Hatzic Region Hydrology and Watershed Stability Assessment

Cascade Creek

Hatzic Slough at Farms Road

Pattison Creek at Sylvester Road

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1 Introduction

This report examines the hydrology and watershed stability of the Hatzic region in the Chilliwack Forest District. The name Hatzic refers to four areas within this report. The "Hatzic region" assessment area is shown in Figure 1, and includes the "Hatzic Lake" watershed, the Cascade watershed, and the Marino watershed. The Hatzic Lake watershed is composed of three major sub-basins: "Hatzic Slough", Chilqua, and Draper, plus some residual area adjacent to Hatzic Lake. The "Hatzic Prairie" is the name of a groundwater aquifer.

Landslides and flooding are significant issues in the Hatzic region. The area requires emergency response to landslides and flooding, and there are significant financial costs for longer-term hazard management practices such as channel diking and sediment excavation. Flooding and slope stability issues occur in part because of the natural conditions within the region, but clearly land use practices have affected the number of hazardous events as well as the extent of the damage. Several consulting and assessment reports are available regarding hydrology, sediment and landslide hazard issues within the Hatzic region and provide a detailed background regarding the Hatzic region. The report by Rob Hudson (1997) specifically addresses forest management issues within the region.

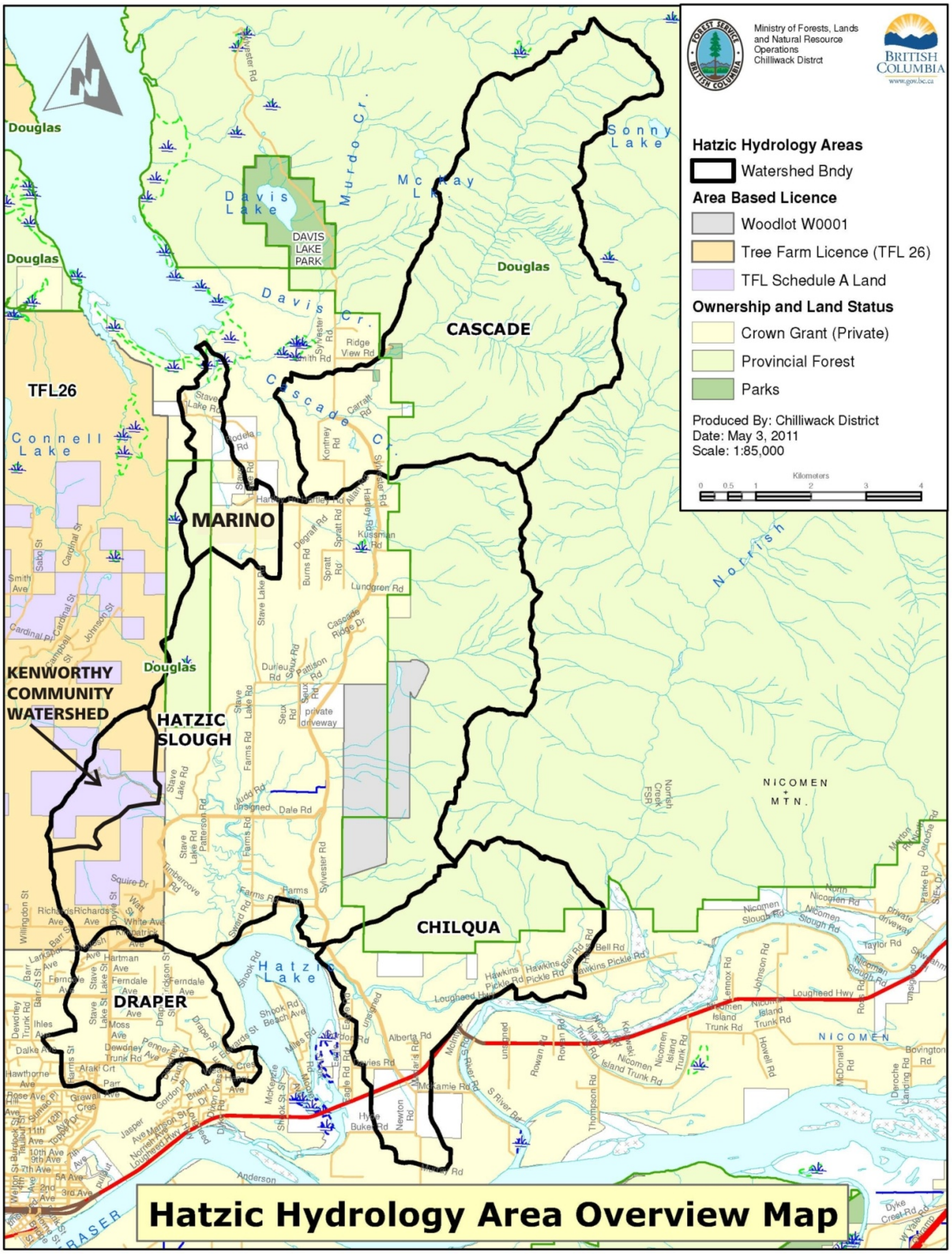
This report is primarily based on extensive aerial photograph interpretation, maps, and previously written report information. Hydrologic recovery calculations are based on forest cover data provided by Mike Smith (Geomatics Analyst, Chilliwack Forest District). Lucy Stad and I examined valley bottom areas on February 15, 2011. Access was not possible to higher elevation areas. I have done field work in the woodlot, along the top of Durieu Ridge and in neighbouring drainages, so I am familiar with the area.

1.1 Objectives

The primary objective of this report is to examine flooding, drinking water quality, landslides and channel stability issues related to forest management. Since the watersheds are mixed-use, the hydrologic and watershed stability effects of private land use and infrastructure are also examined. The Draper watershed is excluded from water quality, landslide and channel stability assessments since it has no Provincial Forest, woodlot, or Tree Farm License (TFL) land. Specific objectives include:

- Update and expand the Equivalent Clearcut Area information contained in Hudson (1997),
- Evaluate the effect of forest management on drinking water sources, as requested in Sharie Conroy's June 9, 2010 letter to Allan Johnsrude,
- Evaluate the effect of forest management on landslide hazards,
- Evaluate the effect of forest management on sediment supply, channel stability and flooding,
- Comment on watershed stability, flooding and forest development and provide recommendations regarding forest development.

Figure 1. Hatzic region assessment area.



1.2 Description of Hatzic region

The Hatzic region is located within the Pacific Ranges of the Coast Mountains (Holland 1976) and is centered along a low-lying glacial trough that extends from Stave Lake to the Fraser Valley. To the east is Dewdney Peak, Durieu Ridge and adjacent peaks within the Cascade watershed, with ridgetop elevations ranging from 800 m to 1300 m. To the west is a more subdued upland area with maximum elevations of 600 m. Bedrock in the area is granodiorite or quartz diorite, with a small portion of the Draper watershed underlain by Kitsilano sedimentary rocks (BC Water Resources Atlas). Pleistocene glaciation resulted in glacial till and deglacial deposits throughout the region, with some lower lying areas such as the bench between Pattison Creek and Scorey Creek having very thick deposits (Maynard 1995). Till deposits at higher elevations are generally thin, but in some locations such as Pattison Creek there are very thick deposits at high elevation.

Watersheds in the region either drain south to the Fraser River, or north to Stave Lake (Figure 1). Cascade Creek and Marino Creek (identified as North Belcherton Creek on some FVRD maps) discharge northwards into Stave Lake. Hatzic Slough, Chilqua Creek and Draper Creek all discharge into Hatzic Lake, which drains into the Fraser River. Hatzic Lake water levels are controlled by a pumping system. Fraser River floodplain sediments occupy the southern end of the glacial trough, and Hatzic Lake is an abandoned oxbow bend of the Fraser River. Elevation of the floodplain area is less than 20 m. North of Durieu Road the ground slopes upwards away from the Fraser River floodplain area, with elevations reaching 140 m in the Miracle Valley area near Hartley Road.

Steep slopes are located along the east and west margins of the valley bottom of the glacial trough and are landslide prone. Extensive debris flow fans at the base of many slopes, particularly at the base of the Durieu Ridge demonstrate that landslides have been an important factor in shaping the valley topography since deglaciation approximately 10,000 years ago (Qcd Geotechnics 2008). Natural historical landslides have occurred since at least 1935 (nhc 1985), and almost certainly have occurred on an occasional basis prior to the aerial photograph record. Aerial photographs from 1952 show natural landslides in several watersheds of Durieu Ridge. On the western upland side, no landslides are evident in the 1952 aerial photographs, but Qcd Geotechnics (2008) notes a few landslide locations along the west side of the valley.

There are multiple land uses in the Hatzic region. Provincial Forest land occupies portions of Hatzic Slough, Chilqua, Marino, and Cascade watersheds. A woodlot is located along the bench between Pattison Creek and Scorey Creek and there is some TFL 26 land in the western portion of the Hatzic Slough watershed. Kenworthy Creek, a tributary of Hatzic Slough to the west of Hatzic Valley, is a community watershed. Private land is dominantly agricultural use and rural residential, with some areas remaining forested and some areas in small-lot subdivisions. Table 1 shows the total watershed size, the amount of land under forest management and the amount of private land.

Table 1. Watershed areas, forest areas and private land areas.

Watershed	Total area	Forest areas [1]		Private land	
	(ha)	(ha)	% of total	(ha)	% of total
Cascade	2718	2330	86	388[2]	14
Marino	410	144	35	265	65
Hatzic Slough	5164	2330	45	2834	55
Draper	719	0	0	719	100
Chilqua	1415	670	47	745	53
Hatzic Lake	7684[3]	3000	39	4684[3]	61

1) Includes Provincial Forest, woodlot and TFL lands.
2) Includes 11 ha in Cascade Falls Regional Park.
3) Hatzic Lake watershed area is the sum of Hatzic Slough, Draper, Chilqua, and 386 ha of residual private land area adjacent to Hatzic Lake.

1.3 Summary of watershed issues

The Hatzic region requires management for landslide hazards, sedimentation and flooding. The steep slopes of Durieu Ridge produce landslides that reach developed areas at the base of the slope. These landslides have resulted in at least one death and significant property damage (Qcd 2008). Qcd Geotechnics (2008) has mapped all of Area F Electoral district for landslide and slope stability hazards and noted the location and year of several landslides. BGC Engineering (2004) has mapped debris flow hazard zones for several Durieu Ridge alluvial fans that were subject to debris flows in 2003.

Landslides also deliver large volumes of sediment to stream channels. This sediment is deposited on alluvial fans along the valley bottom margins and result in unstable channels in areas of private land development. To contain the unstable channels, dikes or other containment measures have been built on Cascade Creek, Carratt Creek, Eng Creek, MacNab Creek, Pattison Creek, Legace Creek and Hatzic Slough. The high sediment load in these creeks raises the creek bed, lowers the channel capacity and increases the frequency of overbank flood events. As a result, excavation of sediment is required on most of these creeks.

Chronic sediment sources are a particular problem in Pattison Creek where they have resulted in frequent channel stability and flooding issues on the Pattison/Lagace fan, and downstream in Lagace Creek and Hatzic Slough (nhc 1985, 2005). Legace Creek and Hatzic Slough have been excavated since at least the 1920's (Daneluz April 15 2009), although the rate of excavation has increased since a large natural landslide occurred, likely in 1935, and subsequent forest management-related landslides (nhc 1985). Cost of channel excavation amounted to almost $0.5 million in 2005 alone (nhc 2005). The early history of channel excavation shows that channel instability, particularly on the Legace/Pattison alluvial fan, is partially natural.

Flooding in Hatzic Slough is common and likely has several causes. Hatzic Slough flows across Fraser River floodplain, which has a much lower gradient than normal for a stream the size of Hatzic Slough. This setting naturally makes Hatzic Slough flood-prone. Backwater effects from Hatzic Lake can also result in floods (nhc 1985). As noted above, sediment deposition within the creeks is partly responsible for frequent flooding. Land use such as forest harvesting and rural development may have resulted in increased flood flows. Climate change has been cited as a possible contributing factor to increased floods (FVRD Hatzic Valley OCP), although local studies do not show any change in extreme precipitation rates currently occurring (Murdock et al. 2007, Jakob 2010).

2 Flood hazard assessment of the Hatzic region.

Forest harvesting and roads can affect the amount of water flowing within a stream. Two standard measures of the hydrologic effect of forest operations are the “Equivalent Clearcut Area” (ECA) and the density of roads within a watershed. Since forest harvesting and road construction occur on private land as well as on forest management land, these analyses were done for both the forest land area and private land areas within the Hatzic region. This provides for an overall evaluation of the watershed and understanding the significance of forest management on watershed health. Private land is defined in this report as all non-forest management watershed areas, including the road network outside of forest management areas, and is dominantly rural habitation and agricultural development. Forest management areas refer to Crown land only.

2.1 The peak flow effect of forest harvesting from forest land and private land

Forests affect the amount of water reaching the stream system by intercepting rainfall and snow, delaying snowmelt, and drawing water from the ground for transpiration. During late summer dry periods when stream flows are lowest, forest transpiration reduces the amount of groundwater that is available for streamflow. Forest harvesting reduces transpiration and therefore tends to increase low flows (Winkler et al. 2010), which is generally not considered a problem. Changes to peak flows (floods) are the main hydrologic concern with forest management. The effect of forest harvesting on flood flows is most pronounced immediately after harvest, and as trees regrow, the effect is reduced (known as “hydrologic recovery”). The Equivalent Clearcut Area (ECA) method of assessing the effect of forest harvesting on stream flows calculates the amount of land that is hydrologically equivalent to a new clearcut. The clearcut area is then expressed as a percentage of the watershed area. The Coastal Watershed Assessment Procedure (MOF/MOE 1995) evaluated a 30% ECA or less as having a low hazard of increasing peak flows, and an ECA exceeding 42% as having a high hazard of increasing peak flows. A recent re-analysis of data from a coastal Oregon watershed with 25% ECA showed significant changes in flood frequency and magnitude (Alila et al. 2009). A frequent practice in high risk watersheds such as community watersheds is to limit harvesting to a 20% ECA level.

This report uses three methods to calculate or estimate ECA for the Hatzic region:

1. Hudson (1997) provided an ECA calculation for the Hatzic Slough watershed. In this report, ECA for the Hatzic Slough was updated from Hudson’s 1997 assessment by inventorying new harvesting, but does not account for increased tree height due to regrowth of forests in any of the previously harvested areas. As such, the ECA is an over-estimate, as including tree growth would increase hydrologic recovery and thus lower ECA.

2. For the forest land within Chilqua, Cascade, and Marino watersheds, ECA is calculated using a modified method of Hudson and Horel (2007) and forest cover data provided by Mike Smith, Geomatics Analyst, Chilliwack Forest District.
3. For private lands within each watershed, ECA was estimated from GoogleEarth images from 2004-2008. Only two classes of forest state were considered. Forested areas are assumed to have mature forest. Farmland and other areas without forest have a 100% ECA. This method may underestimate true ECA for private lands, since some young forested areas may not be fully recovered.

To understand the relative importance of forest management or other land use, the ECA is calculated three ways:

1. The ECA for forest or private land use is calculated as a percentage of the land base available for forest or private land use, respectively. The forest management ECA is calculated as a percentage of the forest land base (*Forest LB ECA)*. The private land ECA is calculated as a percentage of the remaining portion of the watershed (*Private ECA*).
2. The watershed ECA for each land use (forest and private) is calculated as a percentage of the entire watershed area (*Forest WS ECA* and *Private WS ECA*).
3. The overall ECA for the watershed combines the Forest WS ECA and the Private WS ECA and is a percentage of the entire watershed area (*Overall watershed ECA*).

Table 2 shows the ECA levels for forest management land. Both Forest LB ECA and Forest WS ECA area are shown. All forest management ECA values are very low, whether measured by forest land base or by watershed area. Forest management ECAs were likely higher in past years, but current ECA reflects low rates of harvesting in recent decades. Current forest harvest levels do not significantly contribute to flooding issues within the Hatzic region.

Table 2. ECA for forest management lands

Watershed	WS area (ha)	Forest land base (ha)[1]	For. LB ECA (%)	For. WS ECA (%)
Cascade	2718	2330	5.7	4.9
Marino	410	144	0	0
Hatzic Slough	5164	2330	4.8	2.2
Draper	719	0	0	0
Chilqua	1415	670	7.3	3.5
Hatzic Lake[2]	7684	3000	5.4	2.1

1) Includes Provincial Forest, woodlot and TFL lands.
2) Hatzic Lake watershed area is the sum of Hatzic Slough, Draper, Chilqua, and 386 ha of residual private land area adjacent to Hatzic Lake.

Table 3 shows the ECA levels on private land. For the watersheds that flow to Stave Lake (Cascade and Marino), Private WS ECAs are low. Intensive private land use within the Hatzic Lake watersheds results in elevated Private LB ECAs – all are at 40% or higher, which indicates a high hazard of increased peak flows. When considered on a watershed-wide basis, the Private WS ECAs are somewhat lower, but with the possible exception of Hatzic Slough, are still at moderate or high hazard levels.

Table 3. ECA for private lands

Watershed	WS area (ha)	Private land area (ha)	Private LB ECA (%)	Private WS ECA (%)
Cascade	2718	388[1]	50	7.1
Marino	410	265	20	13
Hatzic Slough	5164	2834	45	25
Draper	719	719	40	40
Chilqua	1415	745	80	42
Hatzic Lake[2]	7684	4684	52	32

1) Includes 11 ha in Cascade Regional Park.
2) Hatzic Lake watershed area is the sum of Hatzic Slough, Draper, Chilqua, and 386 ha of residual private land area adjacent to Hatzic Lake.

Forest WS ECA and Private WS ECA are summed in Table 4 for the overall watershed ECA. Cascade and Marino have low overall ECA levels and peak flows have likely not changed in response to land management within these watersheds. The Hatzic Slough watershed has an overall ECA of 27%, which is approximately where changes to flood flows are likely to be measureable. Within the Hatzic Slough watershed, the Kenworthy Community watershed has an ECA of 14%. Draper and Chilqua watersheds have overall ECA levels at which changes to flood levels are likely. The Hatzic lake watershed has an overall ECA of 34%, a moderate hazard for changes to peak flows.

Table 4. Overall watershed ECA level

Watershed	Forest WS ECA (%)	Private WS ECA (%)	Overall Watershed ECA (%)
Cascade	4.9	7.1	12
Marino	0	13	13
Hatzic Slough	2.2	25	27
Draper	0	40	40
Chilqua	3.5	42	46
Hatzic Lake[1]	2.1	31	34

1) Hatzic Lake watershed area is the sum of Hatzic Slough, Draper, Chilqua, and 386 ha of residual private land area adjacent to Hatzic Lake.

2.2 The peak flow effect of roads from forest land and private land

The paved or compacted surface of a road is nearly impervious and thus almost all rainfall or snowmelt on a road surface turns into surface flow, as opposed to entering the soil and becoming subsurface flow. Ditchlines are often directly connected to the stream system and therefore increase the speed at which runoff is delivered to the stream system. Hydrologic evaluation of a forest road network is typically done by calculating the density of roads within a watershed, measured as the total road length (in kilometres) divided by the watershed area in square kilometres. A road density of less than 1 km/km^2 is considered to be low hazard, and a road density greater than about 2 km/km^2 is considered a high hazard for changes in flood flows (MOF/MOE 1995). This analysis is applied to both forest management lands and private land areas. Table 5 summarizes the road density within each watershed and by land use. Note that these summaries do not account for road width or surfacing material (paved or unpaved), both of which influence the hydrologic effect of roads. Paved roads and wider roads both result in a higher runoff of precipitation, and therefore the results for private land road density are likely a slight understatement of the peak flow effect of roads on private lands. Similar to the ECA analysis, the entire road network outside of the forest land base is considered as part of the private land.

Table 5. Road densities in Hatzic region watersheds.

Watershed	Forest road density (km/km^2)	Private land road density (km/km^2)	Overall road density (km/km^2)
Cascade	1.7	3.5	2.0
Marino	1.0	1.8	1.5
Hatzic Slough	1.3	2.0	1.7
Draper	0	2.6	2.6
Chilqua	0	2.2	1.1
Hatzic Lake	1.0	2.2	1.7

Forest road density is low to moderate for most of the watersheds, and private land road densities are generally high. The overall road densities are moderate or high. These road densities likely increase flood hazards.

2.3. Summary of peak flow hazards

Most of the watersheds within the Hatzic region are multiple-use watersheds, with hydrologic influence from both forest management and private land use. Current forest harvesting levels are low and not a significant factor for flood hazards. Forest road densities in Cascade, Marino and Hatzic Slough watersheds are at low to moderate hazard levels. There are no forest roads in Chiqua or Draper watershed. Private land use in the Hatzic Lake watershed is likely increasing flood flows as a result of the removal of forests and the relatively dense road network. The Hatzic Lake watershed and its tributaries have moderate to high hazard levels of both overall WS ECA and road densities, and are therefore most likely to have increased flood flows.

3 Water quality assessment of the Hatzic region

Ensuring safe potable water supplies was identified as a major concern by Shari Conroy of the Hatzic Valley Logging Committee (June 9, 2010 letter to Allan Johnsrude). In particular she expressed concern with forest management activities affecting the groundwater supplied by the FVRD Hatzic Prairie Water Supply. Safe potable water supplies requires both a sufficient supply of water as well as no contamination of the water. In addition to the Hatzic Prairie Water Supply, Hatzic region residents have surface water licenses and other groundwater wells that are used to supply domestic water.

3.1 Surface water resources

Figure 2 shows 14 licensed points of diversion for surface water extraction in the Hatzic region (BC Water Resources Atlas, note there are two diversion points near Chilqua Creek at Sylvester Road). Most of these licences are located along the base of Durieu Ridge and extract water from Scorey Creek, Dale Creek, Eng Creek, or small un-named creeks or springs. Three licenses are located on the west side of the valley, including the community watershed license on Kenworthy Creek. Unlicensed water extraction points also exist in the region and may be identified by contacting Sharie Conroy of the Hatzic Valley Logging Committee. Water quality for water extraction points on streams with headwaters in forest management areas may be affected by forest management activities.

Forest operations may affect surface water sources in several ways. Roads, forest harvesting and stand tending can all affect water quality and quantity. Major effects can include increases in discharge, suspended sediment, temperature, coliform bacteria and parasites, and changes in nutrients or other chemical parameters (Summit Environmental Consultants 2002). Increased sediment loads or debris flows that result from forest operations can damage intake structures. Petrochemical spills may also contaminate water supplies. Forest operators need to account for downstream water users when operating in watersheds that supply domestic water, and use appropriate forest practices to ensure no damage occurs.

Rural and agricultural development may also affect surface water sources. Effects are similar to forest operations, and can include increases in discharge, suspended sediment, temperature, coliform bacteria and parasites, changes in nutrients or other chemical parameters, and petrochemical spills.

3.2 Groundwater resources

Four groundwater aquifers are located within the study area (excluding Draper watershed), all within sand and gravel deposits (BC Water Resources Atlas, Figure 3). All four aquifers have low demand and are moderately productive. The Cascade, Hatzic Prairie and Nicomen aquifers are all highly vulnerable because the aquifer sediments extend from depth to the land surface, so any contaminants introduced on the surface can easily contaminate the aquifer as precipitation percolates through the aquifer sediments. The Miracle Valley aquifer has low vulnerability because the aquifer is capped with relatively impermeable sediments, which prevents contaminants from entering the aquifer. Recharge sources to all these aquifers is likely a combination of direct precipitation onto the aquifer surface (particularly those aquifers that are highly vulnerable), drainage from adjacent upland areas, and Stave Lake and the Fraser River (Lepitre 2009).

The Hatzic Prairie Water Supply provides water to 230 lots within Hatzic Prairie (Hofer, Mar 18 2009 Area F meeting). The wells are located at the Durieu Elementary School on Seux Road, within the Hatzic Prairie aquifer. Recharge of the aquifer is from the area of the aquifer itself, and likely other sources include the Fraser River and the adjacent sideslopes where forest management occurs.

Figure 2. Licensed water points of diversion

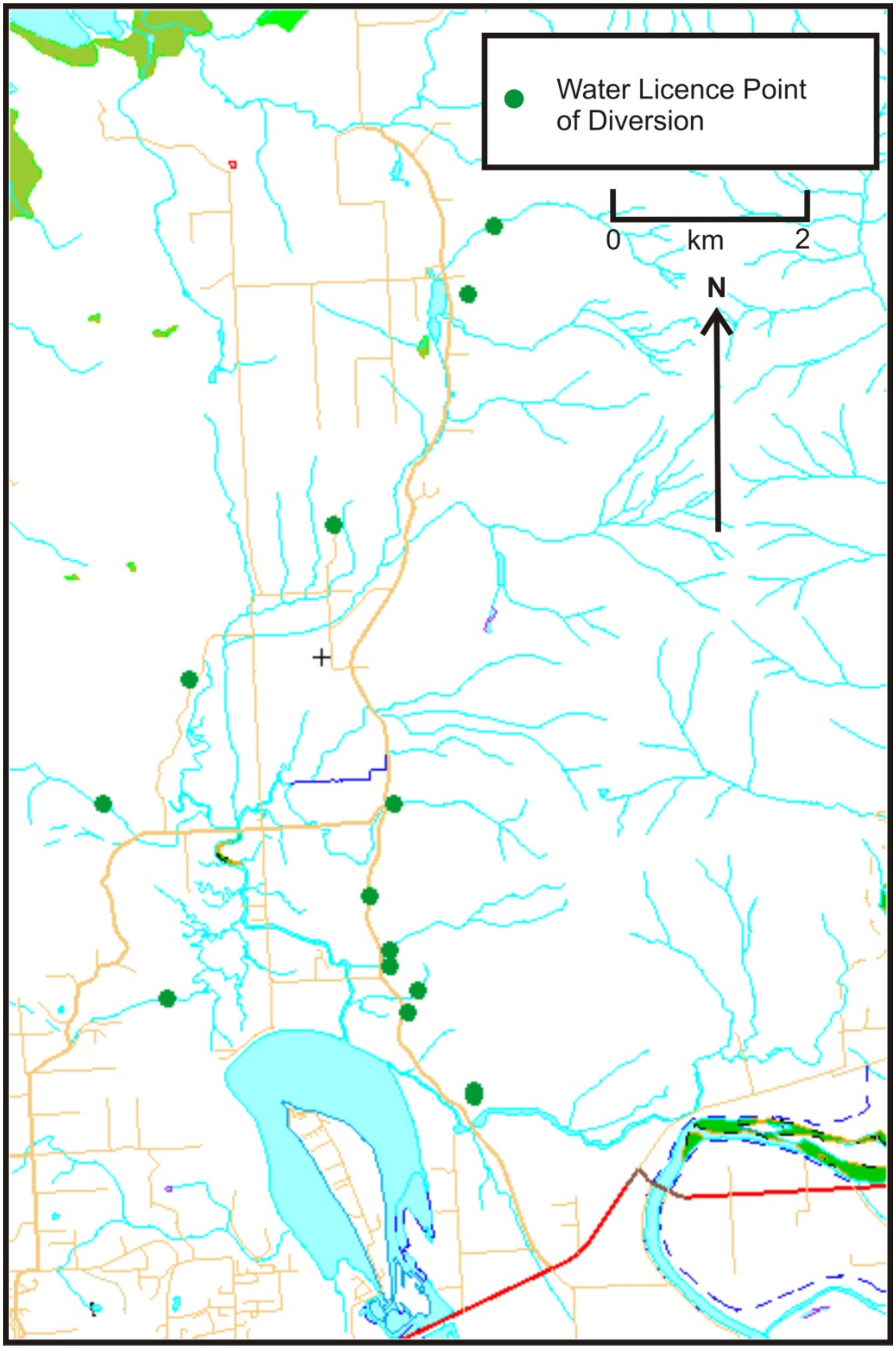
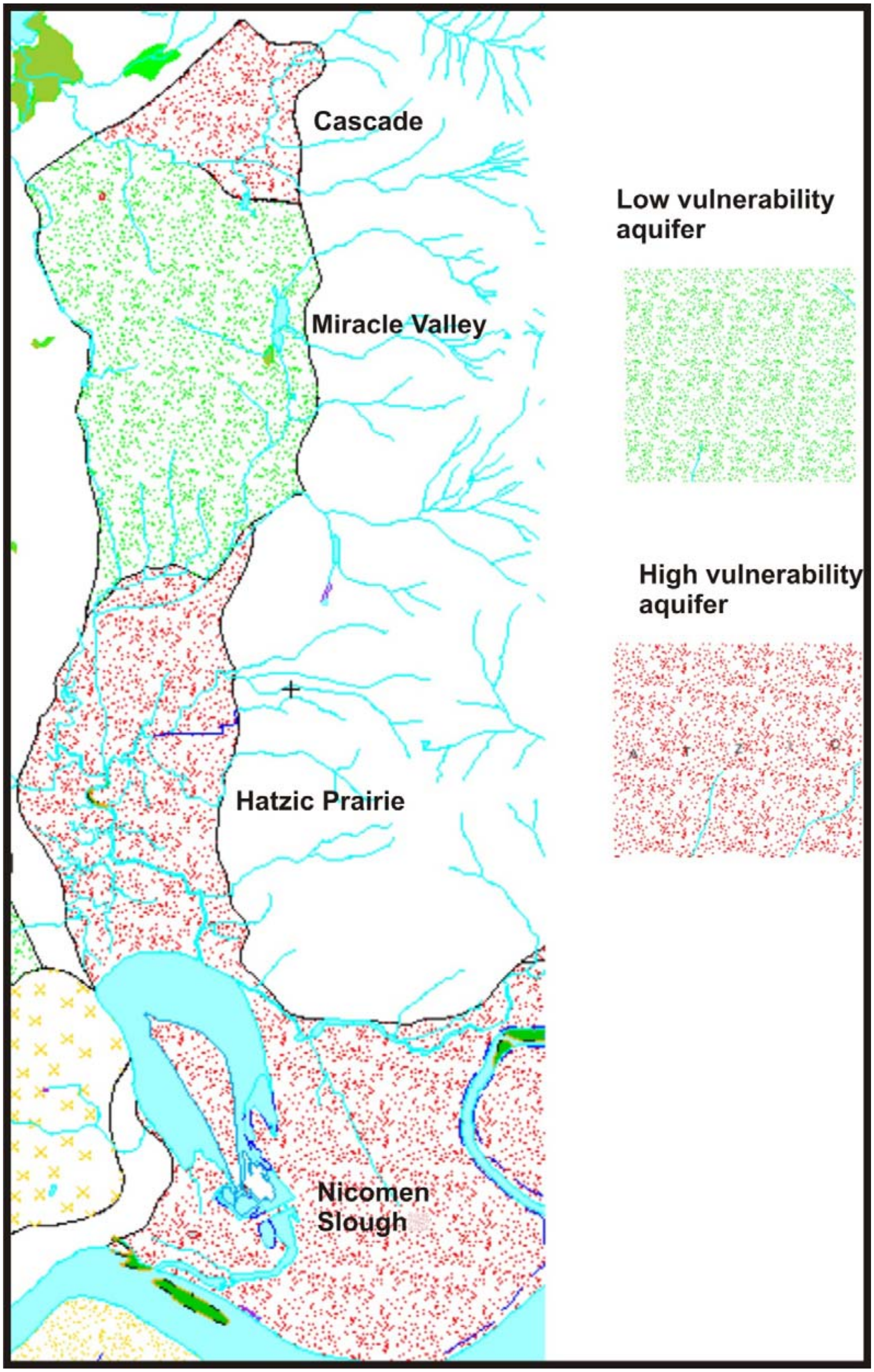


Figure 3. Aquifers in the Hatzic region



Michele Lepitre, Regional Hydrogeologist for the B.C. Ministry of Environment, presented information on groundwater resources within the Hatzic region at a FVRD Area F meeting in 2009. She noted that contaminant sources of groundwater include agricultural handling of manure, fertilizer or pesticide use, septic systems, fuel storage tanks, surface mining activities, stormwater runoff, industrial activities and urban gardening practices. Although she did not specifically cite forest practices, they may include fertilizer or pesticide use, and harvesting and road building operations could result in fuel or other chemical spills. Similar to other land managers such as farmers and local residents, forest operators needs to address hazards that may contaminate groundwater supplies in the Hatzic region.

Michele Lepitre also indicated that forest practices have the potential to increase water supply to aquifers due to a loss of evapotranspiration once forests have been harvested. Given the low forest land ECA levels in the Hatzic region, this effect is not likely to be significant.

4 Landslide hazard assessment of the Hatzic region

The steep slopes of Durieu Ridge and the Cascade watershed are landslide-prone. The west side of the Hatzic region and some other locations also have steep slopes, but these areas are less prone to landslides. Development at the base of these landslide-prone slopes has resulted in hazardous landslides that have resulted in one death and significant property damage. Government response to numerous landslides in October 2003 cost $3 million, and does not include private costs to repair damage (FVRD Area F Draft OCD).

Landslides were inventoried using aerial photographs and satellite imagery from 1952 to 2008. Available aerial photograph coverage for some years is not complete for all Hatzic region areas, and so for some years the landslide totals are not complete. Satellite imagery was viewed using GoogleEarth and is a combination of 2004, 2005, and 2008 imagery. Most of the Cascade watershed has 2005 imagery, while most of Durieu Ridge has 2004 imagery. Snow cover at higher elevations in the 2004 imagery limits interpretation slightly.

The primary land use on steep slopes in the study area is forest management. The landslides were classified as either natural (no land use), harvest-related (areas where the forest was harvested), or road-related (for landslides originating from roads). Landslides smaller than about 0.1 ha were not included in the inventory to avoid bias when comparing natural landslide numbers to forest management landslide numbers. Table 6 shows landslide numbers for the Cascade watershed; Table 7 shows landslide numbers for all areas draining to Hatzic Lake. No landslides were observed in Marino watershed.

Table 6. Landslide counts in Cascade watershed

Time Period	Natural	Harvest-related	Road-related	All forest management-related
1952 – 1957	2	10	3	13
1957 – 1968	1	17	7	24
1968 – 1979	11	29	7	36
1979 – 1993	18	23	0	23
1993 – 1996	0	0	0	0
1996 – 2005	0	1	0	1
Total	32	80	17	97

Table 7. Landslide counts in Hatzic Lake watershed

Time Period	Natural	Harvest-related	Road-related	All forest management-related
1952 – 1957	7	1	3	4
1957 – 1968	0	2	0	2
1968 – 1979	0	3	3	6
1979 – 1993	2	14	3	17
1993 – 1996	3	0	0	0
1996 – 2004	6	5	3	8
Total	18	25	12	37

A total of 184 landslides occurred in the Hatzic region in the period from 1957 – 2005. Seventy percent of these landslides originated in the Cascade watershed. Almost all other landslides occurred along Durieu Ridge, primarily from Pattison to Carratt Creek watersheds. For both the Cascade and Hatzic Lake watersheds, forest management has significantly increased the numbers of landslides, with forest management having quadrupled the rate of landslides within the Cascade watershed, and has tripled the rate of landslides in Hatzic Lake watershed. A small number of the landslides identified as harvest-related or road-related may have occurred naturally even if the slope had not been harvested or roaded, however this would not alter the overall results significantly.

Seventy-nine percent of forest management-related landslides are classified as harvesting-related. Some of these landslides may have been affected by road drainage, however, clearly the majority of forest management-related landslides reflect harvesting location as opposed to road drainage issues. The Cascade watershed has a large number of harvest-related landslides. Most of these landslides are within the two tributaries to Cascade Creek to the east of the main channel, primarily on heavily gullied slopes that likely are on relatively thick till deposits. Thick gullied till deposits are also located in many of the steep watersheds of Durieu Ridge and also show an elevated landslide response. In portions of Pattision watershed the till is particularly thick and chronic landslides have developed (Maynard 1995).

The number of forest management-related landslides peaked in the 1968 – 1979 period for the Cascade watershed, and between 1979 – 1993 period in the Hatzic Lake watersheds. Of the 134 forest management-related landslides, only 10 have occurred since 1993. Almost all of the steep slope logging within the study area occurred prior to 1980 and therefore the landslide rates reflect the practices of that period of time.

Within Pattison watershed a forest management-related landslide in deep glacial sediment has developed into a chronic sediment source. The slide initiated at the bottom of a cutblock and downslope of a road sometime between 1952 and 1957, and since then has increased significantly in size. I have not been able to visit the site, but it appears that the slide is likely to remain a chronic source of sediment, possibly for decades.

4.1 The 2003 landslide events

Several landslide or debris flow events occurred October 16 – 18, 2003 along Durieu Ridge. This event caused numerous landslide and flooding events across the south coast of British Columbia. The Mission West Abbey weather station recorded 123 mm, 62 mm, and 16 mm of rain on October 16, 17 and 18, respectively. The October 16 rainfall exceeded the 50 year event (Environment Canada). The Stave Falls weather station recorded 182 mm, 67 mm, and 27 mm for October 16, 17, and 18, respectively. The landslides were concentrated along Durieu Ridge and did not extend into the Cascade watershed, suggesting that a locally intense precipitation cell resulted in very high rainfall rates along Durieu Ridge. Debris flows occurred in Field Creek, Carratt Creek, Eng Creek, MacNab Creek, Saporano Creek, and North Herford Creek (BGC 2004). Houses were evacuated and some houses had damage (BGC Engineering 2004). Based on assessments from 2003 (Dunkley 2003a, b) and later satellite imagery, the following events occurred in these creeks:

- Field Creek had one natural landslide.
- Carratt Creek had 2 natural, 1 clearcut, and 3 road landslides.
- Eng Creek had 1 natural and 3 clearcut landslides.
- MacNab Creek had 2 clearcut landslides.
- Saporano Creek had a natural landslide.
- Pattison Creek had 2 natural landslides, and the large chronic landslide likely contributed additional sediment.
- North Herford Creek had at least one landslide, likely natural (no landslides are visible in GoogleEarth imagery, but almost all steep areas are in natural forest).

About half of the 2003 landslides were forest management-related (8 natural, 9 forest management-related). This is a lower proportion of forest management-related landslides than the historical average and may indicate that harvested slopes are recovering some natural stability. The road landslides in Carratt watershed indicate that the old road built in the 1960s and 1970s may be subject to further instability, possibly as a result of rotting wood in the fillslope.

4.2 Summary of landslide hazards

Slopes along Durieu Ridge and within the Cascade watershed are naturally unstable. However, historical forest management practices have tripled or quadrupled the landslide rate within the Hatzic region. Private property and infrastructure at the base of Durieu Ridge has been damaged by both natural and logging-related landslides, and at least one life lost. Careful forest operations on steep slopes are critical to safety within the Hatzic region. Most valley bottom locations that are subject to logging-related landslide hazards are also subject to natural landslide hazards. While there is a trend of decreasing numbers of logging-related landslides, residents will still be exposed to natural landslide hazards even if forest operations no longer produce landslides.

5 Sediment sources, flooding and channel stability assessment of the Hatzic region

Landslides from Durieu Ridge and within the Cascade watershed supply large amounts of sediment to the channel network. Cascade Creek and the channels draining Durieu Ridge have steep channel gradients until they reach the lower valley. Most of these channels flow across alluvial fans where the steep hillslope channel enters into the valley bottom. Channels on alluvial fans are often naturally unstable and the size, number and location of channels can change depending on sediment supply or the amount and type of vegetation (Millard et al. 2010). Higher rates of sediment supply result in a larger channel network and more frequent avulsions on alluvial fans (Millard and Campbell 2011). The high rate of landslides along Durieu Ridge and within Cascade watershed results in high sediment loads in several of the local creeks. Unstable channel locations and frequent overbank flooding result from sediment deposition on these alluvial fans.

In response to frequent flooding and unstable channel location, many of the creeks in the Hatzic region have been diked and sediment is excavated from the channel. Cascade Creek has diked banks on its fan below Cascade Falls to maintain channel stability. Gravel removal is required to maintain flood capacity (Sigma Engineering 1999). Carratt Creek is also diked on its alluvial fan and sediment removal is required to maintain flood capacity. Pattison Creek and Legace Creek are diked and frequent gravel excavation occurs (nhc 2005). Debris flows on Eng and MacNab creeks resulted in informal dikes constructed to maintain channel location.

Cascade Creek and the Durieu Ridge channels that are currently diked and have gravel excavation would likely have unstable channels and require dikes and channel excavation to maintain current land use even if landslide rates and sediment supply were not increased by historical forest management. Land managers often confine streams on fans so that more of the fan is available for development. Removal of forests on alluvial fans may also result in a greater tendency for channels to spread across the fan (Millard and Campbell 2011) and therefore land development often necessitates construction of dikes and gravel excavation. In part, the rural development of these fans has ensured there will be problems with the channels. However the frequency of flooding and avulsions on most of the alluvial fan areas has almost certainly increased as a result of forest management-related landslides.

6 Discussion

The Hatzic region is a mixed-land use area, and effective watershed management will require coordinated management between all parties. Forest practices have the potential to increase peak flows, initiate landslides, and contaminate groundwater. Conscientious forest management addresses these concerns.

6.1 Landslides and forest management

The most significant hydrology or watershed stability issue in the Hatzic region is the legacy of landslides from past forest practices. These landslides are continuing to occur in areas that were harvested decades ago, although the rate of forest management landslides has declined in recent decades. Most of these landslides occur on clearcut-harvested slopes and do not appear to be related to the road network. The increase in landslides following clearcut harvesting indicates that careful selection of harvest location is critical to reducing the number of logging-related landslides.

Harvesting affects slope stability by loss of rooting strength, altered hydrologic response, and damage to soil structure from falling and yarding of the trees. Roberts et al. (2001) found no difference in landslide rates for gullied slopes that were clearcut harvested and helicopter-yarded compared to gullied slopes that were clearcut harvested and cable-yarded. For open slopes, there was a slight decrease in the number of landslides in the helicopter-yarded areas compared to cable-yarded areas; however it should be emphasized that the helicopter-yarding results of Roberts et al. were based on a limited number of relatively recently harvested locations, and the occurrence of an additional two landslides would have changed their statistical results. Roberts et al.'s different results for open slopes compared to gullied slopes suggests that helicopter yarding has minor effects on clearcut-harvesting landslide rates. Cable-yarding methods which attempt to reduce soil damage are unlikely to be better than helicopter-yarding at reducing landslide rates. Therefore the most effective means of reducing the number of harvesting-related landslides is to avoid harvesting potentially unstable slopes.

For landslide initiation, a clearcut can be considered any patch that is bigger than approximately 0.1 ha. Most forest management-related landslides have an initial width of 10 – 30 m, and therefore a patch of 0.1 ha (31.6 m x 31.6 m) will have lost all rooting strength within the typical width of a landslide initiation location. Forest harvesting methods that attempt to reduce the likelihood of landslides would need to maintain rooting strength and hydrologic response across zones as little as a few metres wide.

Single tree harvesting may result in more stable slopes compared to clearcut slopes, since retaining trees should maintain partial tree canopy and root strength. To my knowledge there are no studies that demonstrate the extent of this effect and expected benefits are based on theory, not evidence.

Landslides initiated as a result of windthrow are becoming more common as cutblock boundaries are located adjacent to potentially unstable areas. Jim MacDonald at Simon Fraser University has documented a large number of windthrow-related landslides that occurred on the west coast of Vancouver Island in 2006/2007 (MacDonald, 2011).

Avoiding landslides that result from forest harvest requires careful assessment of the terrain. The specific types of slopes that are landslide prone are best identified by a terrain stability specialist. Stability assessments of slopes need to be particularly thorough when proposed harvest areas are upslope of developed areas and landslides may present a safety hazard. ABCFP and APEGBC (2010) note that the level of fieldwork is partially dependent on adjacent elements at risk (e.g. houses), and that extensive fieldwork may be warranted where landslides have already occurred in areas within or connected to the assessment area. APEGBC/ABCFP (2010) also notes that fieldwork “typically needs to consider... landslide transport and deposition zones in the vicinity of high value elements at risk”. For many areas within the Hatzic region, a thorough assessment of landslide risk will include extensive fieldwork from the potentially unstable slope to the deposition zone.

Old roads have contributed 21% of the forest management-related landslides in the Hatzic region. The 2003 landslide events show that old roads are still capable of producing landslides. Road deactivation would reduce or eliminate the potential for further landslides from old roads. Modern forest road practices are notably better at preventing landslides and I would expect few, if any, landslides from new roads if effective road construction methods are used.

Proponents of any future harvesting should evaluate whether landslide risk from forest development is unacceptable (APEGBC/ ABCFP 2008). The Fraser Valley Regional District provides a set of criteria for unacceptable landslide risk related to development within its boundaries (Cave 1993). Forest operators should consider the applicability of these criteria when evaluating potential forest operations located upslope of development. Safety and watershed stability within the Hatzic region will depend strongly on thorough slope stability assessments and careful forest operations.

6.2 Flooding hazards

Flooding hazards in the Hatzic region result from the natural setting of the channels, elevated sediment supply which reduces channel capacity, and likely increased flood flows as a result of roads and removal of forests. Because of the natural setting, flooding should be expected to occur. However, forest and watershed development have increased flooding hazards and should be addressed.

Increased sediment supply to Pattison Creek, Legace Creek and Hatzic Slough is now a chronic problem that requires excavation of the channel to maintain flood capacity. Until sediment supply decreases, the problem will continue and continued gravel excavation will be required. The chronic landslide in Pattison Creek likely supplies the majority of this sediment. More detailed evaluation of this landslide may provide a better understanding of the scope of the problem. Increased sediment supply in Cascade Creek should decline as the sediment delivered from forest management-related landslides from the 1952 – 1993 period is carried out of the system.

The hazard of increased flood volumes is assessed using ECA. Overall ECA hazard levels in the Hatzic region ranges from low to high. Watersheds draining to Stave Lake (Cascade and Marino) have low overall ECA, and moderate levels of forest harvesting could safely occur in these watersheds without increased flood hazards. The Hatzic Lake watershed and its sub-basins have higher ECA levels that require careful consideration of flooding hazards.

Both Draper and Chilqua watersheds have moderate to high ECA levels (40% and 46%, respectively), primarily as a result of agricultural and rural development. However, flood hazards in these watersheds do not appear to be an issue due to their channel locations. Draper Creek flows in a confined ravine which limits the extent of any flooding. Chilqua Creek appears to occupy an abandoned channel of the Fraser River. The large capacity of this channel can accommodate any increased discharge that Chilqua Creek is likely to experience. Although both of these channels are not likely to experience flooding hazards, the high ECAs and high road densities are likely resulting in higher discharges delivered to Hatzic Lake during flood events. This may result in higher lake levels and backwater flooding on Hatzic Slough (nhc 1985).

The Hatzic Slough watershed appears to be most sensitive to flooding. The natural setting on Fraser River floodplain, an elevated ECA of 27%, a moderately dense road network (1.7 km/km^2), and excessive sediment supply all contribute to increased flood hazard. With the exception of the excessive sediment supply and the forest road network, these factors are unrelated to forest management. Overall ECA is 27%, of which only 2% is from forest lands, and 25% from agriculture and rural development. Forest road density is 1.3 km/km^2 compared to private land road density of 2.0 km/km^2. Although current forest harvesting has a very minor contribution to the increased peak flow hazard in Hatzic Slough, increased forest management ECA levels may result in a higher flood hazard than currently exists. A cautious approach to forest harvesting within the Hatzic Slough watershed is warranted. Effective watershed management would also consider overall ECA levels within the watershed and consider the role of private land development. Restricting forest ECA levels may not be effective if rural development continues to increase road density and decrease private land forested areas.

6.3 Professional practice

Forest Professionals, Professional Geoscientists and Professional Engineers have obligations to protect the interests of the public, the environment and worker safety (APEGBC/ABCFP 2008). For managing terrain stability, APEGBC/ABCFP provide guidelines for the establishment of a Terrain Stability Management Model which systematically addresses all aspects of terrain stability. The model "provides guidance:

- as to when and where a terrain stability assessment (TSA) should be carried out;
- for managing terrain stability, whether or not a TSA has been carried out;
- for establishing risk criteria for specified values (elements at risk)
- for selecting forest development strategies that are consistent with the risks; and
- for establishing a consistent and logical decision making process to analyze and document decisions concerning the management of terrain stability." (APEGBC/ABCFP 2008)

Terrain stability, peak flows, and water quality all require specific management for forest operations in the Hatzic region. The APEGBC/ABCFP terrain stability management model can be extended to consider peak flow hazards and water quality issues to ensure protection of public interest, environmental protection and worker safety.

7 Conclusion

Broad valley bottoms and steep hillslopes characterize the Hatzic region. Forest management, agriculture and rural habitation are the dominant land uses within the region. All of these land uses have the potential to affect watershed processes. Two major watershed concerns are identifiable within the region. Historical forest practices have resulted in numerous landslides and excessive sediment delivered to valley-bottom streams. These landslides present safety and flooding hazards and cost millions of dollars to mitigate. A number of the watersheds are characterized by moderate to high ECA levels which may be increasing flood levels. This issue is primarily a result of extensive rural and agricultural private land development. While sediment supply should decline at some point in the future as chronic sediment sources stabilize and historical forest practices are avoided, the elevated ECA levels are likely to be a permanent feature of these watersheds and may increase with further rural development. Successful management of watershed issues in the Hatzic region must include rural land management in addition to forest management. In addition, gravel removal will be required on an ongoing basis, albeit at a reduced rate once the historical forestry-related landslides stabilize.

Although forestry is only one land use within the Hatzic region, it has a legacy of adverse effects that need to be avoided in the future. An important aspect of forest management under the *Forest and Range Practices Act* is reliance on professionals to identify slope and watershed stability issues, and to plan and conduct forest operations so that adverse affects are avoided.

There are a number of management factors that are strongly recommended for professionals' consideration when planning forest management activities in the Hatzic region. They can include but are not limited to:

- Consideration of available information from existing terrain, hydrological, or watershed reports.
- Approaching forest management in the Hatzic region with the same level of due diligence as conducted in a community watershed, including obtaining appropriate specialist advice for evaluating hydrological or watershed impacts. Specialist advice should include recommendations to avoid impacts to resources, infrastructure, and public safety within the Hatzic Region.
- Proposed cutblocks and roads should be carefully evaluated for terrain hazards, sediment delivery to stream channels, and risk to public safety and infrastructure. Professionals should consider the relevance of landslide risk standards that are applied to residential development areas where forest development may impact public safety or private property.
- Locations of licensed and unlicensed water intakes should be determined, with appropriate management to maintain these resources.

Past forest practices have left a legacy of unstable hillslopes along Durieu Ridge that present landslide hazard to downslope residents. A road deactivation program should be considered for roads on Durieu

Ridge. Assessment of the chronic landslide within Pattison watershed may provide useful information for watershed management.

The cumulative effects of forestry, agriculture and rural development combine to create significant watershed management issues within the Hatzic region. Ideal watershed management include all stakeholders and would address all sources of disturbance.

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