MOUNTAIN PINE BEETLE INFESTATION: HYDROLOGICAL IMPACTS

by

EDI ENVIRONMENTAL DYNAMICS INC.

for

Ministry of Environment Mountain Pine Beetle Action Team

BRITISH COLUMBIA
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Ministry of Environment

March 2008

This document was produced under contract to the ministry of environment mountain pine beetle action team (MPBAT) by EDI Environmental Dynamics Inc, PO Box 5, Prince George, B.C. the primary author was Hanna van de Vosse

Library and Archives Canada Cataloguing in Publication Data
Main entry under title:
Mountain pine beetle infestation: hydrological impacts [electronic resource]

Includes bibliographical references: p.
ISBN 978-0-7726-6022-0

1. Forest hydrology - British Columbia. 2. Forest management – Environmental aspects - British Columbia. 3. Mountain pine beetle - British Columbia. 4. Pine – Diseases and pests – British Columbia. I. British Columbia. Ministry of Environment. II. British Columbia. Mountain Pine Beetle Action Team. III. Environmental Dynamics (Firm)

GB842.D48 2008 551.4809711 C2008-960128-9

TABLE OF CONTENTS

1. INTRODUCTION

The mountain pine beetle (MPB) is a small insect that is commonly found in low numbers throughout the province. Although periodic and small outbreaks of this insect have occurred before, the current outbreak has risen to unprecedented and epidemic levels. B.C. Ministry of Forests and Range estimated that nearly 20% of the province's total forested area was affected by MPB in 2006 (Figure 1). The infestation is expected to run its course by 2018. At that time, 34% of the province's total forested area and 78% of B.C.'s mature pine forests will be killed. Currently, the damage extends from Fort St. John and Terrace to the US-Canadian border. To put this in perspective, the affected area to-date is roughly four times the size of Vancouver Island.

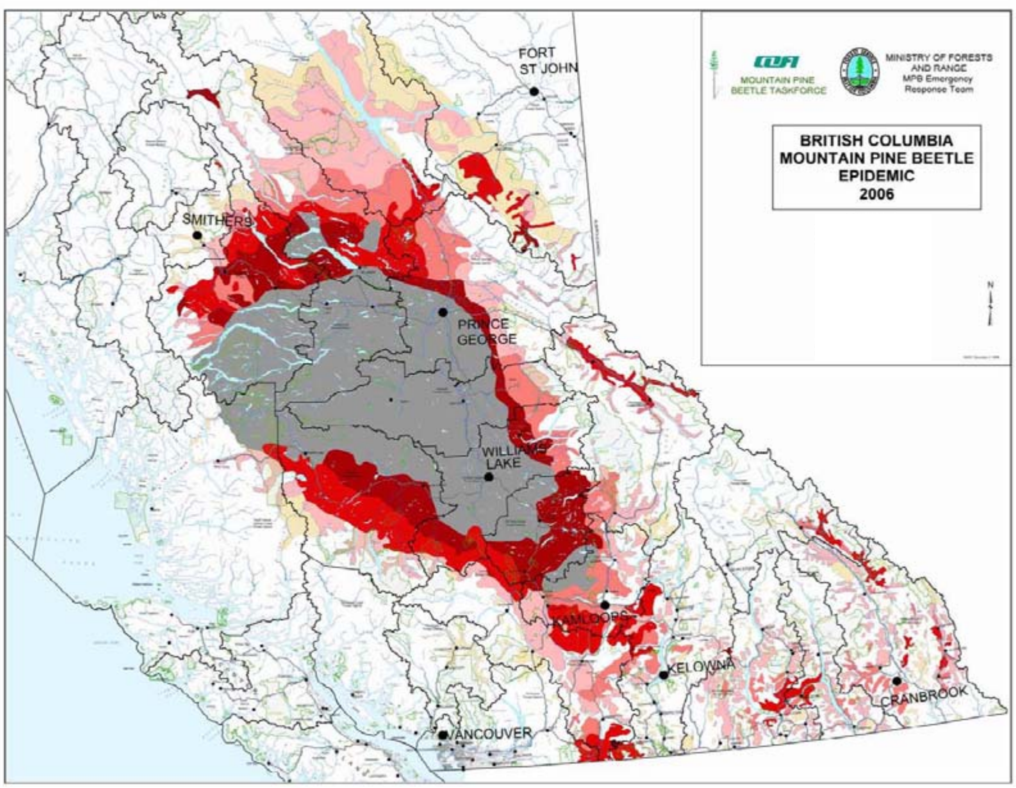

Figure 1: Mountain pine beetle distribution in 2006. Orange to pink is light to moderate, red and dark red indicates severe infestation and grey indicates areas of grave concern. **Source: B.C. Ministry of Forests and Range**

Given the scale of the outbreak, there is heightened concern as to how MPB will impact the province environmentally, economically and socially. This document provides a review of the forest hydrological cycle, as well as a condensed summary of the trends identified by researchers studying the effects of MPB on forest hydrology. Since MPB forests are commonly salvage harvested, hydrology research that assesses clearcut logging impacts will also be used to identify potential effects of MPB. This is followed by a discussion of the implications of changes to forest hydrology in B.C. Alterations to forest hydrology as a result of MPB affect the environment through changes in the amount and quality of water and can impact our daily lives in many ways.

2. WATER CYCLE

To better understand the potential effects of MPB on forest hydrology, it is necessary to first discuss the water cycle that exists in a mature and uninfected forest. A large portion of precipitation in the form of snow and rain is collected or intercepted by the forest canopy, with much of this water being returned to the atmosphere through evaporation. In addition to evaporation from the ground and vegetation, water can also be released back into the atmosphere by a process called transpiration. This is the process by which plants take up water from the soil and release water vapour through their leaves or needles. Eventually, water that is not taken up by the forest contributes to streamflow through surface runoff, subsurface flow, or groundwater (Figure 2).

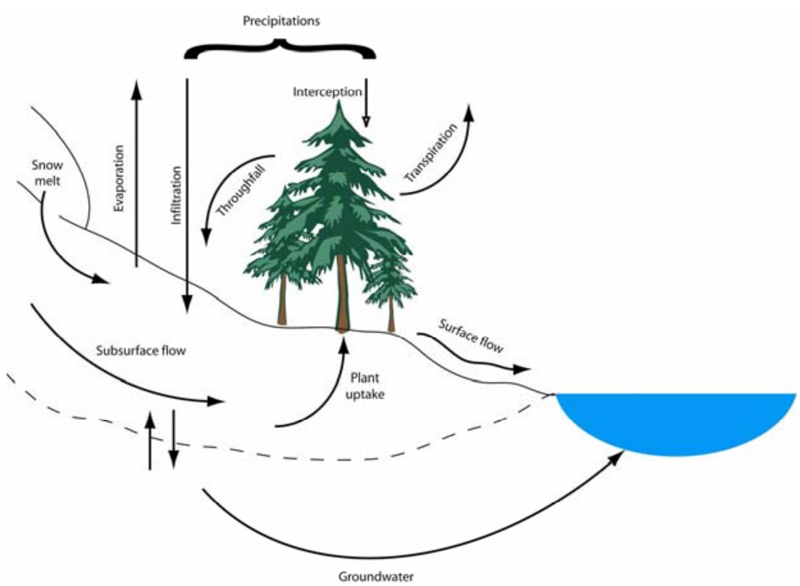

Figure 2: Water cycle depicting various hydrological processes in a mature and healthy forest.

3. HOW MPB CHANGES FOREST HYDROLOGY

Any number of factors such as elevation, topography, vegetation type, and changing weather patterns can influence the hydrologic processes illustrated in Figure 2. Given the variability of these factors among different provincial regions, and even among watersheds within regions, it becomes very difficult to describe hydrological changes on a large scale. This is one reason why much of the current research related to the effects of MPB and salvage logging has been done at the stand-level by comparing two or three smaller areas that have similar characteristics (e.g. elevation, slope).

A. ADDING WATER TO THE FOREST FLOOR

Initial research has shown that MPB ultimately leads to an increased amount of water reaching the forest floor. The question is: how?

Forest stands affected by MPB generally have more water reaching the forest floor through reduced interception and increased throughfall which causes snowpacks to increase and alters melt timing. Studies have shown that snowpacks are deeper in clearcuts when compared to mature forests and that grey attacked MPB stands lie roughly between the two. The loss of needles and small branches that characterize the grey stage of a MPB attack allows for an increased amount of snow on the ground when compared to mature forest stands. Grey attack tree snags and their larger branches appear to provide some interception when compared to clearcuts.

Recent studies have also indicated that reducing vegetation can also cause snowpacks to melt earlier. Not only does the amount of shade within a stand decrease as needles and branches are lost and tree snags fall, but wind speeds can also increase within the stand as openings become larger. Generally, the combined result of increased air temperatures in the forest as a result of greater exposure to sunshine, and increased wind is that snow melts faster. However, results of recent studies appear conflicted. While one study suggests that grey stands have similar snowpack melt rates when compared to mature forests, another suggests that melt rates in grey stands are intermediate between mature forest and clearcuts. On-going studies are examining how tree height, density and percentage of crown closure can affect snowmelt rates.

Few stand-level studies in B.C. have linked hydrological effects of MPB to increases in soil water as a result of reduced transpiration and evaporation rates. However, a study in Alberta modeled the amount of water lost through transpiration and interception in lodgepole pine forests that had not been attacked by MPB. Researchers found that transpiration accounted for a water loss of nearly 20% of the total annual precipitation. While these results are not directly comparable to B.C., they do provide an indication that we can expect the loss of transpiration to contribute to increases in soil water. The magnitude of this increase will depend on climate, geographic area, presence and composition of an understory, and age of the stand.

B. WHERE DOES THE EXTRA WATER GO?

So now we have an idea that a reduced forest canopy as a result of MPB attack leads to a net increase in water reaching the forest floor through a variety of processes. The question becomes: Where does this water go?

Stands affected by MPB can "water up" or experience an increase in soil water. Studies in the Vanderhoof area appear to indicate that "watering up" results from an increase in water table elevation and/or poor surface drainage due to increased amounts of precipitation reaching the ground surface and lower transpiration rates. Predicting which areas are susceptible to "watering up" depends on a variety of factors, including soil and watershed characteristics, as well as the size, age, and severity of infestation. For example, soil tends to become more saturated over time in an infected stand, and cooler north-facing slopes can slow snowpack melt which may increase the amount of water absorbed into the soil. Water tables have also been seen to be higher in clearcuts than grey stands and may be due to the lack of understory within the clearcuts.

Determining the amount streamflow changes as a result of MPB infestation at the watershed level is difficult because streamflow consists of excess water that has drained from stands with different characteristics. For example, stands can differ in the amount of MPB infestation, terrain, or elevation; all of which can result in different hydrological effects within these stands. However, by using hydrologic models researchers can calculate various responses to different characteristics over larger areas and generate predictions with greater certainty. Predictive modeling is therefore a vital tool in transferring knowledge from the stand-level to the watershed level.

Most recently, a modeling study was conducted within the Baker Creek watershed near Quesnel to determine the effects of MPB on streamflow. The watershed model predicted peak streamflow generated during spring melt and annual water yield under the following four scenarios.

Scenario	Year	Percentage of Watershed Harvested	Stage of MPB Infestation	Percentage of Watershed Attacked by MPB
1	1970	13	pre-MPB	0
2	1996	28	early	2
3	2005	34	current levels	53
4	2017	80	post	17

Scenario 3 predicted a 60% increase in peak streamflow (refers to rate of stream discharge) and a 30% increase in annual water yield (yearly amount of water that is released from a drainage area). Scenario 4, a worst case situation, predicted that following large-scale salvage harvesting, peak streamflow would rise by 92% and annual water yield by 52%. Scenario 4 also predicted an increase in the frequency of large floods; for example, the 20 year flood could be expected every three years.

C. WATER BALANCE RECOVERY

The next question is: how long will it take for the forest water balance to recover from the effects of MPB? Again, the answer depends on a number of variables: amount of understory, how quickly the area can be revegetated by natural or artificial means, the severity of the attack, and even how hydrological recovery is measured. Studies looking at canopy and tree height characteristics estimate that snow accumulation and melt rate recovery begin once trees reach 4m in height with more than

10% crown closure (% of ground that is shaded by vegetation). Full snow accumulation recovery is reached once crown closure is 60%. Generally, hydrological recovery is considered to be achieved once the trees reach 9m in height and may take between 20-60 years.

4. HOW DO THESE CHANGES AFFECT US?

It is believed that increases in water yield and streamflows are likely to last several decades. It is therefore necessary to understand the many effects these changes will have on the environment and the way we use the forest for industrial and recreational purposes. Increased soil water and streamflow can lead to decreased slope stability, increased flooding, and to changes in water quality and aquatic habitat. The combined results, or cumulative effects, also need to be considered since many of these effects are interconnected.

A. FORESTRY OPERATIONS

Increased soil water retention and rising water tables are causing some areas to "water up". Logging operators within these areas, notably the Vanderhoof Forest District, have already experienced harvesting difficulties. The use of heavy equipment has become difficult during summer months. Heavy equipment causes the wetter soils to rut much easier than drier soils and equipment frequently sinks. Some logging operators have had to switch to low ground pressure equipment in these areas. Rising water tables will also affect how areas are replanted following harvesting as some species are less water tolerant.

B. FLOODING

The routing of water from hillslopes to streams is also affected by road networks. Subsurface water is often intercepted in the cutslopes of roads and transferred to gullies and streams by ditches, thereby adding to streamflows. If more road networks are required for salvage harvesting following MPB attack, increases in road densities will likely contribute additional road surface flows throughout the watershed at the same time. This could result in downstream flooding especially if it occurs during spring melt when water is already higher because of MPB.

Large scale flooding can potentially result in considerable impacts, at least locally. This becomes evident when considering cumulative effects of flooding in larger watersheds since more water is added as the flood progresses downstream. Existing culverts and bridges, both public and private, may need to be assessed to ensure they will pass water at increased flows without failing. When designing new crossing structures, possible increases in streamflow and frequency need to be incorporated. This is especially important if peak streamflows and water yields predicted in Baker Creek occur. If increases in peak flows are not accounted for when crossings are designed, there is a greater chance that they will fail. Failed culverts not only disrupt road use but can also prevent upstream fish use. This can happen even if the culvert does not structurally fail; undersized culverts often result in water velocities that are too fast for fish to swim upstream.

C. STREAM HABITAT

Peak water discharge is also a key component in the process that determines the characteristics of a stream. Changes in water volumes and velocities alter how a stream transports material downstream. Water with higher energy can increase erosion of stream banks and beds, moving larger sized particles farther downstream. Particle movement includes not only gravels and boulders but also woody debris along stream banks which provides important fish habitat required for different life stages. Altering fish habitat by either removal of woody debris or addition of excess material can result in changes to fish distributions and populations within the stream.

The introduction of soil particles into a stream, or sedimentation, is not only affected by increased streamflow which can erode stream banks, but also by road networks and landslides. Roads are sources of sediment as run-off flowing in ditches and over gravel surfaces can pick up soil particles before being routed to streams. While less frequent sources of sediment than roads, landslides can transport soil material to streams. Increased water retention can increase the likelihood of landslides as steep slopes become saturated and unstable. Disturbance of these susceptible areas through additional road networks created during salvage operations may also increase the potential for landslides.

Physical and biological processes are often regulated by stream temperature. For example, increased temperatures can increase formation of algae which can in turn decrease the amount of oxygen available for fish. While the effects of harvesting on stream temperatures have been widely documented, few studies have looked at the direct impacts MPB has on water temperatures. Harvesting of stream bank vegetation has been shown to increase summer temperatures, especially in small and shallow streams. Therefore, it could be anticipated that reduction of stream cover by MPB may have a similar effect. Temperature increases could be compounded if the areas adjacent to streams experience both MPB attack and salvage logging. Stream temperature is also influenced by the input of groundwater and other heat transfer processes that cool the water. Recently, a model to predict cooling or warming stream temperatures was developed to help forestry managers plan timber harvesting activities that minimize potential thermal impacts.

D. NUTRIENTS

Another aspect of MPB pertains to changes in water chemistry with particular emphasis on nitrogen and carbon cycles. Organic matter, like wood and leaf debris, contains most of the nitrogen and carbon found within the forest. Carbon and nitrogen are added to soil through decomposition of this organic matter. Although growing vegetation absorbs nitrogen from the soil, carbon is sequestered in vegetation from the atmosphere during photosynthesis. Excess nitrogen that is not absorbed by vegetation or sequestered in soils is transported through the groundwater to streams. Carbon that does not diffuse through the soil and enter the atmosphere is dissolved in soil water and also transported through groundwater to streams. Few studies have been conducted to determine how MPB influences the carbon and nitrogen cycles. It may be supposed that concentrations within soil could increase as 1) fewer nutrients are absorbed by vegetation, and 2) more nitrogen and carbon are released by decomposing additional amounts of fallen needles, branches and dead trees. Additional nitrogen and carbon transported to streams may eventually result in changes to aquatic insects and fish populations.

5. MANAGEMENT TOOLS

Managers realize that there is little we can do to stop the spread of the outbreak and that we must now focus on managing the impacts of MPB. But given the huge area of the province that has been or will be affected, where do we start?

The first step is to identify the areas that will experience the greatest impacts. B.C.'s Ministry of Environment is currently using the Watershed Evaluation Tool (WET) to evaluate and designate Fisheries Sensitive Watersheds (FSWs) under the *Forest and Range Practices Act*. WET ranks fisheries values and sensitivity of a watershed based on various physical and biological attributes. The first step of the process uses available data at a provincial scale to create a prioritized FSW list of watersheds in the province. This list is then forwarded for regional review and consultation as well as verification using regional data. At this point, watersheds with the highest priority may be designated as FSWs and legislation will require forest managers to undertake practices that maintain natural watershed processes to protect and sustain fish and their habitat. This may assist in maintaining conservational goals in FSWs that are impacted by MPB. The Kamloops Timber Supply Area (TSA) has also developed a watershed ranking procedure to provide timber licensees and stakeholders a means of identifying and prioritizing high risk watersheds to assist in planning MPB salvage operations. In this case, a watershed's level of risk is rated based on assessments that incorporate amounts of disturbance and physical attributes as well as social and economic values.

While both procedures result in prioritizing high risk watersheds, there are key differences between the two approaches. Unlike the Kamloops TSA procedure, WET does not consider economic or social values in its assessments. In addition, while the end result of WET defines a legislative requirement, the Kamloops TSA procedure prioritizes areas that require additional assessments to assist in developing preferred mitigation strategies among licensees and stakeholders.

Once a high risk watershed has been identified, the next step is to evaluate these impacts within the high priority areas and develop management strategies. One way to do this is through watershed risk assessments. These assessments are used to identify sites within a watershed that pose the most concern and develop site-specific management strategies. For example, in highly sensitive areas with grey stands that have well developed understories, it may be more advantageous to retain the grey stands rather than salvage log these areas. The understory has been shown to contribute to reducing the amount of water reaching the forest floor. As the MPB killed trees drop needles and branches, more sunlight penetrates through the canopy allowing the understory to flourish and grow. The decaying needles and branches will also provide valuable nutrients for the growing plants.

6. CONCLUSION

General consensus among hydrological professionals is that the MPB infestation will result in increased water yield and peak flows through a variety of processes and that it will take upwards of 30 years or more before the water balance returns to pre-MPB levels. Combining these effects with those of salvage harvesting will result in more widespread and farther reaching impacts. However, the exact magnitude of hydrological change is still uncertain due in large part to the vast number of influencing factors such as climate, local weather patterns, and geographic characteristics.

Much of the current research appears to indicate that hydrological processes within grey stands are somewhere between a mature forest and clearcut. However, as the grey stand begins to age and snags are blown down, hydrological processes will likely move toward those in the clearcut. Exactly how much a grey stand transitions to that of a clearcut will depend largely on re-growth of vegetation and the amount of disturbance that occurs within the stand. The presence of an understory therefore appears to play a vital role in mitigating the potential hydrologic impacts of MPB. Though how much the understory will reduce these effects will depend largely on the type and stage of vegetation, terrain characteristics, and climatic factors.

Currently there is much debate regarding the hydrological value of an intact and infested pine forest compared to a salvage harvested stand that is artificially regenerated. It is important to note that while the infested forest may have limited economic value that decreases over time, the forest also contains inherent values at conservational and hydrological levels. Unfortunately the hydrological benefits of retained stands cannot be easily quantified and as such it is difficult for forest managers to effectively balance economic gain while minimizing potential impacts. Modeling, watershed evaluations such as WET, and risk assessments will provide additional management tools to assist forest managers in making these decisions.

7. ACKNOWLEDGEMENTS

This project was initiated and directed by Chris Ritchie (MoE). Review efforts provided by Eric Mellina and Cathy Mackay were greatly appreciated. In addition, the author would like to thank Rita Winkler (MoFR) and co-authors for providing a draft copy of "Mountain Pine Beetle Forest Practices, and Watershed Management" as background reference material for this document. Jennifer Burleigh (MoFR) also assisted in gathering background information. The following government staff also provided valuable insight and knowledge:

Ministry of Environment - Doug Lewis, Susanne Williamson, Allan Chapman and Art Tautz;

Ministry of Forests and Range - Rita Winkler, and Pat Teti.

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