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Implementing Water Footprint at Volvo Car Corporation

Master of Science Thesis

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Abstract

This thesis concerns the implementation of Water Footprinting as a part of the strategic environmental work at Volvo Car Corporation. The aim of the thesis is to determine if and how Volvo Car Corporation should use Water Footprint to calculate and present its environmental impact on global water resources, and to create an accounting tool that can be used to calculate operational blue and grey water footprints. Volvo Car Corporation is a multinational corporation with headquarters in Gothenburg, Sweden, with manufacturing sites in Sweden and Belgium. A Microsoft Office Excel Water Footprint Accounting Tool that can be used for calculating the operational blue and grey water footprint of any production site has been created. The tool is customizable and can be used for sites in any region with any conditions if necessary data is entered. Region specific data has already been included for Sweden and Belgium, where the Volvo Cars Manufaturing sites are located. An inventory of these sites has also been performed to evaluate how well they are equipped to implement Water Footprinting at present, and what needs to be done before a complete operational water footprint can be determined. A number of possible applications for how to use the results from the Water Footprint Accounting Tool have been formulated. Finally, an evaluation of the grey and blue parts of the Water Footprint methodology using a sustainability indicator reviewing framework has been performed. One of the conclusions of the thesis is that the Water Footprint indicators are good in the sense that they convey important information about the impact on water resources. However, standardization is necessary in order to use Water Footprinting to its full potential. Also, data collection for the Grey Water Footprint has proven to be very difficult. Volvo Car Corporation are recommended to use the tool developed during this thesis to calculate its blue and its grey operational water footprint at a site level. The inventory show that this can be achieved using mostly already installed equipment. The results can be used to present the company's impact on water resources, and to formulate environmental goals for the company.

Sammanfattning

Detta examensarbete avhandlar implementering av Water Footprint som en del av det strategiska miljöarbetet på Volvo Car Corporation. Syftena med uppsatsen är att avgöra om och hur Volvo Car Corporation bör använda Water Fooprint för att beräkna och presentera sin påverkan på globala vattenresurser, och att skapa ett beräkningsverktyg som kan användas för att beräkna företagets direkta blå och grå fotavtryck. Volvo Car Corporation är ett multinationellt företag med huvudkontor i Göteborg, Sverige, som har tillverkningsanläggningar på olika orter i Sverige och Belgien. Ett Microsoft Office Excel-verktyg för beräkning av blå och grå direkta fotavtryck för industrianläggningar har tagits fram. Verktyget är anpassningsbart och kan användas för anläggningar i vilken region som helst om nödvändig data finns tillgänglig. Regionspecifik data för Sverige och Belgien, där Volvo Car Corporation har sina tillverkningsanläggningar, har redan lagts till verktyget. En inventering av dessa anläggningar har också utförts för att utvärdera hur väl anläggningarna i nuläget är utrustade för en implementering av Water Footprint och vad som behöver göras innan en fullständig implementering kan utföras. Ett antal möjliga tillämpningar för Water Footprint har identifierats för resultaten som kan erhållas med hjälp av verktyget. Slutligen har en utvärdering av det blå och grå delarna av Water Footprint-metodiken utförts. En av slutsatserna är att Water Footprint-indikatorerna är bra på så sätt att de påvisar de effekter som vattenanvändning har på miljön. Dock behövs standardisering om Water Footprint ska kunna användas till sin fulla potential. Dessutom har datainsamlingen till det grå fotavtrycket visat sig vara mycket svår. Volvo Car Corporation rekommenderas att använda verktyget som har utvecklats under examensarbetet för att beräkna sitt blå och grå fotavtryck på anläggningsnivå. Inventeringen visar att detta till stor del kan utföras med redan installerad utrustning. Resultaten kan användas för att presentera företagets påverkan på vattenresurser och för att formulera mål för företaget.

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Contents

1 Introduction

1.1 The Global Water Issue

Water is a prerequisite for all life as we know it. It is a scarce resource essential for nearly all human activities which means that sustainable water management is essential for nearly all human activities in the long run. Sadly, as of today, organized water management has yet to be implemented at all in many parts of the world. There are many examples of how uncontrolled exploitation of water resources has lead to large environmental, social and economic problems. Heavily polluted or dried out lakes and streams and depleted ground water resources are common occurrences impacting drinking water availability, food supply, sanitation, biological diversity, industrial development, and many other important resources.

It is estimated that, globally, nearly 900 million people do not have access to safe drinking water and around 2.6 billion people do not have access to basic sanitation (UN Water, 2010). However, these alarming figures are not simply a consequence of too low water levels in the local wells or streams in water scarce areas. In today's globalized society, water can no longer be viewed as a solely local resource. Many countries are relying heavily on water imports in the form of virtual water, i.e. the imports of products that have been produced using water resources outside the country's borders (Water Footprint Network, 2010). With this in mind, the conclusion that water is a truly global issue is not far fetched. This makes the water issue much more complex since the water policies in a water abundant region can have impacts on water resources in water scarce regions and vice versa.

1.2 The History of Water Footprint

In 2002 a new indicator for water use, based on the supply chain thinking, was introduced; the Water Footprint (Hoekstra 2002). The indicator includes the direct water use of a consumer, a producer or a country as well as indirect water use.

The Water Footprint is divided in three different indicators; Blue, Green and Grey Water Footprint. The Blue Water Footprint is a measure of the consumption of global fresh water resources, i.e. ground and surface water. The Green Water Footprint refers to consumption of rainwater stored in the soil as soil moisture. The Grey Water Footprint is a measure of pollution, expressed in the amount of fresh water needed to assimilate the load of pollution to acceptable concentrations. Each of the footprints are expressed in liters of freshwater and specified to a geographical area and a specific time period. (Hoekstra et al., 2009)

The agricultural sector has the largest water consumption of all sectors. Therefore, the method is at present adapted for agricultural operations to a large extent. However, the intention is that the indicators will be usable for all sectors and some guidelines for how to use Water Footprint in the industrial sector have also been published.

The concept of Water Footprint is not finalized, it is still relatively new and under development. Even in agriculture there are many questions about the methodology that have to be answered before the method is fully consistent. All the same, the concept has already created a growing awareness of the importance of water management as a global issue and at present, the International Organization for Standardization is developing a standard (ISO, 2010). In the future it might become an important tool in the work towards reaching sustainable global water management.

1.3 Volvo Car Corporation's Water Policy

Volvo Car Corporation (VCC) has a long history of working proactively with environmental issues and one of the company's core values is environmental care. To become even better in this field a common environmental strategy for the whole company was developed in the beginning of 2010. Water is included in this strategy since it is a very important resource. According to the environmental policy of the company, resource efficiency and energy are very important areas.

The Water Footprint is seen as an upcoming area of concern due to lack of fresh water in the world. Therefore it is included in the strategy for water to implement a Water Footprint approach on an appropriate level at all Volvo Cars Manufacturing (VCM) plants. These plants are expected to stand for the vast majority of water consumption and water emissions within the company and therefore, the water footprints of these sites can be said to represent the operational or direct water footprint of the whole company. Implementing this operational water footprint is expected to be a complex challenge since VCC is such a large and diverse company. Because of this, the choice was made by VCC to initially only include the operational water footprint and not the entire supply chain in the Water Footprint analysis. Also, the operational water footprint is the part of the total water footprint that a company has the largest possibilities to influence directly.

In the VCC environmental strategy, a goal is formulated regarding water to become a *"leader in water conservation and water emission performance"*. The implementation of Water Footprint is seen as a step in this direction since it is expected to create an even larger knowledge of the company's water consumption and emissions from a sustainability point of view. This will make it easier to formulate reasonable goals related to water and in the long term develop and implement a global corporate water protection standard at all VCC manufacturing units. In addition, VCC sees an opportunity to become pioneers within the automotive industry by being the first to implement Water Footprint. Hence, this thesis was commissioned aiming to create a tool for calculating the operational water footprint of Volvo Car Corporation and to give advice on how to include Water Footprinting in the environmental goal formulations of the company.

1.4 Aim

The aim of this thesis is to determine if and how Volvo Car Corporation should use Water Footprint as a tool to calculate and present its environmental impact on global water resources. Knowing in detail the pressure by the company on global water resources is essential for proactive and efficient efforts to minimize environmental degradation, business related risks and social inequities caused by scarcity of water.

1.5 Objectives

Four objectives have been formulated to satisfy the aim presented above. The objectives are the following.

1. To design and create a tool that can be used by Volvo Car Corporation to calculate its operational blue and grey water footprint.
2. To make an inventory of existing measurement points suitable for calculating the blue and grey water footprint of the existing Volvo Cars Manufacturing sites and determine what measurement points that should ideally be implemented.
3. To identify applications for the calculated operational blue and grey water footprints.
4. To evaluate the Water Footprint methodology.

1.6 Limitations

The tool developed for this thesis will only include the operational water footprint of VCC manufacturing plants. Even though VCC has many different sites around the world this footprint is regarded to represent the whole operational water footprint of the company. This limitation is reasonable since the VCM-plants stands for the majority of water consumption and emissions to water within the company.

The tool will not include the water footprint of the supply chain or the consumer phase which leads to a limited life cycle view. Implementing the water footprint of VCC's own operations is considered a complex task since VCC is a large company. Therefore the choice was made to exclude the rest of the supply chain to have a reasonable scope. It should be noted, however, that until the supply chain and the consumer phase is included the calculated water footprint is only operational and does not represent the company's total water footprint.

Since the report handles industrial operations the green part of Water Footprint will not be included in the analysis since rain water is not used in industrial processes.

The thesis will focus on the water footprint of VCC at a corporate level. This means that the result will not necessarily be directly usable to determine the water footprint of a specific car or car model without some alterations to the methodology. However, more or less rough estimates can be achieved through some kind of weighting, for example by comparing the value of the car with the company's volume of sales.

2 Theoretical Background

This section is an overview of what is currently the state of the art methodology when calculating and assessing a water footprint. Even though Water Footprint as a tool is rather new, a comprehensive set of literature has been published by the Water Footprint Network based in the Netherlands. The Water Footprint manual (Hoekstra et al., 2009) describing how to perform a Water Footprint assessent was first published in 2009 and will be revised continuously. This section is based on the manual to a large extent. The ISO standard for Water Footprint mentioned in section 1.2 is currently under development and is therefore not used as a source of information.

2.1 The Four Phases

A Water Footprint assessment consists of four distinct phases; setting goal and scope, Water Footprint accounting, Water Footprint sustainability assessment and Water Footprint response formulation. In order for a full study to be carried out, each of these phases need to be included in the analysis. However, different stages in water management call for different analyses. Depending on the context in which the study is carried out, the main focus will be on different phases and some may even be excluded entirely. This section will give an overview of the four phases.

2.1.1 Setting Goal and Scope

As in all types of studies, the goal and scope of a Water Footprint assessment is what determines what will be the outcome once the study is finished. The goal and scope determines very important issues such as what will be the object or objects under study, what methodological choices will be made, what level of detail will be required from the data used, etcetera. Therefore, setting a clear and realistic goal and scope is essential for a good Water Footprint assessment to be carried out.

The goal of a Water Footprint assessment is a statement that defines the purpose of the study. It presents and answers a number of questions regarding the scope. Since the Water Footprint concept is rather new, it is useful to borrow formulations from other, more developed, tools and apply them on the framework. Life Cycle Assessment (LCA) is a methodology closely related to Water Footprinting that has been extensively used during the past decades. The ISO standard for LCA states that the goal definition *"shall unambiguously state the intended application, the reason for carrying out the study and the intended audience"* (ISO 14041 1998). The intended application of the study and the reason for carrying out the study, i.e. what the results are going to be used for, determines the scope of the study to a large extent. For example, a study aiming at hotspot identification demands much more detailed knowledge about individual processes than a study aiming at calculating the total water footprint of business units for comparison between the units. The intended audience of the study can also have some impact on the scope. Who will read the study in the end determines for example what level of aggregation should be used to present the final results.

Once the goal of the Water Footprint assessment is decided, the scope can be delineated. In essence, the scope determines the boundaries of the study, i.e. what shall be included and what shall be excluded. Hoekstra et al. have made a useful checklist containing choices to consider when developing the scope:

- Consider blue, green and/or grey water footprint?
- Where to truncate the analysis when going back along the supply chain?
- Which level of spatiotemporal explication?
- Which period of data?
- For consumers and businesses: consider direct and/or indirect water footprint?
- For nations: consider water footprint within the nation and/or water footprint of national consumption; consider internal and/or external water footprint of national consumption?

The answer to each of these questions should be chosen to correspond to the goal of the Water Footprint assessment. Thereby, an analysis can be made that satisfies the intended application as stated in the goal. However, as the work progresses and as new findings are discovered, the scope might have to be changed to better represent the real situation. Setting a scope is an iterative process.

2.1.2 Water Footprint Accounting

In the Water Footprint accounting phase, the water footprint of the object or objects under study is calculated as stated in the goal and scope definition. In order to do this, relevant and reliable data has to be collected when possible, and estimates have to be made when no data is available. This might very well prove to be the most time consuming activity during the entire Water Footprint assessment. Once the data is collected, the footprints can be calculated. It is important to stress that the colour components of a water footprint; i.e. the blue, green and grey components; are calculated separately from each other and cannot be added together to form one indicator. The reason for this is that the components are so different by definition that a joined index would carry no meaning. The processes of calculating the blue, green and grey components of the water footprint are explained in detail in section 2.2 of this report.

In the most simple case where a producer produces one product from a number of inputs, the accounting is rather straight forward. The respective water footprints of inputs are simply added together to form the water footprint of the final product. However, this is seldom the case in real life examples. Most companies and even most production sites produce more than one product at any given time from a number of inputs. In cases where an input product or material is used in the production of several output products, allocation of the input's water footprint on the different outputs must be made if the goal of the study is to determine the water footprint of a product. This allocation can be made based on various criteria such as weight, volume or economical value. In LCA, the most common practice is allocation based on economical value (Baumann et al., 2009). It should be noted, however, that there is no strong connection between the price of a product and the product's water footprint. This means that other factors such as weight or amount should be considered when allocation must be done. Also notable is that allocation invariably yields an uncertain result, as can be seen in the Water Footprint literature (Ercin et al., 2009).

In Water Footprint accounting, a production site or business unit can either be viewed as the sum of all processes within the site or business unit or as a black box. If the calculations are correct, the result will be the same. In the case where the processes within the object under study are known and accounted for, each process can be attributed to specific products and therefore allocation can be kept at a minimum. This will yield a more accurate result when calculating the water footprint of a product since allocation is a crude tool, especially regarding water. The high level of detail can also be useful when calculating the water footprint of a production site or business unit since it can be used to identify the processes in which the water footprint is most critical. In the black box case, only inputs and outputs are accounted for and therefore, if there are several outputs the inputs must be allocated among the outputs for a product water footprint to be calculated. Since many modern production sites are very complex systems, the black box approach is often the most realistic choice in order for the analysis to be carried out without requiring to much time and resources.

Also water use not directly related to any specific product or service must be allocated in product water footprinting. Examples of such water use in offices or production sites are drinking water, water used for kitchen appliances, toilet water, etcetera. This is commonly referred to as overhead water footprint and can be calculated in the same way as raw materials or other input into the production lines through allocation.

2.1.3 Water Footprint Sustainability Assessment

The concept sustainability has three different sides; environmental, social and economic. For an activity to be considered sustainable, it must fulfil the requirements associated with each side. In many cases, conflicts arise when for example economic interests are held back by environmental consideration. Water, being a prerequisite for all three sides of sustainability, gives rise to many such conflicts.

From a social perspective, the sustainability analysis is closely related to fairness. For example; is the amount of water that is consumed by one actor acceptable or are there others who have nothing to drink because of it? Or; is the pollution downstream in a river caused by an industry upstream acceptable? There are no standard questions; the social consequences have to be evaluated case by case.

The economic consequences of a water footprint is related to water use efficiency. On a local level, the question is whether the same good could be produced with less water consumption and pollution, but with the same benefits gained. This is once again something that needs to be decided case by case. On a higher level, the question is whether a good should be produced at a certain location at all or if it would be more beneficial to produce the good elsewhere. However, this is a question for the authorities rather than for a single company like VCC and it will therefore not be discussed further in this thesis.

The procedure of evaluating the environmental impacts from a sustainable perspective is possible to make more standardized than the social and economic impacts. Therefore a section of this thesis will be dedicated to the suggestions of how to make the environmental perspective of the analysis presented in the Water Footprint literature, see section 2.3.

2.1.4 Water Footprint Response Formulation

A Water Footprint response formulation is in essence a question of how much, where and when to reduce the water footprint. A general rule of thumb is that efforts should be concentrated on the least sustainable hotspots. However, this is not to say that water abundant regions or areas where the water footprint is relatively small should be neglected completely.

2.2 Calculating the Water Footprint

When all data of interest has been collected in the Water Footprint accounting phase, the water footprint of the object under study can be calculated. In this section the blue, green and grey water footprints will be described in detail. It is very important to note that they are three different indicators; they should always be presented separately and not added together.

2.2.1 Blue Water Footprint

The Blue Water Footprint describes the consumptive use of blue water, a common name for fresh surface water and groundwater. Until recently when studying fresh water use it has been common practice to study water withdrawals. However, this kind of statistics is flawed when studying water use from a sustainability perspective. Fresh water needs to be regarded as an issue of resources and when looking at water use it is the amount of water consumed that is of interest. Figures of water withdrawal only tell how much water that has been used regardless of whether it has been returned to its origins or lost. This is what distinguishes the Blue Water Footprint from figures of water withdrawals; the Blue Water Footprint looks at the actual water consumption (Hoekstra et al., 2009). It should be highlighted that "water consumption" does not mean that the water actually disappears. Most water on Earth stay in the cycle and returns somewhere else when lost from an area. Consumption related to water is instead a question of availability; if the water ends up elsewhere, it is possible to withdraw water from an area faster than it is recharged. In other words there are always limits to how much water that is available for use within an area in a certain time period. Therefore the term "water consumption" can be justified if the catchment area is defined both in space and time.

According to Hoekstra et al., water consumption can be divided in four different cases (Hoekstra et al., 2009):

- Water evaporates.
- Water is incorporated into the product.
- Water does not return to the same catchment area, e.g. it is returned to another catchment area or the sea.
- Water does not return in the same period, e.g. it is withdrawn in a scarce period and returned in a wet period.

The blue water footprint can be calculated by adding together these different types of consumption (Hoekstra et al., 2009):

$$\begin{aligned} WF_{Blue} &= BlueWaterEvaporation + BlueWaterIncorporation \\ &\quad +LostReturnFlow \end{aligned} \tag{1}$$

where the unit of the footprint is volume of water per unit of time.

Complete standards of how to define catchment areas and return flows do not exist yet. Often, the definition has to be made case by case. One example where no standard exists is when water is taken from a river. It then has to be decided if the water that is returned downstream should be viewed as a lost return flow or not since it is returned to the river but no longer available at the point where it was extracted (Chapagain et al., 2010).

2.2.2 Green Water Footprint

Green water is the precipitation that is stored in soil, or temporarily stays on top of the soil or vegetation. Eventually it will evaporate or transpire through plants. The part of the precipitation that recharges the groundwater or runs off does not count as green water (Hoekstra et al., 2009).

The Green Water Footprint is a measure of human use of green water. It can be either through evaporation from fields and plantations or through incorporation in products. Thus, the green water footprint is equal to (Hoekstra et al., 2009):

$$WF_{Green} = GreenWaterEvaporation + GreenWaterIncorporation \tag{2}$$

where the unit is the same as in the case of blue water; volume per unit of time.

Consumption of green water mainly occurs within agriculture and forestry; other kinds of businesses often have a very small or non-existing green water footprint. If they do have a green water footprint it is generally due to use of agricultural or forestry products as inputs into the processes.

It is very important to distinguish between blue and green water use. The social, environmental and economic impacts largely differ depending on whether blue or green water is used. A large green water footprint can in many cases be regarded as positive, since rainwater is used instead of the Earth's resources of fresh surface water or groundwater.

2.2.3 Grey Water Footprint

The Grey Water Footprint is an indicator that shows the degree of freshwater pollution. It is defined as "the volume of fresh water that is required to assimilate the load of pollutants based on existing ambient water quality standards" (Hoekstra et al., 2009). In other words; the Grey Water Footprint is a measure of the volume of water that would be required to dilute the pollutants to reach acceptable concentrations in the receiving water body. However, it should be noted that this is only a way of defining how toxic the pollutants are. It does not mean that pollutants should be diluted instead of reduced (Hoekstra et al., 2009).

The grey water footprint is calculated as:

$$WF_{Grey} = \frac{L}{c_{max} - c_{nat}} \tag{3}$$

where L describes the amount of pollutants that are released in the receiving water body, defined as the pollutant load measured in mass per time unit. When evaluating the impacts of freshwater polluting activities it is not only the amount of pollutants that matters, it also depends on the water body that the pollutants are released into. c_{max} and c_{nat} are both related to the quality of the water that is receiving the pollutants.

c_{max} is the maximum acceptable concentration of a pollutant in the receiving water body, measured in mass per volume. These water quality standards are defined by policy and they are different for different substances and water bodies. There are regions where this kind of standards are completely missing or only exist for some substances, causing problems in implementing Grey Water Footprint.

c_{nat} is the natural concentration of a pollutant in a receiving body, also measured in mass per volume. This concentration shows the concentration of the pollutant that the water body would have had if there were no human activities emitting the pollutant to the water. If a pollutant is a human made substance that does not occur naturally, c_{nat} will be zero (Hoekstra et al., 2009).

The difference between c_{max} and c_{nat} is a measure of the assimilation capacity of a receiving water body (Hoekstra et al., 2009). If the assimilation capacity of a pollutant is small it will give a large grey water footprint, since just a small amount of the pollutant may be enough to reach the maximum acceptable concentration. If the assimilation capacity is large the same amount of pollutant would be less severe since it would consume a smaller part of the available assimilation capacity.

The reason that the natural concentration is used as reference for the assimilation capacity is that the Grey Water Footprint is an indicator depending on approved assimilation capacity (Hoekstra et al., 2009). By looking at the difference between approved maximum acceptable concentration of the water body and its natural concentration, a measure of how much it is acceptable to toxify the water body according to policies can be obtained. This gives a constant number that can serve as a reference for each water body.

In many cases it is not a single pollutant that is emitted; instead the waste flow contains several different pollutants. When this occurs the grey water footprint is generally determined by the pollutant that is most critical. This means that the grey water footprint of a pollution flow containing several pollutants will be determined solely by the pollutant yielding the largest grey water footprint (Hoekstra et al., 2009). This makes sense when studying an amount of water toxified by a number of different pollutants. If enough fresh water is added to dilute the most critical pollutant to an acceptable concentration all the other pollutants will reach their acceptable concentration as well since they require less fresh water to do so.

The grey water footprint based on a critical substance serves its function if the intention is to look at the overall toxicity of an emission. However, in many cases a more detailed grey water footprint will be required. For example; a company may not be able to reduce the emissions of their most critical pollutant, but maybe it would be possible to reduce the emission of other pollutants. In such cases it is better to give a grey water footprint for each pollutant, so called pollutant-specific grey water footprint (Hoekstra et al., 2009).

Equation 3 describes the grey water footprint of a pollutant that is undiluted when it is emitted to the water body. This is often not the case; instead the pollutant is often a part of effluent, water mixed with waste matter. In such case it is possible to calculate the amount of pollutant by measuring the concentration of the pollutant in the effluent, c_{effl}, and multiply it with the effluent volume, $Effl$. However, this is not necessarily the pollutant load. If the water that was abstracted for the operations was already polluted, the original amount of pollutants must be substracted from the amount of pollution in the effluent. This amount is calculated by multiplying the volume of abstracted water, $Abstr$, with the actual concentration of the intake water, c_{act}. The equation for grey water footprint when there is an effluent then becomes (Hoekstra, 2010):

$$WF_{Grey} = \frac{L}{c_{max} - c_{nat}} = \frac{Effl \times c_{effl} - Abst \times c_{act}}{c_{max} - c_{nat}} \tag{4}$$

Sometimes when waste water is disposed it can have a higher temperature than the receiving water. This may cause environmental impacts since the ecosystem in the receiving water body could change. One example is when seawater is used as coolant in nuclear power plants, in those cases it has been noted that the ecosystem has changed in the surrounding waters (Ehlin, 2009). Therefore, a grey water footprint for thermal pollution has been formulated and is calculated as (Hoekstra et al., 2009):

$$WF_{GreyThermal} = \frac{Effl \times (T_{effl} - T_{nat})}{T_{max} - T_{nat}} \tag{5}$$

where T_{effl}, T_{max} and T_{nat} describes the temperature of the effluent, the maximum acceptable temperature of the receiving water and the natural temperature of the receiving water, respectively. The difference between the maximum acceptable and the natural temperature gives the acceptable temperature increase of the receiving water. This may be different for different types of water. If there are local guidelines for the maximum temperature increase it should be used, otherwise the Water Footprint Network recommends a default value of 3°C, according to the European Directive on the quality of fresh waters needing protection or improvement in order to support fish life (EU, 2006).

In the case of industrial waste flows the effluent is often treated before it is disposed. In such cases the grey water footprint should be calculated after the treatment since the footprint is a measure related to the impact on the environment. Sometimes the waste water can be treated to such extent that the amount of pollutants in the effluent is equal or smaller than the amount of pollutants in the intake water. Then the grey water footprint is zero (Hoekstra et al., 2009). If this occurs it is advised to instead consider the water use for the treatment process and account for it as blue water footprint (Hoekstra et al., 2008a).

How severe the magnitude of a grey water footprint is has, to some extent, to do with the volume of the water flow of the receiving water body. Imagine two water bodies with water flows of different volumes, but with the same maximum acceptable and natural concentration. If the same amount of pollutants is added to the water bodies, the one with the smallest flow will have the largest reduction in water quality since there is less water to dilute the pollutant. If the grey water footprint is smaller than the existing run-off of the receiving water body there is still enough water to dilute the pollutants to a concentration that meets the standards. The critical load of the pollutant is reached when the volume of the flow is just enough to dilute the pollutants to exactly the maximum acceptable concentration in the water body. If the flow is smaller than the grey water footprint the assimilation capacity will not be enough to dilute the pollutants and the concentration will be higher than the maximum acceptable. The fact that the footprint can exceed the available volume shows that the grey water footprint is not a measure of polluted water volume, but an indicator of the severity of water pollution (Hoekstra et al., 2009).

2.3 The Environmental Perspective of the Sustainability Analysis

Whether the size of a footprint is to be considered as significant or not becomes clear when looking at the local situation in the area were the water consumption or pollution occurred. One way of making it easier to compare the effects of water footprints that have occurred in different locations is to calculate a weighted Water Footprint. This can be done by calculating a Water Footprint Impact Index, $WFII$, which has been defined for the Blue, Green and Grey Water Footprint. The basic idea is to multiply the calculated water footprint, WF, with a scarcity factor, WS, see equation **??**. The scarcity factor expresses how large part of the available resource, fresh water, rain water or assimilation capacity, that is consumed in the area were the footprint has been created. Both the water footprint and the scarcity factor is calculated for a certain area, x, during a certain time period, t.

$$WFII[x,t] = WF[x,t] \times WS[x,t] \tag{6}$$

The $WFII$ will indicate the significance of the water footprint in the area were the footprint has occurred. For example, a very large footprint in an area where only a small percentage of the available resource is used will be significantly reduced when weighted. On the other hand, a small water footprint in an area where almost all available water is already used can have about the same size when weighted. Therefore the impact factor makes it possible to compare footprints from different areas to see in which area the water consumption or pollution is most critical.

There are different variations of equation 6 depending on which kind of footprint that is to be weighted. The calculation of the actual footprints follows the equations that have been presented previously, while the scarcity factor is different depending on whether blue, green or grey water is studied. The *Blue*, *Green* and *Grey Impact Index* will therefore be presented separately.

2.3.1 The Blue Water Footprint Impact Index

The water scarcity factor regarding fresh water resources should describe how large percentage of the available fresh water in a catchment area that is consumed during the studied time period. This includes the water consumption of all actors that withdraw water from the catchment area. The water scarcity factor can be calculated by dividing this consumption with the available water in the catchment area. There are two different ways two calculate this factor.

In the Water Footprint Manual a scarcity factor is introduced where the amount of water consumed in an area is the blue water footprint of the whole catchment area, $WF_{Totalblue}$. The available water, WA_{Blue}, in the area is expressed as the total run-off from the area, WR_{Total} minus the flow needed for the environment, $WR_{Environment}$. The scarcity factor becomes (Hoektra et al., 2009):

$$WS_{blue}[x,t] = \frac{WF_{Totalblue}[x,t]}{WA_{blue}[x,t]} = \frac{WF_{Totalblue}[x,t]}{WR_{Total}[x,t] - WR_{Environment}[x,t]} \tag{7}$$

Where x is the catchment area for which the water scarcity is calculated and t is the time period that it is calculated for, monthly measurements are recommended.

The scarcity factor recommended in the Water Footprint Manual is derived from a more common, but simpler scarcity factor named the water withdrawal-to-availability ratio. This factor is calculated by dividing the annual water withdrawal, WD_{Total} from the catchment area with the annual run-off , WR_{Total} from the area.

$$WS[x] = \frac{WD_{Total}[x]}{WR_{Total}[x]} \tag{8}$$

There are three major differences between the two scarcity factors; the factor recommended in the manual looks at water consumption instead of water withdrawal, it takes the required flow for the environment into account and it is possible to calculate for shorter time periods than a year to be able to see seasonal variations. These three differences make the scarcity factor introduced in the manual more scientifically accurate. However, it requires very extensive data collection. For smaller studies the authors of this thesis recognize the withdrawal-to-availability ratio to be a better choice since it requires much less data.

The Blue Water Footprint Impact Index is calculated by multiplying the blue water footprint of the studied actor, WF_{Blue}, with the scarcity factor, WS_{Blue}, of the catchment area. If the withdrawal-to-availability ratio is used as scarcity factor, the Blue Water Footprint Impact Index, $WFII_{Blue}$, becomes:

$$WFII_{blue}[x,t] = WF_{blue}[x,t] \times WS_{blue}[x,t] = WF_{blue}[x,t] \times \frac{WD_{Total}[x]}{WR_{Total}[x]} \tag{9}$$

2.3.2 The Green Water Footprint Impact Index

The first step to calculate the availability of rain water in a catchment area, WA_{Green}, is to look at the total evapotranspiration, ET_{Total} in the catchment area. Evapotranspiration is the sum of the evaporation and plant transpiration from an area. The evaporation is the movement of water from the soil and water bodies to the air and plant transpiration is the movement of water to the air via plants.

A certain part of the total evapotranspiration can be used in for example farming. To calculate the availability of green water, the evaporation reserved for natural vegetation, ET_{Env} has to be withdrawn from the total evapotranspiration. The part of the evapotranspiration that cannot become productive, ET_{Unprod} has to be withdrawn as well. The equation for the availability of green water becomes:

$$WA_{Green} = ET_{Total}[x,t] - ET_{Env}[x,t] - ET_{Unprod}[x,t] \tag{10}$$

The green scarcity factor, WS_{Green}, can then be calculated by dividing the total green water footprint of all actors in the catchment area, $WF_{TotalGreen}$, with the availability of green water, WA_{Green}. The *Green Water Footprint Impact Index*, $WFII_{Green}$, is then obtained by multiplying the scarcity factor, with the green water footprint of the studied actor:

$$WFII_{Green}[x,t] = WF_{Green} \times WS_{Green} = WF_{Green} \times \frac{WF_{Totalgreen}[x,t]}{ET_{Total}[x,t] - ET_{Env}[x,t] - ET_{Unprod}[x,t]} \tag{11}$$

2.3.3 The Grey Water Footprint Impact Index

The grey water scarcity factor differs from the two other scarcities since it does not depend on availability of water. Instead, it depends on how much of the assimilation capacity of the receiving water body that is available. This can be calculated by dividing the grey water footprint of the receiving water body in a catchment area, $WF_{Totalgrey}$, with the total runoff R from that catchment area (Hoekstra et al., 2009):

$$WS_{grey}[x,t] = \frac{WF_{Totalgrey}[x,t]}{R[x,t]} \tag{12}$$

When calculating the total grey water footprint of a receiving water body the load is the total mass of the studied pollutant in the receiving water body. It can be calculated by looking at the actual concentration, c_{act}, of the pollutant in the water body and multiplying it with the total volume, V_{Total}. The other two factors in the equation, c_{max} and c_{nat}, have the same value as when the grey water footprint of a discharge to the water body is calculated. The total grey water footprint of a catchment area becomes:

$$WF_{Totalgrey} = \frac{c_{act} \times V_{Total}}{c_{max} - c_{nat}} \tag{13}$$

The *Grey Water Footprint Impact Index* is then calculated by multiplying the grey water footprint of the studied object, $WFGrey$, with the scarcity factor, WS_{Grey}:

$$WFII_{Grey}[x,t] = WF_{Grey}[x,t] \times WS_{Grey}[x,t] \tag{14}$$

2.4 Business Water Footprint

When making a business water footprint the methodology differs somewhat from other types of water footprinting. The Water Footprint concept is based on a lifecycle view which means that it is not sufficient to consider only water use within the company to calculate a complete water footprint. Instead, in best practice water accounting, water use both upstream and downstream in the supply chain is included in the case of businesses. When the analysis is carried out by a company, the water footprint of its own operations is usually referred to as operational or direct water footprint, the water footprint of its supply chain is referred to as supply chain or indirect water footprint and the water footprint that arises from consumption of the product or service is referred to as consumer phase or end use water footprint. To obtain the total water footprint indicators, the water footprints along the supply chain are added together. The most important implications of each of the phases within the supply chain will be handled in this section (Gerbens-Leenes, 2008).

2.4.1 Operational Water Footprint

The operational water footprint of a business is the water footprint that arises from a corporations own activities. This is the part of the water footprint that businesses tend to have most control over and is therefore a good place to start when making the analysis. However, in most production chains, one single actor rarely accounts for most of the water footprint. Instead, each actor contributes to only a fraction of the total water footprint associated to a product or service. Therefore, the operational water footprint of each actor can be expected to be small in relation to the water footprint of a full supply chain.

2.4.2 Supply Chain Water Footprint

The supply chain water footprint arises from the water footprints of input products, materials and services into a business. Calculating the water footprint of an entire supply chain is an impossible task since modern supply chains are extremely complicated systems. Therefore, making delimitations in the scope of the study regarding where to stop the supply chain water footprint accounting is essential for making a water footprint assessment that is possible to achieve in practice. In order to make a stringent analysis it can be useful to set up criteria for what parts of the supply chain to include. An example of such a criteria is to only include activities that make up for a certain percentage of the total water footprint.

2.4.3 Consumer Phase Water Footprint

The consumer phase water footprint is derived from water consumption related to the use of products or services. This can be for example water used to wash a car or water polluted by soaps during the end use phase of the respective products. It is generally very difficult for businesses to control or even assess the consumer phase water footprint. Since it is impossible in practice to keep track of exactly how much water each consumer consumes due to each product sold, estimates of the average consumer rather than real data must be used. Issues of system boundaries arise aswell. For instance, decisions must be made regarding whether or not to include the water footprint of related products that might not have been consumed were it not for the product under study. As in the case of the supply chain water footprint, the analysis of the consumer phase water footprint can be limited by applying criteria for what activities to include. Due to the complexity of the system and the likelyhood of a relatively small contribution to the total water footprint, consumer phase water footprint is often omitted from the study.

3 Volvo Cars Manufacturing Sites

In this section, the existing Volvo Cars Manufacturing sites are described. A short introduction of the main activites of each site is followed by a description of how the sites' water resources are handled. The information for writing this section was obtained from internal documents at Volvo Car Corporation, environmental reports and interviews with employees.

3.1 Torslanda

The site in Torslanda is the main Volvo Cars Manufacturing plant in Sweden, producing about 163,000 cars per year and employs around 9,000 people. The manufacturing process starts in the press shop where metal sheets are shaped by four press lines. Thereafter the car bodies are assembled in the body shop. When leaving the body shop, the car bodies are complete and ready to be pre-treated and painted. The pre-treatment includes degreasing, phosphating and electrocoating processes. When the car bodies have been painted they enter the last step in the manufacturing where they are fitted with engines, gear boxes, suspension systems and all other remaining parts. The finished cars are then filled with the required fluids and subject to quality tests.

The site obtains water for sanitary and process purposes from the city of Gothenburg which takes its water from Lärjeholmen in the river Göta Älv. The primary types of waste water produced are sanitary waste water, process water from the pre-treatment processes and the paint shop, and vehicle wash water. The sanitary waste water is released directly into the municipal sewer system while the process water is pre-treated in an on-site treatment plant. The municipal waste water is treated in a municipal treatment plant, Ryaverket, which after treatment releases the water into Göta Älv at a point close to the sea, downstream from Lärjeholmen.

The on-site treatment plant has three different treatment lines, line A, B and C. The water from line A is discharged into the recipient via storm water tunnels that ends up in Göta Älv downstream from Lärjeholmen. The other two lines are discharged into the municipal sewer network. The storm water run-off from roofs and hard surfaces is drained directly to the rivers Göta Älv and Nordre Älv via two storm-water channels; Torsvikentunneln and Kålseredsbäcken. Furthermore there is one storm water pond on the site, this water ends up in the creeks Kålseredsbäcken and Låsbybäcken.

3.2 Ghent

The site in Ghent, Belgium, is the only Volvo Cars Manufacturing site outside Sweden. The plant produces around 180,000 cars per year and employs around 3,900 people. The difference in the production processes between the site in Ghent and the site in Torslanda is that no body parts are pressed and manufactured in Ghent but instead delivered from other VCC sites. Apart from that, the sites engage in the same activities.

Fresh water is delivered from the city of Ghent through the municipal water system. All waste water is treated in two on-site treatment plant, one for treating sanitary waste water and one for treating process waste water. The industrial waste water is discharged into the nearby water body Sifferdock, a part of the Albert Channel, and the sanitary waste water is discharged into Langerbrugge Kreek. No waste water is treated in municipal treatment plants. Rain water run-off from roofs and hardened surfaces is collected in a storm water sewage system before being released into nearby surface waters.

3.3 Olofström

The main activity at the Volvo production site in Olofström is to produce manufacturing equipment for car body components, aluminium and steel stampings and to produce body parts for Volvo Cars and Volvo Trucks. About 50 million body components are manufactured in Olofström each year and the site employs about 2,100 people. The materials used in production are delivered to the factory from external sources and are mainly galvanized sheet steel and aluminium.

The site is divided into three factory units; the upper plant, the southern plant and the western plant. Water intake into the site is mainly city water from the Olofström municipality originating from the river Halen, and cooling water collected from the nearby creek Holjeån. The upper plant is equipped with a water treatment facility which treats process water generated by production within the site. After the water is treated it is discharged together with sanitary water from the entire site into the municipal sewer system which leads to a municipal treatment plant that discharges the water into Holjeån after treatment. At the southern plant, water is mainly used for non-contact open circuit cooling in dot-welding processes. The cooling water is discharged into Holjeån, close to where it was first collected. Process water used in the southern and western plants for other purposes than cooling is transported by truck to the upper plant for treatment. Storm water run-off from hard surfaces on the site is drained into oil-water separator dams and then discharged into Holjeån.

3.4 Skövde

The main activities in the production site in Skövde are machining, assembling and testing petrol and diesel engines with four or five cylinders. The engines and engine components are exported to internal and external customers of the company. The site has an annual production of about 470,000 engines and employs around 1,500 people.

Water for sanitary and process use is obtained from the city of Skövde which takes its water from the lake Vättern. Biocides are added to water used for cooling of the machining installations, otherwise there is no pre-treatment. The cooling water is kept in a closed loop, and when the circuits are cleaned the cooling water is discharged to the storm water system. Sanitary waste water, osmosis water and water from compressor blow down after pre-treatment is discharged to the municipal sewer system. The main municipal treatment plant in the city of Skövde is Stadskvarn, where most of the municipal waste water ends up. After treatment it is discharged into the creek Mörkebäcken and eventually runs off into the river Ösan. Process water from cleaning activities and cutting processes is sent by pipeline to a nearby Volvo Power Train site where it is treated in a waste water treatment plant. Rainwater from roofs and hardened surfaces on the site is collected in two rainwater collector basins which are constructed with oil-water separators. After the separation the water is discharged to the creek Svesån which ends up in Ösan.

3.5 Floby

The main activity in the Volvo Cars Manufacturing site in Floby is to produce disc brakes, conrods for cars and hub modules for trucks. The site's permit includes machining of components to the automotive industry to a maximum of 100,000 tonnes of raw materials. The components are manufactured at a number of other VCC sites. The site employs a total number of 448 people.

The sanitary and process water is delivered from the municipality of Falköping which has the lake Vättern as their main source of fresh water. Sanitary waste water is discharged to the municipal sewer network and is treated in the municipal plant in Torrevalla, which discharge the water into the river Lidan via the creek Salaholmsbäcken. The process waste water generated within the site is pre-treated in an oil water separator and then collected by Stena Recycling and transported as hazardous waste. The storm water is directed to two oil separators and then discharged to the storm water system which ends up in the creek Salaholmsbäcken.

4 The Water Footprint Accounting Tool

In this section, the Water Footprint Accounting Tool created for this thesis is presented. The tool had to meet some specifications set in collaboration with the commissioner of the thesis. These specifications are the following.

- Easy to use so that no programming or other special skills are needed from the user.
- Quick to use so that performing the analysis does not require too much time.
- Recource efficient, i.e. that the analysis builds upon existing measurements to the greatest extent possible.
- The tool must incorporate Blue and Grey Water Footprint since these components are estimated to be the most significant.

4.1 Method for the Water Footprint Accounting Tool

The methods for designing and creating the Water Footprint Accounting Tool presented in this thesis were chosen to satisfy the specifications stated above. The tool was developed and programmed in Microsoft Office Excel using Visual Basic since Excel is a very wide spread computer application that most VCC employees are skilled at using.

The tool is divided into two separate workbooks; one for using the tool and one working as a database containing the necessary data and the template worksheets generated when using the tool. For the purpose of application handiness, the user interfaces for both of the workbooks were designed using window forms generating necessary data and worksheets on demand so that users do not have to write any code or handle worksheets themselves. This enables users to conveniently add and remove substances in the database workbook, add template worksheets containing regions specific maximum acceptable and natural concentrations of substances, and add worksheets containing data concerning how much of each substance under study is removed in both on-site and municipal treatment plants. In the workbook designed for using the tool, users can create worksheets for entering data and calculating the water footprint as well as create worksheets containing graphs depicting the result. The procedure of finding data for the maximum acceptable and natural concentrations is described in section 4.1.1 below.

The Water Footprint calculations build on equation 1 for blue and equation 4 for grey water footprint and are embedded in the Excel workbooks, invisible to the users. A top-down approach, i.e. that the site can be viewed as a black box, was chosen for the tool to enable calculating the water footprint of a site without knowing all the processes within the site. As a complement to the top-down approach, the possibility to add process specific data was also added to enable specific processes to be a part of the analysis.

4.1.1 Data Collection of Maximum Acceptable and Natural Concentrations

To be able to calculate the grey water footprint caused by a certain pollutant, the maximum acceptable concentration and the natural concentration of the pollutant in the recipient is needed. To make it possible to calculate the grey water footprint without extensive data collection, a number of pollutants is included in the database from the beginning. However, the number of pollutants in the tool is unlimited and thus, more pollutants can be added at a later time.

A pollutant can be included in the Water Footprint Accounting Tool if a maximum acceptable concentration can be found for the substance. If a natural concentration can be found as well that concentration is inserted in the database, otherwise the natural concentration is set to zero. Since VCC has manufacturing sites in Sweden and Belgium, data for these regions is included in the tool.

Ideally all the pollutants that are included in VCC's environmental reports would be included in the tool. However, for some of the pollutants the existing sources of information do not include a maximum acceptable concentration. Therefore these pollutants have to be excluded. In table 1 all the substances that are included in VCC's environmental reports are listed. This contains all substances that VCC has a permit for and some additional ones. For each substance it is presented whether it is included in the tool and, if so, whether the maximum acceptable and natural concentration is inserted. The actual values of c_{max} and c_{nat} and the source of each value can be found in appendix A.

There are five different sources for the maximum acceptable concentrations presented here; The European Directive for Environmental Quality Standards (EU, 2008), a study performed by the Swedish Chemicals Agency on behalf of the Swedish Environmental Protection Agency (Naturvårdsverket, 2008), a list of maximum concentrations received by VCC from the authorities in Belgium, Canadian Environmental Quality Guidelines (CCME, 2007) and a report about environmental quality criteria for lakes and watercourses (Naturvårdsverket,

Substance	Included	c_{max}	c_{nat}
B	X	X	
Cd	X	X	X
Cr	X	X	X
Cu	X	X	X
Fluoride			
Fe	X	X	
Hg	X	X	X
Mn	X	X	
N	X	X	X
Ni	X	X	X
Oil			
P compounds	X	X	X
Pb	X	X	X
Sulphate			
TOC			
Zn	X	X	X

Table 1: The substances that is included in VCC's environmental reports. For each substance it is presented whether it is included in the tool and if so, whether the maximum and natural concentration has been inserted in the database.

1999). These sources include maximum acceptable concentrations for all water bodies. No data for specific water bodies has been found. In some cases the maximum acceptable concentration depends on the size of the water body. However, all water bodies that VCC discharges pollutants to are considered large.

The European Directive for Environmental Quality Standards (EU, 2008) includes environmental quality standards for 33 prioritized substances. The substances are seen as the most important ones to monitor in the water bodies within Europe and therefore maximum acceptable concentrations for these have been decided. The member states are obligated to take measures to ensure that concentrations stay equal to or below the maximum acceptable concentrations in the water bodies within their countries. These concentrations are therefore used as maximum concentrations in Sweden and Belgium.

The Swedish Chemicals Agency has suggested a number of maximum concentrations for water bodies in Sweden on behalf of the Swedish Environmental Protection Agency (Naturvårdsverket, 2008). A number of different substances that are seen as a problem in different parts of Sweden have been studied and maximum concentrations for each substance have been suggested. These values have not yet been used as official targets, but they are based on the situation in Swedish waters.

The Swedish Environmental Protection Agency suggests at their homepage that Canadian Environmental Quality Guidelines (CCME, 2007) should be used if there are no available Swedish values (Naturvårdsverket, 2010). The Canadian environmental guidelines for protection of aquatic life are formulated to protect the water from anthropogenic impacts that can influence the aquatic life (CCME, 1999). Even though these maximum acceptable concentrations are set for a country in another part of the world with a different environment, it still gives an idea of a reasonable order of magnitude for the concentrations.

VCC has received a list of substances from Belgian authorities which states the maximum allowed concentrations for water bodies in Belgium. The maximum concentrations are the same as in the European Directive for Environmental Quality Standards for the 33 prioritized substances, but a number of other substances are included as well for which Belgium has its own maximum concentrations.

The Swedish Environmental Protection Agency has written a report about environmental quality criteria for lakes and watercourses (Naturvårdsverket, 1999). It contains a scale with five different classifications depending on the concentration for a number of different substances. Classification 1 is a concentration that gives no known negative environmental impacts while classification 5 is a concentration that gives sever impacts. In the Swedish Environmental Protection Agency's homepage it is suggested that the limit between classification 3 and 4 can be used as an acceptable value of pollution, i.e. a maximum acceptable concentration (Naturvårdsverket, 2010).

The database contains two different regions with individual c_{max} and c_{nat}; Sweden and Belgium. It is also possible to add additional regions at a later time. Even though VCC has four different sites in Sweden the same data can be used for all of them since the water hardness is the same in all concerned water bodies. If a new site was built in Sweden which had emissions to a water body with a different hardness a new region would be needed, since some of the maximum concentrations depend on the hardness of the water.

In the database for Sweden the following prioritization order is used if the c_{max} for a pollutant is included in two of the existing sources; The European Directive, the suggested maximum concentrations by the Swedish Chemical Agency, the Canadian Environmental Quality Guidelines, the report about environmental quality criteria by the Swedish Environmental Agency and the list of maximum concentrations that VCC has received from Belgian authorities.

In the database for Belgium the following prioritization order is used for c_{max}; the list if maximum concentrations that VCC has received from Belgian authorities, the Canadian Environmental Quality Guidelines, the suggested maximum concentrations suggested by the Swedish Chemical Agency and the report about environmental quality criteria by the Swedish Environmental Agency.

Measurements taken by the Swedish Environmental Agency are used as natural concentrations for metals in the database for Sweden and Belgium. These measurements have been taken in lakes located in the north of Sweden and the Swedish Environmental Agency uses them as approximations of natural concentrations for metals for the water bodies in Sweden (Naturvårdsverket, 1999).

For P compounds and nitrogen the concentration for classification 1 in the environmental quality criteria formulated by the Swedish Environmental Protection Agency (Naturvårdsverket, 1999) are used as natural concentrations. Since classification 1 is defined as a state where no negative impacts are known, the concentration at that state is here regarded as a natural concentration.

4.2 Results for the Water Footprint Accounting Tool

In this section, the Water Footprint Accounting Tool is presented. First an overview of the functions of the tool is given followed by the methodological choices made during the development of the tool and finally the equations used in the tool are presented.

4.2.1 Description of The Water Footprint Accounting Tool

This section gives an overview of the Water Footprint Accounting Tool developed for Volvo Car Corporation. The tool is divided in two different workbooks; the actual tool where users can insert data for sites and processes and a database where all additional data needed to calculate the water footprints are located.

The main workbook which contains the Water Footprint Accounting Tool consists of only a start page with a number of buttons to begin with. These make it possible to add different sites and processes and to make the tool create different graphs automatically when data has been inserted. When a site or a process is created, two worksheets appear, one where data has to be inserted by the user and one where the footprints are calculated automatically. Templates for these sheets are stored in the database workbook and are taken from there when a site or process is created.

To make it possible to calculate the blue water footprint, the amount of incoming water as well as how much of the water that returns to the original catchment area needs to be inserted for each site and process. For a site, it is also possible to insert data for three different usage areas; the water used in processes, the water used for sanitation and the water used in cooling systems. This gives an overview of the flows within the site.

Inserting different processes makes the mapping of the flows even more detailed. For each process that is created, the site where the process is located has to be given. One of the three usage areas also needs to be identified for the process. A process does not necessarily need to be a production process in the factory it could also be for example a toilet or a cooling tower. Creating different processes makes it possible to map which processes that stand for the majority of water use in each usage area. It also makes it possible to calculate how large part of the flows within a site that are known.

The Water Footprint Accounting Tool creates three different graphs related to Blue Water Footprint. The first one shows the total operational blue water footprint for each inserted site and the total footprint of all the sites. The second graph is created for each inserted site separately. It shows the blue water footprint of each site by area of usage. The third graph shows the blue water footprint in each site by added process and area of usage.

The Water Footprint Accounting Tool takes three different polluted water flows into account for a site; the site's waste water, the site's storm water and the polluted rainwater. The equations are different for the three different flows and they will be described in section 4.2.3. The waste water is the water that is treated in a municipal treatment plant after leaving the site. The storm water is the water from a site or process that ends up in the storm water system i.e. is released directly to the environment after leaving the site. However it could be treated in an on-site treatment plant first. The pollution of rainwater occurs when rain flows on a site's hard surfaces.

For a site it is possible to give the magnitude of each of these three flows and the concentrations of a number of different pollutants in each flow. It is also possible, but not mandatory, to give the concentrations of the pollutants in the inflowing water. The tool will then calculate the grey water footprint for each pollutant in each flow. It will also summarize the grey water footprint in each flow to get the site's total grey water footprint for each studied pollutant. The critical grey water footprint of the site is identified by finding the pollutant with the largest grey water footprint, this will be the critical grey water footprint of the site. For a process it is only possible to give data for the waste water and storm water, otherwise it works in the same way.

The tool creates four different graphs related to the Grey Water Footprint. The first one shows the critical grey water footprint of each added site and the total critical grey water footprint of all added sites. The total grey water footprint is calculated by summarizing the critical grey water footprint of each site, even if they have different critical pollutants. The three other graphs are created for each added site. The second one show the grey water footprint by studied pollutant, the third one shows the critical grey water footprint by added process and the fourth one shows the critical grey water footprint for each type of polluted water; waste water, storm water and rainwater.

The database contains, in addition to the sheets for the sites and processes, all additional data that the tool needs to calculate the grey water footprint after insertion of site or process specific data. When a site is created an available region needs to be chosen. Regions are stored in the database and contain data for the maximum acceptable and natural concentrations for each region. As already mentioned the database currently has two different regions; Sweden and Belgium. It is possible to add more regions in the database and insert data for c_{max} and c_{nat} for these regions.

Some of the equations for the Grey Water Footprint needs data for treatment plants, therefore it is possible to add both municipal and on-site treatment plants to the database. Currently the database contains data for the municipal treatment plant Ryaverken in Gothenburg. This data is used if no other treatment plant is chosen when a site is created. If another municipal treatment plant was added to the database it could be chosen instead. When a process is created is has to be stated whether its water is treated in an on-site treatment plant and if so, which on-site treatment plant.

It is also possible to add new substances in the database and to remove old ones. These will then appear or disappear in all concerned sheets; the regions, the treatment plants and the two sheets for the sites and processes. The user can then insert data for the new substances.

For a detailed description of how to use the tool, see the User's Manual in appendix F.

4.2.2 Methodological Choices

Some issues not sufficiently handled in the literature had to be defined when designing the tool. These methodological definitions will be presented here.

Excluding c_{nat} As mentioned in section 4.1.1 above, c_{nat} is difficult to find for some of the substances included in the database. It is possible to obtain an estimate of the grey water footprint even though c_{nat} is excluded. Since the denominator in the Grey Water Footprint equation, see equation 4, is enlarged this way, a grey water footprint excluding c_{nat} will be a best case estimate with respect to c_{nat}, i.e. the footprint becomes smaller than the true value.

Rivers The consumption of blue water is divided in four different cases; evaporation, incorporation and lost return flow, either because the water does not return to the same catchment area or in the same time period, see section 2.2.1. In most cases, it is an easy task to decide whether water has been consumed according to one of these cases. However, in the case of a river it is not obvious whether water collected at one location and returned at another, downstream, has been consumed or not. Since the water is returned to the same water body the question arises whether the water is returned in the same catchment area or in another. There is no standard on how to define catchment areas in the case of a river. Therefore a definition has been formulated to be used in the tool.

Consumption of water is related to the availability, see section 2.2.1. Water very seldom disappears after use, it merely returns somewhere else in the Earth's water cycle; i.e. the water is no longer available in the catchment area and it can therefore be said to have been consumed. With this in mind it is reasonable to say that water collected in a river has been consumed if someone downstream could have collected it before it is returned. When water is collected, the availability of water for other actors between the point of collection and the point where the water is returned is reduced. Therefore the definition of consumption when the water is collected and returned in the same river is formulated as: *The water is considered to be consumed if it would be possible for another actor to collect water between the point in the river where the water is collected and the point where the water is returned.*

Treatment Plants There is at present no clear standard regarding how to calculate the grey water footprint when an effluent is treated in a treatment plant together with effluent from other sources before being discharged into the recipient or transferred to a sewer system. Therefore, a way to do these calculations was formulated and implemented in the tool. To the Grey Water

Footprint equation, see equation 4, a new term was added yielding the equation below.

$$WF_{Grey} = \frac{Effl \times c_{effl} - Abst \times c_{act}}{c_{max} - c_{nat}} \times TP \tag{15}$$

Where *TP* is the treatment plant factor, a number between zero and one telling how much of a specific pollutant is left in the effluent after the treatment plant. It is calculated as

$$TP = \frac{Output}{Input} \tag{16}$$

where *Output* is the amount of a specific pollutant in the effluent of the treatment plant during a specified time period and *Input* is the amount of the pollutant going into the treatment plant over the same time period. The time period for which these measurements are taken is ideally the same time period that the Water Footprint assessment is being made for.

Grey Water Footprint Due to Rainwater Pollution The most obvious source of water pollution at a manufacturing site is the pollution that occurs in the processes that use water within the site. However, pollution also occurs when rainwater flows on the hard surfaces of the site's area. Tools kept outside, spills of various kinds, and oil dropping from cars are all examples of how different pollutants can end up on the hard surfaces. These pollutants will pollute the rainwater and therefore the grey water footprint of this pollution needs to be calculated. Rainwater is often collected in some sort of collector basin before being discharged into a water body, often a small water stream. Such small streams could be used as the receiving water body for the polluted rainwater, but since it is very hard to find data for small water streams it is better to investigate which major water body the stream ends up in. This larger water body can then be used as the receiving water body, and c_{max} and c_{nat} should regard that body.

When the receiving water body has been decided for the polluted rain water, the load of the pollutants need to be calculated. To do that, the average pollution concentrations in the rainwater, c_{rain}, is needed as well as the total volume of rain water, V_{rain}, that has been flowing on the site's hard surfaces. The average concentration can be calculated if regular measurements of the concentrations of the studied pollutants in rainwater were measured regularly over the year at various locations on the site's surfaces. The volume of the rainwater can be calculated by multiplying the total area of the site, A_{site}, with the annual precipitation, P_{year}. The equation for calculation the grey water footprint due to rainwater pollution then becomes:

$$WF_{grey}^{rain} = \frac{c_{rain} \times V_{rain}}{c_{max} - c_{nat}} = \frac{c_{rain} \times A_{site} \times P_{year}}{c_{max} - c_{nat}} \tag{17}$$

4.2.3 Equations Used in the Water Footprint Accounting Tool

When calculating the blue water footprint of a site, the data entered by the user into The Water Footprint Accounting Tool is the magnitude of the water input into the site and how much of that water the returns to its original catchment area. The equation used for calculating the blue water footprint of a site is the following.

$$WF_{blue} = BlueWaterInput - BlueWaterBackToSource \tag{18}$$

For the grey water footprint, the data entered into The Tool consists of pollution concentrations in outgoing waste, storm and rain water as well as the magnitudes of their respective flows. If the incoming water is not cleaned before use, the pollution concentrations in that water must also be entered. The database workbook included in the tool contains background data needed for calculating the grey water footprint of Volvo Cars Manufacturing sites. This includes the maximum acceptable and natural pollution concentrations in the receiving water bodies and the extent to which municipal and on-site treatment plants in connection to the VCM sites remove pollutants from waste water.

The equations for the three polluted water flows; waste water, storm water and rainwater; accounted for in the tool, differ from each other. The equation for waste water is the following:

$$WF_{Grey} = \frac{Effl \times c_{effl} - Abst \times c_{act}}{c_{max} - c_{nat}} \times TP \tag{19}$$

Where the equation is similar to the regular Grey Water Footprint equation, see equation 4, but with the term TP described in section 4.2.2.

The equation for stormwater is the regular Grey Water Footprint equation.

$$WF_{Grey} = \frac{Effl \times c_{effl} - Abst \times c_{act}}{c_{max} - c_{nat}} \tag{20}$$

The equation for rainwater, described in section 4.2.2, is the following.

$$WF_{grey}^{rain} = \frac{c_{rain} \times V_{rain}}{c_{max} - c_{nat}} = \frac{c_{rain} \times A_{site} \times P_{year}}{c_{max} - c_{nat}} \tag{21}$$

If there are two or more waste water or storm water flows, an average concentration, $c_{MeanEffl}$, must be calculated manually outside the tool and the magnitude of the flows must be added together in order to include all flows in the analysis. This can be done for each pollutant under study as follows.

$$c_{MeanEffl} = \frac{\Sigma_X c_{EfflX}}{\Sigma_X Effl_X} \tag{22}$$

Where c_{EfflX} is the pollution concentration in flow X and $Effl_X$ is flow the volume of flow X.

The data needed for calculating the blue water footprint of a process is the magnitude of the fresh water input and the percentage of the water discharged from the process that is returned to its original catchment area. The equation used is the same as for the site. The reason that the user again must state the amount of water that returns to its origins is that certain processes can differ from the site average in this respect.

For the Grey Water Footprint calculations of a process, the pollution concentrations in the waste water flows from the process and the magnitude of the flows are needed as input data. Process water can either be treated in an on-site treatment plant or a municipal treatment plant, neither, or both. Different equations are used for different scenarios. If the water is not treated at all, the common Grey Water Footprint equation is used, see equation 4. If the water is treated in either an on-site or a municipal treatment plant, the equation used is equation 15, with values for the level of cleaning depending on the treatment plant. Lastly, if the water is treated in both an on-site and a municipal treatment plant, the equation used is the following.

$$WF_{Grey} = \frac{Effl \times c_{effl} - Abst \times c_{act}}{c_{max} - c_{nat}} \times TP_{on-site} \times TP_{municipal} \tag{23}$$

Where $TP_{on-site}$ and $TP_{municipal}$ are the treatment plant factors for the on-site and the municipal treatment plants, respectively, as defined in section 4.2.2.

4.2.4 Examples of Results that the Water Footprint Accounting Tool Generates

In this section the existing measurement points in VCC's manufacturing sites are used to show results that the Water Footprint Accounting Tool can generate with the existing data from 2009. In appendix D the data that is used in this example are presented. The diagrams that the tool generates with these measurements are presented, but only with the intention to give the reader an idea of the diagrams that the tool can create. The meaning of the results is not discussed since it is not within the scope of the thesis. However, even though it is not discussed here, some of the results could be used by the company further on.

VCC's five VCM-sites are added in the tool to be able to insert data for the Blue and Grey Water Footprint. Data for water consumption is taken from an internal document that includes the water consumption of bought water. With this data the tool calculates the blue water footprint and generates the figure 1 which shows the blue water footprint of each site as well as the total blue water footprint of the company which has a value of 541 million litres.

The grey water footprint cannot be calculated for Skövde and Floby, this will be explained further in the inventory of the different sites, see section 5. Therefore data is only inserted for Torslanda, Ghent and Olofström. The data comes from the environmental report of 2009 for each site. For Torslanda and Olofström the measurements included in the environmental report are from 2009 while the latest measurements in Ghent's environmental report are from 2008. In diagram 2, 3 and 4 the grey water footprints of Torslanda, Ghent and Olofström can be seen. The grey water footprint for each pollutant that is measured in the environmental report is included; the one with the highest value is the critical pollutant of the site. In figure 5 the critical grey water footprint of each site is included as well as the total critical grey water footprint when each critical footprint of the three sites is added together. The total critical grey water footprint has a value of 16,918 million litres.

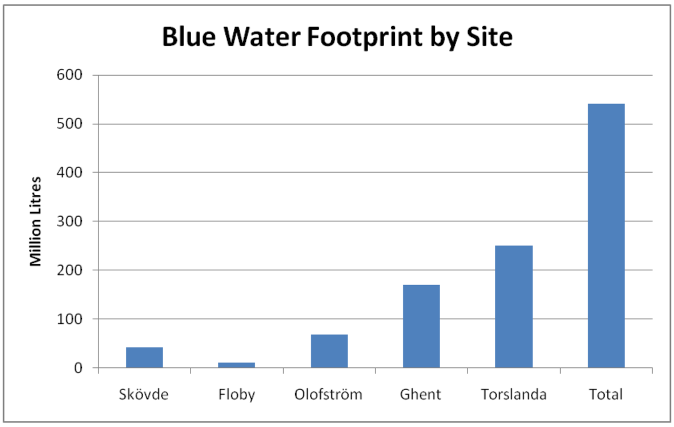

Figure 1: The blue water footprint for each site and the total footprint of all sites.

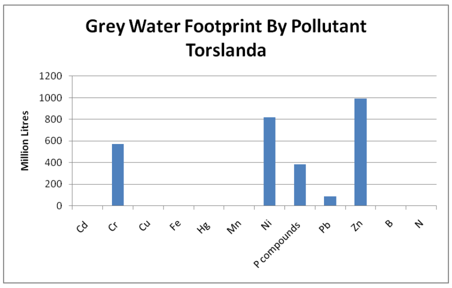

Figure 2: The grey water footprint by pollutant for Torslanda.

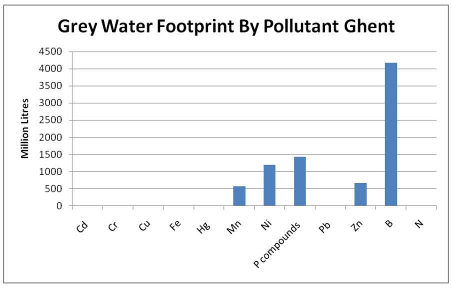

Figure 3: The grey water footprint by pollutant for Ghent.

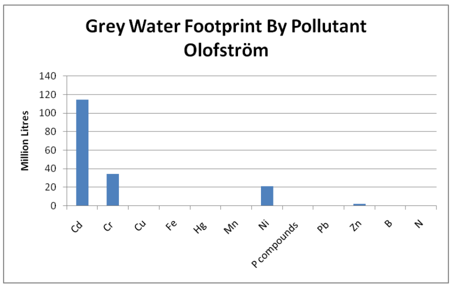

Figure 4: The grey water footprint by pollutant for Olofström.

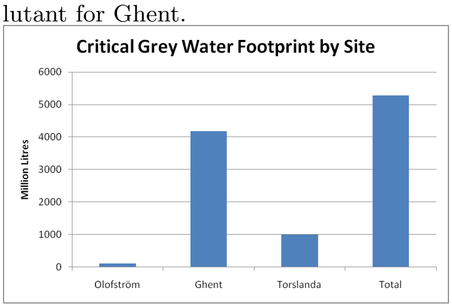

Figure 5: The critical water grey footprint for each site and the total critical grey water footprint

The diagrams that are presented in this example show the total operational water footprint of each site. If a deeper study was made, the blue water footprint for different usage areas and processes could be included as well. The division of the grey water footprint between waste water, storm water and rainwater can also be included in a diagram, as well as the grey water footprint of individual processes. In appendix C an imaginary site is created to show which diagrams that the tool can generate if all the internal flows of a site is included.

4.3 Discussion Regarding the Water Footprint Accounting Tool

Choices made during designing and creating the Water Footprint Accounting Tool as presented in the result section of this thesis is discussed in this section. The tool is powerful in the sense that it is versatile and customizable with little effort from potential users, but there are some inherent limitations. These limitations are also presented and discussed below.

The fact that the tool presented in this thesis is made in Microsoft Excel carries some advantages and some disadvantages. The most important advantages of Excel is that many people possess the basic skills necessary to use it, that the results are presented in a way that gives a good overview, and that all information is handled in a convenient cell format. But there are also limitations. First of all, Excel is not very fast when computing. This is not an important limitation as far as the tool is concerned, but it takes a few seconds for some commands to execute. Excel also has built in limitations on how long text strings in cells can be, how long worksheet names can be, and how large numbers that can be plotted in charts. This means that users must take care when naming worksheets and variables in order to prevent errors, and a suitable unit must be chosen so that the data output does not exceed the limitations of the embedded graphs. These limitations differ between different versions of Excel so what works on one computer might not work on another. Since Volvo Car Corporation uses the Microsoft Office 2003 version of Excel, the tool was programmed to work with this version and newer ones. This means that the tool can be used even if VCC chooses to change to a newer version of Excel but it is possible that errors can occur if older versions are used.

User friendliness and that people without programming skills or knowledge about Water Footprint are able to use the tool are parts of the specifications stated in section 4. This is achieved through the use of macros and window forms that allows users to change both the tool workbook and the accompanying database workbook on demand without handling worksheets or entering code. The Water Footprint equations are also generated automatically which means that the user of the tool does not have to have any deeper understanding of the Water Footprint methodology.

In order to calculate the operational water footprints of industrial sites, a top-down or black box approach is used in the tool. In theory, this only requires two points of measure; one measuring the water flow into the site, and one measuring the water flow out of the site, since the site is viewed as a black box and what happenes inside the black box is not analysed. In practice, at the car manufacturing sites of Volvo Car Corporation, a handful of measurements has to be made. A downside with using a black box approach is that it is difficult to determine the water footprint of a specific product. If this is to be done, some sort of allocation must be made. However, as stated in section 2.1.2, allocation invariably yields an uncertain result which means that the tool presented in this thesis is not optimal for such analyses.

It would also be possible to use a bottom-up approach, i.e. calculate the water footprint of each individual process within each site and add them together. In this way, it is possible to achieve an in-depth analysis that allows for the water footprints of processes to be assigned to the products made within a site with great precision. However, there are also drawbacks with this approach. The most important drawback is that such an analysis can easily become an extremely complex and difficult endeavour, especially in such a diverse industry as the automotive industry. A car consists of thousands of components and the production of each component requires several processes. This makes identifying and assessing all contributing processes very time consuming. It also means that meters to measure flow magnitudes and levels of pollution must be installed in connection to each process to be included. This is not realistic in most cases and not possible in some. Therefore the black box or top down approach is a more realistic choice.

Even though a bottom-up approach is not used for calculating the water footprints of whole sites, the tool presented in this thesis can be used to identify processes that yield large water footprints, so called hotspots. This require a level of detail that cannot be achieved through a top-down or black box approach alone. To enable hotspot idenification and assessment, process specific data can be entered into the tool so that the water footprints of processes can be calculated. The water footprints of various processes within a site can be compared to each other and processes in other sites, as well as the complete operational water footprint of a site as a whole. Through these comparisons, knowledge about what processes consume and pollute most water is gained, and thereby where the largest possibilities for improvements are. In order to include specific processes in the analysis, measurements of magnitude of water flows and water pollution must be implemented before and after each process to be included, and also take into consideration how much water treatment is performed in waste water treatment plants at the site where the process is located. It is important to note that processes entered into the tool do not have to be production processes. For example, it is possible to enter data for sanitary appliancies or cooling systems as well since the basic equations needed are the same.

The data that needs to be entered by the user to obtain a blue water footprint of a site or a process is the amount of water going into the object under study during a specified time period and the amount of this water returning to its origins. This means that it is not possible to obtain a result from the tool where the blue water footprint is divided among the four ways in which water can be consumed; water evaporation, water incorporation and the lost return flows; see section 2.2.1. If this division is of interest to the user, the calculations must be made outside of the tool.

The total critical grey water footprint is calculated in the tool by summarizing the critical grey water footprint of each site included in the anlysis. This means that it will not have the same scientific meaning as a normal grey water footprint since it will include different critical pollutants for different locations. Another way to calculate the grey footprint of the company would have been to add together the grey footprint of each studied pollutant for each site separately. The pollutant that gets the largest grey footprint after the summation will be the critical pollutant. However, this would not give the incentive to reduce the discharge of the most harmful pollutant for each site. Instead, the focus would be on the same pollutant for each site even though the grey water footprint related to that pollutant can be close to zero for some sites.

For the grey water footprint, if a user wishes to add a new region or treatment plant to the database, data searching is unavoidable. When adding a new region, the maximum and natural concentrations of that region should be found and entered manually into the region worksheet to get an as accurate result as possible. If region specific data is unavailable for a substance, the pollutant can either be left out of the analysis or data for another region can be used to get a more or less rough estimate of the footprint. When adding a new treatment plant, whether it is municipal or on-site, the efficiency of the treatment plant must be entered manually. If no municipal treatment plant is specified, a template treatment plant is used based on the efficiency of Ryaverken in Gothenburg. This, of course, means that if the actual treatment plant is not given, the result is only an estimate and will differ more or less depending on how much Ryaverken differ from the actual treatment plant.

It is very important that a standardized way to handle blue water in rivers is defined in order for different studies to yield comparable results. A gap in the Water Footprint methodology that had to be filled when creating the Water Footprint Accounting Tool was how to define what is to be regarded as blue water consumption when collecting and discharging water from the same river, see section 4.2.2. A definition stating that abstraction of water counts as consumption if other actors would have been able to collect water between the point of abstraction and the point of discharge was formulated. One of the ways in which the Water Footprint Manual defines water consumption is if the water is returned in another catchement area (Hoekstra et al., 2008). What constitutes a catchment area is not clearly defined, but since it is a matter of resource availability for mankind a definition based on whether or not somebody else loses the opportunity to use abstracted water is not far fetched.

Another gap in the methodology that had to be filled was how to account for the cleaning of water in treatment plants since it is the pollutants that reach the environment that are of interest and not necessarily the water pollutants that VCC emits before cleaning. A choice was made that if an effluent is treated before discharge into a recipient, the grey water footprint is multiplied with a cleaning factor that correlates to the amount of pollution removed from the effluent, see section 4.2.2 for a more elaborate definition. It is clearly stated in the Water Footprint Manual that a grey water footprint is proportional to the amount of pollution that reaches a recipient (Hoekstra et al., 2009). Therefore, if water is cleaned before discharge, the cleaning must be taken into account. Another way to account for cleaning is to look at the outgoing concentrations of pollution from the treatment plant and assume that all pollution above this concentration has been removed. However, this will yield an erronious result if water from other sources with other concentrations of pollution is treated at the same time as water from the source under study; if polluted water is diluted before being cleaned, the pollution concentration might be lower but the load will still be the same. As in the case of Blue Water Footprint in rivers discussed above, standardization on how to account for treatment plants is essential for making results from different studies comparable.

5 Inventory of Measurement Points at the Volvo Car Corporation's Manufacturing Sites

In this section, the inventory of existing measurement points that can be used to calculate the blue and grey water footprints of the Volvo Cars Manufacturing sites is presented.

5.1 Method of the Inventory of the VCM Sites

The inventory of existing measurement points at the Volvo Cars Manufacturing sites was carried out through studies of environmental reports, interviews with employees and questionnaires sent out to the environmental coordinators of the sites. See appendix E for the questionnaires.

The analysis was carried out at three different levels; site level, area of water usage level, and individual process level. At the site level, how much was known about water flows and level of pollution in and out of the sites was mapped. At the area of water usage level, the sites' blue water flows were divided into three categories; process water, sanitary water, and cooling water. How much is known about water flows and pollution in and out of individual processes was then investigated.

Flowcharts were chosen to be the format in which the inventory would be presented. Figure 6 is the flowchart used in the blue water inventory and figure 7 is the flowchart used in the grey water inventory. The flows out of the factory is divided into four different kinds in the grey water inventory. This can be seen in figure 7.

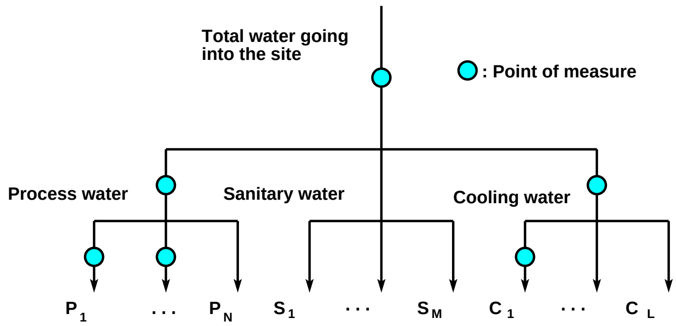

Figure 6: Flowchart used to display what blue water points of measurement are known at a site. The lines in the flowchart represent different blue water flows and the dots represent blue water measurement points. This chart does not represent any specific site and the dots have been placed ideally as an example.

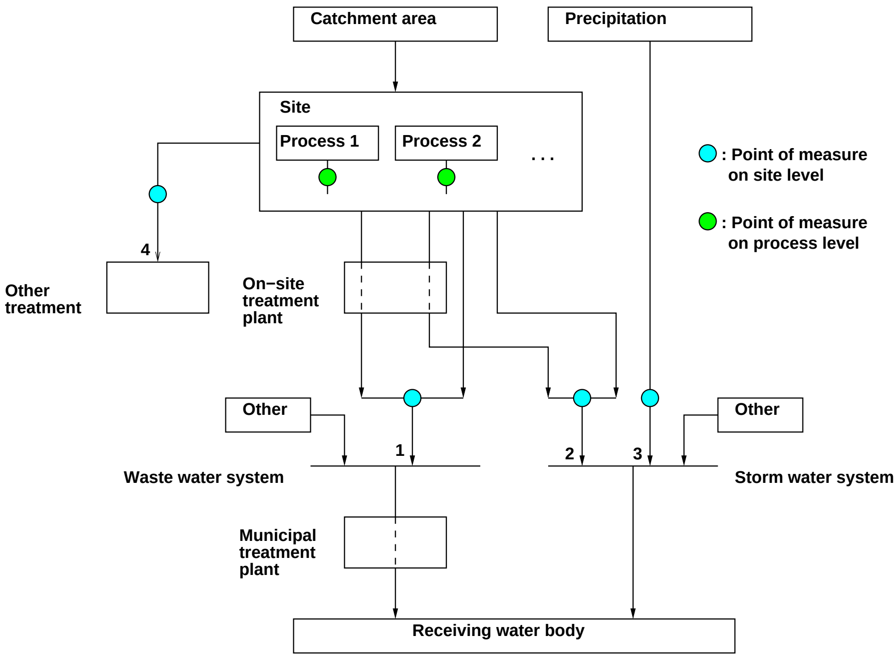

Figure 7: Flowchart used to display what grey water points of measurement are known on a site. The arrows in the flowchart represent water flows and the dots represent grey water measurement points. Flow 1 is the waste water flow, flow 2 is the storm water flow, flow 3 is polluted rainwater and flow 4 is polluted water being shipped away for external treatment. Flow 4 often end up in a different recipient than the other flows, depending on where the water is treated. The boxes named Other represent polluted water that originates from other sources than the VCM site but use the same sewer systems. This chart does not represent any specific site and the dots have been placed at random as an example.

5.2 Results and Discussion Regarding the Inventory of the VCM Sites

In this section, the results from the inventory of existing measurement points of water flows and pollution are presented and discussed.

5.2.1 Inventory of the VCM Site in Torslanda

Figure 8 is a flowchart showing what blue water flows are known at the site in Torslanda. Each building at the site is equipped with water flow meters measuring the amount of water going into the houses, making it possible to calculate the total amount of water going in to the site. It is also possible to calculate how much water is used for processes, sanitation, and cooling systems. Last time this was done was in 1993 but it would be possible to do today as well. At a process level, meters are installed in connection with the most water consuming processes; electro coating, diphosphation, painting and some of the cooling systems. There are no reliable flow meters that measure the outflow from the site. The water is both collected and discharged in Götaälv. However, the point of abstraction and the point of return is located so far from each other that the abstraction can be seen as consumption, see the definition in section 4.2.2.

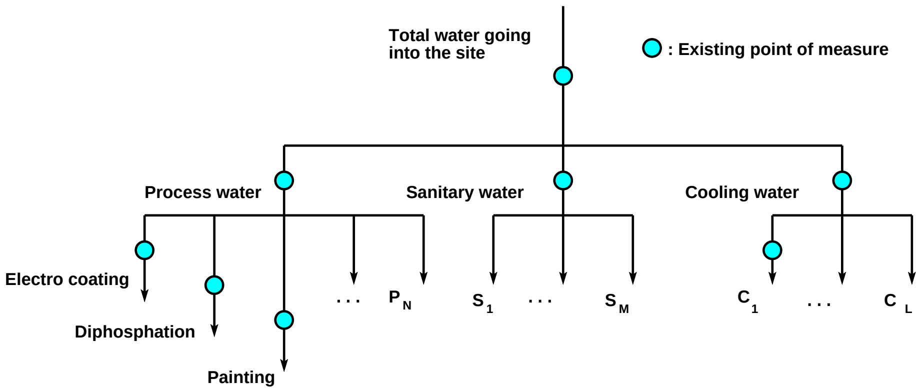

Figure 8: Diagram displaying what blue water flows are known at the VCM site in Torslanda. P, S and C represent production processes, sanitary appliancies and cooling systems, respectively. The blue water flow within each house on the site as well as the flow of the most water consuming processes and some cooling systems are measured continuously.

With existing points of measure, an accurate blue water footprint for the site in Torslanda as a whole can be calculated. It is possible to determine what most of the water is used for, i.e. divide the footprint between the three areas of usage; process, sanitary and cooling water. The water usage in some of the processes are also known, but not all. This means that it would at present not be possible to sum up all known processes and obtain a completely accurate measure of the blue water footprint of the site as a whole. However, the water consumption of the most water consuming processes are known so a good estimation can be calculated. That there are no reliable flow meters measuring the amount of water leaving the site is not a problem for the calculation of the blue water footprint since no water returns to its origins.

Pollution levels in outgoing water flows are known to some extent, see figure 9. Measurements are regurarly made in the main wastewater sewer that eventually leads to the municipal treatment plant Ryaverken. This measurement point is not optimal since it includes not only the VCM factory but the entire Torslanda site, and one other industry located in the area. Also it is very difficult to measure the flow in the main sewer due to undertow in the pipes. This means that the grey water footprint of the wastewater from the VCM site can at present only be calculated as an estimate; the real grey water footprint will be smaller than the calculated.

The situation for stormwater is better. The only process water flow that reaches the storm water system is one of the treatment lines from the on-site treatment plant. The magnitude of the flow and the level of pollution is monitored systematically, allowing for an accurate grey water footprint to be calculated.

There is no measurement point where rainwater pollution can be measured accurately. The only existing point of measure would be in an on-site barrier dam, but it is unlikely that this would yield a useful result since it is likely that pollution levels in the dam differ significantly from the mean pollution in the rainwater running on the hard surfaces of the site.

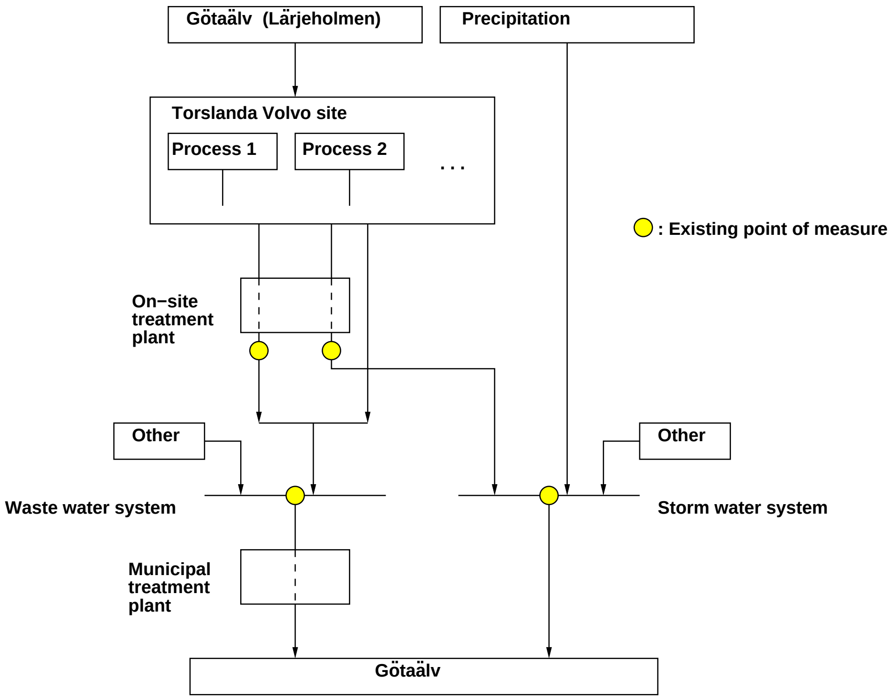

Figure 9: Diagram displaying what measurement points at the VCM site in Torslanda exist where water flow and pollution concentrations are measured. Measurements are made continuously on the waste water coming out of the on-site treatment plant and in the main sewer systems.

In order to obtain a more accurate result for the grey water footprint of the VCM site in Torslanda, one or several points of measure need to be used that include all the waste water from the factory but no other water. For example, since the effluent from the on-site treatment plant is known, if the other sources of waste water within the factory would be identified and measured or estimated, a more accurate result would be obtained than from using the main sewer.

Since pollution levels are not measured in connection to individual processes, it is not possible to calculate the grey water footprint at a process level. In order to do so, both water meters and pollution measurement points must be implemented in conjunction to all processes within the site. This would require an extreme amount of measurements to be taken. However, it is likely that most of the pollution from within the VCM factory originates from only a handful of different processes and if those processes would be identified, most of the grey water footprint of the entire site could be attributed to individual processes.

As there is no good point of measure for rainwater, it is best to exclude it entirely from the analysis until an accurate measurement can be made. Exactly how or where an accurate measurement can be done is very difficult to tell.

5.2.2 Inventory of the VCM Site in Ghent

Figure 10 shows what blue water flows are known at the site in Ghent. The amount of water going in to the site is known, as well as the amount of water used in around 90% of the processes and around 75% of the cooling systems. The most water demanding production processes are the same in Ghent as in the site in Torslanda; electro coating, diphosphation and painting. Water meters are installed by each of these processes. There are no accurate measurements of flows leaving the site except for the outflow from the on-site treatment plant.

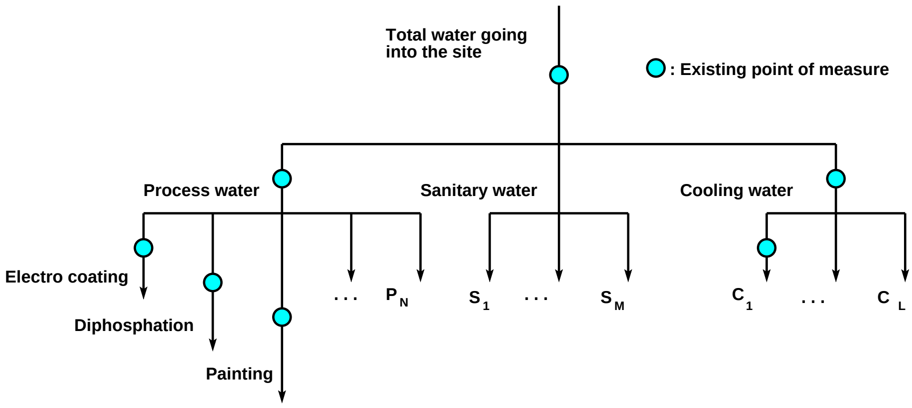

Figure 10: Diagram displaying what blue water flows are known at the VCM site in Ghent. P, S and C represent production processes, sanitary appliancies and cooling systems, respectively. The blue water flows of approximately 90% of the production processes and 75% of the cooling systems are measured continuously.

Since the water going in to the site is known and no water is returned to its origins, calculating an accurate blue water footprint of the VCM site in Ghent is easily achieved. Due to that the water flows in most of the processes and cooling systems are known, it is possible to make estimations of water use by area of usage through backwards counting; the amount of sanitary water is equal to the total water use minus process water and cooling water. The high resolution also allows for the blue water footprint of most processes and cooling systems to be calculated. This means that not much effort is needed to be able to calculate a complete operational blue water footprint for the site with high resolution.

Figure 11 shows where pollution levels and magnitudes of the flows are measured at the VCM site in Ghent. No water from the site is treated in municipal treatment plants but instead treated in an on-site treatment plant. This also includes sanitary water. Therefore, there is no flow of waste water out of the site in Ghent, all polluted water flows are regarded as storm water. Measurements of pollution in the effluent and the magnitude of the flow from the treatment plant is regurarly undertaken. At a process level, however, measurements of water pollution are not made regularly. There are also no measurement points that would yield an accurate mean pollution in the rain water running on the site's hard surfaces.

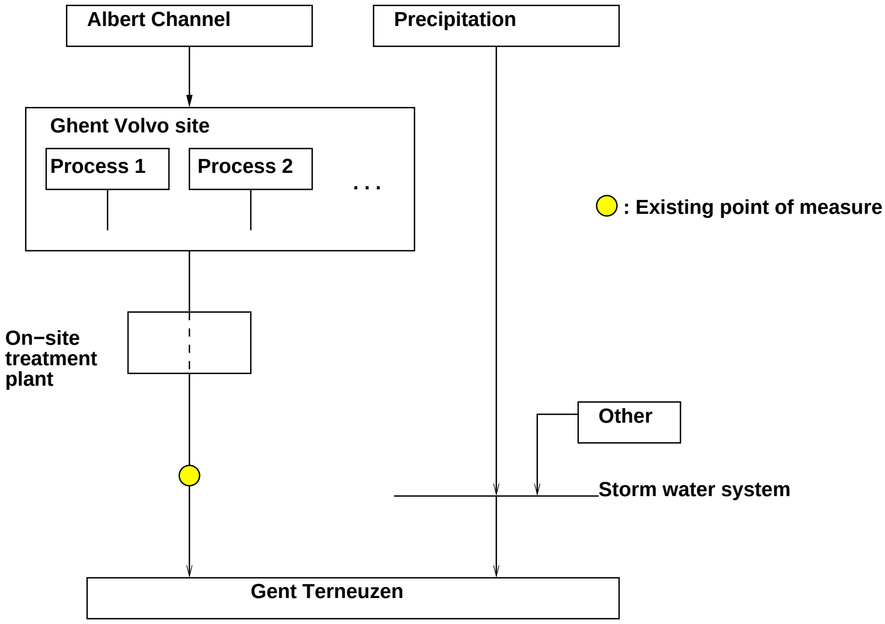

Figure 11: Diagram displaying what measurement points exist at the VCM site in Ghent where water flow and pollution concentrations are measured. Measurements are continuously made on the waste water coming out of the on-site treatment plant.

Almost all polluted water is treated in the on-site treatment plant. Therefore, the effluent from the plant is a good point of measure to determine the grey water footprint of processes and sanitation. Since there is no municipal or off-site treatment plant, the amounts of substances in the effluent are the same that reach the surrounding environment. Since levels of pollution in effluents from specific processes are not monitored regularly, new measurements on the effluents of processes need to be implemented if a grey water footprint is to be calculated at a process level. It is at present not possible to determine how much pollution is in the rainwater that runs on the site's hard surfaces, therefore the rainwater part of the grey water footprint cannot be included in the analysis if such a point of measure is not found.

5.2.3 Inventory of the VCM Site in Olofström

Figure 12 shows what water flows are known at the site in Olofström. The amount of water going in to the site is known, but it is not possible to fully distinguish between process water, sanitary water and cooling water. The water usage in some of the production processes is known, but not for all. Water flows leaving the site or most of the processes are not measured. There is one cooling system obtaining its water from a nearby creek that also returns the water at about the same spot where its collected. This means that this water should not be seen as consumed water and thereby not be included in the blue water footprint. It is possible to calculate the operational blue water footprint of the

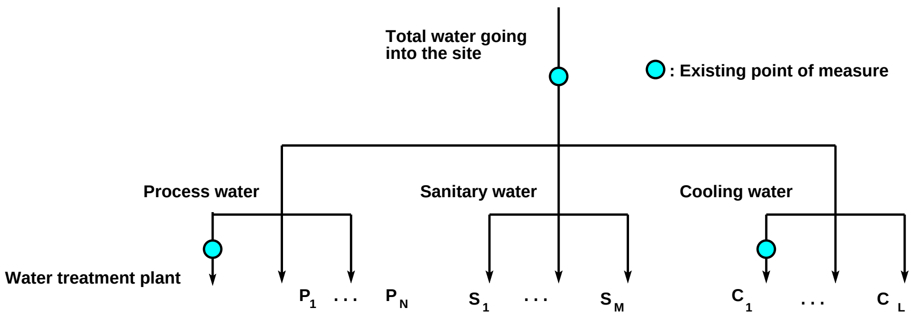

Figure 12: Diagram displaying what blue water flows are known at the VCM site in Olofström. P, S and C represent production processes, sanitary appliancies and cooling systems, respectively. The blue water flows to water treatment plant and some cooling systems are known.

site in Olofström. However, the site differs from the other sites in that it actually has a return flow to an original catchment area. The blue water footprint of the site would then be the total amount of water going in to the site minus the return flow. The return flow is at present not measured but as an estimate, the entire cooling system connected to the return flow could simply be excluded from the blue water footprint since the losses from the system are expected to be small in comparison to other flows. It is at present not possible to calculate the blue water footprint of areas of usage or processes. In order to do so, flow meters need to be installed at the most water consuming processes. This would also make it possible to calculate the footprint of the areas of usage.

Figure 13 shows where pollution levels and magnitudes of the flows are measured at the VCM site in Olofström. Water pollution at the site is well known. Measurements are regurarly taken in the waste water flow from the on-site treatment plant and in the main waste water sewer leading to the municipal treatment plant in Jämshög. No process water ends up in the storm water system.

It is possible to calculate the grey water footprint in Olofström for some pollutants since measurements are regurlarly taken in the on-site treatment plant and in the main waste water sewer. Rainwater cannot at present be included in the analysis since there is no accurate point of measure of rainwater pollution.

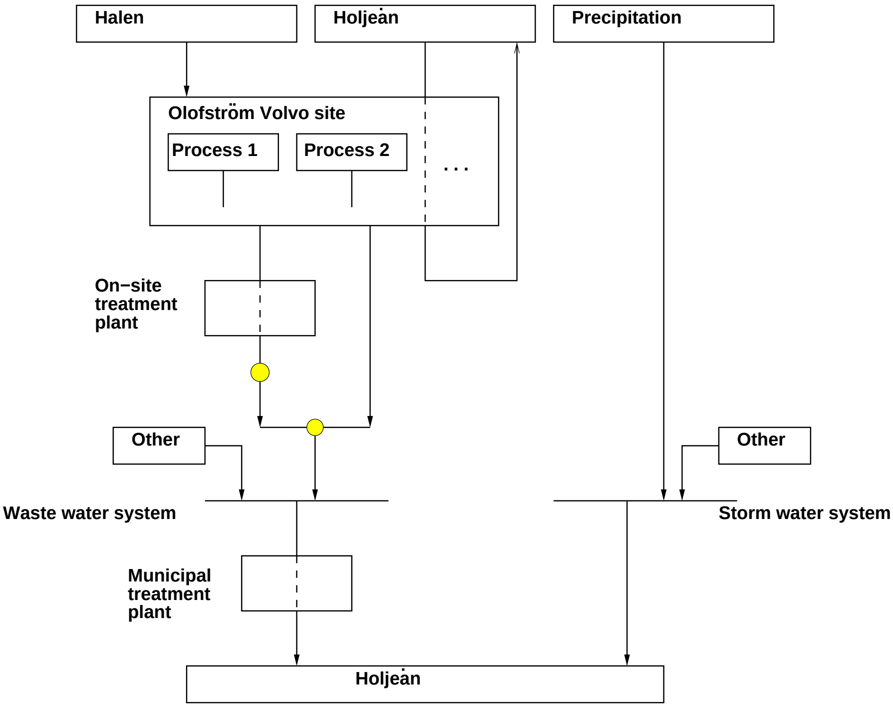

Figure 13: Diagram displaying what measurement points exist at the VCM site in Olofström where water flow and pollution concentrations are measured. Measurements are continuously made on the waste water coming out of the on-site treatment plant and in the main wastewater sewer.

5.2.4 Inventory of the VCM Site in Skövde

Figure 14 shows what water flows are known at the site in Skövde. The amount of water going in to the site in Skövde is known, but it is not possible to fully distinguish between process and sanitary water. At a process level, most water is used as cutting fluid, in washing machines, and in cooling systems. The water usage in the cutting processes and in the cooling systems are known but at present, there are no water meters by the washing machines. Water flows out of the site or any of the processes are not measured.

It is possible to calculate the operational blue water footprint of the site in Skövde since the water flow going in to the site is known and no water is returned to its origins. However, little is known about the water flows within the site so it is not possible to divide the water footprint in areas of usage. However, the processes that are estimated to consume most water are known. In order to determine a more complete operational blue water footprint of the flows within site, water flows going into the production processes that are estimated to consume most water should be monitored. This means that the water consumption of the washing machines should be measured or estimated. If this is done, and since the cooling water systems are already monitored, the usage of sanitary

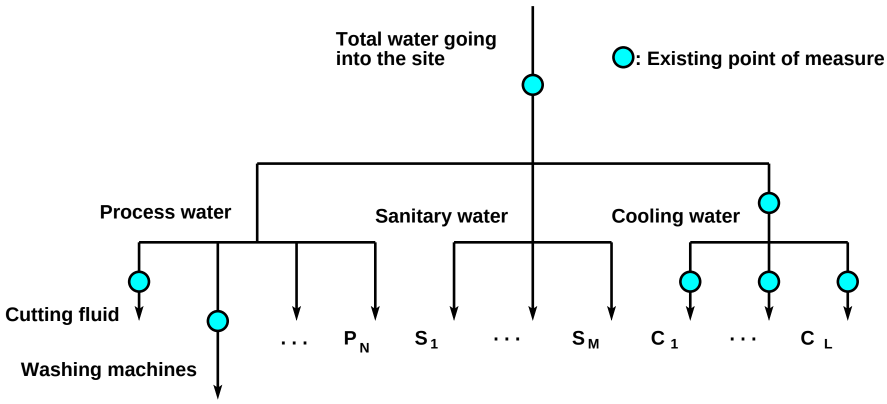

Figure 14: Diagram displaying what blue water flows are known at the VCM site in Skövde. P, S and C represent production processes, sanitary appliancies and cooling systems, respectively. The blue water flows to cutting processes and cooling systems are known.

water can be calculated. This would yield a high resolution of the blue water consumption within the site.

Figure 15 shows where pollution levels are measured at the VCM site in Skövde. There are very few measurements of water pollution at the site. The most heavily polluted water is treated in an off-site treatment plant owned by Volvo Powertrains. No measurements of pollution concentrations in this water is carried out but there is a water meter connected to the flow. The pollution level in the remaining waste water is measured on a yearly basis, but the size of the effluent is unknown. There is no accurate point of measure to determine pollution in rainwater.

Due to the few measurements at the site, it is at present not possible to calculate an operational grey water footprint of the site in Skövde. If the grey water footprint of the site is to be determined, pollution in the water being shipped away for off-site treatment need to be monitored regularly. Also, the flow of the waste water going in to the municipal sewer system need to measured and the frequency of the pollution measurements should be increased. In order to calculate the grey water footprint of specific processes, measurements of pollution and flow must be made in the effluents of the processes. Also, a good point of measure for pollution in rainwater should be found.

The tool does not support several wastewater or stormwater flows from one site simultaneously. In Skövde, there are two wastewater flows; the flow that goes to the municipal sewer system and the flow that is shipped away for off-site treatment. If the tool is to be used to calculate the grey water footprint of Skövde, the magnitude of the two flows must be added together and a mean value of the various pollutants need to be calculated using a simple mean value equation, see equation 22.

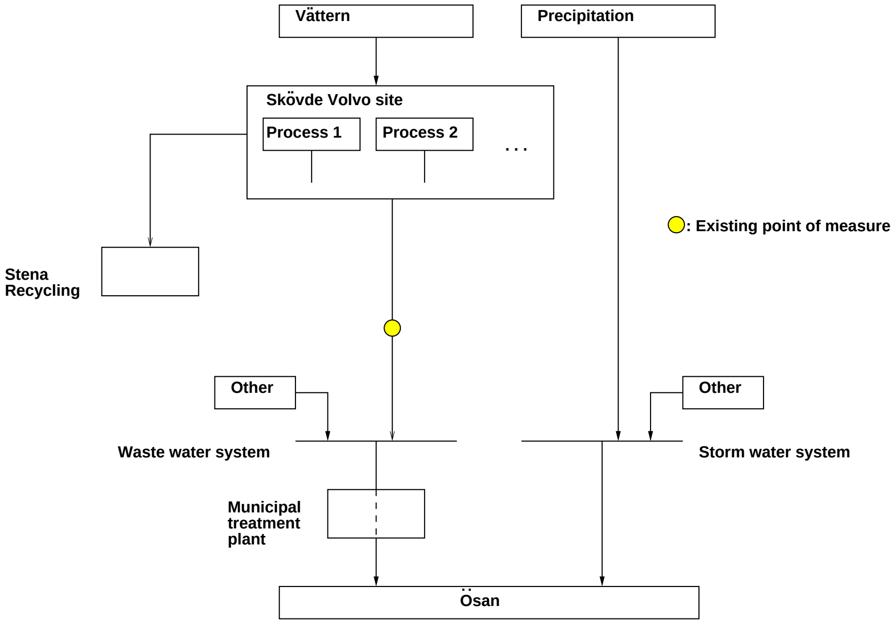

Figure 15: Diagram displaying what measurement points exist at the VCM site in Skövde where water flow and pollution concentrations are measured. Level of pollution is measured occationally in the main sewer system but the magnitude of the flow is not measured. The flow of the water going to the off-site treatment plant is measured but not the pollution concentrations.

5.2.5 Inventory of the VCM Site in Floby

Figure 16 shows what water flows are known at the site in Floby. The amount of water going in to the site is known, and it is possible to distinguish between the three areas of usage. The most water consuming processes in the VCM site in Floby are grinding, washing machines, emulsion processing and surface treatment. The water usage for each of these processes is known. The on-site cooling system is completely closed so very small amounts of water is lost. Water flows out of the site or any of the processes are not measured.

It is possible to calculate the operational blue water footprint of the site in Floby. The footprint can also be divided among the three areas of usage; production processes, sanitation and cooling systems. Since the water going to the most water consuming processes are known, the blue water footprint can be calculated at a process level.

Figure 17 shows where pollution levels are measured at the VCM site in Floby. The situation in Floby is very much like the one in Skövde. The most heavily polluted water is shipped for off-site treatment while sanitary water and auxiliary process water is discharged into the municipal sewer system. Some measurements are occationally taken in the water being shipped away and pollution levels are measured once or twice per year in the main sewer. There is

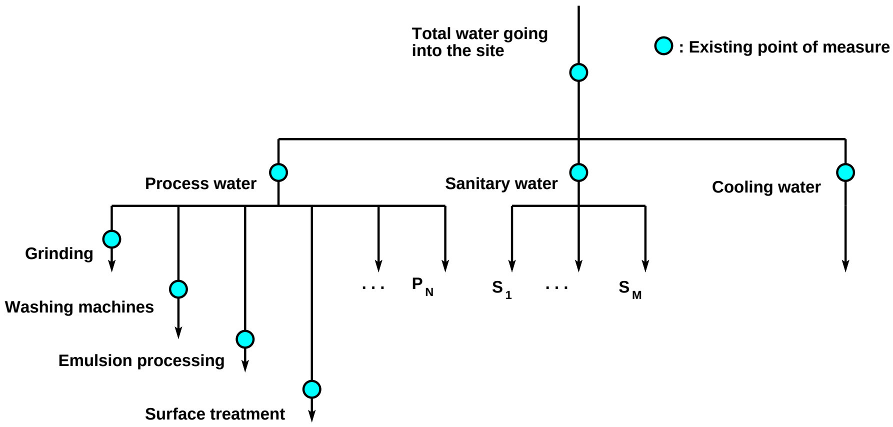

Figure 16: Diagram displaying what blue water flows are known at the VCM site in Floby. P, S and C represent production processes, sanitary appliancies and cooling systems, respectively. The blue water flows to the most water consuming processes are known.

no reliable point of measure for rainwater.

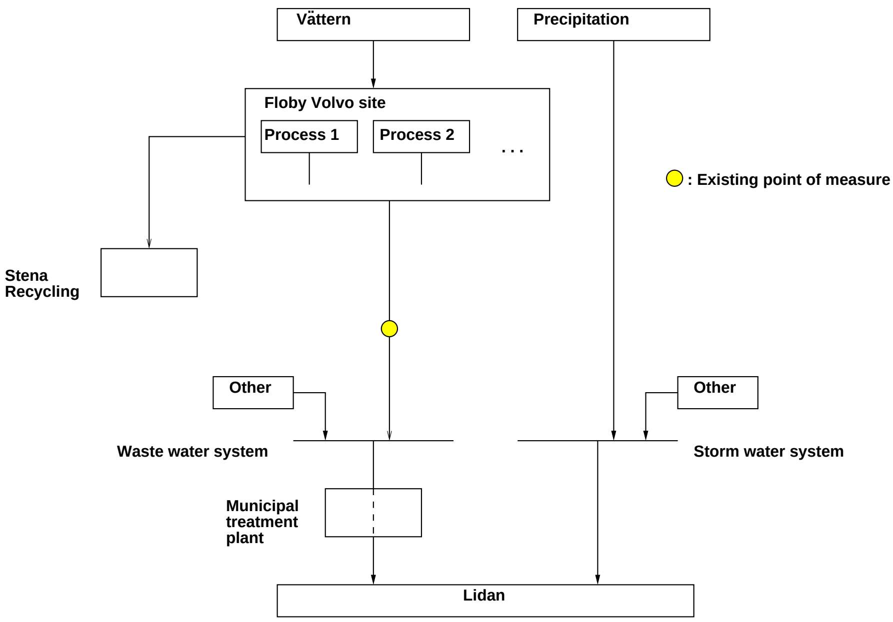

Figure 17: Diagram displaying what measurement points exist at the VCM site in Floby where water flow and pollution concentrations are measured. Level of pollution is measured occationally in the main sewer system but the magnitude of the flow is not measured. Measurements are taken occationally on the wastewater flow being shipped for off-site treatment.

At present, a very limited grey water footprint can be calculated. In order to calculate a complete operational grey water footprint, measurements of water pollution must be made regurarly in the water treated off-site and in the main sewer. The magnitude of the flow in the main sewer must also be monitored. It is also necessary to find a reliable measurement point of polluted rainwater.

As in Skövde, there are more than one waste water flows in Floby. Since the tool presented in this thesis does not support this, mean pollution concentrations must be calculated outside the tool. This is done using equation 22.

6 Applications for the Results from the Water Footprint Accounting Tool

In this section a number of applications for the results from the tool are presented. It is assumed that all necessary data to calculate the water footprint for each process in the sites are available and accurate; this makes it possible to visualize the full potential of the tool. The applications for the Blue and Grey Water Footprint are presented separately.

6.1 Applications for the Blue Water Footprint

The following applications for the results of the Blue Water Footprint are possible:

1. The Company's total operational blue water footprint can be used in Sustainability Reports to present the company's water consumption.
2. The results can be used for comparisons between different sites to analyze for which sites that water reduction should be prioritized.
3. The blue water flows within the site can be analyzed to be able to increase the knowledge about the site and to find possible reductions.
4. The blue and grey water footprints of each site can be compared to see which one that yields the largest impact.

The first application for the Blue Water Footprint is to present the company's total operational blue water footprint in sustainability reports. This can be done by creating a diagram that shows the total operational blue water footprint for different years. The tool will calculate the company's operational water footprint if the total amount of water in is added for each site. A diagram that shows the company's operational water footprint can be created by doing this repeatedly for different years. The tool does not create the diagram itself; instead the total blue water footprint needs to be saved for each year and it can then be used to create the diagram in a separate program. An example of such a diagram is presented in appendix B. The total operational blue water footprint of the company can be a good indicator to include in a Sustainability Report since it clearly shows how the company's water consumption has developed. However, it is very important to clearly state that the diagram only represents the operational or direct blue water footprint of the company and does not include the supply chain or consumer phase.

Another diagram that can be included in a sustainability report in addition to the total operational blue water footprint is the operational blue water footprint per car for different years. This can be calculated by dividing the company's blue water footprint for each year with the number of cars that were produced during that year. An example of this is presented in appendix B. A car is a good reference since all VCM sites are included in a chain to produce cars. The calculated footprint per car will only be an average value; in reality different car models has different water footprints, but such an analysis is not included in the scope of the tool. If a sustainability report includes diagram of both the total operational blue water footprint and the operational blue water footprint per car it will make it possible to show if an increase in water consumption is due to increased production. These two diagrams are therefore useful if the purpose is to communicate with customers and other stakeholders. However, if the intention is to use Blue Water Footprint to create reasonable goals for reductions in water consumption, a deeper analysis is needed.

The second application for the Blue Water Footprint is to compare the footprints of different sites with each other. This can be done in two different ways; either by comparing the blue water footprint of the sites or by comparing the *Blue Water Footprint Impact Index* of the sites.

If the blue water footprint of two sites are compared it will give an indication of which site that are the most efficient one when it comes to water consumption. If the sites manufacture the same kind of product and approximately the same amount of products per year their blue water footprints can be compared directly. If they manufacture the same products, but different amount of products per year, the blue water footprints needs to be divided with the amount of manufactured products or with the volume of sales before they can be compared. If the sites manufacture different products there is no use to compare the sizes of the footprints. Since the sites probably have different production processes it would give no indication of the efficiency of the sites if their total footprints were compared. However, if the sites have some processes of the same kind, the blue water footprints of these processes can be compared to see if they use the same amount of water.

When the most efficient site, or process, has been identified this can serve as a reference value. If two similar sites are compared, and they have footprints of different sizes, it should be theoretically possible to reduce the one with larger footprint to the same size as the smaller one. The reference value can also be used if another site that manufactures the same product is built. The goal can then be that the new site should have the same blue water footprint as the most efficient existing site, since this site already exists this is known to be possible. It can be possible to reduce the water footprint of the most efficient site as well, but this demands a deeper analysis.

In section 2.3 the *Blue Water Footprint Impact Factor*, $WFII_{blue}$, from the Water Footprint Manual was introduced as a way to identify the impact of a blue water footprint on the environment. It was defined as the blue water footprint of the studied object multiplied by the water scarcity factor of the catchment area, x. The recommended scarcity factor was calculated by dividing the annual water withdrawal,WR_{Total}, with the annual water run-off from the same catchment area. The recommended equation for the *Blue Water Footprint Impact Factor* then becomes:

$$WFII_{blue}[x] = WF_{blue}[x] \times \frac{WD_{Total}[x]}{WR_{Total}[x]} \tag{24}$$

The *Blue Water Footprint Impact Factor* can be used to compare the different sites to each other; the site with the largest *Blue Water Footprint Impact Factor* is the one that has the largest impact on the environment.

The user needs to collect data for the annual run-off and the water withdrawal to be able to calculate the *Blue Water Footprint Impact Factor*. The annual average water-bearing, expressed in m^3/s, of the water body that the water is taken from needs to be collected. Then the total run-off can be calculated for a year. This volume of water can be taken from the catchment area without affecting the amount of water in the area since it would have left anyway. The average bearing of a river is equal to the average flow in the river. The average bearing of a lake is related to how long time it takes to renew the water in the lake.

The water withdrawal can be calculated if water treatment plants that collect water in the catchment area are identified. Then the annual withdrawal will be the amount of water that they collectively abstract annually. If the studied site receives water from a river, the water treatment plants that collect water for the society where the site is located should be included. The catchment area will be the point in the river where the water treatments plants take up water according to the definition in section 4.2.2. If the catchment area is a lake, all water treatments plants that take up water from the lake need to be included in the water withdrawal analysis.

The advantages of comparing the *Blue Water Footprint Impact Factor* of different sites is that it will be a comparison between the environmental impact of the sites due to water consumption. The site with the largest footprint is not necessarily the one that has the largest impact on the environment. If the site with the largest blue water footprint is located in a water abundant area while a similar site with a smaller footprint is located in a water scarce area, it is possible that the site with the smaller footprint has the largest impact on the environment. Therefore, it is preferable to calculate the *Blue Water Footprint Impact Factor* for each site, because then it becomes possible to compare the environmental impact of the sites with each other. The decision of which sites that should be prioritized for water reduction can then be based both on their efficiency and their environmental impact.

The scarcity factor can also be used when a new site is to be built. If there is more than one possible location for the new site, it is possible to predict in which location the environmental impact due to water consumption would be most severe by calculating the scarcity factor for each location. If the blue water footprint would be the same regardless of the location, the site would yield the largest environmental impact due to water consumption if it is built in the area with the largest scarcity factor. To be able to calculate the scarcity factor it needs to be known from which water body the site would receive its water. Then the annual water run-off and withdrawal needs to be collected for that body. Calculating the scarcity factor for an area where a future site can be built makes it possible to predict the environmental impact before the site is built. Already existing water scarcity maps could also be used, but the scarcity is often calculated for quite large areas in such maps. Therefore, water scarcity maps are rarely detailed enough to draw conclusions without a deeper analysis, but they can serve as a first indication before the scarcity factors for the actual catchment areas are calculated and the local conditions assessed.

The third application is to use the tool to map blue water flows within the sites. It is possible to insert the water consumption for the three usage areas; processes, sanitary use and cooling water; as well as for different processes. In that way, the major flows within the site can be mapped. This can be used to identify possible reductions, for example the footprints of similar processes can be compared to see if they consume the same amount of water. The mapping also has the additional value that all information becomes gathered in the same place, this make it easier to overview and to create reasonable goals for water consumption reduction.

The fourth application is to compare the blue and grey water footprints of one site to see whether water consumption or water pollution is the largest contributor to the site's environmental impact. One way to do this is to divide the blue water footprint of the site with the annual water run-off of the water body where the water is collected. This will show how large percentage of the available water in the catchment area that the site uses. The grey water footprint can be divided with the total run-off of the receiving water body, this shows how large percentage of the available assimilation capacity that the site uses. These two percentages can be compared to each other to see whether it is the water pollution or consumption that takes up the larger part of the available resources in the catchment area.

However, this only takes the studied site into account and not the whole situation of the area. If a very large part of the available water in the area is used when looking at all actors, the blue water consumption can be considered worse even if it has a lower percentage in the comparison with the grey water footprint. Therefore it is preferable to compare the *Blue* with the *Grey Water Footprint Impact Factor*, this requires more data collection but takes the situation of the whole area into account. If the *Blue Water Footprint Impact Factor* is the largest, the site creates the largest environmental impact due to its water consumption. If the *Grey Water Footprint Impact Factor* is the largest, the largest environmental impact is due to the water pollution. In the next section it will be explained how the grey water footprint impact indicator can be calculated.

6.2 Applications for the Grey Water Footprint

The following applications for the results of the Grey Water Footprint are possible:

1. The total critical operational grey water footprint of the company can be used as an indicator for water pollution in sustainability reports.

2. The pollutants that have the largest impact on the environment can be identified for each site.

3. The grey water flows within a site can be mapped to see where different pollutants come from and to find possible reductions.

4. The grey water footprint can be used to analyze for which sites that water pollution reduction should be prioritized.

5. The blue and grey water footprints of each site can be compared to see which has the largest impact.

The first application is to use the total critical operational grey water footprint in sustainability reports. The total critical operational grey water footprint of the company is calculated in the tool by summarizing the critical grey water footprint of each site. The total critical grey water footprint can be calculated for different years with help of the tool. The value of the total critical operational grey water footprint for each year can be stored outside the tool to create a diagram to show trends in the company's water pollution. As in the case of blue water, it is recommended to complement with a diagram that shows the grey water footprint per car for each year. This can be calculated by dividing the footprint for each year with the number of cars that were produced during that year.

The operational grey water footprint is a good indicator for a sustainability report, however; the clearest way to describe a company's water pollution in a report is to present the actual load that the company discharges of each pollutant. These are actual measurements and will therefore be directly comparable to other companies' measurements. Therefore, the historical discharges of the most significant pollutants are recommended to be included in a sustainability report. To include the historical development of the Grey Water Footprint as well give additional value to the report. It will show the environmental impact of the company due to water pollution; something that the measurements do not contain.

The second application is to identify the pollutants that have the largest environmental impact in each site. The tool will calculate the grey water footprint for each studied pollutant, this will show which pollutant that has the largest impact on the environment. This can be used to decide which pollutants that should be prioritized to reduce the discharge of. This possibility is one of the largest advantages of calculating the grey water footprint of a site. If the actual discharge of a pollutant is studied it gives no information about the environmental impact of the pollutant, the pollutant that the site discharges the most of does not need to be the one that yields the largest environmental impact. The water body could be able to assimilate a large amount of that pollutant which would reduce the environmental impact. The Grey Water Footprint takes the assimilation capacity into account and therefore the pollutant with the largest footprint will be the one that causes the largest impact on the environment

The third application is to map the grey water flows within a site to see where the most harmful pollutants originate from. The tool will give a division of the grey water footprint of the waste water, storm water and polluted rain water. It is also possible to insert data for different processes to see which processes that contribute the most to the total grey water footprint of the site. In this case there is also an advantage of looking at the grey water footprint of different processes instead of the actual amount of discharged pollutants. The equation for the grey water footprint of a process takes into account how much of the pollutants that ends up in the environment. If the amount of the pollutants in a waste water stream after a process was studied instead, it would not be shown whether parts of the pollutants are taken away in on-site or municipal treatment plants. Consider two similar processes, one from which the waste water ends up in the municipal system and one from which the waste water ends up in the storm water system. If the receiving water body is the same, the later process will have the largest footprint since none of the pollutants are taken away in a municipal treatment plant. It would therefore be possible to conclude that it is better to reduce the pollutant in the process from which the polluted water ends up in the storm water system. Such conclusions are not possible to draw if waste water flows out of processes are studied without considering whether the pollutants actually ends up in the environment.

The fourth application is to use the Grey Water Footprint to decide for which sites that reduction of water pollution should be prioritized. To do this it is necessary to take into account the water quality of the receiving water body. It is not possible to understand the environmental impact due to a grey water footprint before it is known how polluted the receiving water body were in the first place. If a large part of the assimilation capacity of the critical pollutant is already consumed it would be worse to discharge more of the pollutant than if a very small part of the assimilation capacity was consumed. The ecological and chemical statuses that authorities formulate for different water bodies are an easy way to get an indication of the status of the receiving water body, and thus whether harder restrictions can be expected. Even better would be if it was possible to gain information about which substances that has caused a poor status of the receiving water body. If these are the same as the pollutants with large grey water footprints of the site it would be important to focus on reducing the discharge of these pollutants.

Another way to see which site that has the largest impact is to compare the *Grey Water Footprint Impact Factor* of the critical pollutant of each site. The site with the largest critical *Grey Water Footprint Impact Factor* will have the largest impact on the environment. This requires more data input from the user, but it has the advantage that it makes it possible to evaluate the environmental impact even if the authorities have not evaluated the water quality.

The *Grey Water Footprint Impact Indicator*, $WFII_{grey}$ is defined as (Hoekstra, 2009):

$$WFII_{grey}[x] = WF_{grey} \times \frac{WF_{Totalgrey}[x]}{R[x]} \tag{25}$$

Where WF_{grey} is the critical grey water footprint of the studied site, calculated by the tool, R is the annual run-off from the receiving water body and $WF_{Totalgrey}$ is the grey footprint of the receiving water body which should be calculated for the critical substance of the site. The grey water footprint for the receiving water body can be calculated as:

$$WF_{Totalgrey} = \frac{c_{act} \times V_{Total}}{c_{max} - c_{nat}} \tag{26}$$

The maximum acceptable concentration, c_{max}, and the natural concentration, c_{nat}, is available in the tool's database. The user will need to collect data for the actual concentration, c_{act}, for the receiving water body as well as its volume, V_{total}, to be able to calculate the grey water footprint for the receiving water body.

As discussed in the previous section, the *Grey Water Footprint Impact Indicator* can also be compared with the *Blue Water Footprint Impact Indicator* of the sites to see whether reduction of the water consumption or the water pollution should be prioritized.

7 Evaluation of Water Footprint

In this section, the evaluation of the Water Footprint indicators is presented. First, the methodology used in the evaluation is introduced followed by a combined results and discussion section.

7.1 Method of the Evaluation of Water Footprint

The evalutation of Water Footprint as an indicator presented in this report is based on a framework for sustainability indicator reviewing developed by Mitchell et al. (Mitchell et al., 1995). The framework consists of eight criteria defining what qualities a useful indicator should possess, that the authors suggest practitioners of indicators should use as an evaluation tool. The criteria are listed and described below.

1. Relevance and scientific validity; indicators should be relevant for the issue of concern, scientifically correct and bias should be minimized.

2. Sensitivity to change across space and/or groups; the indicator under study has a spacial resolution that makes it possible to identify where the situation is acceptable and where it is not acceptable.

3. Sensitivity to change over time; indicators should show whether or not the state of the issue under study is improving, not changing, or deteriorating with time.

4. Consistency of data; indicators should be supported by consistent data that allows for scientifically rigid analyses of past trends.

5. Comprehensible; indicators should be easily understood by practitioners and stakeholders so that interested parties are able identify whether the situation is acceptable or not.

6. Appropriate data transformation; by definition, indicators are compositions of measured data that increases the understanding of an issue of concern. This composition must be made in an appropriate way that yields more information than the used data alone.
7. Measureable data; the data used for calculating an indicator must be measureable in a reasonably cost effective manner.
8. Possible target or threshold; it should be possible to distinguish between acceptable and not acceptable states using threshold values and targets related to the indicator value.

7.2 Results and Discussion Regarding the Evaluation of Water Footprint

As stated above, the evaluation of operational Business Water Footprint presented in this report is based on an sustainability indicator review framework developed by Mitchell et al. (Mitchell et al., 1995). The eight criteria will be addressed in this section.

7.2.1 Evaluation of Blue Water Footprint

In this section, the evaluation of the Blue Water Footprint indicator is presented and discussed. The focus is on an operational business level but in some cases, the entire life cycle must be studied to see the full implications of a business Water Footprint.

Relevance and Scientific Validity One of the strengths of the Blue Water Footprint indicator is that it is a measure of water consumption rather than water use. This makes Blue Water Footprint a relevant indicator in the sense that it is a measure of the true local impact of water abstraction. However, there is still a need for standardization regarding what is to be viewed as water consumption in order for Blue Water Footprint to gain full scientific validity. An example of this is the case of a river, see section 4.2.2 for a definition of what is to be seen as blue water consumption in rivers. Without clear definitions of boundaries, the outcome of a Blue Water Footprint study lies to a great extent in the hands of the practitioner and different studies of the same system could yield significantly different results.

Sensitivity to Change Across Space and/or Groups A blue water footprint in itself does not carry any information regarding whether or not an activity is sustainable. However, if it is put in the right context, it does. If the abundance of water where a blue water footprint arises is known, the activity responsible for the footprint can easily be put in a sustainability context regarding water consumption. This means that the severity of a blue water footprint can be analyzed in a spacial dimensions, e.g. a blue water footprint in a water scarce region is more severe than the same footprint in a water abundant region.

Sensitivity to Change Over Time Blue Water Footprinting can be used to establish temporal trends in water consumption. However, in order to discern a relevant trend, the functional unit of the study must be chosen wisely. This report has focused on a site or business unit as the object under study. Assuming that there are only small variations in the activities of a site over time, it can be a sufficient functional unit. If there are large variations, however, the trend would be more relevant if other functional units would be used, for example one produced good. The reason for this is that in the end, what matters is not only environmental impact in absolute terms but environmental impact per value created.

Consistency of Data Many companies monitor their water consumption regurarly. This, in combination with data of water availability in the local are can be used to establish temporal trends. It is safe to say that most companies will continue keeping track of their water use since water is a commodity they pay for.

Comprehensible The meaning of a blue water footprint of a site or company is easily understood. Consumption of water is something that most people can relate to, and understand the importance of. Out of the four ways in which water can be regarded as consumed, see section 2.2.1, the only one that require some extra pondering is the fourth one, i.e. that the water is returned in another time period. However, understanding all the mechanisms behind consumption is not necessary to get a feeling for the severity of a situation. When compared to the total availability of water, the significance of a water footprint is not difficult to comprehend regardless of how the water was consumed.

Appropriate Data Transformation In a simplified system, the data used to calculate an operational blue water footprint of a production site is the amount of water going into the site, and the amount of water going back to where it was first collected in the same time period. When the two values are viewed separately from each other, neither carry enough information to establish the water consumption of the site. When put together, however, they do. It is clear that the blue water indicator indeed enhances the understanding of the severity of water abstraction, i.e. the data transformation is appropriate.

Measureable Data The data required to determine the blue water footprint at a site level is easily acquired. All that is needed to measure the data is flow meters installed in the right positions to measure all relevant flows.

Possible target or threshold The water availability of the water body from which a site obtains its water sets the limits of how much water can be abstracted. Exactly how much water a speific actor can be allowed to collect without jeopardizing sustainability is difficult to tell without analyzing the local conditions thoroughly, but it is possible to do.

7.2.2 Evaluation of Grey Water Footprint

In this section, the evaluation of the Grey Water Footprint indicator is presented and discussed. The focus is on an operational business level but in some cases, the entire life cycle must be studied to see the full implications of a business Water Footprint.

Relevance and Scientific Validity One of the strengths of the Grey Water Footprint indicator is that it uses the assimilative capacity of the recipient based on the judgement of the public authorities instead of other weighting methods. The credibility of the result is therefore resting on the shoulders of the decision makers rather than the practitioners of Grey Water Footprint. As a result, the methodology is free from bias of the practitioner to a large extent. Thereby, Grey Water Footprint assessment can be a powerful and relevant tool for comparing the impact of pollution of different kinds with each other and the total assimilative capacity of a recipient. However, as in the case of Blue Water Footprint, the methodology is in need of standardization. An example of this is the question of how to calculate the effects of treatment plants, se section 4.2.2 for the definition formulated in this thesis on how to handle off-site treatment plants when calculating a grey water footprint.

Sensitivity to Change Across Space and/or Groups If all data necessary for calculating a grey water footprint has been acquired, the result is sensitive to change across space since it by definition includes values for the assimilation capacity of the receiving water body. However, the severity of the sitation cannot be fully analyzed before the current state of pollution in the recipient is taken into consideration. Once this is done, however, an in depth analysis can be made that displays the current or past situation of the object under study.

Sensitivity to Change Over Time Much like the Blue Water Footprint, Grey Water Footprint can be used to discern trends assuming that a good functional unit is used. However, since the Grey Water Footprint relies on the maximum acceptable concentration of a pollutant in a recipient as defined by governing authorities, the grey water footprint change if the maximum acceptable concentration is changed. There is a need for a definition what happens in such instances.

Consistency of Data Just like for blue water use, many companies measure and monitor pollution levels in the effluents from their sites. In some cases, regional environmental organizations measure levels of pollution in water bodies. Past data is often possible to come by and it is likely that measurements will continue in the future in a consistent manner. This data can be used to establish trends in water pollution. However, there will always be some pollutants that are not monitored that will have to be excluded from the analysis. As mentioned above, it is also possible that the maximum acceptable concentrations of substances change over time.

Comprehensible A grey water footprint can be viewed as the imaginary amount of water that is required to dilute a pollutant to acceptable levels.

Compared to just studying the discharged load, Grey Water Footprint is rather complicated. It takes time and effort to fully understand all implications of the indicator, perhaps more than many stakeholders can afford. However, it is difficult to find a more simple indicator without losing relevance. Developing indicators that can be used for weighting and comparing environmental impacts is a balance act. If Grey Water Footprint were to be simplified it would on the one hand gain comprehensiveness, but on the other lose other values. With this in mind, Grey Water Footprint can be said to be comprehensible enough.

Appropriate Data Transformation The data needed to calculate a grey water footprint is the load of the pollutant under study that is discharged into the recipient, the maximum acceptable concentration of the pollutant in the recipient and the natural concentration of the pollutant in the recipient. The Grey Water Footprint works as a weighting system putting the discharged load into its context so that the severity of the pollution can be seen. A weighting system is invariably biased in one way or the other, but without it, it is impossible to compare environmental damage. Grey Water Footprint transforms the data so that different pollutants and different receiving bodies can be compared with each other and thereby enables a more detailed analysis.

Measureable Data The greatest weakness of the Grey Water Footprint methodology lies in the collection of data. Water body specific data for the natural and maximum acceptable concentrations of pollutants has not been found for any of the studied water bodies. Instead, data applying to all water bodies has been used were such data can be found. But even such flawed data has proven very difficult to find in some instances, especially for substances that vary much in abundance between water bodies and substances that do not occur naturally in most regions

Since the concentrations of substances are changed once human activities have influenced water bodies, it is in almost all cases impossible to directly measure natural concentrations. Therefore, c_{nat} must be determined through indirect measurements. One way to do this is to collect values for water bodies far away from human activities, chosen to represent natural conditions. These numbers, however, can only serve as estimates. Even if it was technically possible to measure the natural concentration of a substance in a water body, it would still only serve as an estimate. The reason for this is that the amount of substances vary over time. In some cases concentrations vary depending on what part of the year is studied, and the concentrations of other pollutants vary over longer periods (Naturvårdsverket, 2009).

The maximum acceptable concentrations of substances in water bodies are defined by governing authorities. Ideally, each water body should have its own set of concentrations to take into account all local circumstances. However, this has not been found to be the case in any of the nations studied in this thesis. Both Swedish and Belgian authorities use documentation such as the European Directive (EU, 2008) and the Canadian Water Quality Standards (CCME, 2007) as guidelines. Using such values, much of the benefits of Grey Water Footprint is lost since the indicator does not account for local conditions. That there is no single organization setting all maximum concentrations for a region or water body is also a consistency problem due to that maximum acceptable concentrations are by definition biased by the values and priorities of the organization setting them.

In order for Grey Water Footprint to become a fully consistent indicator it is necessary that both natural and maximum acceptable concentrations in receiving water bodies are clearly set and documented. This should ideally be done by one single organization to ensure consistency. Without a generally accepted database containing these values, the results from a Grey Water Footprint assessment are estimations.

Possible target or threshold On a societal level, the Grey Water Footprint is an excellent indicator to use when setting local and regional targets and thresholds for how much pollution that can be discharged into a water body before the conditions are not acceptable any more, i.e. the pollution concentrations in the recipient exceed the maximum acceptable concentration. The reason for this is that the grey water footprint by definition corresponds to the amount of a certain pollutant that can be allowed to be in a water body. On a business level, similar assessments can be made if the business is put in its context, i.e. that the amount of pollution that a site can be allowed to discharge corresponds to how much value is generated on the site. However, this is for authorities to decide rather than individual businesses.

8 Concluding Discussion and Conclusions

8.1 Concluding Discussion

The tool presented in this thesis is powerful in the sense that it is easy and quick to use, require no special skills of the user, and is very customizable. This means that the tool can be used by current employees att Volvo Car Corporation for analyses of the company's operational water footprint in studies with many different scopes.

The inventory of measurement points that can be used to calculate the blue and grey water footprints of the existing Volvo Cars Manufacturing sites showed that calculating the blue water footprint on a site level is easily done for all sites since the flows of water going into the sites are known and no water returns to its origins. In some of the sites the blue water footprint can be divided on the three areas of usage defined in this thesis; process water, sanitary water, and cooling water. At a process level, the majority the most water consuming processes are known at the sites. The inventory also showed that the grey water footprint can be calculated on a site level for the sites in Ghent and Olofström. In Torslanda, estimations can be made with existing installed equipment and in Skövde and Floby, more measurements must be made before any grey water can be calculated. The grey water footprint can generally not be calculated on a process level at the VCM sites.

The blue and grey water footprints of the sites can be analysed using the applications presented in this thesis to determine the sustainability of the company's own operations and compare different sites, locations and processes. Both the actual and weighted water footprints can be used in the comparison.

The evaluation of the Water Footprint indicators show that the Blue Water Footprint is a usable indicator in its current state, even though some standardization is needed. The Grey Water Footprint, on the other hand, require more extensive standardization and documentation before it can be used to its full potential. The most important developments of the Grey Water Footprint is to create a set of values for the maximum acceptable and natural concentrations of various substances in water bodies, to fill in gaps in the methodology, and to standardize the methodology.

This thesis has concentrated on the operational blue and grey water footprints of Volvo Car Corporation. The task turned out to be a good place to start working with Water Footprinting at the company. The next step would be to turn to the supply chain to gain a life cycle perspective. However, the supply chain of a car manufacturing company such as VCC contains thousands of actors. Therefore, including the entire supply chain in a state of the art Water Footprint assessment is a too complex task to be realistic. A more reasonable approach would be to include only the most important suppliers in a limited analysis. This can be done for example through sending out a questionaire asking for information about the suppliers' impacts on global water resources. This analysis should at first only include blue water since grey water can become overly complex.

Volvo Car Corporation should keep up to date with the latest state of the art methodology. Therefore, keeping track on the upcoming ISO standard as well as new publications by The Water Footprint Network is essential. If the methodology changes, VCC must adapt to the new standards. Also important is to update the maximum and natural concentrations of pollutants in the tool presented in this thesis if recommendations for these concentrations are published or changed.

The current situation regarding global water resources demands action from governments as well as the private sector. Implementing Water Footprint and other methods of analysis is an important step towards sustainable water use. The fact that the water issue is gaining more and more attention gives hope for the future.

8.2 Conclusions

The conclusions of this thesis are the following.

- The tool presented in this thesis can be used by Volvo Car Corporation to calulate its blue and grey operational water footprints.
- Volvo Car Corporation is at present able to calculate its operational blue water footprint on all Volvo Cars Manufacturing sites, and the operational grey water footprint on some of the sites.
- The applications that Water Footprint can be used for presented in this

thesis can be used to analyse the results from a Water Footprint assessment in a sustainability context.

- The Water Footprint methodology is useful, but standardization and centralization of databases need to be done before it can be used to its full potential. This is especially true for grey water footprint.

8.3 Recommendations for the Use of Water Footprint at Volvo Car Corporation

With all this in mind, we recommend that Volvo Car Corporation implement Water Footprint as described below. For Blue Water Footprint, Volvo Car Corporation should do the following.

- Install meters that measure the most significant blue water flows within the VCM sites.
- Present the blue water footprint in sustainability reports to show that the company is working with the issue.
- Compare the blue water footprint of different sites manufacturing similar products.
- Formulate goals for water consumption and motivate these goals with the Blue Water Footprint analyses.
- Identify what processes and areas of usage consume the most water and find hotspots.
- Use the Blue Water Footprint methodology to identify what needs to be known about water consumption in order to sort information and determine what needs to be known in a sustainability context.
- Compare the blue water footprint with the grey in order to see what the largest sustainability issues are related to water.

For Grey Water Footprint, we recommend that Volvo Car Corporation should do the following.

- Volvo Car Corporation should at present not put to much resources into Grey Water Footprint, like for example install expensive equipment, since more improvement such as standardizing is needed before the indicator is ready to be used to its full potential. However, estimates at site level should still be undertaken.
- Keep up to date with the development of the Water Footprint methodology in so that once it is fully developed, the company will be in a leading position. The tool presented in this thesis can easily be adapted to updates.
- Present the grey water footprint in sustainability reports to show that the company is working with the issue.

References

Baumann H. and Tillman A.M., 2009, The Hitch Hiker's Guide to LCA, Studentlitteratur, Sweden.

CCME, 1999, Canadian Water quality guideline for the protection of aquatic life; Introduction, http://ceqg-rcqe.ccme.ca/, Canada.

CCME, 2007, Canadian Water quality guideline for the protection of aquatic life; Summary table, http://ceqg-rcqe.ccme.ca/, Canada.

Chapagain A.K. and Orr S., 2010, Water Footprint of Nestlé's "Bitesize Shredded Wheat", WWF, the Netherlands.

Ehlin U., Lindahl S., Neuman E., Sandström O. and Svensson J., 2009, Miljöeffekter av stora kylvattenutsläpp, Elforsk, Sweden.

Ercin A.E., Aldaya M.M. and Hoekstra A.Y., 2009, A Pilot in Corporate Water Footprinting Accounting and Impact Assessment, UNESCO-IHE, the Netherlands.

EU, 2006, Directive 2006/44/EC of the European Parliament and of the Council of 6 Sepember 2006.

EU, 2008, Directive 2008/105/EG of the European Parliament and of the council of 16 dec 2008.

Gerbens-Leenes P.W. and Hoekstra A.Y., 2008, Business Water Accounting, UNESCO-ICH, the Netherlands.

Hoekstra A.Y. and A. K. Chapagain, 2008a, Globalization of Water, Blackwell Publishing, the Netherlands.

Hoekstra A.Y., 2008b, Water Neutral, UNESCO-ICH, the Netherlands.

Hoekesta A.Y., Chapagain A. K., Aldaya M. M. and Mekonnen M. M., 2009, Water Footprint Manual, Water Footprint Network, the Netherlands.

Hoekstra, 2010, email correspondence with Arjen Hoekstra, 14/10 2010.

ISO 14041, 1998, Environmental Management - Life Cycle Assessment - Goal and Scope Definition and Inventory Analysis, International Organization for Standardization.

ISO, 2010, ISO considers potential standard on water footprint, http://www.iso.org/iso/iso-focus-plus_index/iso-focusplus_online-bonus-articles/isofocusplus_bonus_water-footprint.htm.

Naturvårdsverket 1999, Bedömnings grunder för miljökvalitet; Sjöar och vattendrag, Rapport 4913, Sweden.

Naturvårdsverket, 2008, Förslag till gränsvärden till särskilda förorenande ämnen, Rapport 5799, Sweden.

Naturvårdsverket, 2010, Bedömning av föroreningsnivå, http://www.naturvardsverket.se/sv/Tillstandet-i-miljon/Bedomningsgrunder-for-miljokvalitet/MIFOFororenade-omraden/Fororeningsnivaer/, Sweden.

UN Water, 2010, New Glaas Report, from http://www.unwater.org/activities_GLAAS2010.html.

Water Footprint Network, 2010, National Water Footprints, from http://www.waterfootprint.org/?page=cal/waterfootprintcalculator_national, the Netherlands.

A Detailed Results of Data Collection

In this appendix the collected values for the maximum acceptable and natural concentrations of the substances included in the tool are presented. The source of each value is also given. Table 2 show the collected values for the database for Sweden, table 3 is for the database of Belgium.

Substance	c_{max} $[\mu g/l]$	Data Source	c_{nat} $[\mu g/l]$	Data Source
B	700	Parameters for Belgium[4]	Missing	
Cd (Depending on water hardness in $CACO_3$ (mg/l))	0.08 (< 50) 0.09 (< 100) 0.15 (< 200) 0.25 (>= 200)			
Cr	3	Swedish recommended values[2]	0.2	Estimated values for Sweden[5]
Cu	4	Swedish recommended values[2]	1	Estimated values for Sweden[5]
Fe	300	Canadian Guidelines[3]	Missing	
Fluoride	260	Study about fluorides[6]	Missing	
Hg	0.05	European directive[1]	0.0001	Estimated values for Sweden[5]
Mn	50	Canadian Guidelines[3]	Missing	
N	1250	Estimated values for Sweden[5]	300	Estimated values for Sweden[5]
Ni	20	European directive[1]	0.5	Estimated values for Sweden[5]
Oil	Missing		Missing	
P compounds	50	Estimated values for Sweden[5]	12.5	Estimated values for Sweden[5]
Pb	7.2	European directive[1]	0.05	Estimated values for Sweden[5]
Sulphate	Missing		Missing	
TOC	Missing		Missing	
Zn	30	Canadian Guidelines[3]	3	Estimated values for Sweden[5]

Table 2: The data collected for Sweden. [1] EU, 2008, Directive 2008/105/EG of the European Parliament and of the council of 16 dec 2008. [2] Naturvårdsverket, 2008, Förslag till gränsvärden till särskilda förorenande ämnen, Rapport 5799. [3] CCME, 2007, Canadian Water Quality Guidelines for the Protection of Aquatic Life; Summary table, http://ceqg-rcqe.ccme.ca/ 13 dec 2010. [4] Document given to Volvo with the maximum acceptable concentrations for Belgium. [5] Naturvårdsverket 1999, Bedömningsgrunder för miljökvalitet; Sjöar och vattendrag, Rapport 4913.

Substance	c_{max} [$\mu g/l$]	Data Source	c_{nat} [$\mu g/l$]	Data Source
B	700	Parameters for Belgium[4]	Missing	
Cd (Depending on water hardness in $CACO_3$ (mg/l))	0.08 (< 50) 0.09 (< 100) 0.15 (< 200) 0.25 (>= 200)			
Cr	5	Parameters for Belgium[4]	0.2	Estimated values for Sweden[5]
Cu	7	Parameters for Belgium[4]	1	Estimated values for Sweden[5]
Fe	300	Canadian Guidelines[3]	Missing	
Fluoride	260	Study about fluorides[6]	Missing	
Hg	0.05	European directive[1&4]	0.0001	Estimated values for Sweden[5]
Mn	50	Canadian Guidelines[3]	Missing	
N	1250	Estimated values for Sweden[5]	300	Estimated values for Sweden[5]
Ni	20	European directive[1&4]	0.5	Estimated values for Sweden[5]
Oil	Missing		Missing	
P compounds	50	Estimated values for Sweden[5]	12.5	Estimated values for Sweden[5]
Pb	7.2	European directive[1&4]	0.05	Estimated values for Sweden[5]
Sulphate	Missing		Missing	
TOC	Missing		Missing	
Zn	20	Parameters for Belgium[4]	3	Estimated values for Sweden[5]

Table 3: The data collected for Belgium. [1] EU, 2008, Directive 2008/105/EG of the European Parliament and of the council of 16 dec 2008. [2] Naturvårdsverket, 2008, Förslag till gränsvärden till särskilda förorenande ämnen, Rapport 5799. [3] CCME, 2007, Canadian Water Quality Guidelines for the Protection of Aquatic Life; Summary table, http://ceqg-rcqe.ccme.ca/ 13 dec 2010. [4] Document given to Volvo with the maximum acceptable concentrations for Belgium. [5] Naturvårdsverket 1999, Bedömningsgrunder för miljökvalitet; Sjöar och vattendrag, Rapport 4913.

B Blue Water Trends

In this section two graphs that shows VCC's historical development of its blue water footprint is presented. In figure 18 the operational blue water footprint of Volvo Car Corporation can be seen. The five VCM sites have been included since it has been decided that they can represent the operational blue water footprint of the company. In figure 19 the operational blue water footprint per car can be seen. All the cars manufactured by the company are included, even if they have been assembled in assembly-plants. The data for these two diagrams has been taken from an internal document at VCC that contains water consumption of bought water and number of manufactured cars.

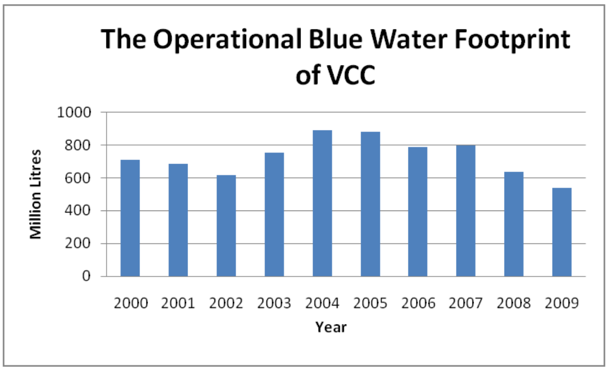

Figure 18: The operational blue water footprint of VCC for different years.

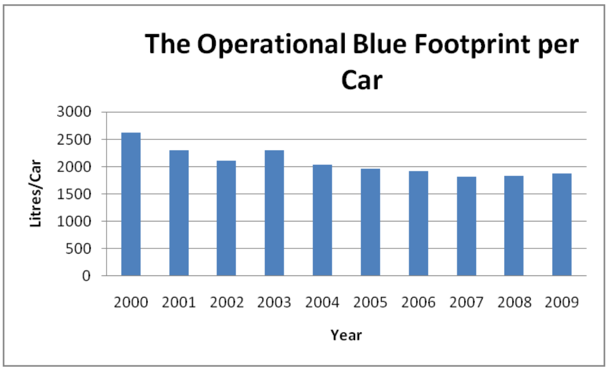

Figure 19: The operational blue water footprint per car of VCC for different years.

C Example of Results for an Imaginary Site

In this section an example where the tool has been used for an imaginary site to show which diagrams that the tool generates at site level is presented. The data added to the tool is completely fictional and has nothing to do with any real sites.

In figure 20 the division between the three usage areas; process water, sanitary water and cooling water can be seen. The diagram also contains the total blue water footprint of the site and how much of the footprint for each area of usage that is unknown.

Figure 21 shows the division of the blue water footprint between six different processes. For each process, the area of usage is given. It is also shown how much water of each area of usage not attributed to any process.

The division of the critical grey water footprint of the site between waste water, storm water and rainwater can be seen in figure 22. In figure 23 it can be seen from which processes that the critical grey water footprint come from.

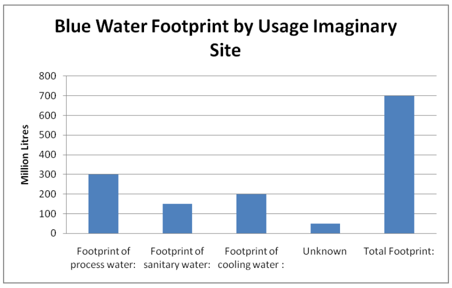

Figure 20: The division of the blue footprint in usage areas.

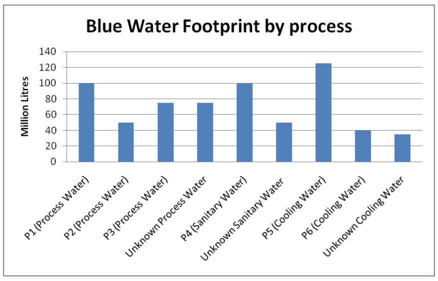

Figure 21: The blue water footprint of the processes.

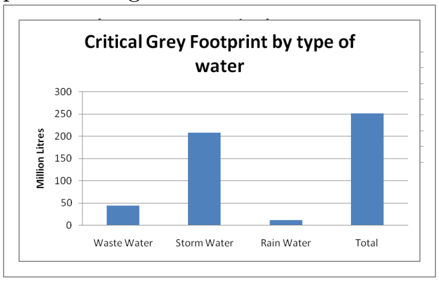

Figure 22: The division of the critical grey water footprint by type of waste water.

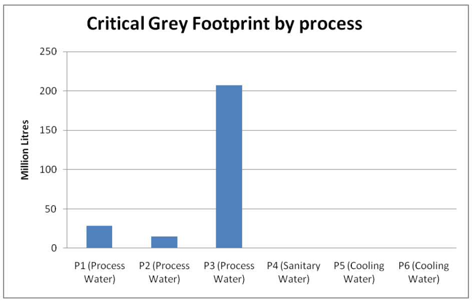

Figure 23: The critical grey water footprint of the processes.

D Data Used for the Example in Section 4.2.4

In this section the data used for the example in section 4.2.4 is presented. In table 4 it can be seen how much water in that has been added for each site for calculation of the blue water footprint. This data was taken from an internal document at Volvo that contained the amount of bought water in 2009. In table 5 the data that was added for calculation of the grey water footprint can be seen. This data was taken from the environmental report for 2009 for each site.

Site	Amount of Water in [Million Litres]
Torslanda	250
Ghent	170,115
Olofström	68,085
Skövde	42,129
Floby	10,85

Table 4: The added data to the tool for blue water.

Substance	Torslanda Waste Water	Torslanda Storm Water	Ghent Storm Water	Olofström Waste Water
Amount of Water out [Million Litres]	1238,54	42,408	101,523	8,589
Cd [mg/l]				0,0093
Cr [mg/l]	0,0047	0,005		0,047
Cu [mg/l]				
Fe [mg/l]				
Hg [mg/l]				
Mn [mg/l]			0,28	
Ni [mg/l]	0,012	0,027	0,23	0,048
P compounds [g/l]		0,34	0,53	
Pb [mg/l]	0,0047	0,005		
Zn [mg/l]	0,17	0,05	0,11	0,05
B [mg/l]			28,8	

Table 5: The data added to the tool for the grey water calculation.

E Questionnaire to VCM Environmental Coordinators

The following questionnaire was sent to the environmental coordinators at the VCM-plants Floby, Olofström and Skövde. In Torslanda the questions were answered orally by Christer Drougge and Allan Dunevall.

1. Vi har tillgång till värden för den årliga vattenkonsumtionen för varje fabrik. Inkluderas någonting utöver fabrikens inköpta vatten i detta värde? Floby: Nej Olofström: (2010) 72805m^3 + sjövatten för processkylning nedre fabriks området. Skövde: Nej.

2. Går det att mäta hur stor del av vattenflödet som går till processer, sanitärt brukrespektive kylvatten? Floby: Ja. 30Olofström: Troligenmen kräver noggrannare analys av tillgänglig data. Skövde: Det är svårt att genomföra då det krävs väldigt många mätare.

3a. Till vilka processer i fabriken använder man huvudsakligen vatten? Floby: Ytbehandlingen, tvättmaskiner, emulsioner bearbetning, slipning Olofström: Betanläggning, reningsverk, verktygstvätt, inspädning för kylkrets och sanitärt. Skövde: Skärvätskesystem, kylvatten och tvättmaskiner.

3b. Mäter man vattenflödet till några av dessa processer? I så fall vilka? Floby: Vattenmätare på dom flesta processutrustninger, översyn kommer att utföras Olofström: Reningsverket ja, övriga processer osäkert om vi har denna möjlighet. Skövde: Skärvätskesystem och kylvatten.

3c. Hur ofta och på vilket sätt dokumenteras de flöden man mäter? Floby: Olofström: Månatligen Skövde: Flöden på total vattenförbrukning och förbrukningen i skärvätskesystem, kylvattensystem rapporteras månadsvis till Skövde Kommun.

3d. Hur många ytterligare flödesmätare skulle man uppskattningsvis behöva installera för att kunna mäta alla betydande flöden i fabriken? Floby: Ca.5-7 st vattenmätare Olofström: 10-20st. Skövde: Tvättmaskiner, uppskattningsvis 10-15 mätare.

4a. Finns det flödesmätare på in- och utflödet på existerande kylvattensystem? Floby: Floby har slutet kylsystem. Olofström: Delvis. Skövde: Det finns energimätare/flödesmätare som mäter de olika fabriksdelarna.

4b. Hur ofta och på vilket sätt dokumenteras i så fall dessa flöden? Floby: Olofström: Loggas i styrdator. Skövde: Går att logga värden i vårat styr och övervakningssystem.

Endast Olofström: Gör man några mätningar på temperaturen på in- och utflödet på det öppna kylsystemet i fabriken? Ja.

5a. Utförs mätningar av föroreningshalter i utflödet av några processer? I så fall vilka processer och vilka ämnen? Floby: Olofström: . Ja. Hårdhet, alkalitet, klorid, pH, konduktivitet, fosfat, ledningsförmåga Skövde: I dagvatten mäts oljeindex 1 gång/månad och årsvis mäts metaller. Spillvatten kontrolleras två gånger/år. Skickar med protokoll från mätningar som Allan Dunevall genomför.

5b. Hur ofta utförs i så fall dessa mätningar och hur dokumenteras de? Floby: Olofström: 6ggr/år, analysprotokoll Skövde: Se Ovan

The following questionnaire was sent to the environmental coordinator In Ghent. Some questions were later answered orally.

1. We have acces to the annual water consumption of the factory in Ghent. Is any other water flow than bought water to the Volvo factory included in this number? The only incomming water is citywater. Study ongoing for the re-use of rainwater

2. Is it possible to measure how much of the water that is used for processes, sanitary appliancies, and cooling water systems, respectively? Yes, for 90% of the processes (measurements/estimations)

3a. In what processes within the factory is water mainly used? Installations to create demineralistion water. This is water mainly used in our diphosfation and electrocoat process and sanding lines

3b. Is the water flow to any of these processes measured? If so, what processes? Yes , all.

3c. How often and in what way are these flows recorded? Continuesly measurement

3d. How many more flow meters would have to be installed to make it possible to measure all large flows within the factory? None

4a. Are there flow meters on the in and out flows from existing cooling water systems? 75 % of our cooling water systems are covered. The no covered installations are the small ones.

5a. Are measurements of pollutants taken in connection to any processes? If so, what processes and what pollutants? What do you mean with this question. Do we take about the measurements on the discharge waste water ?

5b. How often are these measurements taken and how are they recorded?

F User's Manual for the Water Footprint Accounting Tool

The Water Footprint Accounting Tool created for Volvo Car Corporation is a Microsoft Excel based computer application. The tool is custom made for calculating the operational blue and grey water footprints of industrial sites in general, and for the Volvo Car Manufacturing sites in particular. This is a manual describing how to use the tool for its intended purpose.

The Water Footprint Accounting Tool is divided in two separate Microsoft Excel workbooks; one named The Tool and one named The Database. In order to use the tool, both workbooks must be located in the same folder in the computer's file system. Otherwise, the tool will not function.

The Tool Workbook

The *The Tool* workbook is where site and process data is entered and where all Water Footprint calculations are made. To begin with, the workbook only consists of one worksheets named *Start*. New worksheets are generated automatically using the buttons on the *Start* worksheet.

Adding a New Site to the Analysis

This section explains how to calculate the operation blue and grey water footprint of an industrial site. For the blue water footprint, the values to be entered are water going in to the site and water leaving the site; water flows within the site is of no interest at a site level. For the grey water footprint, the pollution concentrations of all flows are the concentrations in the water leaving the site, i.e. after any possible on-site treatment plants but before possible municipal treatment plants. The following list is a guide for calculating the operational Blue and grey water footprint of an industrial site using the Water Footprint Accounting Tool.

1. Click the *Add Site* button on the *Start* worksheet in the *The Tool* workbook and a window appears.
2. Enter the name of the new site.
3. Chose which region the site is located in.
4. Chose a municipal treatment plant that the site's water is treated in.
5. Click OK and two worksheets are automatically generated. One is named *Site Name* and one is named *Name Datasheet*, where *Name* is the name chosen for the new site.
6. To calculate the operational blue water footprint of the site, enter values in the dark grey cells in the B column of the *Site Name* worksheet.
7. To calculate the operational grey water footprint related to waste water flows that are treated in a municipal treatment plant, enter the corresponding values in the dark grey cells in the E column of the *Site Name* worksheet.

8. To calculate the operational grey water footprint related to storm water flows not treated in any municipal treatment plant, enter the corresponding values in the dark grey cells in the G column of the *Site Name* worksheet.

9. To calculate the operational grey water footprint related to rainwater, enter the corresponding values in the dark grey cells in the I column of the *Site Name* worksheet.

10. If the water going in to the site is untreated before use, enter values for pollution levels in the in-going water for each pollutant in the dark grey cells in column K.

11. The calculated values appear in the *Datasheet Name* worksheet.

To remove an unwanted site from the analysis, simply delete the two worksheets related to the site.

Add a New Process to the Analysis

1. Click the *Add Process* button on the *Start* worksheet and a new window appears.

2. Enter the name of the new process.

3. Chose which site the process is connected to.

4. Chose an on-site treatment plant that the water from the process is treated in, if any.

5. Click OK and two worksheets are automatically generated. One is named *Site Name Process* and one is named *Site Name Datasheet*, where *Site* is the name of the site where the process is located and *Name* is the name chosen for the new process.

6. To calculate the operational blue water footprint of the process, enter values in the dark grey cells in the B column of the *Site Name Process* worksheet.

7. To calculate the operational grey water footprint related to waste water flows from the process that are treated in a municipal treatment plant, enter the corresponding values in the dark grey cells in the E column of the *Site Name Process* worksheet.

8. To calculate the operational grey water footprint related to storm water flows from the process not treated in any municipal treatment plant, enter the corresponding values in the dark grey cells in the G column of the *Site Name Process* worksheet.

9. The calculated values appear in the *Site Name Datasheet* worksheet.

To remove an unwanted process from the analysis, simply delete the two worksheets related to the process.

Automatically Generating Graphs

To generate graphs depicting the calculated operational water footprints of various sites included in the analysis, simply click the *Generate Results* button on the *Start* worksheet in the *The Tool* workbook. A number of new worksheets will automatically be generated; one named *Result Sheet*, one named *Data Collection Sheet* and one sheet for each site entered into the tool. Clicking the *Generate Results* button will delete all previously generated graphs so be sure to save graphs of interest that might have been changed since last generating graphs.

The worksheet named *Result Sheet* contains two graphs depicting information for all sites included in the analysis. The graphs are:

- A graph showing the operational blue water footprint for each site and the total operational blue water footprint for all included sites added together.
- A graph showing the operational critical grey water footprint for each site and the total operational critical grey water footprint for all included sites added together. It is important to note here that the combined grey water footprint is the sum of the grey water footprints of the critical pollutants for each site. This means that it is possible, or even likely, that it is a sum of different pollutants since different sites can have different critical pollutants.

For each site included in the analysis, a worksheet containing five different graphs is generated. These graphs are the following:

- A graph showing the blue water footprint divided on the three different areas of usage; processes, sanitation and cooling systems.
- A graph showing the blue water footprint divided on processes.
- A graph showing the grey water footprint arising from each pollutant.
- A graph showing the the grey water footprint for of the criticial pollutant for each process.
- A graph showing the critical grey water footprint for the three different polluted water flows; waste water, storm water and rainwater.

Using the results from the Water Footprint Accounting Tool, many more graphs depicting various trends can be made. However, the ones described above are the only ones that can be automatically generated.

What Data is Needed for The Tool?

To calculate the operational blue water footprint at a site level using the tool, all data that is needed is the amount of water going in to the site and the amount of water going back to its origins. It is also possible to distinguish between the three different areas of usage; process water, sanitation and cooling systems. The water intake to each of these areas of usage can be entered into the *The Tool* workbook as well. If no such values are available, simply exclude them.

To calculate the operational grey water footprint at a site level using the tool, the data needed is the volume of water and pollution concentrations of the water flows going to the waste water system and the storm water system, respectivelly. These flows need to be measured at the point where the water is leaving the site, so after any on-site treatment plants but before any municipal treatment plants. Also, polluted rainwater can be included in the analysis. For this, the total area of the hard surfaces of the site and the mean annual precipitation is required as well as the mean pollution concentrations in the rain water.

To calculate the operational blue water footprint of a process using the tool, the data needed is the amount of water used in the process and the amount of this water that returns to its origins.

To calculate the operational grey water footprint of a process using the tool, the data needed is the volume of polluted water going out of the process and the pollution concentrations in that water. This means that measurements must be made before the water is treated in any on-site treatment plant.

The Database Workbook

The *The Database* workbook contains all information that is used to calculate the blue and grey water footprint of industrial sites. This includes the maximum acceptable and natural concentrations of the regions where the sites are located, the cleaning rate of municipal and on-site treatment plants connected to the studied sites, and all template worksheets generated in the *The Tool* workbook on demand. The *The Tool* workbook reference information in the *The Database* workbook so information added to the database will be readily available in the tool.

The *The Database* workbook consists of a number of worksheets. It is very important not to remove any of the pre made worksheets since it may cause the workbook to not function properly. There are five different types of worksheets; the user interface worksheet, template worksheets for the *The Tool* workbook, region worksheets, municipal treatment plant worksheets and on-site treatment plant worksheets.

The worksheet named *Start* is the user interface of the *The Database* workbook. The *Start* worksheet is equipped with six buttons; *Add Pollutant*, *Remove Pollutant*, *Add Region*, *Add Municipal Treatment Plant*, *Add On-Site Treatment Plant* and *Update Frontpage*. The buttons are coupled with macros that automatically generate information when clicked.

Adding a Substance

It is possible to add additional substances to the database. This is done as follows.

1. Click the *Add Pollutant* button on the *Start* worksheet.
2. Enter the name of the new pollutant and click OK.

3. The pollutant will appear automatically in all worksheets in the *The Database* workbook. Maximum acceptable and natural concentrations for the new pollutant must be added manually in the region worksheets and cleaning ratio of the treatment plants must be added to the municipal and on-site treatment plant worksheets.

Removing a Substance

It is possible to remove unwanted substances from the *The Database* workbook. This is done as follows.

1. Click the *Remove Pollutant* button on the *Start* worksheet.
2. Chose the pollutant to remove from the list and click OK.
3. The pollutant is automatically removed from all worksheets in the *The Database* workbook.

Adding Region Worksheets

The region worksheets contain the natural and maxiumum acceptable concentrations of pollutants in specific regions. A new region is added as follows:

1. Click the *Add Region* button on the *Start* worksheet.
2. Enter the name of the new region and the water hardness in the window that appears.
3. Click the OK button in the window. A new worksheet with the name *Database Name* will be automatically generated, where *Name* is the name chosen for the region.
4. Click on the worksheet tab and enter the values for the natural and maximum acceptable pollution concentrations manually.

Adding Municipal Treatment Plant Worksheets

The municipal treatment plant worksheets contain the cleaning rate of municipal treatment plants. A new municipal treatment plant is added as follows:

1. Click the *Add Municipal Treatment Plant* button on the *Start* worksheet.
2. Enter the name of the new municipal treatment plant in the window that appears.
3. Click the OK button in the window. A new worksheet with the name *Name MT* will be automatically generated, where *Name* is the name chosen for the treatment plant.
4. Click on the worksheet tab and enter the ratio between the values for the ingoing and outcoming amounts of pollution to and from the treatment plant manually.

Adding On-Site Treatment Plant Worksheets

The on-site treatment plant worksheets contain the cleaning rate of on-site treatment plants. A new on-site treatment plant is added as follows:

1. Click the *Add On-Site Treatment Plant* button on the *Start* worksheet.
2. Enter the name of the new on-site treatment plant in the window that appears.
3. Click the OK button in the window. A new worksheet with the name *Name OST* will be automatically generated, where *Name* is the name chosen for the treatment plant.
4. Click on the worksheet tab and enter the ratio between the values for the ingoing and outcoming amounts of pollution to and from the treatment plant manually.

Removing Region and Treatment Plant Worksheets

Sometimes, it can be useful to remove region or treatment plant worksheets from the *The Database* workbook. This is done simply by right clicking the worksheet to remove and then clicking the delete option. In order for the frontpage information to be correct; after deleting a worksheet, click the *Update Frontpage* button on the *Start* worksheet. Do not delete any of the default worksheets since the tool might not work if this is done.

What Data is Needed for The Database?

When adding a new region to the database, the data needed is the maximum acceptable and natural pollution concentrations in that region.

When adding a treatment plant, municipal or on-site, the data needed is the ratio between the amount of pollutants going out of the treatment plant and the amount of pollutants going in to the treatment plant on an annual basis. Often, the available data is the amount of pollutants going in to the treatment plant and the amount of pollutants leaving the treatment plant. Dividing the outgoing pollution with the incoming must be made outside the *The Database* and the calculated ratio must be entered manually.