

Water profiles of the forest products industry and their utility in sustainability assessment

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ABSTRACT: Sustainability has become a key element of environmental management programs at most forest products companies. However, describing sustainability in terms of natural resource use and management can be challenging, owing to the evolution of practices deemed to be consistent with the concept. This paper provides quantitative and qualitative assessments and discussion of water resources as they relate to the activities of the forest products industry. Water resource use and management from the forest, through manufacturing, and on to potential effects of treated effluents on receiving waters is considered. Important findings from this work are that forests act to process precipitation into high-quality surface waters, and in North America, most surface waters are derived from forested areas. Forest management can affect water quality, but the use of forestry best management practices greatly minimizes harmful effects. Manufacturing of pulp and paper is water-use intensive relative to most other industries, although the amount of water consumed (i.e., evaporated or exported with product or residuals) represents a small fraction of the overall water used. The potential for treated effluent to affect receiving water systems has been widely investigated, and while effects are sometimes observed, aquatic community structures most commonly are not altered by well-treated mill effluents. Water profile results and water sustainability metrics are also briefly compared.

Application: These findings will help industry environmental managers seeking to characterize sustainable water management in the forest products industry, particularly in North America.

Operations of the forest products industry are highly dependent on the use, and therefore the responsible management, of water resources. Over the past three decades, pulp and paper mills in North America have reduced process water use by approximately 50%, and the quality of effluents has improved dramatically through in-process measures and ongoing refinement of wastewater treatment operations [1,2]. The North American forest products industry is a large user of fresh water, but consumes comparatively little of the water it uses. Further, the reliance of the industry on forest-derived raw materials represents an extension of its footprint with regard to water resources. In recognition of increasing pressure on access to water resources in some areas, forest products companies commissioned the National Council for Air and Stream Improvement (NCASI) to prepare comprehensive water profiles of the United States and Canadian industries [3,4]. These profiles include quantitative and qualitative measurement of water influenced through forest management, manufacturing, and treated effluent discharge. These freely available reports also contain comprehensive and lengthy reference.

The broader recognition of increasing human pressures on worldwide freshwater resources has led to the establishment of numerous initiatives targeting sustainable use of water [5]. Although the specific objectives and components of these

initiatives differ somewhat, those that are related to business commonly include metrics describing the amount of water used or consumed and the environmental impact associated with water use. This report provides a summary of forest products industry water profiles and compares the metrics used in these profiles with those defined through popular water sustainability initiatives. This comparison allows the utility of the water profiles to be better understood in the context of the broader water sustainability dialogue.

FOREST MANAGEMENT

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. Forests act to process precipitation into high quality surface waters, and, in North America, most 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 stream flow. With respect to changes in water quantity, timber harvesting can decrease evapotranspiration, resulting in increased stream flow 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 Canada and the United States, and reduce or eliminate impacts of harvest on surface waters when properly implemented [6]. 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 [7,8].

Alternative land uses (e.g., agriculture, urban development) typically have much greater negative effects on water quality with respect to loads of sediment, pesticides, nutrients, and some other pollutants to streams than properly managed forest operations. Compared with these other land uses, forests are also better for managing peak flows [9]. These observations, coupled with the knowledge that most fresh water originates from forested lands, suggest that maintenance of timberland, in lieu of deforestation for alternative land uses, is essential to the continued availability of high quality fresh water supplies.

NCASI water profiles provide rough estimates for precipitation onto timberlands in Canada and the United States, as well as stream flow and groundwater recharge and evapotranspiration from them. Calculating the annual availability of fresh water, particularly over large spatial scales, is not a straightforward task. Precipitation and runoff amounts vary widely between and within regions, 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 the National Oceanic and Atmospheric Administration (NOAA) [10] listed the annual area-weighted precipitation total in the contiguous United States as 743 mm (standard deviation 58 mm) for the period 1931 to 2000. However, a study of changing precipitation patterns in the United States and Canada suggested that precipitation measurement techniques can underestimate precipitation amounts [11], and the authors placed annual area-averaged (century-long) precipitation for the contiguous United States at 914 mm (standard deviation 71 mm), 20% higher than the NOAA estimate.

Rainfall onto land will be lost to evapotranspiration, infil-

trate into the soil and percolate into the groundwater, or be exported out of the watershed as stream flow. In most locations, groundwater will eventually make its way to surface waters and be measured as stream flow. Thus, calculations of the fate of precipitation usually assume, as did we, 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 stream flow is usually considered to be losses to evapotranspiration and interception (here the term evapotranspiration is used to cover both processes of water loss).

Owing to initially independent projects, we calculated total annual precipitation for Canada and the United States differently. In the United States (excluding Alaska and Hawaii), the amount of timberland is estimated to be 202.9 million hectares, or about 81% of forest land and 26% of the total land area [12]. 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 ft³ per acre annually. 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 stream flow in the contiguous United States (approximately 1.14 trillion m³/yr) originates from forested land [13]. The proportion might be expected to be roughly similar to the proportion of stream flow 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 United States. The calculation (which assumes 762 mm 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 United States as precipitation of 3.15 trillion m³/yr.

The relative amount of water exiting as either stream flow or evapotranspiration is highly site-specific (**Table 1**). Data from four watersheds examined in the United States show that just over 50% of the precipitation for those watersheds exits fully forested areas as evapotranspiration and most of the

Watershed	Precipitation (mm)	Runoff (mm) ^a	Evapotranspiration (mm)
Needle Branch	2336	1346 [58%]	990 [42%]
Coweeta, North Carolina	1854	1041 [56%]	813 [44%]
Grant Forest Watershed, Georgia	1320	406 [31%]	914 [69%]
Wagon Wheel Gap, Colorado	533	152 [29%]	381 [71%]
Average		44%	56%

^a percent of precipitation in brackets

1. Precipitation, evapotranspiration, and stream flow in four forested watersheds.

Ecozone	Area (million ha)	Area of Managed Forests (million ha)	Mean Annual Precipitation (mm)	Total Annual Precipitation (trillion m3)	Mean Annual Runoff (mm)[%]	Mean Annual AET* (mm)[%]
Boreal Plains	88.4	30.7	462	0.14	125 [27%]	337 [73%]
Boreal Shield	180.3	65.6	1,000	0.66	400 [40%]	600 [60%]
Montane Cordillera	48.1	15.1	550	0.08	350 [64%]	200 [36%]
Pacific Maritime	48.1	10.7	2,250	0.24	1,500 [66%]	750 [34%]
Atlantic Maritime	15.1	4.7	1,212	0.06	700 [58%]	512 [42%]
Mixwood Plains	14.8	.93	860	0.01	400 [47%]	460 [53%]
Boreal Cordillera	41.9	10.7	500	0.05	400 [80%]	100 [20%]
Taiga Plain	54.9	18.1	500	0.09	400 [80%]	100 [20%]
Prairies	49.8	3.3	500	0.02	75 [15%]	425 [85%]
Total:	541.5	160		1.35		

* Actual evapotranspiration calculated from water-balance (AET = mean annual precipitation – mean annual runoff).

II. Area and annual precipitation estimates, runoff, and evapotranspiration rates for nine forested terrestrial ecozones in Canada.

remainder exits as stream flow. Applying 45% of the precipitation to stream flow yields 1.42 trillion m³/yr of runoff and 1.73 trillion m³/yr of evapotranspiration from timberland. This estimate for stream flow is higher, but of the same magnitude as the U.S. Department of Agriculture (USDA) estimate (1.14 trillion m³/yr) [13] adjusted to timberland of 0.9 trillion m³/yr.

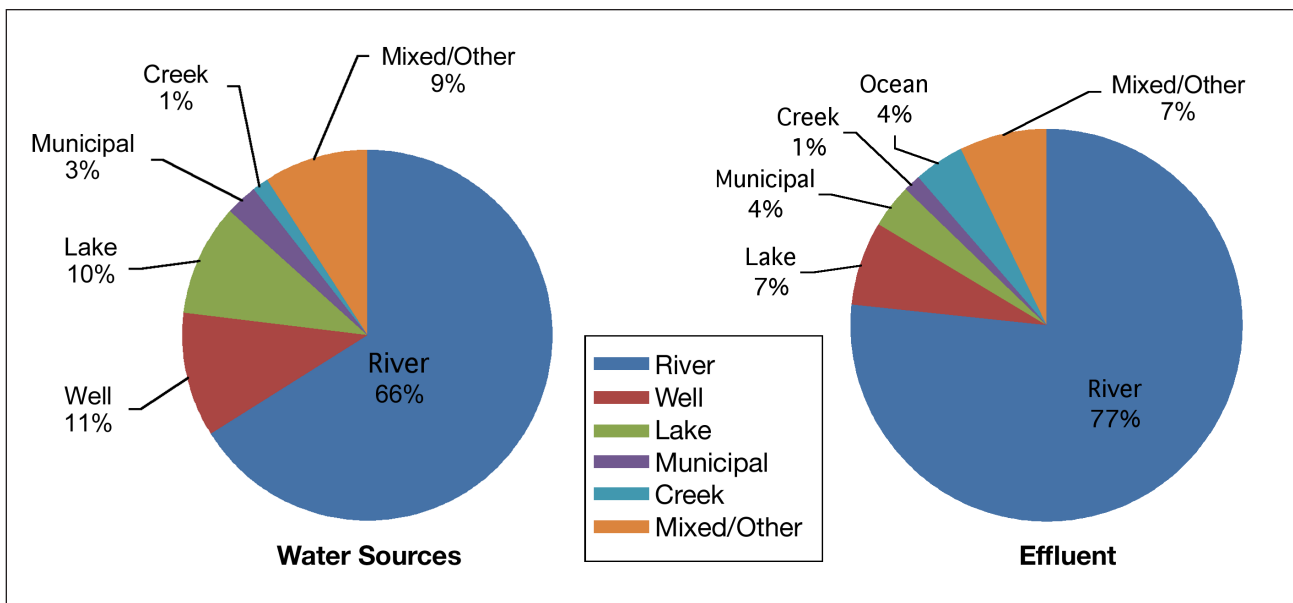
For the Canadian water profile, an ecozone-based approach was employed whereby total precipitation on timberlands was calculated using the amount of area in timber production in each of nine ecozones (**Table II**). The relative amount of water exiting as either stream flow or evapotranspiration is highly variable, both between and within ecozones. Annual precipitation was estimated from *Atlas of Canada* data [14], runoff data was estimated based on precipitation patterns and general watershed topography [15], and annual evapotranspiration rates were calculated from the difference between the two.

Applying these estimates of runoff for each ecozone to the estimates of precipitation yields an annual total of 0.67 trillion m³ of runoff and 0.68 trillion m³ of actual evapotranspiration, for a total of 1.35 trillion m³/yr of precipitation on Canadian timberlands. This estimate of stream flow would seem reasonable, given that Laylock [16] suggested a total Canada-wide estimate of 3.3 trillion m³/yr, managed forests represent roughly 14.7% of the Canadian landmass, and forests tend to be associated with soils and precipitation regimes that receive greater than average levels of precipitation [17].

WATER USE IN MANUFACTURING

The quantity of water used for manufacturing pulp, paper, and wood products in North America was estimated by generating independent estimates of each water import and export vector for each operating facility wherever possible. In many cases this was possible via access to various sources including those maintained by the American Forest and Paper Association [1], the Forest Products Association of Canada [2], Fisher International [18], and NCASI's own data. However, reliable information on water intake from surface and groundwater sources was not available because most mills do not measure water intake flows directly. Fortunately, water discharges in the form of treated effluents typically represent around 90% of mill water use and, in nearly all 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, defined here as water lost to evaporation or exported with solid residuals or products, was determined as a function of water intake. Process and cooling water uses are included in the profile. The water contents of purchased fossil fuels and storm water managed outside mill wastewater treatment systems are not included.

Figure 1 shows the sources of fresh water used in the North American pulp and paper industry and the destinations of treated effluents. Solid wood products and wood panel manufacturing are minor contributors to industry water with-



1. Fresh water sources and effluent destinations for the North American pulp and paper industry.

drawals and the water source and effluent destination information from this sector of the industry are not accounted for in the figure [3,4].

A complete discussion of the techniques used to estimate water use and fate in wood, pulp, and paper manufacturing operations is presented elsewhere [3,4]. **Table III** lists the primary elements of the water balance and the basis for import/export vector estimates [19]; **Table IV** lists the numeric values for the import/export vectors.

The North American forest products industry withdraws approximately 7.46 billion m³ of water annually from surface and groundwater sources. About 93% of this amount, or 6.94 billion m³, is reintegrated directly into the surface water cycle. The North American forest products industry relies upon groundwater sources for about 11% of total water withdrawal, but most of this withdrawal occurs in the United States. Consumptive water losses (the sum of evaporative losses from process operations and secondary waste treatment, water in solid residuals, and water in products) amount to 12.6% of the water from surface and groundwater sources. The amount of water in wood, recycled paper, and purchased chemicals is approximately 46% of consumptive water losses. With respect to wood products, 89% of water inputs (290 million m³/yr) are with wood (logs, bark, purchased veneer, etc.), and the remainder are collected from surface water for process and nonprocess uses. About 28% of the water input to wood products facilities is exported with products, sold wood chips, or sold hog fuel to pulp mills. Virtually the entire remaining amount is lost to evaporation from process vents or via combustion of the biomass as fuel.

Overall, of the water used to produce forest products within North America, about 95% is from surface or groundwater sources. Approximately 88% is returned directly to surface waters following treatment; about 11% is converted to water

vapor in pulp, paper, and wood products manufacturing processes; and about 1% is imparted to products or solid residuals.

EFFLUENT MANAGEMENT

Over the past several decades, the effect of forest product industry effluents on aquatic systems has been the focus of substantial laboratory-, mesocosm-, and field-based research. Much of the data assessing potential effluent effects has been generated through laboratory assessment using short- and long-term bioassays to evaluate acute (survival) and chronic (growth and reproduction) responses. Life cycle tests assess survival, growth, and reproduction of biota by monitoring from the embryo through to the subsequent generation, and are considered a more comprehensive assessment of potential effluent effects than shorter-term laboratory bioassays. Mesocosm and artificial stream studies are much less common than laboratory assessment; field studies in receiving water environments and those examining population and community level effects are even more rare. Although mesocosm studies are designed to mimic natural stream conditions and are an important link between laboratory and receiving water studies because they allow for replication and controls, these studies are unable to reproduce key components of natural systems, which make in-stream studies invaluable.

Collectively, these studies have provided considerable insight into the compatibility of aquatic organisms, populations, and communities with treated effluents. Life cycle testing conducted on forest product industry effluent to determine potential effects on physiology and reproduction [20] has shown that among endpoints typically examined (e.g., gonadosomatic index, hepatosomatic index, condition factor, number of head tubercles, gonadal histology, and the number and hatchability of eggs); egg production is the most common endpoint showing a dose response pattern. Changes in sec-

Import (I)/Export (E)	Primary Basis for Estimate
Surface water (I)	Calculated based on effluent flow, consumptive losses, and fraction of total water withdrawn from surface waters.
Groundwater (I)	Calculated based on effluent flow, consumptive losses, and fraction of total water withdrawn from groundwater.
Water in wood (I)	Calculated using average moisture content of wood (50% wet mass basis) and pulp yield for each pulping process.
Non-fiber raw material (I)	Based on water in primary purchased chemicals and estimated usage by each pulping/papermaking process.
Recovered fiber (I)	Calculated using national average paper recovery rates and moisture content of 10% (wet mass basis).
Surface water (E)	Final effluent flow rate measured at each facility.
Groundwater (E)	Essentially zero.
Evaporation (E)	Based on coefficients for each production process [19].
Products (E)	Calculated from production and average moisture level (10% for pulp/paper; product-specific for wood products).
Residuals (E)	Calculated from mill specific survey data on waste generation rates and typical moisture levels for each waste.

III. Basis for estimates of water imports and exports to pulp and paper mills.

ondary sex characteristics, including masculinization and feminization, changes in sex hormones, and delayed sexual maturity also have been observed [21-23], although such effects often are seen at effluent concentrations much higher than typically present in actual receiving waters.

Mesocosm and receiving water studies have examined different taxa groups, including periphyton (algae), macroinvertebrates, and fish. Ongoing in-stream studies include Canada's Environmental Effects Monitoring (EEM) Program and NCASI's Long-Term Receiving Waters Study (LTRWS). The EEM program examines effects indicators in populations of sentinel fish species (condition factor, liver size, gonad size, age, and weight at age) and assesses fish habitat through the examination of benthic macroinvertebrate endpoints (abundance, Bray-Curtis similarity, richness, and evenness) [24]. Assessments are made on three year cycles at an upstream and one or two downstream sites. The LTRWS examines spatial patterns of biotic community structure and biomass (algae/periphyton, macroinvertebrate, and fish), habitat conditions, and water quality parameters multiple times per year at replicate sites in four representative mill effluent receiving streams. The LTRWS design includes multiple sites upstream (two or three sites) and downstream (three or four sites) of effluent discharges, shows the consistency of endpoints across seasons and years, and allows naturally occurring spatial and temporal variations to be separated from effluent effects [25,26].

The response of periphyton, macroinvertebrates, and fish to forest products industry effluents is variable. Increased nutrient concentrations downstream of pulp and paper mill discharges have been implicated in increases in periphyton biomass and shifts in community structure in mesocosms [27,28], but effects on in-stream periphyton communities have been inconsistent with increased effluent exposure [29], present only under low flow conditions when effluent dilution was high [30], or not observed [31,32]. The discrepancies in observations from artificial stream studies compared to in-stream studies may reflect low nutrient systems where even slight increases in nutrient concentrations can affect periphyton, or indicate that mesocosm studies may not accurately represent environmental variables that can affect the assimilative capacity of a water body.

Macroinvertebrate response to forest products industry effluent is also variable with increased growth rates [33], higher density and biomass, and shifts in community structure [28] seen in mesocosms and artificial streams exposed to (1% to 10% v/v) effluent. Natural receiving stream studies showed similar variability with no significant changes in macroinvertebrate community structure, abundance, or diversity measures at sites downstream of mill discharge relative to an upstream site [34]; shifts in community structure at effluent exposed sites [35]; and changes in invertebrate density and biomass [30] downstream of mill discharge relative to an un-

Import (I)/Export (E)	United States	Canada	North America
Surface water (I)	4,751	1,882	6,633
Groundwater (I)	791	31.8	823
Water in wood (I)	279.4	131.9	411.3
Non-fiber raw material (I)	7.95	2.34	10.3
Recovered fiber (I)	4.77	1.74	6.5
Surface water (E)	5,150	1,794	6,944
Groundwater (E)	~0	~0	~0
Evaporation (E)	621	231.5	852
Products (E)	44.7	19.9	64.6
Residuals (E)	18.5	4.66	23.2

IV. Values of water imports and exports within the North American forest products industry (in million m³/year).

exposed upstream site. Macroinvertebrate patterns in Canada's EEM program have shown relatively consistent patterns, with a subset of receiving waters showing nutrient enrichment based on changes in macroinvertebrate endpoints at effluent-exposed sites relative to an upstream control [36]. In contrast, macroinvertebrate data collected during the LTRWS between 1998 and 2006 showed differences in community structure across sites, but no effluent-related changes [25]. Seasonal and annual variations in macroinvertebrate metric responses (e.g., taxa richness) were seen in all streams, with changes related to the discharge of forest products industry effluents seen in only one metric (Hilsenhoff's Biotic Index) in one stream.

Effluent-related changes in fish populations have been seen in mesocosm and field studies [37], with alterations in reproductive indicators receiving the most attention. Findings from the EEM program have shown that effluents have improved over the course of the program, but patterns of increased condition, growth rate, and relative liver size in effluent-exposed fish persist, together with decreased relative gonad size [36]. Nutrient enrichment has been suggested as a contributing factor to increased condition factor. In NCASI's LTRWS, which has sampled fish at least twice per year since 1998, fish communities were variable across seasons and years. No effluent-related changes were detected in species type and relative abundance at sites downstream of discharges relative to upstream sites [26]. Effluent-related changes in community-level metrics (e.g., abundance, richness) were limited to a single metric (% dominant taxa) in one stream. The general absence of effluent-related changes in fish communities corroborate patterns from laboratory studies using fathead minnow life cycle tests, which showed no reproductive changes at effluent concentrations seen in U.S receiving waters [38].

WATER PROFILE AND SUSTAINABILITY METRICS

The metrics used for quantitative and qualitative analysis in the NCASI water profiles are largely conventional in water management parlance. Metrics suggested for use in water sustainability analysis, in contrast, can be of recent origin. Further, while usage of water sustainability terminology is becoming increasingly common, similar or identical terms may be defined differently among the initiatives. A full discussion of water sustainability terminology is beyond the scope of this paper, but a comprehensive glossary developed by the World Business Council for Sustainable Development and NCASI is available [5].

Table V provides a comparison of water profile metrics and water sustainability metrics. Owing to the number of water sustainability initiatives and the sometimes large number of metrics developed by them, the metrics shown in the second column of Table V are general, describing water use, and environmental and social impacts that derive from the use of water. Many of the metrics used in the water profiles (Table V) are more specific owing to their application in the context of water management within the forest products industry.

In most cases, metrics describing water sustainability pertain to an entity's direct use of water resources and to the environmental and social impact of that use. Most metrics related to the actual use of water are quantitative while many of the metrics that concern the impacts which derive from that use are qualitative. Metrics associated with water use in manufacturing (Table V) are usually quantitative, and easily defined. The forest products industry water profiles cover many of the typical metrics identified in water sustainability initiatives. Of those that are not present in the profiles, the amount

Forest Products Industry Water Profile Metric	Related Water Sustainability Initiative Metric
Water Use in Manufacturing <ul style="list-style-type: none"> • water imports • water exports • water sources • water destinations • water consumption 	Water Use in Manufacturing <ul style="list-style-type: none"> • water imports • water exports • water sources • water destinations • water consumption • water recycled • water availability • in-stream water use (e.g., hydropower)
Potential Impacts on Surface Water Resources <p><u>Hydrologic Modification</u></p> <ul style="list-style-type: none"> • change to runoff/evapotranspiration • change in peak flow (amount & timing) • change in low flow (amount & timing) <p><u>Water Quality Modification</u></p> <ul style="list-style-type: none"> • sedimentation (forestry) • temperature (forestry) • pesticides/herbicides (forestry) • nutrients (forestry and effluents) • BOD, TSS, AOX (effluents) • effluent toxicity • acute bioassay response (laboratory) • chronic bioassay response (laboratory) • full life cycle (mesocosm) • in-stream physiological changes • in-stream community structure changes 	Potential Impacts on Surface Water Resources <p><u>Hydrologic Modification</u></p> <ul style="list-style-type: none"> • change to runoff/evapotranspiration <p><u>Water Quality Modification</u></p> <ul style="list-style-type: none"> • pollutant loads from forestry, various • pollutant loads from manufacturing, various • sensitivity of aquatic systems • permit compliance • spills/unauthorized environmental releases

V. Comparison of water profile and water sustainability initiative metrics.

of water recycled in a process, the regional water availability, and in-stream water use would likely be known by each facility, even though industry wide data were not available for use in the water profile analysis.

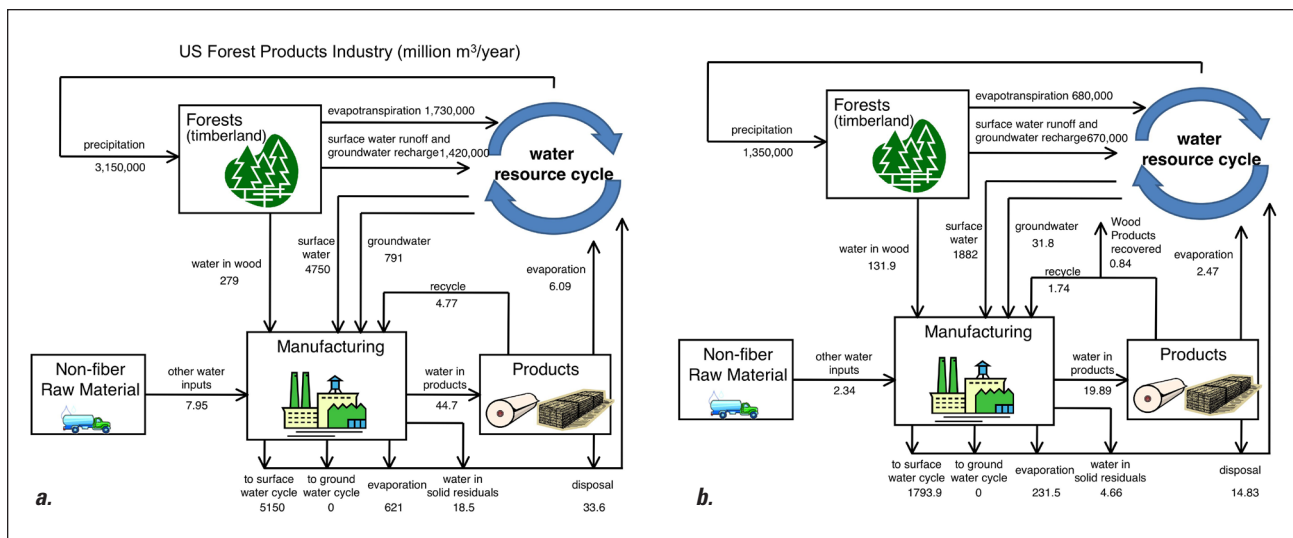
A comparison between the water impact-related sustainability metrics and the metrics considered in the water profiles reveals the generality that is necessary in broadly applicable sustainability initiatives and the specificity that can derive from an industry-specific assessment. For example, while sustainability initiatives are interested, broadly, in actions by a water user that might alter hydrologic patterns, an industry-specific profile might more narrowly consider specific and relevant hydrologic modifications, in this case including changes to the amounts and timing of peak and low stream flows resulting from forest management actions or water withdrawal for use in manufacturing. Water quality modification metrics provide another example of the value of profiles in interpreting the interests as described in water sustainability initiatives. In the case of water profiles, industry-specific detail can be conveyed in terms of pollutants commonly measured (e.g., BOD, total suspended solids [TSS]) and those more unique to the industry (e.g., adsorbable organic halogens [AOX] and pesticide/herbicide). The NCASI water profiles also provided an opportunity to illustrate the value of extensive assessment of biological responses to treated mill efflu-

ents, including the compatibility of well-treated effluents with biologically healthy receiving waters [25,26,32,38].

The social aspects of several water sustainability initiatives are not included in the NCASI profiles. These aspects can include metrics related to equitable and transparent governance of water supplies, including the equitable distribution of water for human, industrial, and ecosystem services, as well as governance over use and subsequent treatment and release of wastewaters. Such aspects are considered to be tightly controlled in North America (as they are in many other parts of the world) and the topic was judged to be an unnecessary component of these water profiles.

CONCLUSIONS

Industry water profiles, as judged by the forest products industry water profiles for North America, can provide a comprehensive review of the interactions between the operations of an industry and water resources. Water profiles may be useful for contrasting water management practices between industries in various parts of the world or between industries. Because profiles are reported as industry-wide (even if they include some facility or site specific information), they are not a substitute for facility-specific information. They do, however, provide a benchmark by which facility-specific information might be compared. **Figure 2** presents schematic water



2. Water resource connections and water balance for the U.S. forest products industry (a) and Canadian forest products industry (b) in million m³/yr.

profiles of the U.S. and Canadian forest products industries.

The metrics used in the NCASI water profiles were generally similar to those that have been identified by various water sustainability initiatives. Some differences are evident, and these differences may present learning opportunities for future water sustainability dialogue. **TJ**

LITERATURE CITED

- American Forest and Paper Association (AF&PA), "AF&PA Environmental, Health & Safety Verification Program, Biennial Report 2008," American Forest and Paper Association, Washington, DC, USA, 2008.
- Forest Products Association of Canada (FPAC), "Forest Products Association of Canada Sustainability Report 2009," Forest Products Association of Canada, Ottawa, ON, Canada, 2009.
- National Council for Air and Stream Improvement (NCASI), "Water Profile of the U.S. Forest Products Industry," Technical Bulletin No. 960, National Council for Air and Stream Improvement, Research Triangle Park, NC, USA, 2009.
- National Council for Air and Stream Improvement (NCASI), "Water Profile of the Canadian Forest Products Industry," Technical Bulletin No. 975, National Council for Air and Stream Improvement, Research Triangle Park, 2010.
- World Business Council for Sustainable Development, "Water for Business: Initiatives Guiding Sustainable Water Management in the Private Sector," World Business Council for Sustainable Development, Geneva, Switzerland, 2010.
- Williams, T.M., Hook, D.D., Lipscomb, D.J., et al., "Effectiveness of Best Management Practices to Protect Water Quality in South Carolina Piedmont," General Technical Report SRS-30, U.S. Department of Agriculture Forest Service, Southern Research Station, Asheville, NC, USA, 2000.
- McBroom, M.W., Beasley, R.S., Chang, M., et al., *Proceedings of the First Interagency Conference on Research in the Watersheds*, U.S. Department of Agriculture, Agricultural Research Service, Tucson, AZ, USA, 2003, pp. 607-613.
- Ice, G.G. and Schoenholtz, S.H., *Hydrol. Sci. Technol.* 19(1-4): 99(2003).
- Poor, C.J. and McDonnell, J.J., *J. Hydrol.* 332(1-2): 54(2007).
- National Oceanic and Atmospheric Administration (NOAA), "State, Regional, and National Monthly Precipitation, Weighted by Area, 1971-2000 (and Previous Normal Periods)," Historical Climatology Series No. 4-2, National Oceanic and Atmospheric Administration, National Environmental Satellite, Data and Information Service, National Climatic Data Center, Asheville, 2002.
- Groisman, P.Y., and Easterling, D.R., *J. Climate* 7(1): 184(1994).
- U.S. Department of Agriculture (USDA), Forest Inventory and Analysis National Program, "2007 RPA Resource Tables," U.S. Department of Agriculture Forest Service, Washington, DC, 2007. Available [online] at <http://fia.fs.fed.us/program-features/rpa>.
- U.S. Department of Agriculture (USDA), "Water & the Forest Service," FS-660, United States Department of Agriculture Forest Service, Washington, DC, 2000.
- Environment Canada, *National Atlas of Canada* 5th edn., National Atlas Information Service, Canada Centre for Mapping, Energy, Mines and Resources Canada, and the Surveys and Information Systems Division, Ecosystem Sciences and Evaluation Directorate, Ottawa, 1993. Available [online] at <http://atlas.nrcan.gc.ca/site/english/index.html>.
- Natural Resources Canada (NRCan), *Forest Ecosystems of Canada*, Canadian Forest Service, National Resources Canada, Ottawa, 2007. Available [online] at <http://ecosys.cfl.scf.nrcan.gc.ca/classification/intro-ecozone-eng.asp>.
- Laylock, A.L., in *Canadian Aquatic Resources* (M.C. Healey and R.R. Wallace, Eds.), Department of Fisheries and Oceans, Ottawa, 1987, pp. 13-42.
- Hetherington, E.D., in *Canadian Aquatic Resources* (M.C. Healey and R.R. Wallace, Eds.), Department of Fisheries and Oceans, Ottawa, 1987, pp. 179-211.
- Fisher International Inc., *Fisher Pulp & Paper Worldwide* (on CD), Fisher International, South Norwalk, CT, USA, 2008.
- National Council for Air and Stream Improvement (NCASI), "Estimating Water Consumption at Pulp and Paper Mills," Technical Bulletin No. 946, National Council for Air and Stream Improvement, Research Triangle Park, 2008.

20. Hewitt, M.L., Kovacs, T.G., Dubé, M.G., et al., *Environ. Toxicol. Chem.* 27(3): 682(2008).
21. Kovacs, T.G., Gibbons, J.S., Martel, P.H., et al., *J. Toxicol. Environ. Health* 44(4): 485(1995).
22. Borton, D.L., Streblov, W.R., Van Veld, P.A., et al., *Proceedings of the Third International Conference on the Environmental Fate and Effects of Pulp and Paper Mill Effluents*, Society of Environmental Toxicology and Chemistry (SETAC), Pensacola, FL, USA, 2003, pp. 459-470.
23. Parrott, J.L., Wood, C.S., Boutot, P., et al., *Environ. Toxicol. Chem.* 22(12): 2908(2003).
24. Walker, S.L., Ribey, S.C., Trudel, L., et al., *Environ. Monit. Assess.* 88(1-3): 311(2003).
25. Flinders, C.A., Minshall, G.W., Ragsdale, R.L., et al., *Integr. Environ. Assess. Manag.* 5(2): 248(2009).
26. Flinders, C.A., Ragsdale, R.L., and Hall, T.J., *Integr. Environ. Assess. Manag.* 5(2): 219(2009).
27. Bothwell, M.L. and Stockner, J.G., *Can. J. Fish. Aquat. Sci.* 37(2): 248(1980).
28. Culp, J.M., Cash, K.J., Glozier, N.E., et al., *Environ. Toxicol. Chem.* 22(12): 2916(2003).
29. Scrimgeour, G.J. and Chambers, P.A., *Can. J. Fish. Aquat. Sci.* 57(7): 1342(2000).
30. Dubé, M.G., Culp, J.M., Scrimgeour, G.J., *Can. J. Fish. Aquat. Sci.* 54(11): 2584(1997).
31. Davis, T.M., Vance, B.D., and Rodgers, J.H., Jr., *Aquat. Toxicol.* 12(2): 83(1988).
32. Flinders, C.A., Minshall, G.W., Hall, T.J., et al., *Integr. Environ. Assess. Manag.* 5(2): 259(2009).
33. Lowell, R.B., Culp, J.M., Wrona, F.J., et al., in *Environmental Fate and Effects of Pulp and Paper Mill Effluents* (M.R. Servos, K.R. Munkittrick, J.H. Carey, et al., Eds.), St. Lucie Press, Delray Beach, FL, USA, 1996, pp. 525-532.
34. Felder, D.P., D'Surney, S.J., Rodgers, J.H., Jr., et al., *Ecotoxicology* 7(6): 313(1998).
35. Rakocinski, C.F., Milligan, M.R., Heard, R.W., et al., in *Environmental Fate and Effects of Pulp and Paper Mill Effluents* (M.R. Servos, K.R. Munkittrick, J.H. Carey, et al., Eds.), St. Lucie Press, Delray Beach, 1996, pp. 533-547.
36. Tessier, C., Lowell, R.B., Willsie, A., et al., *National Assessment of Cycle 4 Data from the Pulp and Paper Environmental Effects Monitoring Program*, 2009, p. 43.
37. McMaster, M.E., Hewitt, M.L., and Parrott, J.L., *J. Toxicol. Environ. Health, Part B* 9(4): 319(2006).
38. Borton, D.L., Cook, D.L., Bradley, W.K., et al., *Integr. Environ. Assess. Manag.* 5(2): 275(2009).

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The use and management of water resources by the forest products industry had not been reported in a comprehensive fashion. Previous reports largely have been limited to the amount of treated wastewater discharged by pulp and paper mills. This work considers water resources more completely, including water in forests, water used for production of products, and the significance of treated effluents in the aquatic environment.

The profile addresses water and the forest products industry in North America. Water sustainability, however is best judged on a local, watershed scale. The information presented is useful for stakeholders interested in exploring water resource management at smaller scales in that it provides techniques useful for making such assessments.

The amount of data related to water management in the forest products industry is quite large; however, it often has been reported narrowly. Thus, there are

opportunities to bring together uncoordinated work in a manner that yields a more comprehensive understanding of water resource management.

In this report, we offer a comprehensive assessment of the intersection between the North American forest products industry and water resources. The information presented provides context for stakeholder discussions concerning sustainable water resource management.

In the future, NCASI hopes to develop tools for use by forest products companies wishing to undertake comprehensive assessments of water resource management for their operations.

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