REPORT

# Water Profile

# for the Swedish forest industry

On behalf of the Swedish Forest Industries Federation

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# Summary

This study analyses the Water Profile for the forest industry in Sweden and the part of Swedish forestry that can be associated with the production of roundwood. **Special importance has been attached to calculating the amount of water consumed, i.e. withheld from other uses.**

By sending out questionnaires to pulp and paper mills and sawmills, we have been able to identify how process water and cooling water are used, as well as the estimated water evaporation. We have developed and used a specific method to describe water withdrawals from source, use in different substreams, discharge, and returning water to nature. The method is in line with CEPI's (Confederation of European Paper Industries) method of describing water use and consumption. As far as possible, we used terminology according to ISO 14046 Water Footprint in its present form, which may be revised.

**It may be concluded that the impact of the Swedish forest industry and forestry on water supply and water quality is limited and, in some cases, positive. Forestry and the forest industry do not contribute to water shortage and do not affect the use of water by other users. From a water perspective, the conditions for the forest industry and forestry are good.**

## Forestry

The Water Profile describes the impact of the quantity and quality of water in the run-off from forest ecosystems attributable to the forestry conducted to produce wood raw material. We suggest that the assessment of a Water Profile, with regard to the production of wood is carried out at landscape level and over a long period of time, such as a rotational period.

In the discussion of the impact of Swedish forestry on water quality and quantity in run-off, a reference (baseline) scenario for comparison purposes is needed. Since there is no single reference scenario relevant to current Swedish forestry, we have studied the consequences of run-off using two alternative reference scenarios:

1. Less intensive forestry compared to today, driven by a decline in demand for wood raw material
2. More intensive forestry compared to today, driven by increased demand for biomass from the forests

The amount of water consumed by forest ecosystems during production of wood used by the forest industry has limited relevance, since lack of water is rarely a problem in Sweden. Instead, the problem is run-off, which is at times excessive, with regular flooding in these areas.

Forestry measures carried out in order to produce wood raw material for the forest industry have essentially a positive impact in terms of reducing the amount of run-off leaving forest ecosystems, as run-off is limited and offset over time. This effect increases as the growth rate of the forest increases. This helps limit the number and magnitude of floods in Sweden. However, after final cutting, the run-off may increase dramatically at local level, temporarily to very high levels.

The impact of forestry on water quality in the run-off from the forest is likely to be negative in some respects, at least over short periods of time, but this assessment depends to a large extent on what you compare it with, i.e. on the reference scenario used.

Effects of forestry on water quality include acidifying effects on soil and surface water associated with root nutrient uptake and removal of biomass from forest ecosystems. However, some researchers argue that the tree roots have a positive effect on soil erosion, and that this would to some extent decrease acidification. Furthermore, greater forest density gives rise to greater dry deposits of acidifying and nitrogen pollutants, i.e. the trees act as filters and capture air pollutants.

Moreover, toxic substances such as mercury that have been taken up in dry deposits and stored in the organic layer of the soil may be released into watercourses and lakes after felling or windthrow.

However, a general conclusion of this study is that the impact of current Swedish forestry on the **quality** of run-off water from the forest is limited. The impact of forestry on water **quantity** is to some extent positive.

## Manufacturing

The Swedish forest industry (pulp and paper mills and sawmills) used about 850 $Mm^3$ of raw water during 2009. About 840 $Mm^3$ of this was returned to water sources after treatment. More than 99 % of the raw water was from lakes and watercourses. If we include the water in raw material used, the total intake of water was approximately 880 $Mm^3$. Water loss in production processes has been estimated at 50–60 $Mm^3$, or 6–7 % of raw water intake, with an uncertainty of around 2 percentage points. The loss as vapour is estimated at more than 90 % of the total loss.

Almost all raw water was used in the pulp and paper industry. Around 60% of the raw water was used in processes, while 40 % was mainly cooling water. Water bound up in raw material amounted to around 23 $Mm^3$, and water in products and waste was around 2 $Mm^3$. If we were to balance water taken in against water discharged, this would give a loss of around 37 $Mm^3$, or 4.4% of the raw water intake. This figure has a high level of uncertainty, since it is calculated as the difference between two large, relatively equal numbers with their own uncertainty. However, the proportion of raw water is the same as the mean values from several mills that used other methods to estimate the figures.

The main part of water loss is from different boilers, drying pulp or paper, and from external wastewater treatment. The proportion of water from boilers and dryers that is condensed during heat recovery varies between plants. An estimate of losses from these main sources in the pulp and paper mills amounted to 40–50 $Mm^3$ or 5–6% of used raw water, but it may also be higher.

Processed wastewater is treated in internal processes as well as in external wastewater treatment plants before being returned to the water sources. The content of pollutants in outflow is regulated via maximum emission limit values for each plant. Total discharge of COD, phosphorous, nitrogen and AOX are presented in the report. As this discharge not only has a limited local environmental impact and normally does not inhibit other use, this water is not considered to have been consumed. The temperature of process and cooling water is higher than that of the intake, but this is not expected to give effects in the receiving bodies of water.

It has not been possible to make detailed calculations of the amount of water consumed in sawmills, since the available data lacks certainty. However, this does not influence the results of this study, as the water used in sawmills constitutes just a fraction of that used in pulp and paper production. Water loss mainly occurs while drying the sawn timber and has been estimated at 10–15 $Mm^3$ water.

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# Definitions

| TERM | EXPLANATION |
|---|---|
| Water Footprint | Characterisation result that describes the contribution to water stress made by the system studied (ISO14046 WD2) |
| Water Profile | A simplified Water Footprint that solely gives an account of water use from a resource and environmental perspective. It does not quantify the impact on ecosystems, people and future generations. |
| Water stress | Situation in a region or nation where the impact on people and ecosystems is a result of difficulties in accessing water. This is either caused by a water shortage or by poor water quality. Water stress is often defined as occurring where the annual water supply is less than 1,700 $m^3$ per person (World Resource Institute). |
| Water quality | Describes the chemical, physical and biological properties of water, often in relation to the possibility of using the water for a specific purpose (ISO 14046 WD2). |
| Water consumption | Describes use of water that leads to water evaporating, being incorporated in for example a product, or moved to a receiving body of water/area where the water is no longer available for further use. |
| Evapotranspiration | The total evaporation of water from e.g. a forest ecosystem to the atmosphere, which includes transpiration from trees, as well as evaporation from soil and any water surfaces. |
| Transpiration | Evaporation of water from the living biomass of trees. Transpiration can be divided into two types: stomata transpiration, which takes place through the stomata of plants, and cuticular transpiration, which takes place through the remaining surface of the leaf (that is not made up of stomata). The surface of the leaf is covered with waxy layer, meaning that cuticular transpiration is often much less extensive than stomata transpiration. |
| Stomata | Microscopic openings in leaves that the plant can open and close. The function of stomata is to let in the carbon dioxide necessary for photosynthesis while preventing too much water being released, which can damage the plant. |
| COD | Chemical oxygen demand, a measure of the amount of organic matter |
| N | The sum of nitrogen compounds |
| P | The sum of phosphorus compounds |
| AOX | Adsorbable organically bound halogens, mainly chlorinated compounds |
| Water exploitation level | The intake of water in relation to the supply |

# 1 Introduction

Freshwater is the world's most important provision. Water is also necessary in several other spheres, including for plantations, factories and livestock. Globally, agriculture uses the most water, followed by factories. Less than a tenth is consumed by households (WWF 2009).

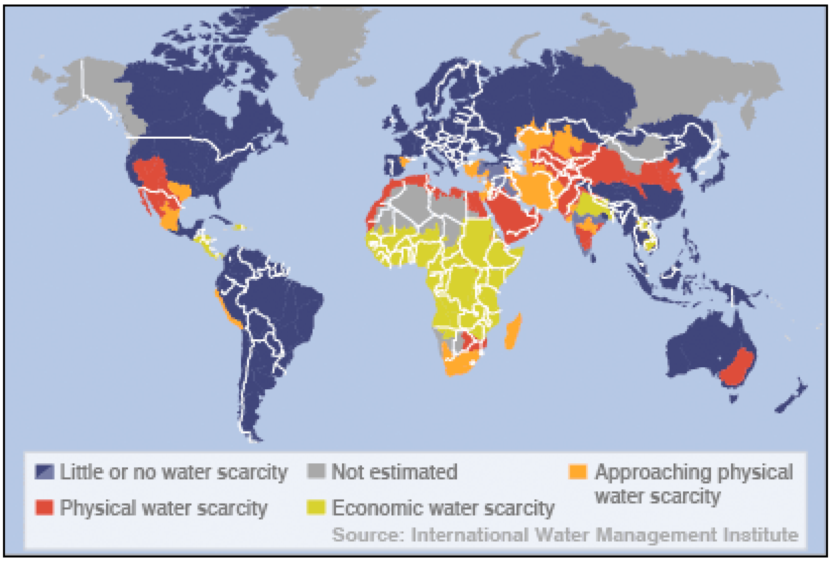


**Figure 1.** Freshwater supply in relation to demand (Source: International Water Management Institute, 2006)[1].

In Europe, pressure on water resources is constantly intensifying due to increasing demand for sufficient water of good quality. The European Environment Agency (EEA) report on the state of the environment confirms the need for measures to protect water resources in both qualitative and quantitative terms (County Administrative Board, 2008). Climate change has also brought the water issue to the fore, as changes in climate have a particular influence on the flow of water. In turn, this creates a need to assess not only water shortages but also water surpluses, risks of flooding and other consequences.

The term 'Water Footprint' was first used in 2002 by Arjen Hoekstra (University of Twente, the Netherlands) to illustrate hidden links between food provision and water use, and between global trade and the management of water resources. A Water Footprint is a form of measurement that includes both direct and indirect water use. A 'footprint' in general terms is a quantitative or semi-quantitative measurement that shows human consumption of a natural resource, or other environmental impact. The Water Footprint of a product is the total volume of freshwater

[1]'Physical water scarcity' concerns freshwater extracted for human activities (industry, agriculture, households) from a water system equivalent to 75% or more of its total flow. 'Approaching physical scarcity' is defined as 60% use of a water system's total flow. 'Economic water scarcity' concerns areas in which there is a surplus of water in relation to demand but e.g. no infrastructure or purchasing power to make use of the water or make it accessible. 'Little or no water scarcity' means that a maximum of 25% of the total water flow is utilised.

consumed in order to manufacture the product, totalled across the various stages of the production chain (Hoekstra 2008, Gerbens-Leenes och Hoekstra 2008). 'Consumed water' usually means that the water is vaporised, bound in the product and waste, or becomes polluted to such an extent that it is no longer accessible in the same place in its original form and cannot be easily utilised. Water Footprints can be divided up in different ways, for example into the following three components: consumption of rainwater and other water produced by vegetation (defined as green water), consumption of groundwater and surface water (defined as blue water), and polluted water (defined as grey water).

At an international level, work began in 2009 within ISO 14000 on compiling international requirements for Water Footprints: ISO 14046. ISO 14046 covers products, processes and organisations. It is planned that the work will result in a completed ISO standard in 2012.

In Europe, the paper and pulp industry is represented by CEPI (the Confederation of European Paper Industries). The organisation wishes to highlight the issue of water use in the European forest industry and, for this reason, has started to develop a method adapted for the industrial sector for mapping water use and water consumption, as international work on ISO standardisation is not yet complete.

The Swedish Forest Industries Federation has given IVL (the Swedish Environmental Research Institute) the task of highlighting the situation of water in forestry and the forest industry in Sweden, based on CEPI's methodology.

# 2 Purpose and scope

The purpose of the study is to describe water use, focusing on the water consumption of the Swedish forest industry. As a standardised method and procedure for calculating Water Footprints is not yet complete at global level, a simplified method has been used here, known as a Water Profile. This method is a means of accounting for water use from a resource and environmental perspective, but it does not include quantifying the impact on ecosystems, people and future generations, for example.

The study covers water use in pulp and paper mills and sawmills, along with (in qualitative terms) the cycle of the water and any impact on the managed forest.

# 3 Forestry

## 3.1 Method

Forest ecosystems, both within and external to Sweden's borders, constitute the source of wood raw material used in the forest industry. In the following, only Swedish forest ecosystems are discussed. The Swedish forest industry takes 90–95% of its wood raw material from Swedish forests.

The main part of the Swedish forest ecosystem is subject to anthropogenic impact and is used for forestry. The total land area of Sweden is 40.8 million hectares, of which 22.5 million hectares (55%) is productive forest land (source: Swedish Forest Agency) (**Figure 2**).

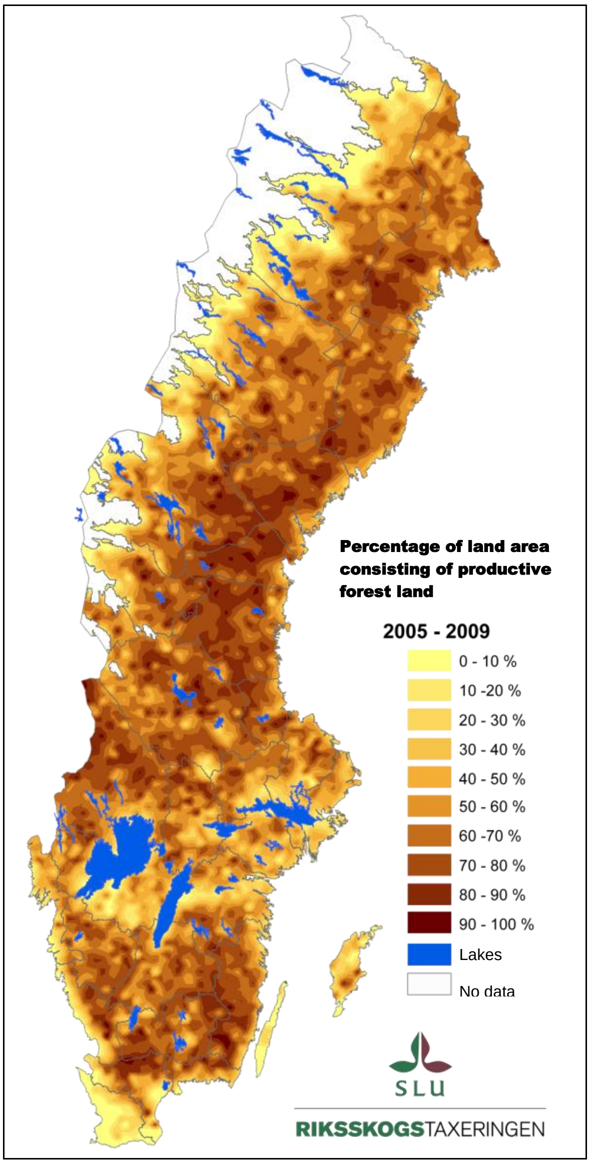


**Figure 2.** Proportion of productive forest land (Source: Swedish National Forest Inventory, 2010)

### 3.1.1 Water flows in the forest

A schematic diagram of overall water flows in the forest is presented in **Figure 3**.

By assessing the impact of the forest on water flows for large areas, variations in terms of age, tree species and different intensities of forestry have been included.

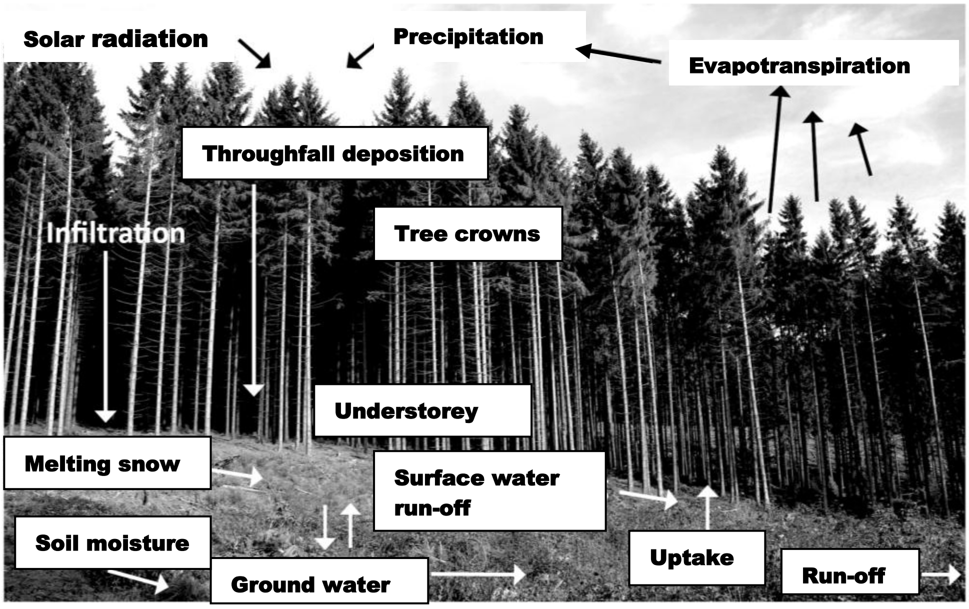


**Figure 3.** Schematic diagram of water flows in the forest.

### 3.1.2 Definition of Water Profile for forestry

A Water Profile for wood raw material is defined in the American study from the National Council for Air and Stream Improvement, NCASI (Flinders et al., 2009) as the impact on the quantity and quality of water in run-off from forest ecosystems that can be attributed to the forestry conducted to produce the wood raw material. This includes methods for felling, replantation and other forestry measures (Flinders at al., 2009).

Thus, the definition of a Water Profile also attaches importance to any change in the quality of the water in run-off, which does not necessarily mean that this water is unusable.

In this study, the Water Profile for the production of wood raw material used in forest industry processes is defined in the same way as in the study from NCASI mentioned above.

### 3.1.3 Basic principles

CEPI is developing the method for how to account for production of wood raw material in the Water Profile. In view of this, the project's steering group decided that the assessments made in this study shall be of a qualitative nature, that principles are to be developed and that an overall method discussion is to take place.

A few basic principles need to be discussed regarding the impact of wood raw material production. The geographical scale to be used in assessments must be defined. The assessment can be limited to exactly the stand that was felled to produce the specific wood raw material used in production, but in that case, the assessment must cover at least one rotation period. Alternatively, the geographical scale can be extended to include the forestry conducted in the region from which the wood raw material originates. By way of comparison, the EU's Water Framework Directive has determined that river basins less than 10 $km^2$ shall not be subject to reporting requirements.

Forestry is planned and conducted over very long periods of time and over large areas. Rotation periods between felling are around 50–60 years in southern Sweden, and considerably longer in northern Sweden. Within a particular region, there are simultaneously stands in all stages: final cut, scarified, planted, thinned and forest in full growth. In order for the Water Profile for forestry to be meaningful, the necessary assessments have been made at landscape level over a long period of time, e.g. a rotation period. A suitable geographical scale may be large river basins, e.g. large watercourses. The area for assessment should, however, include forest worked in accordance with more or less similar principles. It should be noted, however, that using large geographic areas and long periods of time risks being subject to criticism. Forestry measures, e.g. final cutting, may temporarily affect water quality in local watercourses, but these effects are extremely limited seen in a rotation period perspective.

There are other drivers for forestry beyond producing roundwood for the forest industry. An example of these drivers is the production of biomass for combined heat and power (CHP) plants. In the future, it may also be relevant to use a greater proportion of forest raw material to produce biofuels and other bioenergy. In theory, a certain portion of the impact of forestry on run-off can be excluded due to the fact that there are other drivers for forestry in a particular region.

In this study, the assessments forming the basis for the Water Profile for forestry have been made at landscape level and over a long period of time, such as a rotation period.

### 3.1.4 Drivers for forestry

The impact of forestry on water quality in run-off during a rotation period has been described in detail by Ring et al (2008). Forestry measures impact on local water quality, for example during cleaning, thinning, final cutting, scarifying, draining and fertilising, and when building forest roads.

The production of the forest industry and the demand it creates for wood raw material is a prerequisite for the forestry conducted in Sweden, both now and during the past hundred years. A link has been identified between consumer demand for products based on wood raw material, the production of the forest industry, forestry measures, and the impact on water quality and quantity in run-off (**Figure 4**).

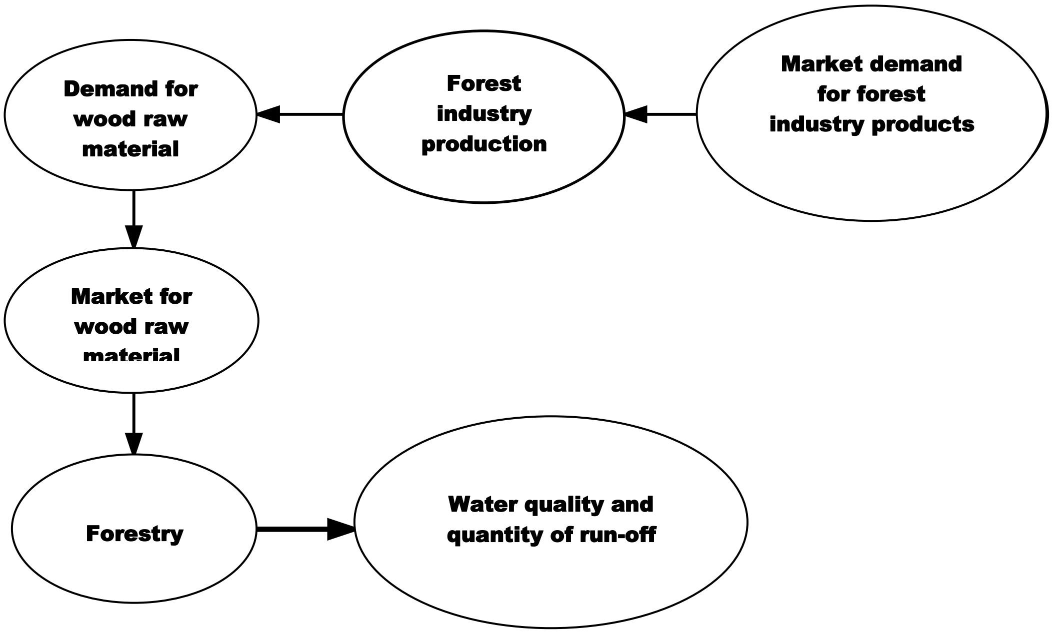


**Figure 4.** An illustration of the links between consumer demand for forest industry products, forestry measures and the impact on run-off.

Forestry is driven by an anticipated future financial gain on the sale of felled wood raw material (Wibe & Carlén, 2008). By purchasing wood raw material, the forest industry contributes to maintaining a certain price level on the wood raw material market, motivating forest owners to continue implementing forestry measures. For this reason, the forest industry is a prerequisite for forestry in Sweden, now and in the future. In this way, the forest industry exerts an influence over the type of forestry conducted and, by extension, over the impact of run-off from forest ecosystems. Consumer demand for products from the forest industry is naturally necessary for the forest industry to continue production. This refers to consumer demand for products based on pulp and sawn timber.

As discussed above, there are also other complementary drivers for forestry, such as selling branches and treetops to CHP plants.

### 3.1.5 Possible reference scenarios for Swedish forestry

In order to assess the impact of current forestry measures on the water quality and quantity of run-off, it is necessary to compare with how the water quality and quantity of the run-off would have been in a reference scenario (baseline). This reference scenario is to represent the situation as it would be in the absence of current forestry measures. This is comparable with the principle used in the EU's Water Framework Directive, which states that the water quality in lakes and water courses is to be assessed based on a comparison with the water status in a reference scenario that represents conditions that are nearly totally undisturbed by humans.

The reference scenario should be relevant in relation to the definition of a Water Profile for forestry, i.e. "the impact of quantity and quality of water in run-off from forest ecosystems that can be considered to be dependent on the forestry conducted to produce the wood raw material". In most cases, the choice of reference scenario has a decisive impact on how the impact of forestry on the quality of run-off is assessed. In theory, there are two ways to generate a reference scenario that reflects a state in which current forestry measures are absent.

The first is a historical approach, in which you assume that the evolution into today's forest industry never took place, and consequently, that forestry never evolved into its current state. The problem lies in making an assumption about how forestry would have evolved instead. This scenario is problematic precisely because it is difficult to assess how forestry would have been.

The other option is to take current forestry as a point of departure and make the hypothesis that demand for forest industry products would sharply decline over a short period of time. This could result in many forest industry companies being forced to make production cutbacks, and demand for wood raw material would fall. The consequence of this would probably be that forest owners would postpone various forestry measures such as felling, planting and thinning, and that they would switch to less intensive forestry. In many respects, this is also an unrealistic scenario because Swedish forestry legislation demands replanting after felling. If demand for wood raw material should fall in the long term, it would be necessary to switch to less intensive forestry than today's. What this would consist of is, however, difficult to predict.

In both the cases described above, it is conceivable that the reference scenario would involve forestry conducted at a lower intensity than today's. However, it can be assumed that the first approach – the historical approach – would result in a scenario with more diversified forestry compared with today's. Low-intensity forestry would probably result in longer rotation periods, which in turn could possibly result in less impact on run-off compared to current forestry. Alternative directions for forestry could include tourism and hunting.

A further reference scenario could be an increase in demand for biomass as a result of policy goals to increase the amount of renewable energy. Thus, in this case, demand for forest industry products is not the driver.

Alternative use of land probably depends to a certain extent on ownership. In southern Sweden there are a large number of private individuals who are forest owners, while in northern Sweden forests are chiefly owned by companies (**Figure 5**).

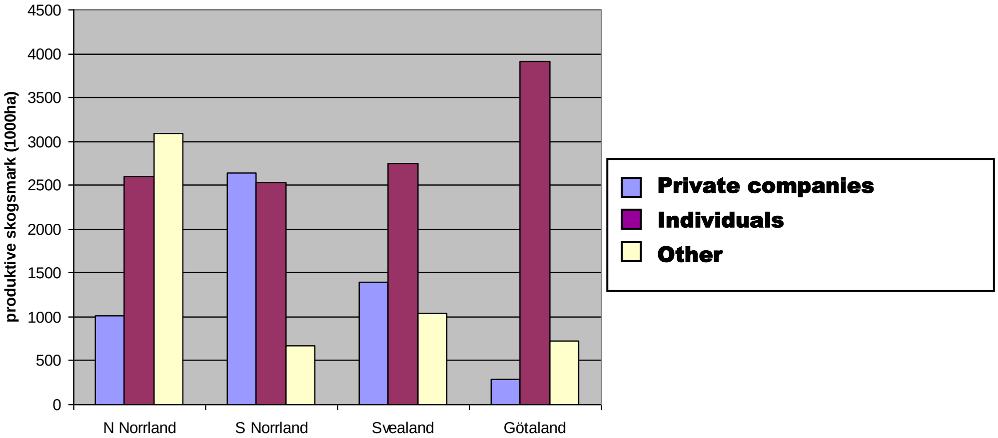


**Figure 5.** An overview of ownership of Swedish forest land in various parts of the country. Here, 'Other' refers to the Swedish government, state-owned companies, and private owners who are not individuals. (Source: Swedish National Forest Inventory, 2010)

Forest land in southern Sweden is highly fertile and therefore has a higher economic value compared to forest land in northern Sweden. This indicates that an alternative land use is more feasible in the south of the country compared to the north. In northern Sweden, a 'passive' response to lower demand for wood raw material is perhaps more likely, with less intensive forestry as a result.

Alternative land use is naturally greatly dependent on future societal developments. There is much to suggest that biomass from the forest will continue to be in great demand in the future. Alternative forestry with maximised biomass production would then be an option. This would probably mean considerably shorter rotation periods compared to today, and most likely a greater impact on run-off.

In view of the discussion above we can confirm that, at present, it is extremely difficult to propose a single plausible reference scenario for current Swedish forestry. Instead, we suggest that we do not make a definite decision at the present time on what is most likely but rather that we analyse two different possibilities:

1. Describe the consequences of less intensive forestry compared to today, driven by lower demand for wood raw material.
2. Describe the consequences of more intensive forestry compared to today, driven by a greater demand for forest biomass.

Options 1 and 2 do not make any assumptions about what would be a relevant reference scenario for current Swedish forestry. They simple give examples of how forestry can affect run-off in relation to two alternative land use scenarios.

## 3.2 Results and discussion

### 3.2.1 Run-off from Swedish forest land

Swedish forestry affects water quality in soil water (mobile water under the root zone on its way down towards the groundwater), groundwater and run-off. Felling, scarifying, cleaning, thinning, fertilising, building forest roads, etc. can affect both the quantity and the quality of the water leaving forest ecosystems in run-off. (Flinders et al., 2009, Löfgren et al., 2009, Ring et al., 2008). However, this only applies during short sections of the total rotation period.

Generally, run-off of water from forest ecosystems to major watercourses and finally to lakes and seas is good (**Figure 6**), possibly apart from on isolated occasions in the summer in southeast Sweden. Instead, a surplus of run-off water may periodically cause problems in the form of resultant flooding. This occurs regularly in the spring after the snow melts as well as in the autumn after heavy rain. A discussion about possible problems with forest ecosystems reducing the amount of water in run-off is thus more or less irrelevant in a Swedish context.

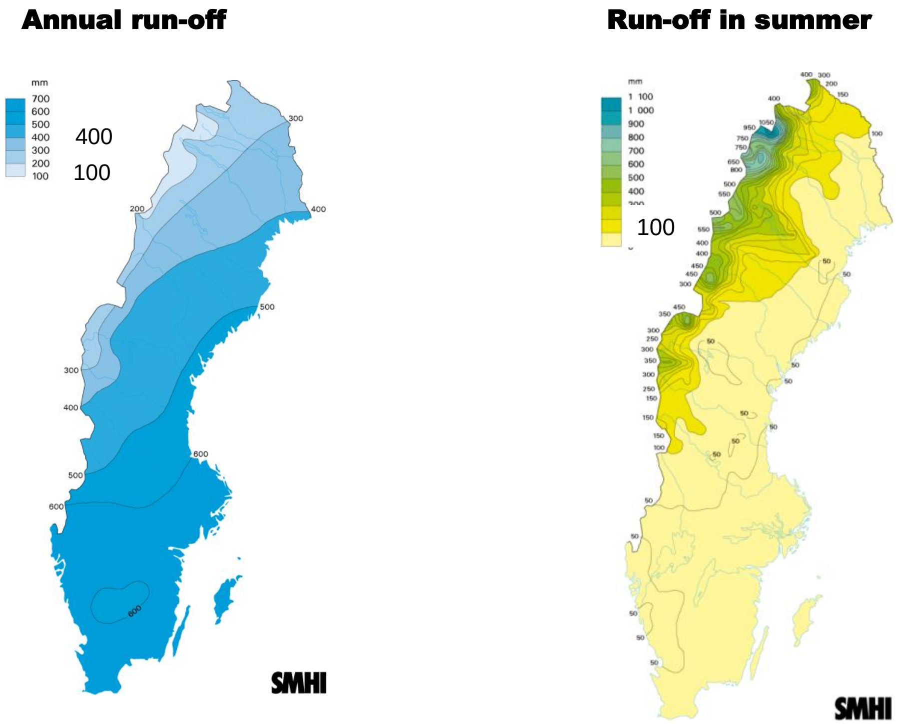


**Figure 6**. Official Swedish hydrological statistics Source: SMHI

Pieter van Oel (van Oel, 2010) has recently proposed a method for calculating the green water footprint of forest industry products based on evapotranspiration from the forest, annual values for forest production and values regarding how much wood raw material is consumed when manufacturing forest industry products. From these rough calculations, values were generated for different paper-producing countries; for Sweden, these were 476–628 $m^3$ green water consumed/tonne of paper produced. Values for other countries ranged from 268 to 1,323 $m^3$ water consumed/tonne of paper produced.

These values have limited relevance for several reasons. The first and perhaps most important reason is that water consumed in forest production was not set in relation to water supply. As discussed above, water shortages, in any case in terms of water volumes, do not pose a problem in Sweden, and the same applies to several other countries. Secondly, water consumption in the forest is not set in relation to a reference scenario as discussed above. Even a natural forest with limited forestry measures needs a considerable amount of water. The same applies to farmland and pasture. A further argument against the method is that a certain proportion of the water lost through evapotranspiration is restored to the forest landscape as rain. Water use should also be divided up among different forest products, i.e. sawn timber, pulp and paper, and energy products.

An alternative method to that proposed by van Oel would be to set forest water consumption in relation to supply as per the simplified equation below (expressed on an annual basis and e.g. at a national level):

$$relWP_{green} = Evapo / (Evapo+run\text{-}off) * 100/felling * F_{conversion}$$

relWPgreen: a relative green water footprint
Evapo: evapotranspiration, the amount of water that evaporates from forest ecosystems into the atmosphere, $m^3$/ha/year
Run-off: the amount of water that leaves forest ecosystems in the form of run-off in the same geographical area, $m^3$/ha/year
Felling: in the same geographical area, $m^3$/ha/year
$F_{conversion}$: amount of wood raw material used in the products in $m^3$/tonne of product

The unit used for $relWP_{green}$ is %/tonne of product, and this index can be interpreted as % of water supply consumed to produce the wood raw material used to produce one tonne of the product.

Using this method, there would be a clear difference between areas and usage methods where water is in short supply and where, like in Sweden, there is normally a large surplus. For this method also, it is naturally important that a comparison be made with a reference scenario as discussed above.

The flow of water to forest ecosystems mainly takes the form of precipitation but can also consist of horizontal flows of groundwater. Some of this water is used for transpiration by vegetation, trees and the understorey. It is inevitable that plants lose water when they take up carbon dioxide for photosynthesis. Some precipitation adheres to the crowns of trees and evaporates directly into the atmosphere after the rain has stopped. The remaining water makes its way down to the groundwater or runs off over the ground surface into local lakes and watercourses.

The type of vegetation that covers a particular area of land has a bearing on the air layer closest to the soil – what is known as the laminar boundary layer. A forest with tall trees produces significantly greater turbulence in the air compared to an open field with low vegetation. In the latter case, air layers may be stabilised during nightly temperature inversions, which to a certain extent limits transpiration from this type of vegetation (Jones, 1992). On the other hand, conifers often display what is known as low conductance, which also limits transpiration. Conductance is a measure of how open the stomata are. Stomata are microscopic pores on leaves that the plant can open and close, thereby regulating transpiration to a large extent. Under conditions where the stomata are completely open, the transpiration has been calculated as 500 mg $H_2O$ per 10 $cm^2$ of leaf surface per hour for spruce and 800 mg $H_2O$ per 10 $cm^2$ of leaf surface per hour for birch (Larcher, 1975). Further, a larger proportion of precipitation adheres to tree crowns in a forest and evaporates immediately compared to the amount that adheres to the leaves of crops. When comparing a forest area with an area containing e.g. crops, the total evaporation is more or less the same (Larcher, 1975).

In spite of what has been discussed above, there is a clear connection between the amount of green biomass per unit of ground surface and daily evaporation from the area during the growth season (Jones, 1992). The most obvious example is that of a finally cut area in which evaporation from vegetation is minor and run-off much greater (e.g. Sörensen et al, 2009). However, the overall interaction between forestry and evaporation depends to a large extent on factors such as how precipitation is distributed over the seasons (Flinders et al, 2009; Sörensen et al, 2009).

Here, it is important to point out that current Swedish forestry most likely has an extremely favourable effect in that forest ecosystems contribute to limiting and offsetting run-off over time, thus counteracting flooding.

In conclusion, it can be said that the overall effect of Swedish forestry on water economy is that run-off is evened out. This effect becomes greater as the growth rate of the forest increases. Evening out run-off is mostly beneficial in a Swedish context in that it limits flooding. During final cutting, however, run-off may increase substantially in a localised area, but this is of less significance when we consider the entire rotation period.

### 3.2.2 Impact of forestry on water quality in run-off

At an overall level, current Swedish forestry measures have a limited impact on the water quality of run-off (Ring et al, 2008). Under certain circumstances, however, these measures may affect water quality locally and temporarily.

Forestry measures can impact on soil water, groundwater and local run-off water. The growth of the forest in itself involves 'natural' acidification due to trees giving off hydrogen ions at the same time as they take up nutrients through their roots, and this contributes to acidifying the soil water (e.g. Ring et al, 2008). If forest biomass is not removed but is instead allowed to decompose within the forest ecosystem, this process is reversed. If on the other hand biomass is removed, e.g. on felling, this cements the acidifying effect, which also increases in proportion to the amount of biomass removed. This means that the acidifying effect of the forest increases as the growth rate increases. This in turn means that intensive forestry increases the acidifying effect of the forest on soil water and, ultimately, on run-off, increasing the risk of aluminium elution. This effect may be considerable (Ring et al, 2008). In recent years, now that acid fallout from the air has substantially declined, the acidifying effect of the forest may be of about the same magnitude as that of acid rain.

However, this effect can be counteracted to some extent by other processes. By leaving branches and treetops when felling, the effect can be reduced, as this is primarily where the alkaline cations absorbed can be found. In this way they stay in the area, raising the pH level when they decompose. If too many branches and treetops are removed, it may be necessary to compensate for this. Some research has shown that weathering, i.e. the release of alkaline cations from minerals, increases under the influence of a tree's mycorrhiza (e.g. Rosling et al., 1998, Rosling, 2009).

Deposition of pollutants from the air to forest ecosystems takes place in two different processes: through pollutants dissolved in precipitation (known as wet deposit), and by pollutants in particle or gas form being deposited on leaves and needles and then rinsed off onto the soil by precipitation (known as dry deposit). Dry deposit is dependent on the concentration of pollutants in the air, along with the size of the surface of leaves or needles per unit of ground surface. The denser the stand, the more efficient the forest is at acting as a 'filter' for capturing dry deposit. In less dense stands, more of the potential dry deposit will be passed on to other areas. There is therefore a link between forestry and the amount of air pollutants deposited in the forest. Nitrogen dpe in forests constitutes one of the most serious remaining air pollution problems in Sweden, and in the southwest of the country, dry nitrogen deposit contributes 30–40% of the total nitrogen deposit.

Forest land, particularly the upper organic layers, is able to store considerable amounts of certain pollutants, including mercury and sulphur. Even if mercury fallout from the air has decreased significantly in recent years, there are large quantities of mercury stored in forest land in southern Sweden that may under certain circumstances leak out into lakes in the form of the toxic substance methylmercury. Leakage into lakes particularly increases when forest land is worked with machinery, such as during felling or as a result of windthrow. Forestry methods that involve working soil with a substantial organic matter content may have great significance for long-term mercury leakage from forest land into lakes.

### 3.2.3 Forestry measures

A great number of forestry measures can be implemented relatively simply and at a limited cost in order to minimise the impact of forestry on the water quality of run-off. These measures are described meritoriously in a manual from Skogforsk (the Forestry Research Institute of Sweden) (Skogforsk, 2008). There is also a scientific publication that describes the benefits of these measures (e.g. Gundersen et al, 2010).

Many of the negative effects of forestry are encountered during final cutting. Any buffer ditches may affect water quality in watercourses exiting the area. Felling increases run-off from the area for a number of years. This may mean a temporary increase in the elution of hydrogen, phosphorus and organic substances. A large amount of nutrients being carried to adjacent lakes and watercourses may lead to oxygen depletion. The impact of run-off can be mitigated by limiting the clear-felled area or by regenerating under shelterwood. Minimising the amount of slurry in run-off is crucial.

Examples of forestry measures include leaving buffer zones of trees along streams and other small watercourses when felling. Selecting the right time for felling is also important, as forest machinery and vehicles cause greater damage when the ground is soft and damp. Such damage results in slurry being formed in lakes and watercourses, and this is hazardous to aquatic organisms. Also, it is necessary to avoid any leakage from forest machinery in the form of fuel, oil or grease, as this can also be harmful to water living organisms. In general, damage caused by forest machinery and vehicles can be avoided by planning forest roads and felling so that driving in damp areas can be avoided as far as possible. Measures to minimise such damage can also be incorporated when planning to thin new growth. It may also be appropriate to clear twigs and branches in nearby lakes and watercourses when felling has been completed.

Scarification increases the risk of slurry being transported into water. In view of this, it is appropriate to leave a buffer zone alongside watercourses. Forest fertilisation can also cause problems. This can also be minimised using buffer zones. It is best to fertilise the forest in early summer when the trees have great capacity to take up nutrients.

It should be pointed out that a large part of these measures have already been incorporated in current forestry practice and that the impact of felling on e.g. run-off water is now significantly less than it was a few years ago.

# 4 Manufacture of pulp, paper and sawn timber

## 4.1 Method

For pulp and paper production, incoming water flows have been calculated as the sum of the raw water intake and the water in fibre raw material, fuel (bark) and chemicals.
Most pulp and paper mills in Sweden have been contacted (representing over 99% of the total production), and various water flows from each individual mill have been recorded in an Excel file. This data has been supplemented with theoretical calculations. The unit processes included are given in **Figure 7**.

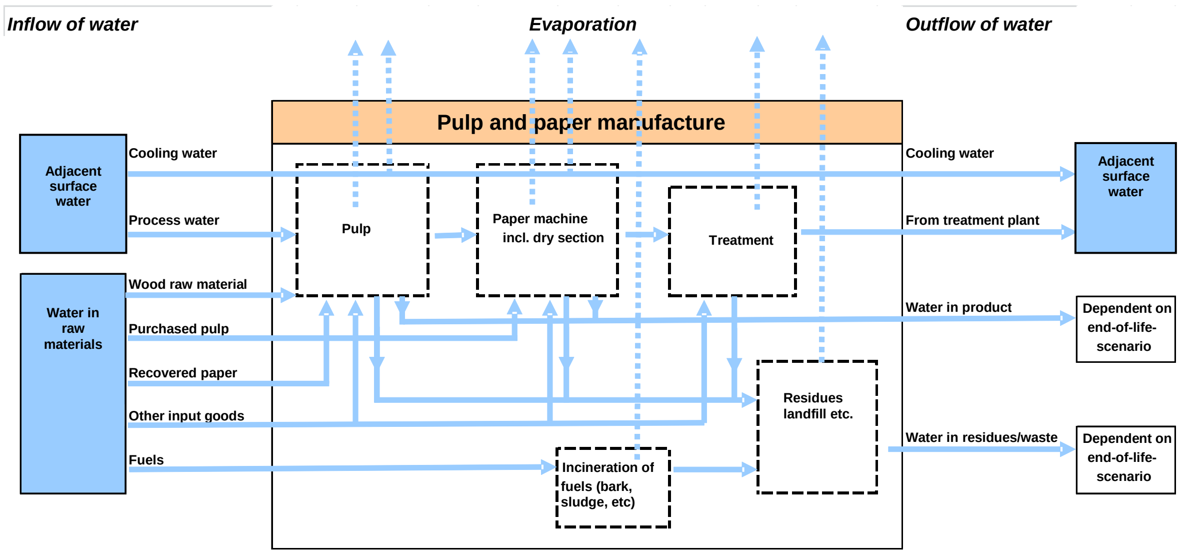


**Figure 7**. Schematic diagram of water flows included in the manufacture of pulp and paper products.

The system studied for sawmills includes incoming and outgoing water flows as in **Figure 8**.

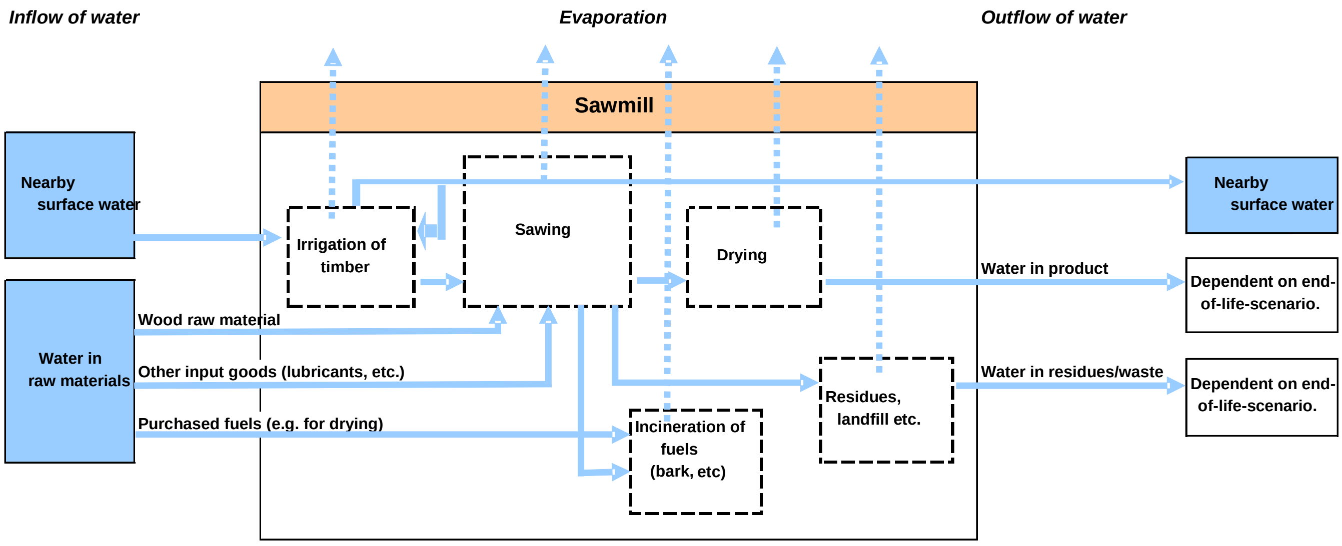


**Figure 8.** Schematic diagram of water flows included in the manufacture of sawn timber.

Water use at two sawmills has been used to scale up the manufacturing flows and the outflow of water to the Swedish sawmill industry as a whole. As the water used and consumed by sawmills makes up a small part of that used and consumed by the forest industry in total, this was considered reasonable. However, the two sawmills account for less than 3% of Sweden's total production. They did not specify inflows of water from other input goods.

### 4.1.1 Water withdrawal ($m^3$ from source)

Water withdrawal is the amount of water that mills or sawmills collect from an external water source in $m^3$ per year, divided up per water catchment. The data is based on the mill's own measurements/estimates. Water flow meters are often a few per cent off the mark, but it can be assumed that the errors cancel each other out overall.

### 4.1.2 Water exploitation (percentage of original freshwater flow)

Water exploitation can be defined as the water withdrawal of an enterprise in relation to the flow in the source, calculated as a percentage of the total water flow along part of the watercourse, lake or other source. Only a few mills located beside watercourses may have a low water flow during certain periods. These and a number of more normally located mills were selected in order to calculate water exploitation.

Data from flow measurements from each receiving body of water has been obtained from the database of the Swedish Meteorological and Hydrological Institute (SMHI) regarding flow statistics (Flödesstatistik för Sveriges vattendrag; QStat20090604 [Flow statistics for Sweden's watercourses; QStat20090604]), where the stated water flow values are calculated to constitute long-term values in a 20th century climate under current regulation conditions, or under natural conditions. SMHI's basic hydrological network consists of 330 measuring points located in Swedish watercourses. These points are not always close to a mill.

At mills for which SMHI does not have a measuring point close by, a mean value has been calculated from two or more nearby measuring points, upstream and downstream from the mill (at varying distances). Thus, flow measurement data does not describe the exact flow at the mills' water intakes; rather, it should be seen as a guideline value for a longer stretch of flow. The data used is mean water flow in $m^3/s$ (mean value of each year's mean water flow). This value is subsequently converted into the mean water flow per year. The reported water withdrawal of the mills for 2009 was then divided by this mean water flow in order to calculate the exploitation value (the water withdrawal of the mills expressed as a percentage of the total water flow along a stretch of water) for the watercourse. Note that the current outtake is compared with the mean water flow over several years. The percentage relevant at a particular time may be much larger or smaller.

### 4.1.3 Water consumption (water lost from the site through e.g. evaporation)

Water consumption is defined here as water that disappears from the mill through evaporation. Several mills have submitted their own estimates of this evaporation. However, it is not clear how complete a review has been made of the various points where evaporation should take place.

For each mill, the difference between reported ingoing and outgoing water amounts has been compared, and the percentage of water consumed has been calculated. A mean value for the consumption proportion of incoming water was also subsequently calculated.

As a complement to this data, consumption was also estimated as the sum of theoretically calculated losses in the stages in which large amounts of water are converted into water vapour. This mainly relates to boilers, cooling towers, the process of drying products, and external wastewater treatment.

### 4.1.4 Water quality

The total discharge of organic matter (COD), nitrogen compounds (N), phosphorus compounds (P) and organically bound chlorine (AOX) was used as a measure of the total pollutant load for the entire industry. As total values, they do not say a great deal about any environmental impact or opportunities to use the water for other purposes. Above all, the values of the discharge can be used to compare with previous years, or loads in other countries, calculated per the amount of pulp and paper produced. The discharge is regulated by the conditions of the mill. These conditions are set for each mill by the environmental court, based on the optimum technology and the condition of the receiving body of water.

### 4.1.5 System boundaries

The study includes water that is included in chemicals as water content, but not water used when producing the chemicals.

### 4.1.6 Data sources and data quality

The data forming the basis of the study comes from questionnaire responses submitted by experts at almost all of Sweden's pulp and paper mills, plus two sawmills. The questionnaire was designed by IVL in consultation with the Swedish Forest Industries Federation. In it, respondents were asked to state amounts of water per year (2009) divided into raw material inflows (wood, purchased pulp, chemicals, etc.), the manufacturing process (process water, cooling water, etc.) and outflows (products, waste, etc.). Also, they were asked to give details of discharge that affects water quality (COD, N, etc.) and attempt to estimate the amount of water that evaporates in the process designated as 'water consumed' in the report.

The data collected has proved to be of varying quality. For example, the response rate varied dramatically depending on what was being asked. Water in wood raw material, outtake of water for the process, and discharge to water are examples of data requested that had an almost 100% response rate, while evaporation in the process is an example of data with a response rate of less than 40%. The accuracy of the data can also be questioned in some respects, i.e. the data contains several uncertainties. For example, it has emerged that many pulp and paper mills have relatively simple flow meters at the water inflow, while the flow meter for the outflow is more accurate.

Questionnaire responses were submitted by 41 out of 42 mills questioned. In some cases, obvious errors in units have been corrected. Where data on water in raw materials, chemicals, products or waste has been lacking, standard values from CEPI (Malmberger and Wiegand, 2009) have been used. Some of the data has been extracted from the respective mill's environmental report for 2009.

For nine mills, the data has been entirely based on data from the Swedish Forest Industries Federation and the standard values and environmental reports mentioned above. In this way, it was possible to include 50 out of Sweden's total of 54 mills in the study. The remaining mills account for less than 1% of the country's total production of pulp and paper.

Water flows in sawmills are examples of information that sawmills do not usually measure or report, which influences the quality of the data.

## 4.2 Results and discussion

Below are the results of the Water Profile for manufacturing in the Swedish forest industry, i.e. pulp and paper production, and production of sawn timber. Sawmills are only touched on briefly, partly because the flows are much smaller and partly due to a lack of data.

### 4.2.1 Inflows of water

The inflow of raw water for the manufacturing process was around 850 $Mm^3$. Less than 0.5% of this was used in sawmills. Almost all water was taken from surface water sources (rivers, lakes, etc.). Reported municipal water makes up 0.2% of the raw water intake.

**Table 1.** Amounts of water in different inflows to the Swedish forest industry.

| **Inflow** | **$Mm^3$/year** |
|---|---|
| Raw water | 849 |
| *Of which as municipal water* | 1.9 |
| Fibre-based raw material: | |
| In wood excl. bark | 26.5 |
| In purchased pulp | 0.17 |
| In purchased recovered paper | 0.25 |
| In fuels (e.g. bark) | 2.8 |
| In chemicals and other input goods | 1.4 |
| | |
| **Total** | **880** |

The distribution of water between incoming wood, pulp and recovered paper is partially estimated; this breakdown was not in the questionnaire. Responses to the questionnaire have been comprehensive, without any major ambiguities. One exception is responses regarding water in bark, which in some cases seems to have been counted as wood raw material. In a few cases, the amount of water intake was missing, but the discharged amount was then used for estimation purposes. Water flow meters are often a few per cent off the mark, but it can be assumed that the errors cancel each other out in the material as a whole and that the total value is largely correct. As regards mills, it is also more important to measure the amount of wastewater discharged.

At around 3 $Mm^3$, the amount reported for the pulp and paper industry of surface water/rainwater and leachate from own landfill is small. This water has not been counted as intake water because there would have been rain on the surface regardless of the activities conducted there. At sawmills, rainwater has much greater significance in terms of keeping the timber damp, and it also becomes more polluted than normal surface water. At the same time, the measurements available are not complete. Based on the stated amounts, the amount for all sawmills would be around 5 $Mm^3$/year. The amounts are not included in the following tables.

As access to water is rarely a problem in Sweden, water-saving measures, closed systems and the like are instead a result of energy-saving initiatives. The industry is attempting to reduce the amount of process water and the level of pollution. Water use has normally been reduced by means of technical solutions such as efficient washing and bleaching in pulp production and closed white water systems in paper production.

However, there are limits to the extent to which systems can be closed and how little water can be used. Often, product quality and/or production problems linked to precipitates and bacterial growth set these limits.

Inflows to the forest industry total around 880 $Mm^3$, of which the pulp and paper industry accounts for around 99% (approx. 870 $Mm^3$).

### 4.2.2 Water flows in the manufacturing process

Around 505 $Mm^3$ of water per year is considered to relate to the process, and around 326 $Mm^3$ is water of various types that has not been involved in the process, mainly cooling water. The actual water flow in the processes is considerably greater because a great deal of water is recirculated. The figures stated can be regarded as net use. The sawmills share of these flows is negligible.

All polluted process water in the pulp and paper industry is treated in some form of external treatment plant. According to data reported, the amount of water treated is around 486 $Mm^3$. Treatment normally starts off with sedimentation, followed by biological treatment and/or chemical precipitation. In many cases, only substreams are treated using the various methods, depending on what the water contains. Larger amounts of water have been reported as being process water than the water stated as having been sent for treatment, which may possibly be due to the fact that leachate from landfill is also treated in some of the treatment plants. This means that for internal streams, and for the discharge in the next paragraph, the amounts reported are incorrect.

At sawmills, methods of treating surface water other than sedimentation and recycling for irrigation are uncommon, and they have probably not been reported as treatment to any great extent.

### 4.2.3 Outflows

The total outflow from the forest industry amounts to around 836 $Mm^3$ of water each year, of which pulp and paper mills accounted for more than 99 %. Around 60 % of the total water outflow in pulp and paper mills is water used in the process, and around 40 % of the outflow consists of water not used in the process, mainly cooling water. Only around 0.4 % leaves the system via the end products, i.e. market pulp, paper and sawn timber, and even less leaves via waste and by-products.

**Table 2.** Amounts of water in different outflows from the Swedish forest industry.

| **Outflow** | **$Mm^3$/year** |
|---|---|
| Process water | 502 |
| Water not affected by processes | 330 |
| In market pulp | 0.45 |
| In paper | 0.86 |
| In residues, waste and by-products | 0.94 |
| In sawn timber | 1.6 |
| **Total** | **836** |

Here, data for outgoing water streams from pulp and paper mills is also relatively certain, while there may be discrepancies in the smaller items. In some cases it is obvious that data has been given in $m^3$ and not in 1,000 $m^3$, and where this is so, the values have been changed. Water in purchased or delivered steam has not been included. We assume that systems are closed and that the water from the delivered steam is recovered.

Initial dilution in the receiving body of water varies a great deal between the different mills, and often also according to season and varying degrees of precipitation. Figures between 30 and 5,000 times have been stated. However, there is no data for any further mills. One mill has given a dilution as low as three times, which is commented on in section 4.3.2.

**Table 3** summarises the data given in sections 4.2.1 to 4.2.3 for **pulp and paper mills only**. The number of value figures does not entirely reflect data certainty. For different parameters, one or two value figures is more fitting.

**Table 3.** Water flows when manufacturing pulp and paper.

| **Inflow** | **Total, $Mm^3$/year** |
|---|---|
| Raw water | 847 |
| In fibre-based raw material | 19 |
| In fuels (bark, sludge, recovered wood, etc.) | 2.3 |
| In input goods (chemicals, starch) | 1.4 |
| **Total inflow** | **870** |
| | |
| **Manufacturing** | |
| Water in the process | 505 |
| Cooling water that is not involved in the process | 327 |
| Water that is not involved in the process (e.g. seal water) | 3.9 |
| Water to treatment plants | 486 |
| | |
| **Outflow** | |
| Process water | 501 |
| Water not affected by processes | 330 |

| | |
|---|---|
| In manufactured market pulp | 0.45 |
| In manufactured paper | 0.86 |
| In residues/by-products/waste | 0.93 |
| **Total** | **833** |

## 4.3 Water consumption

For pulp and paper mills, water loss was 870 - 833 = 37 $Mm^3$ in 2009. This means an average of 4.3% of all incoming water, or 4.4% if the calculation is based on volumes of raw water intake. This is a reasonable figure, but widely varying figures have been obtained for individual mills – from a 36% loss to a 17% increase at the two extremes, based on raw water intake. The most extreme values must be attributable to erroneous measurements, misunderstandings in reporting or misinterpretation of the questionnaire responses. By including mills with estimated losses of between 19 and -1% only, average water consumption is 4.6%.

The pulp and paper mills were also asked to make their own estimates of total evaporation. Thirteen mills responded, and the mean value for water losses in these mills was 4.3% of raw water intake. One mill has estimated its water losses in more detail. In this case, estimated water consumption was 3.7% and 3.8% of incoming water for 2008 and 2009 respectively. There, the drying process for paper and pulp accounted for just under half, and evaporation from external treatment accounted for about the same amount. They do not have a cooling tower but did not anticipate any losses via boilers. Once again, the result is in the region of 4–5% of water intake.

In view of the uncertainty in a figure that is the difference between two more or less equally large numbers, attempting to calculate the water loss in theoretical terms is also justified. There are many processes in which evaporation can occur without steam condensing completely and being returned. This is mainly the case in boilers of various kinds, in the final stages of drying delivered pulp and paper, in any cooling towers, and in treatment plants.

### Rrecovery boilers and bark boilers

In order to estimate water loss from all recovery boilers, we base our calculation on measured/estimated loss from five boilers and calculate the specific water loss expressed as $m^3$/tonne of unbleached pulp. The average value was 0.99, with a large standard deviation of 0.53. Evaporation is driven to different extents, and there are different systems for recovering energy and condensing, which explains the broad spread. The amount of pulp has been recalculated as unbleached pulp to correspond to the same capacity in the recovery boilers. According to NCASI (Malmberg and Wiegand, 2009), the yield of unbleached sulphate pulp is 0.55 tonnes/tonne of wood, and for bleached sulphate pulp it is 0.47 tonnes/tonne of wood. This means that one tonne of bleached pulp comes from 1.17 tonnes of unbleached pulp.

Using this calculation method, the total discharge of water from Sweden's recovery boilers is around **9 $Mm^3$** of water/year, but with an uncertainty of at least 4 $Mm^3$ water/year.

With bark boilers, we base our calculations on the amount of wood needed for current pulp production. The yield figures are taken from NCASI (Malmberg and Wiegand, 2009) as above for chemical pulp, 0.8 tonnes/tonne of wood for semi-chemical pulp, and 0.93 tonnes/tonne of pulp for mechanical pulp.

The measured/estimated water evaporation for three boilers was 0.20 $m^3$/tonne of wood, with a standard deviation of
0.13 $m^3$/tonne.

On this basis, it is then possible to make an estimate for all the bark boilers in the country: around 4 $Mm^3$ water/year. If an adjustment is made to account for the fact that around 20–25% of the wood raw material for pulp manufacture consists of hogged chips without bark, the figure is closer to **3 $Mm^3$** water/year. The uncertainty is close to 2 $Mm^3$ water/year.

## Drying pulp and paper

If, in a theoretical calculation, we use the value of 45% DM (dry matter) for pulp entering the drying section and 90% DM for pulp leaving it, water evaporation resulting from drying market pulp in 2009 would amount to around 4.5 $Mm^3$. In the same way, for paper production, with 45% DM in and 96% DM out, the figure is around 12.9 $Mm^3$. These theoretical figures should be decreased, as many mills practise some form of energy recovery with water condensation. Based on six mills that measured actual water evaporation when drying paper and paperboard, the actual water loss was around 70% of the theoretical water loss. If we assume that the relationship is the same for drying pulp, the total figure for drying market pulp and paper would be around **12 $Mm^3$ water/year**. The uncertainty is around 4 $Mm^3$ water/year.

## Cooling towers

Cooling towers function by the water being vaporised and the temperature of the remaining water sinking in relation to the vaporisation energy. We have identified data for flows and drops in temperature for five plants in previous questionnaires (data for Sivard and Simon, 2010). For these five plants, we have calculated the theoretical amount of vaporised water and compared it with the total flow of water into the tower. From these percentages, we have calculated the mean value: 3.8±2.0%. The large standard deviation is attributable to the fact that the drop in temperature varies. As we did not have any data on temperature drops in the other four cooling towers, we have used the mean value to estimate their water loss. Estimated in this way, total evaporation is around **4 $Mm^3$ water/year**. The uncertainty is around
2 $Mm^3$ water/year.

## Wastewater treatment plants

For sedimentation basins and aerobic biological systems, it is possible to make a simplified calculation in the same way as for cooling towers; lost energy should to a large extent have resulted in evaporation. Admittedly, the retention time is longer, so more of the heat can be carried off via the walls and ground, but in an initial estimate, this can be disregarded. On the other hand, the extra energy added by adding air should be included in the calculation. This is approximately the effect used in blowers or immersed aerators. In our simplified calculation, we have assumed that surface aerators do not add any thermal energy to the water.

In the biological stage, the energy released during oxidation of organic matter should also be taken into consideration. 1 kg of degraded COD should yield around 4 kWh, but only part of the energy becomes heat; the rest is stored in the biomass formed. We have assumed that all the biological processes give relatively little slurry, and that each kilogram of degraded COD provides 3 kWh of heat to the system.

In previous questionnaires (data for Sivard and Simon, 2010), we have identified drops in temperature for a total of 15 different treatment plants (in some cases an increase due to a large input of energy, a high level of organic content, and a compact plant). For these plants, we have calculated the theoretical evaporation in a way similar to that for cooling towers, but taking added energy into account. From the percentage evaporation (of the flow through biological processes), we have calculated the mean value separately for compact plants and for plants with longer retention times (aerated lagoons and long-term aerated active sludge plants). The mean values were 0.7±0.4% for nine compact systems and 3.1±1.3% for six conventional systems.

For the remaining 30 biological steps, we only had data for the flows. Here, we used the respective mean values for percentage evaporation that matched best with the type of treatment plant – 23 compact and 7 conventional. The estimate for all of Sweden's external treatment systems ended up at around **10 Mm$^3$ water/year**. Uncertainty in the calculation is around 3 Mm$^3$ water/year, plus the systematic overestimate due to no other heat losses being observed than those occurring through evaporation. The conventional systems with longer retention times accounted for around 75% of this amount.

## Total for pulp and paper mills

Calculated in this way, the total water loss would thus be 38 Mm$^3$ water/year, or around 4.5% of raw water intake. Estimated as a standard deviation, the uncertainty is in the region of 15 Mm$^3$ water/year. As there are several small sources of evaporation, this figure is more on the low side than too high. The mean value for the calculations made by the mills themselves was 4.3%, but this did not include all sources either. **40–50 Mm$^3$/year or 5–6% of raw water intake** seems therefore to be a relatively good total estimate**.** The uncertainty is around 20 Mm$^3$ water/year, or two percentage points, probably mainly upwards.

### Sawmills

As mentioned, the amount of raw water intake at sawmills is small and is not always measured. On the other hand, it is possible to make a rough estimate of the amount that evaporates when drying sawn timber and chips (which are mainly supplied to pulp mills).

Based on 16 Mm$^3$ sawn timber with a 16–18% moisture content (85% DM), and around 50% water in fresh timber, you arrive at 5.6 Mm$^3$ water that has dried up. In the same way, based on deliveries of chips of around 4 million tonnes/year and around 80% DM, you arrive at around 2.4 Mm$^3$ water that has dried up. Based on these assumptions, the total would be 8 Mm$^3$ of water. If you add losses in boilers (Trätek 2001) and timber irrigation, you arrive at a total loss of **10–15 Mm$^3$**.

## Total for the forest industry

According to tables 1 and 2, water loss in the manufacturing units of the forest industry (pulp and paper mills and sawmills) amounted to 880 - 836 = 44 Mm$^3$ in 2009. This is equivalent to 5% of all incoming water, or 5.2% of raw water intake to the plants. Based on the theoretical assessments made above, you arrive instead at the interval of 50–60 Mm$^3$ ± 20 Mm$^3$.

The total water loss for the Swedish forest industry is thus estimated to be **50–60 Mm$^3$** or **6–7%** of raw water intake, with an uncertainty of 2 percentage points. Evaporation during various stages accounts for more than 90% of this total water loss.

## 4.3.1 Water quality

**Table 4** shows the total discharge of organic matter and nutrient salts from pulp and paper mills in 2009.

**Table 4**. The total discharge of organic matter and nutrient salts.

| Emission parameters | tonnes/year |
|---|---|
| COD (total organic matter) | 169,000 |
| N (nitrogen compounds) | 2,600 |
| P (phosphorus compounds) | 270 |
| AOX (primarily chlorinated organic matter) | 470 |

Here, all mills have well-substantiated data. The total amount of discharge says nothing about how loaded or affected a certain receiving body of water is; this depends entirely on local conditions. All mills normally meet the discharge requirements set by the environmental court. The requirements vary according to the process and receiving body of water, and are set such that the discharge shall not have any unacceptable negative impact on the receiving body of water.

The mills strive to reduce discharge as far as this is justified from an environmental perspective, through both internal measures and by treating wastewater. Soon, all Swedish pulp mills and most paper mills will have biological treatment in order to reduce the discharge of organic matter (COD, AOX and toxic substances), and many also have chemical precipitation (mainly for suspended solids and phosphate).

COD is in itself a generic measure of all organic matter, regardless of whether it is biodegradable, toxic, or potentially bioaccumulative. Thus, a high COD value after biological treatment does not necessarily have a more significant negative impact on water quality than a much lower value in water that has not been treated at all. The main part of COD discharged from the forest industry's treatment plants is relatively stable and consists to a large extent of humus-like substances from the wood's lignin.

AOX is a measure of the amount of chlorinated organic matter. This mainly comes from bleaching pulp with chlorine dioxide. Like COD, it is a generic parameter that does not differentiate between toxic, highly chlorinated substances that were the result of former chlorine bleaching processes and the low-chlorinated substances that result from bleaching with chlorine dioxide, which are much less hazardous.

Discharge of nitrogen compounds (N) and phosphorus compounds (P) is more defined.. For N, a distinction should really be made between discharge of nitrate and discharge of ammonia, but this is seldom the case. Discharge of N and P can have both local and more large-scale effects, at least in the Baltic Sea. It may result in eutrophification and, as a consequence of this, anaerobic areas. The Swedish forest industry's share of the total load in the Baltic Sea is bigger for P than for N**.** With chemical precipitation, it is possible to separate P, while N requires biological nitrification and denitrification, a more complex process in the areas of concentration in question.

Discharge of COD and AOX has decreased dramatically over the past 30 years, despite a 30% increase in production; see **Figure 9**. Discharge of COD has decreased from 1,400,000 tonnes in 1980 to 169,000 tonnes in 2009, and discharge of AOX has decreased from 28,000 to 468 tonnes during the same period.

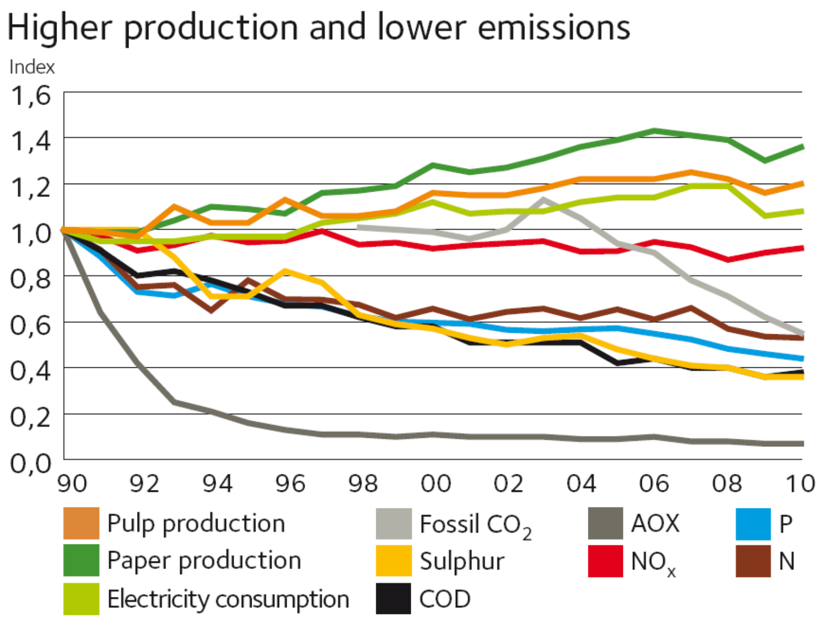


**Figure 9.** Emissions and production in the Swedish forest industry from 1990 to 2009 (Swedish Forest Industries Federation).

The decrease in COD during the 1980s was mainly due to better washing and the introduction of oxygen bleaching that enabled more complete closure. The expansion of external treatment plants also played a part at that time, and it is mainly due to continued expansion that this decrease has continued up until the present day. Nowadays, most pulp mills have biological treatment, and some also have chemical precipitation. The dramatic decline in AOX has in turn been due to oxygen bleaching, backwashing and replacing chlorine bleaching with chlorine dioxide bleaching and chlorine-free chemicals. Improved external treatment has also had a significant effect.

Discharge of the nutrient salts N and P has not declined as quickly over time. Before the introduction of faster, more compact and more oxygen-demanding biological systems, nutrient salts were not normally dosed into biological treatment. Also, many mills lacked biological treatment facilities. This resulted in the discharge being determined by what entered the plant along with the wood and chemicals, and to some extent on nitrogen fixation in aerated lagoons.

The new treatment plants require higher nutrient salt contents in order to maintain the degrading rate and slurry properties. This was reflected in a certain rise in discharge up until the start of the 21st century. Over the last ten years, great efforts have been made to correctly set the dosage of nutrient salts.

The desire to reduce COD discharge has meant, at least periodically, that it has been necessary to purchase and discharge higher levels of nutrient salts, but the trend has now been broken. The new systems have also meant an increase in the use of electricity in order to remove as much COD as possible. On average, a decrease of 1 kg of COD in the aeration requires around 1 kWh, with the energy required being even greater for the final kilograms.

In the questionnaire, respondents were asked to state concrete measures they had taken to reduce water use and the amount of pollutants in discharged water. Most seem to have interpreted the question as applying to the last few years. As most major measures as described above were taken earlier, most of the work being done now is fine-tuning, and many have neglected to mention this work. Examples mentioned are recovering process water, using more completely closed white water systems, introducing dry barking, and making the transition from low to medium concentration technology.

There is not enough data for discharge from sawmills.

### 4.3.2 Level of water exploitation

The water withdrawal of the mills is regulated through decisions or permits under the Swedish Environmental Code (decisions under the Swedish Water Act apply under the same Code).

For the mills where water is taken from sources with limited water flow, water withdrawal is regulated by decisions. Through these decisions, outtake is limited to what is considered environmentally acceptable.

In terms of environmental impact in Sweden, however, the amount of water that mills take from lakes and watercourses has never been cited as a problem, because Sweden has no shortage of water.

For this report, the level of water exploitation was still to be calculated for a few mills where it was expected to be high. Ten mills were studied in total, of which several had a normal water supply for comparison purposes. Based on mean water flow in each water catchment, three mills had an exploitation level of over 10%, between 12 and 20%. This can be compared with the assessment by the International Water Management Institute (2006) that if a maximum of 25% of the total water supply in a location is used, there is only a small or non-existent water shortage.

The level of exploitation for a certain mill may, however, vary dramatically with the seasons, with greater water stress in late spring and summer. One example is that of a mill that had an outtake of 4% for the entire year, but took out 18% of the flow in the river in question from May to June. It may also be the case that mills take in water from a larger, more distant water catchment during periods of low water in their regular water catchment.

At a mill with a high level of exploitation, a clear increase in temperature downstream from the mill has been measured, but no effects on aquatic organisms have been observed (Grotell and Karlsson, 2007).

Other mills analysed (seven in total) had water exploitation levels ranging from 0.1 to 3.5%. What effect, if any, there will be on the local watercourse depends on several different parameters, including location, type of soil, season and water flow. For this reason, it is difficult to compare the level of exploitation of different lakes and watercourses and to evaluate the effect of a high level of exploitation without studying the hydrography in the systems in detail. The effect on the watercourse is likely to also depend on where the water is returned to and how much is returned; for many mills, this means the same watercourse and the same amount of water as the volume of water taken in. This probably means that the effect of water being removed from the system is not so great, since the same amount of water of acceptably good quality is returned to the watercourse.

The water exploitation level of Swedish mills is generally low, and the outtake has no significant effect on water catchments.

# 5 Conclusions

**The impact of forestry**
In conclusion, it can be said that forestry conducted to produce wood raw material for the forest industry has in all material respects a positive impact on the quantity of run-off that leaves forest ecosystems, due to the fact that run-off is limited and offset over time when the water passes forest ecosystems. This helps limit the number and scope of floods in Sweden. The water consumption of forest ecosystems does not constitute a problem in a Swedish context because there is rarely a shortage of water.

The impact of forestry on water quality in run-off from the forest is normally limited. The effects of today's forestry include acidification when trees take up nutrients, trees functioning as a filter and capturing air pollutants, and toxic substances stored in the organic layer of the soil potentially being released to watercourses and lakes during felling and windthrow. How these effects should be assessed depends to a large extent on what they are compared with.

An overall conclusion, however, is that the impact of current Swedish forestry on run-off from the forest is limited, and that good access to water makes active forestry suitable for Sweden.

**The impact of the forest industry**
The term Water Profile is used here to describe flows and impact. The wider term Water Footprint is used at international level to describe water stress, i.e. water shortage and changes in water quality that limit the possibilities of using the water. In this project, we have been able to confirm that there is generally no shortage of water in Sweden, with a few exceptions during short periods of the year. Such temporary local shortages are not affected by water use by the mills, as they adapt their use to these conditions.

The quality of the outflow of water from the mills meets the requirements set by the environmental authorities in order that the water shall be fit for various purposes, which is why there should be no unacceptable environmental impact.

The Swedish forest industry's (pulp and paper industry and sawmills) intake of raw water for manufacturing processes was 850 $Mm^3$ of water in 2009, of which 840 $Mm^3$ was returned to the water body after treatment. If the water in the raw materials is included, the total intake is around 880 $Mm^3$. Consumption has been estimated at 6–7% of raw water intake with an uncertainty of around 2 percentage points.

Almost all raw water intake went to pulp and paper mills. Their water consumption consists primarily of evaporation during the process, for example from boilers, drying processes, and treating wastewater. A total of around 40–50 $Mm^3$ of water per year, 5–6% of raw water intake, disappears, 90% of which through evaporation. A much smaller amount is bound up in the products and in the waste formed.

The data for calculating water loss from Swedish sawmills has been insufficient, largely because the mills are not required to report all current discharge. Water use in sawmills is, however, less than 1% of that in the pulp and paper industry. Water lost when drying sawn timber, when using boilers and during irrigation is estimated at 10–15 $Mm^3$/year.

Even if the estimates of water loss are uncertain, it is clear that the losses have a negligible effect on the general water balance, in view of the good access to water in Sweden.

Compared to many other countries, forest production and the forest industry in Sweden have a positive influence in this respect.

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