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PROBLEMS AND OPPORTUNITIES IN CANADIAN FOREST HYDROLOGY

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ABSTRACT

Large scale insect and disease attacks of forests are a natural and recurring event. The most recent spruce budworm outbreak in eastern Canada and the northeastern United States presents us with an opportunity to study the evapotranspiration physiology and regime of partially defoliated forest stands. The mountain pine beetle, which has recently reached epidemic proportions in southeastern British Columbia and southwestern Alberta, presents an opportunity to study altered evapotranspiration of forests composed largely of dead trees. Both types of outbreaks should be viewed as opportunities to improve our predictive capabilities of their effects on local and regional hydrology.

The PROSPER evapotranspiration model and the snowmelt portion of the WATBAL model are suggested as suitable building blocks or starting points for further process understanding and model building. An opportunity exists to extend the WRENSS procedure, based on the above two models, to Canadian basin studies in order to improve this simplified procedure's application in Canada.

Lastly, the current interest by the forest industry and Government forest management personnel in forest renewal and intensive management is an opportunity for forests hydrologists to put their knowledge of techniques to manipulate forest microclimate to good use in improving soil moisture and other site conditions conducive to forest regeneration and tree growth.

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RESUME

L'attaque des forêts par des insectes ou par des maladies sur une grande échelle constitue un phénomène naturel récurrent. La récente prolifération de la tordeuse des bourgeons de l'épinette à l'est du Canada et au nord-est des Etats-Unis nous fournit une occasion d'étudier la physiologie et le régime d'évapotranspiration de forêts partiellement défoliées. Le dendroctone du pin Ponderosa dont la prolifération a récemment atteint des proportions épidémiques, au sud-est de la Colombie-Britannique et au sud-ouest de l'Alberta, constitue une occasion d'étudier l'évapotranspiration modifiée de forêts comportant une forte proportion d'arbres morts. Ces deux types de prolifération devraient être perçues comme des occasions d'améliorer notre capacité de prédiction de leur effet sur l'hydrologie locale et régionale.

On suggère d'utiliser le modèle d'évapotranspiration PROSPER ainsi que la portion du modèle WATBAL portant sur la fonte des neiges comme points de départ ou comme éléments de base afin d'approfondir notre compréhension du processus et d'élaborer un modèle. L'occasion se présente également d'étendre la portée de la méthode WRENSS, basée sur les deux modèles mentionnés ci-dessus, aux études de bassins canadiens afin d'améliorer l'application de cette méthode simplifiée à des situations canadiennes.

Ces derniers temps, l'intérêt montré par les responsables de la gestion forestière dans l'industrie et les gouvernements pour la régénération des forêts et leur exploitation intensive, constitue une occasion choisie pour les spécialistes de l'hydrologie forestière de mettre à profit leur connaissance des techniques de manipulation des micro-climats forestiers en améliorant l'humidité du sol et d'autres conditions pertinentes à la régénération de la forêt et à la croissance des arbres.

INTRODUCTION

This is a symposium on hydrological processes of forested areas. It sems fitting to me that we look at some of the major problems that foresters are concerned with in Canada and the opportunities that these present to us as forest hydrologists.

Canada is a nation of forests and her economy is highly dependent upon the 1-million primary and secondary industry jobs and the $15 billion in export earnings that the exploitation of this forest resource involves (Reed, 1980a). It is important that these forests be wisely managed for the betterment of all Canadians, whether they directly exploit the forest or enjoy the regulating effects that forests have on streamflow.

We hydrologists tend to focus our attention on any change in water supply or quality at some point removed from the actual forestry operation. Our tendency is to lump the many kinds of forestry practice that can take place together under a general category such as 'the effect of forest cutting on stream flow, water quality, snow accumulation, etc.' I think we should turn our attention to the forest, to better understand the practice, how it relates to the hydrologic cycle, and how we can predict effects both on and off site from an analysis of the practice rather than an analysis of streamflow.

I would like to address three problems that I feel forest and land use or perhaps even general hydrologists should be looking at in greater depth. Although my references are to Canadian conditions and applications, I don't feel that they are unique to Canada. These are:

- -The problem of wide spread and recurring insect and disease attack on forests.
- -The problem of transfering research results from experimental to operational situations.
- -The integration of hydrological techniques and knowledge into the practice of renewing and growing forests.

EVALUATION OF INSECT AND DISEASE OUTBREAKS

The spruce budworm

The spruce budworm is an insect native to North America. In spite of its name, it feeds mainly on the foliage of balsam fir with white and black spruce as secondary food sources. Periodic outbreaks are a natural phenomena in the Boreal forest (Blais, Kettela and Moody, 1981). During this century, major outbreaks occured in eastern Canada and the northeastern United States in 1910 - 1920, 1940 - 1960, and from 1970 to the present. The spruce budworm has been described as a "super silviculturist" because of its ability to devistate old and mature stands of balsam fir-spruce to allow replacement by a stand that is younger, more vigorous and initially more resistant to the insect itself (Baskerville, 1975).

Spruce budworm outbreaks are important hydrologically because of their effect on evapotranspiration and the very wide spread nature of such outbreaks. A 1974 map of the most recent outbreak, 1970 to present, Figure 1, shows moderate to severe defoliation in much of eastern Ontario, southern Quebec, New Brunswick and Maine (Kettla, 1981). When severe outbreaks occur, the ultimate result is death of about 80% of the merchantable (mature) stand (Miller, 1975). Widespread outbreaks should be expected to have an effect on both local and regional water supply.

Spruce budworm attacks effect canopy resistance to transpiration loss. In the initial four years of an outbreak, they defoliate about 30% of the new shoots. At 6 to 7 years, the population peaks to strip all of the new growth and some of the old needles from the trees. By the 8th and 9th year, some trees with dead tops are evident. And by the 11th through 14th year, mortality reaches its peak at about 80% of the mature trees (Miller, 1975).

One of the aspects of this cycle of defoliation and death that I found noticeably absent from the literature was how does it effect evapotranspiration at various stages in the attack? Transpiration is a major component of forest evapotranspiration. The vapour loss represented by the transpiration process is subject to stomatal control and overall canopy resistance to vapour loss is normally related to stomatal resistance and leaf area (Monteith, 1973). The only article I could find that even indirectly alluded to stomatal function of balsam fir was a 1961 article on photosynthesis (Clark, 1961). These results indicated that about 80% of the photosynthesis occurs in the current and two years' prior growth. Brix (1962) has shown that transpiration and photosynthesis rates are closely correlated. This stands to reason because the stomata must be open for either carbon dioxide entry or water vapour exit. Stand transpiration is probably reduced by 30% in the first 4 years of a budworm attack and by 80% or more after the 6th to 7th year.

I'm rather curious as to why stomatal resistance of balsam fir has not received more attention. Clearcutting experiments have occured on two watersheds in Canada that had a high proportion of fir and spruce on them. Both the ruisseau des Eaux-Volée catchment near Quebec, and the Nashwaak near Fredericton are in the general area affected by the current spruce budworm outbreak. The preliminary water yield results from these two catchments are markedly different: essentially no effect on water yield at ruisseau des Eaux-Volée (Plamondon and Oullet, 1980) and a fairly substantial increase in water yield on the Nashwaak (Nashwaak Experimental Watershed Project, 1981). It is possible that several factors have contributed to these contrasting results, but I for one, would look at how canopy resistance may have been altered prior to harvest by the spruce budworm.

Mountain pine beetle

The mountain pine beetle is the most serious native insect enemy of mature lodgepole pine in western Canada. It attacks in mid summer, boring through the outer bark of the stem to cut egg galleries in the

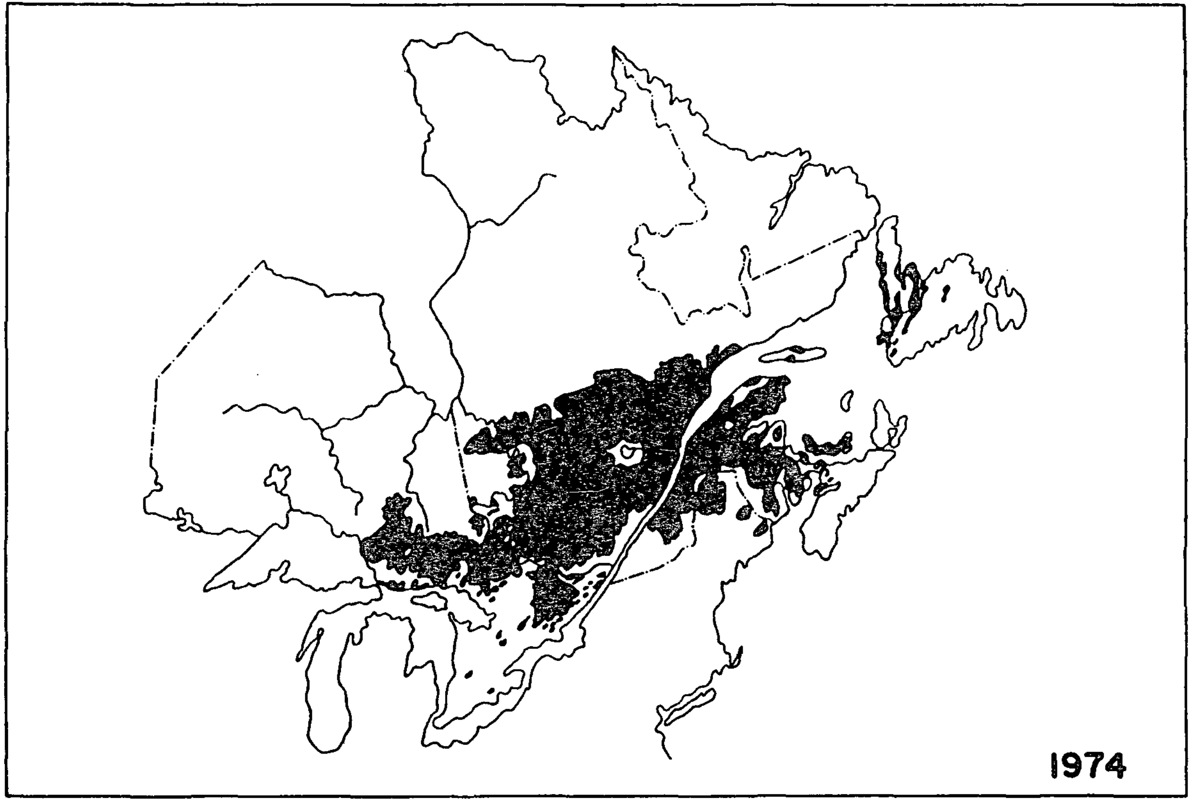

Figure 1. Map showing location of moderate to severe defoliation of balsam fir and spruce caused by the spruce budworm in eastern Canada and the New England States (Kettela, 1981).

inner bark area. When the eggs hatch, the larvae feed circumferentially on the soft inner bark material. This feeding may girdle the tree. But perhaps even more serious is a blue stain fungus that accompanies the beetles. This fungus rapidly infests and kills the living cells of the bark and sapwood and the tree begins to die within a few weeks of being infested (Environment Canada, 1982).

The mountain pine beetle has been recorded in British Columbia since 1910. Outbreaks occur at irregular intervals, generally last for 8 to 9 years and severly deplete the mature (80 + year old) pine component of a forest. Younger trees (40 to 80 years old) are often attacked when the beetle population is very large (Environment Canada, 1982). The areal extent of any given infestation is dependent upon the area of mature pine available. Lodgepole pine tends to occur in large contiguous stands of similiar age. Therefore most stands are highly susceptible to almost total decimation at some point in their life span. At present severe outbreaks exist in interior British Columbia and southwestern Alberta. We are fortunate so far in that none have occured on any of the experimental watersheds in Alberta or British Columbia.

Hydrologic effects of insect and disease attacks

Death occurs much quicker in pine after bark beetle attack than in fir-spruce under budworm attack. The interface with the hydrologic cycle is evident as a direct cut off of transpiration upon the death of a beetle-attacked tree. Tree death may or may not occur as a result of budworm attacks. Even when death does occur, it may be several years before the this is obvious. Both types of insect attack cause a reduction in canopy surface. Therefore both types of attack ultimately lead to the same hydrologic effect: reduced individual tree transpiration and stand evapotranspiration. The problem is to determine the degree of change from normal at any given stage in an attack so that any adverse effects on water yield or regime can be predicted and planned for.

The challenge that insect-disease outbreaks present us as forest hydrologists is several fold. First there is the effect during and following the attack. How rapidly is evapotranspiration changed by the action of the insect? What evapotranspiration regime should one expect during the initial buildup of the insects' numbers - versus that at tree death. Will an under-canopy be exposed upon defoliation of the mature trees that will take up the evapotranspiration slack caused by their death? How long before a replacement stand restores evapotranspiration to normal? Beetle kills are often followed by wildfire. What will be the effect of such a sequence of events?

Secondly what will be the effects of control measures? Does spraying the spruce budworm forests maintain the transpiration rate of the stand at some reduced percentage of 'normal'? Will clearcutting the dead trees cause a greater or lessor hydrologic impact than no corrective action at all? Effects on both water quality and water yield are of concern in most instances.

Thirdly, the effects of preventative management. Since both spruce budworms and pine beetles seek out and attack mature trees, one of the preventative options available to the forest manager is to opt toward younger stands and shorter rotations. Do more vigorous younger trees transpire more water than mature or partially defoliated trees and if so, would the creation of such younger stands alter local or regional water management plans?

I do not believe that these questions are receiving adequate attention in Canada. In most cases we can only make intelligent guesses as to the order of magnitude of hydrologic effects because we lack specific measurements and interpertation of the important physiological linkage with the hydrologic cycle that canopy resistance to vapour flux provides.

UTILIZATION AND DEVELOPMENT OF TECHNOLOGY TRANSFER TOOLS

Alden Hibbert made a statement in 1965 that many of us in forest hydrology wish had been left unsaid. He stated as a generalization referring to the effect of forest clearing on water yield, that "response to treatment is highly variable, and for the most part, unpredictable" (Hibbert, 1967). I personally don't feel that unpredictable part of the statement has ever been qualitatively correct if one used good judgement in interperting forest treatment results in light of the physical, physiographical, physiological and micrometeorological features of the situations in question. I do agree with him that the response is variable. In addition, I feel that most of our catchment studies are so sparsely reported that it is difficult for a reader to analyse treatment and response unless he has a personal acquaintance with the experimental site and treatment.

I think that we need to ask ourselves two somewhat more fundamental questions before we consider predicting the effect of a forest treatment. First, what are we being called upon to predict? Usually the question we are asked goes something like this: "what is the effect of clearcutting on water yield on the XYZ timber lease?" Our answer could be simply that annual water yield will increase by the amount that annual evaporative loss is decreased. This last we should be able to calculate or model fairly accurately with physiological and microclimate measurements relating to the given type of forest and practice. Unfortunately this is rarely the answer they want. They are really asking us to predict not only water yield increases, but to route the increase as well as normal water yield through unspecified catchment properties and predict a daily efect on even less well-specified users!

Secondly, how accurate does the prediction have to be? We will never be able to answer their real question without very site specific measurements and then the answer will no longer be a prediction but an-after-the fact evaluation. However we can predict a range of possible **change** in flow under various cutting patterns, and with some help from the meteorologists, even offer some probalities of how often and to what degree changes in certain runoff events might occur. It is far easier to predict change in runoff than it is to predict runoff. Change is largely a function of the type of forest and cutting practice which are relatively stable from year to year. Runoff is a function of precipitation, vegetation, harvesting practice and the catchment topography.

With the above in mind, I would like to discuss a few of the tools we have at our disposal to help in answering such requests.

Informal qualitative descriptions

I mentioned one category of these earlier on - that of using reasoning and judgement based on experience and acquaintance with various experiments and their results. The work that Hillman and I did in Alberta in 1973, 1974 is an example of this type of prediction. We reasoned from our experience that the clearcutting on the St. Regis leasehold in west-central Alberta, would produce results more similiar to those from the Wagon Wheel Gap, Colorado, experiment than those from the Fool Creek, Colorado, experiment (Bates and Henry, 1928; Leaf, 1975) because snow accumulation patterns and melt rates would not be significantly altered by the very large clearings involved (Swanson and Hillman, 1977). Similiarily, we predicted an annual yield increase of 20 to 30 percent based on the average of a number of catchment experiments conducted in similiar climatic types. Bosch and Hewlett (1982) indicated that their general function, derived from the results of 92 catchment experiments, may be useful for estimating "the direction and approximate magnitude of future changes in streamflow as a function of forestry operations." Certainly the **reasoned** aplication of experimental results and statistical summaries can be a useful tool and it should receive more use.

Formal quantitative models

The word 'model' means vastly different things to most of us. I wish to define it in this paper as a quantitative, physical and dynamic description of a process. When a process is altered by forestry operations, the model describing it must contain physically and physiologically relevant relationships between soil, vegetation and atmospheric and/or energy parameters. The more commonly used hydrologic models available to us, such as STANFORD, SSARR, and SACREMENTO, are not particularily relevant to forest-hydrologic interraction because of their weak descriptions of the evapotranspiration process. An understanding of stomatal function with respect to vapour loss and the influence of the multi-layered surface geometry of a forest on vapour exchange with the overlying atmosphere is fundamental to understanding the role of forests and forest clearing on the hydrologic cycle.

A second process fundamental to understanding the role of forests in shaping the hydrology of an area is that of snow disposition. The mix of edge, trees and clear areas that exist after forest cutting creates a very complex aerodynamic and energy exchange problem for the forest hydrologist. None of the existing models describe the quantitative 3-dimensional aerodynamics and energy exchange processes operating in such situations.

In spite of these limitations, I think there are two models that we should make more use of as I feel that they are suitable building blocks for us to start with and to modify as we find necessary. PROSPER (Goldstein and Mankin, 1972; Swift, et al, 1975) is built around the Penman-Monteith equation which is a reasonably good description of the evapotranspiration process. The model has been used in a number of situations and is the core routine for the more comprehensive TEHM model (Huff, Luxmore, Mankin and Begovich, 1975). I think that the weakest point in PROSPER is the lack of quantification of canopy resistance in terms of measureable canopy parameters. This is an area where our research could be directed to improve the usefulness of this model.

The second is the snowmelt routine used in WATBAL (Leaf and Brink, 1973a,1973b). We have had fair success using the snowmelt routine in Alberta. It does not describe the 3-dimensional system but local experience and results have enabled us to empirically relate it to snow deposition. Similiar work needs to be done for snowmelt for a range of forest cutting practices.

Lastly, the U.S. Forest Service has produced a handbook to assist forest managers in evaluating the hydrologic effects of various silvicultural practices. It is called WRENSS and the hydrology portion is based on applications of the PROSPER and WATBAL models mentioned above (United States Forest Service, 1980). The authors of WRENSS applied PROSPER and/or WATBAL to the data from a number of experimental catchments in the Unites States and simulated generated runoff under various forest cutting options. To make matters simple for the user, they have stratified the results into several hydrologic regions. Within each region they have produced curves relating seasonal precipitation and simulated seasonal evapotranspiration. The procedure is extremely simple to use; all one need is seasonal precipitation, and maps of vegetation and topography in order to make estimates of forest cutting effects on annual yield. We have used WRENSS hydrologic regions 4 (Rocky Mountains) and 6 (Continental) in Alberta without modifications and have had quite good success. I think that the main precautions one should observe in applying WRENSS are 1) to be sure that the climatic-hydrologic region is a reasonable match, and 2) to remember that it is not a model but a series of fitted curves relating simulated evapotranspiration to precipitation. One tinkers with these curves at his own risk!

The WRENSS procedure works 'as is' in Alberta. However it could be improved. The authors of the hydrology section of WRENSS, C. F. Leaf and C. A. Troendle, are willing to work with us to extend the simulation base into Canada. Forest hydrologists and watershed managers in both countries would benefit from such cooperation.

INTEGRATION OF RESEARCH INTO FORESTRY PRACTICE

Even with a limited number of fairly useful tools to translate the results of hydrologic research from one place to another so that the effects of proposed practices can be predicted, there is still the problem of actually getting any proposed practice put into effect. Forest managers are very resistant to the implementation of new procedures - particularily new silvicultural prescriptions - when they are satisfied with the existing ones. For example, forest management options to increase water yield are often perceived by forest managers as activities that 1) will reduce their freedom to carry out normal forestry operations, 2) are more costly to manage and harvest and 3) will reduce the allowable cut of timber in successive years.

In order to overcome these objections, we must demonstrate that forest management practices designed to enhance some water benefit will not reduce the total benefit that society enjoys from a particular forested watershed. From the standpoint of water users, this means that the water benefits derived from altered forestry practice must be valued sufficiently high so that the imposition on a non standard silvicultlural practice can be made economically viable for the forest industry. This is difficult to do when water is viewed as a free commodity. Fortunately there may be a second avenue of approach.

Over the past few years, foresters have become increasingly alarmed at, and dissatisfied with, the poor state of forest renewal in Canada. Stands were being cleared but replacement stands of equal value were not being created. The Canadian Forestry Service has placed high priority on forest renewal and strongly emphasized the need for more sound forest management than in the past (Reed, 1980b). According to Armson (1980a), "the political environment which nourishes forestry is changing from one that has been generally benign to it, to one where there is a clear understanding of forests as a sustained yield, crop orientated production system." He goes on to suggest opportunities for improved forest management through enhanced silviculture and tree improvement programs. The director of research in the Canadian Forestry Service stated that forest insect problems must be addressed by multidisciplinary research teams in the context of forest management rather than as an entomological problem (Cayford, 1981). These are encouraging signs that our efforts to 'integrate' ourselves into forest management would not be rebuffed.

I think that hydrologists should lend the foresters a hand in this effort. Armson (1980b) states that implementation of management requires that the tree crop be related to the available soil water and nutrients. We, who call ourselves forest or land use hydrologists, are the experts in manipulating the microclimate influence of forest stands to increase soil moisture, to redistribute snow and to protect the soil and/or vegetative surface from the full drying effects of wind. For some reason we have never been a part on mainstream forestry - either in research or in practice. We can help the forester create sites more conducive to regeneration and growth. It may even be that such management will enhance both the water and timber products because of improved site conditions.

SUMMARY

I have outlined three problems facing Canadian forest and land use hydrologists.

1) The impact of large scale insect and disease attack on forests on the hydrology of affected areas.

2) The limited number of tools for using forest and land use hydrological research results to evaluate existing forest management situations or to predict the effects of proposed ones.
3) The lack of integration of forest and land use hydrologists into multidisciplinary teams to improve forest renewal and growth.

We should seize the opportunity that spruce budworm infestations have created to seek an understanding on the interaction between partial defoliation and evapotranspiration. We need more studies comparing the evapotranspiration of damaged and undamaged stands. We should more fully utilize the framework offered by the PROSPER and WATBAL models in our efforts to understand and to quantify evapotranspiration and snow disposition. We should cooperate with our fellow hydrologists in the U. S. Forest Service to extend and adapt the simplified WRENSS procedure in Canada. And finally we should look on current efforts to promote forest renewal and more intensive management as opportunities for us to apply our hydrologic insight toward the enhancement of tree regeneration and growth conditions.

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