Yellow Point-Cedar watershed modelling case study – final report

PREPARED FOR

Cowichan Valley Regional District,
Environmental Initiatives Division

PREPARED BY

J. Straker, Integral Ecology and ALCES Groups; R. MacDonald, ALCES Group; & K. Stehle, Silvatech Consulting

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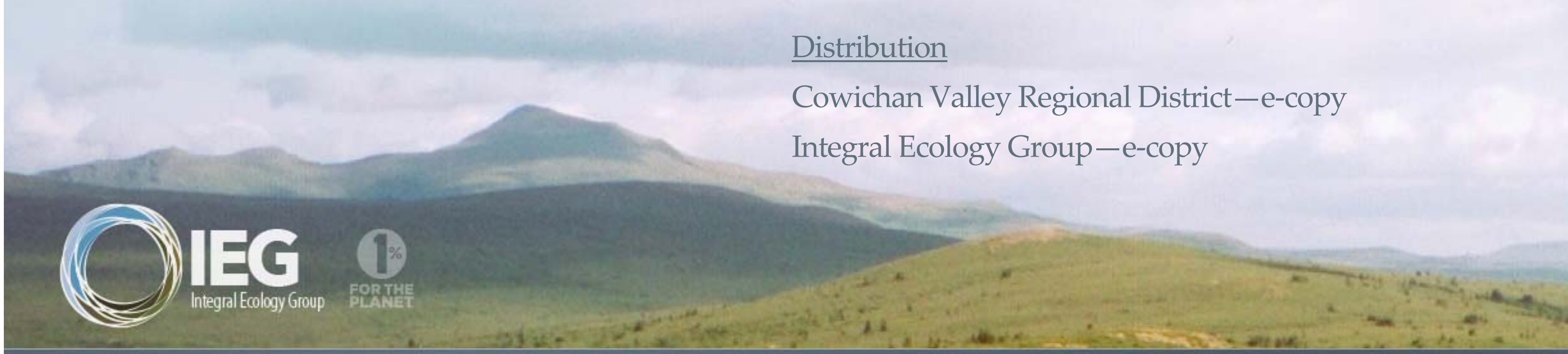

September 9, 2015
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Environmental Initiatives Division
Cowichan Valley Regional District
175 Ingram Street, Duncan, B.C., V9L 1N8

ATTENTION: KEITH LAWRENCE

REFERENCE: YELLOW POINT – CEDAR WATERSHED MODELLING CASE STUDY REPORT

Dear Keith:

Please find below our final report on the watershed-modelling case study conducted for the Yellow Point – Cedar watershed area of the Cowichan Valley Regional District and Regional District of Nanaimo. It has been a pleasure working with you and your team on this project, and we thank you for the opportunity to support the CVRD in its environmental initiatives.

Yours sincerely,

Justin Straker, M.Sc., P.Ag.
Integral Ecology Group Ltd.
Soil Scientist, Forest Ecologist, Principal

jstraker@iegconsulting.com
250 701 0600

ACKNOWLEDGMENTS

This study received substantial support and expertise from Keith Lawrence and Kate Miller of the Cowichan Valley Regional District's Environmental Initiatives Division, and from Kai Rietzel, Executive Director of the Cowichan Land Trust. In addition, the study included a field-verification program that could not have been completed without the generosity and knowledge of a number of volunteers. We would like to specifically thank Richard Wilson and Arthur Jim of the Stz'uminus First Nation, who contributed their knowledge to the field verification program and allowed access to Stz'uminus reserve lands. We also thank David Haley of the Coastal Douglas-Fir and Associated Ecosystems Conservation Partnership (CDFCP) and Julie Pisani of the Regional District of Nanaimo for their oversight and coordination.

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EXECUTIVE SUMMARY

The Cowichan Valley Regional District (CVRD) requested that a watershed-modelling case study be conducted in the Yellow Point – Cedar watershed, located in the northeast corner of the CVRD. The project was designed to support the CVRD Environmental Initiatives Division in:

1. protecting freshwater areas from degradation and contamination as a result of urbanization and land use practices;
2. developing and testing the use of automated mapping to identify key surface-water resources for protection;
3. developing and testing the use of automated mapping to identify critical ecological areas at risk or for restoration prioritization; and
4. educating decision makers and the public on the importance of key ecological function and relationship to long term sustainability.

The study was completed through processing and analysis of LIDAR data provided by the CVRD for the study area, integration with other existing mapping and GIS products, upgrading key ecosystem mapping, producing ecologic and predictive hydrologic maps, and working with community environmental groups to ground-truth these maps. This report primarily provides information on study methods, as most study deliverables are being provided in digital (ArcGIS) format. Overall, this study was successful in meeting project objectives.

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APPENDICES

Appendix A - Information on the Woodley Range and Yellow Point Bog Ecological Reserves
Appendix B - Methods and results of predictive ecologic modelling
Appendix C - Field verification site locations and data
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Appendix E - Assumptions used in the ALCES Online model to generate analyses presented in Section 7

1. INTRODUCTION

The Cowichan Valley Regional District (CVRD) Environmental Initiatives Division retained the Integral Ecology Group Ltd. (IEG), along with its collaborators, ALCES Landscape and Land Use Ltd. (the ALCES Group) and Silvatech Consulting (Silvatech), to conduct a watershed-modeling case study in the Yellow Point-Cedar watershed, located in the north-eastern portion of the CVRD. The project included three key steps:

1. build, refine and verify GIS modeling based on field validation;
2. provide a set of analytical and interpretive maps; and
3. work with the CVRD and partners to provide an opportunity for public outreach and education on the importance of the ecosystem and species it supports by a community-based science approach to field data collection.

These steps were completed through a combination of processing data provided by the CVRD, generating new data through mapping and analysis of provided data, and interpreting results. These processes and their outcomes are described in the following sections.

2. STUDY BACKGROUND

The Yellow Point – Cedar case-study watershed (Figure 2-1) is primarily located on a peninsula on the leeward side of Vancouver Island within the Georgia Basin, and lies between the Town of Ladysmith and the Regional District of Nanaimo. The watershed encompasses 41 km^2, which includes mostly rural residential areas and agricultural land, and is located in the Coastal Douglas-Fir (CDF) biogeoclimatic zone, considered to be among the top four most endangered ecosystems in Canada. Only 1% of the original old-growth forests remain in the CDF ecosystem, and about 50% of the entire ecosystem has already been completely eliminated by agriculture and urbanization. This ecosystem is characterized by its mild, Mediterranean-like climate, tree species like Douglas-fir, Garry oak and arbutus, and large numbers of species-at-risk. There are two ecological reserves in the watershed (Woodley Range and Yellow Point/Ladysmith Bog; Appendix A) which together contain 10 plant species and 4 animal species of management concern.

There are no significant lakes in the watershed; however, the topography is undulating and the location and importance of the key wetlands and permanent and ephemeral riparian areas is not clearly understood. With a lack of natural surface water storage, the area is more susceptible to periods of drought and flood. The effect of climate change in conjunction with population growth is expected to apply additional stress to critical ecology and supporting riparian ecosystems.[1]

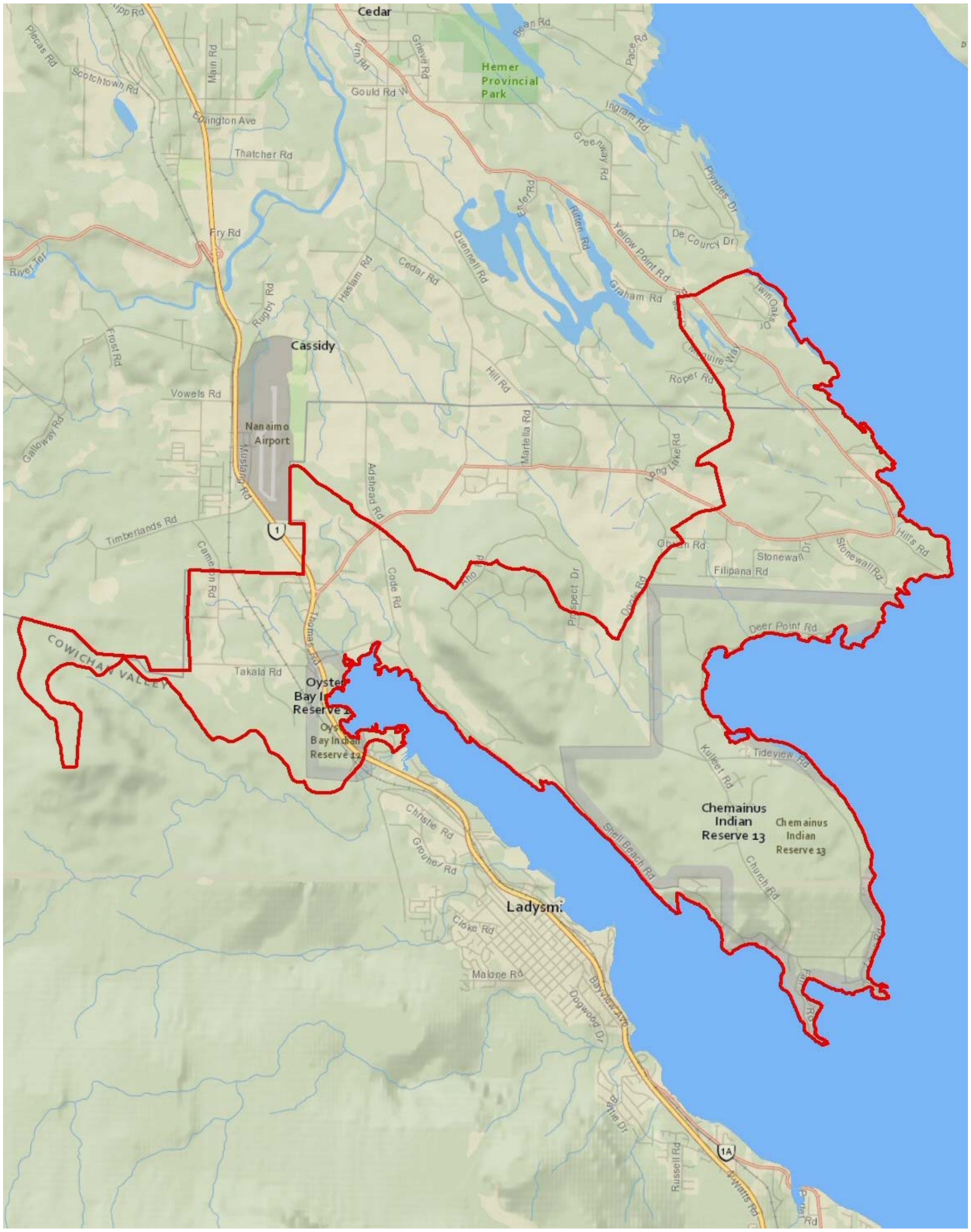

Figure 2-1. Yellow Point – Cedar watershed study area.

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[1] This background material is adapted from the December 2014 CVRD Request for Proposal.

2.1. PROJECT GOALS AND OBJECTIVES

This study was designed to support achievement by the CVRD Environmental Initiatives Division of the goals and objectives listed below.

2.1.1. Project goals

1. To protect freshwater areas from degradation and contamination as a result of urbanization and land use practices.
2. Develop and test the use of automated mapping to identify key surface water resources for protection.
3. Develop and test the use of automated mapping to identify critical ecological areas at risk or for restoration prioritization.
4. Educate decision makers and the public on the importance of key ecological function and relationship to long term sustainability.

2.1.2. Project objectives

1. Develop a GIS model for the case study watershed utilizing remote sensing technology.
2. Develop a community mapping process, stewardship awareness and science based capacity at a community level, providing field training opportunities and verification of the model.
3. Incorporate findings into a long term future watershed management plan including action items to improve the protection and restoration of the riparian and freshwater habitat.
4. Communicate the project successes through a variety of mechanisms including the CVRD website, workshops and meetings.
5. Share findings and methodology with others.
6. Provide science base leadership and training to community stewards.

2.2. STUDY TEAM

This study was completed for Keith Lawrence and Kate Miller of the CVRD Environmental Services Division. The study team consisted of Justin Straker, MSc, PAg (project lead) and Clint Smyth, PhD (ecosystem mapper) of IEG; Ryan MacDonald, PhD (hydrologist) of the ALCES Group; and Kevin Stehle, BSc (GIS analyst) of Silvatech. Additional project support was provided by Katherine Garrah, MSc and Jeff Anderson, MSc of IEG. The volunteer field-verification program was coordinated and led by Kai Rietzel of the Cowichan Land Trust.

3. METHODS

3.1. LIDAR PROCESSING AND ANALYSIS

LIDAR data provided by the CVRD were processed to create a Digital Surface Model (DSM), Digital Terrain Model (DTM or Ground), and Canopy Height Model (CHM or Vegetation Height) for the study area, as illustrated in Figure 3-1.

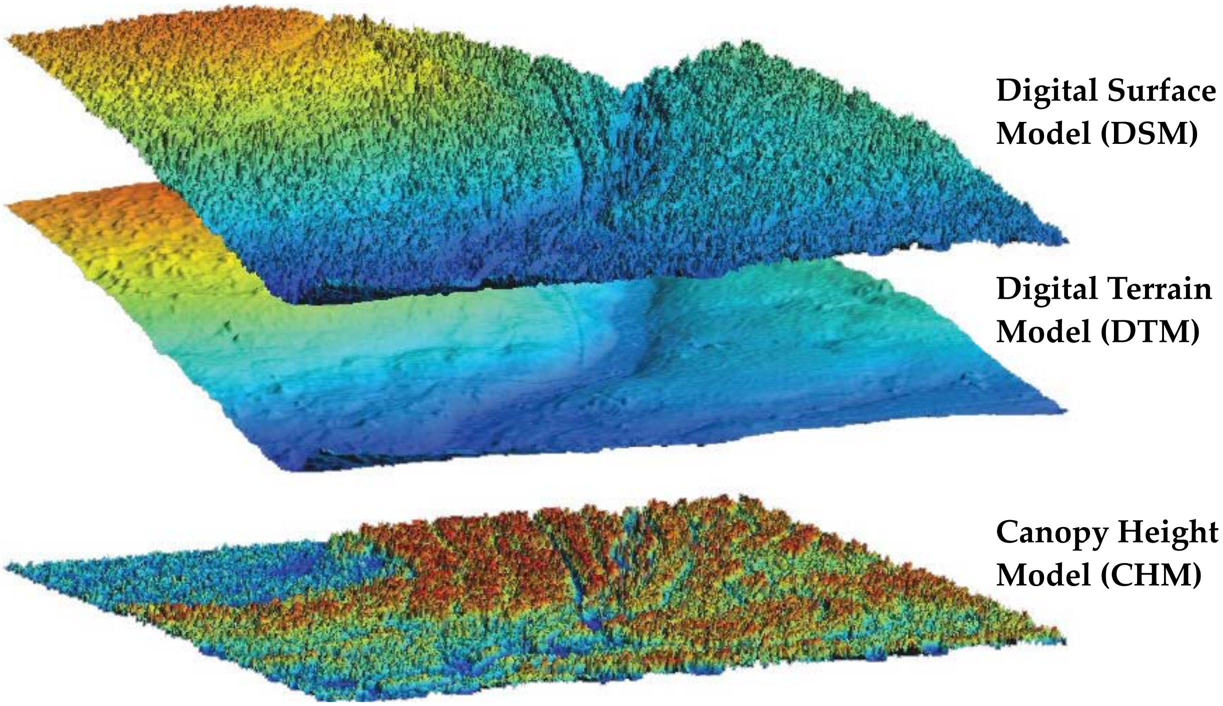

Figure 3-1. LIDAR-derived Digital Surface, Terrain, and Canopy-Height models.[2]

This processing is based on the existence in the LIDAR dataset of multiple returns for a given location, as shown in Figure 3-2.

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[2] http://www.forestresearch.ca/workshops/LIDARWoods.pdf

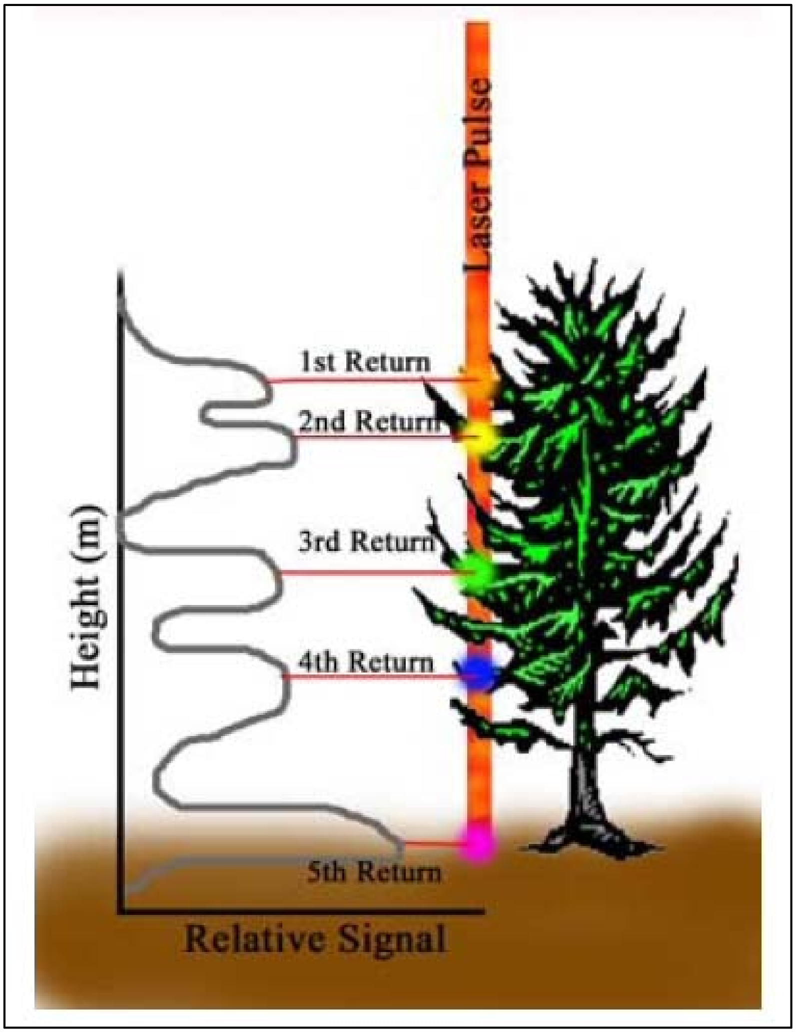

Figure 3-2. Multiple returns in LIDAR data.[3]

LIDAR data reduction and analysis was accomplished through the following steps:

1. filter the LIDAR so that only the first returns are used;
2. build a Triangulated Irregular Network (TIN) of the first returns returns;
3. convert the TIN to a raster of 1m resolution (this raster is the DSM);
4. filter the LIDAR so that only the ground returns are used (ASPRS class 2 – Table 3-1);
5. build a TIN of the ground returns;
6. convert the TIN to a raster of 1m resolution (this raster is the DTM); and
7. subtract the DSM from the DTM to create the CHM, using the raster calculator in ArcGIS.

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[3] https://www.e-education.psu.edu/LIDAR/l8_p3.html

Table 3-1. ASPRS[4] classification of LIDAR returns.

ASPRS Classification	Description
0	Created, never classified
1	Unclassified
2	Ground
3	Low Vegetation
4	Medium Vegetation
5	High Vegetation
6	Building
7	Low Point (noise)
8	Model Key-point (mass point)
9	Water
10	Reserved for ASPRS Definition
11	Reserved for ASPRS Definition
12	Overlap Points
13-31	Reserved for ASPRS Definition

3.2. HYDROLOGY

The primary hydrologic task associated with the study involved development and mapping of a groundwater/surface-water-interaction sensitivity index based on terrain analysis.

Near-surface (localized) groundwater systems are regularly driven by topography. Topographic features often dictate the distribution of groundwater recharge and discharge zones due to bedrock structure, geomorphic features, and drainage-basin characteristics (Winter, 1999). When other drivers of groundwater flow (i.e., compaction, density, etc.) are largely absent, terrain can be used to predict groundwater behavior at a large spatial scale (Gleeson and Manning, 2008). Hydrologic and geomorphometric principles were employed to complete a terrain analysis and predict the overall basin sensitivity to groundwater-surface-water interaction in the CVRD. Sensitivity indices were developed independent of other indicators, such as vegetation and land cover, providing the opportunity to spatially and qualitatively verify results.

TauDEM software was used for spatial analysis of inputs into the groundwater/surface-water sensitivity estimates.[5]

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[4] American Society of Photogrammetry and Remote Sensing

[5] http://hydrology.usu.edu/taudem/taudem5/downloads5.0.html

3.2.1. Logic model used for predictive hydrologic mapping

Distributions of predicted groundwater-surface water interaction were assessed using terrain attributes known to affect subsurface water near or at the land surface. A sensitivity dataset was generated using a pixel-by-pixel aggregation of sensitivity criteria throughout the CVRD, and mapped to demonstrate relative spatial sensitivity to groundwater-surface-water interaction. The aggregate dataset was derived from several terrain criteria that were combined using an additive multi-attribute utility. Each of the criteria were assigned ranks and summed into an aggregate score for each pixel, which was subsequently scaled to an index between 0 (not sensitive) and 1 (sensitive) using the range of results. To complete the analysis, the following terrain criteria were computed for the case-study watershed using a digital elevation model (DEM) generated by LIDAR.

Surface Roughness

Relative degrees of terrain roughness were evaluated using a slope standard-deviation calculation. This analysis is beneficial for determining localized regions of "ruggedness", which can be used to note differences in geomorphology (McKean and Roering, 2004). For example, regions covered with till deposited in higher-energy glacial environments, or covered in colluvium, often exhibit a higher degree of surface roughness with respect to sediment such as till deposited at lower elevations and in valley bottoms. These data provide insight into the speed of groundwater drainage in an area, largely due to variability in sediment grain size.

A slope dataset was created using an eight-cell neighborhood, where the eight surrounding cells are used for slope calculations in any particular cell in the digital elevation model. Secondly, the standard deviation of slopes for each cell was determined using a 24-cell neighborhood. The dataset was smoothed 20 times using an averaging filter over an eight-cell neighborhood to remove isolated effects of valley edges, as ridges naturally result in high surface roughness values.

Convergence

Groundwater with relatively low residence times is often constrained by bedrock structure and may converge and induce large upward gradients (upwelling). Topographic convergence as a result of bedrock structure is one of the most influential terrain features on upward groundwater gradients, which often results in saturation of upper soil layers and potentially discharge (Sabzevari et al., 2010). The flow accumulation of topography calculated at the surface can easily be used as a proxy for bedrock topography and indicate where groundwater flow potentially converges.

The change in flow accumulation to determine regions of convergence was computed by first filling the sinks of the DEM, computing eight-direction flow accumulation (D8), and evaluating cell-to-cell flow accumulation. Isolated regions at valley bottoms and in tributary confluences were reclassified using the relative change in flow-accumulation values. A maximum filter using an eight-cell neighborhood was completed 10 times to improve the isolation of regions and to smooth region boundaries (negate effects of up-stream branching). These regions were verified as convergent (occasionally flow accumulation is high in a region of confluence, even though the topography is divergent due to valley widening) by computing the standard deviation in flow direction to check regions of overlap between the two datasets. Regions with higher variability in flow direction enhanced the probability of a region being convergent when overlapping a high change in flow accumulation.

Slope

High topographic gradients result in higher groundwater gradients, given the assumption that groundwater flow is topographically driven. A topographic slope threshold (in degrees) was determined to indicate lower sensitivity to account for steeper regions that are likely well-drained. A threshold was calibrated based on a visual examination of the DEM to determine regions exhibiting slope instability. These regions were assumed to be well-drained given the presence of significant drainage (Gleeson and Manning, 2008).

Alluvium

The presence of alluvium was predicted throughout the basin using a prediction of river systems and river sedimentation dynamics. Regions where the rate of change of river-slope rapidly decreases indicate potential zones of erosion/deposition thresholds. Steep rivers with high energy and high sediment loads are forced to release and deposit material with sudden changes in slope (Benda et al., 2005). As such, the process of delineation included:

- calculating flow accumulation to predict the locations of potential rivers;
- calculating the slope of predicted rivers;
- taking the derivative of stream slopes to determine the rate of change in river slope; and
- using river areas with high slope derivatives as seed points for a region-growing algorithm (flood fill) using slope variability to terminate cell-by-cell region growth.

Ocean Buffer

A buffer was applied to areas of low topographic slope around the coastline to constrain regions near the ocean that are potentially brackish or undergo rapid pressure fluctuation due to tidal influence.

Integrated model

Aggregate scores calculated at each pixel using the multi-attribute utility were completed using the ranks and indices presented in Table 1.

Table 3-2. Integrated sensitivity model ranks and respective values

Criteria	Value	Sensitivity Rank
Surface Roughness	< 0.5	1
	< 0.4	2
	< 0.3	3
	< 0.2	4
	< 0.1	5
Convergence	Yes	5
	No	0
Topographic Slope	> 25 º	0
	< 1 º	1
	< 0.6 º	2
	< 0.3 º	3
Alluvium	Yes	5
	No	0

3.3. TERRESTRIAL ECOSYSTEM MAPPING

Terrestrial Ecosystem Mapping (TEM) revisions were completed for the Yellow Point – Cedar watershed. TEM for this study are was completed in 2008 as part of a larger CDF TEM project mapped at a scale of 1:20,000 (Madrone Environmental Services Ltd., 2008). However, the current study required that a larger-scale ecosystem map be available to better characterize the abundance and distribution of ecosystems on the landscape. The objective of the TEM map revisions were to better delineate ecosystems and provide a more accurate spatial input layer.

On-screen digitizing of the using ArcGIS 10.2 was performed using imagery supplied by the Cowichan Valley Regional District (CVRD). The GIS input layers used in the TEM map refinements included the following:

- the 2008 CDF TEM (project base map);

- the provincial-government biogeoclimatic-zone map layer;
- 5-m contours derived from processed LIDAR data; and
- British Columbia Imagery Web Map Service (WMS) data.

The first phase of the mapping process involved a pre-mapping reconnaissance survey of the study area, undertaken on January 14, 2015. The second phase involved making adjustments to the existing polygon lines within the study area. During this process, roads and related infrastructure, wetlands, and structural stages were more accurately delineated. The lines of virtually all polygons were modified. In the third phase, the attributes in the revised polygons were updated. Attribution of polygons relied, for the most part, upon the previous TEM product with modifications made to polygon attribute decile proportions. In many instances, complex (multiple-inclusion) polygons were converted to single-attribute polygons. Only under the most obvious circumstances were revised polygons assigned different codes (e.g., when line-work changes resulted in the creation of new polygons which did not exist previously because of the map scale used). Existing ecosystems and surficial geology features were maintained throughout the revision process. Adjustments were made in surface and subsurface parent materials, ecosystems, and structural stages where appropriate.

Although mapping was conducted at a scale of 1:5,000, the quality of the imagery used for mapping is such that the terminal scale of the updated TEM product – or the maximum scale at which it should be used – is 1:10,000.

3.4. PREDICTIVE ECOLOGIC MAPPING

Information from the TEM, LIDAR, and predictive hydrologic mapping was used to test the ability to identify rarer natural ecosystems in the study area, defined as drier (xeric) or wetter (hygric-hydric) than normal site series.

A logistic-regression approach was used for this work, where cells including presence of target site series or ecosystems[6] for identification were assigned a value of 1 and cells in which target site series or ecosystems were absent were assigned a value of 0. The logistic function is of the form:

$$F(x) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 x_1 + \cdots)}}$$

where F(x) is the probability of a site series or ecosystem n ecosystem type occurring in a cell, β_0 is the intercept term, and β_1, β_2, etc. are coefficients for covariates x_1, x_2, etc.

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[6] Our approach attempted to use predictive mapping to identify both individual site series and multiple site series grouped to form an aggregate ecosystem type such as xeric or hygric-hydric.

When fitting models, stepwise forward selection using AIC was used to decide which covariates should be included.

A full discussion of approach to and results of predictive ecologic mapping is presented in Appendix B. This predictive modelling was only attempted within the CDF portions of the study area (due to the very small area of CWH), and was only possible in portions of the study area with LIDAR coverage.

4. RESULTS

4.1. TOPOGRAPHY

As discussed in Section 3.1, LIDAR data provided by the CVRD was processed to produce various topographic models, such as a Digital Surface Model, Digital Terrain Model, and Canopy-Height Model. These model are being provided in digital (ArcGIS) format.

4.2. HYDROLOGY

The groundwater/surface-water-sensitivity mapping described in Section 3.2 was completed for the study area. This mapping shows three large zones of high sensitivity that are oriented roughly southeast to northwest across the study area and are likely connected by surface and subsurface hydrology:

1. Michael Lake and associated drainages and wetlands, in the centre of the study area;
2. a large wetland in agricultural land between Cedar and Adshead roads, on Hokkanen Creek, approximately 1700 m east of the north end of the Cassidy airport (YCD) runway; and
3. a wetland complex with an upstream origin in relatively undisturbed terrain to the west of Kulleet Bay (between the Stz'uminus reserve and the Woodley Range Ecological Reserve), and with a large downstream area in agricultural land crossed by Doole Road.

Additional smaller areas of mapped sensitivity are found in the following locations:

- approximately 550 m to the west of Hazelwood Herb Farm on Adshead Road;
- in agricultural land to the south of the junction of Cedar and Code roads;
- in a wetland in agricultural land approximately 300 m to the north of Yellow Point Road, between Hill and Quennell roads;
- in relatively undisturbed ecosystems between Priest and Long lakes, including the Yellow Point Bog Ecological Reserve;
- in a wetland complex in agricultural land to the southeast of the end of Seidel Road,

which branches south off of Yellow Point Road; and

- in an unnamed lake (to our knowledge) east of Barney Road, which branches north off of Yellow Point Road near Seidel Road.

Primary areas of potential water-quality issues are those listed above in association with agricultural lands, and include all areas except those associated with Priest and Long lakes and the Yellow Point Bog, and the unnamed lake east of Barney Road. The largest of these areas of potential water-quality issues is Michael Lake and its associated wetland complexes.

4.3. ECOLOGY

The updated TEM includes less deciled or complex polygons than the original 1:20,000 TEM. For the revised TEM map, wetland, and rock outcrops are better delineated. The revised TEM map contains the Fescue – Camas (00 | FC) site series which was not captured previously because of the size of the individual polygons and map scale used. The map also includes a greater abundance of the Cladina – Wallace’s Selaginella (00 | SC) and Wetland Fen (00 | WF) units. Coniferous, deciduous and mixed-wood forests as forested structural-stage attributes are better represented in the revised TEM. As well, anthropogenic features such as cultivated fields (00 | CF), roads (00 | RZ), rural (00 | RW), urban/suburban (00 | UR), industrial facilities (non-conventional code 00 | IN), and gravel pits (00 | GP) are now more accurately mapped.

Table 4-1 provides information on the area and proportion of the various mapped units in the study area. This information indicates that the zonal CDFmm site series (Fd – Salal) is the single dominant unit, occupying over 1600 ha, or approximately 44% of the study area. The second most abundant unit is the anthropogenic cultivated-field (CF) unit, occupying over 400 ha, indicating the prominence of agricultural activities in the watershed. Other abundant map units (>5% of the study area) include the wetter CwBg – Foamflower site series in the CDFmm, and rural residential areas.

Table 4-1. Area and proportion of TEM units in the Yellow Point – Cedar study area.

BEC Subzone	Site Series/ Description		Area (ha)	Proportion of study area	Natural (N) or Anthropogenic (A)	Broad Ecosystem Unit[7]	SMR
CDFmm[8]	01	Fd - Salal	1612.4	44%	N	Coastal Douglas-fir	subxeric, submesic, mesic
	06	CwBg - Foamflower	229.8	6%	N	Coastal Western Redcedar - Grand Fir	subhygric, hygric
	13	Cw - Indian-plum	201.2	5%	N	Coastal Western Redcedar - Grand Fir	hygric
	12	Cw - Vanilla-leaf	194.7	5%	N	Coastal Western Redcedar - Grand Fir	subhygric
	02	FdPl - Arbutus	81.7	2%	N	Douglas-fir - Arbutus	xeric
	04	FdBg - Oregon grape	77.9	2%	N	Coastal Douglas-fir	subxeric, submesic, mesic
	14	Cw - Slough sedge	61.7	2%	N	Wetland	subhydric
	00	Cladina - Wallace's selaginella	48.2	1%	N	Upland Meadow	subxeric
	05	CwFd - Kindbergia	10.7	<1%	N	Coastal Western Redcedar - Grand Fir	subhygric, hygric
	11	Cw - Skunk cabbage	9.8	<1%	N	Wetland	subhydric
	00	Fescue - Camas	6.4	<1%	N	Upland Meadow	subxeric
	00	Qg - Brome	0.5	<1%	N	Garry Oak	subxeric
CWHxm1[9]	01	HwFd - Kindbergia	138.4	4%	N	Coastal Western Hemlock - Douglas-fir	submesic, mesic
	06	HwCw - Deer fern	9.4	<1%	N	Coastal Western Hemlock - Douglas-fir	subhygric, hygric
	05	Cw - Sword fern	7.4	<1%	N	Coastal Western Hemlock - Douglas-fir	submesic, mesic
	07	Cw - Foamflower	1	<1%	N	Coastal Western Hemlock - Douglas-fir	subhygric, hygric
	15	Cw - Slough sedge	0.5	<1%	N	Wetland	subhydric

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[7] Ecosystems Working Group, 1998.

[8] CDFmm is the Moist Maritime Coastal Douglas-Fir subzone

[9] CWHxm1 is the Eastern variant of the Very Dry Maritime Coastal Western Hemlock subzone.

BEC Subzone	Site Series/ Description		Area (ha)	Proportion of study area	Natural (N) or Anthropogenic (A)	Broad Ecosystem Unit[7]	SMR
Generic	CF	Cultivated Field	428.6	12%	A	Agriculture	
	RW	Rural	306.6	8%	A	Residential	
	RZ	Road Surface	126.2	3%	A	Transportation	
	IN	Industrial	29.2	1%	A	Industrial	
	OW, LA	Open Water, Lake	25.1	1%	N	Lentic	
	Ws	Wetland, Swamp	18	<1%	N	Wetland	hygric
	RO	Rock Outcrop	7.7	<1%	N	Rock	
	Wm	Wetland, Marsh	7.1	<1%	N	Wetland	hygric
	PD	Pond	7	<1%	A	Lentic	
	GC	Golf Course	5.2	<1%	A	Recreation	
	RI	River	4.5	<1%	N	Lotic	
	RN	Railway Surface	4.2	<1%	A	Transportation	
	Wf	Wetland, Fen	2.2	<1%	N	Wetland	hygric
	MU	Mudflat Sediment	2.1	<1%	N	Intertidal Marine	
	BE	Beach	0.1	<1%	N	Intertidal Marine	
Total Natural				75.3%			
Total Anthropogenic				24.7%			

4.3.1. Rare species and ecosystems

Rare plant and animal species and the ecosystems that support them, tend to be found at the extreme ends of the hydrologic/soil-water-regime spectrum, on both very dry (xeric) and very wet (hydric) sites. In this study area, these ecosystems include:

- **Xeric sites –** the CDFmm 00 (*Cladina* – Wallace's *selaginalla*, Fescue – Camas, and Qg – Brome), and 02 site series and Rock Outcrop ecosystems; and
- **Hydric sites –** the CDFmm 11 and 14 site series, the CWHxm1 15 site series, and the Wm, Wf and Ws wetland types.

In total these sites comprise approximately 6.6% of the study area, and are found in the following locations:

- **Xeric sites –** found in the Woodley Range ecological reserve and ridge topography to the southeast, including around Shell Beach, and along the coastal-bluff shoreline from Kulleet Bay to the north and east;
- **Hydric sites –** associated with larger wetlands to the west of Kulleet Bay and south of Michael Lake, and to the west of Church Road in the Stz'uminus reserve, and with wetlands in the vicinity of the Yellowpoint Bog ecological reserve.

The majority of these ecosystems are located either within the municipal and provincial parks, the provincial ecological reserves, or in the Stz'uminus reserve, but there may be additional conservation opportunities for xeric ecosystems in the vicinity (north and northwest) of the Woodley Range reserve, and for hydric ecosystems in the vicinity of the Yellowpoint Bog reserve, along Yellow Point Road.

4.3.2. Predictive ecologic mapping

Results for each tested site series or ecosystem type[10] are presented in Table 4-2, along with model coefficients. Model discrimination is summarized using with a pseudo R2 (Nagelkerke R2) and the concordance index. The concordance index (C) is interpreted as the proportion of times when the model predicts a higher probability of ecosystem presence when the ecosystem is present, and can be interpreted using the following guidelines:

- $C = 0.5$ means no discrimination;
- $0.7 \leq C < 0.8$ means acceptable/reasonable discrimination;
- $0.8 \leq C < 0.9$ means excellent/strong discrimination; and

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[10] Model fitting did not converge for some ecosystem types, likely due to their rarity. These include QB (4 presences), Wf (14 presences), Wm (29 presences), Ws (135 presences).

- C ≥ 0.9 means outstanding discrimination[11].

This predictive ecologic mapping produced excellent/strong fits (predictions) for the following sites series/ecosystem types:

- SC, 00, Cladina – Wallace's selaginalla;
- DA, 02, FdPl – Arbutus;
- FC, 00, Fescue – Camas;
- RO, Rock Outcrop;
- RC, 11, Cw – Skunk cabbage; and
- The "xeric" ecosystem type, which is a combination of the SC, DA, FC, RO and QB (00, Qg – Brome) site series.

In addition, this modelling produced acceptable/reasonable fits for the CS (14, Cw – Slough sedge) and "hygric-hydric" ecosystem type, which is a combination of the RC, CS, Wf (fen), Wm (marsh) and Ws (swamp) sites series/ecosystems. Prediction of most of the wetland site series and the aggregate ecosystem type was poorer than for the xeric sites in part because of limited observations on which to construct the regression model, and in part because the occurrence of these systems in the study area can be hard to predict. For example, the Yellow Point bog occurs in an area with no interaction with groundwater, which is somewhat atypical or unexpected for a wetland, but a diagnostic characteristic of a bog. Overall, this approach to predictive modelling of rarer ecosystem types was sufficiently successful to allow its future application to other CDF areas within the CVRD where similar input data (e.g., LIDAR) is available.

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[11] http://www.natalialevshina.com/Documents/Part%205_Logistic%20regression.pdf. A similar interpretation is described at http://mchp-appserv.cpe.umanitoba.ca/viewDefinition.php?definitionID=104234, whereby models are considered reasonable when the C-statistic is higher than 0.7 and strong when C exceeds 0.8.

Table 4-2. Results of logistic regression for predictive ecologic modelling.

Parameters/coefficients[12]	Site series/ecosystem types[13]							
	SC	**DA**	**FC**	**RO**	**RC**	CS	**Xeric**	Hygric-Hydric
R2	0.609	0.385	0.227	0.602	0.144	0.160	0.365	0.142
C	**0.958**	**0.844**	**0.880**	**0.968**	**0.805**	0.746	**0.829**	0.722
Intercept	-4.8692	-3.6221	-1.7711	3.4411	-5.7238	-4.9499	2.6700	-5.7279
Mean_GWSW	-13.0465	-4.2086**		-24.2104	-6.7787**	-3.9276	-16.0858	
ElevationMean	0.0307		-0.0928	-0.2055	-0.0561	-0.0151	0.0073	-0.0136
AspectMin		0.0058		-0.0053*				
AspectMax	-0.0070					0.0060	-0.0055	0.0068
AspectMean	-0.0124	-0.0027				-0.0029	-0.0014**	-0.0017*
SlopeMean	0.0125**	0.0379			-0.0704**		0.0159	-0.0109**
SlopePosition1_m2	0.0007	0.0011				0.0011***	0.0006	
SlopePosition2_m2	0.0003	0.0004				0.0003		0.0003
SlopePosition3_m2	0.0005	0.0003		0.0002	0.0003*	0.0002	0.0001	0.0002
SlopePosition4_m2			-0.0003	-0.0005	0.0004*	0.0002	-0.0003	0.0002
SlopePosition5_m2	0.0006	0.0004			0.0005	0.0002	0.0002	0.0003
SlopePosition6_m2	0.0007	0.0007				0.0002	0.0005	0.0002*
CanopyHeightMean	0.0221**	0.0812		-0.1155		0.1067		0.0796
CanopyHeightMin							-0.3579	
CanopyHeightMax		-0.0702		-0.0236**	0.0258**	-0.0196	-0.0487	

---

[12] All coefficients shown are significant at $p<0.05$ except the following: * $p<0.1$, ** $p<0.2$, *** $p>0.2$

[13] **Bold font** indicates C values >0.8 (excellent/strong discrimination) and associated site series/ecosystem types.

5. FIELD VERIFICATION PROGRAM

A field ground-truthing program was conducted, coordinated by the Cowichan Land Trust and the CVRD, to check the ecosystem and predictive hydrologic mapping, and to provide information for potential adjustment of this mapping. Field visits occurred on March 6, 10, 12, and 13 of 2015. Sites for field visits were selected based on the following:

- Predictive hydrologic mapping – 176 potential sites were generated, based on the goal of representing site of low, moderate, and high sensitivity to surface-water/groundwater interactions. Sites were selected to be either within one of the four parks/ecological reserves in the area (Woodley Range, Yellow Point Bog, Yellow Point Park, and Roberts Memorial Park) on the Stz'uminus reserves, or to be visible from public roads. These selection criteria were designed to minimize logistical challenges associated with gaining access to private property.
- TEM – 38 sites were selected by the TE Mapper, Clint Smyth, for verification of air-photo interpretation and for provision of additional information.

Of these sites, volunteers were requested to prioritize field-checking sites identified as having high sensitivity for groundwater/surface-water interactions. Over the four days of field checking, 105 sites were visited (site locations and data are provided in Appendix C).

An explicit objective of the field verification program was to check 10% of key sites in the study area. Key sites were defined as forested sites (including the Coastal Douglas-fir, Coastal Western Hemlock – Douglas-fir, Coastal Western Redcedar – Grand Fir, and Douglas-fir – Arbutus Broad Ecosystem Units) and wetlands. TEM for the study area indicated that there were 259 forested polygons in the study area, of which 85 had field verification points, for a survey intensity of approximately 33%. TEM indicated 77 wetland polygons, of which 14 had field verification points, for a survey intensity of approximately 18%. More detailed information on survey intensity by TEM unit is provided in Appendix D.

5.1. HYDROLOGY

Results from field observations corresponded well with the groundwater-surface water sensitivity mapping. Areas that were observed to be dry and mesic corresponded with less sensitive zones, while areas identified as wet corresponded with more sensitive zones. Observed lentic and lotic systems also correlated well with the mapping.

5.2. TEM

A quality assurance/quality control (QA/QC) assessment was performed on the TEM map revisions. The QA/QC process utilized the following steps:

- field training of community volunteers;
- assignment of site-series codes to volunteer data sheets;
- merging of previously coded IEG data with volunteer data;
- intersection of point data with TEM map layer; and
- categorization of field data / TEM map polygon attribute agreement.

Field data and map polygon attributes were categorized as Y (full agreement), Q (qualitative agreement) or N (non-agreement). The reasons for disagreement, where present, were documented. Interpretation was based on field-reconnaissance site and floristic data and on-screen orthophotography interpretation. The site-series descriptions provided by Green and Klinka (1994) and the site-series map codes (Province of British Columbia 2015) were used in the QA/QC process.

A total of 145 intersected points – including pre-mapping points visited on January 14, 2015 – were classified (Table 5-1). Full agreement was achieved on 80% of the intersected polygon-points. Qualitative or conditional agreement was assigned to 17% of the intersected polygon-points while agreement was not achieved on 3% of the polygon-points. The reasons for qualitative or conditional agreement or non-agreement were map scale / mapping resolution (93%) and species/site call inconsistencies (3%). Full or conditional approval for the revised TEM is 97 percent.

Table 5-1. TEM QA/QC based on field visits.

Category	Number	Percent
Full Agreement (Y)	116	80
Qualitative/Conditional Agreement (Q)	25	17
Non-agreement (N)	14	3
Total	145	100

Overall, there is good agreement between the field reconnaissance data and revised map polygons and their attributes. However, there were particular issues that reduced this agreement:

- There are inconsistencies in site descriptions (i.e., ecological moisture, regime mesoslope position and species composition) and edatope characterization in the volunteer data – increasing agreement between mapping and volunteer field verification in the future would require additional training of community participants.
- Interpretation of site series in the volunteer data was complicated by the absence of cover abundance estimates – only presence/absence data was provided. Again, if increased accuracy is desired in future projects, we suggest the addition of some qualitative

assessment of prominence be assigned by field volunteers.

- The provincial classification is based primarily on climax stage ecosystems but many of the Yellowpoint ecosystems are seral and so site calls by inexperienced volunteers would be difficult.

6. DELIVERABLES

A concordance table of deliverables required by the CVRD Request for Proposal and those delivered through this project is presented in Table 6-1. Many deliverables required as part of the study will be delivered as ArcGIS files through digital data transfer, and some will be provided as part of the ALCES Online license provided to the CVRD.

Table 6-1. Deliverables concordance table.

TASK	DELIVERABLES	CONCORDANCE
Planning		
Kickoff meeting	Workplan	Completed on Friday, January 9, 2015
Execution: Watershed topography		
Develop surface map and 3D model; use LIDAR to create a terrain model and DEM	High-accuracy ground topography 3D model of watershed structure	Delivered in February, 2015 Delivered in February, 2015
Execution: Watercourse and wetland connectivity		
Integrate groundwater data to interpolate surface and groundwater interaction areas Link land use and risk factors Link agricultural water-balance model data	Watercourse and wetland connectivity mapping Soil moisture and flow topography Soil moisture mapping Mapped areas of potential water-quality issues Identify areas of potential water deficits	Provided by a combination of TEM and hydrologic mapping, complete Soil moisture mapping provided by UVic was not interpretable without additional meta-data As directly above Provided by hydrologic mapping of groundwater/surface-water sensitivity Provided by TEM and ALCES Online
Execution: Predictive ecological mapping		
Utilize LIDAR structure data to develop vegetation structure analysis	Predictive ecological mapping and TEM identification at relevant	TEM upgraded to 1:10,000 for the study area; predictive ecologic

TASK	DELIVERABLES	CONCORDANCE
Use available data to identify key ecosystem types Identify key correlation sites Field-verify modelled mapping and refine as necessary Train volunteer stewards	scale Identify riparian areas and green-infrastructure zones Field verification of key sites Predicted mapping of key species	mapping provided by ALCES Online Riparian areas identified in TEM; green infrastructure identified in ALCES Online Completed as per Section 5 Provided by TEM and ALCES Online
Completion: Produce ecosystem and hydrological maps		
Link ecosystem types to species diversity and key species/ecosystems at risk	Produce draft ecosystem and hydrologic maps for field verification Final maps QAQC	Completed March 1, 2015 Completed for this report
Develop recommendations on how to best apply GIS model elsewhere Short summary of projected changes to area based on climatic projections	Summary report with recommendations and/or identified issues Predicted changes to hydrology and ecosystem units based on climate projections	Complete with this report Can be provided in ALCES Online given appropriate projections

7. MAP PRODUCTS

All map products generated by this study have been provided to the CVRD in ArcGIS format and/or online through the ALCES Online model. Some of the ALCES Online analysis results are presented and discussed briefly below. Analytic rules used to create these maps are provided in Appendix E.

7.1. ELEVATION

Figure 7-1 shows elevation above sea level in the study area in ALCES Online with a terrain base map, and is an example of the biophysical data imported to allow derivative analyses. Low-elevation areas are primarily associated with the coastline and areas in the plain at the head of Ladysmith harbour, while high-elevation areas are associated with the Woodley Range ridge and western (CWHxm1) edge of the study area.

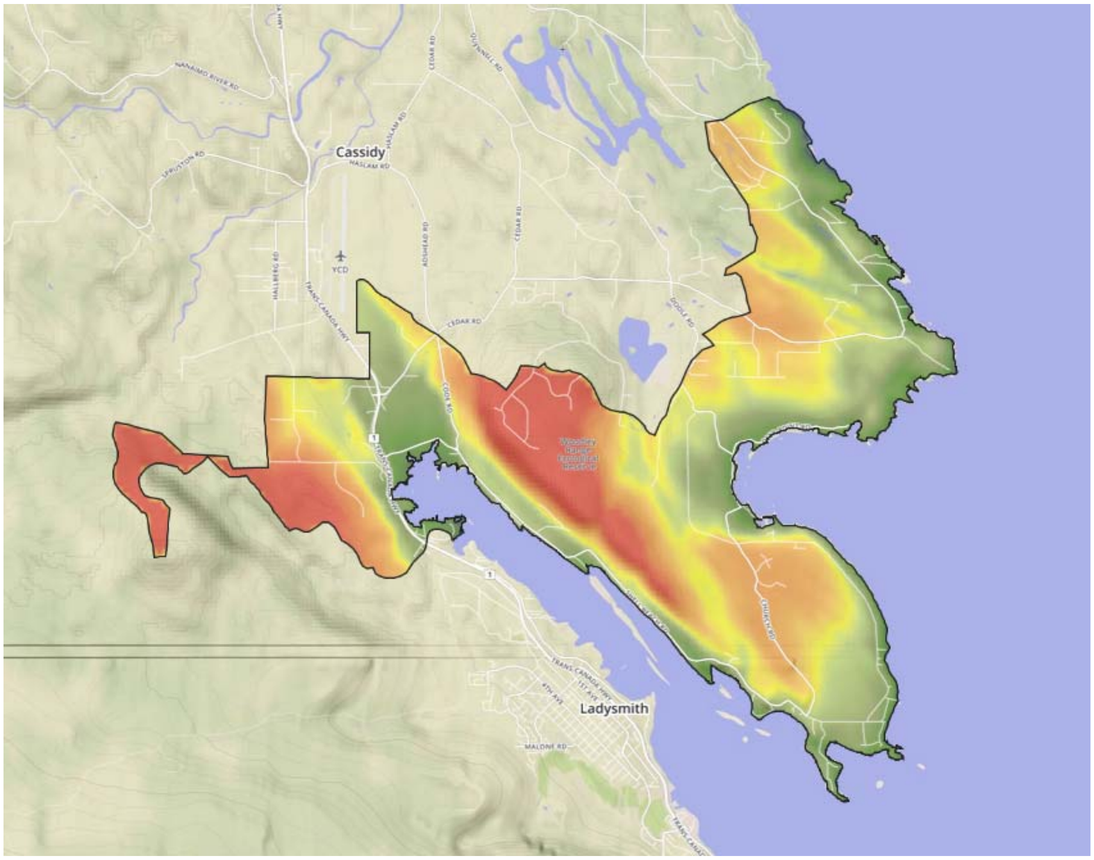

Figure 7-1. Elevation in the Yellow Point – Cedar study area, where dark green indicates areas of lower elevation and dark red indicates areas of higher elevation.

7.2. HUMAN FOOTPRINT

Figure 7-2 shows all types of human footprint in the study area, based on provincial data imported into ALCES Online. Like the biophysical data, these data are used in the model for derivative analyses. Areas of high human footprint are associated with the industrial areas to the south of Cassidy airport, with agricultural areas at the head of Ladysmith harbour and to the south of Michael Lake, and with residential settlement along Yellowpoint Road.

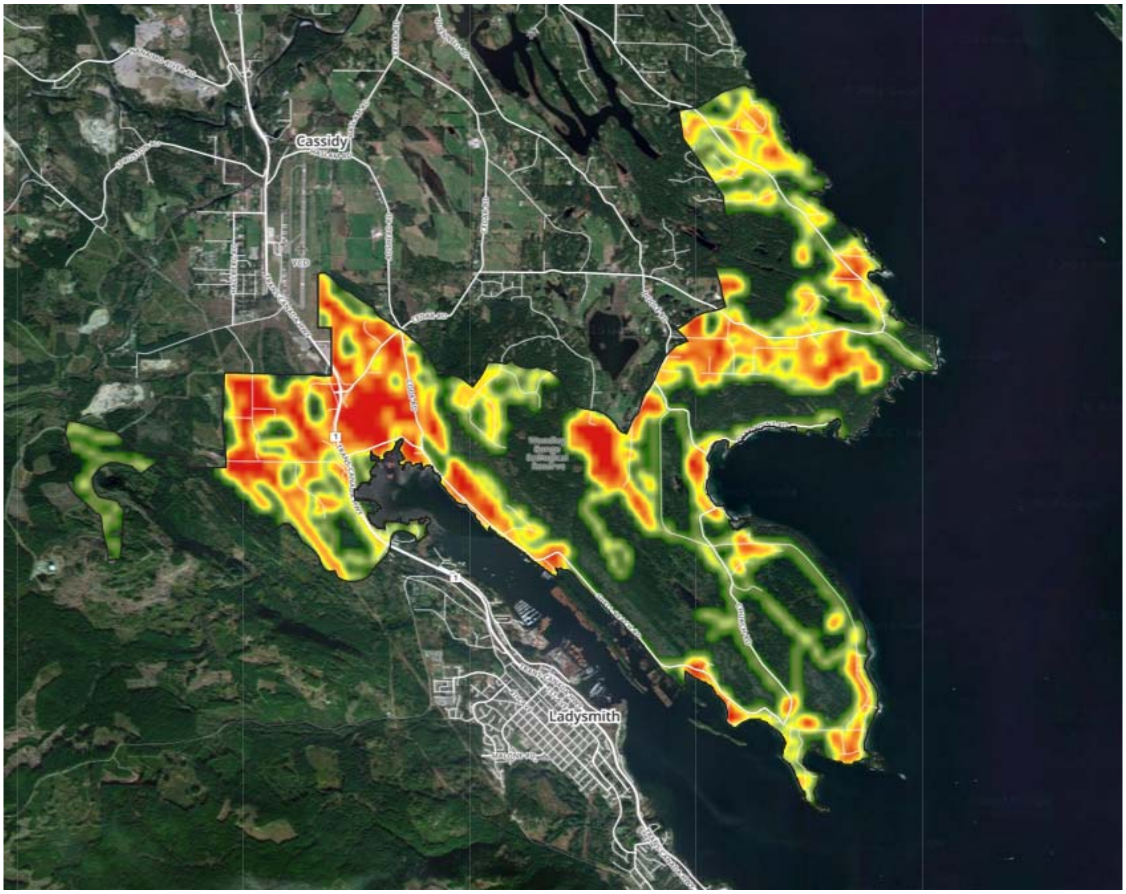

Figure 7-2. Human footprint in the study area, where dark red indicates highest footprint intensity.

7.3. AREAS OF POTENTIAL GROUNDWATER-QUALITY EFFECTS

Figure 7-3 shows identified areas of increased potential surface-water – groundwater interactions, based on methods discussed in Section 3.2 and results discussed in Section 4.2. Areas of highest potential interactions are found in the lowlands at the head of Ladysmith harbour and to the south of Michael Lake. Analytic results in the RDN (Regional District of Nanaimo) should be regarded as preliminary only, as these analyses are based on LIDAR, which was not available for the RDN portion of the study area.

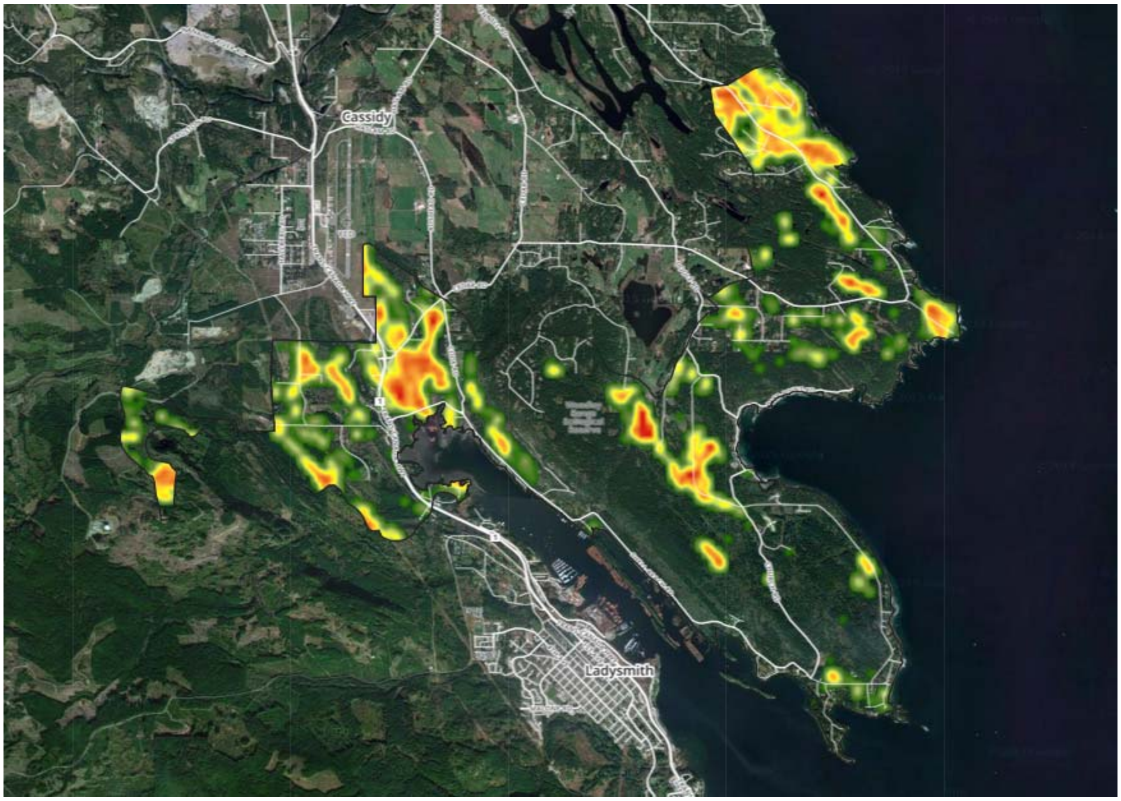

Figure 7-3. Areas of increased potential surface-water – groundwater interaction in the study area, where dark red indicates the greatest potential for interaction.

Figure 7-4 shows areas with increased potential for nutrient and/or contaminant loading in surface runoff. These areas were identified as agricultural areas, where excess nutrients could be generated from chemical fertilizer application and/or animal manure, and other footprint types that could generate nutrients and/or contaminants, such as human residences (generating nutrients from septic fields and residential fertilizer use), and roads (generating hydrocarbons from vehicle leaks). This map is similar but not identical to Figure 7-2, as not all footprint types were designated as potentially nutrient/contaminant-generating.

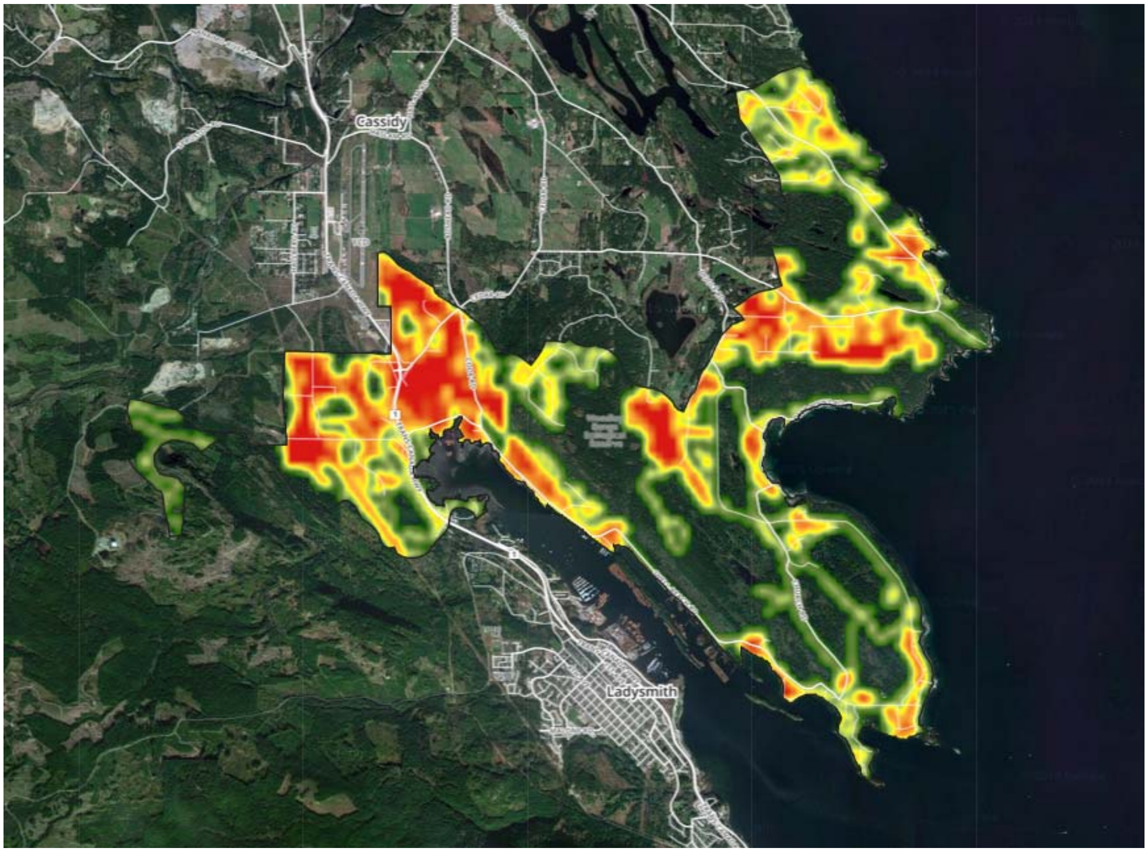

Figure 7-4. Areas on increased potential for nutrient and/or contaminant loading in runoff, where dark red indicates highest potential.

When the analyses represented by Figure 7-3 and Figure 7-4 are combined, we can identify areas of the highest potential for nutrient and/or contaminant loadings in surface water to interact with groundwater - this combined analysis is shown in Figure 7-5.

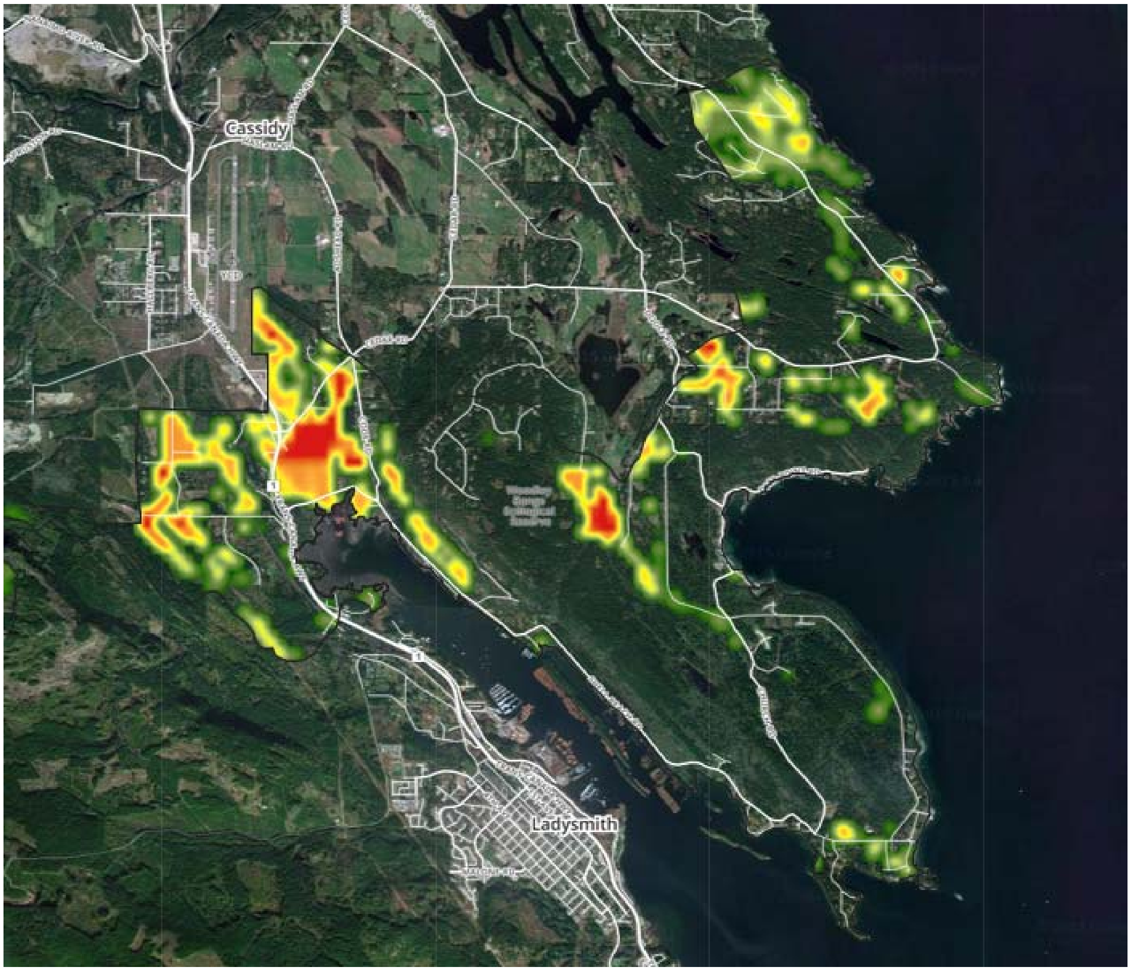

Figure 7-5. Areas of potential groundwater-quality effects, where red indicates zones of highest potential effect, based both on hydrologic interactions and potential nutrient/contaminant generation.

7.4. AREAS OF POTENTIAL WATER-SUPPLY VULNERABILITY

The next sequence of figures shows a progression similar to the previous section, where a biophysical analysis (Figure 7-6) is combined with an analysis of human land use (Figure 7-7) to generate an integrated analysis (Figure 7-8). In this case, areas of reduced groundwater recharge (reduced interaction between surface and groundwater) are shown in Figure 7-6.

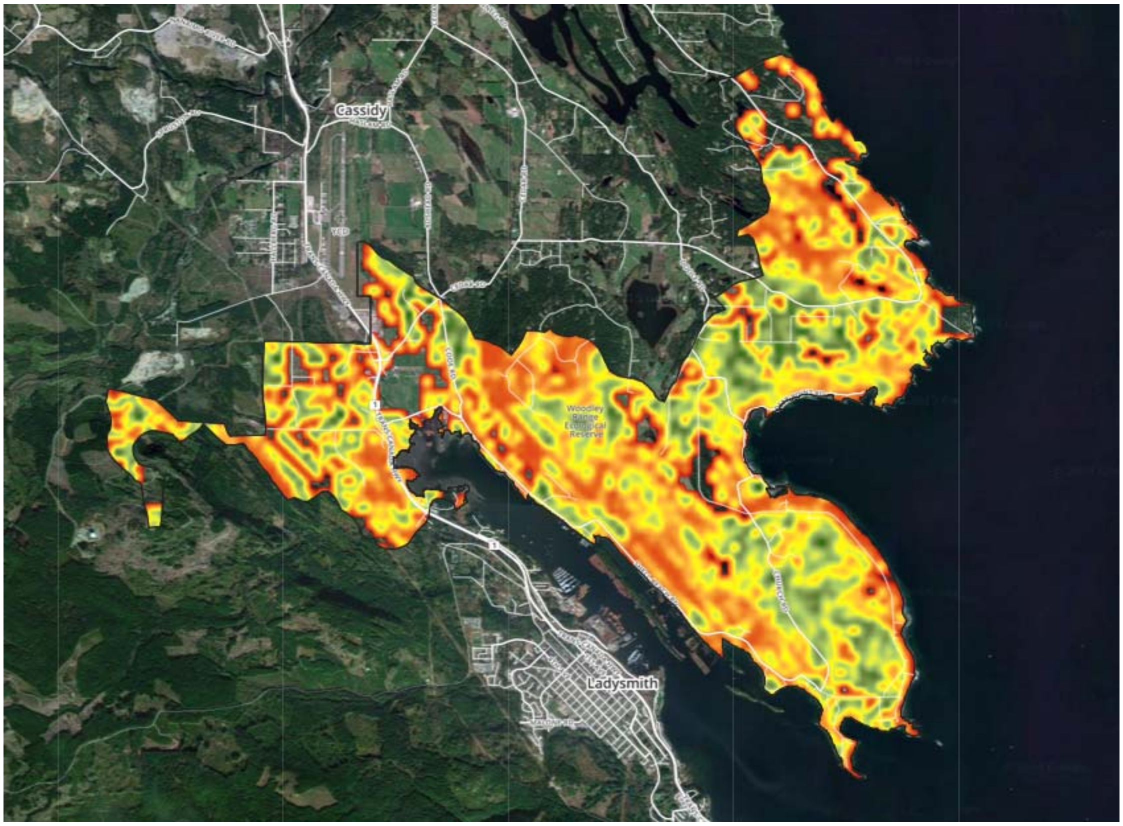

Figure 7-6. Areas of reduced groundwater recharge from surface water, where red colours indicate zones with most limited recharge.

Figure 7-7 shows areas of increased water use, based on information on residential, industrial, and agricultural water demands. Areas of highest use are associated with the agricultural and industrial areas at the head of Ladysmith harbour, and with areas of more concentrated residential settlement throughout the study area.

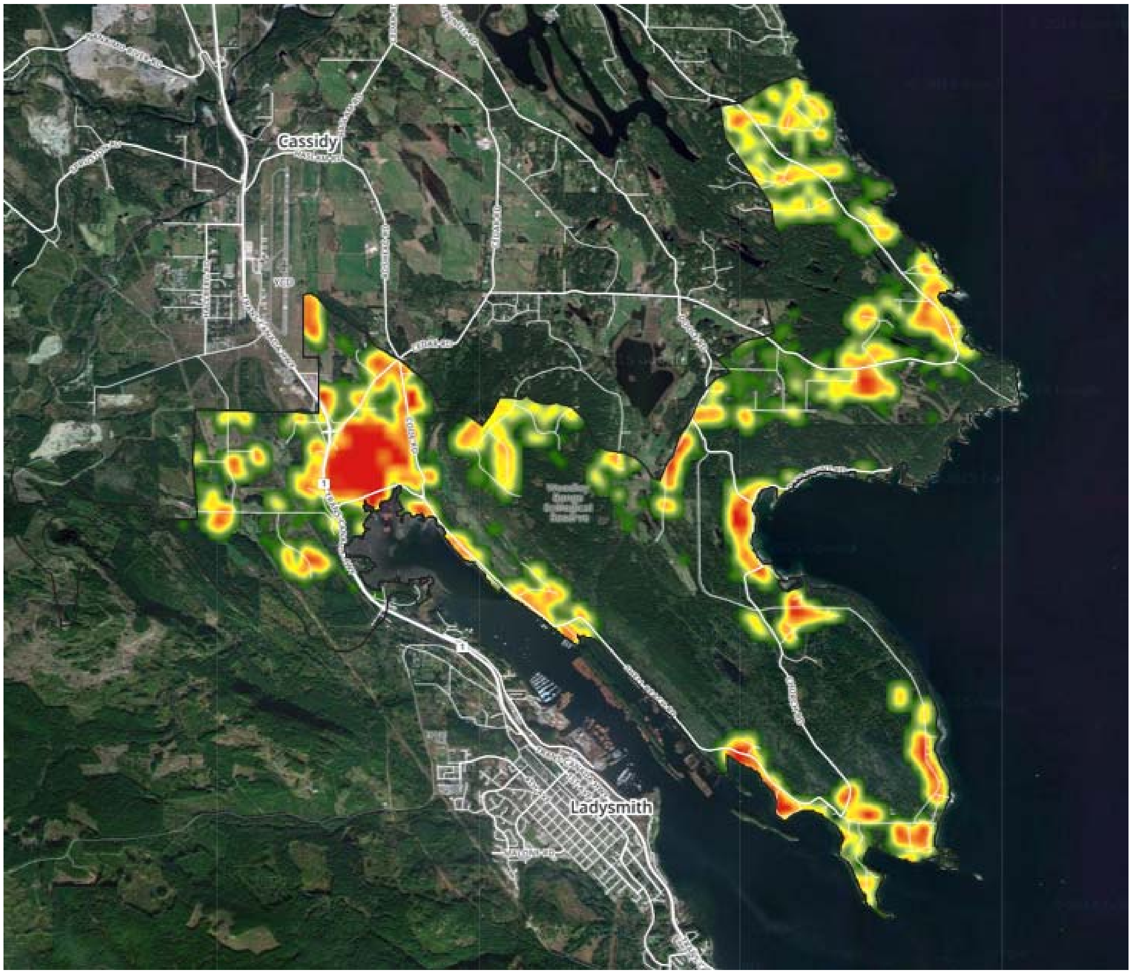

Figure 7-7. Areas of higher water demand, where dark red colours indicate highest water demand.

Figure 7-8 shows areas of increased water-supply vulnerability based on the integrated analysis of biophysical constraints and human use. Areas of highest vulnerability are the residential areas at the north end of Woodley Range, around Kulleet Bay, and at the eastern corner of Yellowpoint Road.

Figure 7-8. Areas of potential water-supply vulnerability based on increased demand and reduced recharge. Yellow-orange-red areas indicate zones of increased vulnerability.

7.5. VEGETATION HEIGHT

The analyses generated in this study can also be used to provide information to help support policy decisions such as potential incentives or "tax-shifting" strategies, and to replicate some of the functionality provided by other tools being used in the region such as the Marxan modelling being conducted by the University of British Columbia. An example is shown in the next two figures.

Figure 7-9 shows mean vegetation height throughout the study area, and generally indicates the predominance of tall intact forests throughout the Stz'uminus reserve, at the eastern corner of Yellowpoint Road, and in the vicinity of Yellow Point park and the Yellow Point Bog ecological reserve.

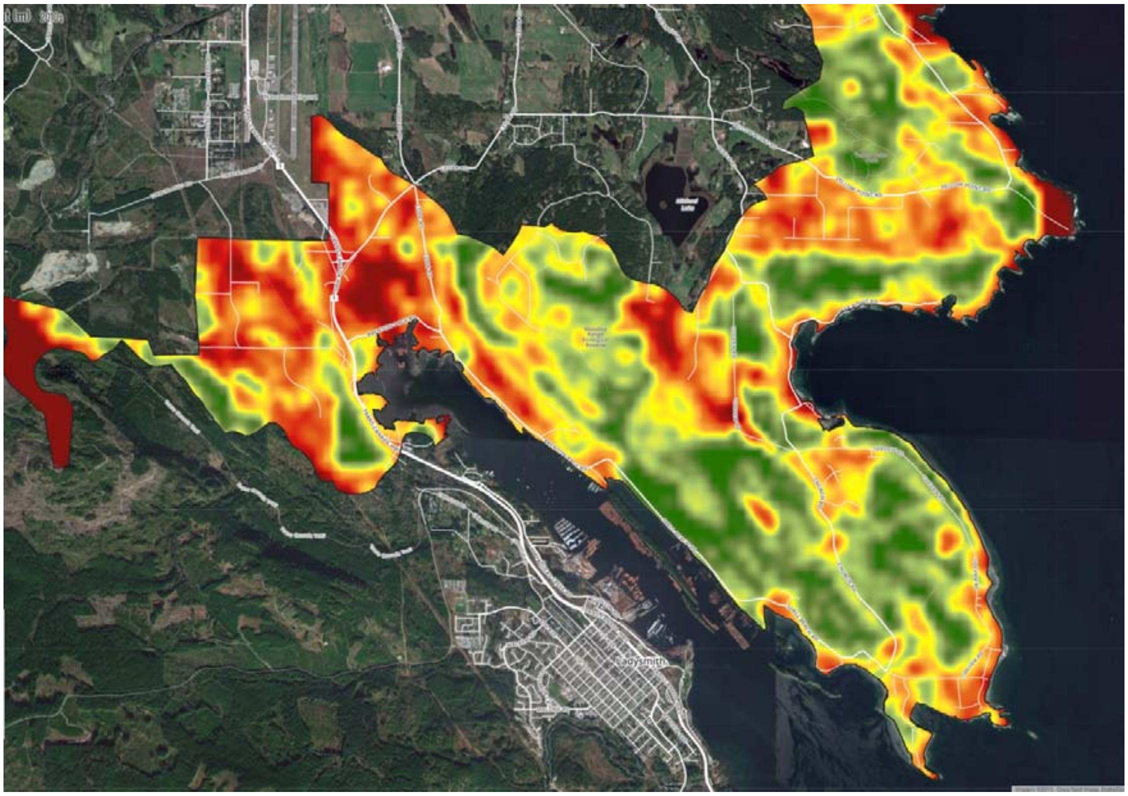

Figure 7-9. Mean vegetation height in the study area, where dark green colours indicate tall vegetation (>20m) and red colours indicate short vegetation (<5m).

In Figure 7-10, the analysis discussed above is presented not by analytic grid cell, but as the mean of these cells by parcel/lot. This analysis is presented as an example of how planners might identify areas with particular environmental characteristics, or the ability to supply desired ecosystem goods and services. In a region where private land ownership is the dominant form of title such as the CVRD, one of the primary management tools available to district staff is mechanisms to encourage desired behaviour in landowners. Mean vegetation height can be used as a proxy indicator of standing carbon, or carbon sequestration. If we wish to encourage or provide incentives for land management that retains this assimilative capacity, we can identify areas by tenure/title in which it is present, and develop retention policies/strategies. In the analysis presented in Figure 7-10, we can see that the primary areas of high standing carbon are the Stz'uminus reserve, the ecological reserves and parks, and certain private parcels in the Woodley Range area and at the eastern corner of Yellowpoint Road. Such analysis could also be used to target parcels for acquisition and conservation, if desired.

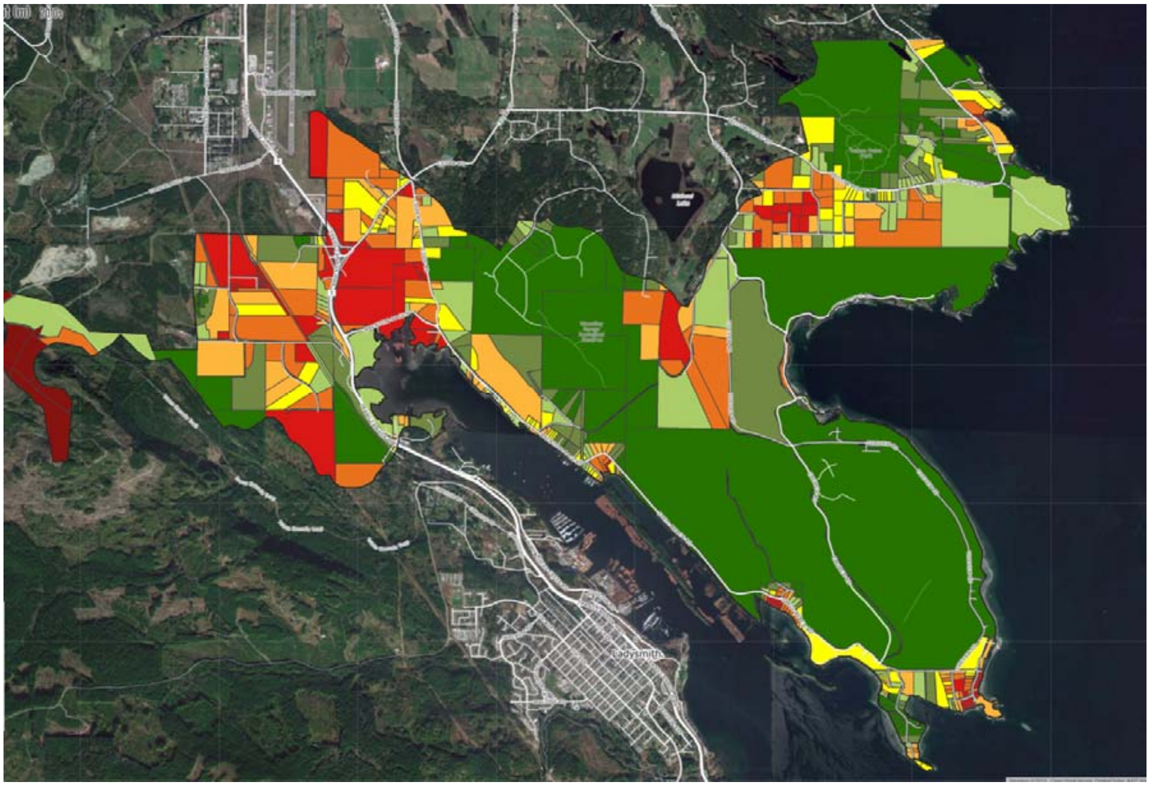

Figure 7-10. Mean vegetation height by parcel. Colour scale is as in Figure 7-9.

The analysis presented above is intended as an example only, as there are many similar analysis that could be conducted for supply of ecosystem goods and services. The analyses already presented around water recharge and supply are examples, and additional work could be conducted around biodiversity metrics and with respect to ecosystem goods and services maintained by agricultural areas.

7.6. AREAS OF HIGH SOLAR-ENERGY POTENTIAL

Information in the Yellow Point – Cedar ALCES Online model can also be used to perform economic analyses based on biophysical characteristics. In Figure 7-11, zones of higher potential for generation of solar (photovoltaic or "PV") energy are identified, based on the assumption that ideal areas for these installations are those with level or southeast-to-southwest-sloping topography (where angles of solar incidence are favourable) and short vegetation heights. Although vegetation can be cleared for PV installations, given other objectives, clearing intact forest for energy installations might not be desirable.

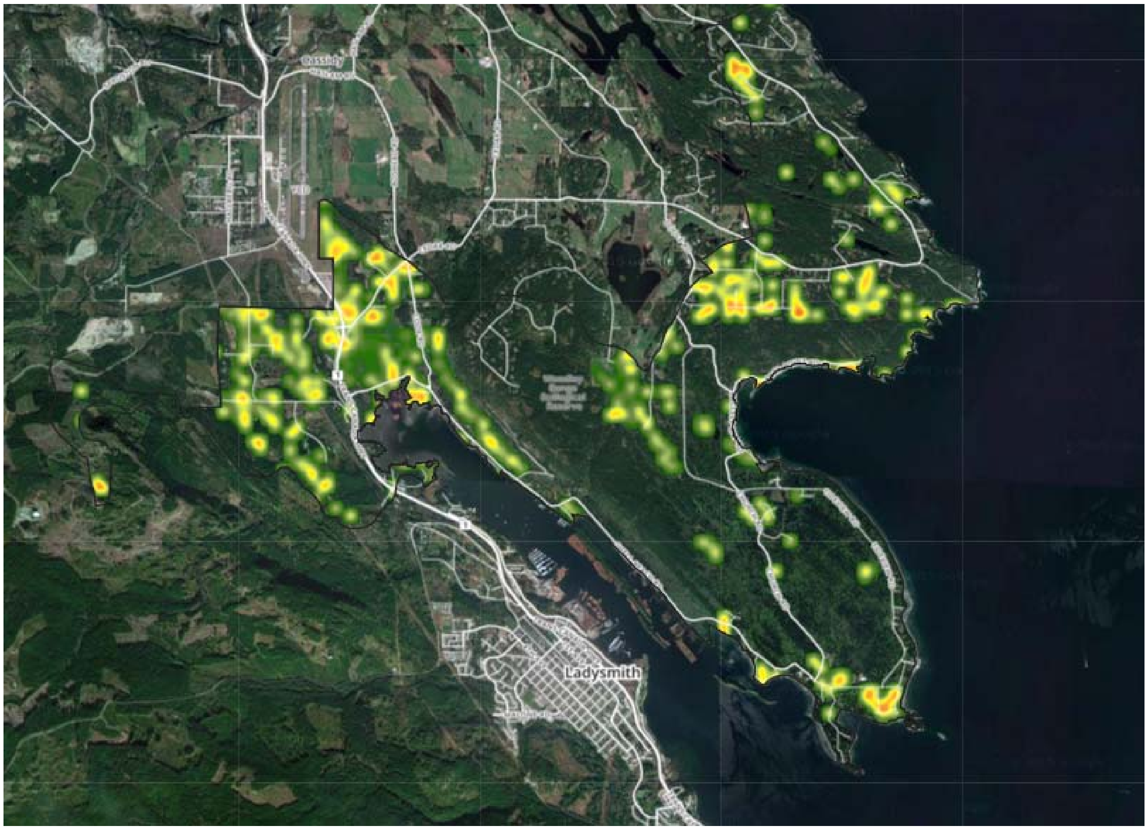

Figure 7-11. Areas of higher solar-energy potential, based on topography and vegetation height.

8. RECOMMENDATIONS AND IDENTIFIED ISSUES

Overall we believe that this project was very successful, and that substantial work was accomplished during a compressed timeframe, due to the commitment and knowledge of project partners, including CVRD Environmental Initiatives Division staff and the Cowichan

Land Trust. The following recommendations are provided with respect to consideration of potential future projects using similar approaches and methods:

- Given access to similar datasets, the approach and analyses used in this project could be conducted throughout the Regional District, and indeed throughout larger surrounding regions. The hydrologic models used in this study are easily transported to other watersheds across Vancouver Island. Predictive ecologic mapping under development as part of this work are largely applicable to the CDFmm biogeoclimatic subzone, and thus would be most directly applicable to other areas in the CDF in the southern and eastern portions of Vancouver Island. Use of predictive ecologic aspects of the ALCES Online model throughout the Regional District or beyond (in CWH areas) would require additional effort on predictive modelling and ground-truthing.
- A large dataset of spatial layers was assembled for this project, with the goal of integrating these data layers in ALCES Online, a web-based GIS and land-use simulator that will be provided to the CVRD by license. We are aware that there are additional ecologic data layers available for the study area that would be excellent to include in ALCES Online, but which we do not have. Principal among these is the biodiversity mapping prepared by Dr. Peter Arcese of the University of British Columbia as part of his work on conservation in the CDF biogeoclimatic zone. Those layers would be an excellent addition to ALCES Online, and include:
    1. various layers associated with birds (old-forest birds, savannah birds, wetland birds, bird β diversity); and
    2. native and exotic Garry-oak and maritime-meadow plant-species richness.
- This project relied substantially on analysis of LIDAR data, but even in this small area the LIDAR data had gaps (Figure 8-1) which caused difficulties in processing these data and in derivative models. If future projects are considered using similar methods, it would be valuable to assess the LIDAR coverage and consider whether any identified gaps could be filled. We realize that this limitation may be beyond control by the CVRD.

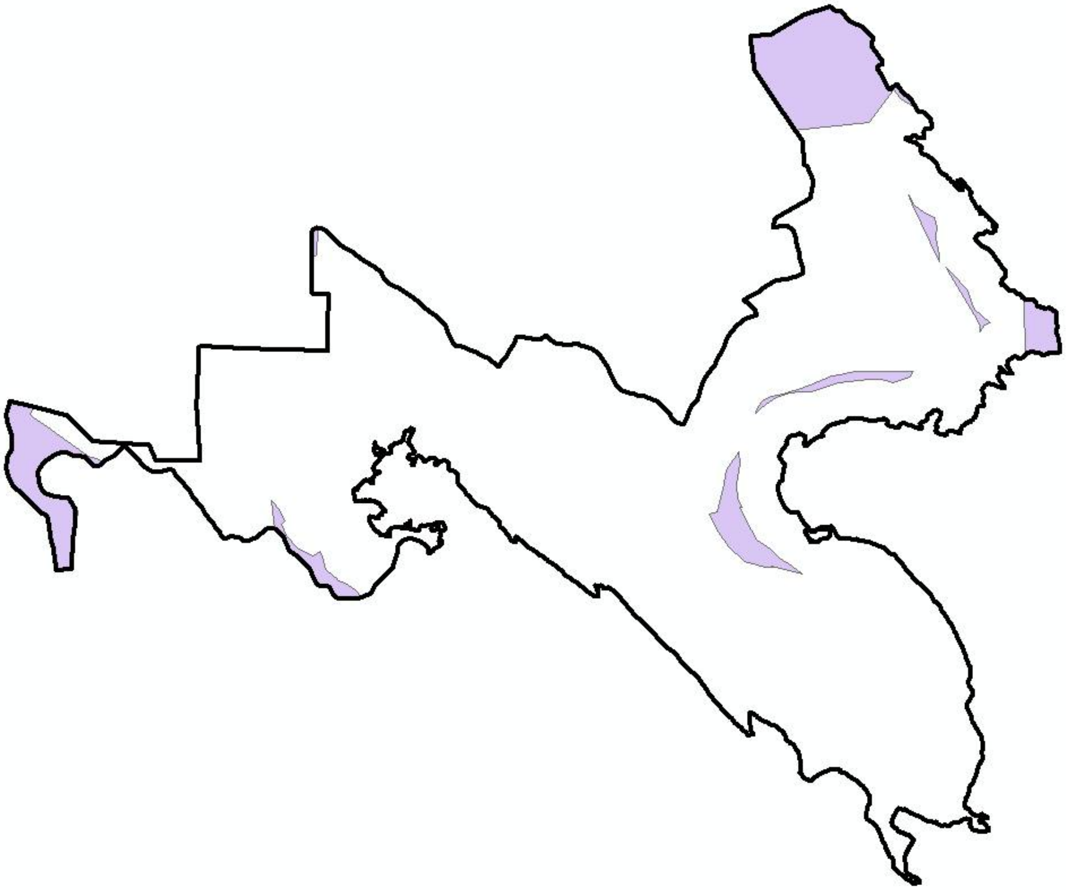

Figure 8-1. Gaps (purple shading) in LIDAR coverage in the study area.

- Some datasets provided as part of this project contained insufficient metadata to allow effective use. We would recommend wherever possible that the CVRD attempt to acquire complete metadata for data from contractors or partners, so that these data may be used in other projects. Again, we realize that these limitations or deficiencies may not be within CVRD control.

9. STATEMENT OF LIMITATIONS

This project and the accuracy of its analyses relies on the accuracy of the data available at the time of project development. Many of the analyses contained in this report and in the supporting ALCES Online model are based on provincial-scale data on anthropogenic footprint contained within the ALCES Online model, and not supplied by the CVRD for this project.[14] Improvement of updating of these data layers may provide different model results with improved accuracy. This limitation applies particularly to data on residential development and water withdrawals within the study area.

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[14] Some data on human land uses, such as agricultural inventory data, were supplied by the CVRD for this work.

APPENDIX A

INFORMATION ON THE WOODLEY RANGE AND YELLOW POINT BOG ECOLOGICAL RESERVES

WOODLEY RANGE ER #142

ORIGINAL PURPOSE	To protect exceptional plant species richness and sensitive meadow and woodland ecosystems developed on cretaceous sandstones

OVERVIEW

Date established:	30 April 1996	**Location:**	2 km N of Ladysmith
ORC #:	4455	**Latitude:**	49º01'N
Map number:	92 G/4	**Longitude:**	123º49'W
Total Area:	166 ha	**Elevation:**	60-180 m

Access:	The reserve is accessible via Aho Road which leads to the western boundary of the reserve, as well as Henry Roethel Road off Aho Road which leads to the northern boundary of the reserve.

Biogeoclimatic Zone:	Coastal Douglas-Fir (CDF)
Biogeoclimatic Variant:	CDFmm Moist Maritime
Ecosection:	Nanaimo Lowlands
Region:	Vancouver Island
Management Area:	Qualicum

COMPOSITION

Physical:

Woodley Range is a prominent NW-SE-oriented ridge with a steep escarpment to the southwest, facing the head of Ladysmith Harbour, and more gentle, smooth slopes towards the northeast. The reserve is located on the moderate NE-facing slopes, except for the extreme southwestern corner which overhangs the escarpment. Soils are generally shallow and are derived from underlying sandstone bedrock and conglomerates of the De Courcy Formation.

Biological:

The vegetative cover of the reserve is divided between forest, open and dry meadows, and wetlands. The open meadows are of particular interest as they provide most of the plant species richness. Glacier-polished, smooth sandstones with very shallow soils and localized springtime seepage support colourful spring flora and rare plant occurrences. Drought and fire have very important functions in maintaining the present vegetation pattern in both the meadows and the forested portions. Forests on Woodley Range are mostly second- growth dry Douglas-fir and arbutus forests developed after logging and/or fire. On sites where water drainage is relatively slow, soils are nutrient rich and stands are dominated in their earlier stages by deciduous trees, including bigleaf maple and red alder. In later successional stages or where residual trees were left during logging, western redcedar, grand fir, western hemlock, and Douglas- fir predominate. The understory is dominated by herbs and include sword fern and vanilla-leaf. Small-forested wetlands occur in a few areas of the reserve, with salmonberry and herb layers of ferns,

skunk cabbage, and slough sedge.
A larger, open wetland is located in the flat area in the western part of the reserve. This is the only portion of the reserve that drains to the southwest, down the steep escarpment. It supports stands of hardhack, crab apple and willows. Bog bird's –foot trefoil (*Lotus pinnatus*) occurs in the stream exiting the wetland.

Naturally tree-less upland areas are rare on Vancouver Island and this is an area where open glades and meadows on very shallow soils provide habitat for many plant species and several plant communities that are uncommon in the surrounding landscape. The reserve protects a diversity of 187 vascular plant species; 27 of these species are considered at least regionally rare. Rare plant species include: dune bentgrass, slim-leaf onion, white-top aster, green-sheathed sedge, Nuttall's quillwort, Howell's violet, and bog bird's-foot trefoil.
Rare wildlife include Turkey Vulture, Big-eared Bat and Keen's Long-eared Myotis.

Cultural: No known cultural sites are present in the reserve. However, many of the plant species present were used by First Nations and it is likely that they gathered plant material in both the meadow and the forest.

MANAGEMENT CONCERNS

SIGNIFICANT SPECIES	BC LIST STATUS	COSEWIC STATUS	CF PRIORITY
dune bentgass			2
slimleaf onion	Blue listed		2
white-top aster	Red listed	Special Concern (2009)	1
green-sheathed sedge	Red listed		2
Nuttall's quillwort	Blue listed		2
Howell's violet	Blue listed		2
bog bird's-foot trefoil	Red listed	Endangered (2004)	1
Turkey Vulture			5
Townsend's Big-eared Bat	Blue listed		2
Keen's Myotis	Red listed	Data Deficient (2003)	1

THREATS

Climate Change: Increased temperatures and changes to rainfall patterns have the potential to dry out wetlands and change ecosystems. In this reserve the management decisions that will positively affect the future outcome of ecosystem changes are related to managing invasive species and human impacts. The compaction from heavily used trails can potentially change natural water flows.

Recreation: Illegal recreational activities such as ATV and motorbike use of trails and equestrian use are negatively impacting ecosystems through degradation of vegetation, trail erosion and noise pollution.

	Intense use of unofficial trials by hikers is causing erosion.
Adjacent land Use	Recent developments along ER boundary could see an increase in trespass issues from adjacent property owners such as dumping or encroachment.
Transportation	The nearby Cassidy Airport is creating noise pollution from the take-off and landing of planes. A right of way goes through the southern part of the reserve. Any use of this right of way will fragment the already small reserve.
Non-native species:	Bull frogs have invaded the wetlands and are dominating the ecosystem. Scotch broom is located in some of the meadows that are habitat for listed species such as Bog bird's-foot trefoil and white-top aster. The ER Warden has been trying to keep it under control. There is potential for the invasion of carpet burweed which could change the character of native ecosystems. This species is introduced by human vectors when seeds are carried in on boots. It generally colonizes disturbed areas.
RESEARCH OPPORTUNITIES	This reserve supplies a reference area for the CDFmm. Monitoring changes in either the terrestrial or wetland ecosystems will help with an understanding of the changes we are seeing due to climate change and can help in ecosystem management decisions throughout the zone.

SCIENTIFIC NAMES OF SPECIES MENTIONED IN THE WOODLEY RANGE ER ACCOUNT

Flora

alder, red (*Alnus rubra*)
arbutus (*Arbutus menziesii)*
aster, white-top (*Aster curtus)*
bentgrass, dune (*Agrostis pallens)*
burweed , carpet *(Soliva sessilis)*
cabbage, skunk (*Lysichiton americanus)*
cottonwood, black (*Populus balsamifera ssp. trichocarpa*)
crab apple, Pacific (*Malus fusca)*
Douglas-fir (*Pseudotsuga menziesii)*
fern, sword (*Polystichum munitum)*
fir, grand (*Abies grandis*)
hardhack (*Spiraea douglasii* ssp. *douglasii)*
hemlock, western (*Tsuga heterophylla)*
maple, bigleaf (*Acer macrophyllum)*
onion, slimleaf (*Allium amplectens)*
quillwort, Nuttall's (*Isoetes nuttallii)*
redcedar, western (*Thuja plicata)*
salmonberry (*Rubus spectabilis*)
sedge, green-sheathed (*Carex feta)*

sedge, slough (*Carex obnupta)*
skunk cabbage (*Lysichiton americanus)*
trefoil, bog bird's-foot (*Lotus pinnatus)*
vanilla-leaf (*Achlys triphylla)*
violet, Howell's (*Viola howellii)*
willow (*Salix spp.)*

Fauna
Bat, Townsend's Big-eared (*Corynorhinus townsendii)*
Bullfrog (*Rana catesbeiana*)
Frog, Northern Red-legged (*Rana aurora)*
Myotis, Keen's (*Myotis keenii)*
Vulture, Turkey (*Cathartes aura)*

YELLOWPOINT BOG ER #139

ORIGINAL PURPOSE To protect a highly diverse mosaic of ecosystem types from aquatic, peat bog and forest to dry-site ecosystems

OVERVIEW

Date established:	30 April 1996	**Location:**	10 km S of Nanaimo
ORC #:	4471	**Latitude:**	49º02’N
Map number:	92 G/2	**Longitude:**	123º46’W

Total Area:	138 ha	**Elevation:**	40-80 m
Land:	138 ha		

Biogeoclimatic Zone:	Coastal Douglas-Fir (CDF)
Biogeoclimatic Variant:	CDFmm Moist Maritime
Ecosection:	Nanaimo Lowlands
Region:	Vancouver Island
Management Area:	Qualicum

COMPOSITION

Physical: The reserve comprises gently undulating lowlands formed by glacially scoured rocks of the cretaceous Nanaimo Formation. For the most part the cover of surficial deposits and soils on the NW-SE –trending, rounded ridges is very thin and some portions show open rock outcrops. Small lakes, ponds and wetlands occupy the depressions. A stream originating in Long Lake diagonally traverses the rectangular reserve from NW to SE. It forms a steep gully in its mid-section.

Biological: Sloughs, marshes and ponds, many of which have been dammed by the resident beaver population, cover about 10% of the property. Except for small, open meadows and rock outcrops, the remainder is forested.
Major documented plant communities include open Douglas-fir – Arbutus forests, Douglas-fir – Salal, western redcedar – swordfern, and red alder – slough sedge forests. Sweet gale – peatmoss, Labrador tea – peatmoss, pond lily – watershield and a variety of other, smaller-scale fen and marsh communities are associated with wet areas and open water. These sensitive ecosystems provide a habitat to rare and endangered bog plants, notably the humped bladderwort (Utricularia gibba), slender-spike mannagrass (Glyceria leptostachya) and the BC endemic Vancouver Island beggarticks (Bidens amplissima). Elsewhere in the reserve, shallow, dry soils are occupied by moss/grass meadows and several Garry oak trees. These meadows are home to a wide variety of mosses, spring wildflowers, and grasses.

Most of the forests were logged about 80 years ago. However, impressive pockets of mature cedar and grand fir remain east of Long Lake.

This area provides habitat for waterfowl and aquatic mammals such as beavers and otters. Small-mouth Bass, Pumpkin-seed Sunfish and Cutthrout Trout are likely residents in the lakes. Black-tailed Deer are resident.

Cultural: Unconfirmed report of an early logging camp used by Chinese workers that were also employed on railroad construction in the area during the late 1890s.

MANAGEMENT CONCERNS

SIGNIFICANT SPECIES	BC LIST STATUS	COSEWIC STATUS	CF PRIORITY
humped bladderwort			4
slender-spike mannagrass	Blue listed		2
Vancouver Island beggarticks	Blue listed	Special Concern (2001)	1
Beaver			5

THREATS

Climate Change: Wetlands are one of the most at-risk ecosystems in a warmer climate due to increased evaporation and changing precipitation patterns. Maintenance of the Beaver population will help keep the area a wetland.

Non-native species: Bull Frogs have invaded the wetlands and are dominating the ecosystem and preying on blue-listed, CF Priority 1, Red-legged Frogs.

Pumpkinseed and Smallmouth Bass are likely residents in the lakes. They will change the ecosystem by eating eggs of native amphibians.

There is potential for the invasion of carpet burweed (*Soliva sessilis*) which could change the character of native ecosystems. This species is introduced by human vectors when seeds are carried in on boots. It generally colonizes disturbed areas.

Recreation: Illegal recreational activities such as ATV and motorbike use of trails and equestrian use are negatively impacting ecosystems through degradation of vegetation, trail erosion and noise pollution. The reserve is adjacent to a regional park with connecting trails and is a popular area with the local population.

RESEARCH OPPORTUNITIES With a known population of beavers that are maintaining much of the area as a wetland, it would be a good area to investigate the efficacy of beavers as wetland keepers in a warming climate.

SCIENTIFIC NAMES OF SPECIES MENTIONED IN THE YELLOWPOINT BOG ER ACCOUNT

Flora

alder, red (*Alnus rubra)*
beggarticks, Vancouver Island (*Bidens amplissima)*
bladderwort, humped (*Utricularia gibba)*
Douglas-fir, coast (*Pseudotsuga menziesii* var. *menziesii)*
fern, sword (*Polystichum munitum)*
fir, grand (*Abies grandis*)
gale, sweet (*Myrica gale)*

Labrador tea (*Ledum groenlandicum)*
mannagrass, slender-spike (*Glyceria leptostachya)*
moss, peat *(Sphagnum spp.)*
oak, Garry (*Quercus garryana)*
redcedar, western (*Thuja plicata)*
salal (*Gaultheria shallon*)
sedge, slough (*Carex obnupta)*
water shield (*Brasenia schreberi)*

Fauna
Bass, Smallmouth (*Micropterus dolomieu)*
Beaver, American (*Castor canadensis)*
Deer, Black-tailed *(Odocoileus hemionus* ssp. *hemionus)*
Frog, Northern Red-legged (*Rana aurora)*
Pumpkinseed (*Lepomis gibbosus)*
Trout, Cutthroat (*Oncorhynchus clarkii)*

APPENDIX B

METHODS AND RESULTS OF PREDICTIVE ECOLOGIC MODELLING

Building Predictive Models for Rare Ecosystem Types in CVRD

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Background

The task was to identify statistical relationships between covariates and rare ecosystem types for use in predictive ecosystem mapping.

The response variables (i.e., ecosystem types) are:

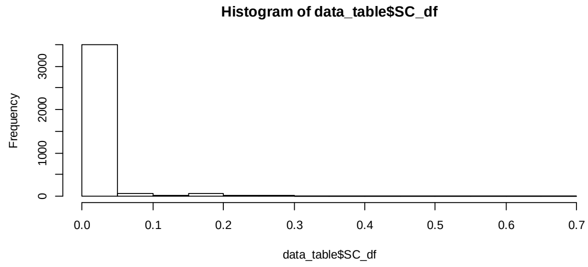
- xeric (SC, DA, FC, QB, RO)
- each xeric ecosystem type on its own
- treed xeric (QB, DA)
- non-treed xeric (SC, FC, RO)
- hygric-hydric (RC, CS, Wf, Wm, Ws)
- each hygric-hydric ecosystem type on its own
- treed hygric-hydric (RC, CS, Ws)
- non-treed hygric-hydric (Wf, Wm)

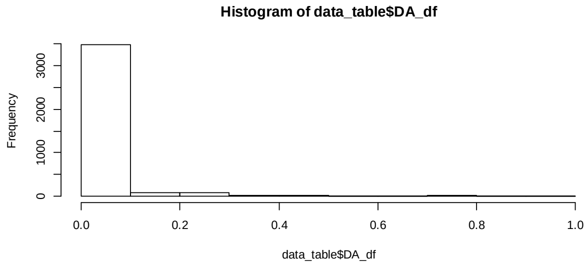
The candidate covariates are:

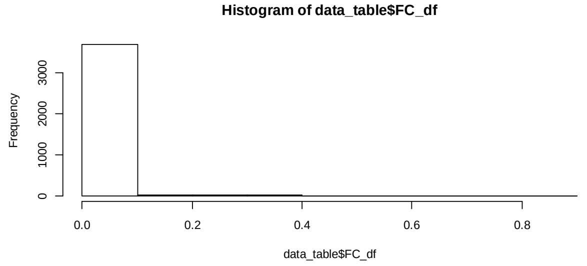
- Mean_GWSW
- Elevation (min, max, mean)
- Aspect (min, max, mean)
- Slope (min, max, mean)
- Canopy height (min, max, mean)
- Slope position 1, 2, 3, 4, 5, and 6 (each as individual covariates)

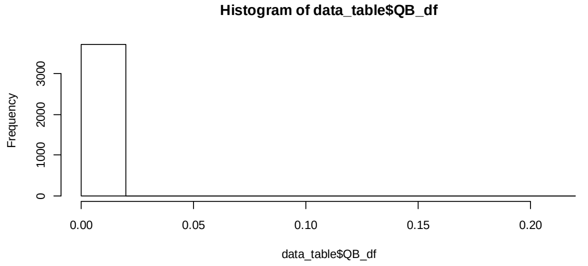
Step 1: response variable distributions

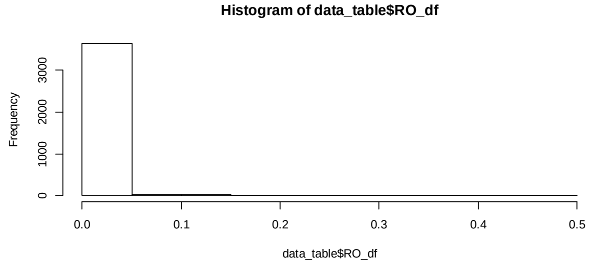
The histograms below show the frequency of various levels of proportional abundance for each ecosystem type. The ecosystem types do not occur in many cells. As well, even when the ecosystem types are present, coverage is almost always less than 50% of a cell. This is of concern because it implies that spatial pattern of the ecosystem types occurs at a scale finer than a cell, which may weaken our ability to identify relationships using cell-based data.

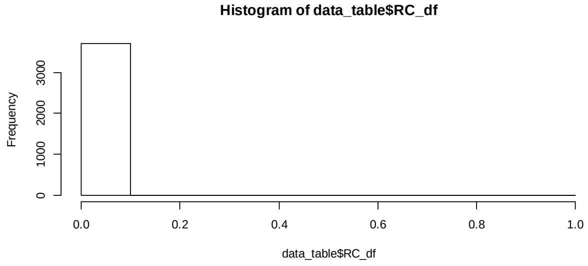


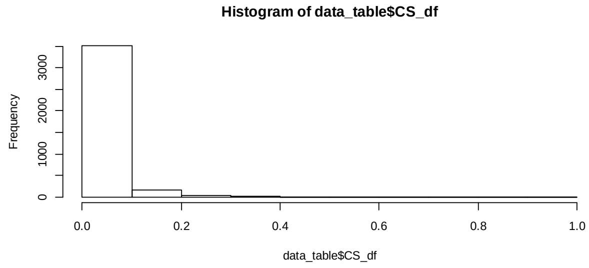


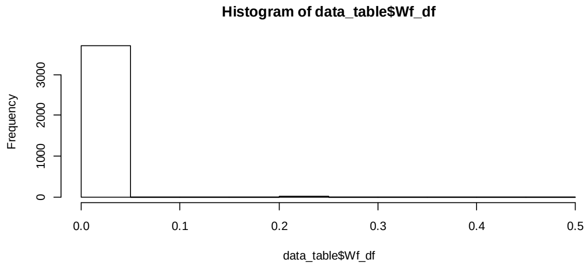


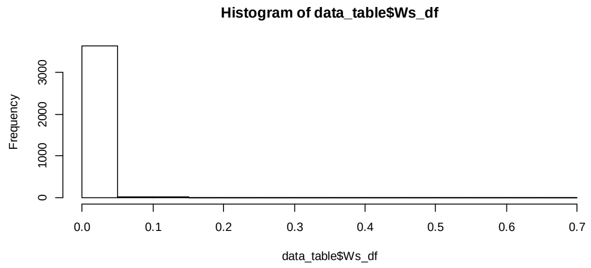


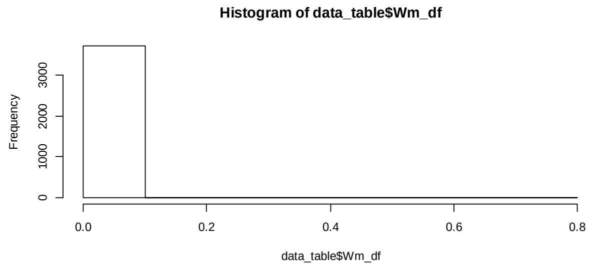


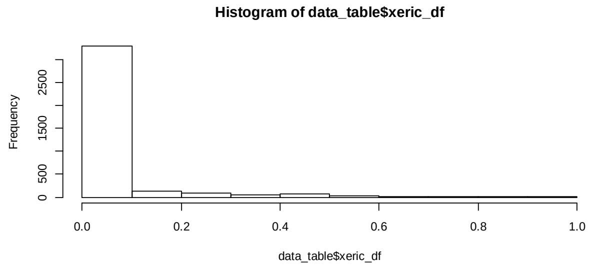


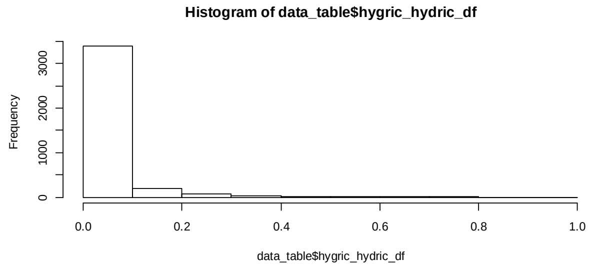


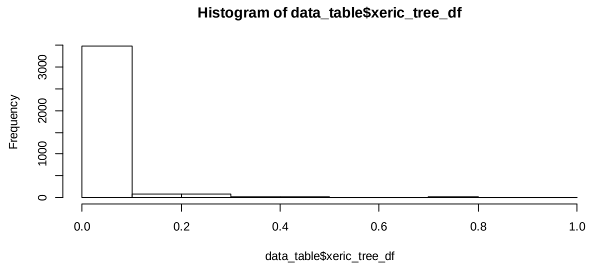


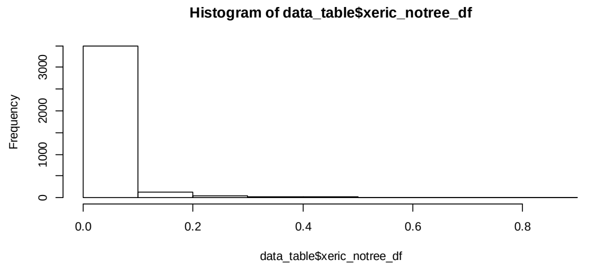


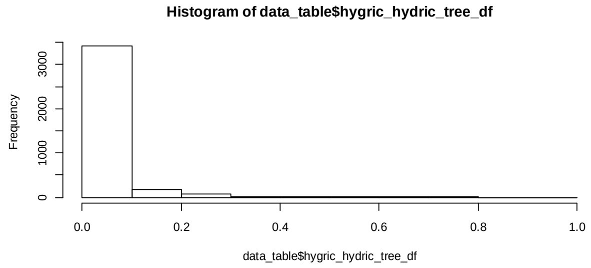


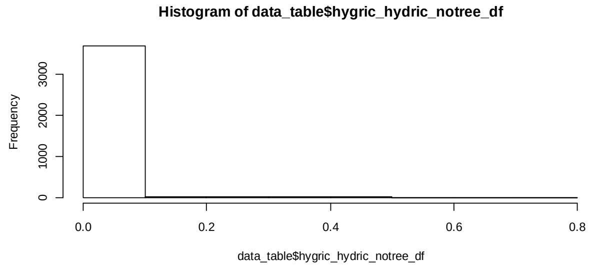












Step 2: explore multi-collinearity

Multi-collinearity was evaluated using variance inflation factors. Variance inflation factor is problematic (>4) for elevation variables and slope variables. Removing elevation min and max and slope min and max eliminates the problem.

Step 3: correlations between ecosystem types and covariates

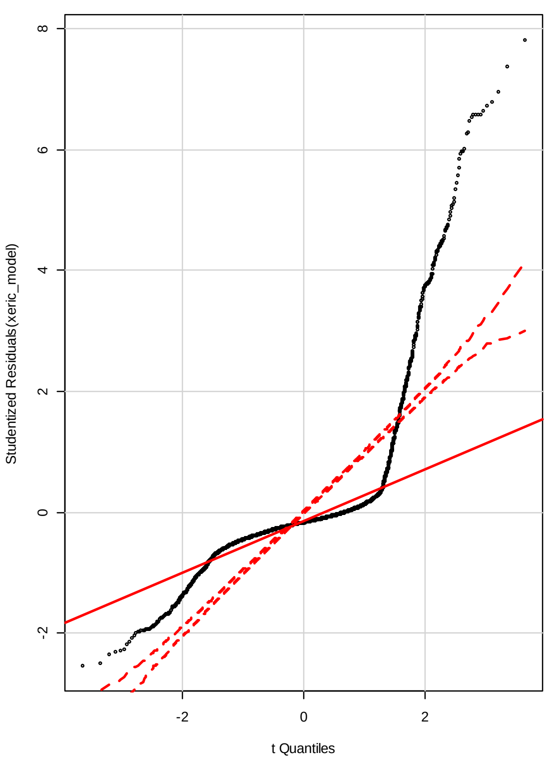
Correlations are low (<0.2), with a few exceptions.

Ecotypes	Mean_GWSW	ElevationMean	AspectMin	AspectMax	AspectMean	SlopeMean	SlopePosition1_m2	SlopePosition2_m2	SlopePosition3_m2	SlopePosition4_m2	SlopePosition5_m2	SlopePosition6_m2	CanopyHeightMean	CanopyHeightMin	CanopyHeightMax
SC	-0.09	0.41	0.03	-0.31	-0.23	0.13	0.18	0.06	0.17	-0.2	-0.04	-0.01	0.06	-0.01	0.01
DA	-0.11	0.16	0.19	-0.15	0.02	0.32	0.36	0.24	-0.04	-0.18	0.06	0.05	0.13	0	0.06
FC	-0.02	-0.07	0	-0.01	0.02	0	-0.01	-0.02	-0.01	-0.04	-0.02	-0.01	-0.06	0	-0.04
QB	-0.02	0.05	0	0	0	0.06	0.22	0.07	-0.05	-0.03	-0.01	0	0.01	0	0
RO	-0.09	-0.14	0.14	-0.13	0.04	0.05	-0.02	-0.03	-0.19	-0.11	-0.02	-0.02	-0.15	-0.01	-0.23
RC	-0.01	-0.06	-0.02	0.02	0.01	-0.04	-0.01	-0.02	-0.02	0.04	0.05	-0.01	0.03	0	0.01
CS	-0.07	-0.09	-0.05	0.06	-0.02	-0.07	-0.04	-0.01	0.03	0.03	0.02	0.02	0.17	-0.01	0.11
Wf	0.02	-0.01	-0.01	0.01	-0.02	0	-0.01	-0.01	-0.01	0.01	0.03	-0.01	-0.03	0	0.01
Wm	0.04	-0.01	-0.01	0.02	0.03	-0.03	-0.01	-0.02	0.02	0.02	-0.02	-0.01	-0.05	0	-0.04
Ws	0.16	-0.02	-0.03	0.04	0.01	-0.03	-0.01	-0.01	-0.01	0.02	0.11	-0.02	-0.03	-0.01	0.04
xeric	-0.15	0.23	0.2	-0.28	-0.07	0.31	0.34	0.19	-0.02	-0.26	0.02	0.02	0.07	-0.01	-0.03
hygric_hydric	0.05	-0.1	-0.06	0.07	0	-0.08	-0.04	-0.03	0.01	0.06	0.09	0	0.08	-0.01	0.08
xeric_tree	-0.11	0.16	0.19	-0.15	0.02	0.32	0.37	0.24	-0.04	-0.18	0.06	0.05	0.13	0	0.06
xeric_notree	-0.12	0.21	0.1	-0.3	-0.14	0.12	0.12	0.02	0.03	-0.23	-0.05	-0.02	-0.05	-0.01	-0.13
hygric_hydric_tree	0.03	-0.1	-0.06	0.07	-0.01	-0.08	-0.04	-0.02	0.01	0.05	0.09	0	0.11	-0.01	0.1
hygric_hydric_notree	0.04	-0.02	-0.02	0.02	0.02	-0.03	-0.01	-0.02	0.01	0.03	0	-0.01	-0.06	0	-0.03

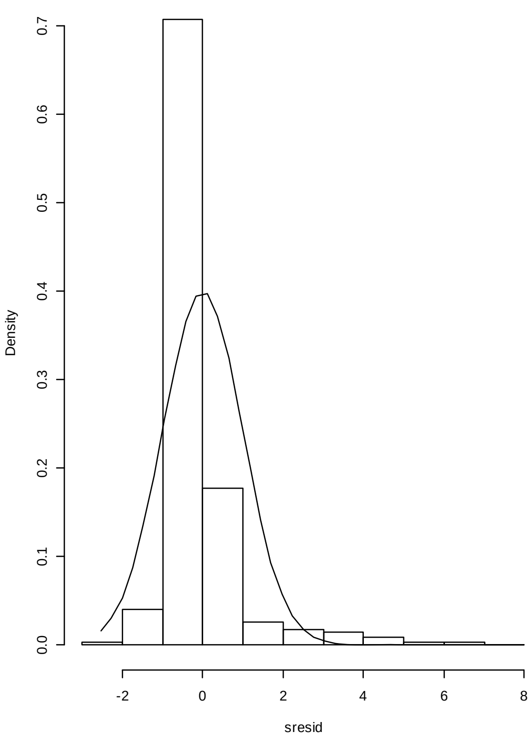
Step 4: multiple linear regression

Attempt multiople linear regression for xeric ecosystem type. Coefficients for Mean_GWSW and AspectMin are not significant, so remove. Resulting model has low R2, and residuals are non-normal and heteroscedastic. Conclude that linear regression is not appropriate.

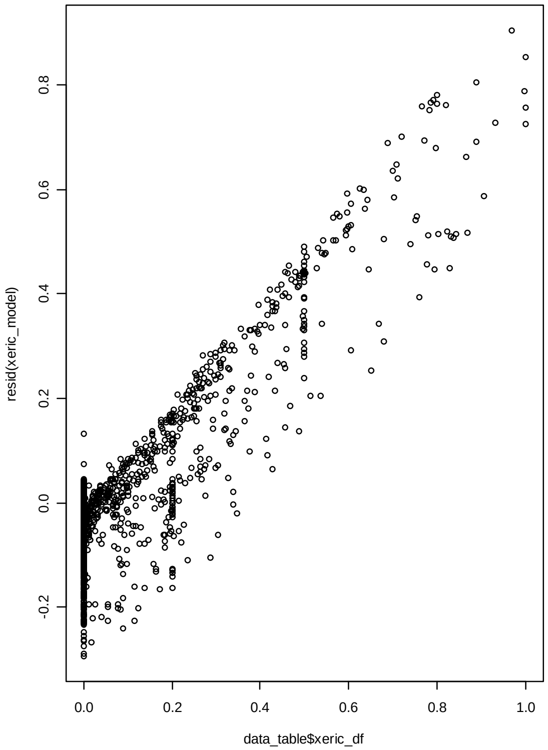
```
Coefficients:
                    Estimate Std. Error t value Pr(>|t|)
(Intercept)        2.511e-01  1.916e-02  13.100  < 2e-16 ***
ElevationMean      1.469e-04  5.429e-05   2.706  0.00684 **
AspectMax         -5.372e-04  5.074e-05 -10.586  < 2e-16 ***
AspectMean        -1.037e-04  3.877e-05  -2.676  0.00748 **
SlopeMean          1.848e-03  2.194e-04   8.424  < 2e-16 ***
SlopePosition12_m2   2.223e-05  1.753e-06  12.678  < 2e-16 ***
SlopePosition3_m2    2.094e-06  9.675e-07   2.165  0.03048 *
SlopePosition456_m2 -3.237e-06  1.103e-06  -2.934  0.00337 **
CanopyHeightMean     1.086e-03  3.852e-04   2.820  0.00482 **
CanopyHeightMin     -6.065e-03  2.318e-03  -2.617  0.00890 **
CanopyHeightMax     -1.685e-03  2.932e-04  -5.747 9.79e-09 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.1168 on 3712 degrees of freedom
Multiple R-squared:  0.2084,    Adjusted R-squared:  0.2063
F-statistic: 97.74 on 10 and 3712 DF,  p-value: < 2.2e-16
```



QQ Plot



Distribution of Studentized Residuals



Step 5: logistic regression

Due to the prevalence of 0's, convert to binary (i.e., ecosystem absence=0 and ecosystem presence=1) and use logistic regression. The logistic function is of the form:

$$F(x) = \frac{1}{1 + e^{-(\beta_0 + \beta_1 x_1 + \cdots)}}$$

where F(x) is the probability of an ecosystem type occurring in a cell, β_0 is the intercept term, and β_1, β_2, etc. are coefficients for covariates x_1, x_2, etc.

When fitting models, stepwise forward selection using AIC was used to decide which covariates should be included. Results for each ecosystem type[1] are presented in the table on the next page. Model discrimination is summarized using with a pseudo R2 (Nagelkerke R2) and the concordance index. The concordance index (C) is interpreted as the proportion of times when the model predicts a higher probability of ecosystem presence when the ecosystem is present. C=0.5 means no discrimination; 0.7<=C<0.8 means acceptable discrimination; 0.8<=C<0.9 means excellent discrimination; and C>=0.9 mean outstanding discrimination[2]. Model coefficients are also provided in the table. All coefficients shown are significant at p<0.05 except the following: * p<0.1, **p<0.2, ***p>0.2

For xeric ecosystem types, model discrimination was better for individual ecosystem type (i.e., SC, DA, FC, RO) models than it was for the aggregate model (i.e., xeric). Therefore, it is preferable to use separate models for each xeric ecosystem type. For hygric-hydric ecosystems, however, models could not be fit for most separate ecosystem types. Therefore, it is preferable to use the aggregate hygric-hydric ecosystem model. In general, model fit was substantially better for xeric ecosystem types than hygric-hydric ecosystem types.

---

[1] Model fitting did not converge for some ecosystem types, likely due to their rarity. These include QB (4 presences), Wf (14 presences), Wm (29 presences), Ws (135 presences), and hygric_hydric not treed (43 presences). As well, xeric treed and xeric not treed are not included because model discrimination did not differ substantially from xeric. Similarly, hygric-hydric treed is not included because model discrimination did not differ substantially from hygric-hydric.

[2] http://www.natalialevshina.com/Documents/Part%205_Logistic%20regression.pdf. A similar interpretation is described at http://mchp-appserv.cpe.umanitoba.ca/viewDefinition.php?definitionID=104234, whereby models are considered reasonable when the C-statistic is higher than 0.7 and strong when C exceeds 0.8.

Ecotypes	SC	DA	FC	RO	RC	CS	Xeric	Hygric-Hydric
R2	0.609	0.385	0.227	0.602	0.144	0.160	0.365	0.142
C	0.958	0.844	0.880	0.968	0.805	0.746	0.829	0.722
Intercept	-4.8692	-3.6221	-1.7711	3.4411	-5.7238	-4.9499	2.6700	-5.7279
Mean_GWSW	-13.0465	-4.2086**		-24.2104	-6.7787**	-3.9276	-16.0858	
ElevationMean	0.0307		-0.0928	-0.2055	-0.0561	-0.0151	0.0073	-0.0136
AspectMin		0.0058		-0.0053*				
AspectMax	-0.0070					0.0060	-0.0055	0.0068
AspectMean	-0.0124	-0.0027				-0.0029	-0.0014**	-0.0017*
SlopeMean	0.0125**	0.0379			-0.0704**		0.0159	-0.0109**
SlopePosition1_m2	0.0007	0.0011				0.0011***	0.0006	
SlopePosition2_m2	0.0003	0.0004				0.0003		0.0003
SlopePosition3_m2	0.0005	0.0003		0.0002	0.0003*	0.0002	0.0001	0.0002
SlopePosition4_m2			-0.0003	-0.0005	0.0004*	0.0002	-0.0003	0.0002
SlopePosition5_m2	0.0006	0.0004			0.0005	0.0002	0.0002	0.0003
SlopePosition6_m2	0.0007	0.0007				0.0002	0.0005	0.0002*
CanopyHeightMean	0.0221**	0.0812		-0.1155		0.1067		0.0796
CanopyHeightMin							-0.3579	
CanopyHeightMax		-0.0702		-0.0236**	0.0258**	-0.0196	-0.0487	

Four additional logistic models were fit for the SC ecotype and the combined xeric ecotype to explore the implications of adding the interaction term SlopeMean*AspectMean, and also not including the slope position variables due to the high cost of gathering slope position data. When fitting the models, AspectMin and AspectMax as well as CanopyMin and CanopyMax were removed to obtain a more succinct set of candidate covariates that are easier to interpret. Covariates were excluded from the model and the model refit if covariate coefficients were not significant at p<0.10.

As shown in the table below, the interaction term caused only a marginal improvement in model discrimination. Excluding slope position variables, on the other hand, caused a larger decline in model discrimination. It is therefore recommended that the models on the previous page be used that exclude the interaction term but include slope position as candidate covariates.

Ecotypes	SC				Xeric			
Model	no interaction, slope position included	interaction, slope position included	no interaction, no slope position	interaction, no slope position	no interaction, slope position included	interaction, slope position included	no interaction, no slope position	interaction, no slope position
R2	0.599	0.605	0.541	0.552	0.333	0.345	0.270	0.279
C	0.956	0.956	0.940	0.941	0.822	0.824	0.792	0.793
Intercept	-8.2174	-6.2633	-3.5440	-1.4725	-0.1262***	1.4371	-0.9430	0.3064***
Mean_GWSW	-8.5939*	-13.1404	-9.0894	-14.4553	-11.3762	-12.6960	-18.4572	-19.6243
ElevationMean	0.0316	0.0315	0.0335	0.0333	0.0080	0.0070	0.0119	0.0113
AspectMean	-0.0136	-0.0234	-0.0170	-0.0286	-0.0021	-0.0104	-0.0031	-0.0103
SlopeMean	0.0228	-0.0573	0.0409	-0.0385	0.0191	-0.0575	0.0555	-0.0057***
AspectMean*SlopeMean	na	0.0004	na	0.0004	na	0.0004	na	-0.0306
CanopyHeightMean	0.0291	0.0286	0.0531	0.0529	-0.0323	-0.0313	-0.0311	0.0004
SlopePosition1_m2	0.0007	0.0007	na	na	0.0005	0.0005	na	na
SlopePosition2_m2	0.0004	0.0004	na	na	p>0.1	p>0.1	na	na
SlopePosition3_m2	0.0006	0.0006	na	na	p>0.1	p>0.1	na	na
SlopePosition4_m2			na	na	-0.0005	-0.0005	na	na
SlopePosition5_m2	0.0006	0.0007	na	na	p>0.1	p>0.1	na	na
SlopePosition6_m2	0.0007	0.0007	na	na	0.0004	0.0004	na	na

APPENDIX C

FIELD VERIFICATION SITE LOCATIONS AND DATA

Date	Field Team	Plot Name /No.	UTM Zone	Easting	Northing	Photo No(s).	Vegetation Type						Aspect				Slope Position							Moisture			Water		Notes
							Forest	Shrubland	Grassland	Riparian	Wetland	Rock Outcrop	N	S	E	W	Crest	Upper	Middle	Lower	Toe	Level	Depression	Dry	Mesic	Wet	Lentic	Lotic	
13-Mar	Kai, Mayta, Erik, Gary (Wardin)	82F	10U	439750	5430284	508	y								y				y					y					82F marked in GPS
		19F	10U	439293	5430610	506					y												y			y	y		
		30F	10U	439980	5429488	505	y							y								y			y				
		73F	10U	439679	5431110	507	y								y				y					y	y				
13-Mar	Myta, Eric, Keith	17	10U	443357	5432667	1099	y								y				y					y					
12-Mar	Kai, Alisha, Erik	41F	10U	442316	5432382	492/491						y		y				y						y					
		51F	10U	442165	5432125	493	y															y			y				
		128F	10U	442508	5432146	494			y													y			y				
		125F	10U	442888	5431858	495	y		y													y			y				
		63F	10U	443417	5432347	498	y							y			y							y					
		130F	10U	443721	5432198	499	y																y			y			
		137F	10U	443671	5432971	502	y						y					y							y				
		42F	10U	443204	5432390	503	y															y		y	y				
		136F	10U	442401	5432704	504	y															y			y				
		131F	10U	442768	5432022	496/497	y															y			y				
		132F	10U	444168	5432237	500/501						y					y						y	y					
		133F	10U	441878	5432389				y								y								y				
		135F	10U	444102	5432490		y						y					y						y					

Date	Field Team	Plot Name /No.	UTM Zone	Easting	Northing	Photo No(s).	Vegetation Type						Aspect				Slope Position							Moisture			Water		Notes
							Forest	Shrubland	Grassland	Riparian	Wetland	Rock Outcrop	N	S	E	W	Crest	Upper	Middle	Lower	Toe	Level	Depression	Dry	Mesic	Wet	Lentic	Lotic	
10-Mar	Kai, Erik, Louise	173F	10U	441879	5428655	486					y												y			y	y		
		120F	10U	437956	5430907	480			y													y			y				
10-Mar	Arthur, Lori, Karen, Keith	108	10U	0443680	5426790	1025 to 1027	y															y			y				
		141	10U	0443630	5426850	1023 to 1024			y													y		y					
		79	10U	0444000	5426855	1028					y											y				y			
		85	10U	0441805	5428501	1047 to 1050	y															y		y					
		89	10U	0441898	5428570	Did not visit. But confirmed from the shoreline at 162F that it was in the lake beyond site 162																					y		
		162	10U	0441970	5428565	1035					y											y				y	y		
		76	10U	0441786	5428604	1044 to 1046			y													y			y				
		143	10U	0441879	5428655	Did not visit. But confirmed from the shoreline at site 162F that it was in the lake beyond site 162																					y		
		165	10U	0441698	5428712	1042 to 1043					y											y				y			
		164	10U	0441897	5428772	1036					y											y				y	y		
		166	10U	0441664	5428828	1037 to 1039					y											y				y	y		
		156	10U	0441611	5428866	1040 to 1041					y											y				y			
10-Mar	Julie, Lindsay, Mayta, Jim	37	10U	443840	5433744	5303	y					y				y		y						y			NA		

Date	Field Team	Plot Name /No.	UTM Zone	Easting	Northing	Photo No(s).	Vegetation Type						Aspect				Slope Position							Moisture			Water		Notes
							Forest	Shrubland	Grassland	Riparian	Wetland	Rock Outcrop	N	S	E	W	Crest	Upper	Middle	Lower	Toe	Level	Depression	Dry	Mesic	Wet	Lentic	Lotic	
10-Mar	Julie, Lindsay, Mayta, Jim	138	10U	444288	5433185	5305	y					y			y		y							y			NA		Christmas tree farm
		81	10U	443311	5433580	5300	y						Flat					y						y	y		NA		
		139	10U	443571	5433580	5301			y				Flat									y		y			NA		
		172	10U	443622	5433823	5302					y		Flat										y			y	y		
		171	10U	443681	5433928	5299					y		Flat										y			y	y		
		163	10U	443400	5433990	5308					y															y	y		photo across the pond; steep slope with maples, salal, fir, cedar, riparian-sedges
		153	10U	443502	5434051	5309					y					flat							y			y	y		waypoint ~20m to W of field rt
		160	10U	443491	5434103	5306																				y	y		took photo; private property, waypoint ~50m W of field coord.
		57	10U	443498	5434137	5307	y			y						y			y						y		NA		
		204	10U	442787	5434292	5311						y			y			y							y		NA		
		64	10U	442610	5434334	5312						y	y		y		y							y			NA		
		205	10U	442940	5434358	5310	y								y							y					NA		

Date	Field Team	Plot Name /No.	UTM Zone	Easting	Northing	Photo No(s).	Vegetation Type						Aspect				Slope Position							Moisture			Water		Notes
							Forest	Shrubland	Grassland	Riparian	Wetland	Rock Outcrop	N	S	E	W	Crest	Upper	Middle	Lower	Toe	Level	Depression	Dry	Mesic	Wet	Lentic	Lotic	
10-Mar	Julie, Lindsay, Mayta, Jim	140	10U	443685	5434548	5313	y						y		y				y						y		NA		
		170	10U	443555	5434777	5314						y			y					y				y			NA		not natural - would've been forest
		60	10U	443412	5434850	5316	y							y	y					y					y		NA		pileated woodpecker cedar
10-Mar	Arthur, Lori, Karen, Keith	1	10U	0443826	5428723	1029 to 1034	y															y			y				
10-Mar	Kai, Erik, Louise	40F	10U	435587	5430705	477			y													y			y				farm field
		115F	10U	436496	5430689	473			y												y					y	y		
		54F	10U	436677	5429866	474	y						y						y						y				
		62F	10U	435891	5430705	475			y				y					y							y				.006 GPS
		65F	10U	436051	5430683	476			y				y			y		y							y				
		169F	10U	437460	5430922	479					y												y				y	y	flowing ditch creek
		50F	10U	438372	5430451	481	y													y					y				
		111F	10U	438939	5429753	482	y															y			y				
		47F	10U	438783	5430007	483	y							y			y							y	y				
		69F	10U	439248	5430115	484	y							y					y						y			y	smooth ephemeral stream
		124F	10U	441418	5431729	485	y															y			y				

Date	Field Team	Plot Name /No.	UTM Zone	Easting	Northing	Photo No(s).	Vegetation Type						Aspect				Slope Position							Moisture			Water		Notes
							Forest	Shrubland	Grassland	Riparian	Wetland	Rock Outcrop	N	S	E	W	Crest	Upper	Middle	Lower	Toe	Level	Depression	Dry	Mesic	Wet	Lentic	Lotic	
10-Mar	Kai, Erik, Louise	55F	10U	440982	5430403	487				y																y			
		117F	10U	440983	5430404	488					y												y			y	y		
		220F	10U	440917	5430237	489	y							y			y							y					
		126F	10U	441561	5431915	490	y															y			y				
		116F	10U	435660	5430713																	y			y				front yard
		56F	10U	439391	5429507																			y	y				front yard
06-Mar	Kai, Alisha, Richard	144F	10U	438085	5429806																	y							
		71F	10U	442572	5428619	465			y				y									y			y				
06-Mar	Arthur (Jon Jim), Jeff, Lori, Keith	98	10U	0443227	5427435	984 to 991	y								y				y						y				
		223	10U	0442570	5428617	1010 to 1013	y							y					y							y			
		222	10U	0442393	5428671	1018 to 1022	y									y		y							y				
		221	10U	0442489	5428708	1014 to 1017	y															y				y			
		7	10U	0743051	5427463	992 to 999	y								y				y						y				
		6	10U	0442569	5428272	1000 to 1008	y								y			y							y				
06-Mar	Julie, Lindsay, Mayta, Louise	20	10U	437318	5429780	5322		y					y		y				y						y		NA		

Date	Field Team	Plot Name /No.	UTM Zone	Easting	Northing	Photo No(s).	Vegetation Type						Aspect				Slope Position							Moisture			Water		Notes
							Forest	Shrubland	Grassland	Riparian	Wetland	Rock Outcrop	N	S	E	W	Crest	Upper	Middle	Lower	Toe	Level	Depression	Dry	Mesic	Wet	Lentic	Lotic	
06-Mar	Karen, Justin	20F	10U	437318	5429780		y						N E						y						y				
		119F	10U	436748	5430934	1133			y													y			y				residential front yard
		66	10U	436728	5430967																								we are skipping it. Private property-fenced
		168F	10U	436822	5431327	1132			-													y							see note on back
		122	10U	436322	5431628																								we are skipping it. Private property-fenced
		38F	10U	436477	5431703	1130	y								y			y						y	y				
		38G	10U	436343	5431786	1131	-	-	-	-	-	-		y						y	y				y				
		48F	10U	436949	5431786	1126		y														y			y				
		43F	10U	437402	5432197	1127			y							y			y						y				residential front yard
		134F	10U	437528	5432349	1128			y													y			y				residential front yard
		167F	10U	436801	5432388	1129			-													y		y					
		129F	10U	437403	5432213				y							y			y						y				residential front yard

Date	Field Team	Plot Name /No.	UTM Zone	Easting	Northing	Photo No(s).	Vegetation Type						Aspect				Slope Position							Moisture			Water		Notes
							Forest	Shrubland	Grassland	Riparian	Wetland	Rock Outcrop	N	S	E	W	Crest	Upper	Middle	Lower	Toe	Level	Depression	Dry	Mesic	Wet	Lentic	Lotic	
06-Mar	Julie, Lindsay, Mayta, Louise	154	10U	443404	543632	5317					y			y									y			y	y		Roberts National Park
		155	10U	443275	5434685	5321	y						y		y							y				y	NA		Roberts National Park
		161	10U	443422	5434690	5319	y						y			y		y							y		NA		Roberts National Park
		100	10U	443333	5434709	5318	y							y				y							y		NA		Roberts National Park
06-Mar	Kai, Alisha, Richard	21F	10U	436910	5430818	469	y								y				y					y					
		29F	10U	437119	5430836	468		y					y								y			y					
		144F	10U	438085	5429813	466			y						y							y			y				
		72F	10U	438118	5429643	467			y						y							y			y				
		146F	10U	437017	5430218	472					y												y			y		y	standing water
	Rob Water, Lindsay, Brian Brown Keith, Jim Fiddick	156	10U	443088	5433353	1073 to 1077					y												y			y		y	
		8	10U	443122	5433856	1083 to 1086	y																y			y			
		28	10U	442527	5433286	1056 to 1059	y															y			y				
		26	10U	442513	5433603	1069 to 1072	y						y		y				y						y				
		35	10U	442890	5433930	1091 to 1094					y												y			y	y		
		88	10U	42843	5432964	1051 to 1055				y													y			y	y		

Date	Field Team	Plot Name /No.	UTM Zone	Easting	Northing	Photo No(s).	Vegetation Type						Aspect				Slope Position							Moisture			Water		Notes
							Forest	Shrubland	Grassland	Riparian	Wetland	Rock Outcrop	N	S	E	W	Crest	Upper	Middle	Lower	Toe	Level	Depression	Dry	Mesic	Wet	Lentic	Lotic	
	Rob Water, Lindsay, Brian Brown, Keith, Jim Fiddick	90	10U	442895	5433566	1078 to 1082					y												y			y	y		
		152	10U	443084	5433881	1087 to 1090					y												y			y	y		
		105	10U	442819	5433997	1095 to 1098	y																y		y				

Date	Field Team	Plot Name /No.	Trees										Shrubs													Herbs							Comments (weather or other notes)
			Arbutus	Big leaf maple	Cottonwood	Douglas-Fir	Grand Fir	Lodgepole Pine	Red Alder	Trembling aspen	Red Cedar	Western Hemlock	Hardhack	Indian Plum	Labrador Tea	Manzanita	Oceanspray	Oregon Grape	Red-Osier Dogwood	Rose	Salal	Salmonberry	Snowberry	Spirea	Willow	Deer Fern	Fescue	Foamflower	Sedge	Skunk Cabbage	Sword Fern	Vanilla-leaf	
13-Mar	Kai, Mayta, Erik, Gary (Wardin)	30F	y	y		y	y				y							y					y								y		moss
		19F									y		y									y			y				y				in the wetland
		73F	y			y	y										y	y			y		y										moss
		82F	y			y											y	y															adjacent to meadows
13-Mar	Myta, Eric, Keith	17	y			y					y						y	y		y	y						y						grass
12-Mar	Kai, Alisha, Erik	133F																									y						from 8m away farm field no photo-front yard
		41F		y														y															11m from map site, may not represent point intended
		51F		y		y					y			y			y	y															11m from map site
		128F																		y							y						11m from MP. Farm field
		125F		y		y															y						y						13m from MP in lawn/yard
		131F	y		y	y	y				y							y			y												
		63F	y			y						y						y		y	y		y								y		broom, honeysuckle
		130F		y					y		y			y								y									y		40m away. Wet forest
		132F	y			y											y						y								y		moss, broom, cherry, Garry oak shrub
		135F	y			y																									y		17m in yard almost at house, honeysuckle
		137F		y		y					y						y	y													y		8m from MP
		42F	y			y					y						y	y			y												dry/mesic, moss, honeysuckle - logged years ago
		136F	y			y	y				y						y	y			y												11 meters MP. Honeysuckle, broom, dry/mesic

Date	Field Team	Plot Name /No.	Trees										Shrubs													Herbs							Comments (weather or other notes)
			Arbutus	Big leaf maple	Cottonwood	Douglas-Fir	Grand Fir	Lodgepole Pine	Red Alder	Trembling aspen	Red Cedar	Western Hemlock	Hardhack	Indian Plum	Labrador Tea	Manzanita	Oceanspray	Oregon Grape	Red-Osier Dogwood	Rose	Salal	Salmonberry	Snowberry	Spirea	Willow	Deer Fern	Fescue	Foamflower	Sedge	Skunk Cabbage	Sword Fern	Vanilla-leaf	
10-Mar	Arthur, Lori, Karen, Keith	141				y			y		y																						soccer field, cleared foreest lands
		108	y	y			y		y		y			y							y										y		huckleberry, moss, thimbleberry
		79		y		y			y	y	y			y								y							y		y		ash maple, moss, vine blackberry, poplar
		1		y			y				y			y							y										y		
		162							y		y			y							y	y							y		y		162 was 18 m into the lake beyond site 162F. thimbleberry
		164		y			y		y		y			y			y					y											164 was 40 m into the lake beyond site 164F. moss, douglas or vine maple, wild clematis, pacific nine bark
		166										y																	y	y	y		holly
		156		y		y					y			y				y			y	y											156 was 40m into the lake beyond 156F. huckleberry, bracken
		165		y		y			y		y			y								y									y		bracken
		76		y							y			y																	y		polypoda fern
		75		y					y		y							y													y		huckleberry
10-Mar	Kai, Erik, Louise	115F			y				y																		y						observe vrom 20metres away (farm field)
		54F	y	y		y	y		y			y		y				y			y										y		cedar close by and thimbleberry
		62F																			y						y						broom/douglas fir nearby
		65F					y	y																			y						observed from30 metres
		116F																															lawn/landscape
		40F																															fresh ploughed farm field

Date	Field Team	Plot Name /No.	Trees										Shrubs													Herbs							Comments (weather or other notes)
			Arbutus	Big leaf maple	Cottonwood	Douglas-Fir	Grand Fir	Lodgepole Pine	Red Alder	Trembling aspen	Red Cedar	Western Hemlock	Hardhack	Indian Plum	Labrador Tea	Manzanita	Oceanspray	Oregon Grape	Red-Osier Dogwood	Rose	Salal	Salmonberry	Snowberry	Spirea	Willow	Deer Fern	Fescue	Foamflower	Sedge	Skunk Cabbage	Sword Fern	Vanilla-leaf	
10-Mar	Kai, Erik, Louise	169F																							y		y		y				rushes
		120F																									y						farm field
		50F		y		y	y										y	y					y										sweet pea, cherry broom/logged - out DF
		111F				y			y		y									y	y												bracken fern, elderberry
		47F	y			y					y					y		y					y								y		steep bank
		69F		y		y					y							y				y									y		old stump - rock awterops
		124F				y	y				y			y			y	y		y	y	y									y		
		173F			y								y	y											y								broom, wet farm field 30 metres away
		55F							y				y	y						y					y								35 metres away/ creek adjacent
		117F																									y						wet pine in farm field dries peat bog in June
		220F		y		y			y		y					y		y	y		y	y	y								y		nice stand of red cedar
		126		y	y		y				y			y			y	y			y	y	y										20 metres away
10-Mar	Julie, Lindsay, Mayta, Jim	60		y							y						y	y													y		pond to south photo 5315; huckle moss
		170	y								y																				y		bare soil - construction; 30m to west (hollow - 5312
		140				y	y				y							y			y			y							y		
		64	y								y																				y		
		204				y			y								y				y												bleeding heart, trailing blackberry
		205				y					y							y			y												
		153																											y	y			cat tails, pond lily

Date	Field Team	Plot Name /No.	Trees										Shrubs													Herbs							Comments (weather or other notes)
			Arbutus	Big leaf maple	Cottonwood	Douglas-Fir	Grand Fir	Lodgepole Pine	Red Alder	Trembling aspen	Red Cedar	Western Hemlock	Hardhack	Indian Plum	Labrador Tea	Manzanita	Oceanspray	Oregon Grape	Red-Osier Dogwood	Rose	Salal	Salmonberry	Snowberry	Spirea	Willow	Deer Fern	Fescue	Foamflower	Sedge	Skunk Cabbage	Sword Fern	Vanilla-leaf	
10-Mar	Julie, Lindsay, Mayta, Jim	57									y																				y		trailing blackberry
		138	y			y		y	y																								spurge laurel (invasive)
		37	y			y					y							y			y												twinflower, huckleberry
		172																						y									invasive iris, canary grass
		139	y			y																					y						hemlock depression pond to south; cherry oak, grasses, moss
		81				y											y		y	y	y						y						
		171																									y						swamp grass
06-Mar	Arthur (Jon Jim), Jeff, Lori, Keith	98		y		y	y		y		y			y				y			y	y									y		blackberry, holly
		7	y			y								y							y												feather moss - highcover
		6		y		y	y		y		y	y									y												honey suckle
		223		y		y			y		y			y						y		y									y		blackberry
		221							y		y												y	y									
		222																			y										y		huckleberry, holly
06-Mar	Julie, Lindsay, Mayta, Louise	20		y					y		y	y		y								y									y		horsetail, blackberry
		155				y					y	y					y														y		terrain had lots of humps muddy ground; historic logging evidence - most recently in 1950s (locals' estimate)
		161									y							y			y										y		huckleberry, small pond to SW of site; historic logging evidence - most recently in 1950s (locals' estimate)

Date	Field Team	Plot Name /No.	Trees										Shrubs													Herbs							Comments (weather or other notes)
			Arbutus	Big leaf maple	Cottonwood	Douglas-Fir	Grand Fir	Lodgepole Pine	Red Alder	Trembling aspen	Red Cedar	Western Hemlock	Hardhack	Indian Plum	Labrador Tea	Manzanita	Oceanspray	Oregon Grape	Red-Osier Dogwood	Rose	Salal	Salmonberry	Snowberry	Spirea	Willow	Deer Fern	Fescue	Foamflower	Sedge	Skunk Cabbage	Sword Fern	Vanilla-leaf	
06-Mar	Julie, Lindsay, Mayta, Louise	100		y							y							y													y		heard pacikie tree frog; historic logging evidence - most recently in 1950s (locals' estimate)
		154									y								y						y				y	y	y		water parsley; culvert in flow to N
06-Mar	Kai, Alisha, Richard	71F																									y		y				sea asparagus
		144F																									y		y				sea asparagus
		72F																									y		y				muddy in tidal zone
		29F		y										y									y										trailing blackberry, thimbleberry
		21F				y					y							y			y												huckleberry, lots of moss
		146F							y					y								y								y			map point far off (gravel driveway); this point was northern end of created wetland
06-Mar	Karen, Justin	20F		y							y	y		y			y					y											
		48F																															
		43F																															veg yard/ residential ornamentals
		129F																															" similar vegetation
		134F		y			y							y																			edge of residential property
		167F																															empty atco trailer lot - gravel
		38F		y		y					y			y																	y		marked pt. is mesic but ridge is dry; walker ck to the east of this point – maybe spring salmon-rearing habitat says property owner
		38G																															orchard - this is original point 38
		168F																															currently dry gravel but walker-backs

Date	Field Team	Plot Name /No.	Trees										Shrubs													Herbs							Comments (weather or other notes)
			Arbutus	Big leaf maple	Cottonwood	Douglas-Fir	Grand Fir	Lodgepole Pine	Red Alder	Trembling aspen	Red Cedar	Western Hemlock	Hardhack	Indian Plum	Labrador Tea	Manzanita	Oceanspray	Oregon Grape	Red-Osier Dogwood	Rose	Salal	Salmonberry	Snowberry	Spirea	Willow	Deer Fern	Fescue	Foamflower	Sedge	Skunk Cabbage	Sword Fern	Vanilla-leaf	
06-Mar	Karen, Justin	119F																															up at culvert and floods here
		119F																															residential front yard-"lawn"
		66																															
	Rob Water, Lindsay, Brian Brown, Keith, Jim Fiddick	10					Y		Y												y	y									y		
		28		y		y	y				y						y				y										y		moss
		26		y		y					y	y						y			y										y		evergreen huckleberry, moss
		150							y		y										y								y	y	y		sample plan location was 20 m away towards the center of the lake. buttercup, canary grass, bracken fern, thistle
		90																											y	y			sample plan location was 80 m away towards the center of the lake. pond lilly, a family of ducks
		8				y			y								y				y								y		y		moss, huckleberry
		152							y				y								y	y							y	y			

APPENDIX D

TEM SURVEY INTENSITY

The proportion of site series or non-vegetated/anthropogenic map units visited are listed in the table below, based on the number of field checks in each BEC unit versus the total number of the same unit in the study area. The numbers approximate the abundance of the ecosystems in the study area.

BEC Zone	Site Series Description	Number	Percent
CDFmm	Fescue - Camas	1	0.7
CDFmm	Qg - Ocean Spray	1	0.7
CDFmm	Hardhack - Labrador tea	1	0.7
CDFmm	Cladina - Wallace's Selaginella	1	0.7
CDFmm	Fd - Salal (01 ǀ DS)	36	24.8
CDFmm	FdPl - Arbutus (02 ǀ DA)	5	3.4
CDFmm	FdBg - Oregon Grape (04 ǀ DG)	5	3.4
CDFmm	CwBg - Foamflower (06 ǀ RF)	9	6.2
CDFmm	Cw - Snowberry (07 ǀ RS)	1	0.7
CDFmm	Cw - Skunk Cabbage (11 ǀ RC)	15	10.3
CDFmm	Cw - Vanilla-leaf (00 ǀ RV)	2	1.4
CDFmm	Cw - Indian-plum (00 ǀ RP)	4	2.8
CDFmm	Cw - Slough Sedge (14 ǀ CS)	8	5.5
CDFmm	Wetland [Fen] (00 ǀ Wf)	3	2.1
CDFmm	Wetland [Marsh] (00 ǀ Wm)	1	0.7
CDFmm	Wetland [Swamp] (00 ǀ Ws)	7	4.8
CDFmm	Cultivated Field (00 ǀ CF)	17	11.7
CDFmm	Mud Flat (00 ǀ MU)	3	2.1
CDFmm	Road (00 ǀ RW)	3	2.1
CDFmm	Rock Outcrop (00 ǀ RO)	2	1.4
CDFmm	Rural (00 ǀ RW)	14	9.7
CDFmm	Shallow Open Water (00 ǀ OW)	2	1.4
CDFmm	Urban / Suburban (00 ǀ UR)	3	2.1
CWHxm	HwFd - Kindbergia (01 ǀ HK)	1	0.7
Total		145	100.0

APPENDIX E

ASSUMPTIONS USED IN THE ALCES ONLINE MODEL TO GENERATE ANALYSES PRESENTED IN SECTION 7

Many of the analyses presented in Section 7 employ data on anthropogenic footprint that is resident in the ALCES Online model, and was not supplied by the CVRD for this project. Thus replication of these results on another platform (e.g., ArcGIS) would require input of similar data layers, and might not generate identical results, depending on differences in these data layers.

The following assumptions were used to generate the analyses discussed in Section 7 of this report. These assumptions are discussed by corresponding figure number.

- **Figure 7-3, areas on increased surface-water – groundwater interaction** – the ALCES Online model was instructed to show values for the groundwater-surface water index where these values were >~0.05, and to scale these values appropriately. Values <~0.05 are not shown. Results are shown as mean values per 1ha grid cell.
- **Figure 7-4, areas of potential increased nutrient and contaminant loading** – the ALCES Online model was instructed to combine information on all farm classes in the Agricultural Land Use Inventory (ALUI) for the study area with information internal to ALCES Online on the following footprint types deemed to have the capacity to generate nutrient and/or contaminant-enriched runoff: golf courses, industrial land, pipeline footprint, transmission-line footprint, rail lines, roads, urban and rural residential footprint, and mapped cultivated fields within the study-area TEM. Results are shown as an intensity (ratio) of footprint types within the overall grid cell.
- **Figure 7-5, areas of increased potential for impacts to groundwater quality –** the ALCES Online model was instructed to cross the analyses in Figure 7-3 and Figure 7-4 and show intensity of the Figure 7-4 footprint types in cells where the mean groundwater-surface water interaction index >0.1. Results are shown as an intensity (ratio) of footprint types within the overall grid cell.
- **Figure 7-6, areas of reduced groundwater recharge** – the ALCES Online model was instructed to show values for the groundwater-surface water index where these values were <0.1, and to scale these values appropriately. Values >0.1 are not shown. Results are shown as mean values per 1ha grid cell.
- **Figure 7-7, areas of increased water use –** the ALCES Online model was instructed to combine areas of recorded irrigation from the ALUI with information internal to ALCES Online on the following footprint types deemed to generate water demands: golf courses, industrial land, urban and rural residential footprint, and mapped points of water diversion and water wells. Results are shown as an intensity (ratio) of footprint types within the overall grid cell.
- **Figure 7-8, areas of increased potential water-supply vulnerability –** the ALCES Online

model was instructed to cross the analyses in Figure 7-6 and Figure 7-7 and show intensity of the Figure 7-8 footprint types in cells where the mean groundwater-surface water interaction index <0.1. Results are shown as an intensity (ratio) of footprint types within the overall grid cell.

- **Figure 7-11, areas of increased potential for generation of solar electricity –** the ALCES Online model was instructed to identify grid cells with:
  - mean slope angles <10%, **or**
  - mean slope aspects between 155 and 205 degrees where slope angles >10%, **and**
  - mean vegetation heights <5m.