

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.2365	**64**	38	10U 652244 6236095	Retrogressive rotational failure	Dormant	Toe	Toe
0.2384	**538**	3	10U 635265 6222327	Retrogressive rotational failure	Dormant	Just below small scarp (intact)	Body
0.2384	**691**	201	10U 655452 6222977	Retrogressive rotational failure	Dormant	Bottom of slide	Toe
0.2407	**608**	168	10U 642871 6251602	Rotational failure	Dormant	Debris apron next to small scarp (intact)	Body
0.2466	**5**	59	10U 646337 6252998	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.249	**63**	38	10U 652244 6236095	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Toe
0.2519	**106**	48	10U 641990 6244350	Rotational failure	Dormant	At base of headscarp (large, intact)	Body
0.2536	**319**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Head
0.2545	**109**	48	10U 641990 6244350	Rotational failure	Dormant	Just above debris apron	Body
0.2559	**619**	175	10U 641263 6274322	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Toe
0.2574	**246**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Backtilt below small scarp (intact)	Body
0.2578	**475**	126	10U 631665 6307193	Rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.2581	**236**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Below small scarp (intact) - near river	Toe
0.2585	**146**	76	10U 633480 6244644	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.2613	**770**	227	10U 673362 6239998	Retrogressive rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.2664	**28**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Below headscarp (large, intact)	Body
0.2759	**155**	62	10U 650179 6264258	Compound failure	Dormant	Just below headscarp (small, intact)	Head
0.2824	**552**	146	10U 635074 6225748	Multi-level rotational failure	Dormant	Above small scarp (intact)	Body
0.2827	**218**	4	10U 637998 6220826	Multi-level rotational failure	Dormant	Below headscarp (large, intact), next to small scarp	Body
0.2869	**266**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Above large scarp (intact)	Body
0.2874	**43**	71	10U 660889 6229983	Shallow retrogressive failure	Dormant	Just at base of headscarp (small, intact)	Head
0.2893	**556**	148	10U 635615 6217619	Retrogressive rotational failure	Dormant	Base of headscarp (small, intact)	Head
0.2906	**304**	87	10U 580867 6250762	Compound failure	Dormant	Within headscarp (small, intact)	Head
0.2919	**174**	81	10U 673096 6235267	Retrogressive rotational failure	Active	Below headscarp (large, intact)	Body
0.2934	**203**	14	10U 655144 6217752	Compound failure	Dormant	Within small scarp (in debris), just below headscarp (small, intact)	Head
0.3078	**66**	38	10U 652244 6236095	Retrogressive rotational failure	Dormant	Just below headscarp (large, intact)	Head
0.3181	**452**	122	10U 619929 6209531	Mobile flow	Active	Centre of slide	Body
0.3193	**248**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Above backtilt	Body
0.3212	**446**	122	10U 619929 6209531	Mobile flow	Active	Near base of slide	Body
0.3226	**480**	127	10U 632593 6304450	Rotational failure	Dormant	Below headscarp (small, intact)	Body
0.3227	**334**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Just above small retrogressive scarp (intact)	Body
0.3239	**427**	114	10U 607383 6243249	Retrogressive rotational failure	Dormant	Base of headscarp (large, intact)	Head
0.3251	**72**	38	10U 652244 6236095	Retrogressive rotational failure	Dormant	Just below headscarp (large, intact)	Head

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.328	**112**	49	10U 641388 6245365	Multi-level rotational failure	Dormant	Below small scarp (in debris)	Body
0.3531	**320**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Just below headscarp (large, intact)	Head
0.3538	**234**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Above small scarp (intact) next to river	Toe
0.3548	**194**	11	10U 656217 6219302	Retrogressive rotational failure	Active	Just above small scarp (in debris)	Body
0.3553	**695**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Below headscarp (small, intact), above small scarp (in debris)	Head
0.3565	**114**	51	10U 642403 6248773	Rotational failure	Dormant	In debris apron below headscarp (large, intact), next to south sidescarp	Body
0.3582	**318**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Toe
0.3589	**239**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Backtilt below headscarp (large, intact)	Head
0.3648	**647**	186	10U 655856 6238250	Retrogressive rotational failure	Dormant	Below small scarp (in debris), right by creek	Toe
0.3731	**633**	182	10U 653926 6268718	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.3802	**68**	38	10U 652244 6236095	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.3815	**245**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Backtilt below headscarp (large, intact)	Head
0.3828	**357**	97	10U 597665 6245826	Rotational failure	Dormant	Just below headscarp (large, intact)	Body
0.3829	**104**	47	10U 640425 6241038	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Head
0.3898	**532**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Below small scarp (intact), by river	Toe
0.397	**739**	211	10U 655836 6216390	Retrogressive rotational failure	Dormant	Base of headscarp (large, intact)	Head
0.4329	**493**	134	10U 634160 6291151	Rotational failure	Dormant	Bottom of slide	Toe
0.436	**694**	159	10U 649510 6220866	Rotational failure	Dormant	Below small scarp (in debris)	Head
0.4523	**270**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Below large scarp (intact)	Body
0.4636	**296**	84	10U 612699 6237705	Retrogressive rotational failure	Dormant	At base of small scarp (intact)	Toe
0.4648	**130**	66	10U 640009 6272311	Retrogressive rotational failure	Very active	Below headscarp, above small scarp (in debris)	Body
0.4707	**70**	38	10U 652244 6236095	Retrogressive rotational failure	Dormant	Just below headscarp (large, intact)	Head
0.471	**10**	57	10U 645882 6252696	Retrogressive rotational failure	Active	Between 2 small scarps (in debris)	Body
0.4942	**9**	59	10U 646337 6252998	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.506	**652**	189	10U 654871 6235759	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Body
0.51	**134**	70	10U 631913 6311160	Retrogressive rotational failure	Dormant	Below headscarp (small, intact)	Head
0.515	**232**	6	10U 638745 6221151	Retrogressive rotational failure	Dormant	Just above small scarp (in debris)	Body
0.519	**178**	18	10U 672960 6219166	Retrogressive rotational failure	Dormant	Above small scarp (in debris)	Body
0.525	**186**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Above small scarp (in debris), below headscarp (small, intact)	Head
0.527	**600**	48	10U 641990 6244350	Rotational failure	Dormant	Base of headscarp (large, intact)	Body
0.528	**267**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Above large scarp (intact)	Body
0.532	**653**	189	10U 654871 6235759	Retrogressive rotational failure	Dormant	Below headscarp (large, intact)	Body
0.547	**208**	7	10U 637199 6218231	Retrogressive rotational failure	Dormant	Below headscarp (east) - (small, intact)	Body

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
0.551	**262**	82	10U 564797 6216748	Rotational failure	Dormant	At base of debris apron	Toe
0.552	**71**	38	10U 652244 6236095	Retrogressive rotational failure	Dormant	Below headscarp (large, intact) , above small scarp (in debris)	Head
0.565	**214**	9	10U 639115 6218246	Rotational failure	Dormant	Below small scarp (intact)	Toe
0.578	**468**	124	10U 621307 6287220	Rotational failure	Dormant	Base of slide, near river	Toe
0.582	**185**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Above small scarp (in debris), just below headscarp (backtilt - small, intact)	Head
0.582	**69**	38	10U 652244 6236095	Retrogressive rotational failure	Dormant	Just below headscarp (large, intact)	Head
0.6	**297**	85	10U 612971 6237140	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Toe
0.601	**148**	76	10U 633480 6244644	Retrogressive rotational failure	Dormant	Below and within small scarp (in debris)	Body
0.606	**494**	135	10U 632986 6245453	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.608	**353**	95	10U 589923 6234772	Multi-level rotational failure	Dormant	Below small scarp (intact) near river	Toe
0.609	**244**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Backtilt below small scarp (intact)	Body
0.614	**787**	235	10U 685591 6226178	Multi-level rotational failure	Dormant	Base of large scarp (intact), in debris apron	Toe
0.617	**253**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Above backtilt	Body
0.617	**8**	59	10U 646337 6252998	Retrogressive rotational failure	Dormant	Just below headscarp (large, intact)	Head
0.627	**237**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Backtilt below headscarp (large, intact)	Head
0.637	**627**	179	10U 636025 6286564	Retrogressive rotational failure	Dormant	Bottom of slide	Toe
0.64	**477**	127	10U 632593 6304450	Rotational failure	Dormant	Below small scarp (intact)	Body
0.648	**555**	147	10U 636595 6219522	Multi-level rotational failure	Dormant	Debris apron	Toe
0.661	**235**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Backtilt below small scarp (in debris)	Body
0.668	**271**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	Below large scarp (intact)	Body
0.672	**295**	84	10U 612699 6237705	Retrogressive rotational failure	Dormant	At base of small scarp (in debris)	Toe
0.675	**333**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Just below headscarp (large, intact)	Head
0.758	**184**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Above small scarp (in debris), in backtilt below headscarp	Head
0.815	**183**	10	10U 652580 6220750	Retrogressive rotational failure	Dormant	Above small scarp (intact)	Body
0.858	**0**	15	10U 655647 6215120	Retrogressive rotational failure	Dormant	Just above small scarp (in debris), below headscarp (small, intact)	Head
0.874	**623**	177	10U 638157 6284497	Rotational failure	Dormant	Above/next to small scarp (intact)	Body
0.917	**495**	135	10U 632986 6245453	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Body
0.965	**103**	47	10U 640425 6241038	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Toe
0.969	**628**	179	10U 636025 6286564	Retrogressive rotational failure	Dormant	Bottom of slide	Toe
0.976	**65**	39	10U 651511 6236995	Rotational failure	Dormant	Debris apron	Toe
0.989	**536**	3	10U 635265 6222327	Retrogressive rotational failure	Dormant	Below small scarp (intact)	Body
1.025	**78**	38	10U 652244 6236095	Retrogressive rotational failure	Dormant	Toe	Toe
1.062	**561**	150	10U 635070 6214869	Retrogressive rotational failure	Dormant	Base of headscarp (small, intact)	Head

Appendix 7 Landslide pond descriptions - Mapsheet 94A - cont'd

Pond Size (ha)	Pond #	Slide #	Slide UTMs	Slide Type	Slide Activity	Pond location on slide	Geomorphic location of pond
1.094	**272**	83	10U 611833 6238026	Retrogressive rotational failure	Dormant	At base of large scarp (intact)	Body
1.14	**487**	131	10U 632364 6300428	Rotational failure	Dormant	Middle of slide	Body
1.22	**105**	48	10U 641990 6244350	Rotational failure	Dormant	At base of headscarp (large, intact)	Body
1.255	**67**	38	10U 652244 6236095	Retrogressive rotational failure	Dormant	Just below headscarp (large, intact)	Head
1.279	**193**	11	10U 656217 6219302	Retrogressive rotational failure	Active	Below small scarp (in debris)	Body
1.314	**74**	38	10U 652244 6236095	Retrogressive rotational failure	Dormant	Just below headscarp (large, intact)	Head
1.355	**177**	18	10U 672960 6219166	Retrogressive rotational failure	Dormant	Below small scarp (in debris)	Toe
1.371	**238**	1	10U 631931 6221078	Retrogressive rotational failure	Dormant	Backtilt below headscarp (large, intact)	Head
1.48	**332**	90	10U 584584 6239849	Retrogressive rotational failure	Dormant	Just below headscarp (large, intact)	Head
1.572	**147**	76	10U 633480 6244644	Retrogressive rotational failure	Dormant	Just below headscarp (small, intact), just above small scarp (in debris)	Head
1.654	**611**	171	10U 641105 6253591	Rotational failure	Dormant	Bottom of slide, partly blocking creek	Toe
2.376	**73**	44	10U 646758 6237400	Retrogressive rotational failure	Dormant	Just below headscarp (large, intact), above small scarp (in debris)	Body
3.227	**629**	179	10U 636025 6286564	Retrogressive rotational failure	Dormant	Bottom of slide	Toe
5.89	**207**	7	10U 637199 6218231	Retrogressive rotational failure	Dormant	Below headscarp (east) - (small, intact)	Body

Appendix 8 Pond size statistics by landslide type

Slide type	Mean pond size (ha)	Minimum pond size (ha)	Maximum pond size (ha)	Median pond size (ha)	Standard Deviation of pond size (ha)
Compound failure	0.054	0.003	0.293	0.026	0.062
Mobile flow	0.077	0.005	0.321	0.048	0.089
Multi-level rotational	0.102	0.004	0.648	0.055	0.131
Retrogressive rotational	0.197	0.001	5.890	0.059	0.430
Rotational	0.125	0.003	1.654	0.046	0.234
Shallow retrogressive	0.051	0.003	0.287	0.014	0.074

Appendix 9 Pond size by geomorphic location per slide type

	Mean pond size (ha)	Minimum pond size (ha)	Maximum pond size (ha)	Median pond size (ha)	SD of pond size (ha)
Ponds on head					
Landslide type					
Compound failure	0.072	0.003	0.293	0.022	0.100
Mobile flow	0.053	0.025	0.109	0.033	0.030
Multi-level rotational failure	0.078	0.012	0.181	0.081	0.047
Retrogressive rotational failure	0.281	0.007	1.572	0.131	0.366
Rotational failure	0.082	0.004	0.436	0.065	0.090
Shallow retrogressive failure	0.064	0.003	0.287	0.009	0.112
Ponds on body					
Landslide type					
Compound failure	0.050	0.007	0.293	0.033	0.046
Mobile flow	0.085	0.005	0.321	0.046	0.100
Multi-level rotational failure	0.104	0.007	0.060	0.058	0.099
Retrogressive rotational failure	0.192	0.001	5.890	0.062	0.489
Rotational failure	0.123	0.003	1.654	0.042	0.222
Shallow retrogressive failure	0.025	0.003	0.068	0.007	0.025
Ponds on toe					
Landslide type					
Compound failure	0.050	0.004	0.201	0.017	0.058
Mobile flow	0.000	0.000	0.000	0.000	0.000
Multi-level rotational failure	0.109	0.004	0.648	0.044	0.160
Retrogressive rotational failure	0.150	0.002	0.358	0.041	0.355
Rotational failure	0.159	0.007	1.654	0.047	0.310
Shallow retrogressive failure	0.072	0.059	0.081	0.075	0.009