Extension Note

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Predicting the risk of wet ground areas in the Vanderhoof Forest District: Project description and progress report

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Abstract

The mountain pine beetle epidemic is changing British Columbia forests and watersheds at the landscape scale. Watersheds with dead-pine-leading stands in the Vanderhoof Forest District of central British Columbia are reported to have wet soils due to raised water tables. They report a conversion of summer logging ground (dry firm soil) to winter logging ground (wetter less firm soil), upon which forestry equipment operation is difficult or impossible before freeze-up. This paper outlines a project that explores this serious operational issue through the perspective of the hydrologic water balance. It aims to determine the spatial extent of wet ground areas and to provide operational guidance through the development of a model that can predict where wet ground may occur at the stand and watershed level. The watershed-level prediction described here will be based on risk indicators developed from available geographic information system data and aerial photographs, as well as local knowledge. Predictions will be qualified through field verification studies at representative stands within ranked watersheds. Preliminary results are presented.

KEYWORDS: *groundwater, mountain pine beetle, risk assessment, risk indicators, soil hydrology, water balance.*

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Introduction

The mountain pine beetle (MPB) epidemic in the interior of British Columbia presents a new challenge to forest managers because of its large spatial extent (currently 87 000 km^2) and its unknown effect on both the ecological condition of watersheds and the economic value of resources drawn from them. In response to the infestation, the allowable annual cut (AAC) was recently increased in the most heavily affected areas to enable recovery of the economic value of attacked pine stands and to expedite the regeneration of new forests. The Vanderhoof Forest District received an increase in the AAC; however, salvage operators have reported difficulties with their operations because of a loss in summer logging ground (summer ground) over the last 3–4 years. That is, where they expected to have dry soils where heavy equipment could be used, they encountered wetter soils, which made equipment use difficult or impossible. These wetter soils may be the result of rising water table levels.

It has been suggested that this loss of summer ground is a direct result of the MPB infestation. If this suggestion is true, it may signal a change in landscape-level ecological conditions and make access to the dead timber more expensive, both of which are substantial management concerns. To address aspects of these concerns, several projects were funded by the Canadian Forest Service Mountain Pine Beetle Initiative (Canadian Forest Service 2005). The project described in this extension note focusses on the development of a predictive model or tool to identify watersheds with higher potential for wet ground areas due to the MPB epidemic. This project addresses the following two questions.

1. Where are these wet ground areas?
2. Do biological and physical indicators exist to identify areas at risk of losing summer ground?

This extension note outlines the project's background and objectives, and describes its assessment approach, risk indicators, and field verification program. Preliminary project results are presented and one study site is highlighted to demonstrate the verification of risk indicator efficacy.

Background

The Water Balance

Observations made regarding the conversion of summer to winter ground in the Vanderhoof Forest District can be explored through the water balance approach,

Dead and dying pine stands may alter the water balance of beetle-infested watersheds by increasing soil water content and surface runoff.

which helps to conceptualize water movement at large scales such as the watershed (Ward and Trimble 2004). The water balance equation can be simplified to the general form:

$$I - Q = \Delta S$$

where: I = input, Q = output, and ΔS = change in storage.

Input refers to precipitation (both rain and snow) and output generally refers to runoff and evapotranspiration. The change in storage refers to a retention or loss of water stores from vegetation, channels, lakes and wetlands, and soils. The loss of summer ground implies that groundwater storage increases. If summer ground is being lost because of increased groundwater storage, the water balance equation will indicate that this is due to either an increase in the input or a decrease in the output of affected areas (or both).

Input, or precipitation, varies seasonally and annually, but the observations for the Vanderhoof Forest District have been relatively consistent with the exception of 2004. Between 2001 and 2003, summer precipitation totals (June–September) were within 4% of the 1971–2000 normal (Environment Canada 2006). Summer precipitation levels for 2004 were considerably greater, being 25% higher than the 30-year normal (Environment Canada 2006). Recent research that took place to the west of the forest district has identified a temporal shift in the annual precipitation pattern. Woods *et al.* (2005) identified an increase in mean summer precipitation in northwest British Columbia and postulated that it aided the spread of *Dothistroma* needle blight. Although this research did not specifically focus on the Vanderhoof Forest District, it does indicate that precipitation patterns can change and identifies a need for more work in this area. Regardless of precipitation patterns, higher groundwater levels may be related to reduced evapotranspiration from dead pine stands.

Dead and dying pine stands may alter the water balance of infested watersheds by increasing soil water content and surface runoff. This is attributed to the lower transpiration and interception (evapotranspiration) rates of dead trees compared to live trees (Bethalmy 1975; Putz *et al.* 2003; Tokuchi *et al.* 2004; Ladekarl *et al.* 2005). Interception by coniferous forest stands can vary between 15 and 35% depending on precipitation amount and form, tree species, and stand characteristics (Dunne and Leopold 1978; Spittlehouse 2002; Banner *et al.* 2005). Similarly, the amount of transpiration will depend on geographic area, climate, tree species, and stand age. Knight *et al.* (1985) determined that transpiration levels in lodgepole pine stands accounted for 50–61% of total evapotranspiration in pine stands of southeastern Wyoming. Still, interception has been considered the important factor accounting for "watering-up" (i.e., an increase in water table elevation) (Dubé and Plamondon 1995). Regardless of the individual contribution of interception-based evaporation and transpiration, the loss of both processes in grey-attack watersheds composed of homogenous pine stands may result in 40–60% more precipitation reaching the soil surface annually than before the MPB infestation. This would exceed the observed reduction in evapo-transpiration (i.e., 6–39%) in comparable watersheds to northern British Columbia (Plamondon 1993). This net increase in precipitation delivered to the ground must be stored or exported from the watershed. If stored, the water table elevation will increase and soils may water-up, a process documented in Quebec and elsewhere by Dubé (1994). Although the water balance response will vary between watersheds based on their respective meteorological and physical conditions, those experiencing watering-up will also most likely show increases in water yield (Potts 1984; Sun *et al.* 2001).

In summary, the observed changes in groundwater storage of Vanderhoof Forest District watersheds may be the result of changes in the pattern or quantity of precipitation *and* changes to evapotranspiration processes. This project concentrates on the latter. It determines which watershed-scale physical and biological characteristics will help to identify watersheds and sites at risk of wet areas due to decreased evapotranspiration and increased water table elevation.

Forest Harvesting and Hydrologic Effects

Although this project initially focussed on the influence of the MPB on groundwater storage, watershed-scale salvage harvesting is also occurring in the Vanderhoof Forest District. As such, salvage and previous harvesting within each beetle-infested watershed may further influence its hydrologic regime by leading to increased water table elevation (Dubé *et al.* 1995) as well as altering drainage patterns and increasing erosion rates (Jones *et al.* 2000). Altered drainage is a concern in areas with a shallow water table where soils can be degraded by compaction and puddling during harvesting operations (Williamson and Neilsen 2000). If a stand's soil infiltration and water storage capacity are decreased because of the combined effects of increased traffic and decreased evapotranspiration, then surface soils will be wetter and surface runoff duration and quantity will increase in the affected stands. Forest roads can intercept and redirect this increased runoff, altering natural drainage patterns and possibly increasing erosion rates (Bilby *et al.* 1989). Soil disturbance such as compaction can exacerbate waterlogging (Aust *et al.* 1993; Groot 1998; Ballard 2000). Such possibilities are a significant resource management concern because of the large spatial scale of the MPB epidemic and the understanding that the effects of excess soil saturation and compaction may persist for decades (Blake *et al.* 1976; Voorhees and Sharratt 1997).

> *This project focussed on the development of a predictive model or tool to identify watersheds with higher potential for wet ground areas due to the MPB epidemic.*

Project Objectives

This project aims to provide a broad-scale assessment of hydrologic risk (defined as a high, medium, or low possibility of wet ground areas) due to the MPB attack and salvage harvesting in the Vanderhoof Forest District. Further, it will provide information on the spatial scale of soil hydrology issues in the forest district and a predictive model for use in other districts that are dealing with the MPB and salvage harvesting activities. The following four project objectives are designed to meet these goals.

1. Predict the extent of disturbance in watersheds of the central interior affected by severe MPB infestations and salvage harvesting using available forest cover information, aerial photographs, soil data, and watershed assessment indicators. This process is referred to as the "landscape approach."

2. Field-verify the predictions made through the landscape approach and identify site-specific indicators that can be used to pinpoint the areas experiencing elevated water tables.
3. Use local knowledge to identify areas where stakeholders have experienced the loss of summer ground. Studying these areas will allow for the refinement of risk indicators identified in the landscape approach.
4. Discuss these findings with government agencies and forest licensees, and provide them with recommendations for sustainable forest management indicators and watershed management in beetle-infested areas.

Methods

Study Area and Units

The Vanderhoof Forest District was chosen as the study area for this project because of widespread concern regarding the loss of summer ground. Further, the district has an extensive MPB infestation due to the prominence of pine-leading stands, which occupy approximately 84% of the Vanderhoof Timber Supply Area (B.C. Ministry of Forests 2004a). The district was subdivided into study units on the basis of third- and fourth-order watersheds because these have been shown as an optimal size for the assessment of water management issues in forest research (Henry 1998; Hogan *et al.* 1998; Tschaplinski 1998). Once delineated, several watersheds were observed to extend beyond the district's boundaries. To prevent bias, those watersheds having less than 90% of their area within the district were removed from further analysis. A total of 176 watersheds remained, the majority of which had areas of less than 50 km^2 (Table 1).

Landscape Approach: Risk Indicators and Salvage Harvesting

The risk indicators used in the landscape approach fall into two general categories:

TABLE 1. Area of third- and fourth-order watersheds in the Vanderhoof Forest District

Watershed order	No. watersheds	Range in area (km^2)	Average area (km^2)
Third	150	2.1–97.9	33.6
Fourth	26	4.7–252.6	88.0

1. beetle infestation characteristics, and
2. watershed characteristics.

Beetle infestation characteristics indicate the extent of beetle presence and the potential for beetle spread, and include:

- the area of grey attack (> 4 years since attack);
- the infestation severity data from a 2004 aerial overview survey; and
- the area of beetle-rearing habitat considered to be pine greater than 61 years old (age class 4 and higher) within each watershed.

Watershed characteristics assess the increased delivery of precipitation to soil by reviewing snowmelt and runoff processes, as well as soil moisture regime, and include:

- slope (where lower slope indicates less runoff potential and more delivery to soil);
- aspect (cooler aspects have slower snowmelt rates); and
- soil moisture regime (based on biogeoclimatic zone classification in Meidinger and Pojar 1991).

Risk indicators have a range of effect from none (0) to large (1) (Table 2).

The ranking process presented here is an iterative one that will be expanded or refined in the future based on information gathered during the interpretation of field verification data.

Risk Indicator Rationale: Beetle Infestation Characteristics

Forest cover – The higher the proportion of mature pine infected by MPB (assumed to be age class 4 and older), the higher the proportion of total precipitation that will reach the soil due to decreased interception, evaporation (sublimation), and transpiration (Bethalmy 1975).

Grey-attack area – As the infected tree progresses from red to grey attack, the amount of interception and evaporation decreases because the needles fall. Further, the older the age of attack, the longer the site has been exposed to decreased interception and evaporation, which increases the likelihood of soil saturation. Schmid *et al.* (1991) determined that net precipitation (i.e., the amount of precipitation reaching the ground) did not increase in dead pine stands that had retained their needles.

Mountain pine beetle severity – Overview flight data was collected in the fall of 2004 using specified survey standards (B.C. Ministry of Forests 2000). Severity of attack is nominally assessed as a light (1–10%), moderate

TABLE 2. Risk indicators and their relative risk values

Risk indicator	Range of condition	Ranking
Beetle Infestation Characteristics		
Forest cover	Pine-leading stand	
	• Percentage cover > age class 4	Percentage value (0 to 1)
	Non-pine-leading stand	
	• Percentage pine > age class 4	Percentage value (0 to 1)
Grey attack area	Grey attack (> 4 years)	Percentage value (0 to 1)
	Non-grey attack (< 4 years)	
Infestation severity	Severe	1.0
	Moderate	0.7
	Low	0.3
	None	0.0
Watershed Characteristics		
Soil moisture	Well drained	
	• Very xeric, xeric, submesic, mesic	0
	Imperfectly drained	
	• Subhygric	0.5
	Poorly drained	
	• Hygric, subhydric, hydric	1
Aspect	Cool	1
	Warm	0.5
Slope (Average gradient)	Level (0–10%)	1
	Gentle (10.1–25%)	0.75
	Moderate (25.1–50%)	0.50
	Moderate–steep (50.1–70%)	0.25
	Steep (> 70.1%)	0

(11–29%), or severe (> 30%) level of infestation based on the observation of red- or grey-attack trees.

Risk Indicator Rationale: Watershed Characteristics

Soil moisture – Soil moisture regime categories follow the biogeoclimatic zone classification (Meidinger and Pojar 1991). The regimes were subdivided into three general classes: well drained (very xeric–mesic), imperfectly drained (subhygric), and poorly drained (hygric–hydric).

Aspect – Watershed aspect, which refers to the geographic orientation of the watershed, was determined using the Predictive Ecosystem Mapping (PEM) II data set and was based on zonal-majority. Cool aspect watersheds have delayed spring runoff and may contribute more snowmelt to the ground than warm aspect watersheds (Dingman 2002). Given the predominance of snowmelt in the regional hydrology, it is a prominent source of recharge and soil saturation. Cool aspects were defined here as having an orientation between 285.1° and 135°; warm aspects were between 135.1° and 285°.

Slope – As the gradient of the watershed increases, the potential for water retention decreases because surface water is delivered to the stream channel (Dingman 2002). Risk rankings were based on five general slope categories provided by the PEM II data set: level (0–10%), gentle (10.1–25%), moderate (25.1–50%), moderate–steep (50.1–70%), and steep (> 70.1%).

Risk indicators were combined to generate a risk score for each watershed according to the following model:

Risk Score = [grey-attack area × (% pine cover > age class 4)] × (infestation severity + soil moisture + aspect + slope)

The above model is weighted toward those watersheds with large areas of grey-attack trees. This approach was taken because our project had a 2-year duration and watersheds with a larger proportion of existing grey-attack stands would have experienced decreased evapotranspiration processes for a longer period of time than those having less grey attack. Watershed characteristics (e.g., soil moisture, aspect, and slope) all have the same weighting at this stage, but will change as field studies identify which attributes have greater influence.

Using the above model, the range of possible values was 0–61.2. For ease of presentation, the risk scores were standardized to a scale of 0–100. Low-risk watersheds had a score of 0, moderate-risk watersheds had a score between 0.1–9.9, and high-risk watersheds had a score greater than 10.0. These scores were selected to distinguish risk classes because each represents a change in magnitude. This first attempt to delineate risk classes will be verified through field observation and adjusted accordingly. The following cases are provided as examples of the risk ranking:

- Case 1: Pine-leading (> 80% cover), low MPB severity, no grey attack, level slope, warm aspect, subhygric soils = Low Risk
- Case 2: Pine-leading (> 80% cover), severe MPB infestation, 2% grey attack, level slope, warm aspect, mesic soils = Moderate Risk
- Case 3: Pine-leading (> 80% cover), severe MPB infestation, 15% grey attack, level slope, warm aspect, submesic soils = High Risk

Once a risk class was assigned to a watershed, the amount of salvage logging and past forest harvesting was used to place it within a harvest class. Watersheds spanned a range of harvest levels, but were generally classed as having no harvest, less than 30%, or greater than 30%. This subdivision provides the opportunity to identify the hydrologic influence of the MPB (unharvested), as well as the cumulative hydrologic effects of forest harvesting. A harvesting level of 30% was chosen as a categorical division because it is typically referenced as an upper limit for harvesting within Pacific region watersheds above which significant increases in water yield and peak flows can occur (Harr 1976; Stednick 1996; Guthrie 2002). This stratified sampling design subdivides the study watersheds into nine distinct sampling populations (see Table 3).

Local Knowledge Approach

In the fall of 2005, a meeting was held with Vanderhoof Forest District licensees to describe the project and gather their local knowledge. This knowledge will be used to qualify the findings of the landscape approach; that is, do the high-risk watersheds identified using the landscape approach experience wet ground? During the meeting, participants were given a map of the district and asked to ascertain the locations and times of year when operational difficulties occurred due to elevated groundwater levels. Using these maps, additional sites will be selected for assessment in 2006. This will enable the study of known problem areas, and the identification of their beetle infestation and watershed characteristics. The annotated maps will be digitized and added as a local knowledge layer in the geographic information system (GIS) data set.

TABLE 3. Stratified sampling design for the MPB study in the Vanderhoof Forest District. Harvesting category is used to partition watershed strata that are determined by hydrologic risk. Each cell in the matrix represents is a separate sampling population.

	Harvest level		
Hydrological risk	**Unharvested**	**Harvest < 30%**	**Harvest > 30%**
High Risk	#	#	#
Medium Risk	#	#	#
Low Risk	#	#	#

Field Verification

Field verification studies are required to qualify the predictions made by the landscape approach and to assess the cause for changes identified through local knowledge. To ensure similar sampling environments between watersheds, study sites will be located in the lower reaches of selected watersheds on hillslopes along the main stem or a significant tributary (S3 or S2 stream). Because these sites have a larger catchment area than middle reaches or headwaters, they should provide a better demonstration of upslope changes in water balance due to the MPB and salvage harvesting. Each site will have three groundwater well transects that run parallel to the contour. Wells 1 m deep will be installed at the level-summit, middle-slope, and toe-slope positions to provide information about the water table. Proximal pedon descriptions will provide information on the range of variability in soil hydrologic properties. To differentiate MPB and salvage harvesting responses, wells are placed in both forest and clearcut sites (Figure 1). Soil structural and textural characteristics will be confirmed in proximal pedons to ensure within-site characteristics are as uniform as possible. Selected slope position will be of similar gradient and aspect between transects. This combination of data will be used to

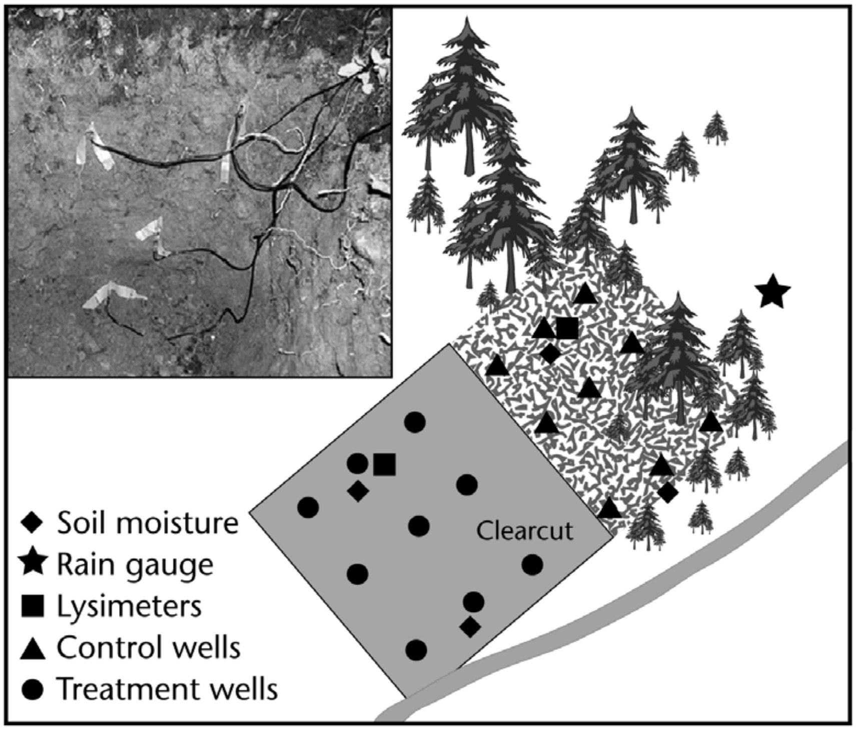

FIGURE 1. Study slope in the Targe Creek watershed showing the well network in the forested and clearcut areas, as well as the placement of lysimeters, rain gauge, and soil moisture probes. Inset photograph shows soil moisture probe installation at the 10, 20, 40, and 60 cm depths.

assess whether the conversion of summer to winter ground is due to increases in water table elevation or poor surface drainage conditions. Slope positions will be identified as "wet" when saturated conditions or almost saturated conditions exist below a soil depth of 30 cm. When soils are at or above field capacity, they are susceptible to compaction and disruption of their hydrologic properties (McNabb *et al.* 2001).

Field investigations for water table elevations and surface drainage conditions will be similar at every study site, but the soil investigations will differ as they will be at either the detailed or qualitative assessment level. Although every site will provide qualitative information, the detailed assessment sites will expand on these observations by providing information on soil hydrologic characteristics. Detailed assessment will be conducted on sites with extreme conditions—the low- and high-risk watersheds that are unharvested or harvested by more than 30%.

Field measurements will be made in early, mid-, and late summer, and early fall. These periods were selected because water table elevations are expected to decrease during the summer with some recharge during early fall storms. This sampling frequency allows for observation of surface ponding and soil saturation. The following parameters will be measured in the detailed assessments.

- Water table elevation: Shallow wells (< 1 m) are excavated by auger and lined with a 4-cm diameter PVC pipe to stabilize the walls and provide a standard reference point from which to measure water table elevation (Weight and Sonderegger 2001). Water table elevations are measured bi-weekly at each site using a dipper or electrical buzzer probe (Dubé *et al.* 1995; Weight and Sonderegger 2001).
- Soil water storage capacity (SWSC): Nachabe *et al.* (2004) define SWSC as the depth (volume per unit area) of water needed to raise a shallow water table to the land surface. Field estimation of SWSC is carried out by repeated determination of volumetric soil water content, measured by capacitance techniques to a 60 cm depth (ECH_2O-20 soil moisture probes by Onset Computer Corporation, Bourne, Massachusetts). These soil moisture probes are installed horizontally at 10, 20, 40, and 60 cm depths at each monitoring location. Using a site- and depth-specific calibration, the probe provides accurate and

reliable surface volumetric soil moisture results (Tsegaye *et al.* 2004).

- Infiltration capacity: This parameter is directly related to permeability and soil macroporosity. Infiltration capacity largely controls water flow in the soil above the water table since soil water moves primarily as unsaturated flow (Reynolds 1993). It is measured using a tension infiltrometer (Perroux and White 1988; Reynolds and Elrick 1991).
- Saturated hydraulic conductivity: This parameter is critical for quantifying changes in soil physical hydrological characteristics as it provides an indication of how easily soil transmits water under saturated conditions. After completion of infiltration measurements, field-saturated or ponded flow is determined by a simplified falling-head technique developed by Bagarello *et al.* (2004) using Philip's equation (1992).
- Particle-size distribution and the organic carbon content: These parameters are determined by the hydrometer method (Gee and Bauder 1986) using the less than 2 mm diameter soil fraction, and corrected for the proportion of particles greater than 2 mm for each horizon (approx. 20 samples per site selected for detailed assessment). Particle size characteristics can explain differences in hydraulic conductivities between soils and depths (e.g., Bosch and West 1998). As well, at lower water content, flow variability is associated with variable soil texture.
- Soil classification: Soils are classified near the location of the infiltration measurements on each site (Soil Classification Working Group 1998). The classification is performed on a pedon at each slope position to define soil horizons and other layers for interpretative purposes and to provide information on soil variability across the sample area. Soil structural, textural, and macropore characteristics are paramount to the hydraulic properties of soils; however, forest soils are known to be very heterogeneous. Therefore, the detailed soil description and the identification of spatial variability are essential in explaining variability in infiltration rates.

Qualitative Assessment Approach

After the spring freshet, bulk density and water content will be measured at each slope position and related to water table elevation. To relate the soil hydrology data to general system functioning, riparian and soil effectiveness evaluation forms (B.C. Ministry of Forests 2004b) will be completed as appropriate.

Detailed Assessment Approach

At the level-summit and toe-slope position for each detailed assessment site (in both forested and harvested areas), infiltration capacity, hydraulic conductivity, and bulk density will be sampled along transects using a systematic grid system. To document the range of variability, spacing between grid points may differ between the sites so that the grid covers the three slope positions. Within each slope position, the sampling area will be at least 10 × 10 m to adequately represent the variability of infiltration properties (Govindaraju *et al.* 1996). Soil water storage capacity will be calculated using data provided by the continuous monitoring of water content (May–October) at the toe-slope and level-summit positions. The water table will be measured weekly along two transects at each slope position.

Although soil structure is paramount to the hydraulic properties of soils, forest soils are very heterogeneous. This confounding effect on the average infiltration rate should be diminished through techniques that filter out heterogeneities. Sampling sites will avoid areas that have received significant natural (e.g., windthrow) or artificial (e.g., landing or bladed trail) disturbance. Data for soil physical properties and water infiltration will be collected at the same time to minimize both temporal (Prieksat *et al.* 1994) and seasonal effects (Emmerich 2003). Such consistency should improve relationships between our chosen factors.

Site Selection

To validate the landscape approach, eight watersheds were selected and monitored in 2005 (Table 4). These watersheds, and their associated study slopes, were

TABLE 4. Watersheds selected for study in 2005 including their assessment approach, hydrologic risk, and level of harvest

Watershed	Assessment approach	Hydrologic risk and harvest level
Peta Creek	Detailed	Low Risk: no harvest
Angly Lake	Detailed	Low Risk: no harvest
Cobb Lake	Detailed	Low Risk: > 30% harvest
Pitka Creek	Detailed	Low Risk: > 30% harvest
Chowsunkut Lake	Qualitative	Moderate Risk: > 30% harvest
Targe Creek	Detailed	Moderate Risk: > 30% harvest
Belisle Creek	Detailed	High Risk: > 30% harvest
Crystal Lake	Detailed	High Risk: no harvest

selected on the basis of a tiered selection process. Initially, over 30 watersheds were selected for overview flights in March 2005. This was followed by inspection of recent aerial photographs (Fall 2004 beetle survey flights) between April and June 2005. The overview flights and photographic inspections were applied in series to ensure that the data used during the landscape-based GIS assessment met expectations and the study site conditions identified for each watershed existed in their lower reaches. For example, were grey-attack areas visually similar to those calculated from beetle infestation records or, if a watershed was selected for a control, had any forest harvesting taken place? This step was necessary before the actual field visits because the GIS data set used was 2–12 months old. Field visits, which determined whether ground conditions were conducive to monitoring equipment installation, were made to select study locations within each watershed.

Selected watersheds represent the extremes of the population ranges (see Table 4), from low risk and no harvest to high risk and high harvest. These watershed types were specifically chosen to assess the sensitivity of the first risk matrix iteration. The selected watersheds are in wet, dry, and intermediate areas (based on biogeoclimatic ecosystem classification zones), have a minimum of 24% pine cover greater than age class 4, and generally have drier soil types (Table 5). The greatest changes in soil water conditions are expected at dry soil sites. Therefore, these sites were selected for study to document a change in soil hydrology (i.e., the conversion of summer to winter ground noted by Vanderhoof Forest District licensees).

Water Table Data Analysis

To demonstrate the application of these data in verifying the risk indicators, water table data from one of the study locations will be analyzed using a one-way ANOVA. Using SYSTAT 11 (SYSTAT Software Inc. 2004), this analysis will indicate the relationship between water table levels, slope position, and site type (clearcut and beetle-kill). We only provide data for one site in this extension note because our data analysis is in its early stages.

TABLE 5. Landscape approach selected watersheds and a summary of their characteristics

Watershed	UTM	BEC zone	Area (ha)	% pine over age class 4	MPB severity	Average slope and aspect[a]	Soil moisture[b]
Peta Creek	381891 6007454	SBSmc2	1747.5	31.4	Low	< 10%, none	Submesic
Angly Lake	393427 6013426	ESSFmv1	609.9	72.6	Low	10.1–25%, cool	Mesic
Chowsunkut Lake	388944 5980837	SBSdw3	3605.6	29.4	Severe	< 10%, none	Mesic
Belisle Creek	392956 5983659	SBSdw3	3764.1	24.0	Severe	< 10%, none	Submesic
Cobb Lake	470959 5975113	SBSdw3	1078.1	46.4	Low	< 10%, none	Submesic
Crystal Lake	398316 5961371	SBSmc3	4157.0	37.4	Moderate	10.1–25%, cool	Submesic
Pitka Creek	405900 6017328	SBSdw3	489.8	34.7	Low	< 10%, none	Very xeric
Targe Creek	386134 5960090	SBSdk	18996.2	40.0	Severe	< 10%, none	Submesic

[a] Based on PEM data; if the watershed is level, it has no aspect.

[b] Based on BEC zone classification.

Results and Discussion

Hydrologic Risk Predictions

The landscape approach showed some general clustering of watershed risk in the Vanderhoof Forest District. The southern portion of the district has the highest concentration of high-risk watersheds; the middle portion is dominated by moderate-risk watersheds, and the northeastern section has the low-risk watersheds (Figure 2). This follows the path of the MPB outbreak, which first occurred in the south and has since moved northward. Given the emphasis of the risk indicator

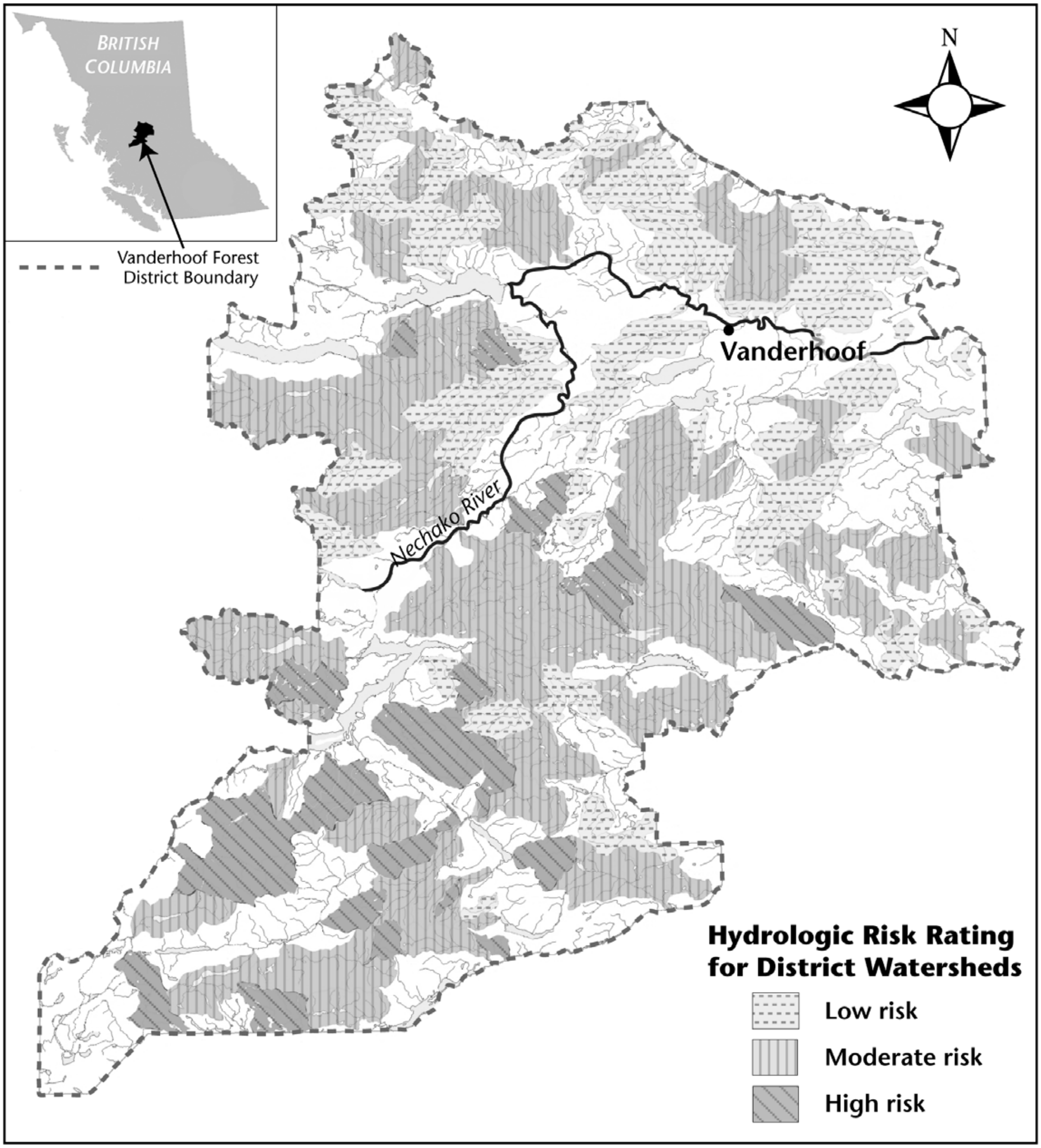

FIGURE 2. The Vanderhoof Forest District hydrologic risk ranking using the landscape approach.

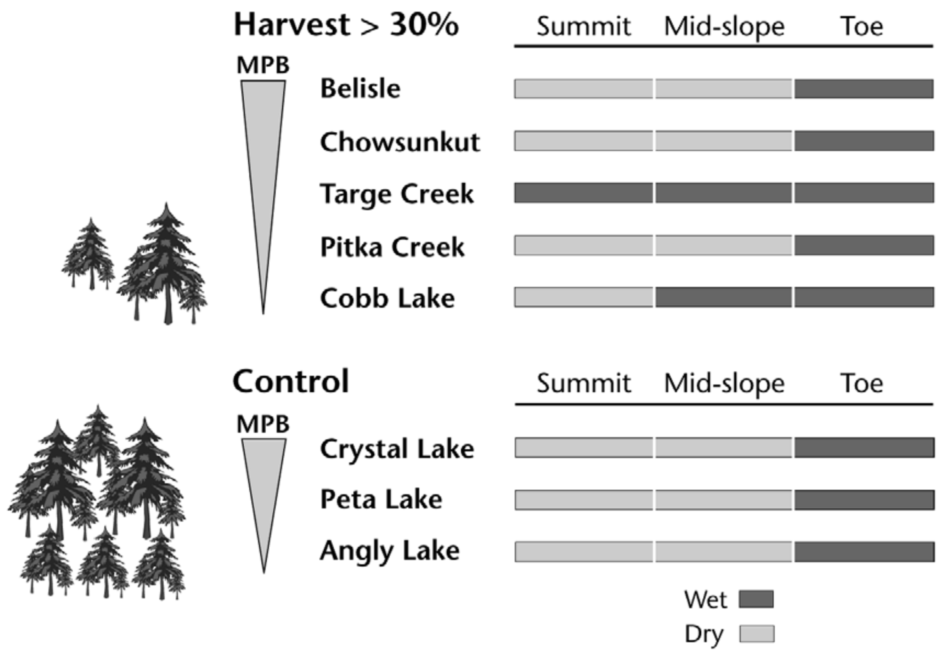

FIGURE 3. Soil moisture conditions at eight sites chosen using the landscape approach. The arrow provides a relative comparison of the level of MPB attack in each watershed (i.e., as the arrow widens, the area affected by the beetle is larger).

process on grey-attack stands, the older infested watersheds should receive a relatively higher level of risk because they will reach grey-attack levels before newly infested stands.

Field Verification

Toe slopes were wet at all sites (Figure 3) in the late summer and fall because of the combined influence of finer-textured soils at the toe and their moisture receiving position in the landscape. Upslope locations were dry in six of the watersheds, but were wet in the Targe Creek and Cobb Lake watersheds. The entire slope was wet at the Targe Creek site (moderate risk and high harvest), but only the mid-slope location at the Cobb Lake site (low risk and high harvest) was wet (Figure 3). It is too early, however, to explain the excess moisture across the slope gradient. Therefore, additional measurements of water table and soil saturation, as well as vegetation description (e.g., understorey) and soil disturbance assessments, will be needed in the final year of this project.

Water Table Elevation

The Targe Creek watershed was classified as having moderate risk and high harvest levels. Water table levels were deeper in the beetle-killed stand than in the cutblock despite the similarity of aspect and slope position ($p < 0.05$). This is likely due to interception loss by red- and grey-attack pine trees, as well as interception and transpiration by understorey shrubs and herbaceous vegetation. The shallower water table levels in the cutblock may be due to the relative absence of vegetation and logging debris, which could have intercepted more rainfall when compared to the beetle-killed stand.

Because of their moisture-receiving positions, the water table was closest to the surface at the toe in both the cutblock and beetle-killed sites. Although upslope positions have deeper, but similar, mean water table depths (Figure 4), these soils are considered at greater risk of losing summer ground conditions because the capillary fringe[1] is significant (up to 30 cm, S. Dubé unpublished data) and soil macrostructure, which controls the rise of water table, does not occupy

[1] Capillary fringe is defined as a zone in the soil just above the water table that remains saturated or almost saturated with water.

significant pore space in poorly drained mineral soil. Therefore, the water table would respond quickly to summer rainfall and lead to poor bearing capacity of the ground during logging. When the water table rises quickly not all pores are filled with water since air bubbles are frequently trapped under the water table (Constantz *et al.* 1988). Furthermore, a significant interaction effect was found between site and slope position for the summit ($p < 0.05$), with the beetle-killed site having water table depths that were almost 20 cm deeper on average than the cutblock (Figure 5). Assuming that runoff and deep drainage were negligible during that period of measurement, this suggests that the clearcut may have less ability to release water, perhaps due to the effects of equipment disturbance on waterlogged soils.

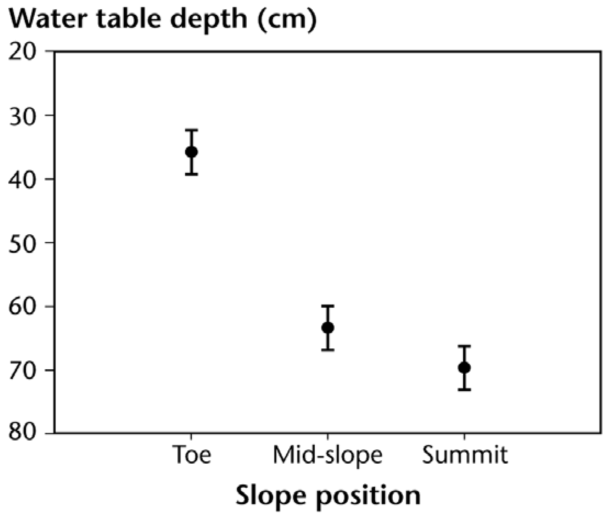

FIGURE 4. Least square mean estimates of water table elevation at each slope location across sites in the Targe Creek stand, including standard error bars (n = three per hillslope location over seven sampling periods).

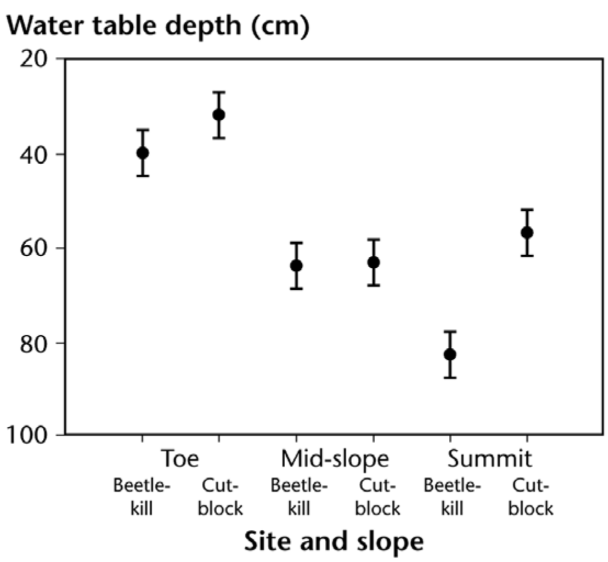

FIGURE 5. Least square mean estimates of water table elevation at each slope location and between sites in the Targe Creek stand, including standard error bars (n = three per hillslope location over seven sampling periods).

Conclusion

The effect of the MPB epidemic on the landscape and hydrology of interior British Columbia is unknown, and management support tools for hydrologic issues have not been developed. The information provided here represents some of the first field observations on soil hydrology conditions in a beetle-affected forest district. Although these data are preliminary, they indicate that watering-up is not occurring in every watershed. Where watering-up is occurring, water table elevations can increase in the toe-slope and upslope positions. Furthermore, our results demonstrate a need for further investigation into the role of the understorey and beetle-killed stands in net precipitation and the soil water balance at the stand level. As shown at Targe Creek, the cutblock had a higher water table than the beetle-killed site, likely the result of lower interception levels from slash and understorey vegetation on the cutblock (Watterston and Iyer 1964; Heikurainen 1967; Borg *et al.* 1988; Dubé and Plamondon 1995). Rising water table levels may also be attributed to disruption of surface drainage following equipment disturbance in harvested areas (Aust *et al.* 1993; Groot 1998), and possibly the loss of cementing agents (e.g., soil fungal species; Lito Arocena, University of Northern British Columbia, pers. comm., September 2005) when pine trees die from beetle attack.

This project was initiated to address concerns about salvage harvesting ground conditions, but it will also provide insights about the effects of the MPB and salvage harvesting on soil hydrology. It will develop a decision support tool through the broad-scale assessment of existing hydrologic conditions in the Vanderhoof Forest District. The observations gathered during this investigation, and the management recommendations that will follow, are designed to aid forest managers dealing with the MPB epidemic in the Vanderhoof Forest District and other forest districts. At its conclusion, this project will provide a list of watershed-based risk indicators and a ranking procedure that can be used for predictive mapping purposes and operations

Although these data are preliminary, they indicate that watering-up is not occurring in every watershed. Where watering-up is occurring, water table elevations can increase in the toe-slope and upslope positions.

management at the watershed and site levels. Once verified in the Vanderhoof Forest District, the procedure will be validated in other districts experiencing the MPB epidemic. This series of validation trials will enhance its applicability as a management tool across those areas affected by MPB.

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Test Your Knowledge . . .

Predicting the risk of wet ground areas in the Vanderhoof Forest District: Project description and progress report

How well can you recall some of the main messages in the preceding extension note? Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. What is the difference between summer and winter ground?

2. How can the MPB influence the water balance?

3. What is soil water storage capacity and how does it relate to a site being designated as winter ground?

Answers

1. Summer ground is a term used in forest operations to describe dry soils where heavy equipment can be used without unduly causing soil disturbance. Winter harvesting requires frozen ground or sufficient snow pack for minimizing soil disturbance.

2. Dead trees have lower interception and transpiration rates than live trees, which result into increased soil water content and surface runoff.

3. It is the depth of water needed to raise a shallow water table to land surface. Soils that have a low water storage capacity have pre-existing saturated conditions so they are wetter and less firm so best designated as winter ground to minimize compaction.