Millar Western Forest Products Ltd.

FORWARD Contributions

2007-2016 Detailed Forest Management Plan

September 21, 2007

EXECUTIVE SUMMARY

The Forest Watershed and Riparian Disturbance (FORWARD) products for the Detailed Forest Management Plan (DFMP) consist of three main components: 1) watershed and stream layer maps and associated datasets; 2) soil and wetland layer maps and associated datasets; 3) a lookup table that permits planners to determine runoff coefficients (the variable selected for hydrological modelling) for functional 1st order watersheds based upon various site factors and time since disturbance. ***The watershed and stream layer*** project was completed in collaboration with GISmo Solutions Ltd. Deliverables were a hydrological network, a hydrologically-corrected Digital Elevation Model (DEM), and Strahler-classified streams and watersheds for functional 1st and 3rd order watersheds in the entire Millar Western Forest Products Ltd. Forest Management Agreement (FMA) area, created using state-of-the-art Geographical Information Systems (GIS) technology and good quality 1:20,000 scale source clients data sets. ***The soil and wetland layer*** represents a combined soil texture and wetland coverage. A spatial dataset was required for an area that included the Millar Western FMA area, along with the landscape draining into the FMA area, that is, the same extent as that covered by the watershed and stream layer. Relatively coarse mineral soils (which drain quickly) and wetlands (which retain water) were the key features that needed to be identified for the FORWARD modelling effort. ***The runoff coefficient lookup table*** integrates predictions of harvest impact on water quantity directly into the forest forecasting software, PATCHWORKS.

Table of Contents

List of Tables

List of Figures

1. Overview

1.1 History of the Program

Upon completion of the previous DFMP, Millar Western Forest Products Ltd. refocused its research direction and resolved to demonstrate leadership in: 1) moving its forest management planning processes related to surface waters away from a focus on riparian buffers, which results in the creation of linear strips on the landscape, towards an integrated watershed approach (*i.e.* dividing the landscape into units based on the direction of water flow); and 2) broadening planning goals from a focus on timber supply and terrestrial biological indicators to encompass issues not previously addressed. At the same time, Dr. Ellie E. Prepas and colleagues at the University of Alberta were completing a project that evaluated the effectiveness of forested riparian buffers around lakes in experimentally harvested catchments, to protect lakes from water quantity and quality changes associated with forest disturbance. A pilot project was also underway which involved Drs. Prepas, Gordon Putz (University of Saskatchewan) and Daniel W. Smith (University of Alberta), to examine hydrology (including contaminants) in the headwater portions of watersheds at the epicentre of the Virginia Hills fire of 1998. Outcomes from these two projects demonstrated that: 1) headwater streams would be more suitable than lakes as experimental units to test effects of watershed disturbance on water, because of their stronger links to upland areas in a water short area such as the Boreal Plain; 2) experimental watershed disturbance should be relatively intense to clearly demonstrate treatment effects on hydrology including contaminants; 3) a close association between industrial planning and the research effort is essential to link research outputs to the industrial planning process; and 4) the process of building the data base, developing and assessing the forecasting tool for forest condition, and affecting the link between the industrial planning process and the research effort requires a long-term commitment from the industrial, academic, and public sector partners.

Thus, the Forest Watershed And Riparian Disturbance (FORWARD) partnership was forged in 2001 to evaluate the hydrologic effects of forest disturbance. Contributions to this DFMP were generated as part of Phase I of the project (2001-2006), but the research is ongoing; Millar

Western is committed to carry the project through 2011 (Phase II). The watershed was chosen as the experimental landscape unit, instead of the forest stand. Headwater watersheds were selected to serve as experimental (intense harvest with and without buffer strips along stream banks, with the inclusion of some watersheds burned in the Virginia Hills fire) and reference sites for intensive field data collection on watershed weather, soil, wetland, vegetation, groundwater, and stream parameters. In this partnership, the data needs of the academic partners from three universities (*i.e.* for research and student training purposes) would dovetail with the data needs of the industry partners (*i.e.* to serve as input and verification data for models to forecast hydrology changes). The effectiveness of this partnership was recognized by the Natural Sciences and Engineering Research Council (NSERC) of Canada in 2004, when it received the prestigious Synergy Award for Innovation.

1.2 Participants

The FORWARD project (2001-2006) was a collaborative research effort linking Millar Western and other forest companies with academic scientists and their trainees (post-doctoral fellows, graduate and undergraduate students, and research associates) from Lakehead University (Dr. Ellie Prepas and initially Dr. Lense Meyer), and the Universities of Alberta (Dr. Daniel W. Smith and initially, Dr. David Chanasyk) and Saskatchewan (Dr. Gordon J. Putz and Dr. Jim Germida). The research was developed in conjunction with experts in specific fields who had an intimate understanding of how companies plan and implement activities on the landscape (*e.g.* The Forestry Corp., GISmo Solutions). Funding in the form of an NSERC Collaborative Research and Development (CRD) Grant (2001-2006) was matched by industry partners. Millar Western was the Major Industry Partner on the NSERC CRD. The partner base also included Blue Ridge Lumber Inc. (a Division of West Fraser Timber Company Ltd.), Vanderwell Contractors (1971) Ltd., Alberta Newsprint Company (ANC Timber), and Louisiana-Pacific Canada. Other funding to the project was provided by a Canada Research Chair Program Grant to Prepas, and NSERC Discovery and Canada Foundation for Innovation Grants to Prepas, Putz and Smith. FORWARD also had well-established contacts with regulatory agencies and scientists in Canada (Environment Canada, Department of Fisheries and Oceans, Canadian Forest Service, and Alberta Sustainable Resource Development) and the United States (U.S. Department of Agriculture, Minnesota Pollution Control Agency, and Wisconsin Department of Natural Resources).

In 2004, after a rigorous national review process, Millar Western earned eligibility for NSERC funds to support research training of scientists, thus advancing the concept that forests can constitute research “facilities” as well as traditional laboratories. Millar Western was awarded an NSERC Industrial Research Fellowship (IRF) to support research into the use of soil classification within the DFMP process. Dr. Ivan Whitson was awarded the IRF for this position, and his work constitutes part of the Soil and Wetland Layer component of the FORWARD products. In addition, Millar Western and Blue Ridge Lumber sponsored three graduate students through the NSERC Industrial Postgraduate Scholarship (IPS) program.

1.3 Research Objectives

The overall objective of the FORWARD (2001-2006) project was to collect and provide research results and to develop a functional framework that enables effective sharing of these results between scientists and forest managers. The specific objectives of the FORWARD project were to: 1) collect appropriate data on a watershed scale (weather, vegetation, soil, wetland, groundwater, surface-water quality and quantity, and bioindicators) to quantify the effects of potential disturbance patterns; 2) adapt a hydrological simulation model to predict effects of watershed disturbance; 3) link components 1 and 2 into the Millar Western DFMP; and 4) apply these decision support tools into practices and planning in managed watersheds.

To address these objectives, a number of small-scale studies were conducted, which addressed specific objectives related to storage and movement of water and related materials (suspended sediments, dissolved nutrients) in reference and disturbed (by wildfire and forest harvest) watersheds. To date, 21 papers have been published in refereed journals, many with student and industry co-authors, which addressed the following questions:

1. What features in a watershed influence the timing and volume of streamflow at the watershed outlet under relatively undisturbed conditions?

2. Do the Alberta Wetland Inventory (AWI) rules sufficiently capture wetland cover in the FMA area?

3. How does harvesting affect watershed soils?

4. How do wildfire and harvest compare in terms of how they affect hydrology?

5. How do wetlands modify water quality?

In addition, efforts to generate effective modelling tools were published because they move the research community closer to an understanding of how the various watershed-scale pools and fluxes of water interact. Modelling research has addressed the following questions:

1. At what spatial scale should input data be collected (*e.g.* precipitation)?

2. How can wetland areas be incorporated into models?

3. What modelling approach is best to capture the temporal variation in streamflow and water quality in streams in the FMA area?

4. How can forest regeneration after harvest be incorporated into modelling?

5. How do frozen ground conditions influence the hydrologic response?

1.4 Research and Modelling Outcomes

The deliverable package generated by FORWARD research included digitized soil and water maps, revised wetland rules for use with the AWI to better capture wetland cover in the FMA area, and a lookup table of runoff coefficients (proportion of precipitation falling on a watershed that becomes streamflow at the watershed stream outlet) for all 1st order watersheds in the FMA area. The FORWARD package was applied in the development of Millar Western's DFMP to assess the changes in runoff associated with alternative harvesting scenarios and to assist in the selection of the preferred forest management scenario. In addition, FORWARD research and modelling laid the foundation for deliverables that will be produced during a second NSERC CRD (2006-2011) grant period. The first of these is a simplified version of the hydrologic model, which requires less input and verification data. The second is the introduction of water quality (primarily suspended sediments, nutrients and herbicides) and riparian bioindicator (amphibian populations) components into the modelling process. The third is to link Millar Western's operational silviculture treatments with hydrologic recovery as forests regenerate. Experimental questions that will be addressed within the second phase of the project relate to water use differences between conifer and deciduous trees, how harvest impacts and recovery trajectories differ in sites with these two vegetation types, water and nutrient retention and release patterns by wetlands, and how forest disturbance (such as harvesting) affects soil temperature, frost depth, snow accumulation and snow melt. The new partner base includes the Province of Alberta through the Alberta Forestry Research Institute, the Forest Resource Improvement Association of Alberta, Millar Western Forest Products Ltd., Blue Ridge Lumber Inc., ANC Timber Ltd., Buchanan Lumber Ltd., Vanderwell Contractors (1971) Ltd., Highpine Oil and Gas Ltd., Real Resources Inc. and Talisman Energy Inc. The First Nations Partner in Alberta is the Alexis Nakota Sioux Nation.

2. Watershed and Stream Layer

2.1 Background

GISmo Solutions Ltd. (in particular, Michael Pawlina) collaborated with the FORWARD industry partners (in particular, Don Thompson, Millar Western) and academic principal investigators to complete this component of the DFMP deliverables package. GISmo Solutions used an initial watershed delineation dataset created in August 2005 for Millar Western as source data for all its GIS processing.

The resulting hydrography networks and classified watersheds data for the entire Millar Western FMA area were stored as binary ARC/INFO coverages (line, polygon, and region types) prepared within the ArcGIS v. 9.1 environment. For both the western (W13) and eastern (W11) Forest Management Units (FMUs) of the Millar Western FMA area, subsets of data with additional attributes were created. An ArcView (v. 3.2) project was also created to allow visualization of the stream network and watershed boundaries within the FMUs. The projection and datum was UTM Z11, NAD 83, with double precision accuracy maintained throughout all processes. The core GIS products were further updated to precisely comply with FORWARD research watershed boundaries. "Atomic" watershed units (***see box***), directionally corrected single-line stream networks, and simplified double- to single-line stream networks were affected by this process. New aggregated watershed units, defined as functional 1st and 3rd order watersheds (***see box***), were built within the core products as regions within the watershed coverage for FMU W13. A flow chart of the process used to develop the datasets is presented in Figure 1.

Atomic watershed unit: smallest watershed units delineated within the coverages. Range from 11 to 250 ha in size (mean 50 ha or 0.5 km^2). Higher functional order watersheds are composed of many atomic watershed units.

Functional 1st order watershed: small watershed unit nominally 6 km^2 in area.

Functional 3rd order watershed: intermediate watershed unit nominally 128 km^2 in area.

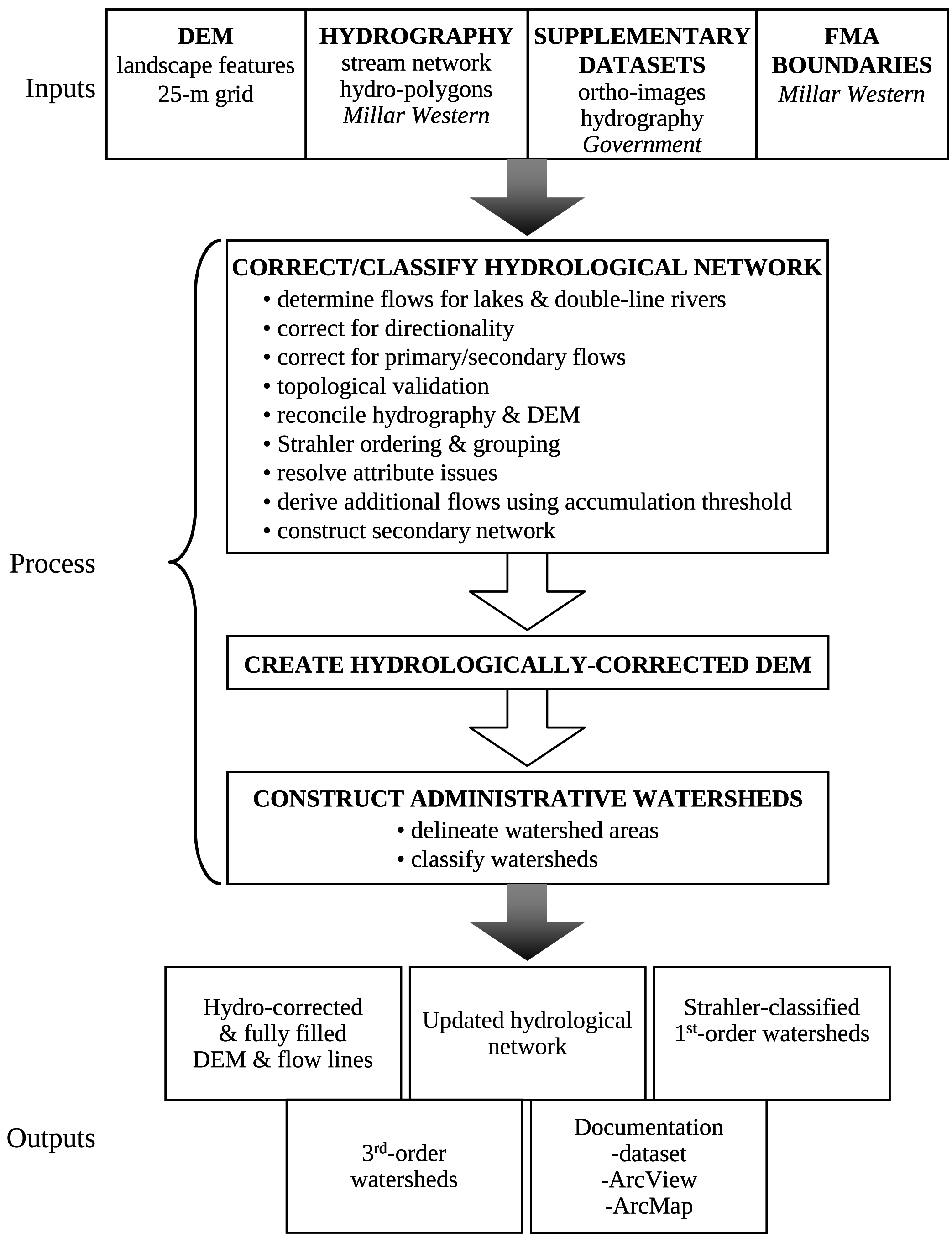

Figure 1. Process used to generate the Watershed and Stream Layer deliverables package.

2.1.1 Input Data

Input data for the Watershed and Stream Layer project consisted of four types (Figure 1): 1) the base features hypsography/ DEM ARC/INFO data were aggregated into a seamless grid; 2) a representation of small source streams and waterbodies was provided as ESRI shape files by Millar Western; 3) additional data on lakes, double-line river representation, stream directionality, primary / secondary streams, and water feature names were obtained from Alberta Sustainable Resource Development government standard Base Features Project hydrography and seamless SLNET and polygon information from RDB (RIMB); and 4) an ArcView shape file was created to approximate height of land and areal extent of the project area using data provided by Millar Western.

2.1.2 Process

The hydrological network was classified by judging the single line network against desired specifications and checking its agreement with DEM data (Figure 1). Parameters considered were connectivity and directionality of streams, primary / secondary flow attributes, and agreement with TOPOGRID processes and watershed creation processes. Strahler attributes (stream order) were added to allow for aggregation of future watersheds by stream class (Strahler 1952). Full connectivity was enforced, to assure that aggregation of catchment areas resulted in a seamless sub-basin (without “holes” for non-connected streams). Validation of the hydrological network was conducted by industry and university field operators based upon field ground-truthing and local knowledge of the study area. A seamless, hydrologically-corrected DEM was then created by application of TOPOGRID (Figure 1). This GIS process enforces proper definition of the terrain using stream network directionality, large lakes, and contours as input. Sink areas in the terrain were removed to enforce complete drainage. Administrative watershed polygons were then created (Figure 1). First, individual atomic watershed polygons were created, then these were aggregated into Strahler groups, polygons for watershed orders greater than three were extracted, and slivers were edited.

2.1.3 Outputs (Deliverables)

1. Hydrologically-corrected and fully filled DEM (Figure 1).

    - Flow lines of DEM reflect adjustments for consistency with observed hydrography.
    - Terrain dataset was fully filled.

2. Updated 1:20,000 scale hydrological network.

    - Completed network with adjusted topology and directionality (full connectivity);
    - Connected “hanging” streams, including sub-network for an isolated lake using derived flows (with appropriate attributes) from the fully filled hydro-corrected DEM;
    - Validated directionality and correct definition with the DEM before the stream network was used for hydro-correction;
    - Preserved original attributes;

- Integrated field validation results for locations of poor DEM hydro-compliance and secondary flows definition;
- Created a simplified network with grouping of segments for a single stream; and
- Updated single- and double-line information (single-line features corresponding to double-line polygons have a linkage allowing for proper processing of catchment areas for crossed waterbodies and headwater lakes).

3. Applied Strahler classification, grouping attributes, and name attributes to all 1st order watersheds.

4. Delineated and classified 3rd order watersheds.

5. Provided additional reference documentation.

- Simplified stream network coverage with drainage accumulation attributes;
- Compiled list of features and locations requiring data validation;
- Constructed data display for effective review of results;
- Defined the threshold for channel initiation as an accumulated area of 30 ha within atomic watersheds for Soil and Water Assessment Tool (SWAT) application within FORWARD project watersheds; and
- Densified stream network and watershed fabric using the 30-ha threshold for the entire FMA area.

2.2 ArcView Project Overview

2.2.1 Western Study Area

The western portion of the FORWARD study area is 4 126 018 km^2 in total area and contains all of the FORWARD research watersheds (see Figure 2). The number and size range of Strahler group functional 1st and 3rd order watersheds within the western portion is presented in Table 1 and shown in Figure 2. The entire area can also be represented by the much smaller (mean 50 ha) atomic watershed units. The original data set did not contain atomic units for a few locations on the southern edge of the FMU where no corresponding streams were indicated. However, these atomic units were derived using the accumulation process. The dominant aspect class, percentage of area of each class, and average channel slope (as percent slope to outflow) was calculated for all atomic watershed units and functional 1st order watersheds.

Table 1. Size distribution of functional 1st and 3rd order watersheds in the western portion of the FORWARD study area.

Watershed	Area range (km^2)	Mean area (km^2)	Number of units
Functional 1st order	0.6-20.4[1]	5.8	709
Functional 3rd order	53-282	128	32

[1]Only 3 watersheds were greater than 11.9 km^2 in area.

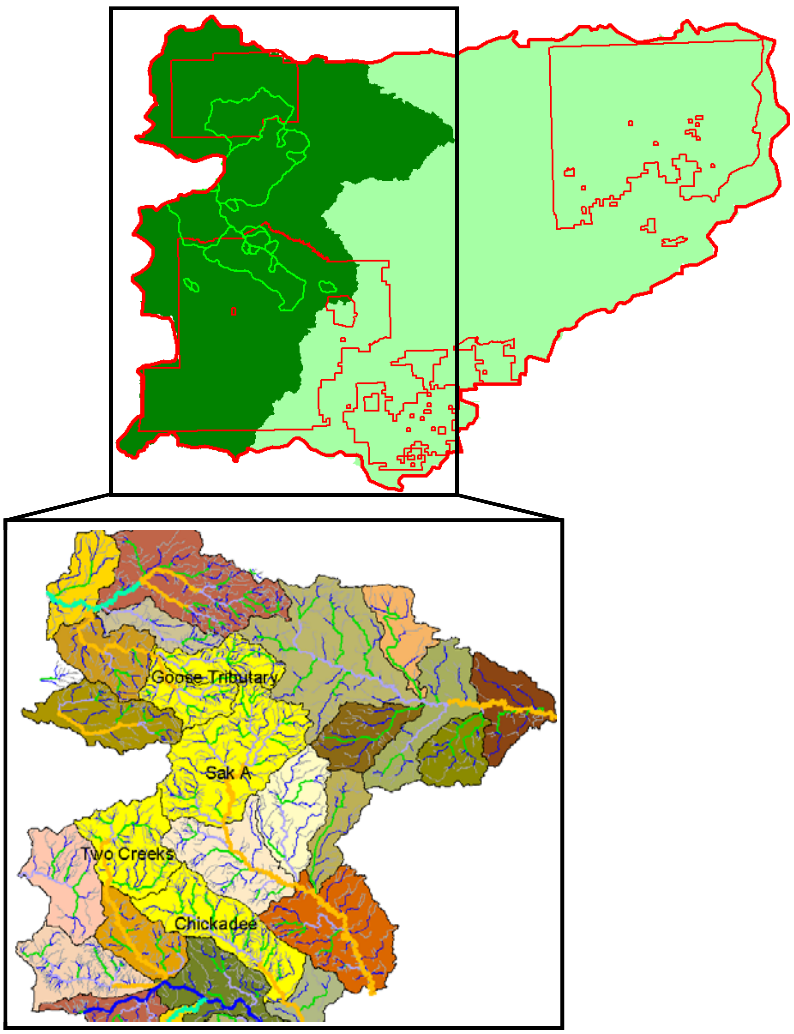

Figure 2. Western portion of FORWARD study area, with Strahler groups (lower panel).

2.2.2 Eastern Study Area

The eastern portion of the FORWARD study area is 7 091 km^2 in total area and contains all of FMU W11 and the eastern portion of FMU W13. The number and size range of functional 1st and 3rd order watersheds within this area is presented in Table 2 and shown in Figure 3. The creation of the watershed and stream network layer in W11 required a different approach because of its flat topography. To illustrate, the three-dimensional area only exceeded the two-dimensional area by 0.06% in W11, compared to 0.31% for the Swan Hills as a whole (Couling et al. in press). True hydrography and an "enhanced" stream network that included DEM-derived flows was utilized in the creation process. Two functional 3rd order watersheds were used to validate the derived watershed and stream network in W11.

Table 2. Size distribution of functional 1st and 3rd order watersheds in the eastern portion of the FORWARD study area.

Watershed	Area range (km^2)	Mean area (km^2)	Number of units
Functional 1st order	0.2-16.3	5.8	1221
Functional 3rd order	49-230	120	58

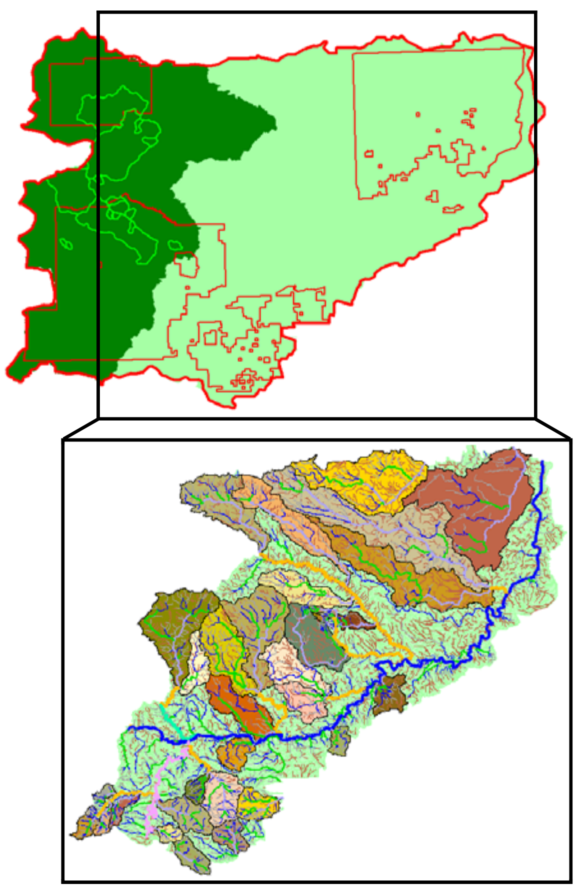

Figure 3. Eastern portion of FORWARD study area, with Strahler groups (lower panel).

3. Soil and Wetland Layer

3.1 Background

This section summarizes the process by which The Forestry Corp. and Kendra Couling (graduate student, Lakehead University), under the direction of Drs. Ellie Prepas and Gordon Putz, derived the soil texture and wetland coverage (the Combined Modelling Coverage or CMC) for the soil and wetland layer component of the FORWARD project deliverables package. A spatial dataset was required for the FORWARD project area, which included the Millar Western FMA area, along with the landscape draining into the FMA area. This area covers the same extent as that covered by the atomic polygons generated for the Watershed and Stream Layer (Section 2), which includes portions of the Blue Ridge Lumber FMA area and some additional areas (Figure 4).

Wetland: An area where water continually or periodically gathers because inflow equals or exceeds outflow. Periodically can refer to a daily or yearly cycle, as long as it is ecologically significant. The wetland area supports hydrophytic vegetation and in the boreal region, plant production generally exceeds decomposition, creating peat. A wetland contains soil indicative of high water tables or poor drainage for extended periods of time.

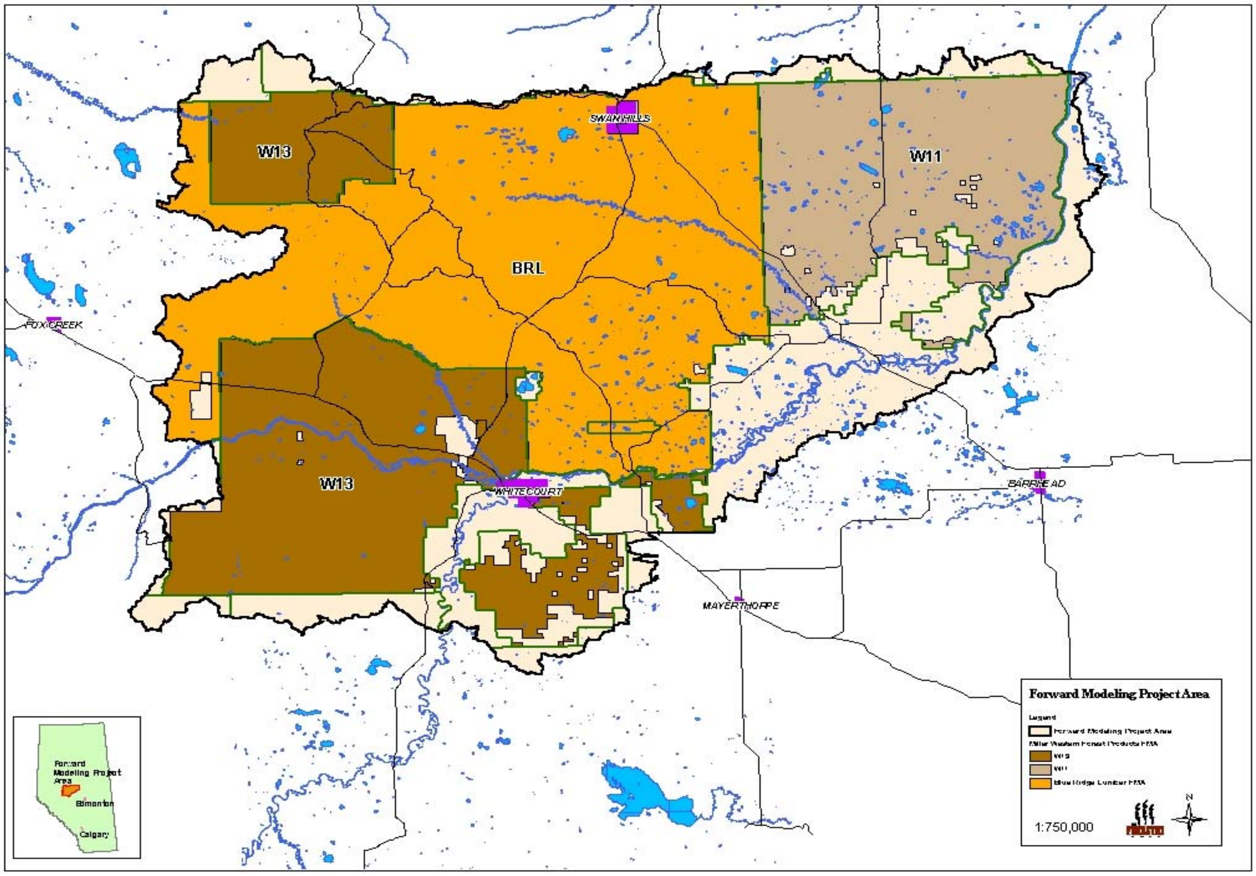

Figure 4. FORWARD project area.

Based on discussions with FORWARD principal investigators Drs. Ellie Prepas and Gordon Putz regarding the soil data requirements for modelling, it was determined that a broad soil / wetland classification would be appropriate. Relatively coarse mineral soils (which drain quickly) and wetlands (which retain water) were the key features that needed to be identified. These features were derived by examining the various data sources available, then using these sources to identify the broad soil / wetland attributes required for the FORWARD project. The basic approach used to derive the CMC for the FORWARD project area was to use available data to generate mineral soil texture and wetland coverages, then combine the two coverages to produce a single coverage (the CMC).

3.2 Soil Coverage

3.2.1 Data Sources

Three distinct sources of information were available to help identify mineral soils and wetlands within the FORWARD project area:

- Soil and parent material classifications completed by the Province of Alberta;

- Alberta Vegetation Inventories (AVI) completed by FMA holders within Alberta; and
- Air photo / orthophoto imagery.

The existing Provincial and other soil coverages were recognized as a logical source for identifying mineral soils. The AVI was used primarily for identifying wetlands, since the scale of the data was more appropriate to this task and a correlation between vegetation (as described by the AVI) and wetlands had been established by Kendra Couling as part of her Master's thesis (Couling et al. in press). Aerial photograph or orthophoto imagery interpretation was the most time consuming and costly option for deriving information, therefore imagery was used only where soil and AVI coverage was not available.

Soil Data

Provincial soil coverages at a scale of 1:126,720 were available for portions of the FORWARD project area (Figure 5). All but the Fort Assiniboine coverage were available from Millar Western in digital format. These coverages included the following:

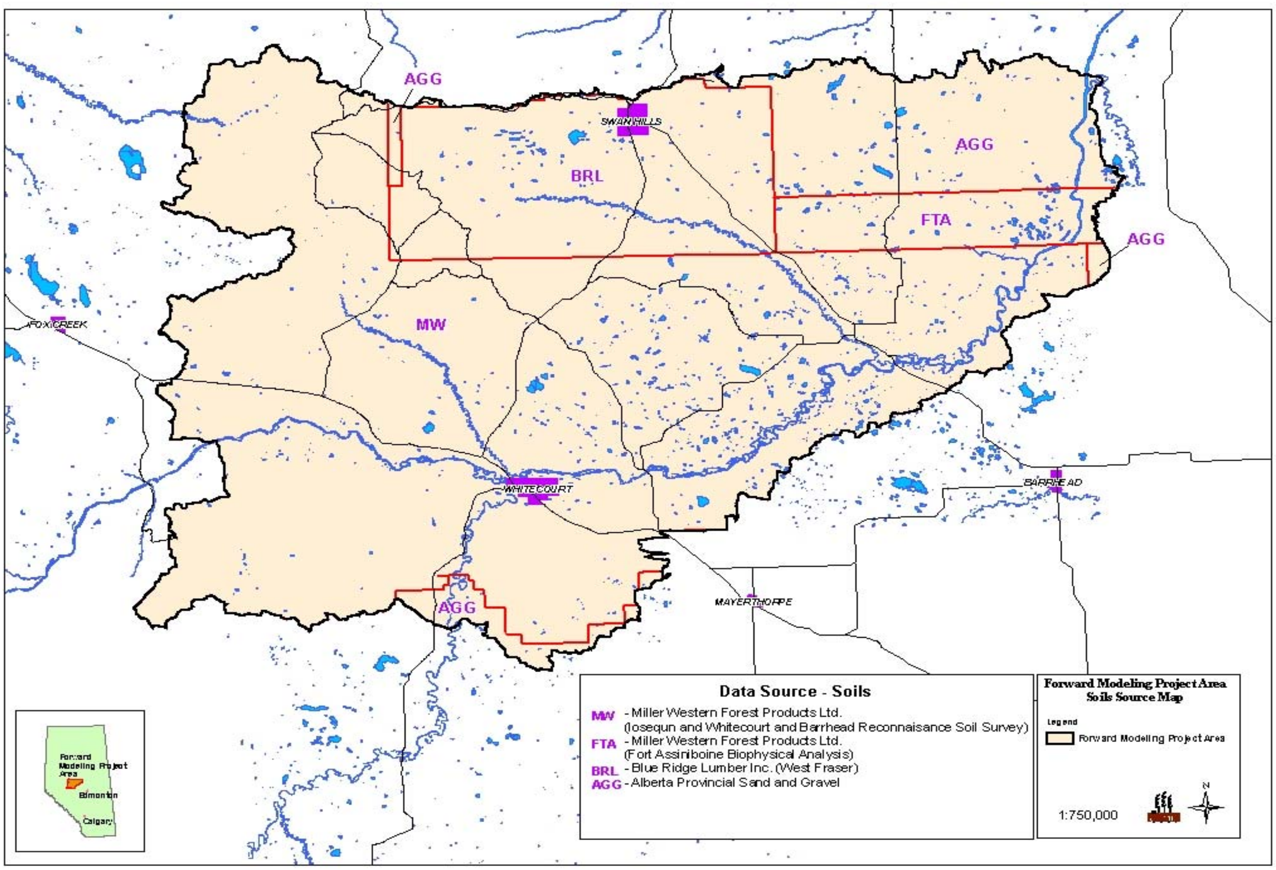

Figure 5. Soil and parent material data sources for the FORWARD project.

- ***The Soil Survey of the Whitecourt and Barrhead Area*** (Wynnyk et al. 1969) identified mapping units comprised of one dominant and up to two significant soil series for each polygon. A topographic class (based on slope), a stoniness class, and a phase modifier (stony, thin or peaty) were used in some cases.

- ***The Reconnaissance Soil Survey of the Iosegun Lake Area*** (Knapik and Lindsay 1983) identified one dominant and up to two significant soil units for each polygon. The topographic class, stoniness class and phase modifier (as above) were used in some cases[1].

- ***The Soil Survey and Land Evaluation of the Hinton-Edson Area*** (Dumanski et al. 1972) identified mapping units comprised of a dominant and a significant soil association for each polygon. Most mapping units also identified a dominant and significant soil series. A topographic class and a phase modifier (stony, shallow or gleyed) were used in some cases.

- ***The Reconnaissance Soil Survey of the Chip Lake Area*** (Twardy and Lindsay 1971) identified mapping units comprised of one dominant and up to two significant soil series for each polygon.

- ***The Fort Assiniboine Biophysical Analysis and Evaluation of Capability Survey*** (Boyacioglu 1975) identified 'land systems' based on parent material. Each system had up to four characteristic soil associations, and drainage and slope were also generally identified. Approximately 5.5 townships were digitally loaded to help generate the soil coverage.

Where Provincial soil coverages were not available, two additional data sources were utilized:

- A digital soil coverage for the Blue Ridge Lumber FMA area was provided by Blue Ridge Lumber. This coverage was developed using existing data sources, including the first two soil surveys listed above and Exploratory Soil Survey - 83J, 83K, 83F, and surficial geology mapping (internal report prepared for Blue Ridge Lumber by Applied Ecosystem Management Ltd. 2000). Soil Order and Great Group (Canadian System of Soil Classification 1998) for the dominant and significant soil components were identified. Stoniness class was used as a modifier.

- The Provincial Sand and Gravel Deposits coverage for 83J, the map sheet in which the FORWARD project area is located, was used. This coverage was developed using various information sources, as identified on the Alberta Geological Survey website[2]. Mapped data used to develop the coverage were at scales of either 1:50,000 or 1:250,000, depending on the source.

---

[1] Although the Whitecourt/Barrhead and Iosegun Lake soil surveys both mapped soil units, there was no attempt at the time they were developed to tie the two surveys together. Because of this, there is no continuity along the boundary between these surveys (*i.e.*, polygons do not line up and attributes are dissimilar along the boundary).

[2] http://www.ags.gov.ab.ca/mapserver/agg/aggpubs.html#NTS83J (spring 2006)

Alberta Vegetation Inventory

The AVI is the Provincial standard for vegetation inventories for forest-related resource management applications. It is completed at a scale of 1:20,000 or 1:15,000 and describes the types of vegetation present, including tree species. The majority of the FORWARD project area falls within the Millar Western and Blue Ridge Lumber FMA areas. Additional small areas were also covered by AVIs from the following companies: ANC Timber Ltd., Gordon Buchanan Enterprises Ltd., Hinton Pulp (West Fraser), Slave Lake Pulp Corporation (West Fraser), Tolko Industries Ltd., Vanderwell Contractors (1971) Ltd., and Weyerhaeuser Canada Ltd., Edson (Figure 6).

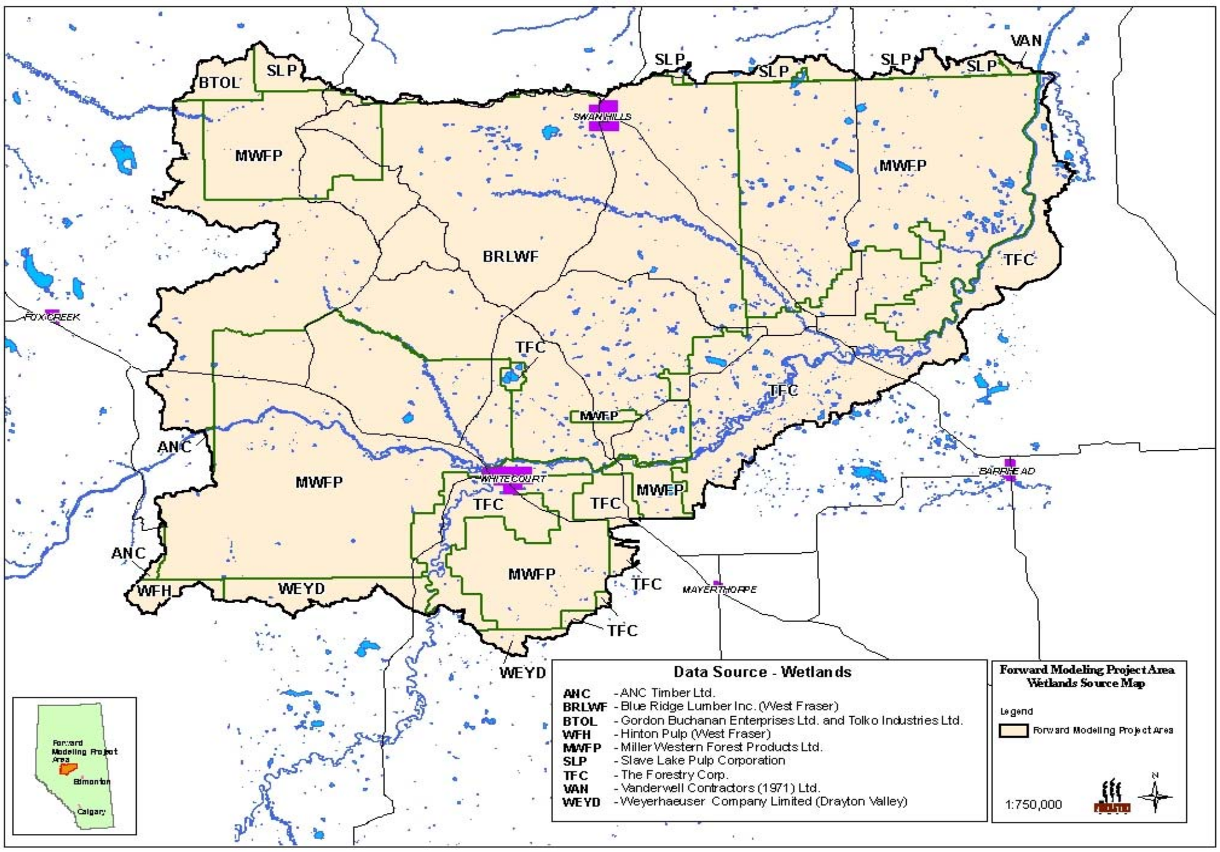

Figure 6. AVI data sources for the FORWARD project.

Aerial Photo/Orthophoto Imagery

Small portions of the FORWARD project area did not have existing AVI coverage (*i.e.* were not in any FMA area). In these areas, aerial photography was used to interpret wetlands. In a few instances, only orthophoto coverage was available, which made wetland identification less reliable than areas with stereographic aerial photo pairs.

3.2.2 Mineral Soil Cover

Mineral Soil Classes

The various soil coverages available for the FORWARD project area were based on several very different soil attributes (*e.g.* soil units, parent material, or sand/gravel class). For modelling purposes, a common classification was needed for the entire project area. In consultation with Drs. Ellie Prepas and Gordon Putz, a very broad classification was developed that would be sufficient for modelling and could be derived from the existing data sources. Dr. Ivan Whitson, the NSERC IRF with Millar Western, assisted with reclassification of the various coverages into this broad classification. The classification recognizes only five categories: valley, coarse mineral soil, medium mineral soil, fine mineral soil, and farmland[3]. The valley, coarse mineral soil and medium mineral soil classes were derived from Provincial soil coverages or the Provincial Sand and Gravel Deposits coverage, on the basis of a set of reclassification rules developed by Drs. Whitson and Prepas. Farmlands were only identified within the vicinity of valleys (*i.e.* along major rivers). They were identified directly from orthophotos at a scale of 1:20,000 and then digitally loaded. By default, any unassigned soil polygons were then classified as ***fine mineral soil***.

Valley soils are generally very coarse textured. They are generally steep-banked and associated with current or historic river courses. Initially, valley soils were classified as either gravels or riparian by the original data sources. However, the two classifications were restricted to watercourses and were differentiated primarily on the basis of the originating data source. The decision was made to combine the two categories into a single class called valley soils.

Coarse mineral soils are primarily associated with current or historic watercourses but also include some dune and esker formations.

Medium mineral soils are not widespread in the project area and are typically associated with dune formations.

Fine mineral soil attributes were assigned to all soil coverages as a default (this applies to all the Provincial, Blue Ridge Lumber FMA area, and the Provincial Sand and Gravel Deposits coverage). All Provincial soil polygons that were not assigned as valley, coarse mineral soil, medium mineral soil, or farmland, were assigned by default as fine mineral soil.

[3] The fifth soil category (farmland) was identified exclusively using aerial photography. It should be noted that initially, Dr. Whitson attempted to reclassify the soil types on the basis of soil texture and stoniness rather than parent material and stoniness. However, this resulted in very widespread assignment to ***coarse mineral soils*** and the decision was made to revert to the broad categories that Dr. Whitson had previously developed that related to soil characteristics and/or physiography.

Farmlands were identified in the vicinity of valley or coarse mineral soils, along major river courses. They represent areas of finer textured soils that occur within or near river courses that were not represented in the soil coverage.

Areas With Digital Provincial Soil Coverage

Dr. Whitson reclassified the Provincial soil units from the four Reconnaissance Soil Surveys (Whitecourt and Barrhead, Iosegun, Chip Lake, and Fort Assiniboine) into broad categories that were related to soil characteristics and / or physiography (see Forestry Corp. 2007 for details regarding reclassification). The Fort Assiniboine soil coverage was re-classified into four mineral soils, using a separate set of criteria based on soil association (Forestry Corp. 2007). By default, any soil types not included in the reclassification tables were assigned to ***fine mineral soil***.

The soil characteristics of each of the original soil series, based on the Province's Agricultural Region of Alberta Soil Inventory Database (AGRASID 2001) were used to characterize texture and stoniness for each of the broad soil categories. Based on input from Drs. Prepas and Putz, soil characteristics were based on the A horizon, to a maximum depth of 40 cm.

Areas Without Digital Provincial Soil Coverage

Existing Provincial digital soil coverage was not available for significant portions of the FORWARD project area. Areas without coverage included much of the area within the Blue Ridge Lumber FMA area, very small areas along the western edge of FMU W13, and portions in the northeast (including the northern half of W11) (Figure 5). Within the Blue Ridge Lumber FMA area, a digital soil coverage based on parent material was used. In other areas without Provincial soil coverage data, ***valley*** and ***coarse mineral soil*** were identified using the Provincial Sand and Gravel Deposits coverage. The reclassification rules for this coverage were developed by Drs. Putz and Prepas (Forestry Corp. 2007).

3.2.3 Additions/Revisions to Soil Coverage

The basic soil categories in the FORWARD coverage represent a reclassification of existing soil polygon coverages (*i.e.* they are assigned to soil polygons), as well as some additional polygons loaded specifically for the project (*e.g.* farmland) or revisions to polygons based on additional data sources (*e.g.* poplar vs. pine).

Delineation of connecting valley polygons was not consistent between the various sources of soil data (*i.e.* valley polygons would stop at the edge of a soil source map). To provide continuity, air photos and / or orthophotos were used to identify and delineate valley polygons in areas where these 'gaps' occurred.

Local knowledge of the area indicated that ***farmlands*** sometimes existed within valley polygons in the vicinity of the Athabasca River. Since farmland is indicative of soils that are relatively productive, farmland extent along the Athabasca River was quantified by inking polygons onto orthophotos and then digitally loading them into ArcInfo.

Tim McCready (Millar Western) identified the presence of eskers in the northeast of FMU W11 that were not identified in the Provincial Sand and Gravel coverage. These were subsequently ground-truthed by McCready and Dr. Prepas, then delineated using aerial photography. They are included in the soil class coverage as a ***coarse mineral soil***.

In some cases, the transition of ***coarse mineral soil*** coverage was not consistent between data sources (*i.e.* polygons would stop abruptly at the edge of a soil map). To provide continuity, aerial photographs were used to identify and delineate the extent of the ***coarse mineral soil*** feature. This information was verified by ground-truthing by Prepas and McCready. Revisions were digitally loaded and the additional area classified as ***coarse mineral soil***.

Where poplar (*Populus balsamifera*) was the primary species in the overstory in valleys, as indicated by the AVI, the soil was classified as ***fine mineral soil***. Additional delineation of fine textured soils along rivers was completed using the AVI coverage. This reclassification was stored in the 'Wetland' coverage prior to the merging of the two datasets into the CMC.

The ***Fort Assiniboine Sandhills Wildland Park*** was established along the Athabasca River because of the area's interesting assemblage of springs, wetlands, and stabilized sand dunes. Within the Park boundary, jack pine (*Pinus banksiana*) was used to indicate the presence of ***coarse mineral soil*** (*i.e.* dunes) and poplar was used to indicate a ***fine mineral soil*** (default). It should be noted that this reclassification was based on AVI information, and was therefore stored in the 'Wetland' coverage, prior to the merging of the two datasets into the CMC.

3.3 Wetland Coverage

3.3.1 Wetland Types

Wetlands were identified using a set of rules developed by Kendra Couling for her Master's thesis (Couling et al. in press). Couling utilized field data to generate a rule set for predicting presence of wetlands based on AVI attributes (*e.g.* presence of black spruce (*Picea mariana*) or larch (tamarack) (*Larix laricina*)). These rules were then applied to the AVI coverage for the project area to predict presence of wetlands on the basis of AVI attributes.

The rules distinguish between ***treed*** and ***non-treed*** wetlands, rather than traditional wetland types (*e.g.* bogs, fens, marshes, swamps, open water).

Areas With AVI Coverage

Couling et al. (in press) developed rules to predict wetlands within the 12 small FORWARD watersheds, which fell exclusively within the Millar Western and Blue Ridge Lumber FMA areas (Figure 4). Separate rules were developed for identifying wetlands in each of these FMA areas, because the inventory specifications differed slightly between the two companies (Millar Western utilized AVI v. 2.1 whereas Blue Ridge Lumber utilized draft AVI v. 2.2) and different interpreters completed the inventories.

The areal extent of the soils coverage required for watershed modelling extends beyond the Millar Western and Blue Ridge Lumber FMA areas. To predict the location of wetlands outside of these FMA areas, AVI information was obtained from the companies identified in Figure 6. The inventories for these FMA areas were completed using AVI v. 2.1, except for Slave Lake Pulp, which was completed using draft AVI v. 2.2. Because of the differences in AVI specifications, all FMA area inventories with 2.1 specifications had wetlands assigned on the basis of rules developed for Millar Western. Slave Lake Pulp's FMA area had wetlands assigned on the basis of the Blue Ridge Lumber rules (draft AVI v. 2.2).

Areas Without AVI Coverage

Areas along the east and southeast edge of the FORWARD project area do not have AVI coverage. Aerial photography was used to delineate wetlands in these areas. At a scale of 1:30,000, this method was economical (compared to using 1:20,000), yet allowed interpreters to identify all but the smallest wetlands. Several small portions of the FORWARD project area did not have overlapping air photo coverage at an appropriate scale for interpretation. However, orthophoto coverage was available for these areas.

The wetland-related fields assigned to each wetland polygon were consistent with those used for the wetland coverage derived from the AVI (*i.e.* ***treed*** and ***non-treed*** wetlands).

Additional details regarding the derivation of assignment of wetlands within the project area are provided in Couling et al. (in press) and Forestry Corp (2007).

3.3.2 Wetland Assignment Rules

The following vegetation types were identified as ***treed*** wetlands within areas with AVI v. 2.1 (*e.g.* Millar Western FMA area and others):

1. Black spruce and/or larch (tamarack) comprising 75% or more of the tree canopy;

2. Black spruce comprising 55% or more of the tree canopy;

3. Black spruce comprising 45 to 54% of the tree canopy, secondary species was not lodgepole pine (*Pinus contorta*) or white spruce (*Picea glauca*);

4. Black spruce comprising 25 to 44% of the tree canopy, primary species was not white spruce; and

5. Relatively dense understoreys of pure black spruce where the overstorey was comprised of an open canopy of predominantly lodgepole pine.

Two slight rule adjustments were made in areas where draft AVI v. 2.2 was available (*e.g.* Blue Ridge Lumber and Slave Lake Pulp FMA areas). Otherwise, the rules were assigned consistently.

2. Black spruce comprising 55% or more of the tree canopy was considered a ***treed*** wetland only when the secondary species was larch.

4. Black spruce comprising 25 to 44% of the tree canopy was considered a ***treed*** wetland provided the primary species was not lodgepole pine nor white spruce.

The following vegetation types were identified as non-treed wetlands:

- Closed and open shrub, excluding areas identified as clear cuts, clearings, burns, well-sites, or pipelines. Areas with snags were also excluded;

- Grass or forb types, excluding areas identified as clear cuts, clearings, burns, well-sites, or pipelines; and

- Flooded lands.

3.4 Combined Modelling Coverage

The soil and wetland coverages were combined to form the CMC by intersecting the two coverages digitally, and then assigning either a single soil or wetland class to each of the resulting polygons. Steps used in this final stage in the soil coverage development (Figure 7) were as follows:

1. Intersect the soil and the wetland coverages. All polygons now have a soil class, a wetland class, and AVI vegetation attributes.

2. Within Fort Assiniboine Sandhills Wildland Park, assign a polygon as ***coarse mineral soil*** if the primary species is pine and as ***fine mineral soil*** if the primary species is poplar. Store assignment in the wetland coverage (attribute WETL) to ensure it takes precedence over the soil coverage assignment. Note that Couling's wetland identification rules did not deal with cover types where poplar or lodgepole pine were the leading tree species, therefore this reclassification did not affect wetland polygons.

3. Within areas that are classified as ***valley*** soils, assign the polygon as ***fine mineral soil*** if the primary species is poplar. Again, this did not impact polygons identified as wetlands.

4. Assign the final CMC CLASS (Table 3), based on either the soil (SOIL_CLASS) or wetland classes (WETL and WTYPE) using the following hierarchy:

- Where a polygon in the wetland coverage is classified as a wetland (Couling's rules or TFC interpretation) or has been reclassified to either a ***coarse*** or ***fine mineral soil*** (Sandhills Wildland Park or ***valley*** soils), this will be the classification retained.

Classify all polygons where the WETL attribute is blank (*i.e.* not a wetland and no soil class reassignment based on species) on the basis of the SOIL_CLASS attribute.

Table 3. Combined Modelling Coverage attribute fields and definitions.

Field	Function	Values	Definition
CMC_CLASS	Identifies basic soil type.	FINE	Default.
		VALLEY	Primarily gravels, coarse mineral soils. Related to watercourses .
		COARSE	All other course mineral soils, including eskers.
		MEDIUM	Medium textured mineral soils, primarily dunes.
		FARMLAND	Cultivated lands near major rivers.
		WL_TREED	Treed wetlands.
		WL_NONTREED	Non-treed wetlands
CMC_SOURCE	Identifies from where the CLASS was taken.	W	From the wetland coverage.
		S	From the soils coverage.

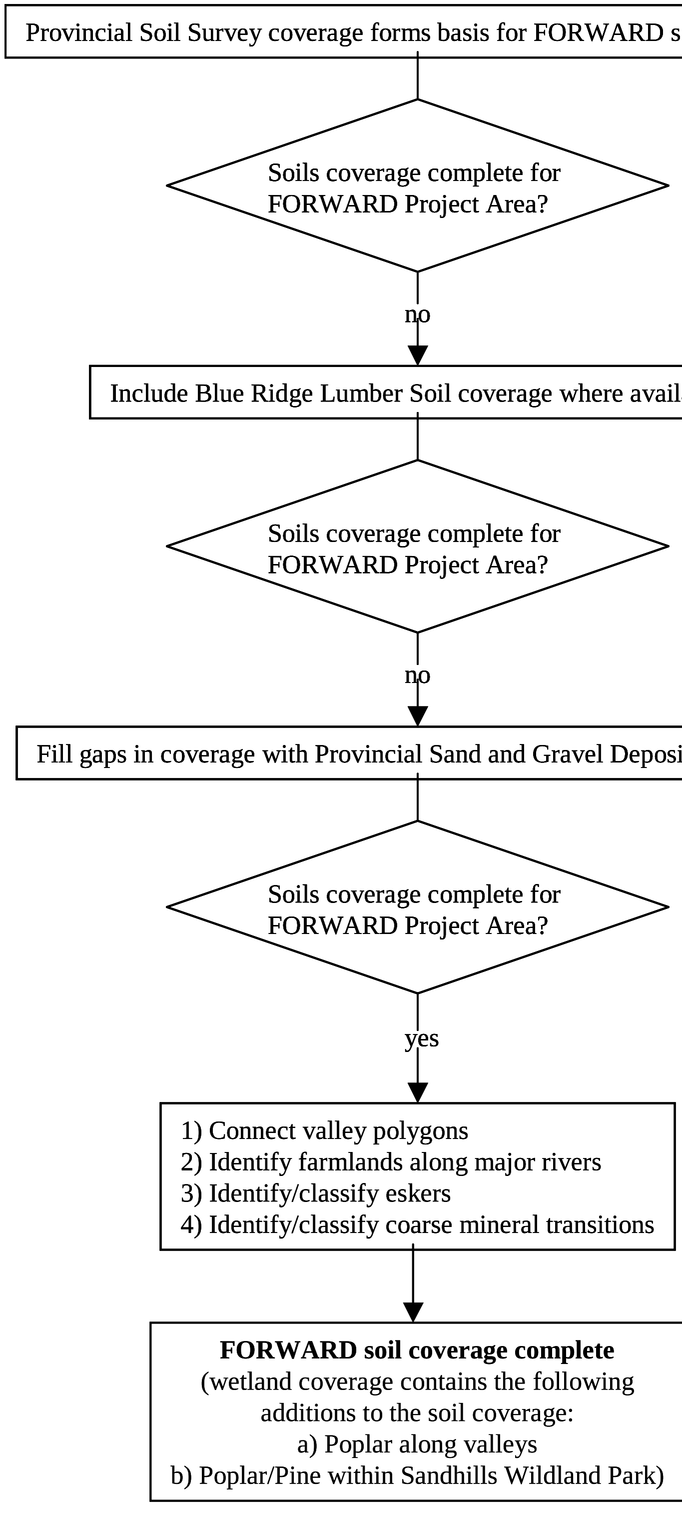

Figure 7. Flowchart with overview of soil coverage development.

4. Runoff Coefficient Lookup Table

4.1 Background

The objective of this component of the FORWARD deliverables package was to integrate predictions of harvest impact on water quantity directly into the forest forecasting software, PATCHWORKS. It was necessary to assign a value to each spatially-defined polygon in the Millar Western Landbase that quantified its contribution to watershed discharge and considered its sensitivity to harvest. A runoff coefficient (RC) was chosen to be this value (Figure 8).

> **Runoff coefficient:** the ratio of stream outflow (expressed as depth per unit area in mm) to precipitation input (expressed as depth per unit area in mm). In other words, the RC is the proportion of precipitation falling on a watershed that becomes streamflow at the watershed outlet.

An aggregate RC for each functional 1st order watershed delineated within the FORWARD Watershed and Stream Layer (Section 2) was calculated as an area weighted sum as follows:

$$RC_{Wf(i)} = \frac{\sum_{j=1}^{n} RC_{P(j)} * A_{P(j)}}{A_{Wf(i)}} \qquad \text{Equation 1}$$

where $RC_{Wf(i)}$ is the RC of 1st order watershed "*i*" calculated as the sum of "*n*" polygons each with an individual RC ($RC_{P(j)}$) times the area of the polygon ($A_{P(j)}$) divided by the area of the watershed ($A_{Wf(i)}$).

The RC for each of 3rd order watershed was then calculated as:

$$RC_{Wt(k)} = \frac{\sum_{i=1}^{m} RC_{Wf(i)} * A_{Wf(i)}}{A_{Wt(k)}} \qquad \text{Equation 2}$$

where $RC_{Wt(k)}$ is the RC of the 3rd order watershed "k" calculated as the sum of "m" 1st order watersheds, each with an individual area weighted RC ($RC_{Wf(i)}$) times the area of the 1st order watershed ($A_{Wf(i)}$) divided by the area of the 3rd order watershed ($A_{Wt(k)}$).

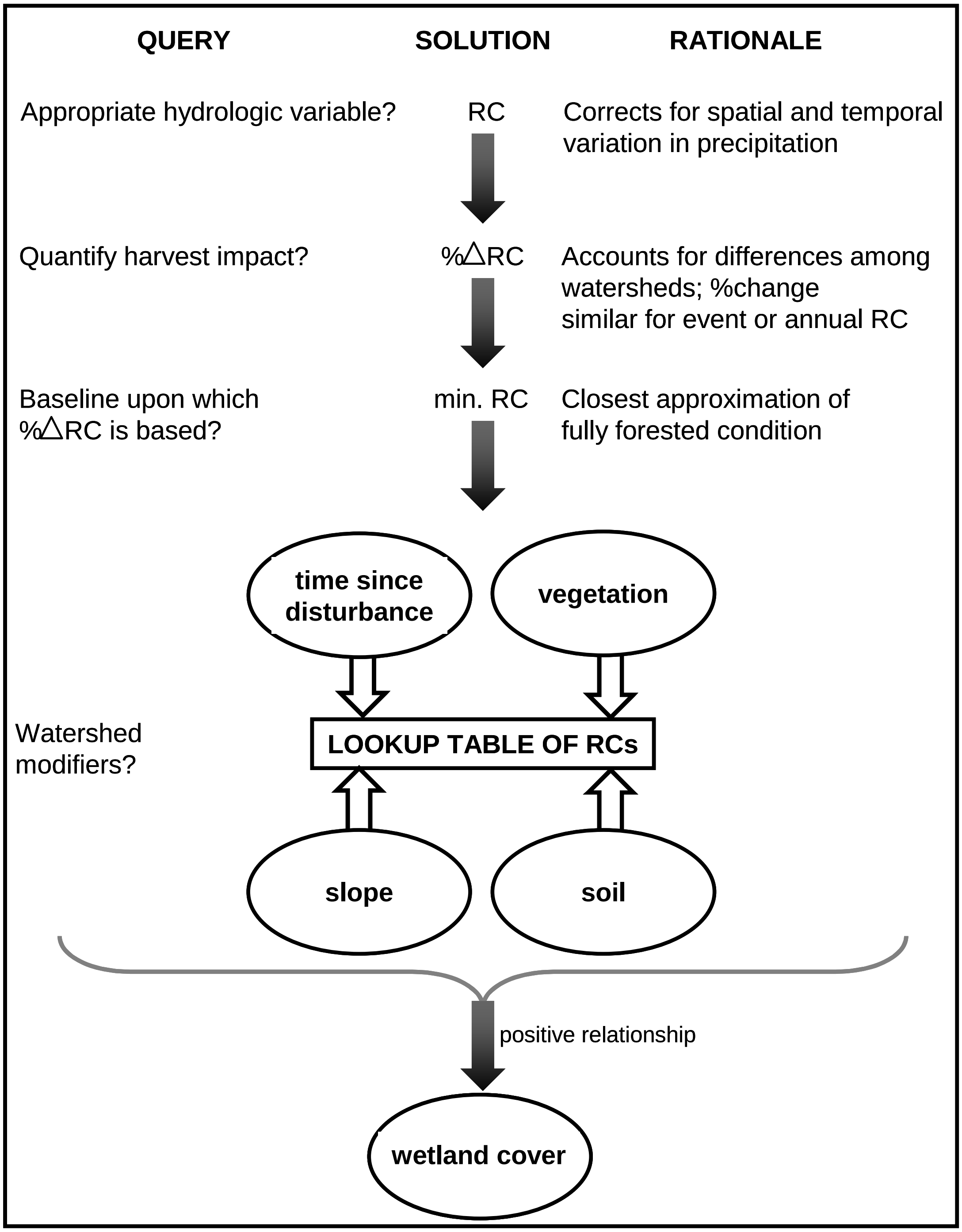

Figure 8. Query based approach used in trade off analysis.

Harvest patterns developed through PATCHWORKS were constrained based on a maximum acceptable change in discharge at the 1st order watershed scale, based upon RC calculations.

4.2 Project Execution

The Millar Western Landbase contained information on landscape features that influence runoff (*e.g.* wetland cover, vegetation, soil, and slope) (Figure 8). To assign a RC to each spatially defined polygon, PATCHWORKS required a lookup table with specific RCs based upon an individual polygon's array of landscape features. To create this lookup table, the SWAT model was used to evaluate how landscape variables influence the magnitude of the RC. SWAT is a semi-distributed river-basin scale deterministic model that simulates daily streamflow. It uses daily weather data and estimates of soil water storage, evapotranspiration, overland flow, lateral flow, and shallow groundwater flow to calculate watershed discharge (Nietsch et al. 2002). The model uses standard soil data from regional soil databases (AGRASID 2001) and is calibrated using a series of adjustable coefficients that allow the model to be fit to a validation dataset (Table 4 and 0). SWAT (v. 2000) had been calibrated for one of the FORWARD watersheds (McKeown et al. 2004).

All model simulations were carried out using these data and the coefficients refined by McKeown et al. (2004) against the validation watershed. Modifications to soil temperature routines were calibrated based on observations from FORWARD soil temperature monitoring stations. Integration of lateral flow through forest floor soil horizons was based on lateral flow equations contained within the SWAT model for mineral horizons. Infiltration to mineral horizons from the forest floor was refined against observed flow data in the validation watershed. A subroutine was developed to calculate modifications to incoming radiation due to changes in aspect, based on solar declination and day length (Revfeim 1978; Tian et al. 2001).

Vegetation growth simulations were carried out using the Agricultural Land Management Alternatives with Numerical Assessment Criteria (ALMANAC) model (Kiniry et al. 1992), which is a plant growth model that was modified ($ALMANAC_{BF}$) to simulate successional boreal forest regeneration after disturbance (MacDonald et al. 2005). The model simulates the simultaneous growth of mixed canopies and undergrowth species after harvest. Simulated total leaf area index (LAI is a unitless ratio of total upper leaf surface divided by the surface area of the land on which the vegetation grows) and total aboveground biomass from parallel simulations of the $ALMANAC_{BF}$ model were transferred to SWAT during simulations. The vegetation growth model uses sigmoid equations to describe leaf area development over time for all species growing on the landscape. SWAT canopy interception simulations were modified to be synchronized with leaf area development. Maximum or ideal leaf area is a fixed input coefficient, but restrictions are placed on leaf area development based on water stress and stand productivity indices.

Table 4. Source of standard data used in SWAT model validation.

Landscape parameters	Millar Western Landbase Classification: Source	Millar Western Landbase Classification: Variable	SWAT Parameter Definition, Mathematical Relationships (min-max): SWAT Variable Input	Mathematical Coefficients and Relationships			
Soils	Overview		Soil physical parameters define water storage and water movement.				
			Soil Series Selected for SWAT input	*Texture (% clay)*	*Saturated Conductivity (mm hr^{-1})*	*Water Holding Capacity (% volume)*	*Coarse Fragment (%)*
	FORWARD Soil Mapping Project. Source information: AGRASID 2001; Couling 2006	Medium to Fine	Hubalta Series, Orthic Gray Luvisol	11-36	10-100	8-10	0-18
		Coarse	Windfall Series, Eluviated Dystric Brunisol	2-4	300-600	1-3	0
		Coarse	Judy Series, Brunisolic Gray Luvisol	6-24	30-300	5-13	2-70
		Riparian	Easyford Series, Orthic Luvic Gleysol	36-43	10-100	5-10	2-5
Vegetation	Overview		The forest canopy defines evapotranspiration from the soil. The forest floor acts as water storage.				
			SWAT Strata Definitions	*Maximum LAI ($m^2 m^{-2}$)*	*Canopy Closure (year after disturbance)*	*[1] Canopy Interception (mm per $m^2 m^{-2}$ of LAI)*	*Forest Floor Depth (mm)*
	Alberta Vegetation Inventory	Strata, lead and secondary species of overstorey canopy	Pure Conifer (Lodgepole Pine)	*4*	*50*	*5.5*	*43*
			Mixed Forest (50% White Spruce, 50% Aspen)	*4.25*	*35*	*3.5*	*36*
			Pure Deciduous (Aspen)	4.5	20	1.5	29
Aspect	Overview		Solar radiation modified by solar angle based on slope direction and gradient. Impacts evapotranspiration and soil temperature.				
	FORWARD Watershed and Stream Layer Project	Polygon slope. Classification by direction and half-steps (i.e. N, NE)	*Aspects Input (degrees)*	*Radiation modifier (coefficient July 1st, 5% Slope)*			
			North (Input as 0)	0.90			
			East (Input as 1.57)	1.05			
			South (Input as 3.14)	1.10			
Slope	Overview		Infiltration modified through empirical relationship developed for curve number runoff approach.				
	FORWARD Watershed and Stream Layer Project	Polygon Area-weighted Slope	Slope (%)	*Infiltration % (100 mm rainfall event)*			
			0.1	*93*			
			1	*92*			
			5	*87*			
			10	*84*			
			20	*81*			

[1] Values calculated from Pomeroy et al. 1997

Leaf area development curves were set to reach their maximum at 20 years post-disturbance for deciduous species and 50 years post-disturbance for coniferous species. Estimates of timing to canopy maximum were based on interpretation of yield tables (Alberta Forest Service 1985), previous Millar Western yield curves (Millar Western Forest Products 1999) and other literature (Lieffers and Stadt 1994; Wang et al. 1995; Ryan et al. 1997). In all simulations, LAI of mature conifer canopies varied between 2.28 and 3.45 annually and deciduous LAI varied from 2.9 to 3.2 inter-annually (dependent on annual rainfall and temperature). These estimates were consistent with typical literature observations of LAI for boreal forests (Smith et al. 1991; Woods et al. 1991; Arp and Yin 1992; Lieffers and Stadt 1994; DeLong et al. 1997; Amthor et al. 2001; Pinno et al. 2001). Both conifer and deciduous simulations had additional contributions of 0.9 to 1.25 LAI by shrub, forb and grass understorey varying inter-annually (Aubin et al. 2000; Blanken et al. 2001).

Simulations of grass, forb and shrub growth after disturbance was based on community transition diagrams developed by a working group of silvicultural specialists specialized in the region of the Millar Western FMA area. Peak leaf area in pioneer grasses and forbs was set to occur at year 5 after disturbance and shrubs at year 10. LAI ranged from a minimum of 1.5 in year one after harvest to 3.7 at in year four after harvest.

Table 5. Modifications incorporated into the original SWAT 2000 code during the calibration and lookup table development process.

SWAT Subroutine	Original Function	Reason for Modification	Modifications
Soil Temperature	Damping effect of soil warming function based on residue and overlying biomass. Damping factor = soil cover / (soil cover + Exp(7.563 - 1.297e-4 * soil cover))	Function range for agricultural conditions was inappropriate for overlying biomass in forests.	Damping factor based on forest floor horizon. Damping factor = Forest floor depth/(Forest floor depth+exp(-2.598182 + 0.844557*Forest floor depth))
Forest Floor	Use of Empirical Curve Number Approach to simulate surface runoff: [2] $Q_{surf} = (R_{day} - I_a)^2/(R_{day}-I_a + S)$	Simulations of curve number approach suggested that curve number approach did not describe water movement through forest floor organic horizons.	Separate subroutine written to simulate lateral flow through forest floor horizon. [3]$Q_{lat} = 0.024*(2*SW_{excess} * K_{sat} * \text{slope (\%)})/(\text{Soil porosity (mm)} * \text{Hill Length (m)})$
Plant Growth Model	Annual crop model, integrates some forest parameters, simulates steady state forest conditions.	Forest model overly simplistic; does not simulate harvest and regrowth.	Linked $ALMANAC_{BF}$ with SWAT, transferred LAI and biomass between models. Wrote external data processing programs that created input files for SWAT simulating harvest and forest regrowth.
Aspect	SWAT had no function to account for impacts of aspect on site characteristics.	Impacts of aspect enhanced in forest environments.	Incorporated subroutine that uses geometrical relationships to modify daily radiation input. Eqautions from Revfeim 1978 and Tian et al. 2001. Daily Radiation= f (latitude, slope, aspect, Julian day)
Evapotranspiration	SWAT did not have parameters required to calulate forest floor (organic matter) water storage.	Forest floor an important source of water storage.	Forest floor subroutine provided parameters for water storage, and forest floor was integrated into the soil evapotranspiration sequence.
	Damping factor for soil evaporation based on total biomass. eaj = Exp(cej * (soil residue + standing biomass + 0.1))	Function range appropriate for agricultural conditions and inapproapriate for overlying biomass in forests.	Reduced soil cover factor to represent only foliar biomass, i.e., 10% of standing biomass. eaj = Exp(cej * (soil residue + 10% standing biomass + 0.1))
Canopy Interception[1]	Canopy interception suboutine in SWAT was fixed value. Maximum canopy retention = Canopy intercept maximum * (LAI / Maximum Potential LAI)	Assumes that the maximum canopy interception remains constant for a site, even after harvest.	Created a variable canopy maximum that increased with forest growth. Maximum Canopy Retention = (canopy maximum*(canopy height /canopy height+exp(7.7-1.5*canopy height))))* (LAI / Maximum Potential LAI)
Dormancy[1]	SWAT described residue for forest litter fall using a fixed value. litter fall=standing biomass * leaf biomass fraction	In initial years after harvest, majority of plant biomass will be annuals and foliar biomass on shrubs and small trees.	Incorporated a variable relationship to simulate change in litter fall with forest growth. litter fall =standing biomass * (exp(-0.5* (canopy height*0.5))+0.1)
	$SWAT/ALMANAC_{BF}$ harvest simulation did not account for residue left on surface.	Surface residue was important factor in reducing soil evaporation in initial years after harvest.	Incorporated an 'if' statement in dormancy subroutine that placed additional 10-20% of residue on the soil surface when harvest occurred in forested polygons representing branch and bark deposition.

[1] Subroutines modified during the process of lookup table development.
[2] Qsurf - surface runoff / Rday - daily ainfall in mm/ Ia - current surfqace conditions / S - surface storage.
[3] Q_{lat} - lateral flow / Ksat - saturated hydraulic conductivity.

4.2.1 Modelling

Reference Conditions

Each landscape feature in the Millar Western Landbase identified as a parameter that influences runoff potential was assigned a range of numerical values that represented the range of variability observed in the Landbase (0). The landscape features of one of the FORWARD experimental watersheds were homogenized to create a simplified watershed made up of three sub-basins, each containing a single land unit. One hundred and eighty simulations were carried out testing each combination of landscape parameters (Table 4) *i.e.* the four soil types were run with three vegetation covers at five different slopes and three different aspects.

Streamflow simulations were run for 15 years based on data collected at FORWARD weather station W3, established in the Millar Western FMA area for the years 2002 to 2004 and Environment Canada data from 1990 to 2001 collected at the Whitecourt, Alberta weather station (Environment Canada 2006). Results were calculated as annual RCs, (*i.e.* annual streamflow volume over watershed area (mm)/annual precipitation (mm), November to October) and event RCs (*i.e.* peak event streamflow (mm)/peak event precipitation (mm)). The peak was interpreted from the hydrograph, but on average was roughly 1-2 days after measured storm end in 1st order streams.

A table was created to record RCs and linear relationships were derived for each combination of simulated landscape features. For example, for each soil type, a RC vs. hillslope relationship was defined as a linear relationship:

$$RC_{soil/slope} = a*hill\ slope+b. \qquad \text{Equation 3}$$

where $RC_{soil/slope}$ is the RC, a function of soil type and slope, and *hill slope* is the basin slope expressed as %.

Each linear relationship was normalized, so that a value of 1.0 represented the predominant polygon type (*i.e.* normal polygon, RC_{norm}) observed in the FORWARD experimental watersheds. The normal polygon was defined as a mature mixed, south facing forest stand on Hubalta soil with 6% slope. The initial value assigned to this polygon was $RC_{norm} = 0.09$. In other words, 9% of the precipitation volume became streamflow under these reference conditions.

Harvest Conditions

Harvest impacts were simulated for Millar Western DFMP simulations by linking SWAT with $ALMANAC_{BF}$. The same simplified watershed used to test landscape variables was used to test harvest impacts. A weather input file was created by appending Whitecourt (Environment Canada 2006) weather station data from 1981 to 2001 to the previous weather input data file from 1990 to 2004 (*i.e.* simulated year 2005 is 1981 weather data). This synthesized weather input file was looped to provide a 70-year weather input file. Parallel 65 year simulations were run, the first with mature forest cover and the second with forest harvest simulated by $ALMANAC_{BF}$ in year 14 (*i.e.* weather year 2004), followed by regrowth of forests to a stand of 50 years of age. As in the reference condition simulations, harvest impacts were simulated for all combinations of landscape features. Initial simulations indicated that SWAT required further modifications to simulate forest harvest (0). Therefore, modifications were incorporated to alter canopy interception coefficients and to leave 10 to 20% of the standing biomass as residue on the soil surface after harvest.

Results were recorded for both reference and harvest conditions. The relative change between RCs occurring from mature stands vs. harvested stands was calculated. A relationship between time after harvest and relative change in RC was derived, in which reference conditions were given a value of 1.0.

Model Outcomes

The following was observed based upon the simulation modelling results:

- Runoff volume is less for coarse soils than fine textured soils (Figure 9A). This difference is due to increased infiltration in the coarse soils.
- The simulated impact of aspect on runoff volume is small (less than 5%). Differences in runoff volume associated with aspect were due to decreased evapotranspiration.
- Increased slope results in increased runoff volume (Figure 9A). Changes were due to decreased infiltration with increased slope.
- Runoff volume is greater from mature deciduous stands than from mature coniferous stands. Differences were due to decreased canopy interception in deciduous stands and increased depth of the organic surface horizons (and soil water capacity) in coniferous stands.
- After harvest, the return of flow volumes to base levels is best described by a linear relationship due to inter-annual variability.
- Harvest impacts are greater in coniferous than deciduous stands. Differences are due to changes in canopy interception and differences in forest floor horizon depth.
- Harvest impacts last longer in coniferous stands (40 years) than deciduous stands (15 years). Differences are due to slower growth and later canopy closure in coniferous stands, therefore a longer period that canopy interception is attenuated.

4.2.2 Lookup Table

Creation

Based on model output, the number of landscape parameters was reduced to eliminate those that were observed to have a small influence on runoff volume.

- Aspect was removed as a landscape parameter because of its small influence on flow relative to variability in model output (Figure 8).
- Hubalta and Windfall soil types represented the extremes in the soil infiltration results and were retained (Figure 8 and Table 4).

After creating a lookup table based on model assumptions, ***predicted*** (model observations) variations in flow and harvest impacts associated with landscape variables were compared to ***observed*** FORWARD flow data.

- Regressions were carried out between measured annual FORWARD RCs and area-weighted watershed slope and forest type (*i.e.* percent deciduous volume).
- Due to the lack of observable relationships at the watershed scale, all differences in RCs associated with forest type were removed.
- A post-harvest RC recovery relationship (Figure 8 and Figure 9B) was used that was based on field observations.
- Given the limited information base for slope, a well-established slope-RC relationship was used (*i.e.* Runoff Curve Numbers from USDA Engineering Handbook (Soil Conservation Service 1972)) (Figure 9A).

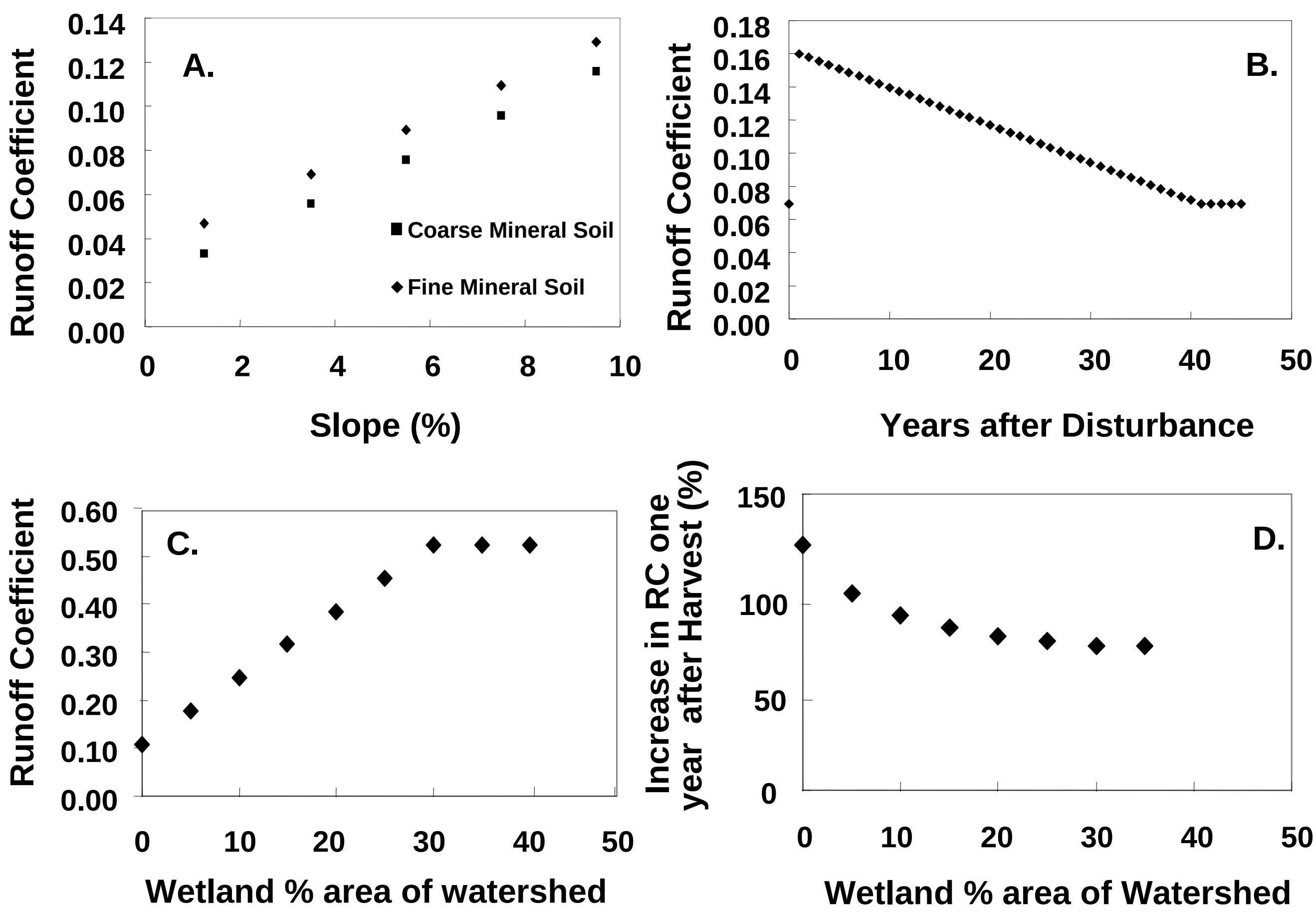

Figure 9. Landscape features incorporated into PATCHWORKS lookup table. A. RC vs. slope for coarse and fine textured soils relationship based on Soil Conservation Service (1972). B. RC impact and recovery following harvest. C. Relationship between RC and watershed percent area of wetland identified in FORWARD data (Figure 10*A*). D. Buffering effect of wetland on harvest impact (Figure 10*B*).

In the final version of the lookup table, RCs were calculated as follows:

$$RC_{soil/slope/veg/\Delta t} = RC_{norm} * C_{soil} * C_{slope} * C_{veg} * C_{\Delta t} \qquad \text{Equation 4}$$

Where $RC_{soil/slope/veg/\Delta t}$ is the value entered into the lookup table, RC_{norm} is the normal RC, and C_{soil}, C_{slope}, C_{veg} and $C_{\Delta t}$ are correction factors representing a percentage change from norm calculated from the normalized linear equations developed for each landscape parameter; Δt represents year after disturbance.

An **empirical relationship** was identified in FORWARD watersheds, which was **consistently observed among watersheds during each of the four data collection years**, relating percent wetland cover to RCs (Figure 10A, Prepas et al. 2006). To integrate the RC vs. wetland relationship into the landscape scale simulations, the calculation was carried out externally in the PATCHWORKS model code to adjust the aggregate RC value for a 1st order watershed (see Equation 1) using the percent wetland in the 1st order watershed as a modifying factor (Figure 8). This relationship covered those 1st order watersheds with less than 30% wetland cover, which constituted the majority of 1st order watersheds in the FMA area (Figure 9C and Figure 10A).

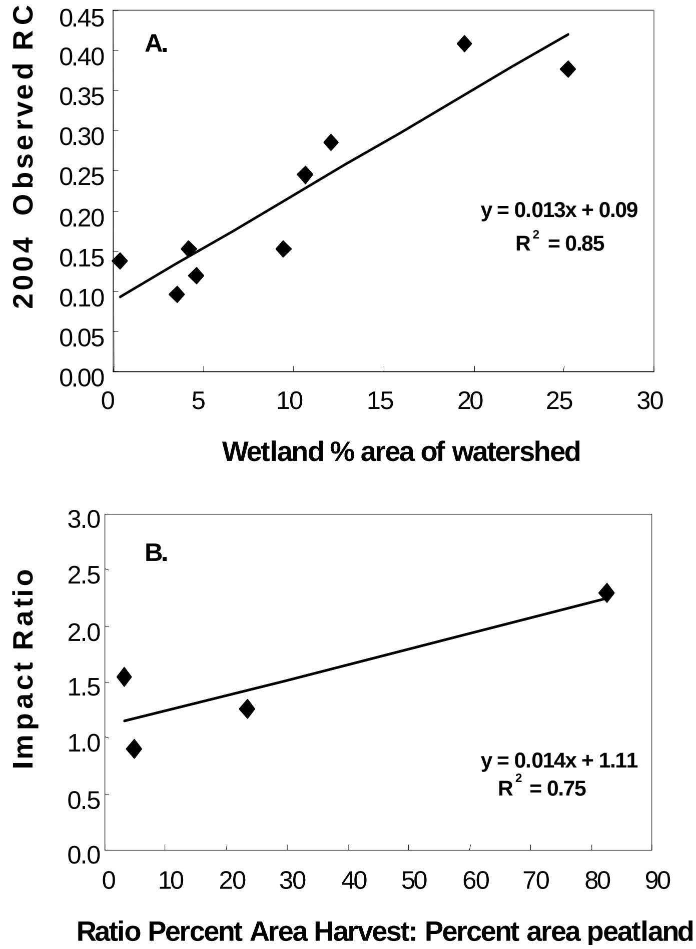

Figure 10. Relationships developed through the FORWARD research program and integrated into PATCHWORKS simulation code. A. RC vs. wetland cover watershed (%). B. Relationship demonstrating that buffering effect of wetlands on RC increases due to harvest impacts. The harvest impact ratio is highest when there is a low wetland area in a watershed (*i.e.* high harvest area to peatland area ratio).

The final calculation of runoff coefficients at the 1st order watershed scale was:

$$RC_{Wf(i)} = RC_{soil/slope/veg/\Delta t} + (0.013 * WA_{Wf(i)}) \qquad \text{Equation 5}$$

Where $WA_{Wf(i)}$ is the percent of the total watershed area that is wetland and the other terms are as defined above. The value 0.013 is taken from the empirical relationship for RC vs. wetland area for the year 2004 (Figure 10B).

A second empirical observation taken from FORWARD data was a buffering effect of harvest impact as wetland area per unit area harvested in a watershed increased (Figure 10B). By correcting the RCs by a constant factor based on the wetland area in a watershed (Equation 5), a buffering effect corresponding to wetland area was automatically incorporated into the calculation of relative harvest impact. Consequently, the harvest impact was higher (up to 130% in year one depending on other watershed factors) in watersheds with no wetlands, than in watersheds with high wetland cover (harvest impact less than 30% in year one) (Figure 9D).

Revisions and Verification

An iterative process was carried out to refine the lookup table developed through the modelling process against observed FORWARD runoff data. The lookup table was submitted to the PATCHWORKS modelling group and landscape scale harvest simulations were carried out for the complete Millar Western FMA area.

- Through seven iterations, the lookup table was refined to fit simulation results to FORWARD data.

- To estimate harvest impact, an impact ratio was calculated for each of the FORWARD watersheds, defined as the ratio of RCs in the harvest year (2004) to the RCs in the preharvest year (2003).

- The percentage increase in RCs one year after harvest was increased until the change in RC calculated by PATCHWORKS simulations was equal to that observed in the FORWARD watersheds.

- The final harvest impact was set at a maximum of 130% increase in RC in the first year after harvest (equal to harvest impact for FORWARD watershed Pierre), while retaining the 40-year recovery curve that was defined by the modelling process.

The final results of simulated and observed RCs in FORWARD watersheds are indicated in Figure 11A and Figure 11B. This comparison suggests that PATCHWORKS simulations are providing reasonable simulations of RCs in the 1st order watersheds monitored by the FORWARD team. They also suggest a reasonable simulation of impact in the first year after harvest, consistent with the impacts observed in the FORWARD monitoring data.

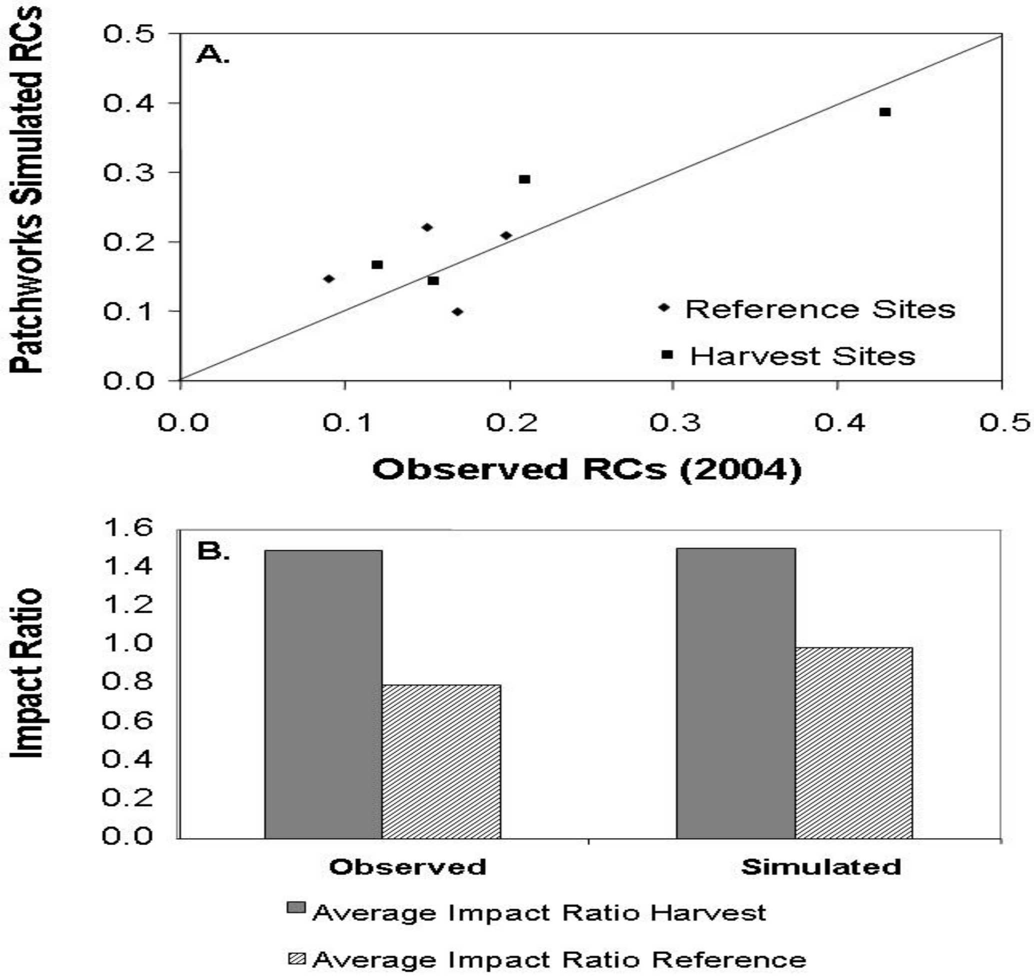

Figure 11. PATCHWORKS simulation results. A. Simulated RCs vs. observed RCs from FORWARD monitoring. B. Observed and simulated harvest impact (ratio of RC 2004:2003) averaged for four watersheds monitored by FORWARD.

Future Outcomes of Water Simulations

Over the next five years, this approach will enhanced to:

1) Use fewer parameters to model streamflow;

2) Include water quality as well as water quantity in the modelling process; and

3) Incorporate a bioindicator component.

5. References

AGRASID. 2001. Agricultural region of Alberta Soil Inventory Database (AGRASID) Version 3.0 [online] Alberta Agriculture Food and Rural Development. Available from http://www.agric.gov.ab.ca/$department/deptdocs.nsf/all/sag3249

Alberta Forest Service. 1985. Alberta phase 3 forest inventory: yield tables for unmanaged stands. ENR Rep. No. Dep. 60a.

American Society for Testing and Materials. 1985. D 2487-83. Classification of Soils for Engineering Purposes: Annual Book of ASTM Standards. Vol. 04.08: 395-408.

Amthor, J.S., Chen, J.M., Clein, J.S., Frolking, S.E., Goulden, M.L., Grant, R.F. Kimball, J.S., King, A.W., McGuire, A.D., Nikolov, N.T., Potter, C.S., Wang, S., and Wofsy, S.C. 2001. Boreal forest CO_2 exchange and evapotranspiration predicted by nine ecosystem process models: Intermodal comparisons and relationships to field measurements. J. Geophys. Res. **106**: 33623-33648.

Applied Ecosystem Management Ltd. 2000. A users guide to Blue Ridge Lumber soil coverage (Version 1.0). An internal report prepared for Blue Ridge Lumber. 25 pp.

Arp, P.A., and Yin, X. 1992. Predicting water fluxes through forests from monthly precipitation and mean monthly air temperature records. Can. J. For. Res. **22**: 864-877.

Aubin, I., Beaudet, M., and Messier, C. 2000. Light extinction coefficients specific to the understory vegetation of the southern boreal forest, Quebec. Can. J. For. Res. **30**: 168-177.

Blanken, P.D., Black, T.A., Neumann, H.H., den Hartog, G., Yang, P.C., Nesic, Z., and Lee, X. 2001. The seasonal water and energy exchange above and within a boreal aspen forest. J. Hydrol **245**: 118-136.

Boyacioglu, E. 1975. Biophysical analysis and evaluation of land capability – Fort Assiniboine. Prepared for Land Use Assignment Committee, AB Energy Nat. Res. 31 pp.

Canadian System of Soil Classification. 1998. Agriculture and Agri-Food Canada Publication 1646, 187 pp.

Couling, K., E.E. Prepas, and D.W. Smith. In press June 2007. Improved estimation of wetland cover in western Canadian boreal forest watersheds. Lake Reserv. Manage. (21 ms pp+2 tables+7 fig.).

DeLong, H.B., Lieffers, V.J., and Blenis, P.V. 1997. Microsite effects on first-year establishment and overwinter survival of white spruce in aspen-dominated boreal mixedwoods. Can. J. For. Res. **27**: 1452-1457.

Dumanski, J., Macyk, T.M., Veauvy, C.F., and Lindsay, J.D. 1972. Soil survey and land evaluation of the Hinton-Edson area, Alberta. AB Inst. Ped. Rep. No. S-72-31. 119 pp.

Environment Canada. 2006. Digital archive of the Canadian climatological data (surface), Atmospheric Environment Service. Canadian Climate Centre, Data Management Division, Downsview, ON.

Kiniry, J.R., Williams, J.R., Gassman, P.W., and Debaeke, P. 1992. A general, process-oriented model for two competing plant species. Trans. ASAE. **35**: 801-810.

Knapik, L.J., and Lindsay, J.D. 1983. Reconnaissance soil survey of the Iosegun Lake Area, Alberta. AB Res. Coun. Soils Dept. Bull. 43. 93 pp.

Lieffers, V.J., and Stadt, K.J. 1994. Growth of *Picea glauca*, *Calamagrostis canadensis* and *Epilobium angustifolium* in relation to overstory light transmission. Can. J. For. Res. **24**: 1193-1198.

MacDonald, J.D., Kiniry, J., Arnold, J., McKeown, R., Whitson, I., Putz, G., and Prepas, E. 2005. Developing parameters to simulate trees with SWAT. *In* Proceedings of the 3rd International SWAT 2000 Conference, 11-15 Jul. 2005, Zurich, Switzerland. *Edited by* K. Abbaspour and R. Srinivasan. Texas Water Resources Institute, College Station, TX. pp. 132-141.

McKeown, R., Putz, G., Arnold, J., and Whitson, I. 2004. Streamflow modelling in a small forested watershed on the Canadian boreal plain using a modified version of the soil and water assessment tool (SWAT). In Proceedings of the 1st Water and Environment Specialty conference of the Canadian Society for Civil Engineering, 2-5 Jun 2004, Saskatoon, Canada.

Millar Western Forest Products. 1999. Crop Plan Yields for Use in Timber Supply Analysis. October 21, 1999. Millar Western Forest Products Whitecourt, AB. 22 pp. plus appendices.

Nietsch, S.L., Arnold, J.G., Kiniry, J.R., Srinivasan, R., and Williams, J.R. 2002. Soil and Water Assessment Tool. User's Manual. Version 2000. GSWRL Report 02-02, BRC Report 2-06. Temple, TX.

Pinno, B.D., Lieffers, V.J., and Stadt, K.J. 2001. Measuring and modelling the crown and light transmission characteristics of juvenile aspen. Can. J. For. Res. **31**: 1930-1939.

Pomeroy, J.W., Granger, R.J., Pietroniro, A., Elliott, J.E., Toth, B., and Hedstrom, N. 1997. Hydrological Pathways in the Prince Albert Model Forest. NHRI Contribution Series No. CS-97004, National Hydrology Research Center, Saskatoon.

Prepas, E.E., Burke, J.M., Whitson, I.R., Putz, G., and Smith, D.W. 2006. Associations between watershed characteristics, runoff, and stream water quality: hypothesis development for watershed disturbance experiments and modelling in the Forest Watershed and Riparian Disturbance (FORWARD) project. J. Environ. Eng. Sci. **5 (Suppl. 1)**: 27-37.

Revfeim, K.J.A. 1978. A simple procedure for estimating global daily radiation on any surface. J. Appl. Meteor. **17**: 1126-1131.

Ryan, M.G., Binkley, D., and Fownes, J.H. 1997. Age-related decline in forest productivity: Pattern and process. Adv. Ecol. Res. **27**: 213-262.

Smith, F.W., Sampson, D.A., and Long, J.N. 1991. Comparison of leaf area index estimates from tree allometrics and measured light interception. Forest Sci. **37**: 1682-1688.

Soil Conservation Service. 1972. Section 4: Hydrology. In National Engineering Haandbook. SCS.

Strahler, A.N. 1952. Dynamic basis of geomorphology. Geol. Soc. Amer. Bull. **63**: 923-938.

Tian, Y.Q., Davies-Colley, R.J., Gong, P., and Thorrold, B.W. 2001. Estimating solar radiation on slopes of arbitrary aspect. Agric. For. Meteorol. **109**: 67-74.

The Forestry Corp. 2007. Development of the FORWARD Soils/Wetland Modeling Coverage – Summary of the input data, processing and final datasets. Report prepared for FORWARD project.39 pp.

Twardy, A.G., and Lindsay, J.D. 1971. Reconnaissance soil survey of the Chip Lake Area. AB Soil Survey Rep. No. S-71-28. 71 pp.

Wang, J.R., Comeau, P., Tsze, M., and Kimmins J.P. 1995. Aboveground biomass and nutrient accumulation in an age sequence of aspen (*Populus tremuloides*) stands in the Boreal White and Black Spruce Zone, British Columbia. For. Ecol. Manage. **78**: 127-138.

Woods, K.D., Feiveson, A.H., and Botkin, D.B. 1991. Statistical error analysis for biomass density and leaf area index estimation. Can. J. For. Res. **21**: 974-989.

Wynnyk, A., Lindsay, J.D., and Odynsky, W. 1969. Soil survey of the Whitecourt and Barrhead area. AB Soil Survey Rep. No. 27. 68 pp.

\\silver\clients\MWFP\Projects\P485_DFMP\Doc\zApp014_FORWARD_Contrib_Rpt\App014_FORWARD_Contrib_Rpt_20070921_Sub.doc