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NATIONAL COUNCIL FOR AIR AND STREAM IMPROVEMENT

# WATER PROFILE OF THE CANADIAN FOREST PRODUCTS INDUSTRY

TECHNICAL BULLETIN NO. 975
MARCH 2010

by

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## PRESIDENT'S NOTE

Canada's fresh water resources are under increasing scrutiny as stewardship of environmental resources becomes an increasingly important component of industrial activity. In view of this, a number of provincial jurisdictions have developed or are developing regulatory policies to protect fresh water resources, their quality and quantity, and to ensure their sustainable use. The forest products industry, being among the largest industrial water users in Canada, figures prominently in local and regional discussions concerning water resources. This report provides both a quantitative and qualitative overview of the role of Canadian forest products manufacturing and forest management to water resource quantity and quality.

Runoff from managed forest watersheds yields approximately one-fifth of Canada's fresh water resource. The application of provincial regulations and forestry best management practices have helped maintain and control streamflow patterns and the quality of the water generated from managed forestlands. The forest products industry draws 0.3% of this water to manufacture wood, pulp and paper products. Most of the water (approximately 88%) is returned directly to surface waters following treatment. In the last fifteen years, Canadian forest products manufacturing has greatly improved water reuse and conservation practices. Furthermore, the implementation of secondary wastewater treatment systems in most pulp and paper mills since the late 1980s and the progressive introduction of significant process changes, such as the use of chlorine-free bleaching in chemical pulping facilities, have resulted in noticeable improvements in mill effluent quality.

The details contained in this report will be helpful in evaluating aspects of current water-related environmental management programs, and in cases where regional water policy actions would benefit from a more quantitative understanding of the connection between the Canadian forest products industry and the country's fresh water resources.

Ron Yeske

Ronald A. Yeske

March 2010

## MOT DU PRÉSIDENT

Puisque l'intendance des ressources environnementales devient un élément incontournable de toute activité industrielle, les ressources en eau douce du Canada font l'objet d'une attention grandissante. En conséquence, certaines juridictions provinciales ont développé, ou sont en cours de développement, des politiques visant à protéger les ressources d'eau douce, leur quantité et leur qualité, afin d'en assurer une utilisation durable. Figurant parmi les plus grands utilisateurs industriels d'eau au Canada, l'industrie des produits forestiers est un intervenant proéminent lors de forums de discussions locaux et régionaux à propos de l'utilisation des ressources hydriques. Ce rapport présente un aperçu quantitatif et qualitatif de l'implication des secteurs manufacturier et de gestion des forêts de l'industrie des produits forestiers en ce qui a trait à la qualité et la quantité des ressources hydriques.

Les eaux de ruissellement des bassins versants reliés à des forêts aménagées comptent pour environ un cinquième des ressources en eaux douces du Canada. La mise en application de règlementations provinciales ainsi que de meilleures pratiques de gestion forestière ont contribué au maintien et au contrôle des débits des cours d'eau ainsi qu'à la qualité des eaux provenant des forêts aménagées. L'industrie des produits forestiers utilise 0,3% de ces eaux pour la production de produits du bois, de pâte et de papier. La majorité de l'eau (approximativement 88%) est retournée directement aux eaux de surface, suite à une étape de traitement des eaux. Au cours des quinze dernières années, le secteur manufacturier de l'industrie forestière canadienne a grandement amélioré ses pratiques de réutilisation et de conservation d'eau. De plus, la mise en place de systèmes secondaires de traitement des effluents dans la majorité des fabriques de pâtes et papiers depuis la fin des années 1980 ainsi que l'introduction progressive de changements au niveau des procédés, tel que l'utilisation de blanchiment sans chlore dans les fabriques de pâte chimique, ont conduit à des améliorations notables de la qualité des effluents d'usine.

Les informations détaillées contenues dans ce rapport seront utiles pour évaluer les différents aspects des programmes actuels de gestion environnementale des eaux. De plus, elles pourront être utiles dans les cas où une compréhension quantitative accrue sur la relation entre l'industrie canadienne des produits forestiers et les ressources en eaux douces s'avère nécessaire pour l'établissement de politiques régionales sur la gestion de l'eau douce.

Ronald A. Yeske

Mars 2010

# WATER PROFILE OF THE CANADIAN FOREST PRODUCTS INDUSTRY

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## ABSTRACT

Runoff from managed forest watersheds yields approximately one-fifth of Canada's fresh water resource. The effects of harvesting activities on water quality and forest hydrology are effectively controlled by the application of provincial regulations and forestry best management practices. Managed forestlands in Canada receive 1.35 trillion $m^3$/yr of precipitation and produce roughly 0.67 trillion $m^3$/yr of streamflow and groundwater. The forest products industry's manufacturing operations draw about 0.3% of these surface and subsurface sources. Approximately 88% of the water used by manufacturing processes is returned directly to surface waters following treatment; nearly 11% is evaporated during manufacturing and wastewater treatment; and about 1% is imparted to products or solid residuals.

Federal pulp and paper mill effluent standards, in conjunction with process improvements and advanced biological treatment systems, have resulted in declining trends in discharge loads of biochemical oxygen demand (BOD), total suspended solids (TSS), adsorbable organic halides (AOX), and dioxins and furans. Laboratory testing and artificial stream assessment of aquatic organisms exposed to these effluents at different concentrations have shown variable effects on organism survival, growth or reproductive capacity. In contrast, extensive in-stream studies carried out to date suggest that treated pulp and paper mill effluents have little effect on aquatic community structure.

## KEYWORDS

aquatic biota, effluent, evaporation, evapotranspiration, footprint, forest management, habitat, paper, land use, process water use, pulp, water consumption, water quality, water quantity

## RELATED NCASI PUBLICATIONS

Technical Bulletin No. 960 (March 2009). *Water profile of the U.S. forest products industry.*

Technical Bulletin No. 946 (February 2008). *Estimating water consumption at pulp and paper mills.*

Technical Bulletin No. 603 (January 1991). *Progress in reducing water use and wastewater loads in the U.S. paper industry.*

# ÉTAT DES RESSOURCES HYDRIQUES EN RELATION AVEC LES ACTIVITÉS DE L'INDUSTRIE CANADIENNE DES PRODUITS FORESTIERS

BULLETIN TECHNIQUE N$^{O}$ 975
MARS 2010

## RÉSUMÉ

Les eaux de ruissellement de bassins versants reliés à des forêts aménagées comptent pour environ un cinquième des ressources en eaux douces du Canada. Les effets des activités de récoltes forestières sur la qualité des eaux et l'hydrologie forestière sont contrôlés de manière effective par l'application de règlements provinciaux ainsi que des meilleures pratiques de gestion forestière. Au Canada, les terres forestières aménagées reçoivent 1,35 trillion $m^3$/an de précipitations et génèrent environ 0,67 trillion $m^3$/an du débit des cours d'eau et des eaux souterraines. Les opérations manufacturières de l'industrie des produits forestiers soutirent environ 0,3% de ces eaux de surface et souterraines. Approximativement 88% de l'eau utilisée dans les procédés de fabrication est retournée directement aux eaux de surface, suite à une étape de traitement des eaux; presque 11 % de l'eau est évaporée durant les étapes de procédés de fabrication et lors du traitement des effluents; la balance d'environ 1 % est contenues dans les produits et les résidus solides.

Les normes fédérales sur les effluents de fabriques de pâtes et papiers de pairs avec les améliorations apportées aux procédés de fabrication et aux systèmes de traitement biologique avancés, ont mené à l'obtention de tendances à la baisse des taux de rejets aqueux de : demande biochimique en oxygène (DBO), matières en suspension (MES), composés halogénés organiques adsorbables (COHA) et dioxines et furannes. Des essais en laboratoire et des évaluations de cours d'eau artificiels sur des organismes aquatiques exposés à ces effluents, à différentes concentrations, ont montré des effets variables sur la survie, la croissance et la capacité de reproduction de ces organismes. Les études exhaustives effectuées à venir jusqu'à maintenant directement dans les cours d'eau suggèrent quant à elles que les effluents traités rejetés par les fabriques de pâtes et papiers ont peu d'effets sur la structure de la communauté aquatique.

## MOTS CLÉS

biote aquatique, effluent, évaporation, évapotranspiration, empreinte, gestion forestière, habitat, papier, affectation des terres, utilisation des eaux de procédés, pâte, consommation d'eau, qualité de l'eau, quantité d'eau

## AUTRES PUBLICATIONS DE NCASI DANS CE DOMAINE

Bulletin technique n$^{o}$ 960 (mars 2009). *Water profile of the U.S. forest products industry*.

Bulletin technique n$^{o}$ 946 (février 2008). *Estimating water consumption at pulp and paper mills.*

Bulletin technique n$^{o}$ 603 (janvier 1991). *Progress in reducing water use and wastewater loads in the U.S. paper industry.*

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# WATER PROFILE OF THE CANADIAN FOREST PRODUCTS INDUSTRY

## 1.0 INTRODUCTION

Canada possesses one of the largest supplies of fresh water in the world (World Resource Institute 2005). Nonetheless, growing stresses are currently placed upon this vast natural resource by industrial demands, urban and rural development, changes in land use practices, and in the future, by possible long-term alterations in precipitation patterns and hydrologic processes (Environment Canada 2004).

Various jurisdictions across Canada have been implementing regulatory policies related to the use and protection of fresh water resources. While the current regulatory focus has been on forest products manufacturing operations themselves, there is increased attention being paid not only to the potential influence of forest management on water quality, but also to its potential effects on water quantities filtering through and emanating from forested watersheds. The aim of this report is to describe the water profile of the Canadian forest products industry in a holistic fashion to help inform ongoing policy discussions regarding the influence of forest management and forest products manufacturing on the availability and quality of fresh water resources.

It is worth noting that this report is similar in structure to its U.S. counterpart (NCASI 2009) in that it addresses the same water profile elements and considers water, in its liquid and gaseous forms, to be a short-rotation material. The content of each section has been, on the other hand, reworked to appropriately reflect the Canadian situation. Accordingly, the first section of this report discusses the key role forests play in the hydrologic cycle, the ecoregional differences in water yields from managed forests in Canada, and the nature of the water quality changes resulting from forest management. The second section quantifies the water associated with the manufacture of pulp and paper and of wood products in terms of total water inputs, consumptive losses of water, water released as treated liquid effluent, and the quantities leaving with solid residuals and products. The final section discusses pulp and paper mill effluent quality trends in recent years and details the responses of aquatic communities to effluent exposures examined in laboratory, artificial stream and in-stream studies, or as part of regulatory initiatives such as Environment Canada's Environmental Effects Monitoring (EEM) program.

## 2.0 ELEMENTS OF THE FOREST PRODUCTS INDUSTRY WATER PROFILE

Figure 2.1 depicts aspects of the forest products industry that may affect water resources. As shown, the influences of industry operations (and most other human uses) on water resources are to alter the form or fate of water between the points at which it is withdrawn from and then returned to the water cycle.

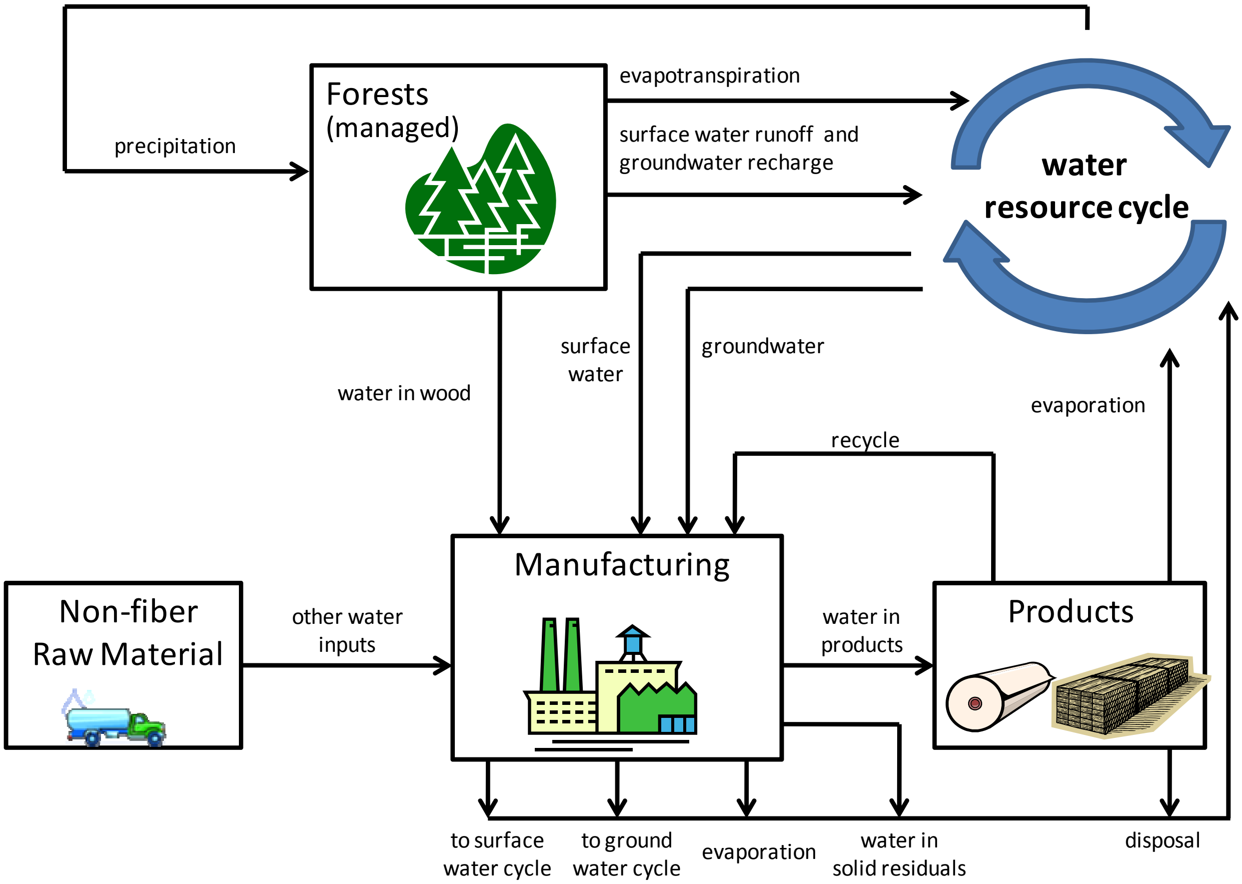

**Figure 2.1** Connection of the Forest Products Industry to the Water Cycle

## 2.1 Forests and Forest Management

The forest products industry is unique in its reliance on the sustainable use of forested landscapes for input of primary raw material. The industry is either directly or indirectly involved with forest renewal, the maintenance of wildlife habitat, and the protection of water resources, among other conservation and societal values. Sustainable use of forestlands not only serves to ensure access to fibre and other biomass, but also to sustain the attributes of the land as an important component of the water cycle.

Water enters the forest as either precipitation or groundwater. Some of that water is used by trees and other forest plants and emitted via evapotranspiration or interception loss as water vapour (throughout this report NCASI will generally use only the term evapotranspiration, but this includes water vapour that is intercepted by vegetation and lost to the atmosphere as well as evaporation and transpiration losses). The remainder either supplements groundwater supplies or flows from forestlands as surface water. Surface and groundwater supplies are the primary sources of water used for manufacturing pulp, paper, and other forest products.

Timber harvesting, site preparation, thinning, roads, and other forest management practices can alter the forest water balance by changing interception, evapotranspiration, and infiltration. These changes can affect how water leaves the forest (as vapour due to evapotranspiration, as groundwater recharge, or as streamflow), but not the total amount of water entering or leaving the forest. Throughout this report, streamflow is used to describe surface water runoff that could also include changes in lake water. Surface runoff is used to describe overland flow from the watershed that feeds streamflow along with subsurface runoff. Local water supplies can benefit from increased water yields (increases in groundwater recharge or streamflows) when interception and evapotranspiration rates are reduced. It has been claimed that reductions in evapotranspiration due to timber harvesting have caused regional droughts, although there is scant evidence of this type of effect (Ice and Stednick 2002).

Reduced interception and evapotranspiration following harvesting can increase total water available downstream from a harvest unit (Ice and Stednick 2004). Whether there is an increase in streamflow and groundwater recharge following harvesting depends on the precipitation pattern, how the growing season coincides with precipitation, and forest species (especially conifers versus hardwoods). There is the potential that timber harvesting can result in increased peak flows (e.g., Eisenbies et al. 2007) as well as increased flows during typically low flow periods although, again, the extent of the effects depends on site-specific conditions. In some cases flows can actually drop below pre-harvest levels as young forest stands recover. Most forest hydrologists believe that water yields increase locally with forest management, but forest recovery is such that it is difficult to detect these changes over large management areas.

Equally as important as any potential changes in the quantity and timing of streamflow from forests due to management are possible changes in water quality. Contemporary forest practices using provincial forest management guidelines and best management practices (BMPs) dramatically reduce water quality impacts compared to historic practices (Ice 2004). Changes in sediment and temperature can be difficult to detect following timber harvesting. The greatest potential for changes in sediment occurs where forestlands are susceptible to landslides or where mechanical site preparation or skidding results in significant disturbance to the forest floor. Nutrient concentrations can increase following timber harvesting as a result of increased mineralization of the forest floor and reduced plant uptake. These changes are attenuated with re-growth of the forest and understory vegetation as well as in downstream aquatic systems.

With contemporary forest practices, water quantity and quality impacts are often within the range of responses observed from natural disturbance events such as wildfires or wind storms (McBroom et al. 2003). Potential impacts must, of course, be considered in the context of other impacts resulting from land use modifications that are large-scale and more permanent, such as converting forest to non-forest uses and more significant landscape disturbances. Section 3 of this report summarizes the scientific knowledge applicable to forest landscapes with respect to water resource impacts. It includes information related to effects of forests and forest management on water quantity and water quality, specifically those topics shown in Table 2.1.

**Table 2.1** Content of Water Profile for Forests and Forest Management

| Water Quantity | Water Quality |
|---|---|
| harvesting practices | nutrient flux |
| low flow (timing and magnitude) | temperature |
| peak flow (timing and magnitude) | sediment flux |
| regional climate effects | dissolved oxygen |
| effects of riparian vegetation and harvest timing on water yields | chemicals used in silviculture<br>forest roads |

## 2.2 Manufacturing

In Canada, the total volume of fresh water withdrawn is dominated by thermoelectric power generation (~54%), manufacturing industries (~14%), agricultural activities (~12%), and domestic use (~20%) (World Resource Institute 2005; Statistics Canada 2008). Within the manufacturing category, the Canadian forest products industry is among the largest industrial water users (Statistics Canada 2008). Unlike some other water users (e.g., agriculture), the vast majority of water used within the forest products industry is returned to surface waters (NCASI 2008a; Statistics Canada 2008). Over the last fifteen years, Canadian pulp and paper mills have greatly improved water reuse and conservation efforts such that the amount of water used for the production of pulp and paper/paperboard has decreased by 34% on a specific production basis since 1992 (Figure 2.2 values from FPAC (2009)). In comparison, the 2007 production-weighted mean specific effluent discharge calculated from this study is 60 $m^3$/admt for the entire Canadian pulp and paper industry.

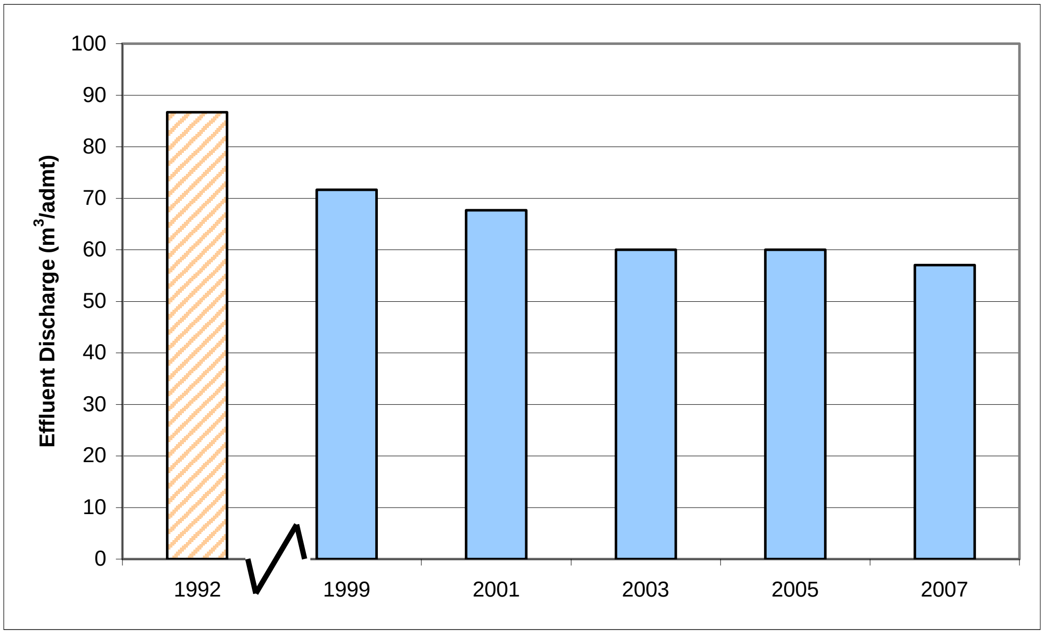

**Figure 2.2** Reductions in Effluent Flow over Time in the Canadian Pulp and Paper Industry [Value from 1992 represents the entire Canadian pulp and paper industry while subsequent values represent the average from FPAC members. Effluent discharge is water discharged from the waste treatment facility.]

Primary water inputs to forest products manufacturing operations are from surface or groundwater supplies. Additional water enters the process with wood and, to a lesser extent, recovered fibre, and non-fibre inputs such as purchased chemicals. Water exports include treated wastewater, separate process cooling water discharge, water vapour emitted to the atmosphere, water contained in finished products, and water leaving the process with solid residuals, including wastewater residuals.

Section 4 of this report details water management in forest products manufacturing operations focusing on the quantity used and quantities released as treated liquid effluent, water vapour, and with products. Water entering the process with non-fibre raw materials and process chemicals is also discussed. The water profile of the U.S. forest products industry was published by NCASI in 2009 and calculation of the Canadian forest products manufacturing water profile uses many of the same elements as in that publication (NCASI 2009).

Some useful definitions pertaining to water within the pulp and paper industry will be used throughout this report.

> **Water Use**: The total amount of water used by a facility for process and cooling needs. Water use is generally equivalent to water intake.
>
> **Water Consumption**: A previous NCASI publication (2008a) reviews some of the more popular definitions of water consumption since there is no universally accepted definition. A common definition of water consumption is the portion of water that is removed from a water source that is not immediately returned to the water source. Examples of consumptive water losses include evaporative losses and water leaving with product and solid residuals.
>
> **Effluent:** Water discharged from a facility. Effluent is often subcategorized into treated process effluent and non-contact cooling water effluent.
>
>> **Treated Process Effluent:** Water that has come into contact with process materials, and thus has a certain degree of contamination from process materials. Process effluent is usually treated mechanically and/or biologically to remove organic material.
>>
>> **Non-Contact Cooling Water Effluent:** Water that is used for cooling duty that does not come into direct contact with process water but is usually of a higher temperature than the water entering a mill.

### 2.3 Effluent Compatibility with Receiving Waters and Aquatic Communities

Section 5 provides a discussion of the quality of treated liquid effluents and the potential of these effluents to affect aquatic communities in receiving waters. Effluent composition in terms such as biodegradable organics (BOD), total suspended solids (TSS), dioxins and furans, adsorbable organic halides (AOX), and bioassay responses are discussed and an overview of scientific research on the degree to which treated effluents are compatible with receiving waters is presented. Compatibility is considered in terms of laboratory bioassays and effects on aquatic communities.

## 3.0 WATER PROFILE FOR FORESTS AND FOREST MANAGEMENT

The forest products industry is unique in its reliance on land that is held in forest. By both direct and indirect means the industry ensures maintenance of productive forestlands and through them a reliable source of raw material for the production of current and future products. The maintenance and management of forestland serves not only to ensure access to fibre, but also to sustain key environmental attributes of the land, including important components of the water cycle. Below, the quantity of water coming from forests and the influence of forest management on streamflow and other water quantity concerns are discussed, followed by a review of the impacts of the forest products industry on the quality of water coming from managed forests.

### 3.1 Quantity of Streamflow from Managed Forests

Canada holds approximately 402.1 million hectares of forests and other wooded land, representing 10% of the world's forest cover (Natural Resources Canada 2009). These wooded lands represent about 40% of Canada's land-base, but lands "suitable and available for commercial timber production" represent only 16% of the land-base. Forests tend to be adapted to regions with higher precipitation than other natural cover types, and thus are closely related to the amount and timing of surface and subsurface flows.

Water enters the forest as precipitation (Figure 3.1). Some is lost when foliage-intercepted water evaporates. Precipitation that reaches the forest floor can recharge soil moisture, run off the forest surface as overland flow, be stored and released from a snowpack, or be taken up by trees (overstory) and other forest plants (understory) and emitted as water vapour via evapotranspiration. The remaining water supplements groundwater supplies or flows from forestlands as streamflow. The timing of water outputs as groundwater recharge or streamflow is determined by inputs and storage in snow packs, soil, and other storage elements (ponds, wetlands, etc.). Forest soils are typically highly effective at providing storage because of the forest floor (composed of partially decomposed forest litter), high organic matter content, and high volume of macropores.

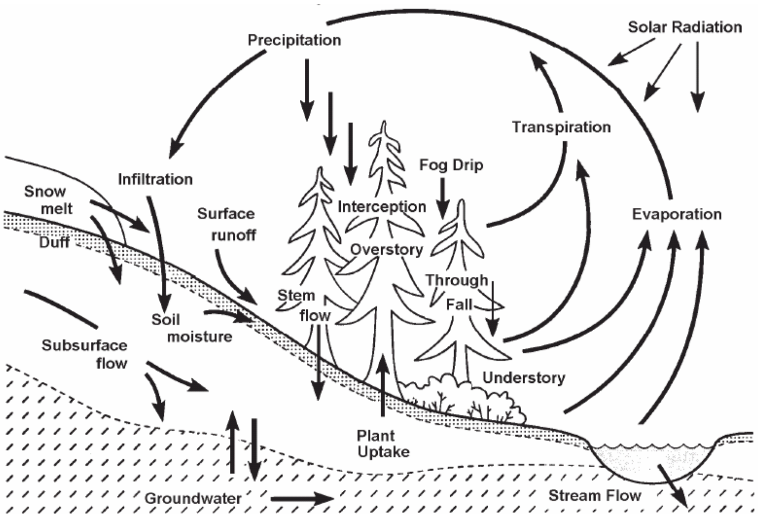

**Figure 3.1** Forest Hydrologic Cycle
[http://www.forrex.org/streamline/ISS24/streamline_vol7_no1.pdf]

### 3.1.1 *Influence of Forest Management on Hydrologic Processes*

In general, forest removal results in a short-term increase in annual runoff or water yield. However, results of watershed-level studies in Canada have noted that increases in runoff and changes to the distribution and timing of that runoff are highly variable between basins. It has been suggested that these large differences are related to variable climatic conditions and forest cover types (Whitehead and Robinson 1993); more definitive conclusions have been difficult to draw (Alila and Beckers 2001).

There are a large number of ways that forest management can alter the hydrological cycle in forests (Figure 3.1), and an equally large number of ways to moderate those alterations. Harvesting trees can directly reduce interception loss and evapotranspiration. Maintenance of riparian management areas, green tree retention, and alternative management systems such as patch-cutting and selective harvesting can all be used to moderate undesirable changes due to reduced interception and evapotranspiration. Roads built for forest management purposes can alter hydrologic processes by compacting the soil, which can reduce infiltration and result in increased surface flows, and by re-routing flow in ditches and culverts. Mitigating practices include adding relief culverts to redistribute concentrated flows off roads and back onto the forest floor, and disconnecting culverts from direct delivery to streams. Yarding (especially ground-based) and site preparation (e.g., burning) activities can alter soil properties through rutting, destabilizing slopes, loss of organic matter, and compaction and displacement of the forest floor and soil. These can alter water infiltration rates, soil hydraulic conductivity, and the potential for soil erosion. These effects can change the amount and timing of runoff, alter flow pathways (e.g., increased overland flow), and change water table levels. The effects of such management-related changes depend on the harvesting system used, site soils and geomorphology, and weather conditions. For additional information on opportunities to control negative impacts from forest management, see the *Canadian Watershed Handbook of Control and Mitigation Measures for Silvicultural Operations* (http://www.ncasi.org/programs/areas/forestry/canadian_program/watershed_mgmt/handbook.aspx).

The presence or removal of trees can have myriad effects, including altering evapotranspiration rates, changing precipitation interception rates (e.g., fog, rain), altering soil infiltration rates, and increasing solar radiation to the soil (which can alter snowmelt and soil freezing patterns and therefore infiltration and runoff). Each of these changes affects the amount of water that may be seasonally available for streamflow. The effects of these factors on flow tend to be of lesser magnitude and shorter-lived in patch-cut treatments than in clear-cut watersheds. Hydrologic recovery times are influenced by the magnitude of hydrologic changes and plant re-growth potential of the sites. With respect to snow, tree removal can alter interception and evapotranspiration rates, and the distribution and melt rate of snowpacks, but it does not alter the amount of snow falling on a large watershed.

Types of vegetation affect hydrologic processes, as changes in species composition can result in changes to evapotranspiration rates and alter the amount of water available for streamflow (Hicks, Beschta, and Harr 1991). Deciduous hardwoods will process snow or rain much differently in the winter than evergreen conifers. Different tree species may also vary in their interception rates of precipitation, as crown volume, length, and density explain the largest portion of snow interception (Winkler 2001).

### 3.1.2 *Effects of Forest Management on Runoff*

Runoff patterns are generally described in terms of water yields (total amount of runoff over a year), peak flows including extreme peak flow events (floods), and low flows. Increases in water yields and low flows are generally viewed as positive, while increases in peak flows are often considered negative. The effects of forest management on water runoff is often a concern for local stakeholders, as changes to seasonal flow rates can affect flooding and drought, and high peak flows may be related to bank and channel scouring that can affect aquatic communities (both on site and downstream).

Water yields have generally been found to increase after forest management, which can influence both peak and low flows. However, the magnitude of response is highly variable and is generally thought to be related to a number of factors, none of which has been found to be consistent across studies or regions. One common factor may be the amount of the watershed area comprised of wetlands, bogs, and fens, which may act as buffers that limit large fluctuations in runoff during peak flows.

For many regions in Canada, melting snow is the main source of water for streamflow and often results in peak flows during spring melting of the snowpack. As described, tree species composition and removal can have significant effects on evapotranspiration, interception, and snow distribution and melt rates, and therefore alter runoff patterns.

### 3.1.3 *Ecoregional and Site-Specific Differences in Water Yields from Managed Forests*

Canada's forested regions cover an extensive area, ranging from the eastern to western coasts and from the 49th parallel to the northern edge of the boreal forest. Only a portion of that range is considered to be economically viable for harvesting. In the far northern boreal forest, small trees and very short growing seasons produce insufficient fibre to be sustainably managed, and other areas are legally excluded from forest management. Precipitation regimes and hydrology vary extensively across this range (Figures 3.2 and 3.3), and therefore may best be characterized by ecozone (Natural Resources Canada 2007).

#### *3.1.3.1 Atlantic Maritime Ecozone*

The Acadian forest region comprises most of New Brunswick, Nova Scotia, and Prince Edward Island and some portions of Quebec, as well as Îles-de-la-Madeleine. Proximity to the ocean results in a cool, humid maritime climate with moderated temperatures ranging from 3.5°C in the Gaspé region to 6.5°C in southern Nova Scotia. Mean summer temperatures range from 13 to 18°C and winter temperatures range from -2.5 to -10°C, and mean precipitation varies from 1000 mm inland to 1425 mm near the coast (Natural Resources Canada 2007).

The ecozone is a transition between the more northern boreal forest and the southern deciduous forest, and includes elements of both (NCASI 2006). Forest composition includes mixed stands of conifers and deciduous species, characterized primarily by red spruce (*Picea rubens*), yellow birch (*Betula alleghaniensis*), balsam fir (*Abies balsamia*), and sugar maple (*Acer saccharum*), with a lesser occurrence of red (*Pinus resinosa*) and white pine (*Pinus strobus*) and eastern hemlock (*Tsuga canadensis*). Some boreal species are present, including black (*Picea mariana*) and white spruce (*Picea glauca*), balsam poplar (*Populus balsamifera*), and white birch (*Betual papyrifera*), with jack pine (*Pinus banksiana*) occurring on sandy soils after wildfires.

Forest watershed research from the Acadian forest region shows varying results. Caissie et al. (2002) documented no effect on annual and seasonal water yield of harvesting 2 to 3% of the Middle Reach basin of the Catamaran Brook, New Brunswick, whereas a 23 to 24% harvest increased peak flow but not total streamflow for a tributary. Over the first six years post-harvesting and the first 12 years post-harvesting of the Nashwaak River Experimental Watershed, Jewett et al. (1995) documented increases in water yields of 8.9 and 9.2%, respectively. The effects of harvesting were approximately the same for Years 1 through 6 as for Years 6 through 12, despite increases in evapotranspiration from vegetation re-growth (Meng et al. 1995; Jewett et al. 1995). These relatively minor changes contrast with results from another study in the region that found that 65% of increases in peak flows during extreme weather events were attributable to forest harvesting, contributing to a substantial increase in water yields over the first year post-harvest (Dickison, Daugharty, and Randall 1981, 1983; Dickison, Palmer, and Daugharty 1986; Daugharty and Dickison 1982).

#### *3.1.3.2 Boreal Shield*

The Boreal Shield ecozone stretches from parts of northern Saskatchewan, across Ontario and Quebec, east to Newfoundland. The ecozone has a strongly continental climate characterized by long, cold winters and short, warm summers, modified by maritime conditions in its coastal margins in Atlantic Canada. The mean annual temperature ranges from -4°C in northern Saskatchewan to 5.5°C in the Avalon Peninsula of Newfoundland. Mean summer temperatures generally range from 11 to 15°C. Mean winter temperatures range from -20.5°C in the west to -1°C in the east. Mean annual precipitation ranges from 400 mm in northern Saskatchewan to 1000 mm in eastern Quebec and Labrador. The maritime influence on Newfoundland results in a higher level of precipitation, ranging from 900 to 1600 mm. The Great Lakes also have a moderating effect on the climate of Boreal Shield areas of central Ontario (Natural Resources Canada 2007).

Forests are characterized by stands of conifer consisting mostly of white and black spruce, balsam fir, and tamarack (*Larix laricina*). More southern parts of the region include larger components of deciduous species such as white birch, trembling aspen (*Populus tremuloides*), and balsam fir, along with conifers such as white, red, and jack pine.

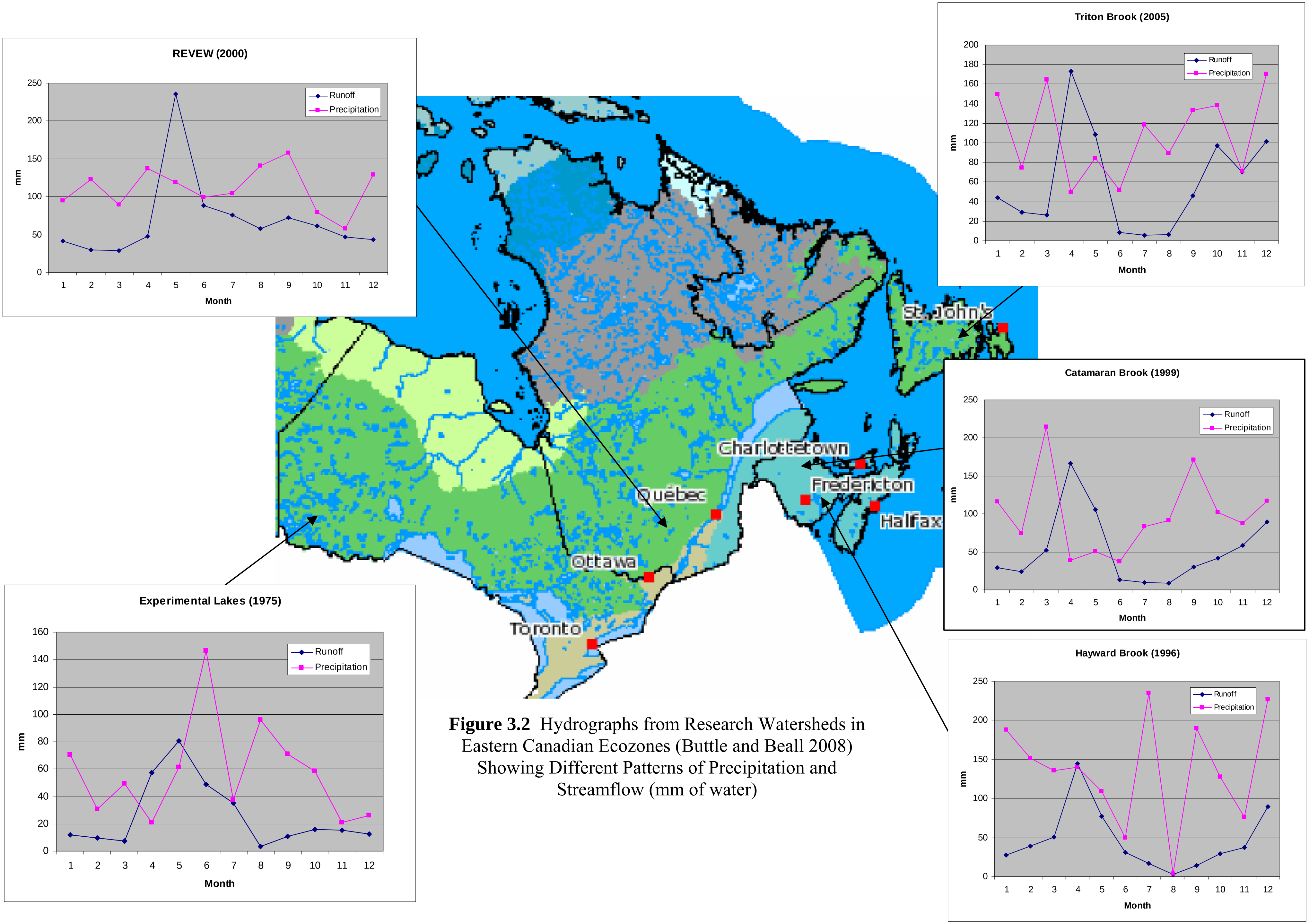

**Figure 3.2** Hydrographs from Research Watersheds in Eastern Canadian Ecozones (Buttle and Beall 2008) Showing Different Patterns of Precipitation and Streamflow (mm of water)

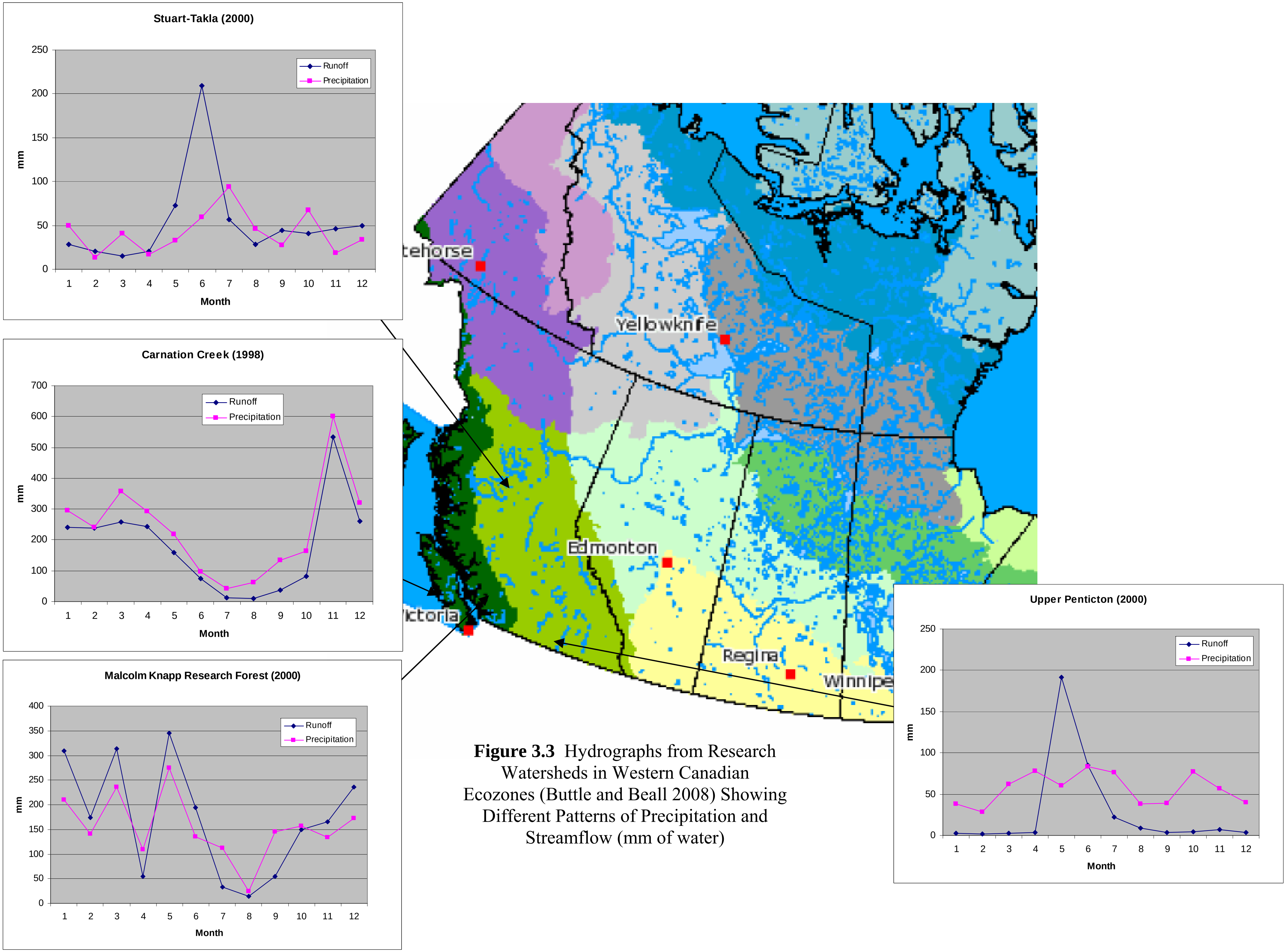

**Figure 3.3** Hydrographs from Research Watersheds in Western Canadian Ecozones (Buttle and Beall 2008) Showing Different Patterns of Precipitation and Streamflow (mm of water)

There is substantial research from the Boreal Shield on the effects of forest management on water yields. Results have been inconsistent, suggesting in some cases that harvesting tends to increase streamflow (Guillemette et al. 2005), particularly during low flow periods (Buttle and Metcalfe 2000), and in other cases showing no effect (Plamondon et al. 1998; Plamondon and Ouellet 1980) and that effects of forest harvesting on streamflow tend to be scale dependent (Buttle and Metcalfe 2000).

#### *3.1.3.3 Boreal Plain*

The Boreal Plain ecozone cuts a wide band from the Peace River country of British Columbia in the northwest to the southeastern corner of Manitoba. Its climate is strongly influenced by continental climatic conditions typified by cold winters and moderately warm summers. The mean annual temperature ranges from -2 to 2°C. Mean summer temperatures range from 13 to 15.5°C. Mean winter temperatures range from -17.5 to -11°C. Mean annual precipitation rises from 300 mm in northern Alberta to 625 mm in southwest Manitoba (Natural Resources Canada 2007).

Throughout this region, white and black spruce, jack pine, and tamarack are the main coniferous species. Deciduous species such as white birch, trembling aspen, and balsam poplar are found mostly in the transitional zone leading to the prairie grasslands. Black spruce and tamarack are more dominant in northern parts of the region.

Research into the relationship between forest management and water yield is limited in this zone, but suggests that due to the region’s variable rainfall and spatial variability in bedrock characteristics and soil water storage, effects are either minimal or inconclusive. However, several authors have suggested that lowland sites may be more susceptible due to reductions in soil strength when water tables rise during most years (e.g., McEachern, Prepas, and Chanasyk 2006).

#### *3.1.3.4 Montane Cordillera*

The Montane Cordillera ecozone covers most of southern British Columbia and a portion of southwestern Alberta. A highly diverse ecozone, it ranges from alpine tundra to dense conifer forests to dry sagebrush (*Tridentata sp.*) and grasslands. The Montane Cordillera encompasses some large, deep lakes and major river systems, including the Fraser River and the Columbia River headwaters. Precipitation varies by region from 300 mm to >1200 mm, and mean annual temperatures vary from 0.5°C to 7.5°C (Natural Resources Canada 2007).

Results of watershed management experiments have been highly variable in this region. The effects of management have resulted in changes to peak flows (-8% to 367% change) and water yields (1% to 193%), with no one factor found to be responsible. Authors have suggested that effects could be related to size and complexity of the watershed, water storage capacity of the soil, amounts of riparian retention, and changes in seasonal evapotranspiration levels. Swanson and Hillman (1977) suggested that effects on streamflow during snow melt could persist for 30 years.

The lodgepole pine (*Pinus contorta*) forests of British Columbia have recently been impacted by a massive mountain pine beetle (MPB) (*Dendroctonus ponderosae*) outbreak that has affected 14,500,000 ha. Extensive salvage logging and forest dieback are likely to affect the region’s hydrology. A comprehensive synthesis of existing information on the impact of MPB is provided by Forest Research Extension Partnership (FORREX) (http://mpbbib.forrex.org/rmwp). FORREX provides a searchable list of almost 1,800 references on MPB. For example, the database includes a *Water Resources Research* article (Cheng 1989) that concluded that salvage logging 30% or more of a large watershed can result in a significant and detectable increase in streamflow. It also includes material from a FORREX-sponsored workshop in 2007: *Mountain Pine Beetle and Watershed Hydrology Workshop: Preliminary Results of Research from BC, Alberta, and Colorado*. Abstracts from that workshop provide a comprehensive synthesis of ongoing research and preliminary findings. Key observations are summarized below.

- MPBs increase available water by reducing evapotranspiration and interception, and can modify snowpack dynamics.
- Changes in interception increase with maturing of attacked stands from red (recently attacked and dead or dying) to grey (dead with loss of needles).
- Salvage logging can further reduce interception.
- MPBs may increase nitrate concentrations through undetermined mechanisms including increased mineralization and reduced plant uptake.
- Riparian zones in lodgepole pine stands may be dominated by other species.
- Concentrate riparian retention within the first 10 m for small streams (<2 m bankfull width).
- Hydrologic effects are spatially variable and may also differ with different weather patterns. For example, snowpack differences between forested and salvaged logged sites were reported to be greater during low snow years than during high snow years.
- Modeling suggests that MPBs and salvage logging will result in increased peak flows.

The scale of this outbreak and anticipated hydrologic responses, especially for the Fraser River Basin that drains much of the affected area, have prompted the Ministry of the Environment to reconsider levee and dam safety.

#### *3.1.3.5 Pacific Maritime*

The Pacific Maritime ecozone covers the mainland Pacific coast and offshore islands of British Columbia. The wettest climates in Canada occur here, as the zone typically receives 1500 to 3000 mm of precipitation per year. Annual precipitation ranges from as little as 600 mm in the Gulf Islands of lower Strait of Georgia to over 4000 mm in the Coastal Gap region to the north. Mean winter temperatures range from -5°C to 3.5°C, and mean summer temperatures range from 10°C to 15.5°C (Natural Resources Canada 2007).

Forests in this ecozone comprise a mixture of western red cedar (*Thuja plicata*), yellow cedar (*Callitropsis nootkatensis*), western hemlock (*Tsuga heterophylla*), Douglas fir (*Pseudotsuga menziesii*), amabilis fir (*Abies amabilis*), mountain hemlock (*Tsuga mertensiana*), Sitka spruce (*Picea sitchensis*), and alder (*Alnus sp.*). Many of these trees reach very large dimensions and grow to great ages, forming the ancient or old growth forests of this ecozone. Variations in altitude account for the presence of widely contrasting ecosystems within the ecozone, ranging from mild, humid coastal rainforest to cool boreal and alpine conditions at higher elevations.

Watershed research has suggested that high levels of clearcut harvesting (90% of a watershed) caused relatively minor changes in peak flows (20% increase) and annual water yields (14%) that persisted for two years after harvesting (Hetherington 1982, 1987). In contrast, Hudson (2002) found that partial harvesting techniques resulted in dramatic increases in peak streamflow of 194% (variable retention, 82% harvest over 44% of the watershed) and 123% (strip shelterwood harvesting, 50% harvest over 32% of the watershed). Hudson suggested that increases were proportional to forest canopy removed, expressed as a percentage of the watershed area.

### 3.1.4 *Effects of Forest Management on Peak Flows*

A meta-analysis by Scherer (2001) suggested that harvesting can have a range of effects on peak flows at the basin level, including changes to instantaneous discharge, storm flow volume, and timing of runoff. Definition of peak flow often determines whether a change resulting from forest management can be detected. For example, for a paired watershed study in the Oregon Cascades Thomas and Megahan (1998) found that

> “peak flows were increased up to 90% for the smallest peak events on the clear-cut watershed and up to 40% for the smallest peak flows on the patch-cut and roaded watershed. Percentage treatment effects decreased as flow event size increased and were not detectable for flow with 2-year return intervals or greater on either treated watershed.”

### 3.1.5 *Effects of Forest Management on Timing of Peak and Low Flows*

Forest management activities can affect the timing of hydrological flows in a number of ways, but research from Canada suggests that these effects are variable, minimal and short-lived. Given the relationship between forest canopy removal and snowmelt, harvesting can have an effect on the timing of peak flow across all regions, particularly as snowmelt may be accelerated, causing larger and earlier peak flows (Winkler 1999). A review by Scherer and Pike (2003) suggested a maximum effect of 18 days advancement. Roads constructed for forest management have compacted surfaces that can increase surface flow, and cutbanks can transform subsurface flows into more rapid surface flows. These changes can deliver water to streams faster and sooner than subsurface flow pathways (reviewed by Reiter and Beschta 1995; Gucinski et al. 2001; Wemple, Jones, and Grant 1996). Cheng et al. (1975) noted that some management may delay peak flows by maintaining soil infiltration but closing some subsurface storm flow, thereby temporarily increasing the water storage capacity of the soil. Alternatively, the timing of low flow periods (when base flow dominates) has been found to be independent of the degree of basin disturbance. Sidle (2006) concluded that ignoring subsurface flow can introduce major errors in models of the timing of headwater storm runoff. Research suggests that changes in the timing of peak and low flows can result from forest management, with effects ranging from an advancement of 18 days to no change (Scherer and Pike 2003).

Much of the analysis of hydrologic response to forest management has focused on the first years or decade after management, often ignoring the pattern of hydrologic response over the full rotation. Some emerging concerns have been raised that young forest stands may transpire more water than older stands (Jones and Post 2004), possibly resulting in reduced water yields and low flows. Another emerging concern is translating small headwater stream research to basin-scale response (Alila and Beckers 2001). For example, data from the Lake States of the United States (Verry 2004) showed that when openings and young forests cover less than 60% of a basin, the peak flow changes are minimal compared to mature forests.

### 3.1.6 *Comparison with Alternative Land Uses*

It is well understood that forest watersheds function differently than urban or agricultural watersheds, due primarily to the existence and persistence of large perennial vegetation, both alive and dead. For a variety of reasons, these features provide for rapid infiltration, access through macropores to subsurface channels, and generally reduce the potential for surface runoff. Current forest management practices are generally much “lighter” than other land uses.

Of the 402.1 million hectares of forested land in Canada, the vast majority (93%) is publicly owned (77% provincial and 16% federal) (Natural Resources Canada 2009). The majority of federally owned forests are parks or other natural areas. Provinces have legislative authority over forest management at the provincial/territorial level. The remainder (7%) is on private property, held by more than 450 000 private land owners. Thus, while conversion of forests to alternative land uses can and does happen in Canada, it is relatively infrequent and is generally a local issue rather than a broad-scale national issue (which is the focus of this report), and it will not be addressed further.

### 3.1.7 *Quantity of Runoff and Streamflow from Managed Forest*

Generally, forest harvesting tends to increase annual water yields from forested watersheds, and may or may not change the timing and distribution of this runoff. Timber harvesting decreases interception loss and evapotranspiration and may modify snowmelt patterns. Increases in water yields decline with re-growth of the forest. Natural disturbance events such as wildfire or insect outbreaks can also result in changes to forest hydrology. Findings on runoff response have been highly variable across Canada. This can be attributed to a range of factors, including

- size and extent of watershed (scale dependence);
- size and extent of harvest and other management activities;
- topography;
- soil characteristics;
- geology;
- precipitation regime; and
- seasonal runoff events.

While some authors have speculated on the length of time a given effect may persist, few (if any) studies of sufficient time span to verify such speculations have been conducted.

## 3.2 Water Quality from Managed Forests

Concerns about changes in water quality resulting from forest management are considered to be of equal or greater importance than possible changes in water quantity. Water quality includes the physical, chemical, and biological character of the water, including sediments, dissolved chemicals (especially key nutrients), temperature, and dissolved oxygen concentrations (Ice 2007). In general, forest watersheds produce very high quality water due to the erosion protection provided by the forest vegetation, forest floor, and soils and the dominant subsurface flow pathways delivering water to streams and lakes. Concerns arise when disturbance agents, either natural or man-made, reduce or remove the effectiveness of forest watershed conditions, thereby lowering the quality of water (Ice 2007; Ice and Schoenholtz 2003).

Historically, water quality was adversely affected by forestry practices, but use of protective measures and best management practices (BMPs) in both the United States and Canada has significantly reduced the negative effects (McBroom et al. 2003; Ice 2004). BMPs include practices such as forested buffers and riparian management areas (RMAs), water bars (earthen mounds that divert water off skid trails), and adequately sized and spaced culverts (see *Canadian Watershed Handbook of Control and Mitigation Measures for Silvicultural Operation*, http://www.ncasi.org/programs/areas/forestry/canadian_program/watershed_mgmt/handbook.aspx). Olszewski and Jackson (2006) summarized six principles that can be used to design effective BMPs for forestry: (1) minimize bare ground and soil compaction; (2) separate disturbed soil from surface water; (3) separate fertilizer and pesticide applications from surface water; (4) inhibit hydraulic connections between bare ground and surface water; (5) provide a forested buffer around streams; and (6) engineer stable road surfaces and stream crossings.

### 3.2.1 *Sediment*

Sediment can be divided into fine suspended particles and bedload (larger, mostly settled or rolling particles). Turbidity, an optical measure of light transfer through water, is often related to suspended sediment. Key to understanding sediments in streams is the realization that some sediment is necessary to maintain ecological function, but that large increases in sediment loads are problematic (at least in the short term). Sediments are introduced to streams through erosion (both surface and stream bank) and landslides. Sediment loads in streams are influenced by water runoff pathways (surface or subsurface) and amounts (e.g., harvesting can reduce evapotranspiration, resulting in increased runoff and stream power to suspended channel sediments).

Watershed research across Canada suggests that management practices such as maintaining riparian management zones or buffers can keep sediment rates within the average for undisturbed watersheds (Christie and Fletcher 1999). Carefully conducted alternative harvesting practices such as shelterwood cuts without RMAs can also result in minimal increases in sediment loads to streams (Kreutzweiser and Capell 2001). Increased sediment rates have consistently been associated with road construction and maintenance, log landing sites, and skidder stream crossings (Krause 1982; Plamondon, Gonzalez, and Thomassin 1982; Kreutzweiser and Capell 2001; MacDonald, MacIsaac, and Herunter 2003), particularly in the short term (Prévost, Plamondon, and Belleau 1999).

### 3.2.2 *Dissolved Chemicals and Nutrients*

Shifts in concentrations of dissolved chemicals and key nutrients make up another significant component of water quality. A number of studies have examined the effects of forest harvesting on nutrients and have attempted to determine the factors that contribute to changes. Biogeochemical cycles can be affected through several mechanisms, including increases in soil temperatures and humidity after tree removal, changes in soil structure caused by equipment disturbance, alteration of nutrient sinks and sources, and post-harvest “net” precipitation patterns (Carignan and Steedman 2000). Export of nutrients such as phosphorous is closely related to soil erosion, and is therefore related to precipitation, soil types and landforms within a watershed (Putz et al. 2003; Chanasyk et al. 2003). Phosphorous loads have been reported to be related to clay content of soils (Evans et al. 2000) and topographic position of the disturbance within the watershed (e.g., upland, low lying, wetland).

In general, forest harvesting can produce a relatively small increase in nutrient loading to surface and/or subsurface flows. Depending on the soil types, nitrate nitrogen concentrations have been found to be higher in stream waters after hardwood harvesting, with no increase after conifer harvesting (Krause 1982). Nitrate concentrations commonly increase in soil water after harvesting, but declined to pre-harvest levels or lower within two to eight years post-harvest (Jewett et al. 1995; Feller and Kimmins 1984). Small but sometimes persistent changes (10-15 years post-treatment, Jewett et al. 1995) such as increases in phosphorous, potassium, iron, calcium, and magnesium have been detected in some studies. Changes in forest composition, such as a shift from conifer to red alder (*Alnus rubra*) can also affect nutrient concentrations due to symbiotic nitrogen fixation (Wigington et al. 1998).

Changes to water chemistry following disturbances have also been suggested to be related to catchment size and degree of disturbance (Carignan, D’Arcy, and Lamontagne 2000), with increased degree of disturbance and drainage ratio (basin area/water body volume) resulting in higher concentrations of total phosphorous, organic nitrogen, potassium, chloride, and calcium.

Interestingly, studies have suggested that overall width of riparian management areas has little effect on nutrient export (Prepas et al. 2001; Steedman 2000) from harvested areas.

### 3.2.3 *Temperature*

Water temperature is important to water quality because it affects other biologically relevant factors such as the metabolic rate of in-stream organisms, biochemical reactions, and the solubility of dissolved oxygen (Horne and Goldman 1984), as well as the environmental toxicity of some chemicals (Hondzo and Stefan 1994). As a consequence, water temperature affects the development and persistence of aquatic organisms (Eckert, Randall, and Augustine 1988). Water temperature is influenced by a range of factors, including groundwater inputs and exchange with the hyporheic zone[1], stream size (width and depth), stream water travel time, discharge rate, and amount of shade over the channel. Given time, surface waters tend to acclimate to the local environment.

The primary means by which harvesting affects stream temperature is through direct solar radiation, particularly as it is influenced by canopy removal (Brown 1969). Research has consistently found that maintenance (through RMAs) of above-stream canopy cover moderates changes in stream temperature (Lee and Smyth 2003; Beschta et al. 1987; Moring 1975; Patric 1980; Johnson and Jones 2000; Barton, Taylor, and Biette 1985; Gomi, Moore, and Dhakal 2006). Stream temperatures can also increase when debris flows scour gravel beds and expose channels to direct solar radiation (Levno and Rothacher 1967; Pollock et al. 2009).

### 3.2.4 *Dissolved Oxygen*

Dissolved oxygen (DO) concentrations are critical to aquatic communities and are an important measure of water quality. Oxygen is sparingly soluble in water but is essential for respiration by aquatic organisms, including fish. There are three mechanisms by which forest management can depress DO concentrations:

- Increased stream temperature reduces the solubility of oxygen in water and increases biochemical reaction rates.
- Biochemical oxygen demand (BOD) is increased by introducing oxidizable organic slash during timber harvesting.
- Movement of oxygen back into oxygen-depleted water (re-aeration) is reduced by impounding flow, usually due to slash deposits.

These problems can largely be avoided by using streamside management zones to limit introduction of slash to streams and by controlling increases in stream temperatures (Ice 1990). Feller (1974) measured DO concentrations related to clear-cut harvesting in southwestern British Columbia and Plamondon, Gonzalez, and Thomassin (1982) reported severely depressed DO levels for low gradient stream reaches in Quebec that were loaded with fresh slash (impounding flow).

### 3.2.5 *Silvicultural Chemicals*

Application of forest chemicals, including herbicides and insecticides, is probably the most controversial management activity conducted on forest watersheds. Use of herbicides can be an effective tool to control unwanted plants and may reduce water quality impacts compared to alternative treatments such as mechanical site preparation (Neary and Michael 1996). Controlling competition can greatly accelerate reforestation and growth of commercial trees. Concentrations of

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[1] The area under a stream channel or floodplain that readily contributes to and exchanges waters with a stream or other water body.

chemicals introduced into streams can be minimized by avoiding direct applications over waters and by drift control strategies (especially for aerially applied chemicals). A study of herbicide spray operations in Oregon reported that "no pesticide contamination levels at or above 1 ppb were found in any of the post-spray samples", even though samples were collected to coincide with when maximum contamination would be expected (Dent and Robben 2000).

While applications of these chemicals to forests tend to get a high level of public attention, the frequency and amounts of chemicals applied to forested areas is consistently very low. Of the 402.1 million hectares of forested land in Canada, approximately 160 million hectares (40%) is considered to be managed forests. Across all provinces and territories annually, a relatively small amount of forested lands receives treatment of pesticides or herbicides. In 2007, for example, 230 712 ha were treated with insecticides and 156 904 ha were treated with herbicides (Canadian Council of Forest Ministers 2009), representing 0.14% and 0.09% of commercial forests, respectively. Thus, while silvicultural chemical application to the forested land base can and does happen in Canada, it is relatively infrequent and is generally a local issue rather than a broad-scale national issue (which is the focus of this report), and it will not be address further.

### 3.2.6 *Forest Roads*

As has been noted, forest roads can have a significant effect on water quality, particularly as they relate to localized, short-term erosion and sedimentation rates (Krause 1982; Plamondon, Gonzalez, and Thomassin 1982; Kreutzweiser and Capell 2001; MacDonald, MacIsaac, and Herunter 2003; Prévost, Plamondon, and Belleau 1999). Forest roads provide essential access to forested areas and are necessary for forest management and the removal of fibre. However, without the use of proper BMPs, forest roads can be a problematic source of erosion and sediments. Road building and maintenance BMPs options, include debris control structures, mulching, seeding and stabilizing disturbed areas, and use of cofferdams or stream diversions around construction sites, to name but a few. Elliot (2010) assessed biofuels harvesting in the western U.S. and concluded that sediment losses might be reduced by removing unnecessary roads, enhanced erosion control practices for remaining roads, and reduced wildfire intensity.

### 3.2.7 *Natural Disturbances for Forest Water Quality*

Natural disturbances can often change water quality metrics far beyond changes resulting from harvesting practices. Wildfire and insect infestations can kill forest stands and remove riparian management areas, and may expose streams to increased sediment loads and stream temperatures (Ice, Neary, and Adams 2004; Ice and Schoenholtz 2003). Carignan, D'Arcy, and Lamontagne (2000) reported that wildfire disturbances produced much higher concentrations of nitrate and sulphate than harvested and control sites. Such effects are likely to persist until vegetative and hydrological recovery has occurred, which will vary depending on the climate, soils, and vegetation. These impacts may persist where wildfire results in loss of the forest floor and degradation of soils.

### 3.2.8 *Synthesis of the Quality of Runoff from Managed Forest*

Forest harvesting can negatively change sediment loads, nutrient export, water temperatures, and dissolved oxygen concentrations in streams and other receiving water bodies. However, potential changes are influenced by a range of factors, such as

- size and extent of watershed (scale dependence);
- size and extent of harvest;

- topography;
- soil characteristics;
- geology; and
- precipitation regime.

Research has consistently shown that sediment loads and stream temperature changes can be mitigated by using BMPs, especially the use of riparian management areas (RMAs). Changes to nutrient export tend to be biologically minor and relatively short-lived. Certain practices such as roads and landings present elevated risks of impact to sediment but there are BMPs to address those risks. Management impacts should be assessed against natural disturbance events that often cause much more significant changes in water quality. Sustainably managed forests with application of contemporary BMPs provide the best opportunity to maintain high water quality.

## 4.0 WATER PROFILE FOR MANUFACTURING OPERATIONS

This section describes the quantity of water associated with the manufacture of pulp and paper and of wood products. Because of the differences between the two manufacturing processes they are treated separately. Water in pulp and paper manufacture is discussed first, followed by wood products manufacture at the end of the section. Figure 4.1 shows the water profile of the Canadian pulp and paper industry. Each import and export vector contained in the Canadian manufacturing water profile will be covered in detail in this section.

### 4.1 Water Profile for Canadian Pulp and Paper Manufacturing, Overview

The Canadian pulp and paper industry withdraws approximately 1897 million cubic metres of water annually from surface and groundwater sources but the vast majority, 1790 million cubic metres, is reintegrated directly into the surface water cycle. The Canadian pulp and paper industry relies upon groundwater sources for only about 2% of their total water withdrawals. Consumptive water loss (the summation of evaporative losses from process operation and secondary wastewater treatment, water in solid residuals, and water in products) is 8.2% of the water input into the process. The amount of water in wood, recycled paper, imported pulp, and purchased chemicals is approximately 33% of the consumptive water losses for the Canadian pulp and paper industry countries. If these sources were considered water consumption credits (i.e., offsets to water losses), the water consumption impact of the Canadian pulp and paper industry would be reduced to approximately 5.5% of water from surface and groundwater sources.

### 4.2 Data Sources and Quality

High quality data for effluent discharge flows are available through a survey undertaken by the Forest Products Association of Canada (FPAC) of the entire Canadian pulp and paper industry. These data are collected biennially in FPAC’s Pulp and Paper Environment Survey, and the latest effluent survey data (for 2007) were used in the water profile calculations. Survey results underwent quality assurance/quality control at NCASI. FPAC survey respondents represent approximately 71% of pulp and paper production in Canada as of 2007. The Fisher Pulp&Paper Worldwide™ database was used to obtain effluent flows for mills not represented in the FPAC effluent database to achieve complete coverage for the Canadian pulp and paper industry (Fisher International, Inc. 2008). In addition, the Fisher Pulp&Paper Worldwide database was used to obtain production and effluent information on mills from one Canadian company who asked that their FPAC survey results not be used in studies because of data quality concerns. Mills included in both the FPAC and the Fisher Worldwide databases were compared to ascertain the accuracy of the Fisher Worldwide effluent data[2]. The average difference between total effluent flows for mills in both databases was 9.1%, with the Fisher effluent data being greater. This difference was deemed sufficiently small to justify using the Fisher Worldwide database to fill in any gaps in the water profile work where FPAC survey data were unavailable.

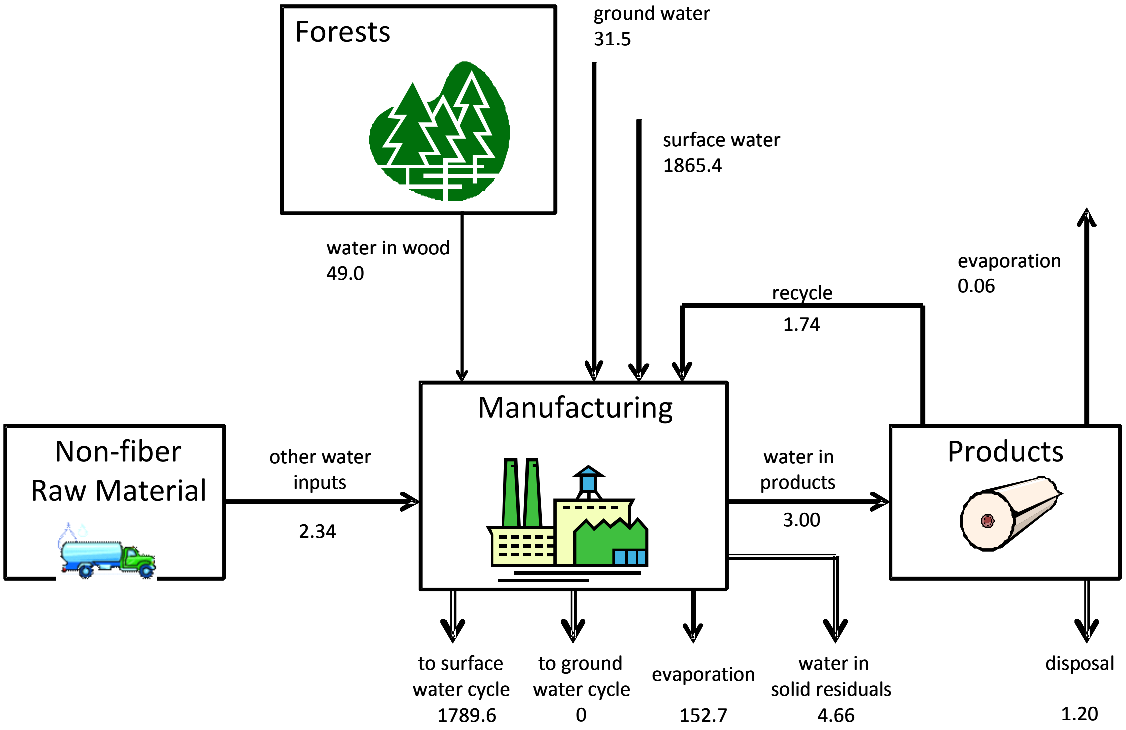

**Figure 4.1** 2007 Water Profile for the Canadian Pulp and Paper Industry (values in million $m^3$)[3]

FPAC survey respondents and the mills queried from Fisher Worldwide were categorized according to the NCASI classification scheme (Appendix A). For the water profile work, 350 operating days were assumed per year when extrapolating daily data from the Fisher database and other sources to annual amounts.

Table 4.1 shows the number of mills and production amounts considered in the water profile calculations. Total Canadian paper and paperboard production was estimated to be 28.5 million metric tons in 2006 (Pulp and Paper Products Council 2006), approximately 5% less than the amount

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[2] The accuracy of the Fisher Worldwide database was evaluated in a previous publication on water use within the North American pulp and paper industry (Bryant, Malcolm, and Woitkovich 1996). Water use data from 27 unbleached integrated mills were compared between the Fisher Worldwide database and a direct phone survey. The Fisher database mean for the 27 mills was 47 ±7 $m^3$/admt, while the mean from the phone survey was 45 ±7 $m^3$/admt.

[3] The inputs and outputs for the manufacturing block may not balance completely due to rounding of individual values.

in Table 4.1. Data from the Canadian Industrial Energy End-use Data and Analysis Centre (CIEEDAC), which used data from PPPC and FPAC to develop Canadian production estimates, reported that Canadian pulp and paper production was 27.7 million metric tons in 2007, approximately 8% less than the amount reported in Table 4.1. Since production amounts in Table 4.1 are slightly greater than the available estimates of total Canadian pulp and paper production, it can be assumed that the water profile calculations have essentially 100% coverage of the Canadian pulp and paper industry.

**Table 4.1** Numbers of Mills and Production Amounts Considered in the Canadian Water Profile Calculation, 2007

| Database | Number of Mills | Production (admt/year) |
|---|---|---|
| FPAC | 68 | 21,260,343 |
| Fisher | 49 | 8,744,779 |
| Total | 117 | 30,005,122 |

Only mills operating in 2007 were considered in the water profile calculation; mills that were closed or idle in 2007 were not considered. Table 4.2 shows the production categories for mills in the FPAC database and mills queried from the Fisher Pulp&Paper Worldwide database. A majority of the production contribution from Canadian mills was from mechanical pulp mills and bleached kraft market pulp mills.

**Table 4.2** Production Contributions from FPAC Survey Mills and Mills Queried from Fisher Worldwide, 2007

| FPAC | | | Fisher | | |
|---|---|---|---|---|---|
| Category | Number of Mills | Production (admt/year) | Category | Number of Mills | Production (admt/year) |
| MECH | 25 | 7,674,503 | MECH | 9 | 1,842,119 |
| BKP | 16 | 5,655,134 | BKP | 5 | 1,834,896 |
| BKO | 7 | 3,665,687 | BKI | 2 | 1,073,211 |
| BCTMP | 7 | 1,853,554 | RCTR | 6 | 857,705 |
| SULD | 2 | 592,097 | SC | 4 | 677,621 |
| UK1 | 2 | 579,515 | RBOX | 6 | 619,736 |
| DNWS | 1 | 439,098 | BKO | 1 | 438,937 |
| SULP | 1 | 262,660 | NIO | 6 | 306,359 |
| RCTR | 1 | 158,078 | DIP | 2 | 205,824 |
| RBOX | 2 | 145,909 | DNWS | 1 | 190,671 |
| NIO | 3 | 118,358 | NIF | 1 | 171,777 |
| DTF | 1 | 115,750 | SULD | 1 | 164,955 |
| | | | BCTMP | 1 | 155,316 |
| | | | UK2 | 1 | 108,274 |
| | | | DTF | 2 | 78,109 |
| | | | RTF | 1 | 19,269 |
| Total | 68 | 21,260,343 | Total | 49 | 8,744,779 |

NOTE: See Appendix A for category definitions.

## 4.3 Approach

The general approach pursued to develop the manufacturing portion of the water profile was to generate independent estimates of each water import and export vector wherever possible. In most cases this was possible. However, reliable information on water intake from surface and groundwater sources is not available because most mills do not measure water intake flows directly. Fortunately, water discharges in the form of treated effluents typically represent greater than 90% of mill water use and, in most cases, are directly measured. These effluent data are of high quality and, combined on a mill-by-mill basis with estimates of other water exports and imports, were used to calculate surface and groundwater imports. Water consumption (i.e., water lost to evaporation or exported with solid residuals or products) was determined as a function of water intake. Thus, it was necessary to use an iterative calculation procedure for closing the water balance for each mill. The procedure used is described in detail in Appendix B. The material herein is organized to first detail directly calculated estimates of water imports and exports. Those sections are followed by discussions of surface and groundwater intake and consumptive water loss calculations.

The water contents of purchased fossil fuels and stormwater managed outside mills' wastewater treatment systems are not included in this profile. The amount of water contained in fossil fuels is expected to be small. The primary fossil fuels combusted at Canadian pulp and paper mills and wood products facilities are residual fuel oil and natural gas, which contain little or no water. Stormwater is not considered because it is highly variable, site-specific, and not expected to be a large contributor to total mill water balances when averaged throughout the year.

## 4.4 Sources of Fresh Water and Disposition of Wastewater

Water source information (i.e., river, lake, municipal, etc.) was queried from the Fisher Pulp&Paper Worldwide™ database (Fisher International, Inc. 2008). Figure 4.2 shows water intake information for the Canadian pulp and paper industry.

Effluent disposition information (i.e., river, lake, municipal, etc.) was queried from the Fisher Pulp&Paper Worldwide™ database (Fisher International, Inc. 2008). When effluent volumetric data were available from the FPAC survey, water destination type was queried from Fisher but effluent amounts were taken from FPAC survey data. Figure 4.3 shows the effluent disposition of the Canadian pulp and paper industry. Most pulp and paper mill effluent is discharged to river systems. It was assumed that no effluent directly enters the groundwater aquifer and that all effluent leaving pulp and paper mills and wood products facilities enters the surface water cycle.

## 4.5 Effluent Flows from Pulp and Paper Mills

Effluent flows are categorized according to whether they originate from process use or non-contact cooling water use. Effluent flow statistics for mills included in the water profile are given in Table 4.3. The data show that the amount of non-contact cooling water discharged from Canadian pulp and paper mills represents approximately 13% of total effluent flow. This is likely low biased because a number of mills reuse cooling water internally to supply process water needs. Data are not available on the extent of cooling water reuse for process application within the Canadian industry. Table 4.4 shows cooling water discharge as a percentage of total effluent, arranged by production category.

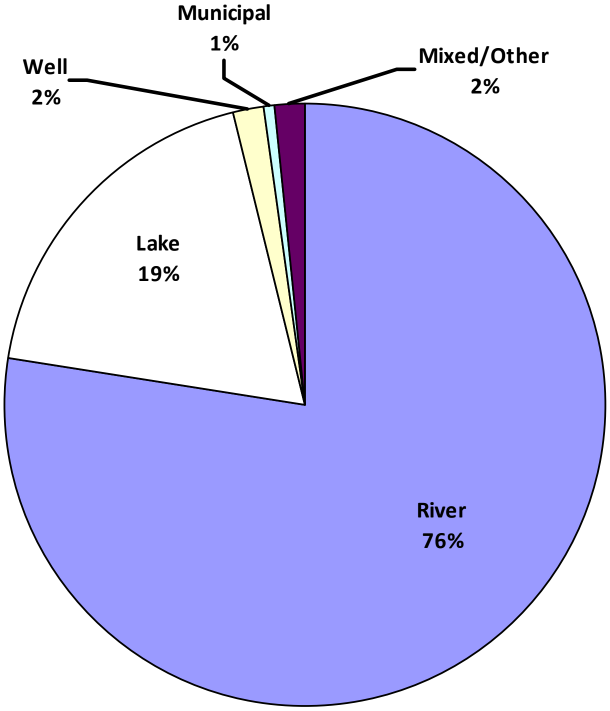

**Figure 4.2** Water Source Information for the Canadian Pulp and Paper Industry

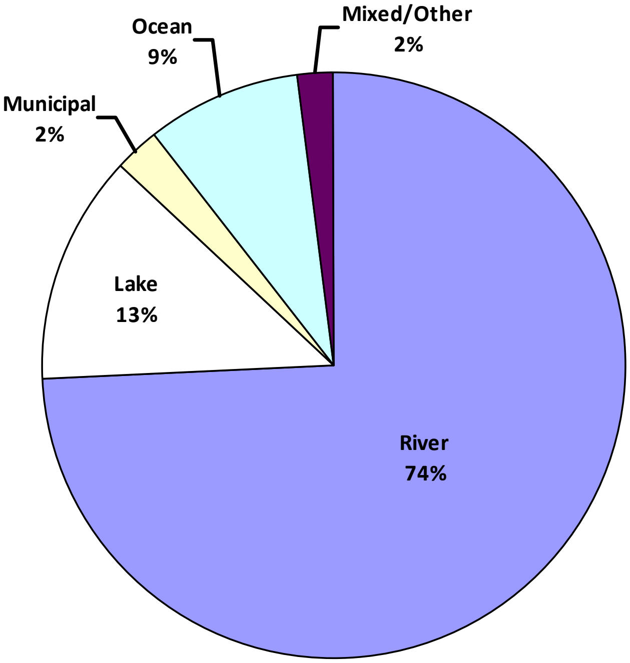

**Figure 4.3** Effluent Destination by Volume for the Canadian Pulp and Paper Industry

**Table 4.3** Pulp and Paper Effluent Volumes and Disposition

| FPAC | | | Fisher | | |
|---|---|---|---|---|---|
| Category | Volume[a] | % of FPAC Total | Category | Volume[a] | % of Fisher Total |
| Total cooling water | 182.7 | 13.6 | Total cooling water | 46.50 | 10.4 |
| Total process water | 1,159 | 86.4 | Total process water | 401.9 | 89.6 |
| Total | 1,341 | | Total | 449.0 | |
| Total (FPAC and Fisher) | 1,790 | | | | |

[a] millions of cubic metres.

**Table 4.4** Pulp and Paper Effluent Volumes by Production Category, 2007

| | FPAC | | | | Fisher | | | |
|---|---|---|---|---|---|---|---|---|
| Category | Effluent Flow[a] | Effluent Flow, %[b] | Non-contact Cooling Water Flow[a] | Non-contact Cooling Water Flow, %[c] | Effluent Flow[a] | Effluent Flow, %[b] | Non-contact Cooling Water Flow[a] | Non-contact Cooling Water Flow, %[c] |
| BCTMP | 28.3 | 2.4 | 3.70 | 11.5 | 12.3 | 3.1 | 1.32 | 9.7 |
| BKO | 241.3 | 20.8 | 72.0 | 23.0 | 23.8 | 5.9 | 5.30 | 18.2 |
| BKI | - | - | - | - | 55.1 | 13.7 | 0.00 | 0.0 |
| BKP | 450.7 | 38.9 | 47.4 | 9.5 | 119.8 | 29.8 | 16.30 | 12.0 |
| DIP | - | - | - | - | 1.0 | 0.2 | 0.00 | 0.0 |
| DNWS | 11.8 | 1.0 | 0.0 | 0.0 | 2.1 | 0.5 | 0.13 | 5.9 |
| DTF | 6.4 | 0.6 | 0.0 | 0.0 | 1.1 | 0.3 | 0.00 | 0.0 |
| MECH | 308.9 | 26.7 | 31.6 | 9.3 | 89.8 | 22.3 | 17.22 | 16.1 |
| NIF | 0.0 | 0.0 | 0.0 | | 2.1 | 0.5 | 0.00 | 0.0 |
| NIO | 6.4 | 0.6 | 0.0 | 0.0 | 4.6 | 1.1 | 0.00 | 0.0 |
| RBOX | 0.8 | 0.1 | 0.0 | 0.0 | 8.0 | 2.0 | 0.66 | 7.6 |
| RCTR | 1.5 | 0.1 | 0.0 | 0.0 | 11.1 | 2.7 | 0.00 | 0.0 |
| RTF | - | - | - | - | 2.6 | 0.7 | 0.53 | 16.7 |
| SC | - | - | - | - | 7.4 | 1.8 | 3.71 | 33.3 |
| SULD | 48.3 | 4.2 | 26.6 | 35.5 | 51.7 | 12.8 | 1.32 | 2.5 |
| SULP | 22.4 | 1.9 | 0.0 | 0.0 | - | - | - | - |
| UK1 | 31.7 | 2.7 | 1.3 | 4.1 | - | - | - | - |
| UK2 | - | - | - | - | 9.3 | 2.3 | 0.00 | 0.0 |
| Total | 1158.5 | 100.0 | 182.7 | 13.6 | 401.9 | 100.0 | 46.50 | 10.4 |
| Total (FPAC+Fisher) | 1560.4 | | 229 | 12.8 | | | | |

NOTE: see Appendix A for category definitions.

[a] millions of cubic metres

[b] percent of total effluent (may not sum to 100% due to rounding)

[c] percent of cooling water flow relative to total (effluent + cooling water) effluent flow

## 4.6 Water Content in Wood Chips

Moisture content for wood chips can be reported on either a dry mass basis or a wet mass basis. All reported moisture contents for wood chips in this work are based upon a wet mass basis. Moisture content varies among tree species, tree age, geographical location, season, and duration after harvesting, among other factors (Kellomäki 2000). For example, average moisture contents in birch trees in Finland range from 39% during the summer when transpiration from leaves is at a maximum to 48% in the spring when the trees are leafless but the root systems are actively conducting water to the stems. Typical moisture contents of fresh sapwood and heartwood for some North American softwoods and hardwoods are reported in Table 4.5 (FPL 1999). An average moisture content of 50% (wet mass basis) for wood chips is used in the water profile calculations for the Canadian pulp and paper industry.

**Table 4.5** Moisture Contents[a] of Fresh Sapwood and Heartwood from Common North American Softwoods and Hardwoods

| Softwoods | Sapwood | Heartwood | Hardwoods | Sapwood | Heartwood |
|---|---|---|---|---|---|
| Red spruce | 56 | 25 | Sugar maple | 42 | 39 |
| White spruce | 56 | 25 | Paper birch | 42 | 47 |
| Black spruce | 56 | 25 | American beech | 42 | 35 |
| Sitka spruce | 59 | 29 | Yellow popular | 51 | 45 |
| Red pine | 57 | 24 | American sycamore | 57 | 53 |
| Lodgepole pine | 55 | 29 | Quaking aspen | 53 | 49 |
| Loblolly pine | 52 | 25 | White oak | 44 | 39 |
| Longleaf pine | 51 | 24 | Northern red oak | 41 | 44 |
| Douglas fir | 53 | 27 | | | |
| Eastern hemlock | 54 | 49 | | | |

SOURCE: FPL 1999

[a] percent, wet mass basis

It is necessary to know total process yield to calculate water inputs with wood chips on a specific water usage basis (e.g., $m^3$ water/admt of product). Typical process yields are shown in Table 4.6 and were applied on a mill-by-mill basis according to the NCASI classification scheme (Appendix A) to estimate water input with wood chips.

**Table 4.6** Overall Product Yield Used to Calculate Water Contribution from Wood Chips

| Classification | Overall Yield[a] | Moisture Content of Raw Material[b] | Water Content of Raw Material[c] |
|---|---|---|---|
| BKI, BKD, BKO, BKP, SULD, SULD | 47 | 0.5 | 1.92 |
| UK1, UK2 | 55 | 0.5 | 1.64 |
| SC | 80 | 0.5 | 1.13 |
| MECH, BCTMP | 93 | 0.5 | 0.97 |
| DIP, DTF, DNWS, RCTR, RBOX | 87 | 0.1 | 0.11 |
| NIF, NIO | 100 | 0.1 | 0.10 |

SOURCE: based on NCASI 2008a

NOTE: See Appendix A for category definitions.

[a] percent, based on final product

[b] fraction, wet mass basis

[c] $m^3$ water/admt

The contribution of water contained in wood can be calculated based on final product by considering wood moisture content and total yield (Equation 1), assuming a 1 metric ton (mt) product basis and that 1 $m^3$ water ≈ 1 mt water. The conversion factor in Equation 1 is to convert from metric tons of bone dry product to metric tons of air-dried product.

$$W = \frac{M \cdot (1/Y)}{1.11 \cdot (1 - M)} \qquad \text{(Eq 1)}$$

where: $W$ = contribution of water contained in wood ($m^3$/admt)
$Y$ = overall yield (fraction)
$M$ = moisture content (wet fraction)

Yields from Table 4.6, based upon pulp production type (NCASI 2008a) and typical moisture contents in raw materials, are used with Equation 1 to calculate the water contribution from raw material.

## 4.7 Water in Non-Fibre Raw Materials

This section considers the addition of water contained in purchased non-fibre materials such as process additives delivered in aqueous slurry form to pulp and papermaking operations. Only the water content of the actual material is considered. Water used to produce offsite manufactured raw materials is not considered.

Pulp and paper mills purchase a variety of chemicals that are delivered in slurry form (i.e., containing the active chemical in a solution of water). The amount of water contained in purchased chemicals used to manufacture pulp was calculated on a mill by mill basis based upon process type, average chemical usage according to process type, and typical water contents in chemical slurries. Individual mills were grouped into five general categories when determining the water contained in purchased chemicals used by mills: unbleached chemical pulp (UK1, UK2, SC); bleached chemical pulp (BKI, BKP, BKO); sulphite (SULD, SULP); mechanical (MECH, BCTMP); and recycle (DIP, DTF, DNWS, RCTR, RBOX).

The data needed to calculate the water contribution from paper machine purchased chemicals on a mill by mill basis are unavailable. Therefore, the water contribution from purchased chemicals in the paper machine area is calculated on an industry aggregate basis. Figure 4.4 illustrates the general scheme used to calculate the water content in purchased chemicals for the Canadian pulp and paper industry.

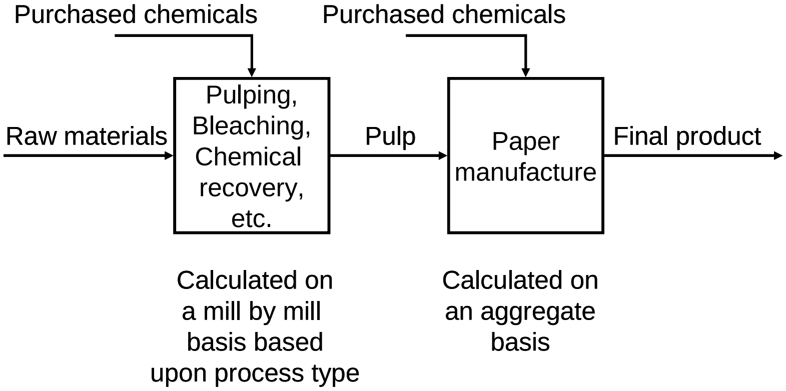

**Figure 4.4** Scheme Used to Calculate Water Contribution from Purchased Chemicals

### 4.7.1 *Water Content in Purchased Chemicals Used in the Manufacture of Pulp*

Two pieces of information are needed in order to estimate the amount of water entering pulp mills via purchased chemicals: typical water contents and typical application rates of the chemicals.

Caustic soda (sodium hydroxide, NaOH) is used as a pulping chemical in chemical pulp mills, as an oxidative extraction agent in pulp bleaching, and for pH control. The commercial methods for producing caustic soda are mercury or diaphragm cell electrolysis and membrane cell cation exchange (Gullichsen and Fogelholm 1999). Caustic soda produced by the mercury cell method is of high concentration (60% NaOH by weight). It is diluted to 50% concentration and shipped to pulp mills. The diaphragm cell method produces dilute caustic soda contaminated with substantial amounts of chloride. Chloride is crystallized from the dilute caustic solution, the solution is concentrated to 50% by evaporation, and the slurry is shipped to pulp mills. Caustic soda produced by the membrane cell method produces very pure sodium hydroxide at 10 to 20% concentration. If transportation distances are small, it is shipped to the pulp mill at that concentration; otherwise it is concentrated to 50% by evaporation and then shipped. Caustic production distribution was 66% diaphragm cell, 5% mercury cell, and 29% membrane cell in Canada as of January 1, 2008 (Chlorine Institute Inc. 2007).

Hydrogen peroxide ($H_2O_2$) is used as a brightening agent in mechanical and deinking processes, and is used in chemical pulp mills either in a stand-alone pressurized peroxide bleaching stage or as reinforcement to an alkaline extraction stage. It is usually manufactured using the anthraquinone process, and is shipped and stored as a 50% aqueous solution before being used at a mill (Gullichsen and Fogelholm 1999).

Sodium silicate ($NaSiO_3$) is used as a buffer, an anticorrosive, an aid to help prevent alkali darkening, and in scale control. It may be used in deinking in the re-pulping and floatation areas as a dispersant, buffer, emulsifier, and to aid in ink collection. For deinking mills that use hydrogen peroxide brightening, sodium silicate is used as a peroxide stabilizer, as a buffer, and to help prevent alkali darkening (PQ Corporation 2008a). Sodium silicate is typically shipped to mills in solution form with water content ranging from 55 to 67.3% (PQ Corporation 2008b).

Magnesium sulphate ($MgSO_4$) is used as a peroxide stabilizer in peroxide brightening of mechanical pulp and as a cellulose protector in oxygen delignification. It can also be an additive in kraft bleaching for mills that have a peroxide bleaching stage or a peroxide-reinforced extraction stage. Magnesium sulphate is typically shipped to mills in slurry form with water content of solution ranging from 73 to 80% (PQ Corporation 2008c).

Sulphuric acid ($H_2SO_4$) is used as an acidification agent in crude tall oil plants or chlorine dioxide plants, and is used to adjust pH in bleach plants and boiler feedwater systems. Concentrated sulphuric acid is typically shipped to mills with 2% water content.

Talc is used as a filler in the paper machine area and for stickie adsorption in deink mills (Estes 1990). Water originating from talc used in pulping operations is calculated herein, while water originating from talc used as a paper machine additive is covered in Section 4.7.2. Talc is delivered in a slurry, as pellets, or as dry powder. In slurry form the dry solids content of talc ranges from 66.5 to 67.0 % (Ahonen 1985). In pellet form the solid content ranges from 87 to 97% (Lehtinen 2000).

Table 4.7 compiles the water contents of major water-bearing chemicals used in the manufacture of pulp. Besides water contents, typical application rates are necessary in order to estimate the water contributions of purchased chemicals used to manufacture pulp. Table 4.8 contains typical amounts of chemicals used according to process type (IPPC 2001). The exception is sulphuric acid values for unbleached and bleached kraft, for which no data were available. Values for sulphuric acid were taken from Valeur et al. (2000) assuming onsite crude tall oil manufacturing for which sulphuric acid is typically used for acidulation. All values in the table are expressed as 100% active chemical and not as commercial solutions containing various amounts of water. Chemicals listed in Table 4.8 that are not explicitly listed in Table 4.7 either arrive at the mill in dry or gaseous form, or do not materially impact the overall amount of water in non-fibre raw materials for the Canadian pulp and paper industry.

**Table 4.7** Water Contents of Major Water-Bearing Purchased Chemicals Used in the Manufacture of Pulp

| Additive | Water Content (% of delivered slurry) |
|---|---|
| Sodium hydroxide (NaOH) | |
| membrane cell | 80 - 90 |
| electrolysis cell | 50 |
| Hydrogen peroxide ($H_2O_2$) | 50 |
| Sodium silicate ($NaSiO_3$) | 55 - 67.3 |
| Magnesium sulphate ($MgSO_4$) | 73 - 80 |
| Sulphuric acid ($H_2SO_4$) | 2 |
| Talc | 3 - 34 |

**Table 4.8** Typical Purchased Chemical Amounts[a] Used in Pulping and Bleaching

| Chemical | Unbleached Kraft | Bleached Kraft | Magnesium-Sulphite | GWP[b] | Mechanical | CTMP[c] | Recycle |
|---|---|---|---|---|---|---|---|
| NaOH | 10 - 20 | 25 - 50 | 10 - 40 | 0 - 10 | 0 - 10 | 0 - 13 | 10 - 20 |
| $O_2$ | | 5 - 25 | 5 - 15 | | | | |
| $NaClO_3$ | | 20 - 50 | | | | | |
| EDTA or DTPA | | 0 - 4 | 0 - 3 | 0 - 5 | 0 - 5 | 0 - 5 | 2 - 3 |
| S | | | 20 - 40 | | | | |
| $SO_2$ | | 2 - 10 | 0 - 70 | | | 0 - 10 | |
| $H_2O_2$ | | 2 - 30 | 10 - 40 | 0 - 15 | 0 - 20 | 0 - 20 | 5 - 25 |
| $O_3$ | | 0 - 5 | 0 - 5 | | | | |
| $MgSO_4$ | | 0 - 3 | | | | | |
| CaO | 5 - 10 | 5 - 10 | | | | | |
| MgO | | | 15 - 25 | | | | |
| $H_2SO_4$ | 0 - 8 | 0 - 13 | | | | | 8 - 10 |
| $NaHSO_3$ | | | | 0 - 12 | 0 - 12 | | 6 - 10 |
| $NaSiO_3$ | | | | 0 - 15 | 0 - 15 | 0 - 15 | 20 - 30 |
| $Na_2SO_3$ | | | | | | 25 - 30 | |
| Soap | | | | | | | 5 - 8 |
| Talc | | | | | | | 10 - 15 |

SOURCE: IPPC 2001

[a] ranges in kg per air dry (ad) metric ton pulp; all chemicals expressed as 100% effective chemical, not as commercial solutions containing various amounts of water

[b] groundwood pulping

[c] chemi-thermomechanical pulping

Table 4.9 shows average water contents from purchased chemicals for pulp production on a specific production basis. The numbers in Table 4.9 were calculated using the values in Tables 4.7 and 4.8. Where ranges were given, the mean of the range was used as an average value. The electrolysis methods used to generate sodium hydroxide were assumed to be the sole sources of sodium hydroxide manufacture when estimating the water content of purchased caustic soda. Talc is assumed to be used in slurry form with a dry solids content of 67%.

**Table 4.9** Water Contents from Purchased Chemicals for Pulp Production

| Production Type | kg $H_2O$/admt | $m^3$/admt |
|---|---|---|
| Unbleached Kraft[a] | 15 | 0.02 |
| Bleached Kraft[b] | 60 | 0.06 |
| Sulphite[c] | 50 | 0.05 |
| Mechanical[d] | 25 | 0.02 |
| Recycle[e] | 77 | 0.08 |

NOTE: See Appendix A for category definitions.

[a] UK1, UK2, SC

[b] BKI, BKP, BKO

[c] SULD, SULP

[d] MECH, BCTMP

[e] DIP, DTF, DNWS, RCTR, RBOX

Given the water contents of purchased chemicals used for pulp production (Table 4.9), the contribution of water in purchased chemicals for the Canadian pulp and paper industry in 2007 is calculated to have been 1.37 million cubic metres of water.

### 4.7.2 *Water Content in Purchased Chemicals in the Paper Machine Area*

Relevant statistics for paper machine additives could only be found for the European pulp and paper industry. In 2007, 14.8% of the total raw material used in paper production in the European paper industry originated from non-fibrous materials (CEPI 2008). As more paper mills switch from acid to alkaline operations, it is expected that the use of alum will continue to decrease and that $CaCO_3$ usage will become more prevalent at the expense of kaolin and talc. The latest CEPI statistics on non-fibrous materials in paper products (Table 4.10) show this to be the case.

**Table 4.10** Non-Fibrous Material Usage in Paper Products in Europe[a]

| Material | 1991 (%) | 2007 (%) |
|---|---|---|
| Clays | 40.1 | 23.6 |
| Calcium carbonate | 28.6 | 49.4 |
| Starches | 10.4 | 11.4 |
| Other | 20.9 | 15.4 |

SOURCE: CEPI 2008

[a] percentage of total non-fibrous material use

Laufmann (1998) surveyed global filler and pigment use in the paper industry. A total of 19.5 million tons of fillers and pigments were used in 1995, and the usage breakdown is given in Table 4.11.

**Table 4.11** World Pigment Usage in Paper and Board, 1995

| Filler or Pigment | Chemical Formula | Percentage |
|---|---|---|
| Clay or kaolin | $Al_4(OH)_8(Si_4O_{10})$ | 46 |
| Ground calcium carbonate | $CaCO_3$ | 28 |
| Talc | $3MgO \cdot 4SiO_2 \cdot H_2O$ | 12 |
| Precipitated calcium carbonated | $CaCO_3$ | 11 |
| Others | | 3 |

SOURCE: Laufmann 1998

The preferred method of shipping ground calcium carbonate (GCC) filler is in slurry form, with dry solids contents ranging from 64 to 78% (Laufmann 1998; also see http://www.omya-na.com/B2BShrtPr.nsf/wmdw/807C0943AB7AE1A585256E24000CBED0?OpenDocument). More than 90% of the natural calcium carbonate used in the paper industry is delivered in slurry form (Lehtinen 2000). Kaolin is usually shipped as a slurry with dry solids contents ranging from 66 to 71% (Lehtinen 2000; also see http://www.thielekaolin.com/images/thieleimages/PaperClayProp.pdf). Precipitated calcium carbonate (PCC) is delivered in slurry form and has dry solids contents of 71 to 75% (Lehtinen 2000; also see http://www.imerys-paper.com/products/pcc/opti-cal-400.html). Talc is delivered as slurry, pellets, or dry powder. In slurry form its dry solids content ranges from 66.5 to 67.0% (Ahonen 1985); in pellet form its solid content ranges from 87 to 97% (Lehtinen 2000). Titanium dioxide slurries have dry solids contents ranging from 65 to 73% (ibid.). Latex binders are supplied in dispersions with 50% dry solids content. Water soluble binders such as starches are supplied as dry powders, which are slurried on site (ibid.). Table 4.12 summarizes the water contents of the most prevalent paper machine additives.

**Table 4.12** Water Contents of Major Paper Machine Additives

| Additive | Water Content[a] |
|---|---|
| Ground calcium carbonate | 22 - 36 |
| Kaolin | 29 - 34 |
| Precipitated calcium carbonate | 25 - 29 |
| Talc | |
| slurry | 33 - 33.5 |
| pellet | 3 - 13 |
| Titanium dioxide | 27 - 35 |
| Latex binder | ~50 |
| Starches | dry |

[a] percent of delivered slurry

Canadian paper and paperboard production was 30.0 million metric tons in 2007 (Table 4.1). If it is assumed that 14.8% of the raw material used in the production of paper and paperboard originates from non-fibrous materials (the same as in Europe, based upon CEPI statistics for 2008), that the percent usage of the types of additives is the same as in Europe (Table 4.10), and that the average water contents of the major additives is the average of the upper and lower ranges of water contents (Table 4.12), the water originating from paper machine additives can be calculated to be 0.97 million $m^3$/yr. The calculations assume that the water contribution from the "Other" additives category in Table 4.10 is zero because of lack of information on what materials comprise the category. If talc use within the paper machine area is classified in the "Other" category, and it arrives at the mill in slurry form, the water contribution from the "Other" category could be up to 0.25 million $m^3$/yr. Filler usage appears to be somewhat higher in Europe than in North America, so the estimated water contribution from paper machine additives could be high as well. Laufmann (1998) provided global statistics on filler loading levels for xerographic copy paper. The loading levels in Europe ranged from 12 to 28%, with an average of 20%. In North America, loading levels ranged from 10 to 15%, with an average of 13%. Unfortunately, statistics comparing filler loading in different geographical regions for all paper types were not provided, so conclusions about overall filler usage comparisons between Europe and North America cannot be drawn.

Table 4.13 combines the contributions of water from purchased chemicals used in the manufacture of pulp and water from purchased chemicals used in the paper machine area. It is estimated that 2.34 million cubic metres of water were imported to pulp and paper facilities in the Canada from purchased chemicals in 2007.

**Table 4.13** Water Contents of Purchased Chemicals for the Canadian Pulp and Paper Industry, 2007

| Chemical Use | Water (million $m^3$) |
|---|---|
| Water in purchased chemicals used in pulping | 1.37 |
| Water in purchased chemicals used in paper machine area | 0.97 |
| Total | 2.34 |

## 4.8 Water in Recycled Fibre

Two types of statistics are reported for recycled fibre: recovered paper utilization rate and recovery rate. The recovered paper utilization rate is the amount of recovered paper used as raw material in the paper industry as a percentage of total paper production. The recovery rate is the amount of recovered paper for material recycling as a percentage of paper usage (Göttsching and Pakarinen 2000). The utilization rate can be less than the recovery rate if large exports of recovered paper and paperboard leave the country. For example, within Europe the utilization rate is approximately 82% of the recovery rate because of exports of recovered paper to counties outside of Europe (CEPI 2008). For water profile calculations, the utilization rate is the pertinent statistic to employ. The Canadian recovery rate was 58% of paper consumed in 2007 but no statistics could be found on Canadian utilization rate (FPAC 2009). It is assumed that the Canadian utilization rate is equivalent to recovery rate for the water profile calculations. In addition to utilization rate, knowledge of the moisture content of recovered fibres is necessary to calculate the amount of water in recycled fibre. In Central Europe, typical moisture contents of commonly recovered paper grades are between 6 and 13% (Göttsching and Pakarinen 2000) and vary due to climatic conditions (i.e., relative humidity at the collection site). An average moisture content of 10% is used in the water profile calculations for the Canadian industry. Canadian paper and paperboard production was 30.0 million metric tons in 2007 (Table 4.1). Assuming that 58% of the 30.0 million metric tons were utilized and that the average moisture content of the recovered paper was 10%, the amount of water contained in recycled fibre entering pulp and paper mills amounts to 1.75 million $m^3$. Miner (2006) reviewed available information for forest products half-lives. Paper and paperboard products have half-lives ranging from 1 to 6 years, and wood products have half lives ranging from 16 to 100 years, depending upon the product. Based upon the relatively short half-lives of paper and paperboard products, it is assumed that their product dispositions can be calculated statically without considering time-dependent behaviour.

## 4.9 Water Contents in Solid Residuals

A number of different types of solid residuals are generated during production of pulp and paper products. These can include pulping rejects, treatment plant residuals, and inorganic wastes such as lime mud, slaker grits, and wet power boiler ash. The residuals generation rate is dependent on mill type, with deinked mills generating two to three times the solid residuals of other types of mills on a per ton of product basis. Two pieces of information are necessary to estimate the amount of water leaving pulp and paper manufacturing in solid residuals: solid residuals generation rates and typical water contents of solid residuals.

A research study classified generation and management of solids residuals within the Canadian pulp and paper industry in 1995 (Reid 1998). A more targeted study conducted in 2002 served as a follow-up to the original 1995 survey and focused upon solid residuals requiring disposal versus solid residuals effectively used within the mill, e.g., woody residue used for energy recovery and recycle of scrap material (Elliott and Mahmood 2005). FPAC collects information on solid residual generation in their Pulp and Paper Environment Survey, and data are available for 2007. Solid residual generation rates on a dry mass basis from the FPAC survey were the primary source of data used in the water profile calculations. Calculated values in the water profile work were compared with previously reported results on solid residual generation within the Canadian pulp and paper industry to ensure consistency among the studies (Reid 1998; Elliott and Mahmood 2005).

Current solid residual generation rates and management practices for wastewater treatment and deinking residues from the Canadian pulp and paper industry were quantified by Mahmood and Elliott (2009). The production-weighted mean of dewatered cake solids of combined wastewater treatment residuals was found to be 29.4%. A moisture content of 70.6% (100% - 29.4%) was used for all combined wastewater treatment residuals in the water profile calculations (Mahmood and Elliott 2009).

Ash generation from power boilers was 684,000 metric ton (dry) in 2002 (Elliott and Mahmood 2005). Sources of ash are primarily power boiler bottom and fly ash, with ash collected from electrostatic precipitator catches from recovery boilers representing only 1% of the total generation rate (Elliott and Mahmood 2006). The moisture content of power boiler ashes is highly variable. Ashes from systems that employ dry ash removal and transportation have essentially no water content. Many ash collection systems add water to cool the ash and reduce dusting problems. Other systems use a wet bottom furnace where the hot ash is combined with recirculation water and sent to a settling pond or treatment system (Campbell 1990). Mockridge (2000) presented results from a power boiler ash survey conducted to collect ash handling and disposal practices in North American pulp and paper mills. Results comprised 67 power boilers from 29 companies and 39 mills. Of the 67 power boilers, 39 (61% of the total) had wet ash systems. Naylor and Schmidt (1989) examined the fertilizer properties of wood ash and presented the moisture content of one wet wood ash as 28%. Assuming that 61% of the ash handling systems are wet ash systems and that the average moisture content of wet ash is 28%, the average moisture content of all ash can be estimated to be 19%.

Sanchez and Tran (2005) reviewed the current treatment of lime slaker grits and green liquor dregs. Slaker grits typically have a moisture content of approximately 75%. The most common method for dregs dewatering is use of a precoat style vacuum drum filter using lime mud as a precoat, and these type of washers discharge solids with approximately 50% moisture content (ibid.). Lime mud discharged from lime mud filters has moisture contents of 15 to 20% for modern filters and 35 to 40% for older units (Jacobs Engineering and IPST 2006).

Folk and Campbell (1990) examined the physical and chemical properties of log yard trash, which is composed primarily of wood fines, hog fuel bark and wood, and rocks. Using their average moisture content from wood fines and typical moisture contents for hog fuel bark and wood, the average moisture content of log yard trash can be calculated to be 44%.

Secondary fibre rejects have a moisture content of approximately 65% (Doraiswamy et al. 1996; Muratore 1998), or 35% if the rejects are compacted (Muratore 1998). A moisture content of 65% was used for all secondary fibre rejects, paper mill rejects, and virgin fibre pulping rejects.

The moisture content of all other entries in the miscellaneous solids residual category was assumed to be 65%. Table 4.14 compiles the moisture contents of individual solid residual streams used in the water profile work.

**Table 4.14** Moisture Contents of Individual Residual Streams

| Solid Residual | Moisture Content (%) |
|---|---|
| Combined wood and bark | 50 |
| Wastewater treatment residuals[a] | 71 |
| Lime mud | 25 |
| Slaker grits | 25 |
| Green liquor dregs | 50 |
| Fibre rejects[b] | 65 |
| Wood yard waste | 44 |
| Ash[c] | 28 |
| All others[d] | 65 |

[a] includes combined sludge, primary clarifier sludge, secondary clarifier sludge, sludge dredged from ASBs, and deinking sludges

[b] includes paper mill fibre rejects, virgin fibre pulping rejects, and secondary fibre rejects

[c] average of wet and dry ash systems

[d] includes broke not recycled to the process and general mill refuse

Using the mass generation rates of solids residuals on a dry basis from the 2007 FPAC Pulp and Paper Environment Survey, and the moisture contents of solid residuals in Table 4.14, the water content of solid residuals leaving pulp and paper mills is calculated in Table 4.15. The mass weighted average moisture content for all solid residuals is 39%.

**Table 4.15** Water Contents of Solid Residuals from Canadian Pulp and Paper Production

| Solid Residual | Residual Amount million mt (dry) | Water content (million m$^3$) |
|---|---|---|
| Unburned wood and bark | 0.27 | 0.27 |
| Wastewater treatment residuals[a] | 1.50 | 3.68 |
| Inorganics[b] | 0.53 | 0.34 |
| Power boiler ash[c] | 0.60 | 0.14 |
| Miscellaneous[d] | 0.11 | 0.21 |
| Total | 3.01 | 4.63 |

[a] includes combined sludge, primary clarifier sludge, secondary clarifier sludge, and sludge dredged from ASBs, and deinking sludges

[b] includes lime mud, slaker grits, green liquor dregs, recovery boiler electrostatic precipitator ash

[c] average of wet and dry ash systems

[d] metal waste, and general refuse

Using the mass-weighted average moisture content of 39% for solid residuals of all types, the water content in solid residuals for different mill types are given in Table 4.16. The values in the table are applied on a mill by mill basis according to the NCASI classification scheme given in Appendix A.

**Table 4.16** Water Contents in Solid Residuals Used in the Water Profile Work

| Classification | $m^3$ water/admt of product |
|---|---|
| BKI | 0.13 |
| BKP | 0.11 |
| BKO | 0.16 |
| UK1 | 0.09 |
| UK2 | 0.09 |
| SC | 0.19 |
| MECH | 0.17 |
| DTF | 0.49 |
| DNWS | 0.27 |
| RCTR | 0.07 |
| RBOX | 0.15 |
| NIF | 0.06 |
| NIO | 0.06 |
| SULD | 0.20 |
| SULP | 0.17 |
| BCTMP | 0.26 |
| RTF | 0.11 |
| DIP | 0.38 |

SOURCE: based on NCASI 1999
NOTE: see Appendix A for category definitions.

## 4.10 Water in Paper Products and Fate of Water in Paper Products

Products leaving pulp and paper facilities usually have moisture contents of 2 to 10%. An average moisture content of 10% for paper and paperboard products is used in the water profile calculations for the Canadian industry.

The disposition of paper and paperboard not recovered is taken from NCASI (2007), which uses the assumptions in the Carbon Budget Model of the Canadian Forest Sector (Kurz et al. 1992; Apps et al. 1999). It is assumed that 95% of the paper and paperboard products not recovered are landfilled. Water contained in paper that is combusted enters the atmosphere while water contained in paper that is landfilled is assumed to enter the groundwater cycle.

## 4.11 Consumptive Water Losses at Pulp and Paper Mills

Consumptive water losses were estimated on a facility by facility basis as a function of fresh water usage and mill type using procedures previously detailed by NCASI (2008a). In that work on water consumption, evaporative losses from secondary wastewater treatment were included in generation of production-specific water consumption coefficient curves as a function of fresh water usage. Production-specific water consumption curves in the water profile work are based upon water consumption in the process and non-contact water cooling circuits, and do not include evaporative losses from secondary wastewater treatment. Rather, evaporative losses from wastewater treatment were estimated on an individual mill basis to take into account the significant differences in evaporative losses between aerated stabilization basins (ASBs) and activated sludge treatment facilities (ASTs). NCASI's secondary wastewater treatment database was used to classify the type of secondary wastewater treatment at individual mills (i.e., ASB, AST, discharge to a publicly owned treatment works (POTWs), etc.). Any gaps in the NCASI secondary wastewater treatment database were filled with information from the Fisher Pulp&Paper Worldwide™ database. If a mill discharged to a POTW, evaporative losses from treating that mill's effluent were not considered. Yearly average evaporative losses from ASTs treating industrial waste were estimated to be 0.95% of total influent, and yearly average evaporative losses from ASBs treating pulp and paper wastewaters were estimated to be 2.1% of the total influent flow (NCASI 2008a). These yearly average evaporative loss estimates from ASTs and ASBs were the result of detailed heat balance modeling of several ASTs treating industrial wastewaters and several ASBs treating pulp and paper wastewaters. A number of parameters materially affect evaporative losses from ASBs and ASTs. They can be grouped into two categories: geographical and meteorological conditions (e.g., latitude, relative humidity, wind speed); and process and site-specific conditions (e.g., aerator power usage, aeration surface area). In order to make more accurate estimates of evaporative losses from secondary wastewater treatment facilities, site-specific process information, such as aerator power usage and aeration surface area, as well as yearly meteorological conditions on a site by site basis, would be required.

Contributions to water consumption in the process include evaporative losses from the process and non-contact cooling water circuits, water losses in solid residuals, and water losses in the product. The process water consumption coefficient is described in Equation 2.

$$\mathrm{E} = \frac{\text{Consumptive Water Losses}}{\text{Total Water Input}} \tag{Eq 2}$$

where: E = consumptive use coefficient
consumptive water losses = process evaporative losses + water losses in product + water losses in solid residuals
total water input = surface and groundwater +water in raw material + water in purchased chemicals

Water consumption as a function of fresh water usage was regressed to a power function that has the correct asymptotic behaviour at large and small fresh water usage. The equation and data used to generate equation coefficients are equivalent to what was previously used by NCASI (2008a), but evaporative losses from secondary wastewater treatment are treated separately. The equation for process water consumption is shown in Equation 3 and the coefficients for the equation in metric units are given in Table 4.17. The parameters in Table 4.17 are the result of regression analysis to best fit Equation 3 to reported full mill water balance results available in the literature, and estimates of evaporative losses from different mill types based on independent engineering calculations (NCASI 2008a).

$$\mathrm{E} = a \cdot W^{b} \tag{Eq 3}$$

where: E = water consumption coefficient defined in Eq 2
$a$, $b$ = parameters dependent on mill type (Table 4.17)
$W$ = total water input (water from surface and ground sources, water in raw material, and water contained in purchased chemicals)

Process water consumption is calculated via Equation 3 and secondary wastewater treatment evaporation is calculated via yearly average evaporative losses estimates based upon treatment type. Water consumption calculations are detailed in Appendix B. Figure 4.5 shows the total water consumption coefficient (i.e., water consumption from process and secondary wastewater treatment) calculated for Canadian pulp and paper mills. Water consumption curves (NCASI 2008a) are overlaid on the data for comparison. Recycled boxboard mills (RBOX) and recycled containerboard mills (RCTR) use small amounts of water, and within Canada there are a few Bleached Chemi-Thermomechanical (BCTMP) mills that are closed-cycle in process and non-process water use. For these mill types water consumption coefficients approach 100% of fresh water usage. All other mill types have consumptive use coefficients that generally range between 3 and 20% of total water input.

**Table 4.17** Coefficients in Water Consumption Coefficient Equation

| | Metric Units | |
|---|---|---|
| Mill Type | *a* | *b* |
| Chemical[a] | 5.5511 | -0.999 |
| Mechanical[b] | 0.7773 | -0.6138 |
| Recycled[c] | 2.3058 | -1.0291 |
| Non-integrated[d] | 1.8437 | -1.0059 |

NOTE: see Appendix A for category definitions.
[a] BKI, BKP, BKO, UK1, UK2, SC, SULD, SULP
[b] MECH, BCTMP
[c] DIP, DTF, DNWS, RCTR, RBOX
[d] NIF, NIO

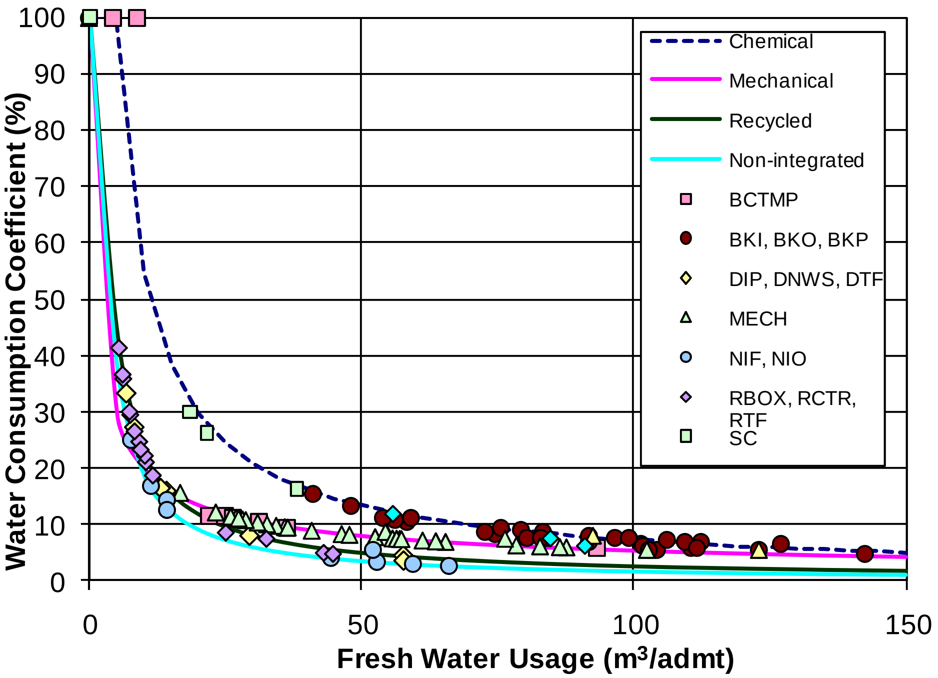

**Figure 4.5** Water Consumption for Canadian Mills as a Function of Total Water Input, with Individual Contributions from Secondary Waste Treatment Type
[See Appendix A for category definitions.]

## 4.12 Surface Water and Groundwater Intake for Pulp and Paper Mills

The total water withdrawal from surface and groundwater sources was calculated via Equation 4.

$$\text{Total Water Withdrawal} = \text{Total Return Flow} + \sum \text{Consumptive Water Losses} - \sum \text{Deliveries} \quad \text{(Eq 4)}$$

where: total water withdrawal = surface and groundwater withdrawn for process and cooling purposes
total return flow = total process and non-contact cooling waters returned to receiving water or discharged to publicly operated treatment works (POTW)
Σconsumptive water losses = process and secondary wastewater treatment evaporative losses + water losses in product + water losses in solid residuals
Σdeliveries = water contained in wood chips + water in purchased chemicals + water in recycled paper

Water withdrawal from surface and groundwater sources was estimated to total 1897 million $m^3$. Applying the fresh water source data, 1865.4 million $m^3$ of this total (98%) is attributed to surface water sources and the remaining 31.5 million $m^3$ (2%) is from groundwater sources.

## 4.13 Water Profile of Wood Products Manufacture

Water use at wood products facilities is substantially smaller than at pulp and paper facilities. Water uses at wood panel facilities may include wet decks, log conditioning ponds, vats and steaming chests, processing area and equipment wash-up and wash-out, wet air pollution control devices such as scrubbers and wet electrostatic precipitators, boiler feed water treatment, boiler blowdown, condensates from wood drying systems and air compressors, primer or paint coating systems, and the use or maintenance of fire water systems. In addition to water used for process and non-process needs, water enters wood products facilities with the raw material and that water is either evaporated during drying, hot pressing, or combustion, or exits the wood products facility with products or co-products.

To characterize the water contained in raw materials, products, and co-products and the evaporative losses from wood products facilities, typical facility wood mass balances are required for each production sector, as well as typical moisture contents of raw materials, products, and co-products. Forintek, a division of FPInnovations, characterized the wood material flows within the Canadian softwood lumber, softwood plywood, oriented strandboard, particleboard, and medium density fibreboard sectors using a cradle-to-gate life cycle assessment (LCA) approach (FPInnovations 2009). Wood mass balances for the wood products sectors in which Forintek has conducted LCAs have been extracted from the Forintek work, and are contained in Appendix C.

The Consortium for Research on Renewable Industrial Materials (CORRIM; http://www.corrim.org) conducted detailed mill surveys to collect life cycle inventory (LCI) data of U.S. wood products mills for the evaluation of environmental impacts of renewable building materials. One of the pieces of information collected in the CORRIM surveys was information on process and non-process water use for various types of wood products facilities including softwood lumber (Milota 2004; Milota, West, and Hartley 2004, 2005), softwood plywood (Wilson and Sakimoto 2005), and oriented strandboard (Kline 2005). Information on process and non-process water use from the CORRIM work was assumed to be applicable to the Canadian wood products industry since the Forintek LCA study did not contain data on water use for process and non-process needs.

Table 4.18 shows the most comprehensive information on wood products industrial production within Canada, which is required to extrapolate the Forintek and CORRIM LCA studies to the entire Canadian wood products industry.

**Table 4.18** Canadian Wood Products Production

| Category | Production[a] 1,000 $m^3$ | Production million mt[b] |
|---|---|---|
| Lumber | | |
| Softwood and hardwood lumber | 78,410 | 43.4 |
| Structural Panels | | |
| Softwood plywood | 3,613 | 2.01 |
| Oriented strandboard (OSB) and waferboard | 10,300 | 9.14 |
| Non-Structural Panels | | |
| Particleboard | 3,080 | 0.91 |
| Medium-density fibreboard (MDF) | 1,351 | 0.97 |
| Hardboard, Insulation board | 118 | 0.14 |
| Total | 96,872 | 56.6 |

[a] Values are from NCASI (2008b) and are valid for 2006.

[b] Conversion factors to convert from 1,000 $m^3$ solid wood equivalent to million metric tons product are taken from Howard (2007) and AF&PA (2008).

[c] Softwood and hardwood lumber production was derived by multiplying capacity amount found in NCASI (2008b) by North American capacity utilization for 2007 found in Spelter, McKeever, and Toth ( 2009).

Detailed water flows for water originating from the raw material of the Canadian wood products industry are given in Appendix C, Table C1. A summary of results for 2007 is given in Table 4.19 and is shown graphically in Figure 4.6. Results were obtained by combining wood mass balances (Appendix C) with typical moisture contents of raw materials, products, and co-products; specific process and non-process water use from the CORRIM work; and total production statistics from Table 4.18. No data exist on whether water used in the wood products industry originates from surface or groundwater sources. It was assumed that the same percentages derived for the pulp and paper industry for water sources (2% groundwater and 98% surface water) are applicable to the wood products industry. Total water usage calculated for the Canadian wood products industry is less than 1% of the total water usage calculated for the Canadian pulp and paper industry.

A co-product is a product that is sold and leaves the facility boundary. Wood chips are an important co-product at wood products facilities. Other typical co-products include bark used for landscaping, sawdust, hogged fuel (shredded bark and wood waste), and veneer. Figure 4.7 shows the interplay of material flows between the Canadian wood products industry and the Canadian pulp and paper industry. It is estimated from this work that approximately 73% of the wood chip demand in the Canadian pulp and paper industry is supplied by the Canadian wood products industry, assuming that all wood chip production at wood products facilities is used for paper and paperboard manufacture. When combining water profile results from the Canadian pulp and paper industry and the Canadian wood products industry, it is important to consider the interactions between the two so that water contained in wood chips is not double counted. There is also a certain amount of hogged fuel and wood waste generated at Canadian wood products facilities that is sold to pulp and paper mills for energy generation, but sufficient information is not available to quantify this amount.

**Table 4.19** Flows for Water Originating from Raw Material for the Canadian Wood Products Industry, 2007

| Source | Flow (million $m^3$/yr) |
|---|---|
| Inputs | |
| Water in raw materials (logs, bark, purchased veneer) | 118.5 |
| Water for process and non-process uses | 17.1 |
| Outputs | |
| Water in products and co-products except wood chips and hogged fuel to pulp mills | 16.9 |
| Water in sold wood chips | 35.6 |
| Evaporative losses from drying and/or hot pressing | 53.6 |
| Evaporative losses from energy generation from the burning of biomass | 12.4 |
| Miscellaneous evaporative losses[a] | 12.8 |
| Water otherwise managed[a,b] | 4.27 |

[a] From process and non-process uses (assumes 75% evaporative loss).
[b] Assumed to go to surface water.

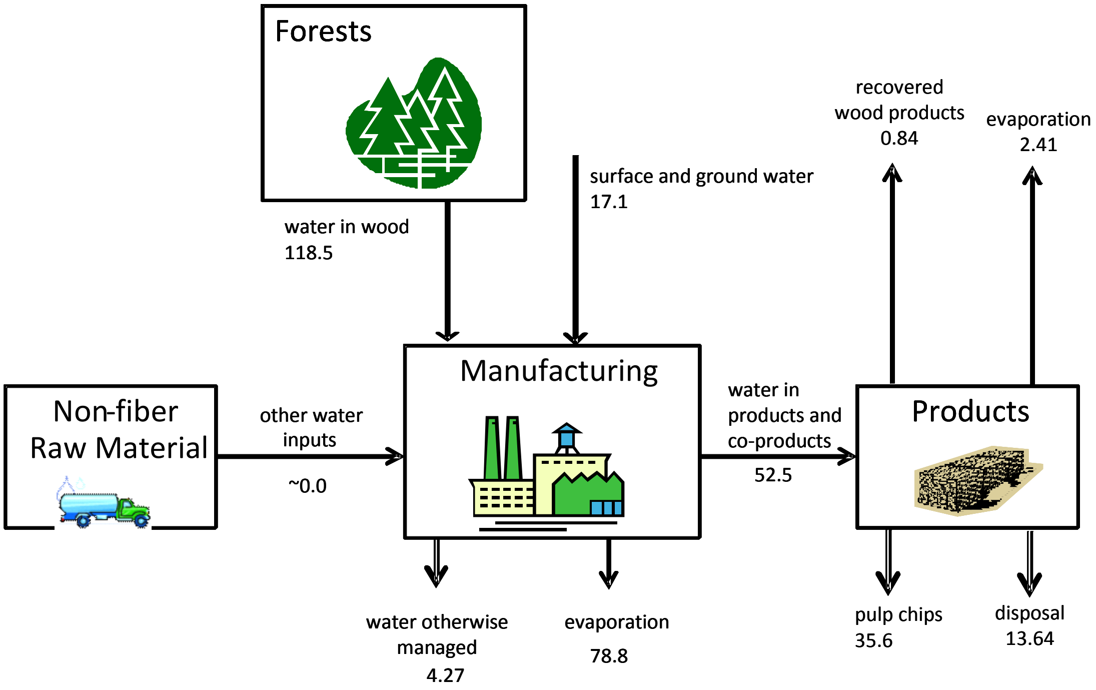

**Figure 4.6** 2007 Water Profile for the Canadian Wood Products Industry (million $m^3$/yr)

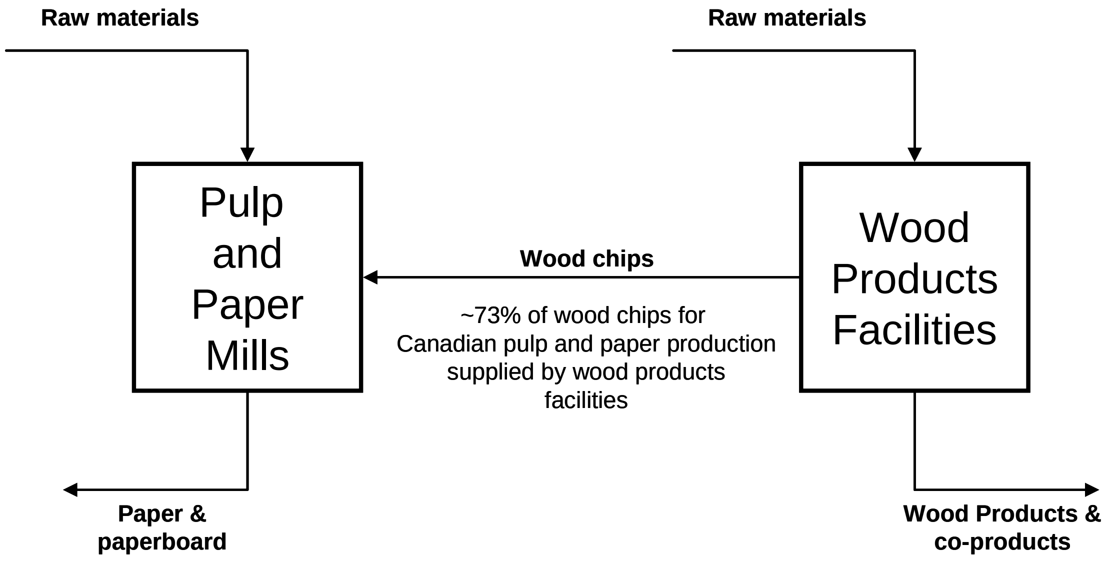

**Figure 4.7** Interplay Between Canadian Wood Products Industry and Canadian Pulp and Paper Industry

The disposition of wood products after use is taken from NCASI (2007), which uses the assumptions in the Carbon Budget Model of the Canadian Forest Sector (Kurz et al. 1992; Apps et al. 1999). It is assumed that 5% of wood products are recovered (most likely in the form of wood pallets) while the unrecovered fraction is 85% landfilled and 15% burned.

## 4.14 Water from Combusted Hogged Fuels

Pulp and paper mills combust large quantities of hogged fuel to supplement mill steam and electricity requirements. FPAC data quantifying the amount of wood and hogged fuels combusted at pulp and paper mills in 2007 are available. In 2007, 6.51 million metric tons of bone dry wood and hogged fuels were reported as being used for energy demands in FPAC’s annual energy use survey. The mills responding to the FPAC energy use survey in 2007 represented 27.3 million air-dried metric tons of production, or 91% of total Canadian pulp and paper production in 2007 (many non-FPAC member mills provide energy use information to FPAC to develop energy use data for the Canadian pulp and paper industry). The water contribution from wood and hogged fuels of 7.2 million $m^3$ of water is calculated by assuming 50% moisture content for wood and hogged fuels, and scaling to total Canadian pulp and paper production by multiplying the FPAC results by a scaling factor of 1.1 (1/0.91). The water contribution from hogged fuel is added to the water in wood contribution in the overall balance (Figure 4.1) and it is assumed that the 7.2 million $m^3$ from hogged fuels contributes to evaporation in Figure 4.1.

## 4.15 Synthesis

Available data and engineering estimates have allowed important water inputs and outputs to be quantified for the Canadian forest products industry.

- Surface and groundwater are the primary water inputs to pulp and papermaking processes, amounting to some 1897 million $m^3$/yr. Water inputs from other sources (non-fibre raw material, wood, and recovered paper) amount to about 53 million $m^3$/year.

- Of the water entering pulp and paper manufacturing, 1950 million $m^3$/yr, most is returned to surface water supplies (91.8%).
- Evaporative losses account for about 7.8% of total water inputs to pulp and paper mills and the remainder 0.4% is exported with product and solid residuals.
- Most of the water inputs to wood products facilities are with wood, and most of this water is lost to evaporation during the production of wood products.
- The forest products industry as a whole (pulp, paper, and wood products manufacture combined) withdraws 1914 million $m^3$/yr of water from surface and groundwater sources, and an additional 136 million $m^3$/yr is brought into the processes with raw materials and purchased chemicals. Of that total, 87.5% is returned to surface waters, 11.3% is evaporated, and 1.2% is exported with products and solid residuals.

Taking into account the interplay between the Canadian wood products industry and the Canadian pulp and paper industry (Figure 4.7), the manufacturing water profile for Canadian forest products industry is given in Figure 4.8.

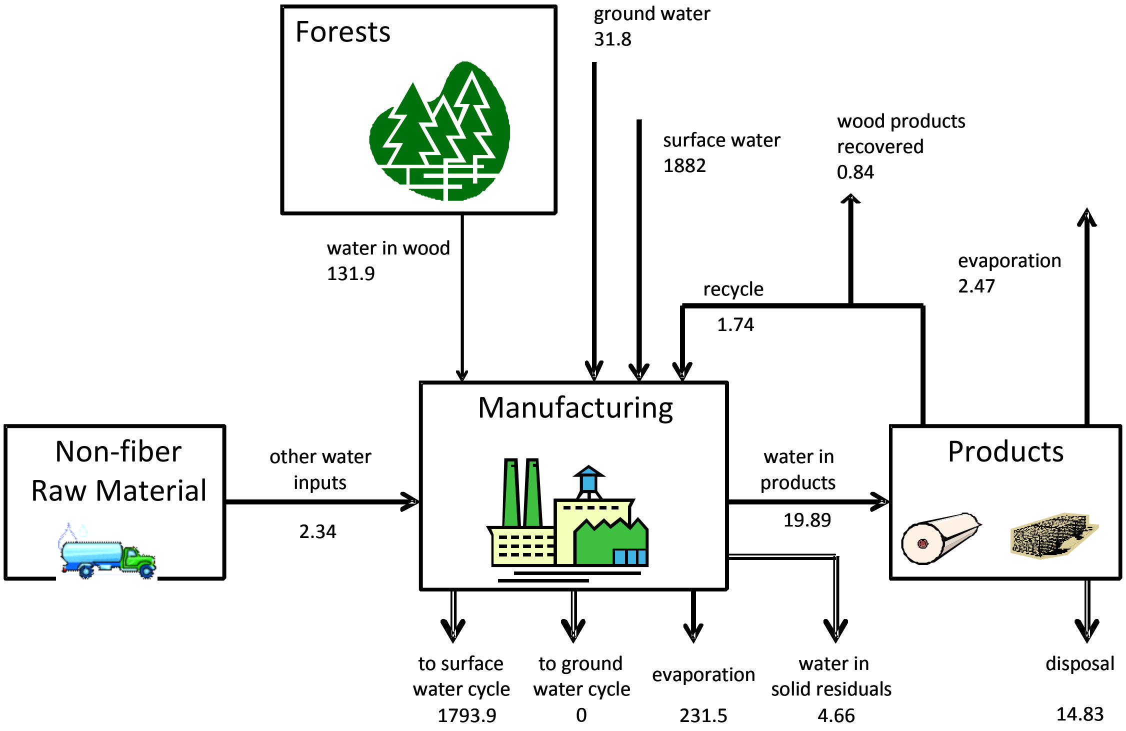

**Figure 4.8** 2007 Water Profile for the Canadian Forest Products Industry (values in million $m^3$)[4]

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[4] The inputs and outputs for the manufacturing block may not balance completely due to rounding of individual values

## 5.0 EFFLUENT COMPATIBILITY WITH RECEIVING WATERS AND AQUATIC COMMUNITIES

While the primary purpose of this report is to consider the quantity, form, and fate of water that is influenced by the forest products industry, due consideration must also be given to potential influences on water quality, particularly those that may be incompatible with the return of water to the water resource cycle. This section deals with the quality of treated effluents from manufacturing operations and the potential for treated effluents to impact stability of aquatic communities resident in waters receiving mill effluents.

### 5.1 Quality of Effluents from Forest Products Manufacture

Wastewater treatment systems used by the forest products industry are, with few exceptions, modeled after water reclamation mechanisms of the natural environment. Treatment systems generally employ sedimentation for solids removal and biological treatment for removal of organic substances. Chemical treatment of forest products industry wastewaters is very uncommon and disinfection of treated effluent is unnecessary because pathogenic organisms are not usually found in treated effluents. The effectiveness of treatment systems designed to mimic natural processes suggests that the resultant treated effluents are likely to be compatible with receiving waters. This likelihood has been the subject of considerable scientific research and is explored in this section.

Canada has been one of the last of the larger pulp-producing countries to implement secondary wastewater treatment (Hewitt, Parrot, and McMaster 2006). Although the first Pulp and Paper Effluent Regulations (PPER) were enacted under the Fisheries Act in 1971, only a few facilities were legally bound by these regulations, and thus most mill effluents were still high in fibre and BOD, and were acutely lethal to fish (McMaster, Hewitt, and Parrot 2006). In the early 1990s, the federal government, in conjunction with the provincial authorities, developed a revised national regulatory framework to ameliorate the quality of pulp and paper mill effluents (Environment Canada 2005). Unlike the first PPER, the revised regulations were mandatory to all pulp and paper mills, established more stringent standards for BOD and TSS, and require final effluents to be non-acutely lethal to rainbow trout at 100% effluent concentration. Provincial governments could adopt federal regulatory limits or implement stricter limits (ibid.). This regulatory framework came into force in 1992 and also included two regulations to prevent and control the release of polychlorinated dioxins and furans (Environment Canada 2005). Since then, the quality of effluents has improved considerably. Figures 5.1, 5.2, 5.3, and 5.4 show discharge trends of BOD, total suspended solids (TSS) (a.k.a. filterable solids), adsorbable organic halides (AOX), and dioxins and furans, respectively, for Canadian pulp and paper mills. Each plot shows substantial declines since the late 1980s. In the case of BOD and TSS, improvements in effluent quality are the result of the application and subsequent improvement of primary and biological treatment systems. In the case of AOX and dioxins and furans, improvements derived largely from the application of elemental chlorine-free (ECF) bleaching of chemical pulps coupled with biological treatment.

The PPER also require mills to conduct receiving environment studies to assess the effectiveness of environmental management measures. In this regard, the Environmental Effects Monitoring (EEM) program is included as a component of the PPER as a tool to identify and measure changes in aquatic ecosystems as a result of pulp and paper mill effluent discharges (Environment Canada 2003). Relevant EEM findings regarding in-stream effects of pulp and paper mill effluents on fish and macroinvertebrates are discussed in Section 5.2, as appropriate.

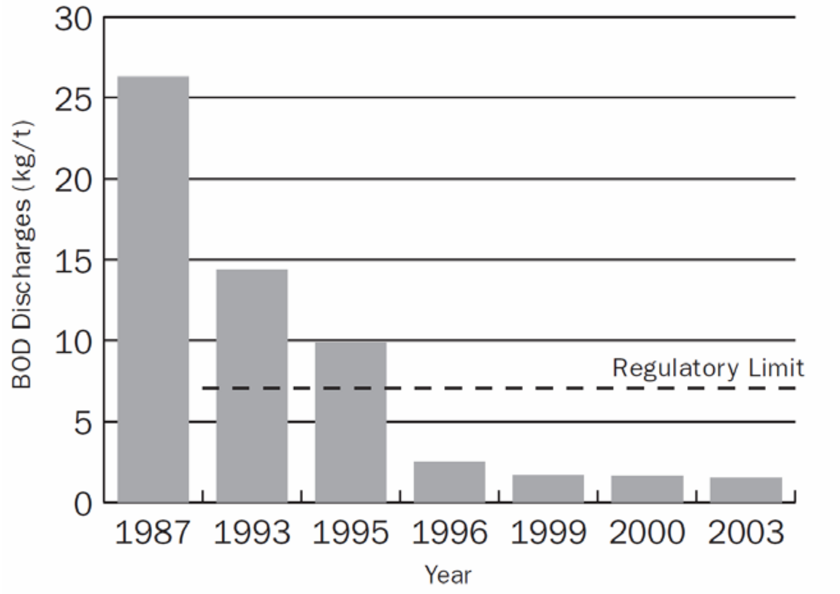

**Figure 5.1** Biochemical Oxygen Demand (BOD) Discharge Trend for Canadian Pulp and Paper Production (Environment Canada 2005) [See data explanation in text.]

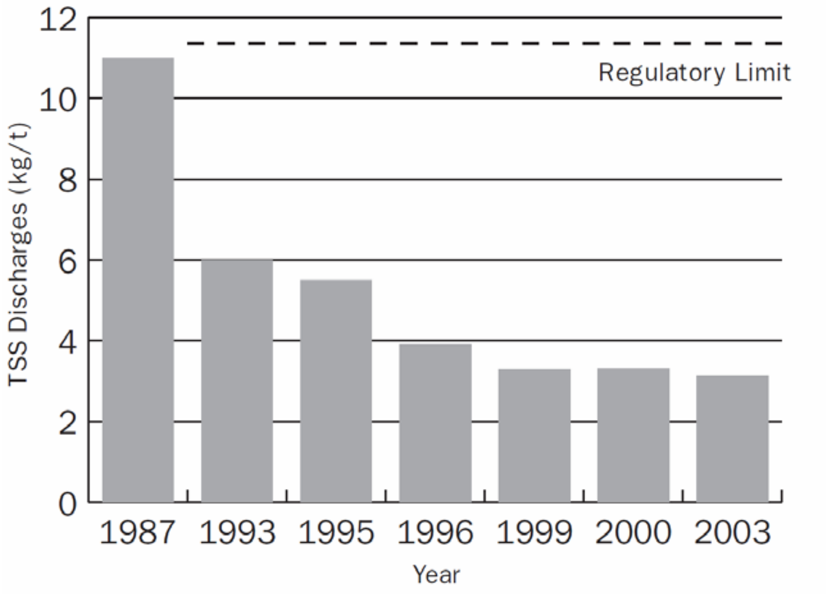

**Figure 5.2** Total Suspended Solids (TSS) Discharge Trend for Canadian Pulp and Paper Production (Environment Canada 2005) [See data explanation in text.]

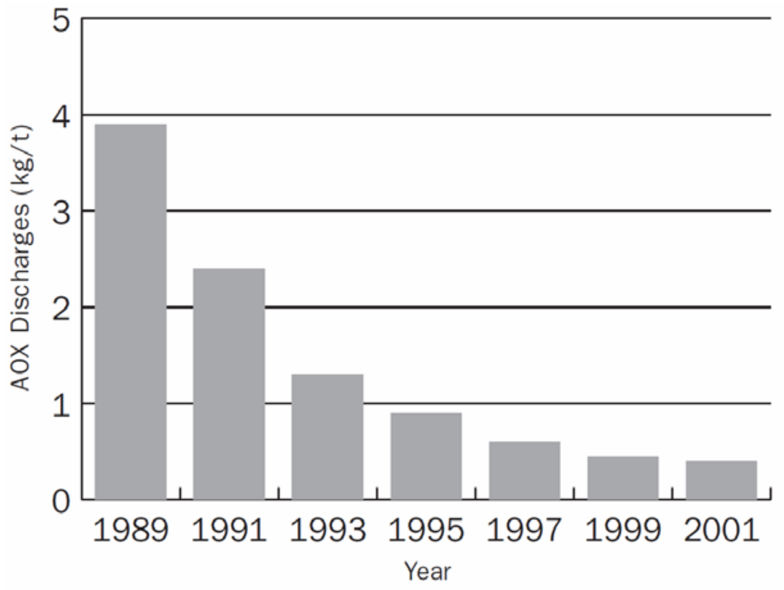

**Figure 5.3** Adsorbable Organic Halides (AOX) Discharge Trend
for Canadian Pulp and Paper Production (Environment Canada 2005) [See data explanation in text.]

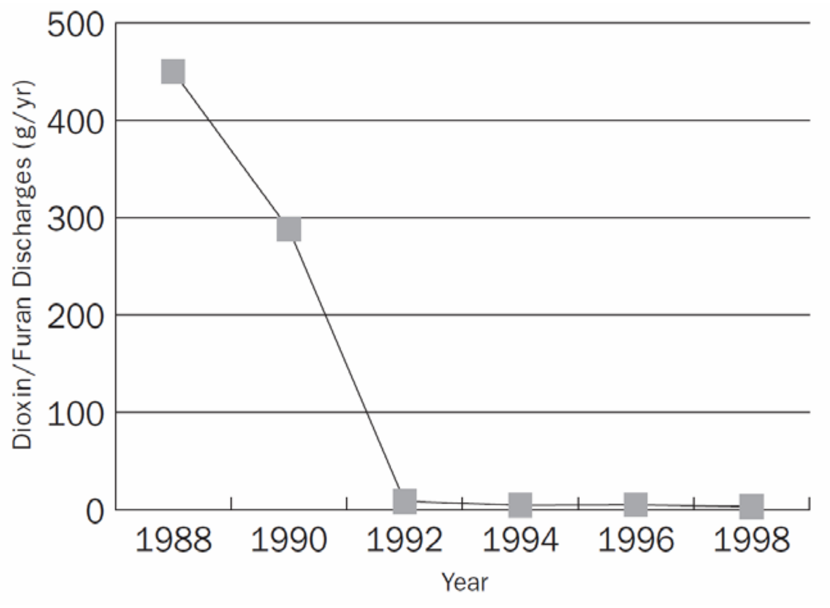

**Figure 5.4** Dioxins and Furans Discharge Trend
for Canadian Pulp and Paper Production (Environment Canada 2005) [See data explanation in text.]

In-stream effluent concentration is an important consideration of the potential significance of effluent effects on biological communities. The EEM program exempts mills with in-stream effluent concentrations lower than 1% (within 250 m of the point of discharge) from conducting a fish survey. According to the latest national assessment of pulp and paper EEM data (Tessier et al. 2009) from the 98 mills that conducted EEM studies, 28 were exempted from performing fish testing. Hence, there is presumably a wide spectrum of in-stream effluent concentrations across Canadian pulp and paper mills. It is worth noting, however, that in the U.S. the volume of effluent discharged into receiving streams is typically a small fraction of overall streamflow[5].

The combination of low in-stream waste concentrations, minimum effluent quality standards, and water quality standards affording protection to local receiving waters act to enhance the compatibility of treated effluent discharges with receiving waters.

## 5.2 Studies of the Effects of Effluents on the Ecology of Surface Waters

Notwithstanding the formal effluent control mechanisms discussed in the preceding section, the potential for pulp and paper mill effluents (PPME) to affect aquatic communities has been the subject of substantial research. Potential effluent effects on aquatic organisms (e.g., tissue, organ, organ system) has been examined through laboratory assessments using bioassays and short- and long-term toxicity testing, while mesocosm/artificial stream studies and in-stream bioassessment have been used to assess population- and community-level biological compatibility with treated mill effluents. Although all testing methods provide information about potential effluent effects on aquatic organisms, the significance of findings to receiving waters, and likelihood of longer term impacts increases with the level of organization of the response organism (Figure 5.5). For example, studies of individual organisms to determine if biochemical or morphological responses occur may be short-term, and the relevance of findings at these lower levels of biological organization (e.g., tissue, organ, organ systems) may not translate to differences at higher levels (e.g., population of a given species or an overall aquatic community). Similarly, population and community changes downstream of effluent discharges may not be the result of lower level changes but rather some other factor (e.g., habitat availability).

Efforts to examine the relationship between aquatic communities and PPME have been largely directed towards laboratory bioassay studies, in part because compliance with discharge permits generally includes a component that assesses the potential for the effluent to cause toxicity to aquatic life. However, because environmental factors make it difficult to predict in-stream effects from bioassay and life cycle testing, mesocosms and in-stream studies have also been employed to examine potential effects. The following sections describe methods of examining potential effluent effects on aquatic organisms, starting with laboratory assessments. Laboratory assessments, including short-term bioassay testing and longer-term life cycle tests, examine effluent effects in a specific organism on endpoints such as survivability, growth, and reproduction. Results of such studies are discussed only briefly because they are relevant only in the context of the effluents with which testing was conducted. In-stream assessments and mesocosm studies of effluent effects examine aquatic organisms in natural systems, or environments that attempt to mimic natural systems. The following sections detail the response of algae, macroinvertebrates, and fish to effluent exposure examined in regulatory programs and the peer-reviewed literature.

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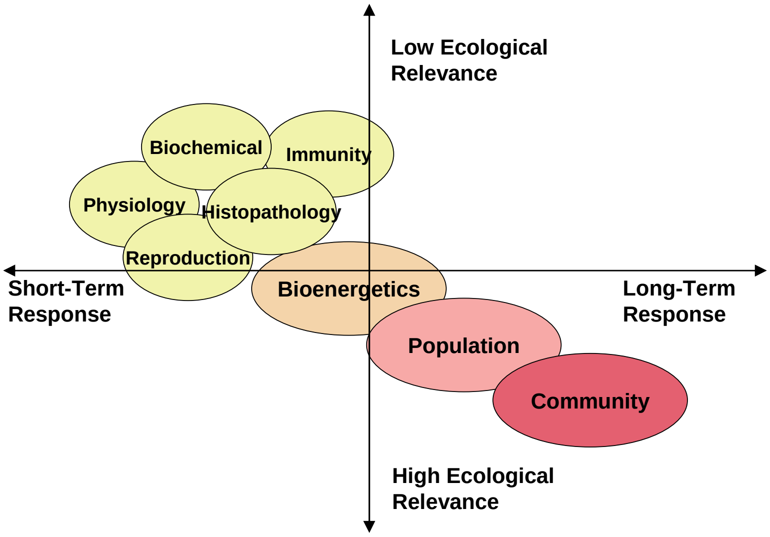
[5] Beebe, Palumbo, and Eppstein (2003) showed that 94% of the approximately 200 U.S. pulp and paper mills examined in their study accounted for less than 10% of the flow contribution to their receiving waters at average flow conditions, and 70% had in-stream effluent concentrations of less than 1%.



Modified from Oak Ridge National Laboratory, http://www.esd.ornl.gov/programs/bioindicators/index.html

**Figure 5.5** Measured Endpoints for Assessment of Effluent Effects for Ecological Relevance and Response Time

### 5.2.1 *Laboratory Effluent Effects Assessment*

Whole effluent toxicity (WET) testing has been developed to assess test organism responses to various concentrations of effluent. The results of such testing are typically interpreted as one line of evidence regarding the potential of effluents to affect the aquatic life in waters receiving effluent discharges. Environment Canada has developed methods for short-term "acute" bioassay tests (48-96 hr) using various organisms. Marine and freshwater test species include water fleas (*Ceriodaphnia dubia*, *Daphnia magna*, *D. pulex*), bivalves (*Mytilius* sp.) fathead minnows (*Pimephales promelas*), rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salvelinas fontinalis*), urchins (Strongylocentrotus sp, Arabacia) and sand dollars (*Dendraster excentricus*), threespine stickleback (*Gasterosteus aculeatus*), luminescent bacteria (*Vibrio fischeri*), and freshwater green alga (*Pseudokirchneriella subcapitata*, formerly known as *Selenastrum capricornutum*).

Toxicity testing is conducted as part of Environment Canada's Environmental Effects Monitoring (EEM) program. This regulatory program evaluates in-stream patterns in fish and macroinvertebrate endpoints downstream of PPME relative to an unexposed reference location, as well as laboratory analyses to determine sublethal toxicity. Evaluations are carried out in three- or four-year cycles, with mills completing the first cycle in 1996. Studies examining the relationship between pulp and paper mill effluent and sublethal toxicity have found that effluent quality improved from the first cycle of EEM (1992-1996) to the second cycle (1997-2000). Test endpoints showed notable shifts to higher concentrations (less toxic) with significantly more tests showing no effect in full-strength effluent during the second cycle (Scroggins et al. 2002). However, effects seen during laboratory toxicity do not necessarily translate into effluent-related changes in in-stream endpoints (Walker, Lowell, and Sherry 2005).

Longer-term tests are conducted to more accurately assess the potential hazards of effluent to biota. Designed in the 1960s, these tests assessed the effects of various substances on life history endpoints (survival, growth, and reproduction) of biota by monitoring from the embryo through to the subsequent generation (Rand 1995). Life cycle testing was initially performed with fish (*P. promelas, S. fontinalis)*, but life cycle tests with invertebrates and algae have been developed which are of shorter duration.

Life cycle testing has been conducted on PPME to determine potential effects on physiology and reproduction (see Hewitt et al. 2008 for review). These studies typically examine several endpoints including gonadosomatic index (GSI), hepatosomatic index, condition factor, numbers of tubercles on the heads of males and females, gonadal histology, and the number and hatchability of eggs. Egg production is the most common endpoint showing a dose response pattern, but changes in secondary sex characteristics, including masculinization and feminization, changes in sex hormones, and delayed sexual maturity have been seen (Kovacs et al. 1995a, 1995b, 1996; Borton and Bousquet 1996; Borton, Bousquet, and Hall 1997; Borton et al. 2000, 2003, 2004; Parrott and Wood 2002; Parrott et al. 2003).

Life cycle studies to corroborate patterns in in-stream communities have also been conducted and shown consistent patterns between laboratory and field measurements. In one study, gonad size reduction, reduced egg production, and increased growth (length, weight, condition factor) were observed in laboratory-based, life-cycle studies with fathead minnow, although some of these effects were only seen at high effluent concentrations (Parrott and Wood 2004). These patterns were similar to those seen in wild-caught yellow perch (*Perca flacescens*) collected downstream of the PPME discharge. In another study, measured indicators did not generally show consistent patterns or dose-response, or predict effects on reproduction during these life cycle bioassays Borton et al. 2009), which reflected in-stream measures of fish community structure and community metrics (Flinders, Ragsdale, and Hall 2009). GSI and tubercles also did not indicate estrogenic or androgenic responses to the effluents although GSI tended to be greater at higher effluent concentrations. The most consistently sensitive test end-point showing a dose-response was the IC25[6] for egg production. Based in this endpoint, effluent had an effect on fish reproduction at concentrations ranging from 8% effluent (v/v) to 100% effluent (v/v) in the four streams examined.

### 5.2.2 *Mesocosm and In-Stream Effluent Effects Assessment*

Although acute bioassays and longer-term life cycle tests are important in assessing the potential toxicity of PPME, it is difficult to extrapolate these findings to receiving waters because of the complexity of natural systems. Biotic communities are influenced by environmental variables at the landscape level (e.g., watershed area, elevation, location in watershed, and land use/land cover), local-scales (e.g., substrate, channel form, depth), and by both long-term flow regime and short-term flow history (e.g., magnitude, frequency, variability, rate of change). Additionally, species competition and predation can interact with environmental variables to influence types and relative abundance of biota. These factors make it difficult to predict the potential effects of forest products industry effluent on in-stream communities.

That said, mesocosm/artificial stream and in-stream studies have been conducted to determine the compatibility of forest products industry effluent with aquatic communities. A mesocosm or artificial stream can be defined as any constructed channel that has a controlled flow of water and that is used to study a physical, chemical, or biological property of natural streams (Lamberti and Steinman 1993). Although studies using artificial habitats are unable to reproduce key components of natural systems exactly, they are considered an important link between laboratory and field studies because of the ability to simulate natural systems while allowing for replication of treatments and controls (Giddings and Eddlemon 1979; Culp and Podemski 1996; Culp et al. 1996). Field studies, despite the

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[6] The IC25, or inhibition concentration 25%, is the effluent concentration at which 25% of the test organisms show a response for the test endpoint.

spatial and temporal variability inherent in natural systems, are crucial for assessing effluent effects because the assimilative capacity of a system is complex and unknown, and numerous abiotic (e.g., flow, substrate, temperature, water chemistry) and biotic (e.g., competition, predation) factors can exacerbate or ameliorate the effects of point sources.

Population- and community-level studies of the effects of PPME have been examined with respect to different taxa groups including algae, macroinvertebrates, and fish. However, the number of studies examining PPME is low relative to studies of other point- and non-point source inputs. The following sections summarize the findings of mesocosm and in-stream studies of PPME with respect to algae, macroinvertebrates, and fish.

### *Algae*

Algae are present in all intact, natural systems and can occur in the water column, or adhering to substrates as periphyton. Chlorophyll *a* (chl *a*) is the green pigment in algae, and is probably the most often used estimator of algal biomass in lakes and streams because it is relatively unaffected by non-algal substances. It is a measure of algal weight and volume and it has been shown to act as an empirical link between nutrient concentration and a number of important biological phenomena in lakes, reservoirs, and streams, although the nutrient-algal relationship in flowing waters is not always as clear as in standing water (Borchardt 1996). Periphyton chl *a* concentrations >100 mg/m$^2$ have been identified as "nuisance" levels (Welch et al. 1988), although concentrations exceeding this threshold can occur naturally in unaltered stream systems, and do not necessarily result in aesthetic or biological impacts.

Research examining the effects of mill effluents on algal communities is available in the published literature and as unpublished reports (e.g., NCASI 1989, 1998), but the response of algal communities to forest products industry effluents is site-dependent. Several published studies have shown significant increases in periphyton chl *a* and shifts in community structure in artificial mesocosm or streams exposed to PPME relative to unexposed controls (e.g., Bothwell 1992; Bothwell and Stockner 1982; Hall, Haley, and LaFleur 1991; Culp and Podemski 1996; Culp, Podemski, and Cash 2000; Culp et al. 2003; Dubé and Culp 1996; Podemski and Culp 1996). However, increases to nuisance levels (>100mg chl *a*/m$^2$) were seen only in some studies (Culp and Podemski 1996; Culp et al. 1996; Dubé and Culp 1996; Podemski and Culp 1996; Culp, Podemski, and Cash 2000; Culp et al. 2003). In some cases, nutrient concentrations of effluents were low (close to or below detection limits), but the addition of very low concentrations of nutrients in very low nutrient (oligotrophic) systems can result in increases in algal biomass (Bothwell 1992). Other published studies have shown no significant effects of forest products industry effluent on algal communities. Davis, Vance, and Rogers (1988) showed no significant changes in in-stream periphyton productivity, although a change in community structure occurred near the discharge relative to upstream communities and those further downstream.

Unpublished mesocosm studies have been conducted in association with NCASI's Long-Term Receiving Water Study (LTRWS). Findings from these studies showed river-specific patterns, with a significant relationship between effluent and chl *a* seen in one stream. Periphyton samples collected from mesocosms at the McKenzie River (Oregon) treated with 0, 1, and 5% effluent (v/v) showed significant increases in biomass with increasing effluent concentration (NCASI 2001a). Mesocosm studies conducted at the other LTRWS rivers (Codorus Creek [Pennsylvania], Leaf River [Mississippi], Willamette River [Oregon]) showed no significant differences in periphyton biomass with increasing nutrient concentration (NCASI 2001b, 2004, 2005) although there was a trend towards increasing chl *a* with increasing effluent concentration.

In outdoor experimental streams, unpublished mill studies and industry reports have shown site-dependent and variable responses of in-stream periphyton and/or water column chl *a* to forest products industry discharges. Periphyton accrual on artificial substrates was significantly greater in streams treated with effluent (in sufficient quantity to add an increment of 0.5 ppm $BOD_5$ to the streams, 0.8 ppm non-settleable biological solids, and ~50 colour units) than in control streams during the early phases of the study (NCASI 1982, 1983), but greater in control streams compared to effluent-treated streams in later stages (NCASI 1984a, 1985). However, reasons for these differences are unclear. Examination of ecological changes following mill process changes showed no effluent-related differences in periphyton chl *a* exposed to mill discharges (NCASI 1993). A similar stream channel study examining effluent effects in a southern, warm water system showed no effluent-related differences in periphyton community structure (NCASI 1984b). More recently, a literature review examining mill consultant reports found that among seven studies examining periphyton and water column chl *a* and algal community structure upstream and downstream of mill discharges, effluent effects were seen on only three occasions (NCASI 1998).

Few in-stream studies have examined algal biomass in effluent receiving streams, and the relationship between PPME and algal biomass is site-dependent with some increases in periphyton biomass occurring following effluent exposure. There were no significant changes in in-stream periphyton standing crop in the lower Sulphur River (Texas-Arkansas, USA), although a change in community structure occurred near the discharge relative to upstream communities and those farther downstream (Davis, Vance, and Rogers 1988). In the Thompson River, Canada, chl *a* increased during the winter months when river flows were low and effluent dilution was reduced (Dubé, Culp, and Scrimgeour 1997). Scrimgeour and Chambers (2000) attributed elevated nutrient concentrations to increases in periphyton biomass in the Athabasca and Wapiti-Smoky rivers (Canada). More recently, analyses of NCASI's LTRWS data set has shown that periphyton chl *a* concentrations measured seasonally over nine years was greater at some, but not all upstream sites in two streams, while site differences related to effluent discharge were not seen on the other two study streams (Flinders et al. 2009a).

Increased nutrient concentrations downstream of pulp and paper mill discharges have been implicated in periphyton increases. The bulk of readily available N and P for algal growth in PPME is largely derived from any excess of nutrients added to wastewater treatment systems to enhance removal of BOD (NCASI 2001c) with the relative percentage of bioavailable nutrients varying widely across mill effluents (Priha 1994; NCASI 1997).

The relationship between PPME and algal biomass is variable by site, with some increases in periphyton biomass occurring following exposure to PPME. However, many of these observations were seen in artificial stream studies, and may not accurately represent environmental variables that can affect the assimilative capacity of a water body. In-stream periphyton-effluent studies conducted at multiple sites over multiple seasons and years are limited to the LTRWS, where an inconclusive effluent-chl *a* relationship was seen only on two streams. Among in-stream periphyton studies where periphyton increases were observed downstream of some PPME, findings were based on sampling from a single season (Scrimgeour and Chambers 2000), or seen only seasonally (Dubé, Culp, and Scrimgeour 1997; Flinders et al. 2009a).

### ***Macroinvertebrates***

The use of macroinvertebrate assemblages to assess the potential effects of point-source discharges and watershed runoff on stream biota has been adopted by researchers assessing stream condition (e.g., Linke, Bailey, and Schwindt 2001; Borisko et al. 2007), and as a regulatory tool in both Canada (http://cabin.cciw.ca/Main/cabin_about.asp) and the U.S. (Barbour et al. 1999). The type and relative abundance of macroinvertebrate species are used to identify overall community patterns (e.g., Winter et al. 2002; Berenzen et al. 2005), and are translated into community-based metrics which provide information on the structure and function of the community through measures of taxa diversity and evenness, autecological characteristics of taxa composition, and trophic and habitat structure (e.g., Griffith et al. 2001; Roy et al. 2003).

Although macroinvertebrates tend to be the most studied taxonomic group in stream bioassessment, there are relatively few field studies, either in mesocosms or natural streams, examining the effects of PPME on macroinvertebrate communities (e.g., Hall, Haley, and LaFleur 1991; Culp, Podemski, and Cash 2000; Culp et al. 2003). In mesocosm and artificial stream studies macroinvertebrate exposure to mill effluents (1–10% v/v) can result in increased growth rates (Lowell, Culp, and Wrona 1995; Lowell et al. 1996), higher density and biomass (Hall, Haley, and LaFleur 1991; Dubé and Culp 1996; Culp, Podemski, and Cash 2000; Culp et al. 2003), and shifts in community structure (Culp et al. 2003), although findings were sometimes inconsistent (Hall, Haley, and LaFleur 1991). In some studies, exposure at higher effluent concentrations (5.0 and 10%) inhibited macroinvertebrate growth rates relative to lower concentration treatments, but were greater than experimental controls (Dubé and Culp 1996).

Findings from studies in natural streams were variable. Felder et al. (1998) found no significant changes in macroinvertebrate community structure, abundance, or diversity measures at sites downstream of an unbleached kraft mill relative to an upstream site. Other in-stream studies showed changes in community structure (Rakocinski et al. 1996), and invertebrate density and biomass (Dubé, Culp, and Scrimgeour 1997) downstream of mill discharges relative to upstream sites. These responses have been attributed to increased nutrient concentration and primary production (Lowell et al. 1996; Culp, Podemski, and Cash 2000; Culp et al. 2003), although increased macroinvertebrate biomass is not always reflected in primary productivity (Dubé and Culp 1996).

Macroinvertebrates are examined as part of Environment Canada’s EEM program. This regulatory program evaluates fish and macroinvertebrate endpoints downstream of PPME relative to an unexposed reference location. Macroinvertebrates collected as part of this program are examined for differences in density, taxa richness, evenness (Simpson’s evenness), and similarity (Bray-Curtis index) downstream of effluent discharges relative to an upstream reference site. Findings from the first four cycles have shown relatively consistent patterns, with a subset of receiving waters showing nutrient enrichment based on changes in macroinvertebrate endpoints at effluent-exposed sites relative to an upstream control. In Cycles 2 and 3, the majority of mills reported significant differences in community structure between sites, suggesting that most sites receiving effluent had suffered habitat degradation. The main response pattern in receiving streams was mild to moderate eutrophication as indicated by increases in abundance, together with some combination of increases, decreases or no change in taxon richness, depending on the degree of eutrophication (Lowell et al. 2005). Macroinvertebrate patterns in the recently published Cycle 4 report were similar to Cycles 2 and 3 and showed changes suggesting nutrient enrichment with increased density and changes in community structure (Bray-Curtis endpoint), together with a variety of responses for taxon richness (Tessier et al. 2009). In response to nutrient enrichment patterns downstream of PPME discharges, the Forest Products Association of Canada (FPAC) has developed a *Nutrient Best Management Practices Guide* (FPAC 2008), which has been adopted by mills demonstrating nutrient enrichment as part of EEM’s Investigation of Cause and Investigation of Solution.

Macroinvertebrates have also been collected as part of NCASI’s LTRWS program (Flinders, Ragsdale, and Hall 2009). Data collected during the LTRWS between 1998 and 2006 showed differences in community structure (species type and relative abundance) across sites, but no changes downstream of PPME discharges relative to upstream sites (Flinders et al. 2009b). Several macroinvertebrate community metrics, which translate community data information into measures of the structure and function of the community, were also examined as part of the LTRWS including richness, density, and %Dominant taxa. Seasonal and annual variations in macroinvertebrate metric response were seen in all streams, but there were no significant changes in all but one macroinvertebrate metric related to the discharge of PPMEs. In all streams, the macroinvertebrate community was representative of good or very good water quality conditions at most sites (Hilsenhoff 1987). In the McKenzie River, an increase in the relative abundance of certain taxa tolerant to organic stress at sites downstream of the discharge contributed to increased mean Hilsenhoff Biotic Index (HBI) scores relative to upstream sites, suggesting a decrease in water quality.

As with algal biomass, the effect of PPME on macroinvertebrate communities is variable and site dependant. The variability in response patterns can be attributed to several factors, including effluent process type and in-stream effluent concentrations; differences in in-stream environmental conditions across study streams such as temperature, flow, depth, substrate, and water chemistry; and naturally occurring seasonal and temporal variation in macroinvertebrate communities.

### *Fish*

Fish were among the first taxa formally adopted for monitoring aquatic conditions. The Index of Biotic Integrity (IBI) developed by Karr (1981) and regional modifications of the original IBI by others (Karr et al. 1986; Leonard and Orth 1986; Moyle, Brown, and Herbold 1986; Fausch and Schrader 1987; Hughes and Gammon 1987; Ohio EPA 1987; Miller et al. 1988; Steedman 1988; Simon 1991; Lyons 1992; Simon and Lyons 1995; Lyons, Wang, and Simonson 1996; Roth et al. 1997) have been adopted by EPA (Barbour et al. 1999). The EPA Rapid Bioassessment Protocol and others identify several reasons fish are ideal taxa for stream assessment (Karr et al. 1986; Barbour et al. 1999). Fish are good indicators of long-term (several years) effects and broad habitat conditions because they are relatively long-lived and mobile, and thus are able to exploit multiple habitats (Karr 1981; Karr et al. 1986; Barbour et al. 1999). However, fish mobility can also complicate interpretation of community metrics related to point-source studies because exposure concentrations and durations are unknown (e.g., Swanson et al. 1994; Gibbons, Munkittrick, and Taylor 1998). Fish communities generally include a range of species that represent a variety of trophic levels (omnivores, herbivores, insectivores, planktivores, piscivores) and tend to incorporate the effects of lower trophic levels. As a result, fish community structure usually reflects integrated environmental health. An important component of bioassessment is the ease with which useful and representative data can be collected. Fish are relatively easy to collect and identify to the species level and most specimens can be field sorted, identified, and released unharmed. Additionally, autecological information, life history, and distribution are typically available for most fish species (Barbour et al. 1999).

Among the three main taxa groups examining the potential community-level effects of PPME in surface waters, outside of studies conducted for regulatory requirement, fish are the least studied group compared to periphyton and macroinvertebrates. Some population-level studies have compared physiological endpoints of certain fish species (Munkittrick et al. 1991; Hodson et al. 1992; Swanson et al. 1994). Studies of community structure in rivers downstream of pulp and paper mill discharges to communities at reference sites (Adams et al. 1996; Kovacs, Martel and Voss 2002; Greenfield and Bart 2005) as well as a few community-level studies in lake and marine environments have also been completed (Hansson 1987; Neuman and Karås 1988; Karels and Niemi 2002).

Fish population studies do not examine the entire fish community, but rather study specific characteristics of a subset of the fish species present. Inconsistent results were seen in three studies of population and physiological characteristics of four fish species exposed to PPME prior to the implementation of secondary wastewater treatment relative to unexposed fish. Munkittrick et al. (1991) found that white sucker (*Catostoma commersoni*) from a Lake Superior site receiving primary-treated bleached kraft mill effluent were older, had a higher condition factor (mass per unit length), smaller gonads, lower fecundity, and secondary sex characteristics compared to fish collected from unexposed sites. In another study, the same species on a different receiving water showed no significant differences in condition factor or gonad sizes, although tissue contamination by dioxins and furans were seen in fish collected from near-field sites (Hodson et al. 1992). Populations of mountain whitefish (*Prosopium williamsonis*) and longnose sucker (*Catostomus catostomus*) showed higher condition factor collected near bleached kraft mill effluent on the Wapiti/Smoky river than at a reference site, but showed no difference in age class structure or reproductive physiology (Swanson et al. 1994).

Fish populations and the potential effects of PPME are also studied through Environment Canada’s EEM program (Walker et al. 2003). The EEM program uses a sentinel species approach basing effects on various indicators seen in individual fish at effluent-exposed sites relative to upstream reference sites. Findings from the first three cycles of the EEM program have suggested enrichment and endocrine disruption downstream of PPME discharges at some sites. On a national average, fish had larger livers, faster growth rates, higher condition factor, and smaller gonads, relative to fish at unexposed sites, although findings across cycles have been variable and inconsistent at many sites (Lowell et al. 2005; McMaster, Hewitt, and Parrot 2006). A similar pattern was seen in Cycle 4 with increased condition, growth rate, and relative liver size, together with decreased relative gonad size (Tessier et al. 2009). The fish results from Cycle 4 might suggest significant reductions in effects relative to the earlier cycles. However, this pattern was largely due to the fact that data from large-effect mills pursuing investigation of cause (IOC) studies were not included in the analyses. When this bias is accounted for, the apparent reduction in effects disappears for all endpoints with the exception of relative gonad size, which showed a significant lessening of the national average effect.

Community-level studies of fish in effluent receiving waters have shown variable results. Fish community structure measured in a PPME receiving stream prior to advanced wastewater treatment showed the integrity of the fish community deteriorated from good-to-excellent at sites upstream of the discharge, to poor-to-very poor at downstream sites (Adams et al. 1996; Yeom and Adams 2007). Kovacs, Martel and Voss (2002) found the fish communities downstream of three mills in the St. Francois River, Quebec to be unaffected by the effluents after two of the three mills installed wastewater treatment systems. The IBI scores indicated average to excellent environmental quality downstream of discharges, and these did not change relative to sites upstream. In an effluent-dominated (in-stream effluent concentration >50%) Florida blackwater stream, a tea-coloured stream from naturally high tannins due to leaching from decaying vegetation, Greenfield and Bart (2005) used archived data to assess the impacts of PPME from a kraft mill on fish community dynamics compared to a nearby stream not receiving effluent. Over the 16-year study, the fish community in the receiving stream had lower species richness and diversity than the control stream at all sites except at the mill discharge outfall where these measures were similar to those in the control stream. Community composition differed between the two streams, with the receiving stream fish community composed largely of the intermediately tolerant species *Lepomis macrochirus* and *Gambusia affinis*, whereas the reference stream was composed largely of stress-intolerant minnows, sucker, and darter species.

A long-term examination of fish communities has been ongoing as part of NCASI's LTRWS in four receiving streams (1998-current; Flinders, Ragsdale, and Hall 2009). The entire fish community is sampled in Codorus Creek using backpack electrofishing, while large-bodied fish in the Leaf, McKenzie, and Willamette Rivers are collected using boat electrofishing. To characterize a greater proportion of the fish community, small-bodied fish are also collected from stream margins in the McKenzie and Willamette Rivers using backpack electrofishing sampling. Over the course of the study, fish community structure did not show seasonal patterns in any of the streams, and was variable across years. As with macroinvertebrate taxa, there were no effluent-related differences in species type and relative abundance in any stream, with significant differences across sites limited to Codorus Creek. An assessment of the structure and function of fish communities using fish community metrics (e.g., Abundance, Richness, %Intolerant Species, %Omnivore) found changes downstream of the effluent discharge relative to upstream sites in %Piscivores and %Dominant Taxa in one stream with the decrease in %Piscivores at effluent-exposed sites likely driven by a decrease in rainbow trout (*Oncorhynchus mykiss*) at sites downstream of the discharge relative to upstream sites. This decrease may be due to a naturally occurring pattern that has been seen in other associated tributaries (ODFW 1991a, 1991b), or related to state agency stocking activities. A decrease in the %Dominant Taxa of small-bodied fish at sites downstream of the PPME discharge suggests a shift in water or habitat quality as the community changes from one dominated by stress-intolerant taxa to one that contains more intermediately tolerant fish species.

Laboratory, mesocosm, and in-stream research has shown that PPME can have physiological effects in multiple fish species. Advanced biotreatment has been effective in reducing some effects, but biotreated effluents also have shown no difference or an exacerbation of effects. In Canada's EEM program, the most common response in effluent-exposed fish was a reduction in gonad size, and the industry continues to identify causes for this effect. Although very few studies have examined community-level effects of fish, PPME had little effect on the fish communities studied. The lack of effluent effects seen at the community level suggests that effluent qualities in these streams were such that fish communities were unaffected, that the effluent concentrations were not sufficient to affect fish community structure, or that naturally occurring community variation obscured possible effluent-related influences.

### 5.3 Summary

Assessing the compatibility of treated mill effluents with in-stream aquatic communities is complicated by site-specific variables including effluent quality, physical habitat conditions and water quality of the receiving stream, land use of the receiving drainage area, and regional climate conditions. That said, site-dependent, in-stream studies examining effects of effluents have shown that:

- Patterns of algal biomass, macroinvertebrate community structure and biomass, and fish community structure can be highly variable with site, season, and year, regardless of effluent exposure.
- Water quality as measured by biotic community structure can remain high despite shifts in community structure downstream of effluent discharges.
- In streams where ambient nutrient concentrations are low, PPME can cause increases in periphyton biomass, although typically not to the threshold considered "nuisance" levels.
- Spatial and seasonal changes in algal biomass may be related to seasonal changes in streamflows, in-stream waste concentrations related to low flow, and seasonal patterns of algal species.

- Although in artificial streams/mesocosms, macroinvertebrate community structure and biomass can be affected by effluent exposure, community patterns in natural receiving waters typically show little change relative to upstream sites suggesting that naturally occurring variation in habitat conditions have a greater influence on community structure than effluent.

- Fish communities are highly spatially and temporally variable, and relatively few studies have examined in-stream community effects related to PPME. For the studies that have been done, including those by NCASI, fish community structure typically does not change downstream of effluent discharges relative to upstream sites with comparable habitat.

Although patterns vary across receiving waters, advanced treatment of PPME has resulted in PPMEs that typically have little effect on aquatic community structure, and naturally occurring spatial and temporal variation can have a greater impact on community patterns than effluent exposure.

## 6.0 SYNTHESIS OF WATER QUANTITY DATA

This report has discussed the amounts and quality of water influenced by the forest products industry through its association with forests from which wood is harvested or through its use in manufacturing operations. This section presents an assessment of the relative amounts of water associated with each major forest products operation (forest management, non-fibre raw material use, product manufacturing, and product export).

### 6.1 Precipitation, Evapotranspiration, and Runoff for Forested Lands

Calculating the annual availability of fresh water, particularly over large spatial scales, is not a straightforward task. Precipitation and runoff amounts vary widely between and within ecozones, and point measurements are often difficult to integrate. For example, estimates of long-term, area-adjusted precipitation (a measure expected to correlate with water availability) can vary considerably. Area-adjusted total precipitation estimates published by NOAA (2002) listed the annual area-weighted precipitation total in the contiguous U.S. as 743 mm (standard deviation 58 mm) for the period 1931 to 2000. However, in a study of changing precipitation patterns in the U.S. and Canada, Groisman and Esterling (1994) suggested that precipitation measurement techniques can underestimate precipitation amounts. They placed annual area-averaged (century-long) precipitation for the contiguous U.S. at 914 mm (standard deviation 71 mm), 20% higher than the NOAA estimate.

Rainfall onto land will be lost to evapotranspiration, infiltrate into the soil and percolate into the groundwater, or be exported out of the watershed as streamflow. In most locations, groundwater will eventually make its way to surface waters and be measured as streamflow. Thus, calculations of the fate of precipitation usually assume that groundwater levels are static (i.e., inflow matches outflow, the latter measured as a non-quantified portion of surface and subsurface runoff), and thus the difference between precipitation and streamflow is usually considered to be losses to evapotranspiration and interception losses (in this report evapotranspiration is used to cover both processes of water loss).

Canada has nine ecozones considered to be forested, comprising an area of roughly 541.5 million hectares (Ecological Stratification Working Group 1995). Within those ecozones, the proportion of land that is considered forested ranges from 15.1% (Mixedwood Plains) to 88% (Boreal Shield) (Natural Resources Canada 2007). In total, forested areas comprise roughly 387 million hectares (Environment Canada 1993). The managed forest is defined as the subset of forestland where harvest access is not completely restricted (e.g., national parks), and where provinces have designated industrial forest management. In Canada, these areas (e.g., Timber Supply Areas, Forest Management

Areas, etc.), in addition to private timberlands owned in some provinces, comprise a total of roughly 160 million hectares (Table 6.1).

Estimates of runoff totals suggest that about 3.3 trillion $m^3$ (3,318 $km^3$) of streamflow occur annually on Canadian soil (Laylock 1987). Annual mean precipitation varies widely across ecozones, from a low of 350 mm/year (Taiga Plain) to a high of 2250 mm/year (Pacific Maritime). Using this data we can therefore create a crude approximation of the precipitation falling on managed forestland in Canada. The calculation (which assumes that the 160 million ha of managed forests are distributed proportionally across ecozones according to forest area in each ecozone) yields an annual quantity of water entering managed forests in Canada as precipitation of 1.35 trillion $m^3$.

Water leaves the forest as streamflow, groundwater, or water vapour emitted from trees and other forest plants (i.e., evapotranspiration). The relative amounts of water exiting as either streamflow or evapotranspiration are highly variable, both between and within ecozones, as discussed in Section 3.1.3. Data from the nine watersheds discussed in that section are summarized in Table 6.1 and show that just over 50% of the precipitation for those watersheds exits fully forested areas as evapotranspiration and most of the remainder exits as streamflow (Table 6.2).

**Table 6.1** Area (Ecological Stratification Working Group 1995) and Annual Precipitation Estimates (Natural Resources Canada 2007) for Nine Forested Terrestrial Ecozones in Canada

| Ecozone | Area (mha) | Area of Managed Forests (mha) | Mean Annual Precipitation (mm) | Total Annual Precipitation (trillion $m^3$) |
|---|---|---|---|---|
| Boreal Plains | 88.4 | 30.7 | 462 | 0.14 |
| Boreal Shield | 180.3 | 65.6 | 1,000 | 0.66 |
| Montane Cordillera | 48.1 | 15.1 | 550 | 0.08 |
| Pacific Maritime | 48.1 | 10.7 | 2,250 | 0.24 |
| Atlantic Maritime | 15.1 | 4.7 | 1,212 | 0.06 |
| Mixedwood Plains | 14.8 | .93 | 860 | 0.01 |
| Boreal Cordillera | 41.9 | 10.7 | 500 | 0.05 |
| Taiga Plain | 54.9 | 18.1 | 500 | 0.09 |
| Prairies | 49.8 | 3.3 | 500 | 0.02 |
| **Total:** | 541.5 | 160 | | 1.35 |

**Table 6.2** Precipitation, Runoff and Evapotranspiration Rates for Seven Experimental Watersheds from Four Terrestrial Ecozones in Canada

| Representative Research Watershed | Ecozone | Precipitation - P (mm) | Runoff - R (mm)[%] | Evapotranspiration - ET* (mm)[%] |
|---|---|---|---|---|
| REVEW | Boreal Shield | 1,332 | 828.3 [62%] | 503.7 [38%] |
| Triton Brook | | 1,295 | 716.1 [55%] | 579.3 [45%] |
| Experimental Lakes | | 688 | 308.9 [45%] | 379.3 [55%] |
| Upper Penticton | Montane Cordillera | 677 | 338.5 [49%] | 328.5 [51%] |
| Carnation Creek | Pacific Maritime | 2,825 | 2,148.9 [76%] | 676.1 [24%] |
| Catamaran Brook | Atlantic Maritime | 1,184 | 630.9 [53%] | 553.0 [47%] |
| Hayward Brook | | 1,633 | 559.5 [34%] | 1,074.5 [66%] |

* Evapotranspiration calculated from water-balance (ET = P – R).

However, there is some concern that data from individual watersheds may not be transferable to other landscapes, or results may not scale up to larger areas such as ecozones (Whitehead and Robinson 1993; Buttle, Creed, and Moore 2005). Unfortunately, broad-scale runoff estimates from ecozones are not available. Runoff data have been estimated based on precipitation patterns and general watershed topography, which can be used to estimate general mean runoff estimates (Environment Canada 1993). These values can then be used to calculate mean annual actual evapotranspiration (AET) rates, based on simple water balance calculations (assuming no significant change in subsurface flows or the water table). See Table 6.3.

**Table 6.3** Mean Annual Precipitation, Runoff and Evapotranspiration Rates for Nine Forested Terrestrial Ecozones in Canada

| Ecozone | Mean Annual Precipitation (mm) | Mean Annual Runoff (mm)[%] | Mean Annual AET* (mm)[%] |
|---|---|---|---|
| Boreal Plains | 462 | 125 [27%] | 337 [73%] |
| Boreal Shield | 1,000 | 400 [40%] | 600 [60%] |
| Montane Cordillera | 550 | 350 [64%] | 200 [36%] |
| Pacific Maritime | 2,250 | 1,500 [66%] | 750 [34%] |
| Atlantic Maritime | 1,212 | 700 [58%] | 512 [42%] |
| Mixewood Plains | 860 | 400 [47%] | 460 [53%] |
| Boreal Cordillera | 500 | 400 [80%] | 100 [20%] |
| Taiga Plain | 500 | 400 [80%] | 100 [20%] |
| Prairies | 500 | 75 [15%] | 425 [85%] |

* Evapotranspiration calculated from water-balance (AET = P – R).

Applying these estimates of runoff for each ecozone to the estimates of precipitation yields an annual total of 0.67 trillion $m^3$ of runoff and 0.68 trillion $m^3$ of actual evapotranspiration. This estimate of streamflow would seem reasonable, given that Laylock (1987) suggested a total Canada-wide estimate of 3.3 trillion $m^3$, and managed forests represent roughly 14.7% of the Canadian landmass. Assuming that water resources were evenly distributed across Canada, this would yield a streamflow of 0.48 trillion $m^3$. However, given that forests tend to be associated with soils and precipitation regimes that receive greater than average levels of precipitation (Hetherington 1987), this calculation yields a result equivalent to 20% of the total streamflow of Canada.

## 6.2 Final Water Quantity Balance

Water quantity values for each element of the water profile have been derived in this report as noted in Table 6.4. The combination of these data represents the water quantity profile of the Canadian forest products industry and the results are depicted in Figure 6.1.

**Table 6.4** Report Sections from which Final Water Quantity Balance Data Originate

| Estimated Water Quantity | Section(s) |
|---|---|
| Precipitation | 6.1 |
| Evapotranspiration and streamflow | 3.1, 6.1 |
| Water in wood | 4.6, 4.13 |
| Use of surface and groundwater | 4.4, 4.12 |
| Water in non-fibre raw material | 4.7 |
| Discharge to surface water | 4.5 |
| Evaporation | 4.11, 4.13 |
| Water in residuals | 4.9 |
| Water in products | 4.10, 4.13 |
| Water in recycled fibre | 4.8 |
| Water in disposed products | 4.10, 4.13 |
| Water evaporated from products | 4.10, 4.13 |

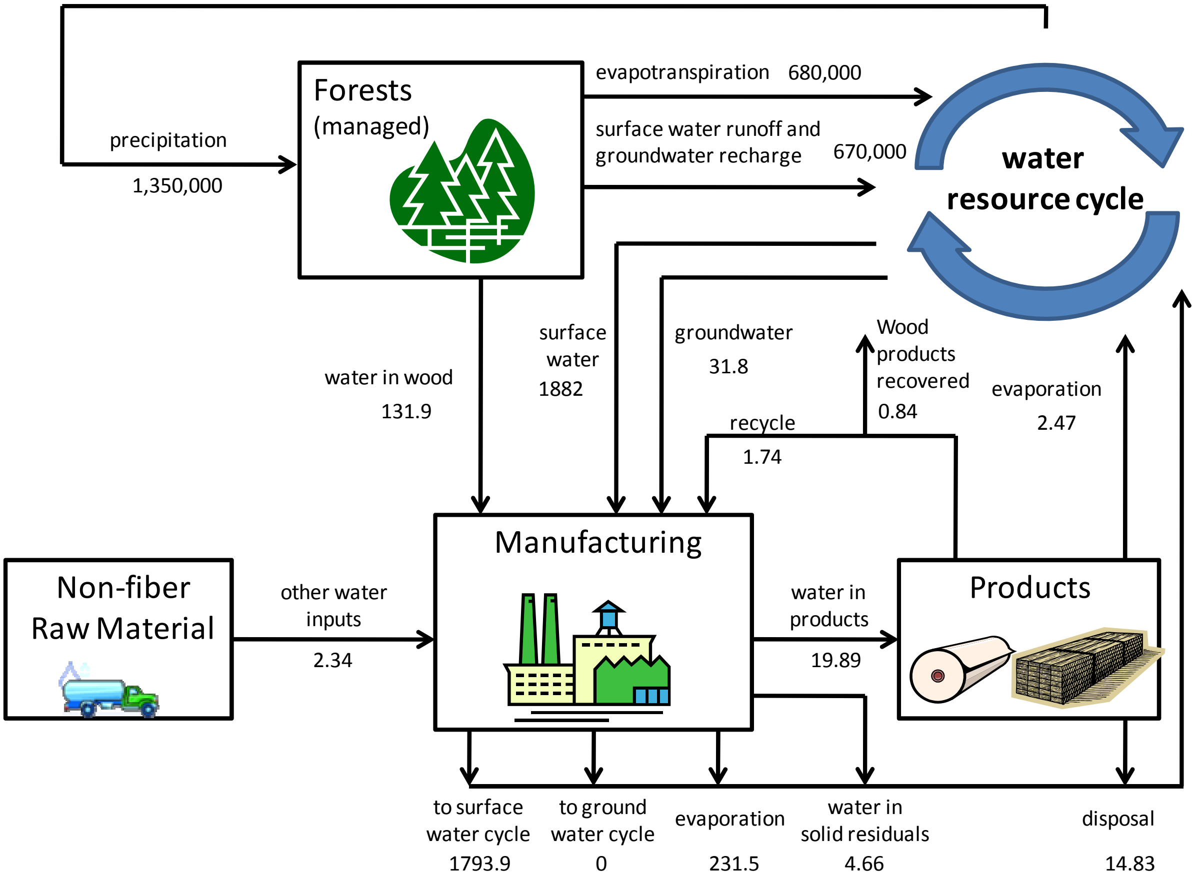

**Figure 6.1** Water Quantity Profile for the Canadian Forest Products Industry (million $m^3$/yr)

Precipitation on forestland from which forest products industry raw material may be drawn is about 1350 billion $m^3$/yr. Approximately 50% of it, 670 billion $m^3$/yr, enters surface water or groundwater. The forest products industry draws an estimated 1.91 billion $m^3$/yr, about 0.29% of the streamflow and groundwater recharge from managed forests. An additional 0.132 billion $m^3$/yr (0.01%) of precipitation on managed forests is drawn in the form of water contained in wood used to manufacture wood and paper products.

The manufacture of forest products in Canada requires about 1.91 billion $m^3$/yr of surface and groundwater, with an additional 0.136 billion $m^3$/yr entering with wood, recovered paper, and purchased non-fibre raw materials. Water from the latter sources constitutes about 7% of total inputs. Of the total water inputs (~2 billion gal/yr), about 88% is returned to surface waters as treated effluent, 11% is lost to evaporation, and the remaining 1% is present in products and solid residuals.

The water in products is returned to the water resource cycle after product use, by evaporation when used products are combusted or as a liquid when used products are disposed.

## 7.0 SUMMARY AND CONCLUSIONS

Fresh water resources are under increasing scrutiny as they relate to industrial activities, urban and rural development, changes in land use practices. In the future, these resources may be affected by possible long-term alterations in precipitation patterns and hydrologic processes. The total volume of fresh water withdrawn in Canada is dominated by thermoelectric power generation, manufacturing industries, agricultural activities, and domestic use. Within the manufacturing category, the Canadian forest products industry is among the largest water users, although, in contrast to other industrial sectors, the vast majority of water used is returned to surface waters. Over the last fifteen years, Canadian pulp and paper mills have greatly improved water reuse and conservation.

Precipitation regimes and hydrology vary extensively across Canadian forests. Precipitation onto managed forestlands, as well as streamflow, groundwater recharge and evapotranspiration from these areas, were calculated using annual precipitation and runoff data from nine geographical ecozones. Estimates of the amount of water used in forest products manufacturing were developed by considering water from surface and ground sources as well as water contained in wood, non-fibre raw material, and recycled fibre supplies. Estimates of water discharged to surface water and contained in products and solid residuals were also undertaken. Water consumptive losses from various manufacturing processes were also estimated, to the extent possible.

Forest harvesting typically results in decreased interception loss and evapotranspiration, and a short-term increase in annual runoff or water yield. However, increases in runoff and changes to the distribution and timing of that runoff are highly variable between the basins examined in this work. These large differences may be related to variable climatic conditions and forest cover types. For many regions in Canada, melting snow is the main source of water for streamflow and often results in peak flows during spring melting of the snowpack.

Forest watersheds typically produce very high quality water due to the erosion protection provided by the forest vegetation, forest floor and soils, and the dominant subsurface flow pathways delivering water to streams and lakes. Forest harvesting may reduce or remove the effectiveness of forest watershed conditions, and thus may also lower water quality. Provincial regulations and forestry best management practices act to control the potential effects of forest harvesting on water quality and forest hydrology. On the other hand, natural disturbances (e.g., wildfire or insect infestations) can often change water quality far beyond changes resulting from harvesting practices by increasing the exposure of streams to increased sediment loads, temperatures, and nutrient concentrations.

Forest watersheds function differently from urban or agricultural watersheds, primarily due to the existence and persistence of large perennial vegetation, both alive and dead. These features provide for rapid infiltration and generally reduce the potential for peak flows. Given that the vast majority of forested land in Canada is publicly owned, the conversion of forests to alternative land uses is relatively infrequent.

With respect to water quantity, about one-third of the fresh surface waters in Canada are produced from total forested lands. Roughly 41% of this area is considered suitable and available for harvesting. These woodlands receive 1.35 trillion $m^3$/yr of precipitation and produce roughly 0.67 trillion $m^3$/yr of streamflow. The forest products industry's manufacturing operations draw an estimated 1.91 billion $m^3$/yr, i.e., about 0.3% of the streamflow from managed forests. Of the water used by manufacturing processes, about 93% is obtained from surface or groundwater sources. Approximately 88% is returned directly to surface waters following treatment; about 11% is converted to water vapour in the pulp, paper, and wood products manufacturing and wastewater treatment processes; and about 1% is imparted to products or solid residuals.

Federal regulations establish stringent standards for BOD and TSS, and require final effluents to be non-acutely lethal to fish. Effluent discharge trends of BOD, TSS, adsorbable organic halides (AOX), and dioxins and furans from Canadian pulp and paper mills show substantial declines since the late 1980s. Federal regulations also require mills to conduct receiving environment studies, coupled with laboratory testing for sub-lethal toxicity, to assess the effectiveness of environmental management measures.

The quality of effluents from pulp and paper manufacturing operations and the potential for these effluents to impact the stability of aquatic communities resident in receiving water streams has been, and continues to be, the subject of considerable scientific research. Laboratory testing and artificial stream assessment of aquatic organisms exposed to these effluents, at different concentrations, have shown variable effects on organism survival, growth or reproductive capacity. In contrast, extensive in-stream studies carried out to date suggest that treated pulp and paper mill effluents have little effect on aquatic community structure, and that naturally occurring variations in habitat conditions may have a greater influence on community patterns.

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# APPENDIX A

# PULP AND PAPER MILL CATEGORIZATION SCHEME

## MILL CATEGORIZATION SCHEME

In order to make comparisons of mill environmental performance as meaningful as possible, mills were grouped based on the types of pulp produced on site and by the products manufactured. The scheme was based in large part on the subcategories use by EPA in its most recent effluent guidelines development work. The categories chosen and their description are detailed here.

1. Bleached kraft Integrated (BKI). Mills that produce paper, market pulp, or bleached board whose total fibre contains at least 75% bleached kraft pulp produced on site, where market pulp represents less than 67% of total product.

2. Bleached kraft Market Pulp (BKP). Mills that produce paper, market pulp, or bleached board whose total fibre contains at least 75% bleached kraft pulp produced on site, where market pulp represents at least 67% of total product.

3. Bleached kraft Other (BKO). Mills that produce bleached kraft or soda pulp comprising at least 18% and less that 75% of the fibre contained in final products. These mills make an assortment of final products that may incorporate mechanical pulps, secondary fibre, or purchased fibre.

4. Unbleached kraft 1 (UK1). kraft mills whose final products contain at least 85% unbleached kraft or semi-chemical pulps produced on site.

5. Unbleached kraft 2 (UK2). kraft mills whose final products contain less than 85% unbleached kraft or semi-chemical pulps produced on site. The balance of the fibre furnish may include non-deinked secondary fibre, mechanical pulps, or up to 18% bleached kraft pulp.

6. Semi-Chemical (SC). Mills producing corrugating medium from semi-chemical pulps produced on site and non-deinked secondary fibre. They may also produce linerboard from recycled fibre.

7. Mechanical (MECH). Mills whose final products are made primarily of mechanical pulp manufactured on site. No chemical pulps are produced on site.

8. Deinked Market Pulp (DIP). Mills that market pulp from deinked secondary fibre produced on site.

9. Deinked Tissue/Fine Papers (DTF). Mills that produce tissue/towelling or fine papers from deinked secondary fibre produced on site.

10. Deinked Newsprint (DNWS). Mills that produce newsprint from deinked secondary fibre produced on site.

11. Recycled Containerboard (RCTR). Mills that produce linerboard and corrugating medium, typically on Fourdrinier machines, from non-deinked secondary fibre produced on site.

12. Recycled Boxboard (RBOX). Mills that produce boxboard, tube stock, and similar products, typically on cylinder machines, from non-deinked secondary fibre produced on site.
13. Non-Integrated Fine or Lightweight Papers (NIF). Mills that produce fine or lightweight papers from purchased fibre.
14. Non-Integrated Other Papers (NIO). Mills that produce tissue, filter, or other papers from purchased fibre.
15. Sulphite Dissolving Pulp (SULD). Mills that produce dissolving grade sulphite pulps.
16. Sulphite Papergrade (SULP). Mills that produce paper primarily from sulphite pulp produced on site.
17. Bleached Chemi-Thermomechanical (BCTMP). Mills that make bleached chemi-thermomechanical market pulps.

# APPENDIX B

# OVERALL WATER BALANCE

A water balance was calculated for each mill entry, ensuring that a water balance was maintained for the Canadian forest products industry as a whole. Final effluent data were supplied by FPAC survey results and from the Fisher Pulp&Paper Worldwide™ database. Coefficients used to calculate consumptive water losses from processes and evaporative losses from secondary wastewater treatment are functions of influent data, so an iterative approach was adopted to converge upon an influent flow amount that simultaneously satisfies the two equations for the process water consumption coefficient. The calculational approach is detailed in Figure B.1.

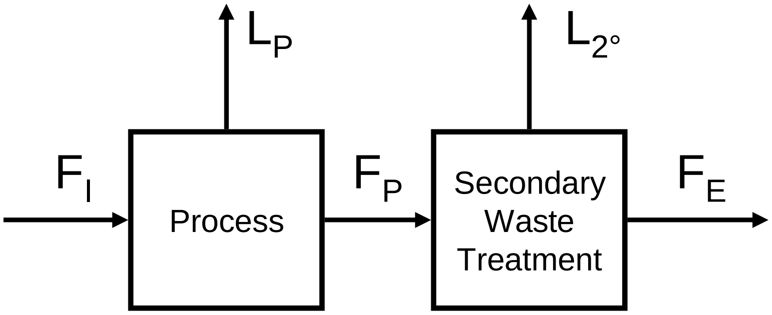

**Figure B.1** Mill Water Balance Components Considered in the Water Profile Work

where: $F_I$ = total fresh water usage (surface and groundwater + water in raw material + water in purchased chemicals)
$L_P$ = process water losses (process evaporative losses + water losses in product + water losses in solid residuals)
$F_P$ = effluent exiting process and entering secondary wastewater treatment
$L_{2°}$ = secondary wastewater treatment evaporative losses
$F_E$ = final effluent

Water contained in wastewater treatment solid residuals (primary clarifier sludge, secondary clarifier sludge, and sludge dredged from ASBs) is accounted for with total solids residuals generation, which is incorporated into process water losses, $L_P$.

Known:

$F_E$, final effluent flow, is taken directly from FPAC data and the Fisher database

$A$ and $b$ are coefficients used to calculate process consumptive water losses as a function of total fresh water usage, $F_I$; coefficients $A$ and $b$ vary by pulp manufacturing type and are found in Table 4.17 of this document.

$x$ is a coefficient used to calculate evaporative losses from secondary wastewater treatment as a function of total flow into secondary wastewater treatment, $F_P$; coefficient $x$ varies by waste treatment system type and are reported in Section 4.11 of this document.

Wanted:

$F_P$ and $F_I$

Evaporative losses from secondary wastewater treatment are calculated via Equation B1.

$$L_{2^\circ} = \frac{x \cdot F_E}{(1-x)} \qquad \text{(Eq B1)}$$

Effluent leaving the process is calculated via Equation B2.

$$F_P = F_E + L_{2^\circ} \qquad \text{(Eq B2)}$$

The water consumption coefficient was defined by Equation 2 in Section 4.11 of the report. Full mill water balance results available in the literature and estimates of evaporative losses from different mill types based upon independent engineering calculations have been regressed to a power law equation that is a function of total fresh water usage, Equation 3 in Section 4.11. The equations for the water consumption coefficient are reproduced in Equation B3.

$$\mathrm{E} = L_P / F_I = f(F_I) = A \cdot {F_I}^{b} \qquad \text{(Eq B3)}$$

where: E = water consumption coefficient

Total fresh water flow is the sum of effluent flow leaving the process and total process losses (Equation B4).

$$F_I = F_P + L_P \qquad \text{(Eq B4)}$$

Use Equation B5 to set the equations for the water consumption coefficient equal to each other.

$$A \cdot {F_I}^{b} - L_P / F_I = 0 \qquad \text{(Eq B5)}$$

Insert Equation B4 into Equation B5 and iterate upon an LP that satisfies Equation B6.

$$A \cdot (F_P + L_P)^{b} - L_P / (F_P + L_P) = 0 \qquad \text{(Eq B6)}$$

Once LP is known, use Equation B4 to calculate $F_I$.

# APPENDIX C

# OVERALL WOOD MASS BALANCES FOR WOOD PRODUCTS SECTORS

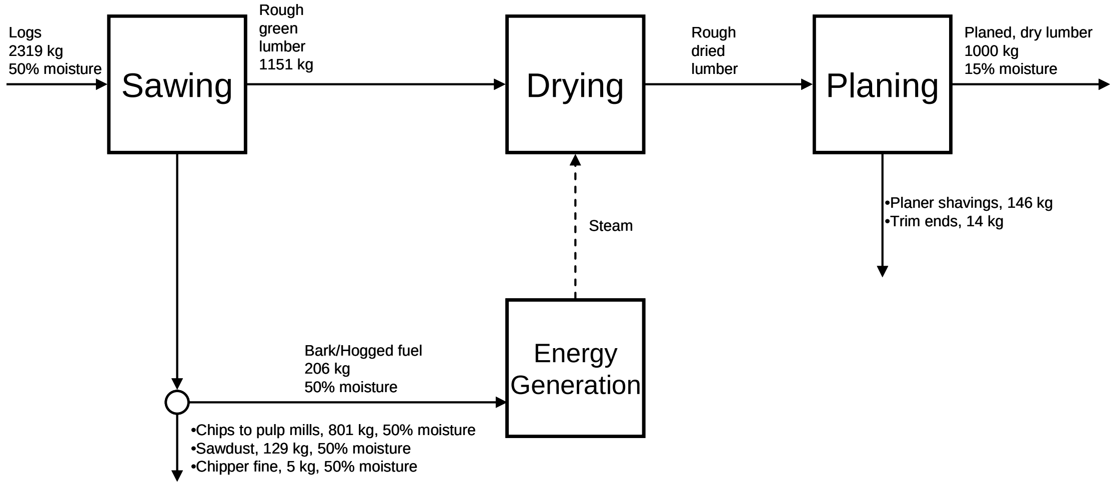

**Figure C.1** Softwood Lumber Mill Weighted Average from 15 Facilities
[wood mass balance extracted from FPInnovations 2009]

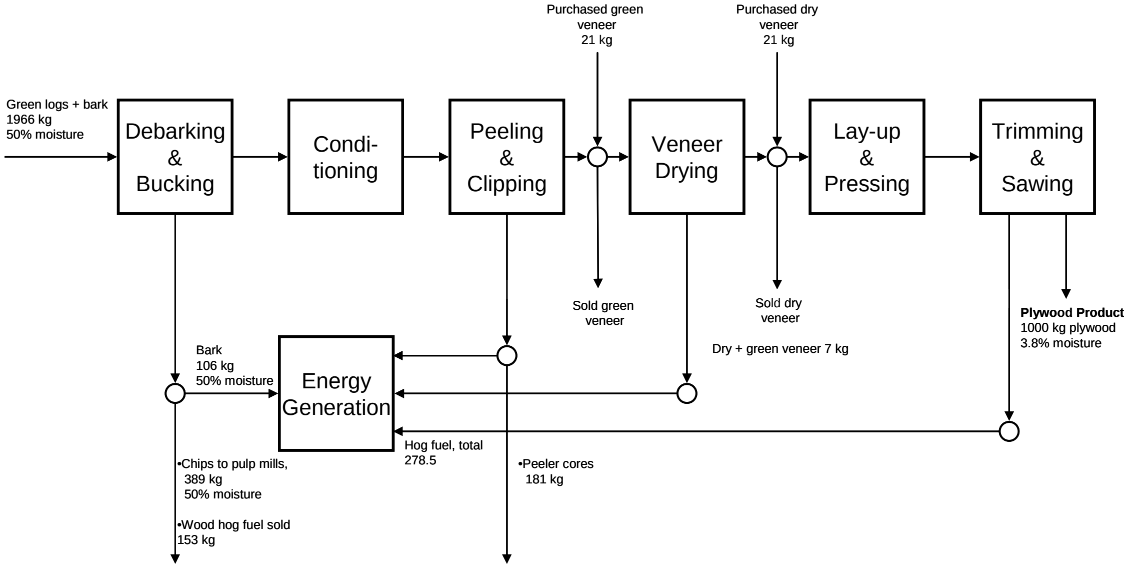

**Figure C.2** Softwood Plywood Mill Weighted Average from Three Facilities,
Wood (dry) Mass Balance
[wood mass balance extracted from FPInnovations 2009]

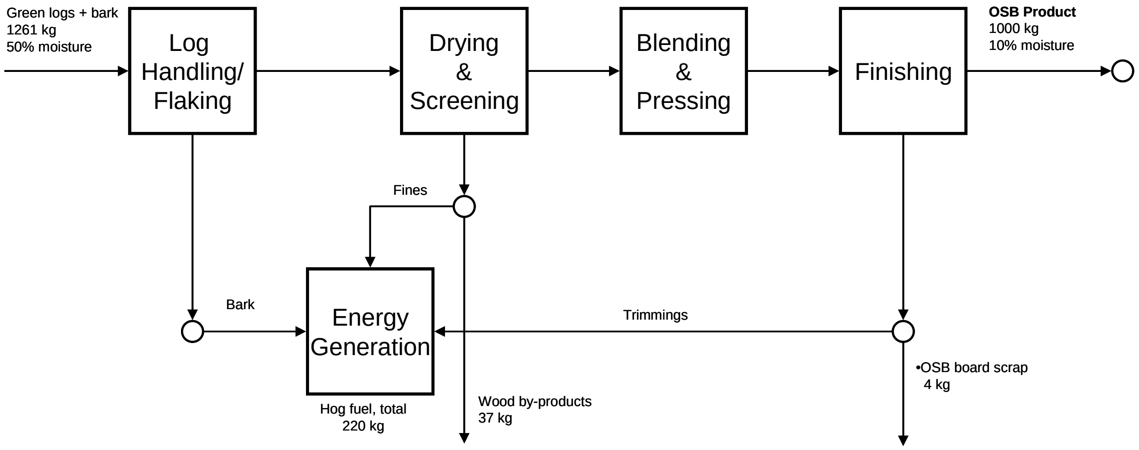

**Figure C.3** Oriented Strandboard Mill Weighted Average from Four Facilities, Wood (dry) Mass Balance
[wood mass balance extracted from FPInnovations 2009]

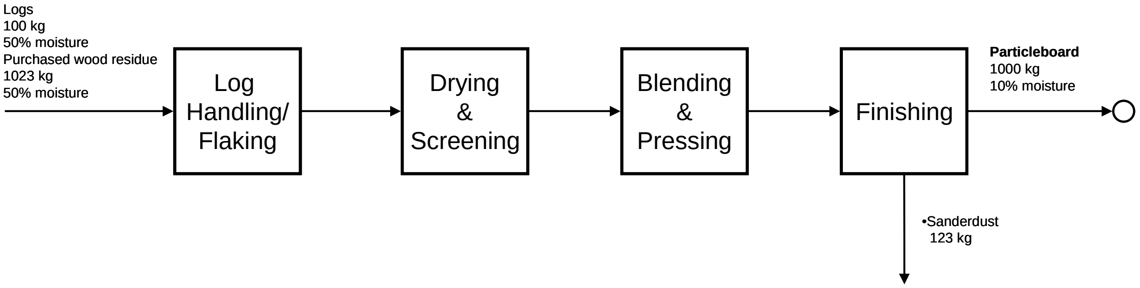

**Figure C.4** Particleboard Mill Weighted Average from Three Facilities, Wood (dry) Mass Balance
[wood mass balance extracted from FPInnovations 2009]

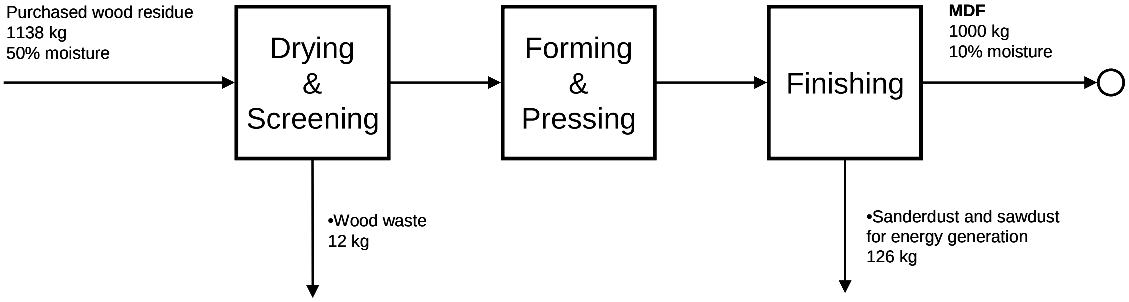

**Figure C.5** MDF Mill Weighted Average from Four Facilities, Wood (dry) Mass Balance
[wood mass balance extracted from FPInnovations 2009]

**Table C.1** Water Flows for Water Originating from the Raw Material for Canadian Wood Products Industry

| Category | Production[a] | Water in raw materials (logs, bark, purchased veneer)[b] | Water in products and co-products except chips and hogged fuel[b] | Water in wood chips[b] | Evaporative losses from drying and/or pressing (by balance)[b] | Evaporative losses from energy generation[b] |
|---|---|---|---|---|---|---|
| Softwood and hardwood lumber | 43.4 | 100.7 | 14.6 | 34.8 | 41.7 | 9.7 |
| Softwood plywood | 2.0 | 4.0 | 0.8 | 0.78 | 1.9 | 0.56 |
| Oriented strandboard and waferboard | 9.1 | 11.5 | 1.4 | - | 8.1 | 2.0 |
| Particleboard | 0.9 | 1.0 | 0.10 | - | 0.9 | |
| Medium-density fibreboard (MDF) | 1.0 | 1.04 | 0.10 | - | 0.85 | 0.08 |
| Hardboard and insulation board | 0.1 | 0.15 | 0.01 | - | 0.12 | 0.01 |
| Total | 56.6 | 118.5 | 16.9 | 35.6 | 53.6 | 12.4 |

[a] million mt product/yr

[b] million m3/yr