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NATIONAL COUNCIL FOR AIR AND STREAM IMPROVEMENT

WATER PROFILE OF THE UNITED STATES FOREST PRODUCTS INDUSTRY

TECHNICAL BULLETIN NO. 960

MARCH 2009

by

Camille Flinders, Dr. George Ice, Dr. Barry Malmberg, and Paul Wiegand

NCASI

Acknowledgments

This bulletin is the result of a collaborative effort between researchers in NCASI's Water, Forest Environment, and Aquatic Biology Programs. Primary authors are listed below. The authors would like to thank Jay Unwin and Laurel Eppstein of the NCASI Northern Regional Center for their assistance with management of mill-specific data on water use.

NCASI also acknowledges and very much appreciates the technical support and suggestions offered by the advisory task group that guided this project. Those individuals were Phil Pagoria, Weyerhaeuser Company (Chairperson); Rich Garber, Boise, Inc.; Ray Andreau, Buckeye Technologies Inc.; Robert Sackellares, Georgia-Pacific Corporation; Steve List, NewPage Corporation; Julie Dieu, Rayonier Inc.; Ken Harris and Mayes Starke, Smurfit-Stone; Jami Nettles and Bob Emory, Weyerhaeuser Company; and Jerry Schwartz and Chip Murray, American Forest and Paper Association.

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Cite this report as:

National Council for Air and Stream Improvement, Inc. (NCASI). 2009. *Water profile of the United States forest products industry*. Technical Bulletin No. 960. Research Triangle Park, NC: National Council for Air and Stream Improvement, Inc.

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PRESIDENT'S NOTE

Stewardship programs for water resources are among the most prominent aspects of environmental management actions employed by the forest products industry. Widespread application of water use reduction techniques, modern wastewater treatment, best management practices to protect forest streams, and instream monitoring programs exemplify this commitment to maintaining the quality and quantity of water available for use in the United States. The significance of these efforts has been considered, individually, in numerous publications by NCASI and others. Until this report, however, the connection between water resources and the entirety of forest products operations in the U.S. had not been assessed.

Activities of the forest products industry that have potentially important effects on water resources include i) the maintenance and procurement of wood inventory in forests and ii) the manufacture of wood, pulp, and paper products. This report provides a comprehensive assessment for both the quantity of water that is associated with forest products industry operations and the potential for these operations to alter the quality of that water.

The findings from this work place the role of the forest products industry in context with water resource issues currently under consideration in the United States. For example, it is well known that the U.S. forest products industry is among the largest of industrial users of process water, but it is less well known that most of this water, approximately 88%, is treated and returned to surface waters. Forest lands in the U.S. yield about two-thirds of the nation's fresh water resource, and this water is of the highest quality relative to that derived from other land uses such as agricultural or urban uses. Further, through its use of wood fiber in combination with sustainable forestry practices, the industry provides an incentive for land owners to keep land under forest cover, thereby ensuring the continued availability of high quality surface waters. Overall, water use by the forest products industry is estimated to be just 0.4% of that released from forested lands in the U.S. from which timber might be harvested.

The details contained in this report will be helpful to members evaluating aspects of their 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 U.S. forest products industry and the nation's water resources.

Ronald A. Yeske

March 2009

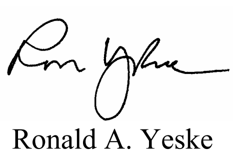
MOT DU PRÉSIDENT

Les programmes de gérance environnementale des ressources hydriques comptent parmi les aspects les plus importants des actions de gestion environnementale de l'industrie des produits forestiers. L'application répandue des techniques de réduction de l'utilisation d'eau, les systèmes modernes de traitement des eaux usées, les meilleures pratiques de gestion visant à protéger les cours d'eau en milieu forestier et les programmes de suivi de la qualité de l'eau des cours d'eau constituent des exemples qui démontrent cet engagement envers le maintien de la qualité et de la quantité d'eau disponible aux États-Unis. NCASI a accordé de l'importance à ces efforts dans de nombreuses publications, de façon individuelle. Jusqu'à la publication de ce rapport toutefois, l'interconnexion entre les ressources hydriques et l'ensemble des opérations forestières aux États-Unis n'a pas fait l'objet d'une évaluation.

L'industrie des produits forestiers réalisent des activités qui peuvent potentiellement générer des effets sur les ressources hydriques. Ces activités consistent en l'entretien et l'approvisionnement en matière ligneuse issue des forêts et la fabrication de produits du bois, de pâtes et de papiers. Ce rapport présente une évaluation exhaustive de la quantité d'eau utilisée dans les opérations de l'industrie des produits forestiers et du potentiel d'altération de la qualité de cette eau par ces mêmes opérations.

Les résultats de cette étude situent le rôle de l'industrie des produits forestiers dans le contexte des enjeux des ressources hydriques faisant actuellement l'objet de discussions aux États-Unis. Par exemple, il est bien connu que l'industrie des produits forestiers américaine compte parmi les plus grands utilisateurs industriels d'eau de procédé mais il est moins connu que la grande majorité de cette eau, approximativement 88%, est traitée et retournée dans les eaux de surface. Les territoires forestiers aux États-Unis produisent environ deux tiers des ressources d'eau douce du pays et cette eau est de la plus grande qualité, en comparaison avec l'eau issue d'autres utilisations du territoire comme l'agriculture ou les zones urbaines. De plus, en utilisant la fibre ligneuse dans le cadre de pratiques de foresterie durable, l'industrie fournit un incitatif aux propriétaires forestiers pour garder le couvert forestier ce qui a pour effet d'assurer la disponibilité en continue d'une eau de surface de qualité. Globalement, l'industrie des produits forestiers utilise seulement 0,4% de l'eau s'écoulant des territoires forestiers américains dans lesquels une récolte forestière est susceptible d'être effectuée.

Les informations détaillées contenues dans ce rapport seront utiles aux membres qui évaluent les composantes de leurs programmes actuels de gestion environnementale reliées à l'utilisation d'eau. Également, ce bulletin sera utile lors du développement de politiques régionales sur l'eau, car grâce aux données quantitatives, il permet d'améliorer la compréhension de l'interconnexion entre l'industrie américaine des produits forestiers et les ressources hydriques nationales.



Ronald A. Yeske

Mars 2009

WATER PROFILE OF THE UNITED STATES FOREST PRODUCTS INDUSTRY

TECHNICAL BULLETIN NO. 960
MARCH 2009

ABSTRACT

The intersection between water resources and forest products operations in the United States is considered. The profile includes the quantity of water potentially impacted by forest management for sourcing of wood and fiber as well as water used during manufacture of wood, pulp, and paper products. The influence of forest management and forest products manufacture on water quality is also discussed. Most fresh water in the U.S. originates in forested areas. While forest management for timber harvest has the potential to alter the fate and quality of water entering the forest via precipitation, responsible harvesting strategies, best management practices, and forest regrowth combine to minimize or eliminate changes in water availability and degradation of water quality over the landscape. Relative to alternative land uses and large-scale disturbance events, forested areas produce the highest quality of fresh water. Water inputs for the manufacture of forest products equal about 0.4% of the surface and groundwater yield from timberland in the U.S. Approximately 88% of this water is treated and returned directly to surface waters, about 11% is converted to water vapor and emitted during the manufacturing process, and 1% is imparted to products or solid residuals. Extensive study and continued monitoring of treated effluents suggests few or no concerns regarding the compatibility of these effluents with healthy aquatic systems.

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. 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.*

Special Report No. 07-09 (October 2007). *Greenhouse gas and carbon profile of the Canadian forest products industry.*

Special Report No. 07-02 (February 2007). *Greenhouse gas and carbon profile of the global forest products industry.*

ÉTAT DE LA RESSOURCE HYDRIQUE EN RELATION AVEC LES ACTIVITÉS DE L'INDUSTRIE AMÉRICAINE DES PRODUITS FORESTIERS

BULLETIN TECHNIQUE N^{O} 960
MARS 2009

RÉSUMÉ

Ce rapport présente l'interconnexion entre les ressources hydriques et les opérations forestières américaines. Il traite de la quantité d'eau potentiellement affectée par l'aménagement forestier lors de l'approvisionnement en bois et en fibres, de même que l'utilisation d'eau lors de la fabrication de produits du bois, de pâtes et de papiers. Le rapport comporte une discussion sur l'influence de l'aménagement forestier et de la fabrication des produits forestiers sur la qualité de l'eau. La plupart des ressources d'eau douce aux États-Unis origine des territoires forestiers. Même si l'aménagement forestier visant la récolte de bois est susceptible d'affecter le devenir et la qualité de l'eau atteignant la forêt lors des précipitations, les stratégies responsables de récolte, les meilleures pratiques de gestion et la régénération de la forêt œuvrent en synergie pour minimiser ou éliminer les changements de disponibilité de l'eau ainsi que la dégradation de la qualité de l'eau à travers le paysage. Comparativement aux autres usages du territoire et aux perturbations à large échelle, les zones forestières produisent une eau douce de la plus haute qualité. Les apports en eau utilisés pour la fabrication de produits forestiers correspondent à environ 0,4% du rendement en eau de surface et en eau souterraine des régions boisées aux États-Unis. Approximativement 88% de cette eau est traité et retourné directement vers les eaux de surface, environ 11% est converti en vapeur d'eau et émis lors de la fabrication et 1 % est réparti dans les produits ou les résidus solides. Une étude exhaustive des effluents traités ainsi qu'un suivi environnemental en continu révèlent peu ou pas de préoccupations reliées à la compatibilité de ces effluents avec des systèmes aquatiques sains.

MOTS CLÉS

Biote aquatique, effluent, évaporation, évapotranspiration, empreinte, aménagement forestier, habitat, papier, aménagement du territoire, utilisation d'eau dans le procédé, pâte, consommation d'eau, qualité de l'eau, quantité d'eau

AUTRES PUBLICATIONS DE NCASI DANS CE DOMAINE

Bulletin technique n° 946 (février 2008). *Estimating water consumption at pulp and paper mills.*

Bulletin technique n° 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 UNITED STATES FOREST PRODUCTS INDUSTRY

1.0 INTRODUCTION

Public and political discourse concerning the appropriate use and management of water resources has become increasingly common in recent years. Localized drought conditions in some parts of the world and floods in others, the potential for climate change to alter water resource availability, and limitations on access to water brought about by changing population dynamics and land use practices contribute to arguments for increased management of water resources. It is to be expected, therefore, that those entities with vested interests in the maintenance of water resources, for whatever use, will be participants in the dialogue.

The forest products industry's manufacturing operations are among the largest industrial water users and thus figure prominently in local and regional discussions concerning water resource decisions. During such discussions, it has frequently been observed that other water resource stakeholders are unfamiliar with the water management practices of the forest products industry. In particular, stakeholders are largely unaware of the role forests and manufacturing play in the availability and quality of water resources. The aim of this report is to describe the water profile of the U.S. forest products industry in a holistic fashion so the influence of forest products company activities on water resources can be better understood from a quantitative as well as a qualitative standpoint.

Activities of the forest products industry that have potentially important effects on water resources include the maintenance and procurement of wood inventory in forests and the manufacture of wood, pulp, and paper products. Accordingly, two sections of this report are devoted to the quantitative and qualitative impacts of forest management and wood, pulp, and paper manufacturing on water resources. Separate sections are devoted to the quality of water emanating from managed forest lands and treated effluents from manufacturing operations. The latter section describes effluent quality trends in recent years and reviews extensive research where the potential for treated effluent discharges to affect the structure of aquatic communities has been under investigation.

This report is similar in some respects to other NCASI publications that have considered the carbon and greenhouse gas profiles of the forest products industry. An important difference between this profile and those related to carbon is that water, in liquid and gaseous forms, is essentially a short-rotation material. Unlike carbon, water is not stored in deep geologic deposits, nor is it "mined" in significant quantities that alter the mass available in the surface and near-subsurface (e.g., groundwater) biosphere. Because the mass of water is conserved, the influence of industrial and human use is to alter the form and fate of water relative to its form and fate in an otherwise unaltered system. It is in this context that the water profile of the U.S. forest products industry is considered.

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.

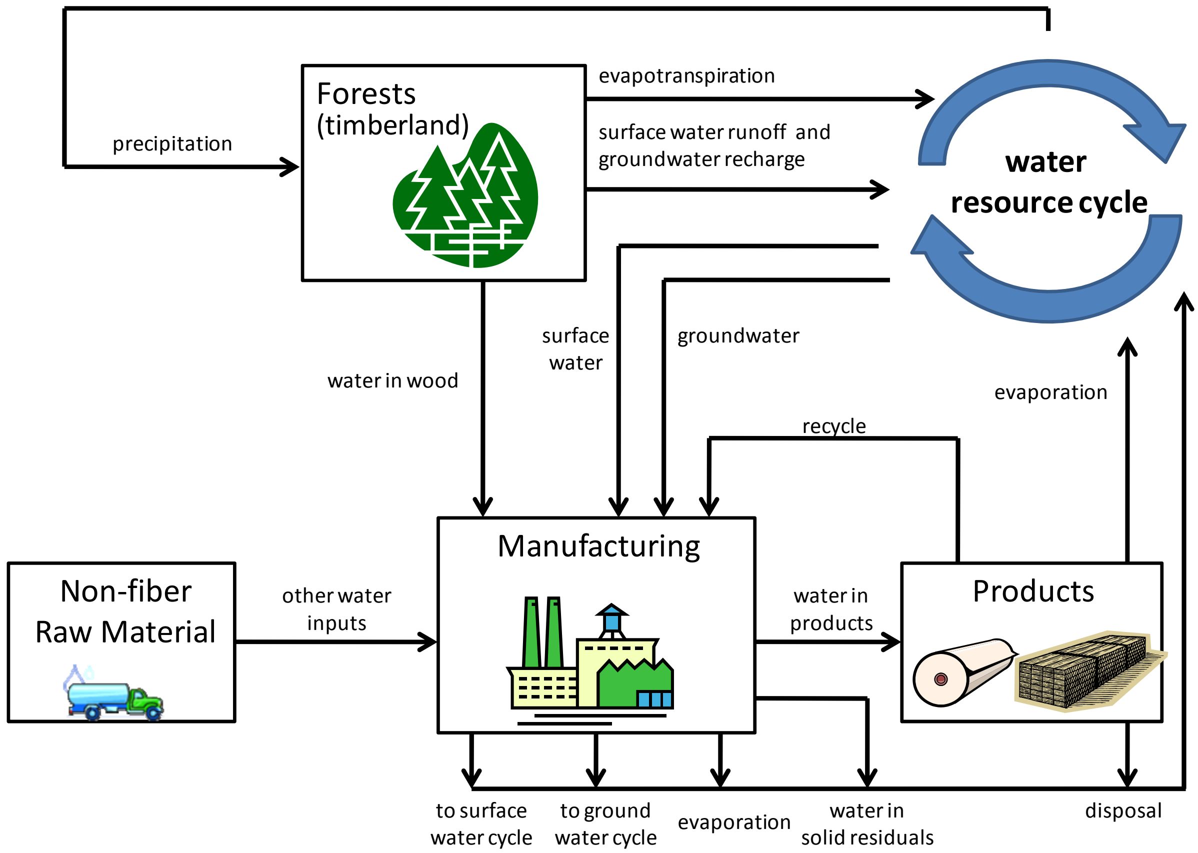


Figure 2.1 Connection of the Forest Products Industry to the Water Cycle

2.1 Forests and Forest Management

The forest products industry is unique in its reliance on land that is held in forest. Either by direct or indirect means, the industry ensures maintenance of productive forest lands, and through them a sustainable source of raw material for the manufacture of forest products. Protection and maintenance of forestland not only serves to ensure access to fiber 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 vapor (throughout this report NCASI will generally use only the term evapotranspiration, but this includes water vapor 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 forest lands 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 vapor 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 state best management practices (BMPs) or Forest Practices Act rules (state regulations designed to ensure reforestation and protection of environmental values including water quality and fish habitat) 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 forest lands are susceptible to landslides or where mechanical site preparation or ground-based yarding 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 regrowth 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. 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
	forest roads

2.2 Manufacturing

The total volume of fresh water withdrawn in the U.S. is dominated by irrigation, thermoelectric power generation (mostly cooling water), and public water supply. Industrial fresh water use ranks below those uses (Hutson et al. 2004). Within the industrial category, the forest products industry is among the larger users of fresh water, although, unlike some other industrial water users, the majority of water used is returned to surface waters (NCASI 2008). Over the last several decades, pulp and paper mills have greatly improved water reuse and conservation efforts such that the amount of water used for raw material processing has decreased by more than 50% since the mid-1970s (Figure 2.2).

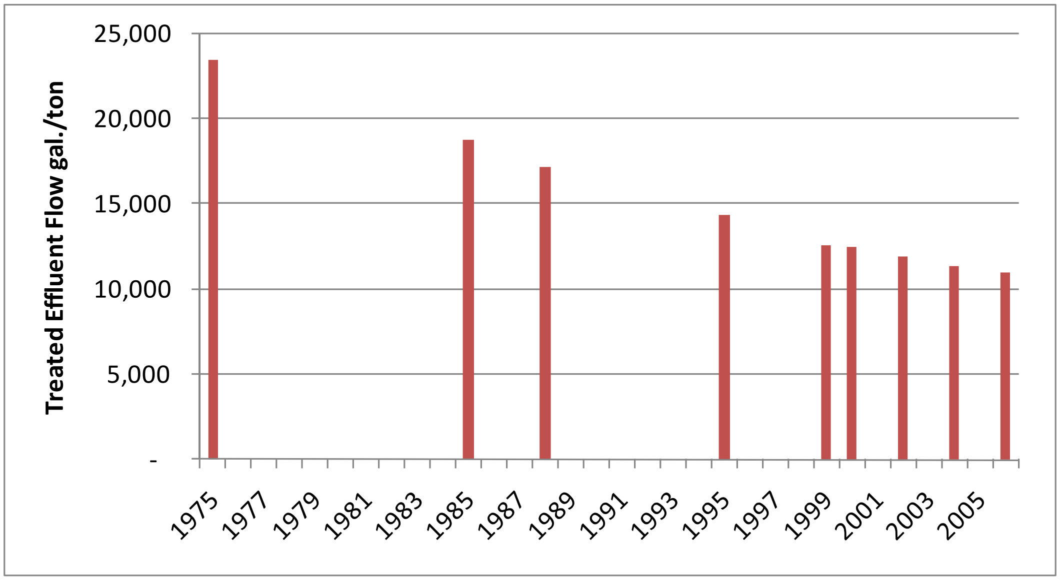


Figure 2.2 Production-Weighted Mean Process Water Discharges for U.S. Pulp and Paper Production [see note in Section 5.1 concerning data shown]

Primary water inputs to forest products manufacturing operations are from surface or groundwater supplies. Additional water enters the process with wood, recovered fiber, and, to a lesser extent, non-fiber inputs. Water exports include treated wastewater, water used for process cooling, water vapor emitted to the atmosphere, water contained in finished products, and water leaving the process with solid residuals, including wastewater residuals.

In the U.S., process wastewaters are biologically or otherwise treated to standards set by local regulating bodies. Further, it is becoming more common for mills to apply processing technology and wastewater treatment practices that are consistent with recognized Best Available Treatment (BAT) practices. Where such practices are insufficient to protect receiving waters, local environmental agencies require additional actions or treatment to provide the needed protection. In this way, effluent quality is made to be consistent with water resource quality objectives set by local agencies.

Section 4 of this report details water management in pulp and paper manufacturing operations, focusing on the quantity used, internal water recycling practices, and quantities released as treated liquid effluent, water vapor, and with products. Water entering the process with non-fiber raw materials and process chemicals is also discussed.

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, filterable (suspended) solids, 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. NCASI's findings from its Long-Term Receiving Water Studies (LTRWS) figure prominently. The LTRWS was initiated in 1998 and represents a comprehensive sampling and data collection effort on four representative U.S. pulp and paper mill effluent receiving waters. The objectives of this ongoing 10-to 20-year study are to investigate whether there are differences in downstream aquatic communities (relative to upstream reference sites) due to point source effluent discharges and, if there are differences, to determine the physical or chemical agents responsible and their biological significance.

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 forest lands 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 fiber, but also to sustain key environmental attributes of the land, including important components of the water cycle. The quantity of water coming from forests and the influence of forest management on streamflow and other water quantity concerns are discussed first; then the impacts of the forest products industry on the quality of water coming from managed forests are reviewed.

3.1 Quantity of Streamflow from Managed Forests

Almost two-thirds of fresh water runoff in the United States originates from forested watersheds (Stein et al. 2005), even though forests cover only one-third of the nation. Forests are typically adapted to regions with higher precipitation than other natural cover types. In a January 3, 2003, letter to the *New York Times,* former Chief of the Forest Service Mike Dombeck wrote that "…water is perhaps the most important forest product" (http://tinyurl.com/62coco).

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 vapor via evapotranspiration. The remaining water supplements groundwater supplies or flows from forest lands as streamflow. The timing of water outputs as groundwater recharge or streamflow is determined by inputs and storage in snowpacks, 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.

Foresters have long recognized the importance of water as part of forest management. Croft and Hoover (1951) anticipated some policy and management issues of today by stating that "the forestry professional must assume responsibility for water management of forest lands as well as for timber management." They predicted that public support to manage forests was dependent not only on perpetuating timber supplies but also on favorable water supplies. They described how forests function to affect streamflow and water yields and noted that "water that enters the forest as precipitation is first stored…" The soil and geologic mantle are "by far the greatest reservoir for water storage…"

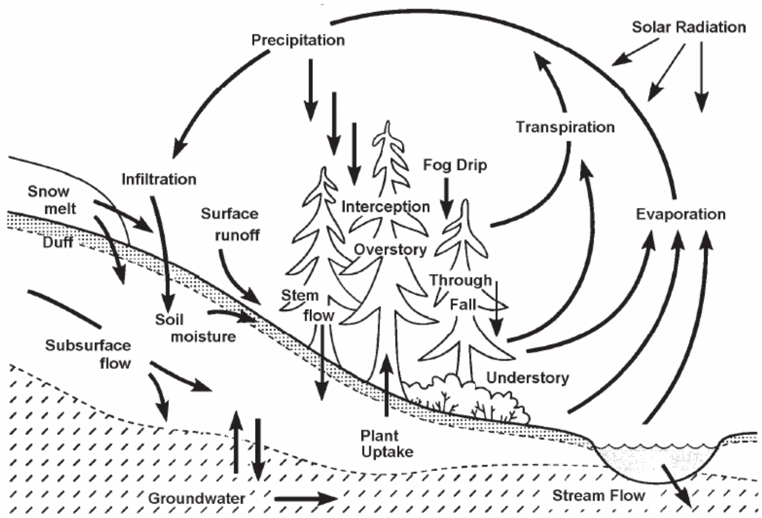


Figure 3.1 Forest Hydrologic Cycle
[http://www.forrex.org/streamline/ISS24/streamline_vol7_no1.pdf]

3.1.1 *Influence of Forest Management on Hydrologic Processes*

Forest management can influence various mechanisms that affect water storage, groundwater recharge, and streamflow by removing or rerouting water. Forest management can alter interception losses by the forest canopy, evapotranspiration and sublimation, snowpack melt rate, and infiltration. Croft and Hoover (1951) concluded that "water yield from forests can be materially increased or decreased as changes in forest cover alter water losses from interception and evapotranspiration." They also went beyond a simple assessment of changes in water yields to consider ***when*** streamflow was occurring and the specific mechanisms contributing to changes in streamflow. They recognized that some important forest functions could vary in different regions and might necessitate different forest management strategies. An example of this can be found in the hydrographs (graphs showing flow versus time) from different parts of the United States (Figures 3.2 and 3.3) that show peak discharges (streamflows) occurring at different seasons, some as a result of rainfall patterns and other in response to snowmelt runoff.

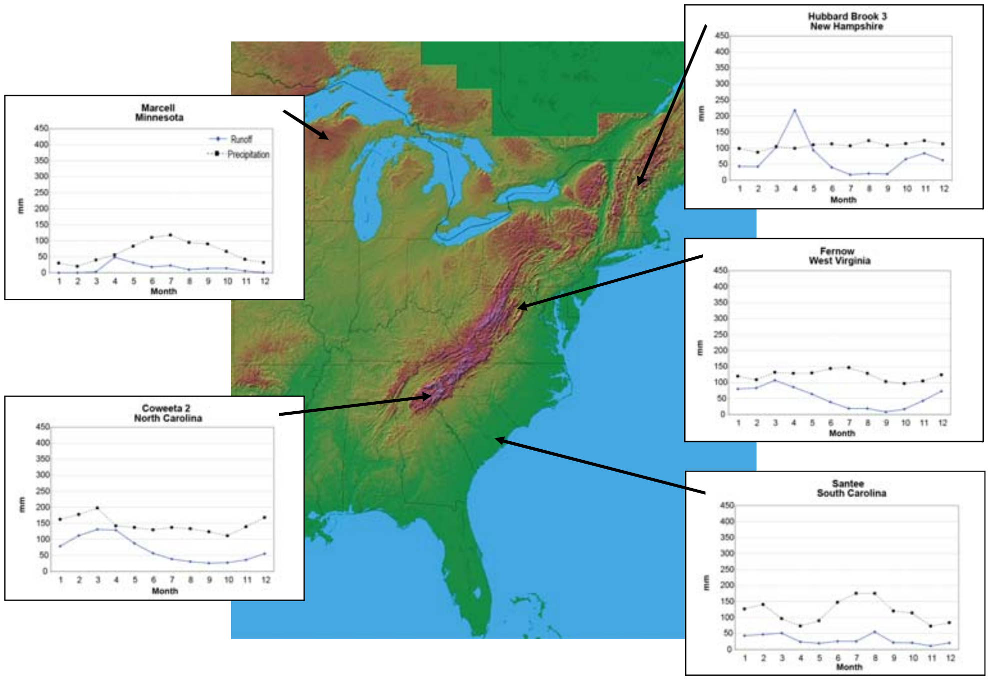


Figure 3.2 Hydrographs (mm of water) from Research Watersheds across the Eastern U.S. Showing Different Patterns in Precipitation and Streamflow [Ziemer and Ryan 2000]

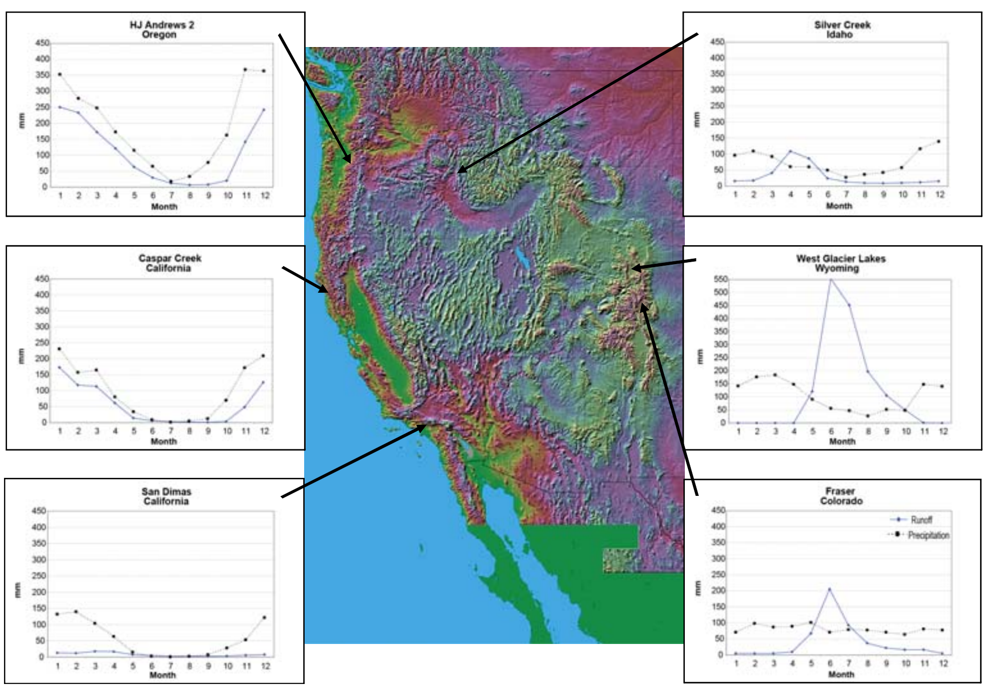


Figure 3.3 Hydrographs (mm of water) from Research Watersheds across the Western U.S. Showing Different Patterns in Precipitation and Streamflow [Ziemer and Ryan 2000]

3.1.2 *Effects of Forest Management on Water Yields*

Forests are treasured for creating favorable watershed conditions, but they may actually reduce water yields compared to other vegetation covers. Afforestation (establishment of a forest in an area that was not previously forested) has been shown to decrease water yields. Farley, Jobbágy, and Jackson (2005) synthesized global literature on the effects of afforestation and found an average reduction in streamflow of 44% for grasslands converted to forests. Over time, however, forests create a forest floor and soil conditions that promote infiltration of water and increase short- and long-term water storage. In addition, if land is converted to irrigated agriculture or urban or rural residential development, water use and evaporative losses may increase. It is estimated that 80% of consumptive fresh water use in the U.S. is for irrigated agriculture (26 trillion gal/yr) (Marlow 1999). It is also important to recognize that consumptive water use by irrigated agriculture and other land uses often occurs during low flow periods when streamflow is most limited. About one-third of the U.S. is in forests today, roughly 70% of the area in forests in 1600 (MacCleery 1994), so afforestation is less common than forest conversion to other land uses.

The area in forest land in the U.S. has been relatively stable since 1920, but since about 1950, the timber volume per acre has increased by 30% (MacCleery 1994). Timber harvesting, site preparation for replanting, thinning, roads, and other forest management practices can alter the forest water balance by changing interception, evapotranspiration, infiltration, snowmelt processes, and routing downslope (timing of surface and subsurface runoff). Local water supplies can benefit from increased water yields (increases in groundwater recharge or surface runoff) when interception and evapotranspiration rates are reduced (Ice and Stednick 2004). For example, MacDonald and Stednick (2003) reported that annual water yields in the North Platte River basin in Colorado have decreased by 150,000 to 190,000 acre-feet over the last century due to increased stand density resulting from increased fire protection and reduced harvesting. If all forest stands suitable for harvesting in that basin (500,000 acres) were cut on a sustainable-yield basis, the increase in water yield could be 55,000 acre-feet, or about 3-4% of current water yields.

Whether streamflow increases following harvesting depends on precipitation pattern, how the growing season coincides with available water, and forest species (especially conifers versus hardwoods). Despite consistently documented increases in available streamflow following timber harvesting, Ziemer (1987) concluded that efforts to deliberately manage forests to increase water yields are generally not practical. Constraints on the amount of timber harvesting that can occur in large watersheds and competing environmental goals, such as protecting water quality, generally limit potential increases in water yields. A recent report by the National Research Council (2008) found that "while it is possible to increase water yield by harvesting timber, water yield increases from vegetation removal are often small and unsustainable, and timber harvest of areas sufficiently large to augment water yield can reduce water quality." Instead, increased water yields from forest management should be considered a supplemental benefit. Harr, Fredriksen, and Rothacher (1979) estimated that this supplemental increase is between 4 and 6% for managed forests in southwest Oregon, but varies for different site conditions. MacDonald and Stednick (2003) estimated that current timber harvesting and fuel treatments on national forests in Colorado increase water yields by less than 1%.

3.1.3 *Site-Specific Differences in Water Yield Responses for Managed Forests*

Not only do the hydrographs for different forested regions differ in terms of timing and magnitude of streamflow (Figures 3.2 and 3.3), but site-specific conditions determine how water yields are affected by timber harvesting. Where precipitation is low or where potential interception and evapotranspiration losses do not coincide with available water, changes in water yields will be low. Where vegetation recovers quickly and plant roots can rapidly recapture water in soil moisture storage, increases in water yields will be short-lived. The WRENSS report (USDA 1980) and Anderson, Hoover, and Reinhart (1976) provided some examples of differences in regional water yield responses to harvesting.

Needle Branch (Oregon Coast): Needle Branch is a small stream in the Coast Range of Oregon. It is largely forested by Douglas fir (*Pseudotsuga menziesii*), with some western redcedar (*Thuja plicata*) and red alder (*Alnus rubra*). Rains are seasonal, with most precipitation occurring in winter and spring. Less than 5% of precipitation occurs in the summer when potential evapotranspiration is greatest, so actual evapotranspiration is limited at times by water stored in the soil. Annual precipitation is about 92 inches. Annual evapotranspiration losses when the watershed is fully forested are estimated to be about 39 inches, so about 53 inches of streamflow are expected. Harvesting is estimated to reduce evapotranspiration by 23 inches. The actual observed change for three years after harvesting averaged 20 inches. Most of this streamflow occurred in winter and spring.

Coweeta (North Carolina Mountains): Precipitation at Coweeta, in the Appalachian Mountains of North Carolina, is about 73 inches annually. Precipitation occurs more evenly over the seasons than for Needle Branch, but is still most prevalent in winter and spring. Estimated evapotranspiration when fully forested is 32 inches, with 41 inches available for streamflow. Harvesting is expected to reduce evapotranspiration just a little over 6 inches. Observed changes in streamflow were 6 inches following timber harvest. Increases occurred mostly in late summer and fall.

Grant Forest Watershed (Georgia): At the lower elevation Grant forest in the Piedmont of Georgia, annual precipitation averages 52 inches, with a very even distribution throughout the year. When forested, evapotranspiration is estimated to be 36 inches, with 16 inches available for streamflow. Harvesting is expected to decrease evapotranspiration by near 21 inches. The observed change following harvesting was estimated to be 11 inches, perhaps reflecting loss to groundwater, interbasin exchange, or underestimates of residual vegetation.

Wagon Wheel Gap (Colorado): The first watershed study in the United States occurred at Wagon Wheel Gap in Colorado in a watershed forested by aspen (*Populus tremuloides*) and conifers. Annual precipitation in this watershed is only 21 inches, with a significant snow component. It was estimated that 15 inches are lost to evapotranspiration when forested. Water yields increased only about 2 inches following harvesting and were coincident with snowmelt.

These examples show that the extent and timing of water yield increases are highly variable and depend on site-specific factors. While Needle Branch experienced the largest increases in streamflow for these four examples, most was during the winter when water was abundant.

3.1.4 *Effects of Forest Management on Peak Flows*

Concerns about increases in peak flows or floods temper the possible benefits of timber harvesting on water yields (e.g., Eisenbies et al. 2007). The extent of the effects of timber harvesting or other forest practices, such as site preparation or roads, is dependent on site-specific conditions. Because soil moisture storage may be partially filled in a recently harvested site experiencing reduced interception and evapotranspiration losses, peak flows can occur earlier and with less intense storms. As the magnitude of precipitation events or antecedent wetting of the site increases, changes due to reduced vegetation become less important.

Much of the debate about whether forest management increases floods depends on how a flood is defined. There is evidence that more commonly occurring peak flows (e.g., a flow that occurs every year on average) are increased, but that this effect decreases with more extreme events (Thomas and Megahan 1998). Kochenderfer et al. (2007), summarizing findings from a study in the Fernow Experimental Forest of West Virginia, concluded that "these results support earlier findings that forests do not prevent floods and that prudent forest harvesting operations do not increase large flood peakflows." A similar review by the USDA Forest Service in the West (Grant et al. 2008) found that "increases in peak flows generally diminish with decreasing intensity of percentage of watershed harvested and lengthening recurrence intervals of flow [larger, less frequently occurring events]." Finally, a report by the Food and Agricultural Organization of the United Nations Center for International Forestry Research (CIFOR 2005) concluded that most watershed studies have shown that removal of forest cover will increase small, frequently occurring peak flows (1- to 5-year return periods) but have little effect on large, infrequently occurring flows (50- to 100- year return periods) that result in catastrophic downstream flooding. Large storms produce so much precipitation that the storage capacity of a watershed's soils is overwhelmed, whether there are trees present or not.

There are conditions, such as widespread and severe soil disturbance following a wildfire, where surface runoff and streamflows may be increased due to reduced infiltration. Forest management can reduce fuel loads and use other practices to minimize the risk of severe wildfires. Anderson, Hoover, and Reinhart (1976) found that "the forest [is] the best natural cover for preventing floods when it is protected from overgrazing, severe fire, or by denudation by insects or disease…[and] the forest can prevent excessive acceleration of floods under sustained-yield timber management."

3.1.5 *Effects of Forest Management on Timing of Streamflow Runoff and Low Flows*

Another key issue involves when increases in streamflow occur. In some regions (e.g., the Pacific Northwest) the largest absolute increase in streamflow occurs during the winter when water is plentiful, although the largest relative increases may occur in spring and summer (Harr, Fredriksen, and Rothacher 1979). Only where reservoirs are available to store water will winter increases provide maximum benefits. In some cases streamflow can actually drop below pre-harvest levels as young forest stands recover. Hicks, Beschta, and Harr (1991) found that upslope timber harvesting exposed riparian vegetation to increased solar radiation. These plants have access to water during low flow periods and therefore can have increased evapotranspiration. As a result, streamflow was reduced during low flow periods following an initial increase due to reduced evapotranspiration from upslope vegetation. Although water yields usually increase locally with timber harvesting, those increases decline with regrowth of the forest.

3.1.6 *Comparison with Alternative Land Uses*

One of the important roles of commercial forest management is to keep forests from being converted to other land uses. Forest watersheds clearly function differently than urban or agricultural watersheds. The presence of perennial, large vegetation, both alive and dead, is one of the major reasons. Trees and understory vegetation create tremendous surface area for interception and evapotranspiration. Probably more importantly, dead plant material on the soil surface and incorporated in the soil results in rapid infiltration and reduces potential for surface runoff. Decay of roots and other processes create macropores in the soil, causing subsurface delivery of water to channels. It can also be asserted that current forest management impacts are generally much "lighter" than those of other land uses, causing less hydrologic modification to watersheds. For example, urban watersheds are extensively "plumbed" with large proportions of impermeable surfaces and extensive networks of stormwater drains. This causes increases in both amount and rate of runoff from the watershed and streamflows. An example of the differences between forested and nonforested watersheds by Poor and McDonnell (2007) compared subbasins in a watershed with three different land uses: forest, agriculture, and urban. They reported that peak streamflows from the agricultural and residential subbasins were 15-275% greater than from the forested subbasin.

3.1.7 *Synthesis of the Quantity of Runoff and Streamflow from Managed Forest*

- Replacing non-forest vegetation with forests can result in less streamflow, but the amount of land in forests in the U.S. has declined by about 30% since 1600 and has remained roughly stable since 1920.
- Alternative land uses, such as irrigated agriculture, can increase consumptive use of water, especially during low flow periods when water supplies can be scarce.
- Timber harvesting generally reduces interception loss and evapotranspiration, making more water available for streamflow or groundwater recharge.
- Increases in water yield decline with regrowth of the forest.
- If forest soils and the forest floor are not severely disturbed, water will move rapidly into the soil and not leave as direct overland runoff.
- While more water is generally available after timber harvesting, it may occur when water is already plentiful in forest streams.
- Maximum increases in streamflow are constrained by other environmental considerations, such as water quality protection, and limits on the amount of a forest watershed in recently cut-over condition at any one time.
- Compared to other land uses, forests are best for managing peak flows, especially if roads and skid trails, overgrazing by cattle, severe fires, and widespread dieback due to insects or diseases are properly managed and controlled.
- A supplemental benefit of forest management may be increases in water yield due to timber harvesting under a sustained management regime, but the magnitude of changes in water yields will vary for different regions and site conditions.

3.2 Water Quality from Managed Forests

Possible changes in water quality are as important as any potential changes in the quantity and timing of runoff from forests due to management (Ice 2007). For example, the greatest potential for changes in sediment in streams occurs where forest lands are susceptible to landslides (NCASI 1985a) or where mechanical site preparation or ground-based yarding results in significant disturbance to the forest floor (McBroom et al. 2007). Forest roads can also have high potential as sources of sediment. Nutrient concentrations can increase following timber harvesting due to increased mineralization of the forest floor and reduced plant uptake (McBroom et al. 2008). Stream temperature increases can occur where timber harvesting exposes streams to direct solar radiation. These changes are attenuated with regrowth of the forest and understory vegetation (Hale 2007). Contemporary forest practices using state best management practices (BMPs) and Forest Practices Act rules dramatically reduce water quality impacts compared to historic practices (Ice 2004).

BMPs include treatments such as mulching and seeding of road cuts and fills (exposed soil), forested buffers and streamside management zones to maintain shade and for wood recruitment near streams, water bars (earthen mounds that divert water off skid trails), and adequately sized and spaced culverts for roads to move water off roadways and avoid severe erosion. 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.

With contemporary forest practices, water quantity and quality impacts are often well within the range of responses observed from natural disturbance events such as wildfires, wind storms, annual leaf fall, seasonal storms, or snowmelt events (McBroom et al. 2003; Ice and Schoenholtz 2003). This section includes summaries of key lessons about responses of sediment, nutrients, temperature, dissolved oxygen, and silvicultural chemicals to forest practices. Water quality issues related to forest roads are also discussed. Water quality impacts from these sources are contrasted with those caused by natural disturbances (e.g., severe storm events, forest fire) and alternative land uses (e.g., urban development).

3.2.1 *Sediment*

Hewlett (1979) conducted a paired-watershed study in the Piedmont Region of the South, looking at impacts of contemporary forest harvesting on water quality. Although impacts were modest compared to other land uses, Hewlett concluded that sediment losses from the watershed could have been reduced by 90% if just three changes in treatment had occurred: adequate buffers; better constructed and maintained roads; and hand planting of seedlings to avoid disturbance of gullies left from past agricultural practices. Williams et al. (2000) conducted another paired-watershed study in the Piedmont Region, this time with the BMPs that Hewlett recommended. As predicted, they found that first year sediment losses were about 90% less than those observed in Hewlett's earlier study. The key lessons are that forest management can increase sediment loads in streams, but with a few BMPs these impacts can be reduced to levels that are difficult to detect from background variations.

3.2.2 *Nutrients*

Management impacts on nutrient levels have long been an issue for the forestry community. A study at Hubbard Brook in New Hampshire found large increases in nitrate-nitrogen where a forest was harvested, the timber was left on the site, and repeated herbicide applications were used to suppress regrowth (Likens et al. 1970).

A more contemporary study at the Alto Watersheds in East Texas found baseflow nutrient concentrations largely unchanged with timber harvesting. McBroom et al. (2008) found small increases in nitrogen (N) and phosphorus (P) runoff in stormwater, especially the first year after timber harvesting or fertilizer applications. P and N did not increase where fertilizer was applied to a five-year-old stand, but a small increase in nutrients was observed for a fertilizer application to a recently clearcut stand. In all cases the changes in nutrient loads were a small fraction of the annual input levels (atmospheric deposition or fertilizer application) and were not believed to be biologically significant.

These studies and companion work (Ice et al. 2008) show that

- geology and other intrinsic site factors, such as vegetation, often predetermine the nutrient status of runoff from forest watersheds;
- specific practices, such as prescribed burning or timing of fertilizer applications, can moderate or increase potential nutrient responses to forest management activities;
- natural disturbance events can affect nutrient loads from a watershed; and

- biological responses to nutrient concentrations are highly variable and depend on the forms of nutrients, light levels, residence times, turbulence, and other factors.

Generally, changes in nutrient concentrations from forest management are found to be small and temporary.

3.2.3 *Temperature*

Changes in water temperature as a result of forest management have been found where trees are harvested near a stream and expose it to direct solar radiation. In the Alsea Watershed Study in Oregon, maximum stream temperatures increased nearly 17°C as a result of clearcutting and burning the watershed with no streamside management zone to maintain shade (Moring 1975). There continues to be some debate about the relative importance of various heating mechanisms such as direct solar radiation, heat exchange with the air, and conductive heating from bedrock, but retention of riparian shade clearly minimizes water temperature increases. A study of riparian buffer effectiveness in Maine (Wilkerson et al. 2005) is typical of recent findings:

> Streams without a buffer showed the greatest increase in mean weekly maximum temperatures following harvesting (1.4-4.4°C). Streams with an 11-m buffer showed minor, but not significant increases (1.0-1.4°C). Streams with a 23-m buffer, partial-harvest treatment, and control streams showed no changes following harvesting.

Another important finding is that any changes in streamwater temperature resulting from forest management are attenuated downstream and reduced with forest regrowth (and recovery of shade). Johnson and Jones (2000) documented very rapid reductions in maximum streamwater temperatures when a stream entered a reach with deep gravel deposits that promoted exchange between surface and subsurface flow. Holaday (1992) found downstream water temperatures in a basin essentially unchanged even though headwater tributary temperatures were dramatically different for different years (caused by regrowth of riparian forest). There are numerous mechanisms that bring elevated water temperatures back into equilibrium with their environment.

Water temperature in forest streams can be managed by maintaining shade near the stream, and all states have adopted BMPs that require riparian buffers or streamside management zones. Even when water temperatures are increased they tend to recovery over time and as flow moves downstream.

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 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 be largely avoided by using streamside management zones to limit introduction of slash to streams and by controlling increases in stream temperatures (Ice 1990).

A recent study of headwater streams at Hinkle Creek in Oregon found that slash left over small streams acted as “dead” shade and helped minimize changes in steam temperature even though harvesting occurred immediately adjacent to the stream (Kiebler 2007). The potential benefits of this temperature control will need to be weighed against other possible impacts such as increased biochemical oxygen demand.

3.2.5 *Silvicultural Chemicals*

Application of forest chemicals, including herbicides, insecticides, and fertilizers, 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 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 forest lands is consistently low compared to agricultural or urban land uses. Monitoring by the U.S. Geological Survey’s National Water Quality Assessment (NAWQA) Program finds more and higher concentrations of pesticides in streams draining urban and agricultural lands than forest lands. For example, Wentz et al. (1998), in a NAWQA study of the Willamette River Basin in Oregon, reported finding 49 and 25 pesticides in streamwater coming from watersheds draining agricultural and urban areas, respectively. The same report found that “only atrazine and deethylatrazine were detected in streams draining forested basins (greater than 90% forest, by area) and these compounds were at extremely low concentrations (0.002 and 0.004 µg/L).” Atrazine is used in forestry but is also used in agriculture and Christmas tree operations that may occur in these predominately forested basins.

3.2.6 *Forest Roads*

Another forest management practice of concern is forest roads. Roads provide essential access to manage forest sites and remove wood products, but can also be a source of sediment. Croft and Hoover (1951), describing historic practices, found that “large quantities of dirt may be dumped directly into the streams, unstable cuts and fills made, and large areas of impervious surface created. Only a comparatively small area of such disturbance is sufficient to muddy runoff water.” These concerns parallel issues today, such as an ongoing review by the U.S. Environmental Protection Agency to consider whether forest roads should be reclassified as point sources of pollution under the Clean Water Act. Fortunately, Croft and Hoover also recognized that there were management practices that could reduce water quality impacts. Some examples they cited were grade controls on forest roads and outsloping or other draining of roads.

In the Pacific Northwest, sidecast road construction (pushing of unconsolidated road cut material to the side to create a road prism) resulted in greatly accelerated landslides. Recognizing this problem, states adopted rules that restrict this practice and have dramatically reduced road failures (NCASI 1985a). In northern California it was found that road culverts were susceptible to plugging that diverted runoff down roads and resulted in greatly accelerated erosion (Hagans and Weaver 1987). This problem is addressed in modern road construction practices by creating crossings where the road is sloped toward the stream crossing. With this configuration, even if the culvert fails the flow will not be diverted. Direct delivery of runoff from forest roads is recognized as a potentially major source of sediment to streams. Mills, Dent, and Cornell (2007) reported that at historic rates 57 to 75% of the road network delivered runoff directly to streams, but recently constructed or upgraded roads have rates of 15 to 34%.

3.2.7 *Natural Disturbances to Forests and Water Quality*

Potential impacts from forest management must, of course, be considered in the context of other disturbances. During the Alto Watershed Study in Texas, Tropical Storm Allison dumped 11.8 cm of rain on saturated soils, generating 73 and 95% of the annual flow and sediment, respectively, for the entire year within a few hours (McBroom et al. 2003). This pre-treatment event produced more sediment and nutrient losses than clearcutting and fertilization did later on the same basins. Larsen and MacDonald (2007) reported that "high severity wildfires can increase hillslope-scale sediment yields by several orders of magnitude." Ice and Schoenholtz (2003) found that fire is generally thought to increase nutrient concentrations and loads in nearby streams as a result of disrupted nutrient cycling, accelerated mineralization of organic matter, and runoff of ash and sediment to streams. Fiscus (1998) showed that N concentrations and loads can increase in streams where defoliating insect outbreaks occur (Figure 3.4). This can involve disruption of nutrient recycling, direct deposition of N-rich frass in streams, and even a change in the rate of detritus processes. Forest management activities tend to be dispersed in space and time and controlled with BMPs, but natural disturbance events can be intense and widespread.

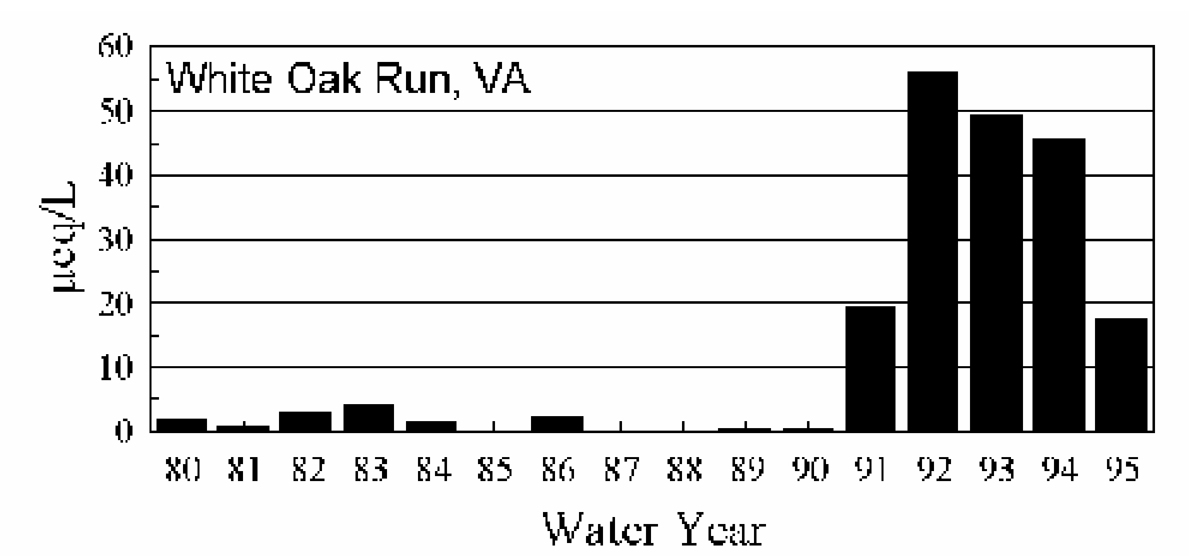


Figure 3.4 Flow-Weighted Annual Concentrations of Nitrate in White Oak Run, Virginia, Following Gypsy Moth Outbreak in 1991 [Fiscus 1998]

3.2.8 *Comparison to Alternative Land Uses*

There is often a focus on relatively small changes in discharges or water quality that can occur immediately following timber harvesting or other forest practices. In this regard it is possible to lose sight of just how valuable forest watersheds are over the long term in providing high quality water and aquatic habitat. As Brown and Binkley (1994) reported, "the quality of water draining forested watersheds is typically the best in the Nation, whether the forests are left untouched or managed." One important difference between forested watersheds and other land uses, especially urban areas, is the amount of impervious surface. Brabec, Schulte, and Richards (2002) reviewed literature that assessed how changes in impervious surfaces affect water quality. They summarized literature showing how percent of impervious surfaces in a watershed affects stream habitat, fish and other biotic measures, and physical and chemical water quality parameters. They noted that "several studies show how pervious cover [beneficially] affects peak flows, water quality, and other stream characteristics." The example of Poor and McDonnell (2007) showed how land use affects nitrate-nitrogen in streams.

Nitrate is a common and mobile form of nitrogen that occurs naturally in runoff. Management activities, such as applications of fertilizers or leaking septic tanks, can elevate nitrate levels in runoff, and these can be either point or nonpoint pollutant sources that contribute to eutrophication. Poor and McDonnell monitored stormwater runoff from three subbasins of Oak Creek, near Corvallis, Oregon, to study how alternative land use activities influenced nutrients. As with all watershed studies, each of the subbasins had somewhat unique characteristics that complicated analysis of management effects. However, the authors selected subbasins that had similar geologies, nearly identical drainage areas, and similar climates. The main differences were that one subbasin was covered by second-growth Douglas fir (*Pseudotsuga menziesii*) forest, one was managed for pasture (sheep) and agriculture, and one had been converted to residential use (although not dense residential development), with 15% of the area covered by impervious surfaces.

Poor and McDonnell reported on discharge and nutrient dynamics for these three land uses in the same watershed. They found that export of nitrate from the forest watershed during three storms was consistently low. Both storm discharge and nitrate concentrations were higher from the residential subbasin, with nitrate export consistently an order of magnitude higher than that from the forested subbasin. The agricultural subbasin showed the most dynamic pattern of nitrate runoff. The first monitored storm had by far the highest nitrate concentrations, probably due to manure and other nitrogen-containing applications to the watershed during the summer. Concentrations from this subbasin dropped over the next two storms.

Alexander et al. (2008) reported that the major source of nitrogen and phosphorus in the Mississippi Basin is agriculture, which contributes more than 70% of these nutrients. Regional atmospheric deposition and urban sources are estimated to be contributing 16 to 18% and 9% of nitrogen, respectively. Forests are estimated to contribute 4% of the basin's nitrogen. The major phosphorus sources other than agriculture are urban (12%) and forests (8%). Foley et al. (2004) estimated that forests represent 25% of land use in the Mississippi Basin. Forested areas are also found in portions of the basin that have higher average annual precipitation amounts, especially compared to the grasslands and shrublands that make up 46% of the basin. Clearly, forest nutrient loads are low compared to the rest of the basin.

Just as for water discharge, keeping a watershed in forest land use promises the best opportunity to maintain high water quality, especially with application of contemporary forest practices and BMPs.

3.2.9 *Synthesis of the Quality of Runoff from Managed Forest*

- Forest management activities have the potential to negatively affect water quality.
- Contemporary BMPs can reduce negative impacts and maintain high water quality. These include the use of riparian management zones.
- Certain practices such as mechanical site preparation or forest roads present elevated risks of impacts to sediment, but there are BMPs to address those risks.

- Natural disturbance events ranging from tropical storms and hurricanes to wildfires and insect outbreaks can affect water quality, often greatly exceeding impacts observed from forest management activities.
- Alternative land uses consistently show greater impacts with regard to sediment, nutrients, pesticides, and other pollutants.
- 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, then wood products manufacture at the end of the section. Figure 4.1 shows the water profile of the U.S. pulp and paper industry.

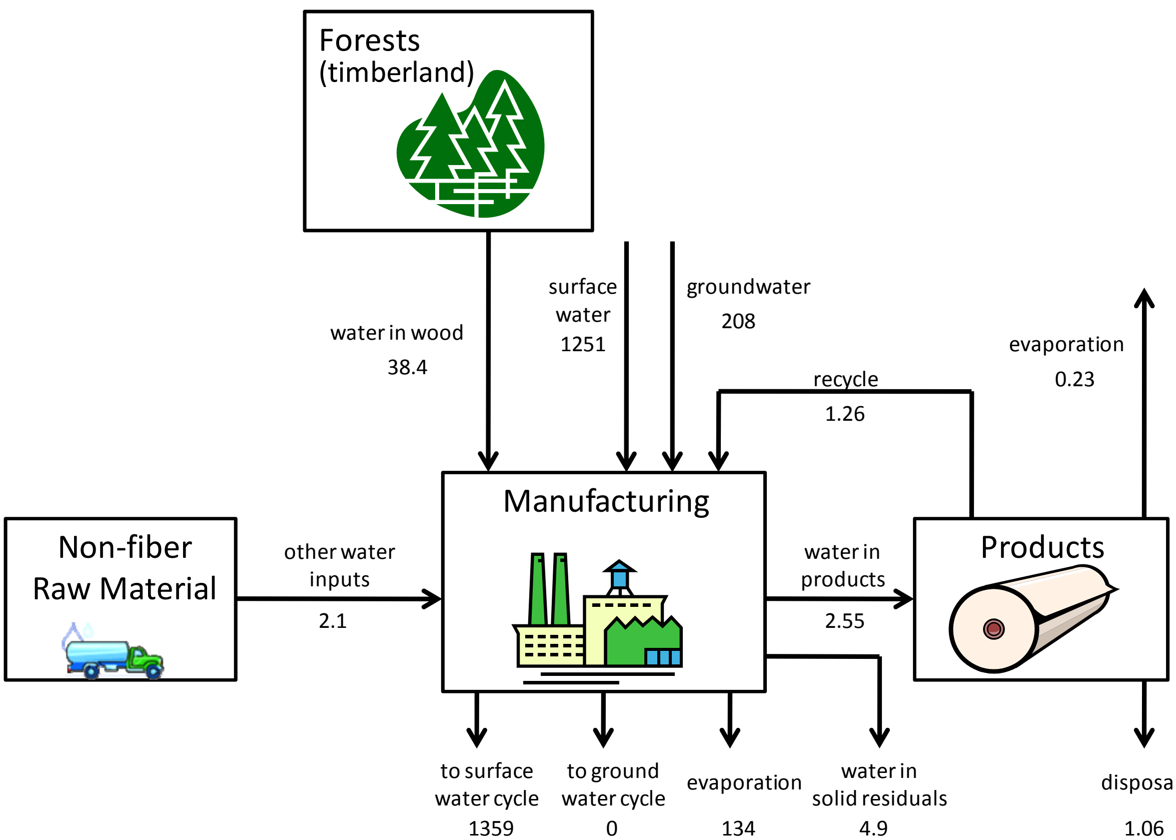


Figure 4.1 Water Profile for the U.S. Pulp and Paper Industry (billion gal/yr)

4.1 Water Profile for U.S. Pulp and Paper Manufacturing, Overview

The U.S. pulp and paper industry withdraws approximately 1.46 trillion gallons of water annually from surface and groundwater sources but the vast majority, 1.36 trillion gallons, is reintegrated directly into the surface water cycle. The U.S. pulp and paper industry relies upon groundwater sources for about 14% of its total water withdrawals. Consumptive water loss (the sum of evaporative losses from process operation and secondary waste treatment, water in solid residuals, and water in products) is 9.7% of the water from surface and groundwater sources. The amount of water in wood, recycled paper, and purchased chemicals is approximately 30% of consumptive water losses. If these sources were considered water consumption credits (i.e., offsets to water losses), the water consumption impact of the U.S. pulp and paper industry would be reduced to approximately 7% of water from surface and groundwater sources.

4.2 Data Sources and Quality

High quality data for effluent discharge flows are available for the American Forest and Paper Association (AF&PA) member mills. These data are collected biennially in AF&PA's Environmental, Health, and Safety (EHS) survey, and the latest survey data (for 2006) were used in the water profile calculations. Survey results underwent quality assurance/quality control at NCASI. AF&PA member mills represent over 75% of the paper, wood, and forest products production in the U.S. The Fisher Pulp&Paper Worldwide™ database was used to obtain effluent flows for mills not represented in the EHS effluent database to achieve complete coverage for the U.S. pulp and paper industry (Fisher International, Inc. 2008). Mills included in both the EHS and the Fisher Worldwide databases were compared to ascertain the accuracy of the Fisher Worldwide effluent data.[1] The average difference between total effluent flows for mills in both databases was 11.5%, with the EHS 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 EHS data were unavailable.

AF&PA member mills 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 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 U.S. paper and paperboard production was estimated to be 93.7 million short tons in 2006 (AF&PA 2007). The primary difference between the 2006 production total in Table 4.1, 106.4 million short tons, and AF&PA statistics is U.S. market pulp production, which was estimated to be 10.2 million short tons in 2006 (ibid.). Mills producing market kraft pulp used as a raw material in the manufacture of final paper products should be considered in the water profile calculations. Between mills represented by EHS data and mills queried from Fisher Worldwide, the water profile calculations have essentially 100% coverage of the U.S. pulp and paper industry.

[1] 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 11.3 ±1.6 MGal/adst, while the mean from the phone survey was 10.9 ±1.6 MGal/adst.

Table 4.1 Numbers of Mills and Production Amounts Considered in the U.S. Water Profile Calculation, 2006

Database	Number of Mills	Production (adst/year)
EHS	190	80,450,567
Fisher	211	25,961,490
Total	401	106,412,057

Only mills operating in 2006 were considered in the water profile calculation; mills that were closed or idle in 2006 were not considered. Table 4.2 shows the production categories for mills in the EHS database and mills queried from the Fisher Worldwide database. A majority of the production contribution from EHS mills was from kraft pulp mills. A majority of the production contribution from mills in the Fisher database was from nonintegrated paper mills and pulp mills using recycled fiber.

Table 4.2 Production Contributions from EHS Survey Mills and Mills Queried from Fisher Worldwide, 2006

EHS			Fisher		
Category	Number of Mills	Production (adst/year)	Category	Number of Mills	Production (adst/year)
BKI	36	21,816,145	NIO	72	4,205,274
UK2	17	15,305,871	RBOX	40	4,076,201
UK1	15	10,973,886	BKI	9	3,957,927
BKO	12	7,386,079	NIF	24	2,650,188
RCTR	22	5,881,041	MECH	10	2,588,964
SC	10	4,397,763	DTF	23	2,270,757
BKP	7	4,140,646	UK1	5	2,014,030
MECH	10	2,964,411	DNWS	3	1,242,254
RBOX	28	2,351,556	RCTR	10	1,063,111
DTF	8	2,038,439	BKP	1	612,500
BKD	2	1,176,885	SULP	2	432,150
NIF	6	961,771	BKO	2	358,870
SULP	2	402,375	RTF	9	280,704
SULD	2	272,023	UK2	1	208,560
NIO	11	233,758	SC		
DNWS	1	124,044	BKD		
RTF	1	23,875	SULD		
Total	190	80,450,567	Total	211	25,961,490

[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 estimating a closed 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 fuels and stormwater managed outside mills' wastewater treatment systems are not included in this profile. 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 influent 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 influent source information for the U.S. pulp and paper industry.

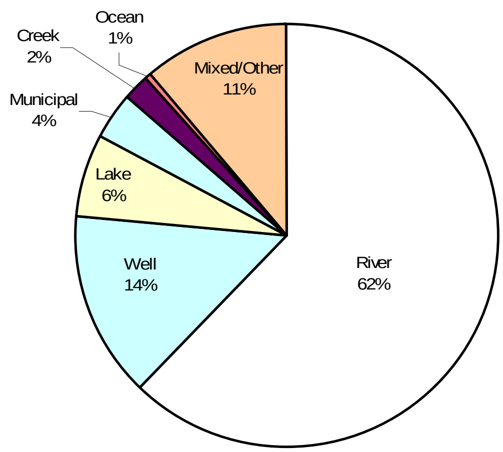


Figure 4.2 Water Source Information for the U.S. Pulp and Paper Sector

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 EHS survey, water destination type was queried from Fisher but effluent amounts were taken from EHS survey data. Figure 4.3 shows the effluent disposition of the U.S. 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.

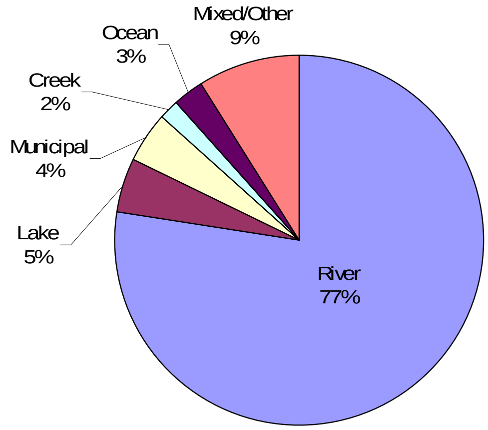


Figure 4.3 Effluent Destination by Volume for the U.S. Pulp and Paper Industry

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. EHS survey data also included information on whether effluent flows entered a surface receiving water or were discharged to a publicly owned treatment works (POTWs). 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 U.S. pulp and paper mills represents approximately 16% of total effluent flow. This is 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 U.S. industry. Table 4.4 shows cooling water discharge as a percentage of total effluent, arranged by production category.

Table 4.3 Pulp and Paper Effluent Volumes and Disposition

EHS			Fisher		
Category	Volume[a]	% of EHS Total	Category	Volume[a]	% of Fisher Total
Cooling water discharged to POTW	9.6	0.9	Total cooling water	20.24	7.1
Process water discharge to POTW	45.1	4.2	Total process water	263.1	92.9
Cooling water discharge to surface water	187.5	17.4			
Process water discharged to surface water	829.3	77.1			
Other flows[b]	4.43	0.4			
Total process and other	878.8	18.7		263.1	
Total cooling	197.1	18.3		20.24	
Total	1075.9			283.3	
Total (EHS and Fisher)	1359.2				

[a] billions of gallons
[b] other flows include onsite sanitary flow, stormwater runoff, unspecified flows

Table 4.4 Pulp and Paper Effluent Volumes by Production Category, 2006

	EHS				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]
BKD	35758	4.1	0	0	-	-	-	-
BKI	371671	42.3	38428	9	64400	24.5	5145	7
BKO	110134	12.5	28761	21	5880	2.2	1050	15
BKP	54592	6.2	13476	20	6650	2.5	350	5
DNWS	1820	0.2	81	4	9555	3.6	1225	11
DTF	21403	2.4	22726	51	17724	6.7	564	3
MECH	20979	2.4	26734	56	25638	9.7	1645	6
NIF	8473	1.0	6262	42	30079	11.4	4743	14
NIO	5670	0.6	0	0	50236	19.1	2527	5
RBOX	2238	0.3	378	14	4351	1.7	609	12
RCTR	5540	0.6	327	6	697	0.3	140	17
RTF	285	0.03	0	0	2833	1.1	0	0
SC	16535	1.9	13021	44	-	-	-	-
SULD	13131	1.5	0	0	-	-	-	-
SULP	8690	1.0	4012	32	15225	5.8	0	0
UK1	94359	10.7	37896	29	21420	8.1	2240	9
UK2	107559	12.2	4961	4	8400	3.2	0	0
Total	878836	100	197065	18	263086	100	20237	7
Total (EHS+Fisher)	1141922		217302	16				

[NOTE: See Appendix A for category definitions]
[a] millions of gallons
[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 U.S. 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
DTF, DNWS, RCTR, RBOX	87	0.1	0.11
NIF, NIO	100	0.1	0.10

[SOURCE: based on NCASI 2008]
[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 mt ton product basis and that 1 m^3 water ≈ 1 mt water.

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

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 2008) and typical moisture contents in raw materials, are used with Equation 4 to calculate the water contribution from raw material.

4.7 Water in Non-Fiber Raw Materials

This section considers the addition of water contained in purchased non-fiber 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); sulfite (SULD, SULP); mechanical (MECH, BCTMP); and recycle (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 pulp and paper industry.

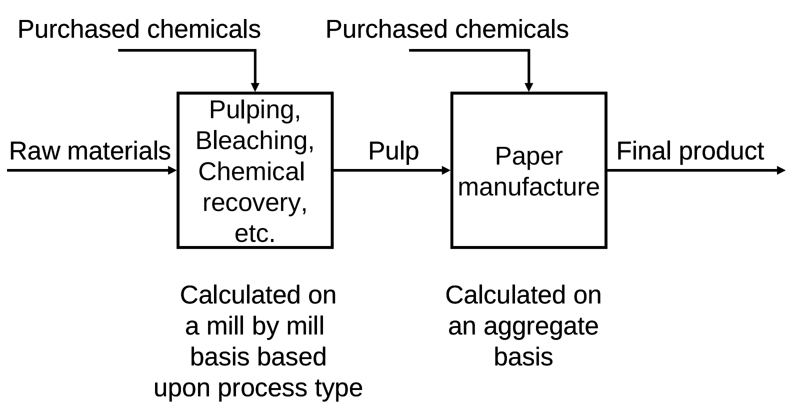


Figure 4.4 Scheme Used to Calculate Water Contribution from Purchased Chemicals

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, 7% mercury cell, 25% membrane cell, and 2% for all other methods in the U.S. 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 repulping 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 sulfate ($MgSO_4$) 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 sulfate is typically shipped to mills in slurry form with water content of solution ranging from 73 to 80% (PQ Corporation 2008c).

Sulfuric 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 sulfuric 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 sulfuric acid values for unbleached and bleached kraft, for which no data were available. Values for sulfuric acid were taken from Valeur et al. (2000) assuming onsite crude tall oil manufacturing. 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-fiber raw materials for the U.S. 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 sulfate ($MgSO_4$)	73 - 80
Sulfuric 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-Sulfite	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/adtp; 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.

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
Sulfite[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] 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 U.S. pulp and paper industry in 2006 is calculated to have been 1.1 billion gallons.

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 1997, 14.9% of the total raw material used in the production of paper in Europe originated from non-fibrous materials; of that, 11% were fillers and pigments, primarily kaolin and calcium carbonate ($CaCO_3$). Chemical additives constituted 3% of the non-fibrous material, of which starch and alum were the largest contributors. Based on Confederation of European Paper Industry (CEPI) 1997 statistics, approximately 1% of the raw materials used in paper production were from synthetic chemical additives (IPPC 2001). In 2007, 16.5% of the total raw material used in paper production in the European paper industry originated from non-fibrous materials (CEPI 2007). 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 2007]
[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/pdf_files/PaperClayProp.pdf). Precipitated calcium carbonate (PCC) is delivered in slurry form and has dry solids contents of 71 to 75% (Lehtinen 2000). Many of the third party plants supplying PCC to U.S. mills are located on site, with water being supplied by the mill water system and wastewater being treated by the mill's wastewater treatment plant. In these cases, careful accounting of water flows would be necessary to correctly characterize the water contribution from PCC. 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

U.S. paper and paperboard production was 93.7 million short tons in 2006 (AF&PA 2007). If it is assumed that 16.5% 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 2006), 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 0.98 billion gal/yr. The calculations assume that the water contribution from the "Other" additives category in Table 4.10 is zero. Filler usage appears to be somewhat higher in Europe than in the U.S., 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 American 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 2.07 billion gallons of water were imported to pulp and paper facilities in the U.S. from purchased chemicals in 2006.

Table 4.13 Water Contents of Purchased Chemicals for the U.S. Pulp and Paper Industry, 2006

Chemical Use	Water (billion gal/yr)
Water in purchased chemicals used in pulping	1.1
Water in purchased chemicals used in paper machine area	0.97
Total	2.07

4.8 Water in Recycled Fiber

Two types of statistics are reported for recycled fiber: 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). For water profile calculations the recovery rate is the pertinent statistic to employ. The recovery rate for AF&PA members was 56% of paper consumed in 2007 (AF&PA 2008). It is assumed that the recovery rate reported by AF&PA membership is applicable to the entire U.S. pulp and paper sector. In addition to recovery rate, knowledge of the moisture content of recovered fibers is necessary to calculate the amount of water in recycled fiber. 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 U.S. industry. U.S. paper and paperboard production was 93.7 million short tons in 2006 (AF&PA 2007). Assuming that 56% of the 93.7 million short tons were recovered and that the average moisture content of the recovered paper was 10%, the amount of water contained in recycled fibers amounts to 1.26 billion gal/yr.

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. NCASI (1999) reviewed the state of solid waste management practices in the U.S. paper industry, compiling data on average moisture contents of wastewater treatment residuals, generation rates, and disposal options for solid wastes. Based upon the latest 2006 EHS data, total solid residuals production was a production weighted mean of 252 dry lb/adst production (126 dry kg/admt production) (AF&PA 2008). 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. NCASI's review of solid waste management practices in the U.S. paper industry categorized solids residual into three groups: wastewater treatment residuals; ash; and miscellaneous solid residuals.

NCASI (1999) compiled dewatering practices for wastewater treatment residuals. The overall average achieved by all dewatering methods on all residual types were 34% solids (median value 35%). The total wastewater residuals generation rate was 5.83 million metric tons (dry) in 1995, or 40% of the total solid residuals generation rate of 14.6 million metric ton (dry) for the U.S. pulp and paper industry. Wastewater treatment residuals encompass primary clarifier residuals, secondary clarifier residuals, and solids dredged from aerated stabilization basins (ASBs).

Ash generation comprised 19% of the total solid waste generation rate, or 2.81 million metric ton (dry) in 1995. 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%.

Miscellaneous solid residuals represent 41% of the total solid generation rate, or 5.9 million metric ton (dry) in 1995. Miscellaneous solid residuals comprise recovery area inorganics such as lime mud, slaker grits, and green liquor dregs; fiber rejects such as paper mill rejects, virgin fiber pulping rejects, and secondary fiber rejects; wood yard residue; raw process water treatment residuals; broke that is not recycled; and general mill refuse (NCASI 1999). 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 fiber 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 fiber rejects, paper mill rejects, and virgin fiber 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]	66
Lime mud	25
Slaker grits	25
Green liquor dregs	50
Fiber rejects[b]	65
Wood yard waste	44
Ash[c]	28
All others[d]	65

[a] includes combined sludge, primary clarifier sludge, secondary clarifier sludge, and sludge dredged from ASBs
[b] includes paper mill fiber rejects, virgin fiber pulping rejects, and secondary fiber rejects
[c] average of wet and dry ash systems
[d] includes broke not recycled to the process and general mill refuse

NCASI (1999) classified the final disposition of solid waste (on a dry basis). Using moisture contents of individual residual streams from Table 4.14, the mass generation rate of solid residuals, and the final disposition of solid wastes, the disposition of water contained in solid waste for the U.S. pulp and paper industry can be calculated, and is presented in Figure 4.5.

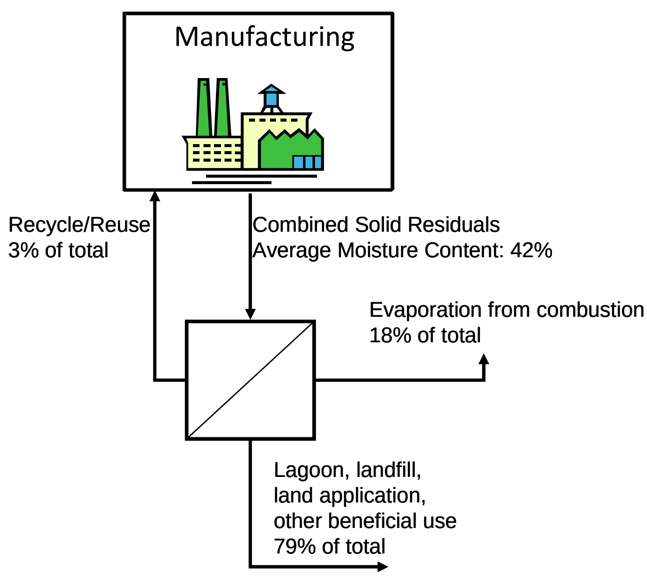


Figure 4.5 Disposition of Water Contained in Solid Waste in the U.S. Pulp and Paper Industry

Using the mass weighted average moisture content of 42% for solid wastes of all types, the water content in solid wastes for different mill types are given in Table 4.15. The values in the table are applied on a mill-by-mill basis according to the NCASI classification scheme given in Appendix A for estimates of water content in solid residuals.

Table 4.15 Water Contents in Solid Residuals Used in the Water Profile Work

Classification	m^3 water/admt of product	gal water/adst of product
BKI	0.30	70.8
BKP	0.25	59.4
BKO	0.27	65.1
UK1	0.16	39.2
UK2	0.16	39.2
SC	0.26	62.5
MECH	0.26	62.5
DTF	1.10	262.6
DNWS	0.64	152.4
RCTR	0.12	29.4
RBOX	0.14	34.3
NIF	0.15	35.4
NIO	0.15	35.4
SULD	0.44	105.3
BKD	0.44	105.3
SULP	0.29	68.8
BCTMP	0.30	70.8
RTF	0.12	29.4

[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 U.S. industry.

The disposition of paper and paperboard not recovered is taken from Skog (2008). In 2005, the latest year for which data were reported, 30% of paper and paperboard not recovered was burned and the remainder was landfilled (Skog 2008, based on USEPA 2005 data). 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. 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 behavior.

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 (2008). In that work on water consumption, evaporative losses from secondary 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 waste 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 waste treatment database was used to classify the type of secondary waste treatment at individual mills (i.e. ASB, AST, discharge to a POTW, etc.). Any gaps in the NCASI secondary waste treatment database were filled with information from the Fisher 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 2008). 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 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.

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

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 behavior 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 (2008), but evaporative losses from secondary waste treatment are treated separately. The equation for process water consumption is shown in Equation 3 and the coefficients for the equation in English and metric units are given in Table 4.16. The parameters in Table 4.16 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 2008).

$$\mathrm{E} = a \cdot W^{b} \qquad \text{(Eq 3)}$$

where: E = water consumption coefficient defined in Eq 2
a, b = parameters dependent on mill type (Table 4.16)
W = total water input (water from surface and ground sources, water in raw material, and water contained in purchased chemicals)

Table 4.16 Coefficients in Water Consumption Coefficient Equation

	English Units		Metric Units	
Mill Type	*a*	*b*	*a*	*b*
Chemical[a]	1323.5	-0.999	5.5511	-0.999
Mechanical[b]	22.45	-0.614	0.7773	-0.6138
Recycled[c]	648.4	-1.029	2.3058	-1.0291
Non-integrated[d]	613.0	-1.041	1.8437	-1.0059

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

Process water consumption is calculated via Equation 3 and secondary treatment evaporation is calculated via yearly average evaporative losses estimates based upon treatment type. Water consumption calculations are detailed in Appendix B. Figure 4.6 shows the total water consumption coefficient (i.e., water consumption from process and secondary waste treatment) calculated for U.S. pulp and paper mills. Water consumption curves (NCASI 2008) are overlaid on the data for comparison. Recycled boxboard mills (RBOX) and recycled containerboard mills (RCTR) use small amounts of water, and several 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.

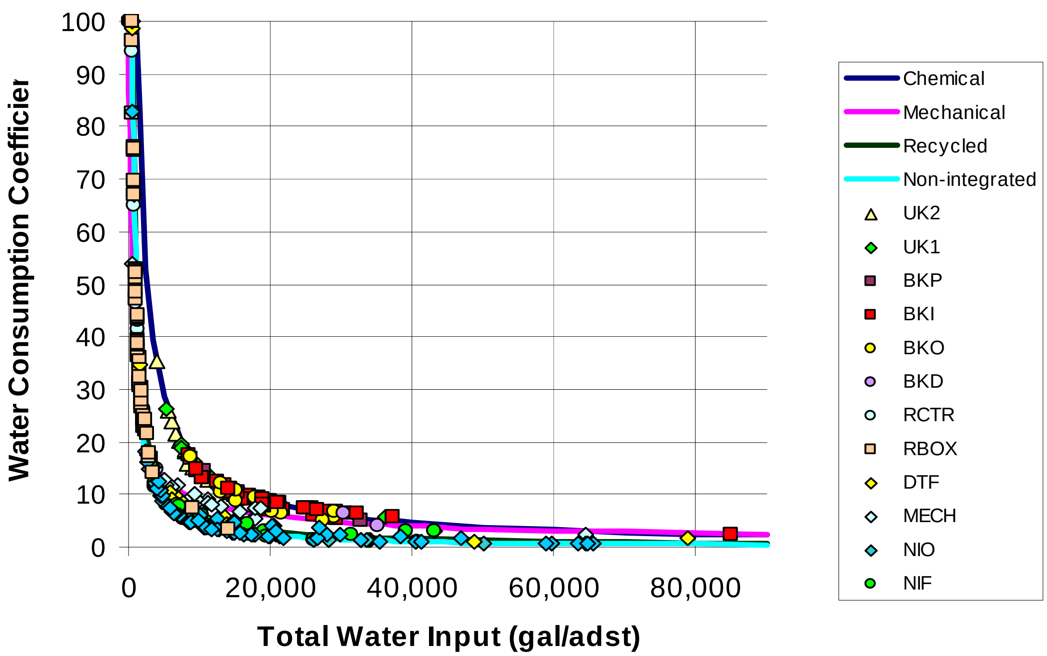


Figure 4.6 Water Consumption for U.S. Mills as a Function of Total Water Input, with Individual Contributions from Secondary Waste Treatment Type
[See Appendix A for category definitions.]

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 waste 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 1459 billion gal/yr. Applying the fresh water source data, 1251 billion gal/yr of this total (86%) is attributed to surface water sources and the remaining 208 billion gal/yr (14%) 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, and most process subcategories in the wood products sector are precluded from discharging process wastewaters directly to a receiving stream. Process waters are reused within mills, while non-process waters can be discharged to a receiving stream if an appropriate National Pollutant Discharge Elimination System (NPDES) permit is obtained. 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. NCASI conducted a survey in 2000 to obtain information on water use in the U.S. wood products industry. The data were not quality assured or quality checked and the degree of industry coverage that was obtained by the survey responses is unknown, so the results should be viewed only as a gross indicator of water use within the U.S. wood products industry. Total wastewater generation rates were reported by 94 facilities. The median reported value was 5.1 million gal/yr, or about 17,000 gallons per operating day (assuming 300 operating days per year) (NCASI 2004b).

Median specific water usage at U.S. wood products facilities was calculated as described herein. The median production rate for AF&PA member wood products facilities from the 2000 AF&PA Environmental Health & Safety survey was 5979 thousand of cubic feet of product (MCF), including lumber, structural panel, and non-structural panel production. An average conversion factor of 16.6 MCF/mt was based upon the relative amounts of production in the major categories of lumber, structural panel, and non-structural panel production in 2000 and the work of McKeever (2002). Using the median water usage from the 2000 NCASI survey, median production from the EHS survey, and the average volume to mass conversion factor, a value of 47 gal water/short ton of production was calculated for the median specific water usage at wood products facilities. Total wood products production in 2005, the latest year for which U.S. data are available, was 87.2 million metric tons of product per year (Howard 2007). Total water usage in U.S. wood products facilities was estimated by multiplying the median specific water usage at wood products facilities in 2000 (assuming no change in specific water usage between 2000 and 2005) by the total U.S. wood products production, to generate a value of 4.49 billion gal/yr in 2005. 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 (14% groundwater and 86% surface water) are applicable to the wood products industry. Total water usage calculated for the U.S. wood products industry is less than 1% of the total water usage calculated for the U.S. pulp and paper industry. Weyerhaeuser Company reported that total water use (process and non-process) at its wood products facilities was approximately 1% of total water use of its pulp and paper facilities (http://www.weyerhaeuser.com/Sustainability/Footprint/WaterUse).

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. The Consortium for Research on Renewable Industrial Materials (CORRIM; http://www.corrim.org) conducted detailed mill surveys to collect life cycle assessment (LCA) data for the evaluation of environmental impacts of renewable building materials. Its information provides a basis for characterizing the water profile of the U.S. wood products industry. Table 4.17 shows the wood products industrial production for 2000 and 2005, the latest years for which data are available, as well as wood product sectors that have undergone LCA under the CORRIM project. The CORRIM work has characterized production sectors that represent over 80% of U.S. wood products production in 2005. Phase II of the work is slated to cover approximately 90% of wood products production by conducting LCAs of the medium density fiberboard (MDF) and particleboard sectors. CORRIM survey results contained sufficient information to develop typical wood mass balances for softwood lumber (Milota 2004; Milota, West, and Hartley 2004, 2005), hardwood lumber (Bergman and Bowe 2008), laminated veneer lumber (Wilson and Dancer 2005), softwood plywood (Wilson and Sakimoto 2005), and oriented strandboard (Kline 2005). Wood mass balances for the wood products sectors in which CORRIM has conducted LCAs have been extracted from the CORRIM work, and are contained in Appendix C.

Table 4.17 Wood Products Production for 2000 and 2005 and Facility Types Evaluated Under CORRIM Work

Category	2000 (million mt/yr)	2005 (million mt/yr)	CORRIM LCA
Lumber			
Softwood lumber	31.9	36.1	✓
Hardwood lumber	19.3	17.7	✓
Laminated veneer lumber	0.8	1.4	✓
Lumber made at pallet plants	0.7	0.7	
Structural Panels			
Softwood plywood	8.7	7.1	✓
Oriented strandboard (OSB) and waferboard	6.8	8.5	✓
Non-Structural Panels			
Hardwood plywood	1.3	1.2	
Particleboard	6.1	5.2	[a]
Medium-density fiberboard (MDF)	1.9	2.3	[a]
Hardboard	1.1	1.2	
Insulation board	0.8	0.8	
Other			
Miscellaneous wood products production	4.49	4.85	
Total	83.7	87.2	

[SOURCE: Howard 2007 (2000, 2005 production)]
[a] to be included in CORRIM phase II

Detailed water flows for water originating from the raw material of the U.S. wood products industry are estimated in Appendix C. A summary of results for 2005 is given in Table 4.18 and is shown graphically in Figure 4.7. Results were obtained by combining wood mass balances (Appendix C) with typical moisture contents of raw materials, products, and co-products.

Table 4.18 Flows for Water Originating from Raw Material for the U.S. Wood Products Industry, 2005

Source	Flow (billion gal/yr)
Inputs	
Water in raw materials (logs, bark, purchased veneer)	45.2
Water for process and non-process uses	4.5
Outputs	
Water in products and co-products except wood chips and hogged fuel to pulp mills	9.2
Water in sold wood chips	9.1
Water in sold hogged fuel to pulp mills	0.7
Evaporative losses from drying and/or hot pressing	20.0
Evaporative losses from energy generation from the burning of biomass	6.2
Miscellaneous evaporative losses[a]	3.4
Water otherwise managed[a,b]	1.1

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

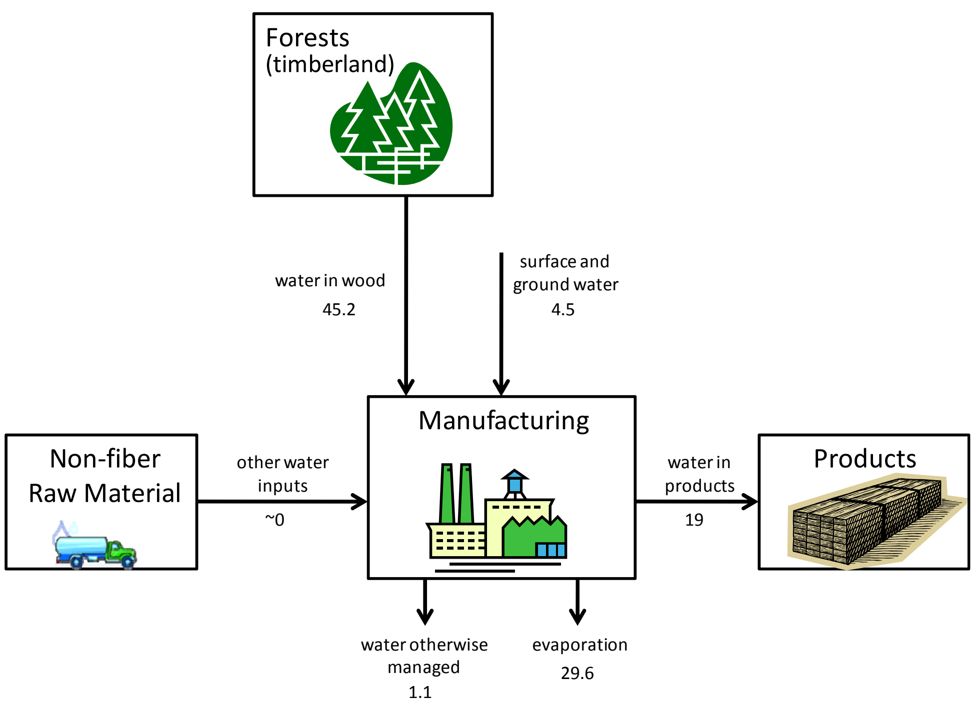


Figure 4.7 Water Profile for the U.S. Wood Products Industry (billion gal/yr)

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 4.8 shows the interplay of material flows between the U.S. wood products industry and the U.S. pulp and paper industry. It is estimated from this work that approximately 26% of the wood chip demand in the U.S. pulp and paper industry is supplied by the U.S. wood products industry, assuming that all wood chip production at wood products facilities is used for paper and paperboard manufacture. In addition, assuming that all sold hogged fuel from wood products facilities is used by pulp and paper mills, approximately 11% of total hogged fuel or 23% of purchased hogged fuel used by the U.S. pulp and paper industry in 2006 was supplied by wood products facilities. A small amount of sawdust from wood products facilities is used at pulp mills operating sawdust digesters for pulp production. Only eight mills in the U.S. have sawdust digesters, with a total capacity of 640,000 air dried mt pulp/yr (Fisher International 2008), so the sawdust contribution from wood products facilities to pulp mills is expected to be small. When combining water profile results from the U.S. pulp and paper industry and the U.S. forest products industry, it is important to consider the interactions between the two so that water contained in wood chips is not double counted.

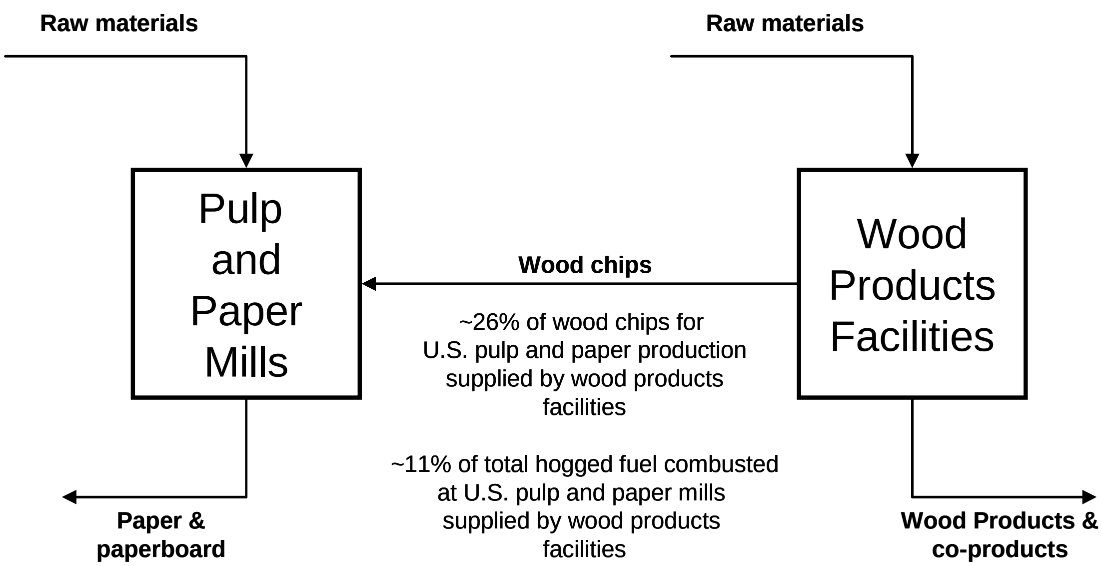


Figure 4.8 Interplay Between U.S. Wood Products Industry and U.S. Pulp and Paper Industry

The disposition of wood products after use in 2005 was 14% burned, 9% recovered, and the remainder (77%) either dumped, landfilled, or composted (Skog 2008). The primary recovery of solid wood is in the form of wood pallets (USEPA 2005). For the water profile calculations, it is assumed that the fate of wood products and co-products, excluding wood pallet recovery, corresponds to reported recovery (Skog 2008): 15% burned and 85% landfilled.

4.14 Water from Combusted Hogged Fuels

Pulp and paper mills combust large quantities of hogged fuel to supplement mill steam requirements. AF&PA data quantifying the amount of purchased and self-generated hogged fuels combusted at pulp and paper mills in 2006 are available. Table 4.19 shows hogged fuel usage and the water content in hogged fuels for 2006. The AF&PA mills responding to the survey represented 76% of total pulp and paper production in 2006. The water contribution from hogged fuels is scaled to total U.S. pulp and paper production by multiplying the AF&PA results by a scaling factor of 1.32 (1/0.76). The scaled value of water content in hogged fuel is somewhat high biased because a majority of the production contribution from mills that did not respond to the survey was in the recycled and non-integrated paper sectors, which typically do not have large hogged fuel boilers to supply steam and energy needs.

Table 4.19 Hogged Fuel Use from AF&PA Mills, 2006

Source	Thousands of Short Tons[a]	Hogged Fuel Water Content[b]	Scaled Hogged Fuel Water Content[b]
Self-generated	20,528	2.5	3.3
Purchased	19,694	2.4	3.1
Total	40,222	4.9	6.4

[a] 50% moisture content
[b] billion gal/yr

4.15 Synthesis

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

- Surface and groundwater are the primary water inputs to pulp and papermaking processes, amounting to some 1459 billion gal/yr. Water inputs from other sources (non-fiber raw material, wood, and recovered paper) amount to about 42 billion gal/yr.
- Most of the water withdrawn for use in pulp and paper manufacturing or otherwise imported is returned to surface water supplies (90%).
- Evaporative losses account for about 9% of water inputs to pulp and paper mills and the remainder is exported with product or 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 1464 billion gal/yr of water from surface and groundwater sources, and an additional 77 billion gal/yr is brought into the processes with raw materials. Of that total, 88% is returned to surface waters, 11% is evaporated, and 1% is exported with products and solid residuals.

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.

Sedimentation and biological treatment of forest products industry wastewaters dates back many decades but became quite common in the 1970s following development of U.S. federal guidelines mandating such treatment. Since that time, the quality of effluents, as measured by conventional parameters, has improved considerably. Figures 5.1 and 5.2 show production-weighted mean discharge loads of biochemical oxygen demand (BOD) and total suspended solids (TSS) (a.k.a. filterable solids), respectively, for U.S. pulp and paper mills. Figure 5.3 shows adsorbable organic halides (AOX) from bleached papergrade kraft pulp mills located in the U.S. Inconsistencies in data collection efforts undertaken between 1975 and 2006 (Figures 5.1, 5.2, and 5.3) warrant special note. Data for 1995 through 2006 represent production-weighted means, while data for prior years are the means of mill-reported loads. Each plot shows substantial declines since 1975. 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, improvements derived largely from the application of so-called elemental chlorine free (ECF) bleaching of chemical pulps coupled with biological treatment.

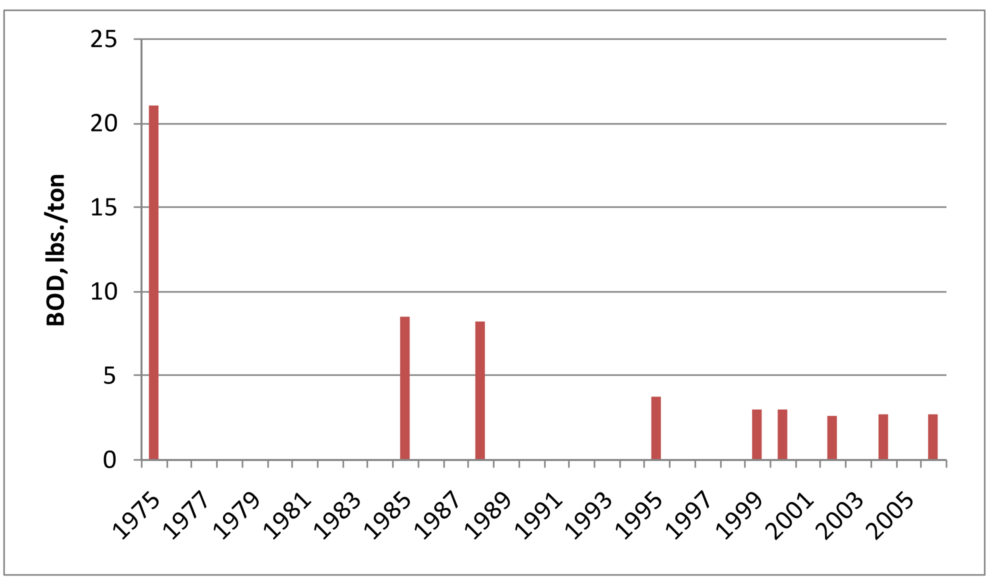


Figure 5.1 Production-Weighted Mean Biochemical Oxygen Demand (BOD) Discharges for U.S. Pulp and Paper Production [See data explanation in text.]

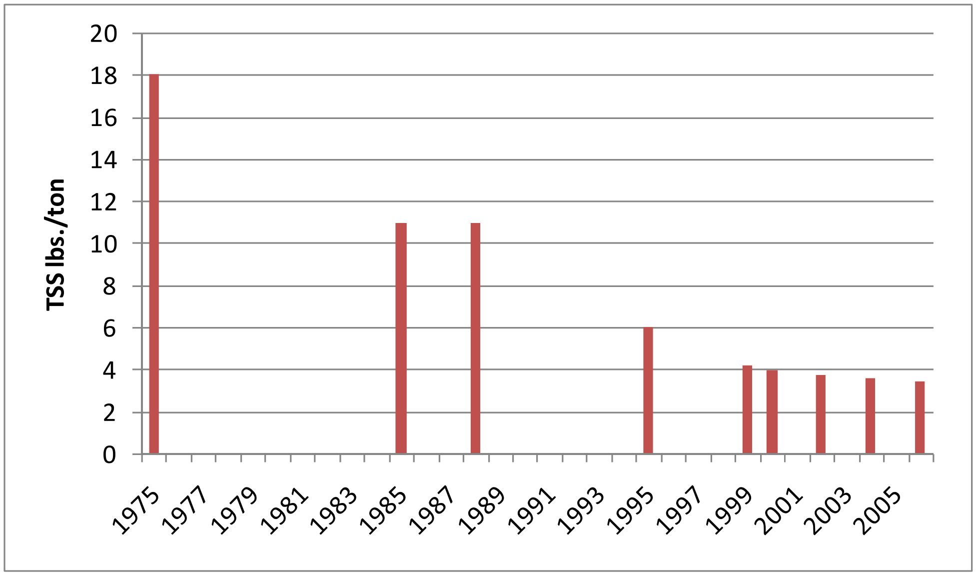


Figure 5.2 Production-Weighted Mean Total Suspended Solids (TSS) Discharges for U.S. Pulp and Paper Production [See data explanation in text.]

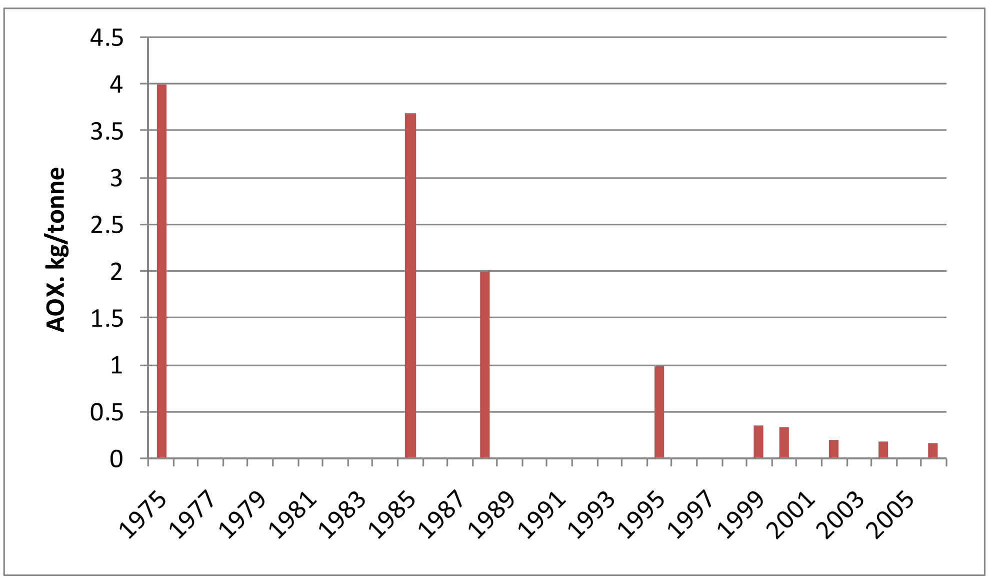


Figure 5.3 Production-Weighted Mean Adsorbable Organic Halides (AOX) Discharges for U.S. Bleached Papergrade Kraft Pulp Production [See data explanation in text.]

Today, the compatibility of effluents with receiving waters is assured by minimum standards for effluent quality and through protection of specific waters receiving treated effluent discharges. Federal rulemaking in the U.S. has established minimum standards for wastewater quality (USEPA 1998). These are predicated, in part, on biological treatment of effluents. The standards limit discharges of specific pollutants, such as BOD and TSS, and impart requirements for monitoring and, if necessary, eliminating toxicity of treated effluents as measured by acute and sublethal (a.k.a. chronic) bioassay tests involving organisms such as algae, water fleas, and fish. In some cases, state regulations more stringent than federal standards are in place.

Beyond the minimum effluent standards, U.S. regulations prohibit effluent discharges from causing or contributing to impairments to water quality, aquatic communities, and wildlife dependent on aquatic communities. The protection of waters receiving effluents is accomplished through two mechanisms. The first is one element of a trio of approaches used to protect against the discharge of toxicity with effluents (USEPA 1991). The trio includes 1) whole effluent testing for toxicity; 2) restrictions on effluent constituents known to be toxic at certain concentrations; and 3) biological criteria and bioassessment and biosurvey approaches for aquatic life protection. The latter targets evaluation and subsequent protection of aquatic communities inhabiting receiving waters. The second, but related, method is establishment of local water quality standards and criteria to protect aquatic life. These standards and criteria are applicable in ambient waters and encompass both toxic substances (e.g., copper) and water quality conditions (e.g., dissolved oxygen, nutrients) that may impair aquatic organisms. Achieving the standards and criteria is accomplished by means of translating them into effluent restrictions contained in discharge permits (ibid.).

Beyond the protection afforded to aquatic systems through biological secondary treatment, minimum standards for effluent quality, and instream protection, it may be observed that the volume of effluent discharged into receiving streams is typically a small fraction of overall stream flow (Beebe, Palumbo, and Eppstein 2003). An analysis of U.S. pulp and paper mills discharging into rivers and streams showed that 94% of the approximately 200 mills examined in the study accounted for less than 10% of the flow contribution to their receiving waters at average flow conditions, and 70% had instream effluent concentrations of less than 1% (Figure 5.4). The low instream waste concentration of the majority of mills is an important consideration of the potential significance of effluent effects on biological communities.

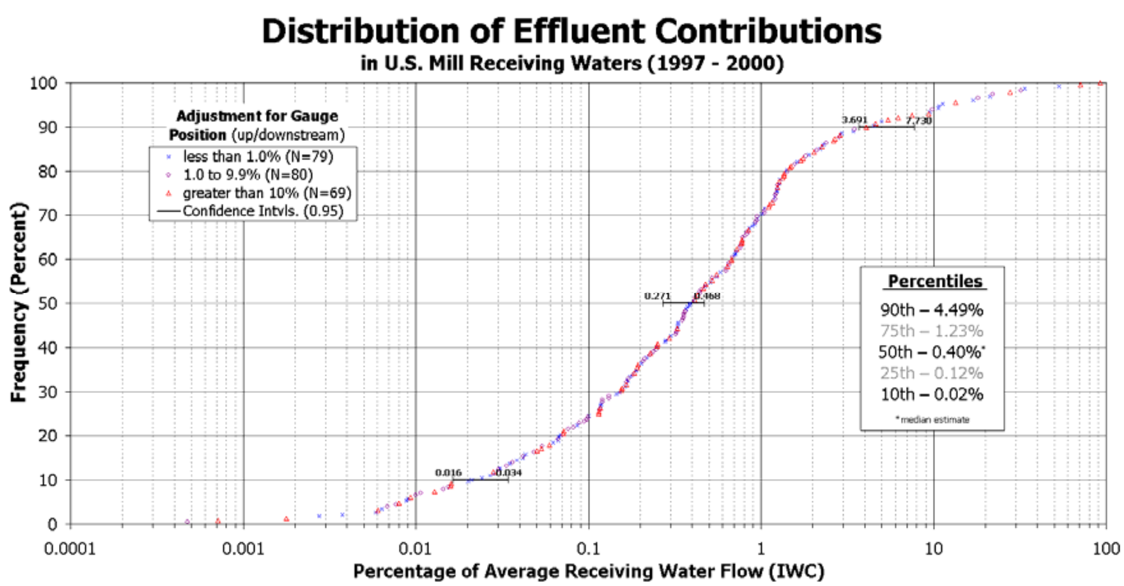
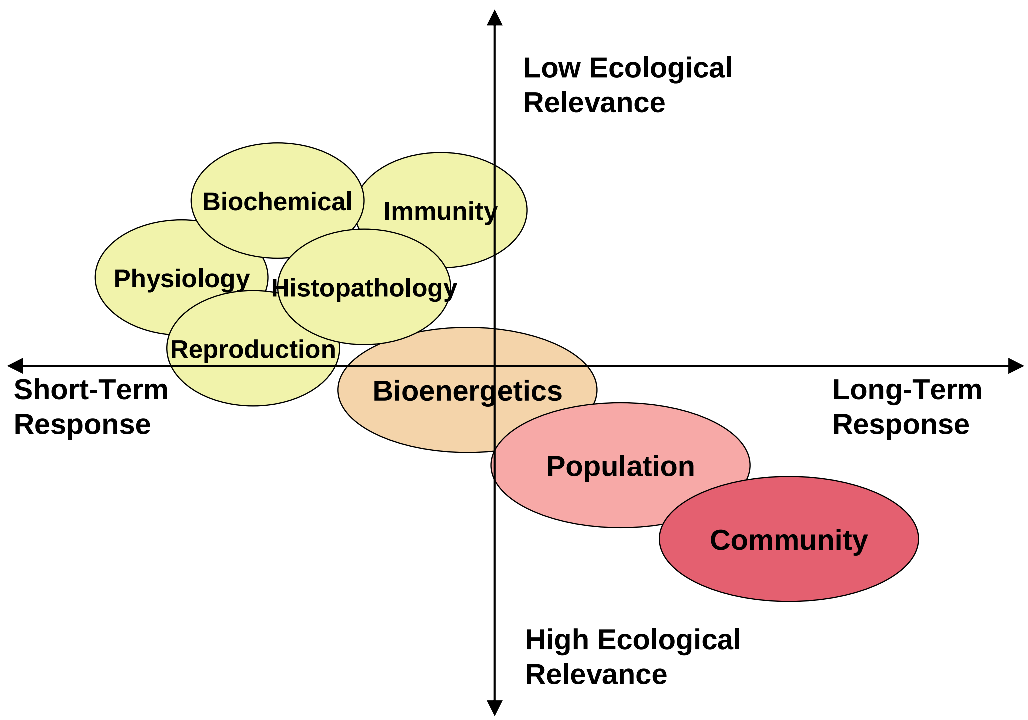


Figure 5.4 Frequency Distribution of Instream Waste Concentrations as Percentages of Average Receiving Water Flows for U.S. Pulp and Paper Mill Receiving Waters, 1997 to 2000 [Beebe, Palumbo, and Eppstein 2003]

The combination of low instream waste concentrations, minimum effluent quality standards, and water quality standards affording protection to local receiving waters has proven effective in ensuring that treated effluent discharges are compatible 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 Section 5.1, the potential for forest products industry effluents to affect aquatic communities has been the subject of substantial research. Potential effluent effects on aquatic organisms has been examined through laboratory assessments using bioassays and short- and long-term toxicity testing, while mesocosm/artificial stream studies and instream bioassessments 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 the likelihood of longer-term impacts increase 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 of some other factor (e.g., habitat availability).



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

Efforts to examine the relationship between aquatic communities and effluents have been largely directed towards laboratory bioassay studies, in part because compliance with National Pollutant Discharge Elimination System (NPDES) 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 instream effects from bioassay and life cycle testing, mesocosms and instream studies have also been employed to examine potential effects. Methods of examining potential effluent effects on aquatic organisms are described herein, 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 not presented because they are only relevant in the context of the effluents with which testing was conducted. Instream assessments and mesocosm studies of effluent effects examine aquatic organisms in natural systems or in environments that attempt to mimic natural systems. This section details the responses of algae, macroinvertebrates, and fish to effluent exposures examined in regulatory programs, peer-reviewed literature, and the NCASI Long-Term Receiving Water Study.

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. The United States Environmental Protection Agency (EPA) has developed methods for short-term "acute" bioassay tests (48 to 96 hr) using various organisms. Marine and fresh water test species include water fleas (*Ceriodaphnia dubia*, *Daphnia magna*, *D. pulex*), brine shrimp (*Artemia salina*), bivalves (*Mytilius* sp.) fathead minnows (*Pimephales promelas*), rainbow trout (*Oncorhynchus mykiss*), brook trout (*Salvelinas fontinalis*), mysids (*Mysidopsis bahia*, *Holmesimysis costata*), sheepshead minnows (*Cyprinodon variegatus*), and silversides (*Menidia menidia*, *M. beryllina*, *M. peninsulae*). Longer-term tests are conducted to more accurately assess the potential hazards of effluent to biota. Designed in the 1960s, these tests assess 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 that are of shorter duration have been developed with invertebrates and algae.

Life cycle testing has been routinely conducted on forest products industry effluents to determine potential effects on physiology and reproduction (see Hewitt et al. 2008 for review). The database of NCASI life cycle tests exceeds 25 (e.g., NCASI 1985c, 1996, 1997a, 1998a,c, 2000a,b, 2003, 2006a,b), including life cycle tests associated with the Long-Term Receiving Water Study (LTRWS). The LTRWS has examined spatial patterns of biotic community structure and biomass (fish, macroinvertebrate, and periphyton), habitat conditions, and water quality parameters multiple times per year at replicate sites in forest products industry receiving streams since 1998. The study design, in which multiple sites upstream and downstream of the effluent discharge are examined, shows the consistency of endpoints across seasons and years and allows naturally occurring spatial and temporal variation to be separated from effluent effects. Additionally, this approach documents improvements in environmental quality as mill operations are refined, identifies early indications of important forest products industry-related environmental impacts, and provides the framework for integration and interpretation of field and laboratory, and point- and nonpoint-source studies.

Fathead minnow life cycle tests were conducted with effluents discharged into four study streams (Codorus Creek, Pennsylvania; the Leaf River, Mississippi; and the McKenzie and Willamette Rivers, Oregon) located in three of EPA's subecoregions representing warm- and cold-water systems, various effluent dilutions, and differing mill process types. The primary objectives of these investigations were to determine if laboratory fish reproduction tests correlate to observations of fish communities during parallel instream sampling, and if instream effects on fish reproduction would be expected based on the life cycle bioassays. Several endpoints were measured 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 (Borton et al. 2009). In general, measured indicators did not show consistent patterns or dose-response or predict effects on reproduction during these life cycle bioassays. 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 endpoint showing a dose-response was the IC25[2] for egg production. Based in this endpoint, effluent had an effect on fish reproduction at concentrations ranging from 8% effluent (v/v) in the Willamette River to 100% effluent (v/v) in Codorus Creek. The margin of safety based on instream effluent concentration and life cycle findings was approximately 3X for Codorus Creek, and 34 to 40X for the remaining three streams.

5.2.2 *Mesocosm and Instream Effluent Effects Assessment*

Although acute bioassays and longer-term life cycle tests are important in assessing the potential toxicity of forest products industry effluents, 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, land use/land cover), local scales (e.g., substrate, channel form, depth), and 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 instream communities.

Mesocosm/artificial stream and instream studies have been conducted to determine the compatibility of forest products industry effluents with aquatic communities. A mesocosm or artificial stream can be defined as any constructed channel that has a controlled flow of water and 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 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.

Community-level studies of the effects of forest products industry effluents have been examined with respect to different taxa groups including algae, macroinvertebrates, and fish. However, the number of studies examining pulp and paper mill effluents is low relative to studies of other point- and nonpoint-source inputs. This section summarizes the findings of mesocosm and instream studies of forest products industry effluents 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 has been shown to act as an

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[2] The IC25 (inhibition concentration 25%) is the effluent concentration at which 25% of the test organisms show a response for the test endpoint.

empirical link between nutrient concentrations and a number of important biological phenomena in lakes, reservoirs, and streams.

Research examining the effects of mill effluents on algal communities is available in the published literature (e.g., NCASI 1989a) and as unpublished reports (e.g., NCASI 1989b, 1998b). 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 mesocosms or streams exposed to pulp and paper mill effluent relative to unexposed controls (e.g., Bothwell and Stockner 1980; Hall, Haley, and LaFleur 1991; Bothwell 1992; Culp and Podemski 1996; Dubé and Culp 1996; Podemski and Culp 1996; Culp, Podemski, and Cash 2000; Culp et al. 2003). However, increases to nuisance levels (>100 mg 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 concentration 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 effluents on algal communities. Davis, Vance, and Rodgers (1988) showed no significant changes in instream periphyton productivity, although a change in community structure occurred near the discharge relative to upstream communities and those further downstream.

Ongoing unpublished mill studies and industry reports have shown site-dependent and variable responses of instream periphyton and/or water column chl *a* to forest products industry discharges. In outdoor experimental streams, 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 color units) than in control streams during the early phases of one study (NCASI 1982, 1983), but greater in control streams compared to effluent-treated streams in later stages (NCASI 1984b, 1985b). The reasons for these differences are unclear. Examination of ecological changes following mill process changes showed no effluent-related differences in periphyton chl *a* downstream of 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 1984a). More recently, a literature review of mill consultant reports found that among seven studies examining periphyton, water column chl *a*, and algal community structure upstream and downstream of mill discharges, effluent effects were seen on only three occasions (NCASI 1998b).

Increased nutrient concentrations downstream of forest products industry discharges have been implicated in periphyton increases. Supplemental nutrient addition is required in forest products industry wastewaters to ensure efficient removal of BOD, TSS, and toxicity. Some residual nutrients remain in the final effluent as indicators of a well-functioning secondary biological treatment system (NCASI 2001c) and may be available for algal growth in receiving waters. However, the amounts of residual nutrients vary across mill effluents (Priha 1994; NCASI 1997b), and because instream waste concentrations of forest products industry effluents are typically low (Beebe, Palumbo, and Eppstein 2003), the level of nutrients available for algal growth is low relative to other sources.

As part of the LTRWS, periphyton samples have been collected from the four effluent-receiving streams at least twice per year (spring and fall) since 1998 and water column chl *a* measurements were conducted in 1998, 2005, and 2006. Between 1998 and 2006, periphyton chl *a* ranged from 1 to 285 mg/m^2 in all study streams except the Leaf River, where it ranged from less than 1 to 32 mg/m^2 on sand and 6 to 38 mg/m^2 on artificial substrates (Flinders, Minshall, Hall, and Rodgers 2009). In Codorus Creek and the McKenzie River, periphyton chl *a* was greater downstream of the effluent discharges than at one of the two upstream sites. Because downstream differences were not consistent among upstream sites, chl *a* patterns may be due to factors other than effluent discharges. Site differences related to effluent discharge were not seen on the other two study streams. Seasonal differences were seen only in Codorus Creek and the Leaf River, with overall chl *a* greater in the spring and summer than in the fall in Codorus Creek and on sand substrates in the Leaf River.

Water column chl *a* concentrations were measured in the LTRWS in 1998, 2005, and 2006, and were low and largely unrelated to mill effluent discharge in all streams (NCASI 2006c, 2007). Similar concentrations across sites were seen in all seasons in Codorus Creek and the McKenzie River, although there was a trend toward greater concentrations in the spring and fall than in the summer in the McKenzie River. In the Leaf and Willamette Rivers, chl *a* concentrations were substantially greater during 2006 than in previous years. This pattern was driven by substantially greater concentrations in the fall in the Leaf River and in the spring in the Willamette River. Seasonal increases in water column chl *a* concentrations in these two rivers coincided with atypically low flows and high periphyton biomass.

To better control effluent concentrations and identify their relationships with chl *a* and macroinvertebrates, mesocosm studies were conducted using effluent and taxa from the four LTRWS streams. Patterns were river-specific, with a significant relationship between effluent and chl *a* seen in only one stream. Periphyton samples collected from mesocosms at the McKenzie River 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 showed no significant differences in periphyton biomass with increasing nutrient concentration (NCASI 2001b, 2004a, 2005), although there was a trend towards increasing chl *a* with increasing effluent concentration.

The relationship between forest products industry effluents and algal biomass was variable by site, with some increases in periphyton biomass occurring following exposure to industry effluents. 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. Instream periphyton-effluent studies conducted at multiple sites over multiple seasons and years are limited to the LTRWS, where a conclusive effluent-chl *a* relationship was seen in only two of four streams and varied with season. Among instream periphyton studies where increases were observed downstream of some forest products industry discharges, findings were based on sampling from a single season (Scrimgeour and Chambers 2000), or increased were seen only seasonally (Dubé, Culp, and Scrimgeour 1997; Flinders, Minshall, Hall, and Rodgers 2009).

Macroinvertebrates: Use of macroinvertebrate assemblages to assess potential effects of point-source discharges and land use runoff on stream biota is common among state and federal agencies and is endorsed by regulatory agencies for evaluating and monitoring stream condition (Barbour et al. 1999). The types and relative abundance of macroinvertebrate species are used to identify overall community patterns (Winter et al. 2002; Berenzen et al. 2005) and are translated into community-based metrics that 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 (Griffith et al. 2001; Roy et al. 2003).

Although macroinvertebrates tend to be the most studied taxonomic group in stream bioassessments, there are relatively few field studies, either in mesocosms or in natural streams, examining the effects of forest products industry discharges on macroinvertebrate communities (Hall, Haley, and LaFleur 1991; Culp, Podemski, and Cash 2000; Culp et al. 2003). In many cases, studies were limited to a single season (Felder et al. 1998; D'Surney et al. 2000) or year (Mayack and Waterhouse 1983). One exception is macroinvertebrate data collected as part of NCASI's LTRWS, which has been conducted on four forest products industry effluent receiving streams for over ten years. In the LTRWS, macroinvertebrates are collected from natural (Codorus Creek, McKenzie River, Willamette River) and artificial (Leaf River) substrates in spring and fall from multiple sites upstream and downstream of discharges, and are examined for spatial and temporal changes in the types and relative abundance of species as well as community metric response.

Data collected during the LTRWS between 1998 and 2006 showed differences in community structure across sites, but no changes downstream of forest products industry discharges relative to upstream sites (Flinders, Minshall, Ragsdale, and Hall 2009). Community site differences were most pronounced in Codorus Creek. However, macroinvertebrate community structure at the most upstream site (5.6 km upstream of the mill discharge) was distinct from all other sites, with no changes in community patterns relative to the discharge. This community pattern corresponds to lower water temperature at the uppermost site than at other sites. Codorus Creek is a cold-water stream, but inflows from a tributary stream and discharges of mill cooling water result in a 5 to 9^{o}C increase in stream temperature downstream of the most upstream site (Hall et al. 2009). In the three remaining study streams (the Leaf, McKenzie, and Willamette Rivers), annual differences in fall community structures were more pronounced than differences across sites, suggesting that seasonal patterns are of greater influence to macroinvertebrate community structure in these streams than inputs of forest products industry effluents.

Several macroinvertebrate community metrics were also examined as part of the LTRWS, including percent dominant taxa, density, taxa richness, Hilsenhoff's Biotic Index (HBI) (Hilsenhoff 1987), Simpson's Index, and ash-free dry mass. These metrics translate community data into measures of the structure and function of the community. For example, the HBI calculates a water quality score on a scale of 1 to 10 for a given site based on the relative abundance of invertebrate taxa and their tolerances to stress.

Seasonal and annual variations in macroinvertebrate metric responses were seen in all streams, but there were no significant changes related to the discharge of forest products industry effluents in any of the four streams. The macroinvertebrate communities in all the streams were 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 HBI scores relative to upstream sites. However, a significant increase in HBI scores was limited to the site immediately downstream of the discharge relative to the site immediately upstream. The general lack of community and metric responses related to effluent discharges in these streams suggests that factors other than forest products industry discharges are of greater importance in driving community structure patterns, or that the sensitivity of these metrics is insufficient to differentiate stress-induced changes from natural variations.

Other researchers have shown that macroinvertebrate exposure to mill effluents (1 to 10% v/v) in artificial streams and mesocosms can result in increased growth rates (Lowell, Culp, and Wrona 1995; Lowell et al. 1996), higher density and biomass (Hall, Haley, and LaFleur1991; 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, at higher effluent concentrations (5.0 and 10%) macroinvertebrate growth rates were inhibited 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 instream 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 concentrations 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). In the LTRWS, instream effluent concentrations in three of the four study streams were low (<1%) with no significant changes in nutrient concentration (Hall et al. 2009) or primary production (Flinders, Minshall, Hall, and Rodgers 2009) downstream of discharges in these streams or in Codorus Creek, where mean effluent concentration is ~33%.

As with algal biomass, the effect of forest products industry effluent on macroinvertebrate communities is variable and site-dependent. The variability in response patterns can be attributed to several factors, including effluent process type and instream effluent concentrations; differences in instream environmental conditions such as temperature, flow, depth, substrate, and water chemistry across study streams; naturally occurring seasonal and temporal variations in macroinvertebrate communities; and finally, the robustness of the dataset on which analyses are based.

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 (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 used to examine potential community-level effects of forest products industry effluents in surface waters, fish are the least studied 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 comparing community structures in rivers downstream of forest products industry 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). In most cases, studies were conducted over relatively short periods of time and provided snapshot assessments of fish conditions, although some studies were designed to examine improvements in fish community measures following mill operational changes that improved treated effluent quality (Kovacs, Martel, and Voss 2002; Greenfield and Bart 2005).

Fish population studies do not examine the entire fish community, but rather specific characteristics of a subset of the species present. Inconsistent results were seen in three studies of population and physiological characteristics of four fish species exposed to forest products industry effluents relative to unexposed fish. These studies were conducted prior to implementation of secondary waste treatment. Munkittrick et al. (1991) found that white sucker (*Catostoma commersoni*) from a Lake Superior site receiving primary-treated bleached kraft mill effluent were older and had a higher condition factor (mass per unit length), smaller gonads, lower fecundity, and secondary sex characteristics than fish collected from unexposed sites. However, because secondary treatment has since been implemented at that mill, it is unlikely that those patterns would be seen today. In another study, the same species on different receiving waters 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 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). In the two latter examples, studies were conducted prior to mill process changes that eliminated use of elemental chlorine. Although these patterns are important in evaluating effluent effects on fish, findings from early studies may not be applicable today given current effluent treatment technology and strict adherence to regulations.

Fish populations and the potential effects of forest products industry effluents are also studied through Environment Canada's regulatory Environmental Effects Monitoring (EEM) (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 (Lowell et al. 2005; McMaster, Hewitt, and Parrott 2006). The studies are done once every three years, and there is no requirement to assess the structure and function of the entire fish community and possible spatial/temporal patterns. Findings from the first three cycles of the EEM program have suggested that enrichment downstream of forest products industry discharges has, on a national average, resulted in fish with larger livers, faster growth rates, higher condition factors, and smaller gonads relative to fish at unexposed sites. Findings across cycles have been variable and inconsistent at many sites.

Community-level studies of fish in effluent receiving waters have shown variable results. Fish community structures measured in receiving streams prior to biological secondary treatment of effluent that 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 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 effluent biotreatment systems. IBI scores indicated average to excellent environmental quality downstream of discharges and did not change relative to sites upstream. Greenfield and Bart (2005) used archived data to assess the impacts of effluent from a kraft mill on fish community dynamics in an effluent-dominated (instream effluent concentration >50%) Florida blackwater stream compared to a nearby stream that did not receive 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. The receiving stream fish community was composed largely of the intermediately tolerant species *Lepomis macrochirus* and *Gambusia affinis*, whereas the reference stream community was composed largely of stress-intolerant minnows, sucker, and darter species.

NCASI's LTRWS collects data on fish community structure in four receiving streams. The entire fish community in Codorus Creek is sampled 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. As with periphyton and macroinvertebrate communities, fish are collected in the spring and fall on three of the four rivers, but just once per year (fall) from the Leaf River.

In over ten years of study, fish community structure did not show seasonal patterns in any of the streams and was variable across years. There were weak site differences in the Leaf, McKenzie, and Willamette Rivers, with similar variability seen in both the large- and small-bodied fish communities of the McKenzie and Willamette Rivers. However, none of these differences were related to effluent discharge. Codorus Creek was the only study stream that showed distinct communities with respect to site. As in the other study rivers, site differences in fish community structure did not appear to be related to effluent discharge location, but rather to habitat differences across sites in terms of temperature, substrate, stream width, and canopy cover (Flinders, Ragsdale, and Hall 2009).

An assessment of the structure and function of fish communities in these streams was examined using fish community metrics. Calculated metrics included fish abundance (standardized for sampling effort), species richness, Simpson's Diversity Index, percent dominant taxa, percent intolerant species, standing crop (total biomass), fish health (relative abundance of fish with deformities, fin erosion, lesions, or tumors [%DELT]), percent omnivore, and percent piscivore. Of these nine metrics, only two on one stream showed differences at sites downstream of an effluent discharge relative to upstream sites. In the McKenzie River, there was a decrease in the percent piscivores driven by a decrease in rainbow trout (*Oncorhynchus mykiss*) at sites downstream of the discharge relative to upstream sites. The more prolific use of upstream segments by *O. mykiss* relative to downstream reaches has been seen in other Willamette River tributaries as well as the McKenzie River (ODFW 1991a, b), suggesting that this is a naturally occurring upstream-downstream pattern rather than a result of forest products industry effluent. A decrease in the percent dominant taxa of small-bodied fish at sites downstream of the McKenzie River effluent 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.

In general, instream research on the effects of forest products industry effluents on fish species within a population has shown that physiological changes occurred prior to the implementation of secondary biological treatment systems. With secondary treatment, population-level effects are variable, but cases of enrichment and shifts in energy allocation have been observed. Although very few studies have examined community-level effects on fish, forest products industry effluent had little effect on the communities studied. The lack of effluent effects seen at the community level indicates that effluent qualities were such that fish communities were unaffected, effluent concentrations were not sufficient to affect fish community structure, or naturally occurring community variation obscured possible effluent-related influences.

Other industrial effluents: It is difficult to gauge effects of pulp and paper mill effluents relative to other industrial point sources. In natural systems, biological communities show a cumulative response to upstream influences. Truly separating the relative influence of one point source from another is not possible in an instream study, and laboratory and mesocosm studies addressing this question are rare. Other effluents, including those from municipal wastewater treatment plants (Birge et al. 1989; Kosmala et al. 1999; Northington and Hershey 2006), mining operations (Dubé et al. 2005), and power plants (Lohner et al. 2001), have been shown to alter biological communities. In some rivers with multiple discharges that include forest products industry effluents, changes in biological communities downstream of other point sources were sometimes greater than those associated with forest products industry effluents (Scrimgeour and Chambers 2000; Galloway et al. 2003). However, the effect of other effluents in relation to forest products industry effluents is not certain.

5.3 Synthesis

Assessing the compatibility of treated mill effluents with instream 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. Effluent flow and loads of BOD, TSS, and AOX have declined dramatically since the 1970s. Although site-dependent, instream studies examining the effects of effluents have shown that

- patterns of algal biomass, macroinvertebrate community structure and biomass, and fish community structure can be highly variable by 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, pulp and paper mill effluent 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 stream flows, instream waste concentrations related to low flow, and seasonal patterns of algal species;
- although in artificial streams and 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 variations in habitat conditions have a greater influence on community structure than effluent; and
- fish communities are highly spatially and temporally variable, and relatively few studies have examined instream community effects related to pulp and paper mill effluents. In the studies that have been conducted, 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, secondary biological treatment of pulp and paper mill wastewater has resulted in effluents 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-fiber raw material use, product manufacturing, and product export).

6.1 Precipitation, Evapotranspiration, and Streamflow on Timberlands

Calculating the annual availability of fresh water, particularly over large spatial scales, is not a straightforward task. Precipitation and runoff amounts vary widely from place to place, 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 29.25 inches (standard deviation 2.27 inches) 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 36.0 inches (standard deviation 2.8 inches), a value 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 nonquantified 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 process of water loss).

The amount of land area in the U.S. (excluding Alaska[3] and Hawaii) that is considered to be forested is 622.6 million acres, or about 33% of the total land area (USDA 2007). Timberland is defined as the subset of forest land where harvest access is not completely restricted (e.g., national parks) and where the potential yield of industrial wood is in excess of 20 ft^3 per acre annually. In the U.S. (excluding Alaska and Hawaii), the amount of timberland is estimated to be 501.6 million acres, or about 81% of forest land and 26% of the total land area (ibid.). As noted in Section 3, the majority of this land is situated in areas that receive precipitation above (sometimes well above) the national average. Estimates of runoff totals suggest that about 67% of streamflow in the continental U.S. (approximately 925 million acre-feet) originates from forested land (USDA 2000). The proportion might be expected to be roughly similar to the proportion of streamflow associated with these timberland areas, though it would vary widely by region due to differences in evapotranspiration patterns. Therefore, a crude approximation of the precipitation falling on timberland can be made for the contiguous U.S.. The calculation (which assumes 30 inches of precipitation per year, 67% of which falls on forest land, and that the geographical distribution of timberland is similar to that of forest land) yields an annual quantity of water entering timberland in the contiguous U.S. as precipitation of 833 trillion gallons.

Water leaves the forest as streamflow, groundwater, or water vapor emitted from trees and other forest plants (i.e., evapotranspiration). The relative amounts of water exiting as either streamflow or evapotranspiration is highly site-specific, as discussed in Section 3.1.3. Data from the four 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.

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[3] Alaska has a large land area and forest land area (126 million acres), but a relatively small area (<10%) defined as timberland (11 million acres) (USDA 2007).

Table 6.1 Precipitation, Evapotranspiration, and Streamflow in Four Forested Watersheds

Watershed	Precipitation (in)	Runoff (in)[a]	Evapotranspiration (in)[a]
Needle Branch, Oregon	92	53 [58%]	39 [42%]
Coweeta, North Carolina	73	41 [56%]	32 [44%]
Grant Forest Watershed, Georgia	52	16 [31%]	36 [69%]
Wagon Wheel Gap, Colorado	21	6 [29%]	15 [71%]
Average		44%	56%

[a] percent of precipitation in brackets

Applying a value 45% of precipitation to streamflow yields 375 trillion gal/yr to runoff and 458 trillion gal/yr to evapotranspiration from timberland. This estimate for streamflow is higher but of the same magnitude as the USDA estimate (925 million acre-ft/yr) (USDA 2000) adjusted to timberland of 244 trillion gal/yr.

As described, timber harvesting can have the short-term effect of increasing streamflow and decreasing evapotranspiration. However, the harvesting cycles required to maintain a sustainable supply of timber allow only a small percentage (e.g., <5%) of the total timberland to be harvested in any one year. Thus, changes in the overall balance of streamflow and evapotranspiration in the continental U.S. as a whole, are very small (i.e., <1% of precipitation).

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 6.2.

Table 6.2 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-fiber 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 fiber	4.8
Water in disposed products	4.10, 4.13
Water evaporated from products	4.10, 4.13

The combination of these data represents the water quantity profile of the U.S. forest products industry and the results are depicted in Figure 6.1.

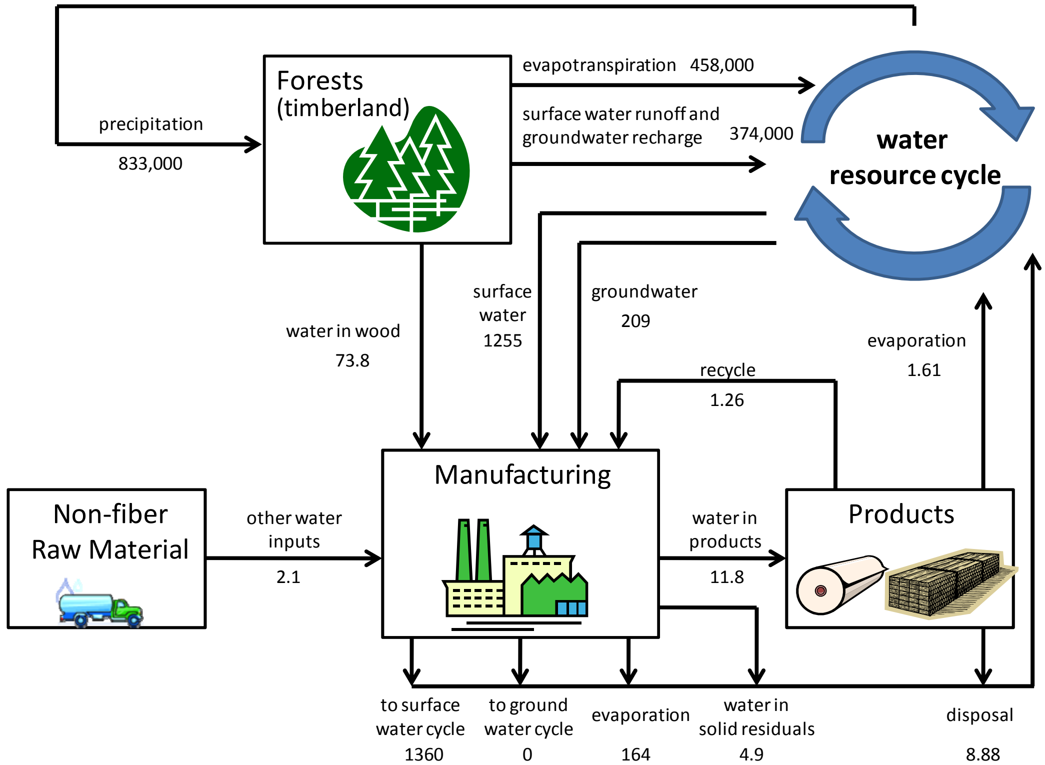

Figure 6.1 Water Quantity Profile for the U.S. Forest Products Industry (billion gal/yr)

Precipitation on timberland from which forest products industry raw material may be drawn is about 800 trillion gal/yr. Approximately 45% of it, 375 trillion gal/yr, enters surface water or groundwater. The forest products industry draws an estimated 1464 billion gal/yr, about 0.4% of the streamflow and groundwater recharge from timberland. An additional 74 billion gal/yr (0.009%) of precipitation on timberland is drawn in the form of water contained in wood used to manufacture wood and paper products.

The manufacture of forest products in the U.S. requires about 1464 billion gal/yr of surface and groundwater, with an additional 77 billion gal/yr entering with wood, recovered paper, and purchased non-fiber raw materials. Water from the latter sources constitutes about 5% of total inputs. Of the total water inputs (1541 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

International dialog concerning the availability of fresh water and its appropriate use has become more prominent in recent years due to population growth, increased recognition of the needs of sensitive aquatic life, the potential for climate change to affect water resources, and other factors. The total volume of fresh water withdrawn in the U.S. is dominated by irrigation, thermoelectric power generation (mostly cooling water), and public water supplies. Industrial fresh water use ranks below these. Within the industrial category, the forest products industry is among the larger users of fresh water although, unlike some other industrial water users, most of the water used is returned to surface waters. Pulp and paper mills have greatly improved water reuse and conservation efforts over the last several decades, so the amount of water used for raw material processing has decreased by more than 50% since the mid-1970s.

Because the forest products industry is among the larger industrial users of fresh water resources, discussions related to water have invariably included companies involved in forest management and the manufacture of forest products. This report was undertaken to inform those discussions. The goal was to develop a quantitative assessment of water associated with timberlands and forest products manufacture. The effects of forest management on the fate of water and the compatibility of treated manufacturing effluents with the waters receiving them were also considered.

Rough estimates are provided for precipitation onto timberland in the U.S., as well as streamflow and groundwater recharge and evapotranspiration from them. Estimates of the amount of water used in forest products manufacturing are more refined and were developed by considering water from surface and ground sources as well as water contained in wood, non-fiber raw material, and recycled fiber supplies. Estimates of water discharged to surface water and contained in products and solid residuals were also made. The fate of water within manufacturing processes was analyzed to the degree necessary to estimate the quantity of water lost to evaporation.

Forests act to process precipitation into high quality surface waters and most of the nation's surface waters are derived from forested areas. Managing forests for timber production can affect the partitioning of water between runoff, groundwater recharge, and evapotranspiration and can affect the quality of streamflow. With respect to changes in quantity, timber harvesting can decrease evapotranspiration, resulting in increased streamflow and groundwater recharge. These increases decrease with regrowth of the forest, and effects are constrained by managing harvest schedules to limit the areas of forest watershed harvested at any one time.

Managing forests for timber production can negatively affect water quality; however, contemporary best management practices (BMPs) are widely used in the U.S. and reduce or eliminate impacts of harvest on surface waters when properly implemented. Natural disturbance events (e.g., wildfires, tropical storms, insect outbreaks) can have effects on water quality greatly exceeding those of forest management for timber production.

Alternative land uses (e.g., agriculture, urban) typically have much greater negative impacts on water quality with respect to loads of sediment, pesticides, nutrients, and some other pollutants to streams than properly managed forest operations. Compared to these other land uses, forests are also best for managing peak flows. These observations, coupled with the knowledge that most fresh water originates from forested lands, suggest that maintenance of timberland, in lieu of deforestation in favor of alternative land uses, is essential to the continued availability of high quality fresh water supplies.

With respect to water quantity, about two-thirds of the fresh surface waters in the U.S. are produced from forested areas. Most of this land is considered "timberland" as defined by USDA, and about 800 trillion gallons of water falls onto this land per year. From this, timberland produces roughly 374 trillion gal/yr of streamflow. The forest products industry's manufacturing operations use an amount of water equal to about 0.4% of this. Of the water used to produce products, about 95% is obtained from surface or groundwater sources. Approximately 88% is returned directly to surface waters following treatment; about 11% is converted to water vapor in the pulp, paper, and wood products manufacturing process; and about 1% is imparted to products or solid residuals.

Treated effluents from pulp and paper manufacture are typically discharged to surface waters. The quality of effluents and their compatibility with these receiving waters has been studied extensively and continues to be monitored. All effluents in the U.S. are variously assayed for toxic effects, and site-specific regulations are in place to manage bioassay outcomes that may suggest the presence of substances toxic to aquatic life. Life cycle testing of aquatic organisms exposed to treated pulp and paper effluents sometimes shows effects on organism growth or reproductive capacity. In nearly all cases, such effects occur at effluent concentrations that are much higher than typically seen in actual receiving waters. NCASI studies of waters receiving pulp and paper mill effluents show few or no impacts on algal, benthic invertebrates, and fish communities due to effluents. These studies are the most comprehensive in terms of scope and duration ever undertaken in the forest products industry, and thus provide considerable evidence of the compatibility of treated pulp and paper effluents with the aquatic environment.

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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 fiber 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 fiber contains at lease 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 fiber contained in final products. These mills make an assortment of final products that may incorporate mechanical pulps, secondary fiber, or purchased fiber.
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 fiber furnish may include non-deinked secondary fiber, 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 fiber. They may also produce linerboard from recycled fiber.
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 Tissue/Fine Papers (DTF). Mills that produce tissue/toweling or fine papers from deinked secondary fiber produced on site.
9. Deinked Newsprint (DNWS). Mills that produce newsprint from deinked secondary fiber produced on site.
10. Recycled Containerboard (RCTR). Mills that produce linerboard and corrugating medium, typically on Fourdrinier machines, from non-deinked secondary fiber produced on site.
11. Recycled Boxboard (RBOX). Mills that produce boxboard, tube stock, and similar products, typically on cylinder machines, from non-deinked secondary fiber produced on site.

12. Non-Integrated Fine or Lightweight Papers (NIF). Mills that produce fine or lightweight papers from purchased fiber.

13. Non-Integrated Other Papers (NIO). Mills that produce tissue, filter, or other papers from purchased fiber.

14. Sulfite Dissolving Pulp (SULD). Mills that produce dissolving grade sulfite pulps.

15. Sulfite Papergrade (SULP). Mills that produce paper primarily from sulfite pulp produced on site.

16. 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 North American forest products industry as a whole. Final effluent data were supplied by AF&PA EHS survey results and from the Fisher Pulp&Paper Worldwide™ database. Coefficients used to calculate consumptive water losses from processes and evaporative losses from secondary waste 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.

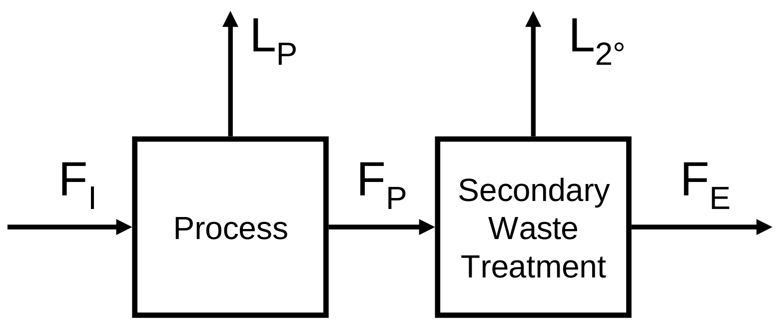

Figure B.1 Mill Water Balance Components Considered in the Water Profile Work

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 waste treatment
$L_{2°}$ = secondary waste 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 AF&PA EHS 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 were reported in NCASI Technical Bulletin No. 946.

x is a coefficient used to calculate evaporative losses from secondary waste treatment as a function of total flow into secondary waste treatment, F_P; coefficient x varies by waste treatment system type and were reported in NCASI Technical Bulletin No. 946.

Wanted:

F_P and F_I

Evaporative losses from secondary waste 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 L_P that satisfies Equation B6.

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

Once L_P is known, use Equation B4 to calculate F_I.

APPENDIX C

OVERALL WOOD MASS BALANCES FOR WOOD PRODUCTS SECTORS

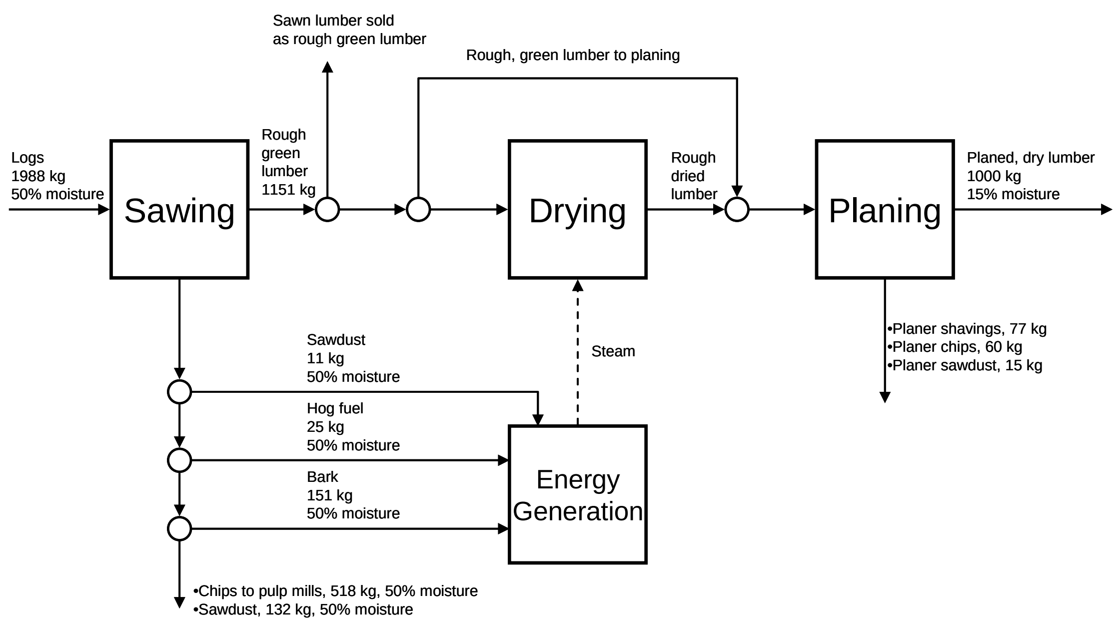

Figure C.1 Pacific Northwest Softwood Lumber Mill Using Douglas Fir and Hemlock [wood mass balance extracted from Milota 2004; Milota et al. 2004, 2005]

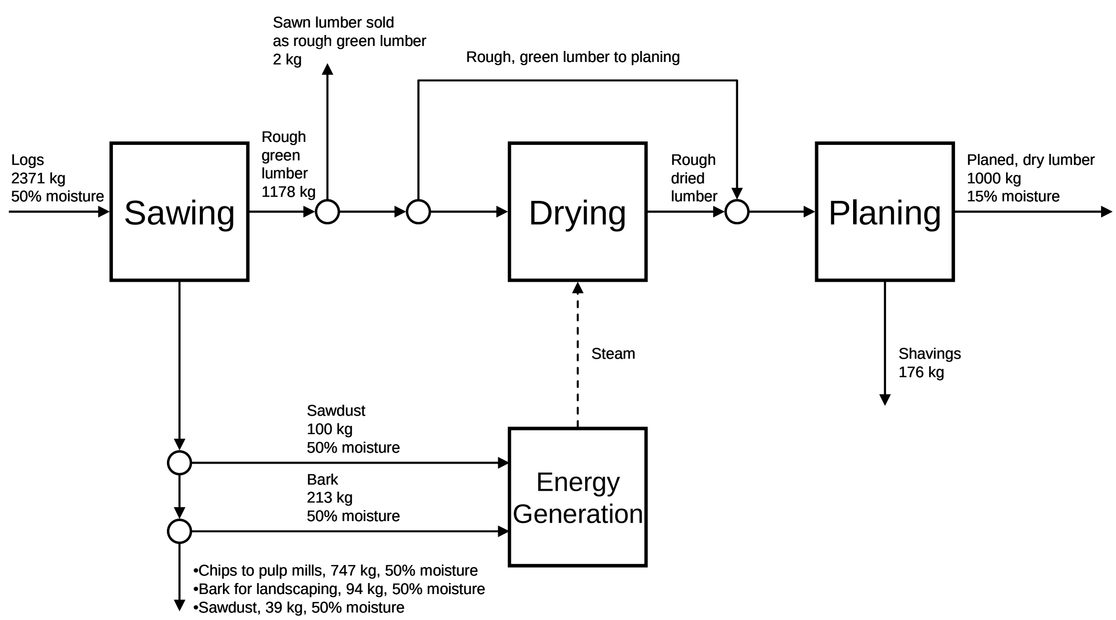

Figure C.2 Southeastern Softwood Lumber Mill Using Southern Pine [wood mass balance extracted from Milota 2004; Milota et al. 2004, 2005]

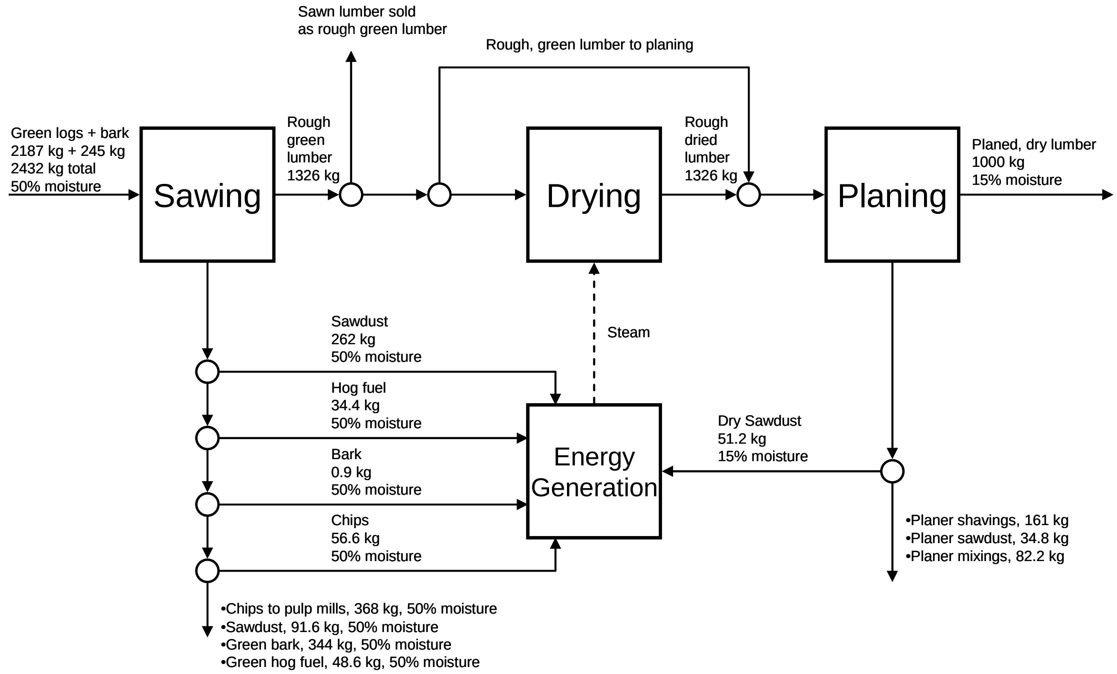

Figure C.3 Hardwood Lumber Mill Weighted Average from 20 Facilities in 20 States, wood(dry) mass balance [wood mass balance extracted from Bergman and Bowe 2008]

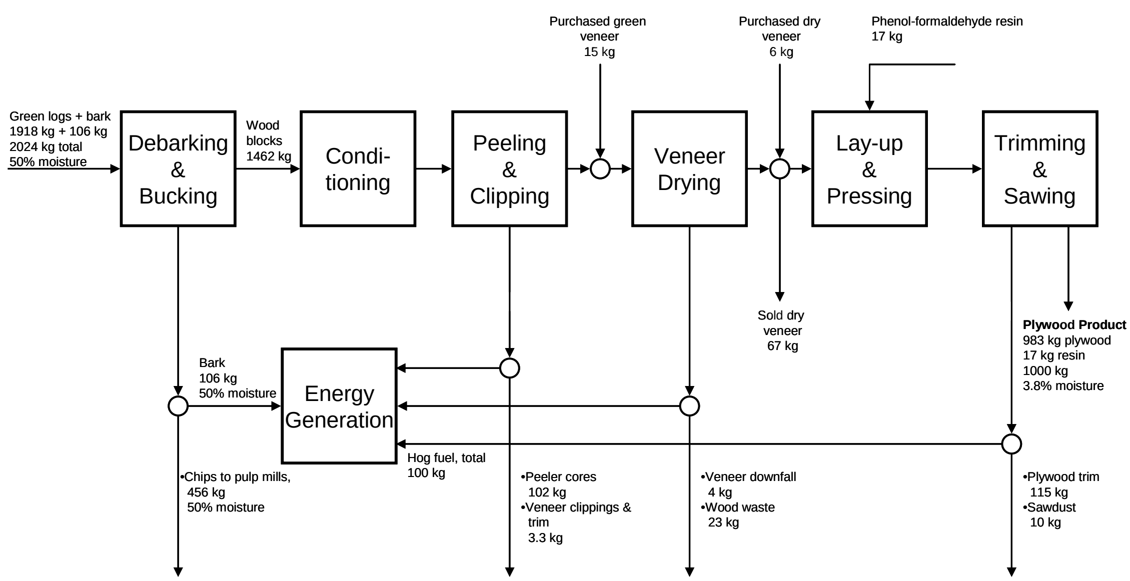

Figure C.4 Pacific Northwest Softwood Plywood Mill Weighted Average from 5 Facilities, wood(dry) mass balance [wood mass balance extracted from Wilson and Sakimoto 2005]

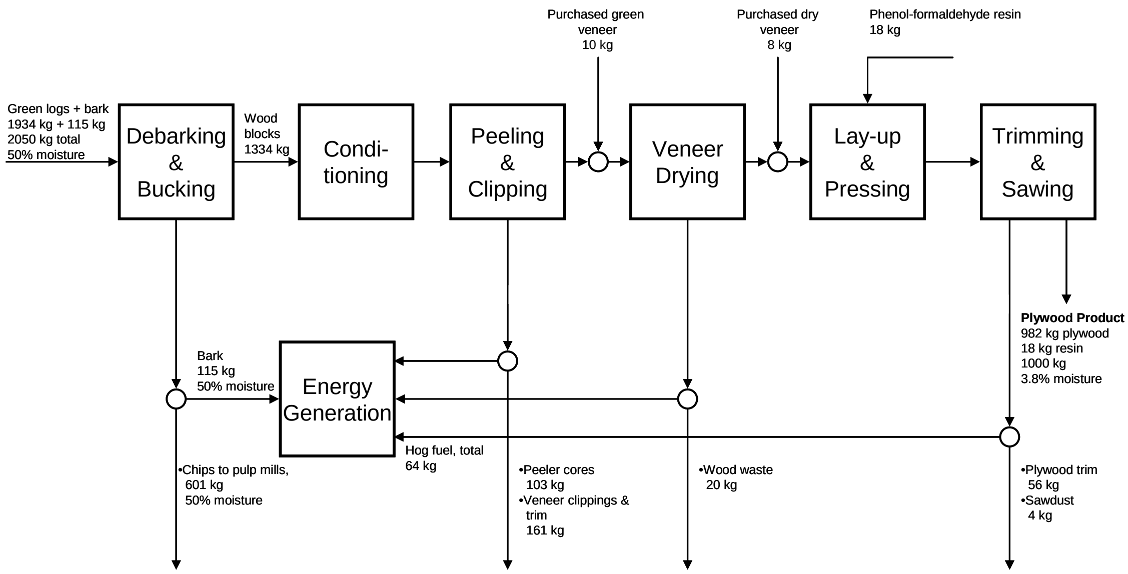

Figure C.5 Southeastern Softwood Plywood Mill Weighted Average from 5 Facilities, wood(dry) mass balance [wood mass balance extracted from Wilson and Sakimoto 2005]

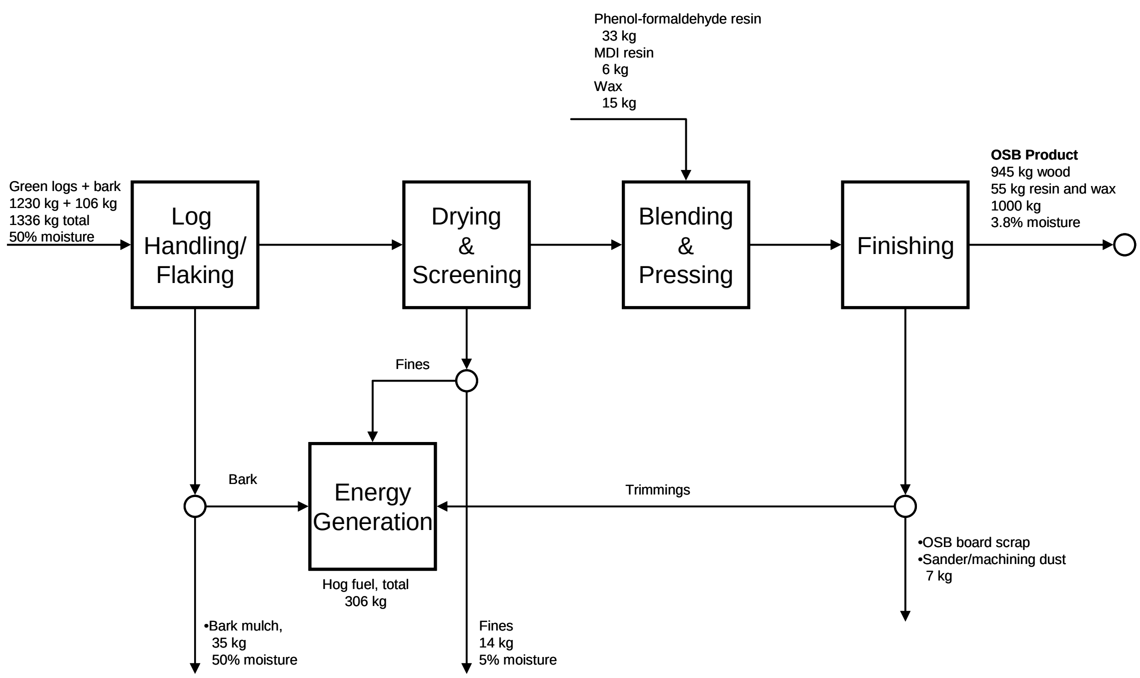

Figure C.6 Southeastern Oriented Strandwood Mill Weighted Average from 4 Facilities, wood(dry) mass balance [wood mass balance extracted from Kline 2005]

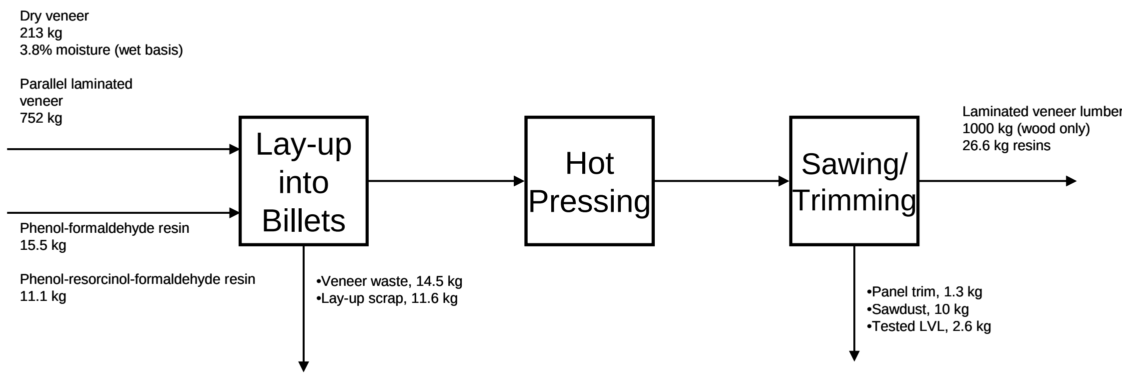

Figure C.7 Laminated Veneer Lumber Mill, Weighted Average from 4 Facilities, wood(dry) mass balance [wood mass balance extracted from Wilson and Dancer 2005]

Table C.1 Water Flows for Water Originating from the Raw Material for U.S. 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 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 lumber	39.7	20.8	4.8	0.7	6.1	7.1	2.4
Hardwood lumber	19.6	11.4	2.7	0.2	1.7	5.1	1.7
Laminated veneer lumber	1.6	0.02	0.02		-	-	-
Softwood plywood	7.8	3.9	0.5		1.0	2.1	0.2
Hardwood plywood[c]	1.3	0.6	0.1		0.2	0.4	0.0
Oriented strandboard and waferboard	9.4	3.0	0.4		-	1.9	0.7
Others[d]	13.1	5.1	0.6		-	3.3	1.2
Lumber made at pallet plants[e]	0.7	0.4	0.1		0.1	0.1	0.0
Total	92.5	45.2	9.2	0.9	9.1	20.0	6.2

[a] million st product/yr
[b] billion gal/yr
[c] calculated using softwood plywood data and scaling by hardwood plywood production
[d] calculated using oriented strandboard LCA data and scaling by "other" production
[e] calculated using softwood lumber LCA data and scaling by lumber made at pallet plants