CHALMERS
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Runoff management on bridges

A decision model for management selection

Master's Thesis in the Master's Programme Infrastructure and Environmental Engineering

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ABSTRACT

Many of the bridges in Sweden have previously been constructed without taking pollutants from runoff into account. This means that there are bridges which do not fulfil necessary runoff pollution requirements of today due to the regulation framework not being established until the late 1990s. The risks for the receiving waters from bridge runoff can mainly be divided into two categories; stormwater pollution and spill events which both needs to be taken into consideration when designing runoff management systems. The purpose of this study was to create a basis for how and when to manage runoff from bridges in Sweden due to the present lack of clear and consistent guidelines. This resulted in a general decision model, based on existing literature and regulations, which can be used on a national level. It includes risk assessments of spill events with dangerous goods vehicles and heavy goods vehicles and the model provides a result with a choice of measure in terms of runoff management while following regulations to the extent possible. The general decision model has been evaluated via a case study of the bridge Angeredsbron in Gothenburg which resulted in spill management recommendations, fulfilling the local environmental regulations. The thesis concludes that there is reason to question the reasonableness of the regulations in some cases. It is therefore recommended that the Swedish Transport Administration, in consultation with concerned authorities and agencies, together looks over and revises current regulations with the purpose of making them easier to interpret. The conducted risk assessment showed that the risks of spill events are generally to be considered as negligible. This concludes that the risk should not govern the selection of management system. Instead the need for protection of the receiving water should be the controlling factor.

Key words: Bridge runoff, Runoff management, Spill management, Stormwater pollution, Water protection area, Risk assessment, Decision model, Dangerous goods vehicles, Heavy goods vehicles, Angeredsbron

Dagvattenhantering på broar

En beslutsmodell för val av åtgärd

Examensarbete inom masterprogrammet Infrastructure and Environmental Engineering

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SAMMANFATTNING

Många broar i Sverige har tidigare konstruerats utan att ta hänsyn till föroreningar från dagvatten och miljöfarliga utsläpp. Detta medför att det finns broar som inte uppfyller dagens krav på utsläppsnivåer och hantering av spill med anledning av att regelverket inte var etablerat förrän i slutet av 1990-talet. För recipienten kan riskerna med avrinning från broar klassificeras till två kategorier; dagvattenförorening och utsläppshändelser. Båda dessa måste tas i beaktning när ett hanteringssystem för avrinning tas fram. Syftet med denna studie var att skapa ett ramverk för hur dagvattensystem hanteras på broar i Sverige eftersom det idag saknas tydliga och konsekventa riktlinjer. Detta resulterade i en generell beslutsmodell, baserad på befintliga studier och föreskrifter, som kan användas på nationell nivå. Den inkluderar en riskanalys för spillhändelser med farligt gods fordon och tung trafik och ger ett åtgärdsval för dagvattenhantering som resultat samtidigt som den följer existerande regelverk i största möjliga utsträckning. Den generella beslutsmodellen har utvärderats via en fallstudie av Angeredsbron i Göteborg. Studien resulterade i rekommendationen av ett spillhanteringssystem, vilket uppfyller de lokala miljökraven. Detta examensarbete drar slutsatsen att det finns anledning att ifrågasätta rimligheten av kravställningen i några fall. Det är därför rekommenderat att Trafikverket, i samråd med berörda myndigheter och organisationer, tillsammans ser över och reviderar de befintliga kraven med syfte att tydliggöra tolkningen för verksamhetsutövaren. Riskanalysen visade att händelser med resulterande spill generellt bör ses som försumbara. Detta innebär att det inte är risken som ska styra valet av dagvattenhanteringssystem utan skyddsbehovet av den berörda recipienten.

Nyckelord: Broavrinning, Dagvattenhantering, Spillhantering, Dagvattenförorening, Vattenskyddsområde, Riskanalys, Beslutsmodell, Farligt gods, Tung trafik, Angeredsbron

Table of contents

Preface

This Master of Science thesis was conducted at the Investment Department at Trafikverket, in Gothenburg, between January and June in 2016. The project was initiated in November, 2015, when the local Environmental Administration observed the lack of a spill management system on the bridge Angeredsbron in Gothenburg.

We would like to extend our gratitude to our supervisor at Trafikverket, Johan Jansson, for his constructive feedback and guidance to provide material during our project. We appreciate the freedom we have been given to develop the project around our own ideas. We would also like to thank our examiner Thomas Pettersson at the division of Water Environment Technology.

Lastly we are grateful for the employees at the Planning Department and Maintenance Department for their assistance with our many questions during the work with the thesis.

Gothenburg June 2016

Johan Blomberg and Tobias Jonsson

Abbreviations

AADT	Annual Average Daily Traffic
DGV	Dangerous Goods Vehicles
EU	European Union
HGV	Heavy Goods Vehicles
MSB	Myndigheten för Samhällsskydd och Beredskap, Swedish Civil Contingencies Agency
NVDB	Nationell Vägdatabas, National Road Database
PAH	Polycyclic Aromatic Hydrocarbon
PFC	Permeable Friction Course
SGU	Sveriges Geologiska Undersökning, Geological Survey of Sweden
STRADA	Swedish Traffic Accident Data Acquisition
TRV	Trafikverket, Swedish Transport Administration
TRVK/TK	Trafikverkets Tekniska Krav, The Swedish Transport Administration's Technical Requirements
VGU	Vägar och Gators Utformning, Design of Roads and Streets
VISS	Vatteninformationssystem Sverige, Water Information System Sweden
WPA	Water Protection Area

1 Introduction

Many of the bridges in Sweden have previously been constructed without taking the stormwater pollutants from bridge runoff and the risk of spill events from Dangerous Goods Vehicles (DGV) and Heavy Goods Vehicles (HGV) into account. Today the management of runoff on bridges is regulated by discharge requirements of the receiving waters on local levels. This means that there are bridges which do not fulfil necessary runoff pollution requirements of today due to the regulation framework not being established until the late 1990s. In addition to this, bridges are often crossing bodies of water which may be important resources for the society. The bodies of water are exposed to direct discharge from the bridges since there in many cases are no runoff pollutant management systems built. This poses a great risk, especially in case of a DGV discharge event. The risks for the receiving waters can mainly be divided into two categories; stormwater pollution and spill events. The stormwater is a continuous discharge which can affect the receiving waters in a long-term perspective, while spill events are highly contaminating point discharges. Both categories of pollutions need to be taken into consideration when designing a bridge runoff management system. In order to manage these risks, existing design models for managing stormwater needs to be assessed and developed.

1.1 Aim

The purpose of this study is to create a basis for how and when to manage runoff on bridges in Sweden, especially those located in protected areas. The focus will be on developing a general decision model which can be used on a national level. The model should take present scientific studies as well as national and local regulations into account. The result from the model should include what choice of measure, in terms of runoff management, is needed for a specified bridge.

1.1.1 Objectives

- Study existing projects and scientific reports, both national and international, within the field of runoff management on bridges.
- Compile the results from the literature study into a general decision model regarding how and when to select stormwater and spill management systems on bridges.
- Conduct a risk assessment regarding events resulting in spill from DGV and HGV on bridges and implement the results in the decision model.
- Evaluate the general decision model by conducting a case study of the bridge Angeredsbron, Gothenburg, and propose a choice of measure, in terms of runoff management, which fulfils the local environmental requirements.

1.2 Delimitations

The thesis will exclude railway bridges since the probability of a discharge event on a railway bridge is estimated to be very unlikely. Bridges crossing only land areas will mainly be excluded and focus will be on bridges crossing bodies of water since these types of constructions will be primary discharge points into the receiving waters. When looking into discharge scenarios it will be assumed that possible events with DGV or HGV will take place on the bridge deck. The majority of the transported hazardous substances are carried in DGV and in the fuel tanks of HGV. The probability of a spill is therefore restricted to HGV and DGV. Spill from car accidents is not considered in this thesis. The focus will be to develop a general decision model for Swedish road administrators and it is therefore based on Swedish conditions.

1.3 Methodology

In order to establish a basis for the thesis a literature study of both national and international experiences within the subject will be carried out. The research within the national field will include existing road bridge runoff management projects, existing runoff management regulations and scientific studies while the international research will be based primarily on scientific reports. When a foundation is established the results will be developed into a generally applicable decision model for selecting the appropriate choice of measure for bridges. A risk assessment regarding DGV and HGV discharge events will also be carried out as a support for the decision model. The model will then be evaluated by conducting a case study of Angeredsbron, situated in northern Gothenburg, where site specific conditions will be applied and a choice of measure for the selection of runoff management will be proposed. The results from the case study will be evaluated and the applicability of the decision model will be discussed.

2 Road stormwater

Stormwater can be defined as temporarily present runoff water from a surface of land or construction e.g. rainwater, melt water, effluent or emergent groundwater (Tekniska nomenklaturcentralen , 1994). When stormwater occurs in road surfaces or other hard surfaces within a road area, it is classified as road stormwater (Trafikverket, 2011). If road stormwater is present, it is important that the road is designed, in such a way, so that water can be led off the road surface and the embankments, both from a perspective of traffic safety and road durability and maintenance (Alm, 2010). During the time the stormwater is present on the road surface, it can collect and transport substances and materials that has been accumulated on the surface, or that has been washed off a passing vehicle (Trafikverket, 2011). Some of these substances or materials are to be considered as pollutants whose potential negative effects on its surroundings may need to be observed.

2.1 Pollution sources

Road traffic is a source of pollution (POLMIT, 2002). Throughout the life cycle of a road structure, both the road itself and the vehicles using it produce compounds that pollute runoff water. The compounds are derived from several sources which mainly are degradation of road surfaces, wear of vehicle components, road maintenance operations and leakage.

2.1.1 Degradation of roads

Every year about 130 000 tonnes of road surface materials are deposited to the surrounding areas in Sweden due to abrasion (Lindgren, 1998). The constituents of road pavement wear are dependent mainly on the type of pavement, where asphalt is the most common form (POLMIT, 2002). The asphalt consists of a mixture of bitumen and mineral aggregates. The bitumen contains traces of both metals and Polycyclic Aromatic Hydrocarbons (PAH), whereas the mineral aggregates tend to be natural geological materials. The road degradation particles are considered large in terms of pollutants, often larger than 100 µm. In regions with colder climate the use of studded tires will increase the wear of road surfaces. The paints and thermoplastic pastes used in road markings are also subjected to mechanical wear and will produce polluting particles.

2.1.2 Wear of vehicle components

The wear of vehicle components such as brakes, tires, engine parts and body work is hard to quantify since the various parts are constructed from different types of materials, which also varies between vehicle models (POLMIT, 2002). Studies estimate vehicular deposition of particles to be 0.31 g/km and vehicle during summer and 0.98 g/km and vehicle during winter. A large part of the deposited materials are metals such as zinc, copper, chromium, nickel, lead and iron.

In Sweden tires are estimated to produce 9 000 tonnes of particle waste from wear (Lindgren, 1998). A tire consists of about 85 % rubber mix, 12 % steel and 3 % textiles (POLMIT, 2002). Within the life cycle of a tire, it loses between 10-20 % of its total weight and is a large contributor to the total zinc deposited.

2.1.3 Maintenance operations

The operation causing the most severe water pollution, besides road and vehicle wear during transportations, is snow and ice control during winter (POLMIT, 2002). Road authorities are required to keep the roads safe and snow-free during winter. In order to do this, mechanical removal of snow is often applied but the ice removal is conducted by applying de-icing chemicals. The most common de-icing chemical is sodium chlorite, commonly called rock salt. The composition varies depending on the material source and may contain impurities such as iron, nickel, lead, zinc, chromium and cyanide. A large part of the applied salt will dissolve and discharge into the drainage systems.

Other maintenance operations such as mechanical sweeping are intended to keep streets and roads clean but may unintentionally cause pollution (POLMIT, 2002). The sweepers may break up litter in smaller components which can be transported by runoff water into the drainage system more easily.

2.1.4 Leakage, litter and spill

Pollutants coming from vehicles, besides regular wear, frequently contribute to the total pollution loading (POLMIT, 2002). Waste oils, hydraulic fluids, fuels, antifreeze fluids are examples of possible leakages from vehicles onto the roads. Litter can also be disposed in the roadside environment, which generally consists of large solids. The roadside vegetation removal operations then produce grit and organic solids by unintentionally shredding the litter into smaller components. These pollutants are hard to quantify due to the wide range of materials being released.

Leakages from vehicles, such as hydraulic systems, provide a discharge of fluid hydrocarbons and lubrication oils containing organic phosphates, metals and PAHs (POLMIT, 2002). Litter is usually not broken down easily in the environment and will result in increased levels of solids. Spill and leakage from events are not considered a major component in terms of total loading. However it is potentially the most severe source of contamination associated with roads due to the unpredictable nature of the involved materials and its volumes. This will be described in Chapter 3.

2.2 Discharge of stormwater

The most frequently occurring pollutants within a road area is mostly carried away airborne from the road surface, both in dry and wet weather condition. The pollutants are usually deposited within a few meters of the road surface (Trafikverket, 2011). The amount of pollutants being transported thorough air and runoff respectively, is depending on a series of parameters such as coating type, traffic load, wind conditions, climate, road gradient and width. It has been evaluated that less than 20 % of the pollutants are transported via runoff in some cases but under certain conditions it may also be close to 100 %. In the case of a bridge the situation with deposition via runoff or wind is especially important (NCHRP, 2014). The airborne deposition occurs when particulate matter that has been accumulating on the bridge deck is re-suspended by vehicles, or wind-induced turbulence. The particular matter can then be deposited into the receiving water below. This means that the wind deposited pollutants are not accessible for treatment, in comparison to an equivalent highway section where the re-suspended particles are caught by the highway shoulder area or along the adjacent road area. The effectiveness of collecting and treating bridge deck runoff is therefore likely modest. For the runoff deposition the pollutants are accumulated during dry periods, and possibly during low flows, on the road surface (Trafikverket, 2011). When heavier rainfall or snow melting occurs, the pollutants from the road surface can be collected and transported with the stormwater. This scenario is commonly called first flush and can be describes as the first proportion of surface runoff containing a significantly higher amount of pollutants.

Where the discharge of pollutants ends up is strongly dependent on the hydrogeological conditions (Trafikverket, 2011). In case of a discharge to roadside areas, infiltration and percolation to the groundwater occurs directly outside the hard surface area. In these cases most of the runoff pollutants can be expected to be collected in the road ditches. Some of the polluted stormwater is also distributed through splashes from vehicles. In this way pollutants generally end up on the side of the roads in an area of about 10-20 meters from the road. Surface runoff which is transported directly to a surface water receiving water is considerably more unusual but it occurs. Here it can be expected that all pollutants follows the same path as the water. An example of this type of scenario could be bridges crossing bodies of water.

3 Spill events

Major discharge events on roads can either originate from DGV or HGV. Previously it was considered that nature tolerated these types of discharges without taking damage. Today it is known that extensive damages can occur without evidence to the untrained eye (Fischer, 1994). In addition to this it has been shown that these types of damages to the environment often are very expensive to remediate.

When a spill event occurs, the environmental properties of a hazardous substance can be analysed based on a short-term and a long-term perspective (Fischer, 1994). The short-term perspective intends to handle the acute introduction phase where the circumstances often are extreme. This perspective is expected to be handled by the Emergency Service. The long-term perspective intends to handle the subsequent period that lasts as long as the substance is considered a threat to the environment. The long-term perspective is expected to be handled by the local authority of the Environmental Protection Agency.

3.1 Transportation of goods

A major part of the goods transportations in Sweden is conducted via roads, more particularly 86 % of the total amount of 584 million tonnes during 2010 (Trafikanalys, 2012). Based on the numbers from 2014 the total amount of transported kilometres with HGV was three billion (Trafikanalys, 2014). The most common fuel type is diesel with a tank volume from 500 to 1000 litres.

When goods, due to its chemical or physical properties, can cause damages on life, health, environment or property during transportation it is known as dangerous goods (MSB, 2015). Dangerous goods can for instance have explosive, flammable, toxic, radioactive or acidic properties. Swedish regulations for the transportation of dangerous goods have existed since the 1860s but in 1956 the European Union (EU) introduced The Orange Book. In Sweden this book is called ADR-S and it contains recommendations for the transportation of dangerous goods. These recommendations form the basis for the development of the regulations for the transportation types; road, railway, naval and aerial.

The transportation of dangerous goods on roads accounted for 74 million kilometres during 2014. Compared to the three billion kilometres of total HGV transportation, the transportation of dangerous goods accounted for 2.5 % (Trafikanalys, 2014). Dangerous goods are divided into nine main classes depending on its characteristics, see Table 1 (MSB, 2015). All substances in class 1 to 9, except class 7, meet the criteria for environmentally hazardous substances and should therefore be considered harmful to the environment. The classes that stand for most of the domestic transportations are class 2, 3 and 8, see Table 1 (Trafikanalys, 2014). Of these classes, flammable liquids accounted for the largest part of the total payload-distance during 2014. Flammable liquids are liquids whose flashpoint is less than or equal to 100°C (MSB, 2009). Some examples of flammable liquids are gasoline, heating oil, alcohols and many solvents.

Table 1 - Dangerous goods main categories and payload-distance during 2014 (Trafikanalys, 2014)

Class	Attribute	Payload-distance (million tonne-km)	Approximated distribution
1	Explosive substances and objects	0	0 %
2	Gases	287	21 %
3	Flammable liquids	527	38.5 %
4.1	Flammable solids, self-reactive substances and solid desensitized explosives	-	-
4.2	Self-igniting substances	5	0.4 %
4.3	Substances which emit flammable gases in contact with water.	-	-
5.1	Oxidizing substances	97	7 %
5.2	Organic peroxides	-	-
6.1	Toxic substances	5	0.4 %
6.2	Infectious substances	-	-
7	Radioactive substances	-	-
8	Acidic substances	326	24 %
9	Miscellaneous dangerous substances and objects	122	9 %
Total		**1369**	**100 %**

Discharge from spill events can cause long-term consequences, besides the short-term acute toxicity, for a receiving water (Naturvårdsverket, 2011). DGV transportation routes, within sensitive areas such as Water Protection Areas (WPA), are controlled by the local traffic regulations according to the Highway Code 1998:1276. The County Administrations and Swedish Civil Contingencies Agency (MSB) can determine and assign the recommended transportation routes. The traffic regulations govern both thoroughfare transports as well as transportations going to local operations within the area (COWI AB, 2015). More about WPAs is found in Chapter 4.1.

3.2 Event statistics

Even though the consequences of a discharge from either DGV or HGV could be severe, the likelihood of a spill event is low. An international study have analysed the frequency of spills associated with discharge to waterways (NCHRP, 2014). Over the 10-year period from 2003 to 2012 there were 140 500 reports of incidents from highways in the USA, with 97 % resulting in spill. Of these loading or unloading accounted for 78 % of the total number of incidents. To determine the discharge related to bridges only in-transit incidents were analysed. This resulted in 23 095 incidents, or 17 % of the total amount. However only 329 incidents where related to discharge into stormwater drains or waterways. Nine of these were identified as being associated with a bridge crossing a waterway. This concludes that these events are extremely rare and correspond to less than 0.01 % of all reported spills during the analysed period.

Similar results are acquired when looking into national statistics from the Swedish Traffic Accident Data Acquisition (STRADA). STRADA collects its data from both police reports and health care and has been in use since 2003 (Transportstyrelsen, 2016). From STRADA data has been acquired for both accidents with DGV and HGV from 2003 to 2013. Accidents with DGV are connected to the number on the vehicle body. This means that accidents with vehicles built for transporting dangerous goods, and with assigned body numbers, were chosen. This does however not necessarily mean that the vehicles were transporting dangerous goods at the time of the accidents. In the same way dangerous goods can be transported by unregistered vehicles and not found in these statistics. This does however give a good indication of the actual numbers. For HGV the total average number of accidents per year is 1 217 and of these an average of seven accidents/year has been identified as associated with bridges crossing a potential receiving water or within 50 m (Transportstyrelsen, 2016). Of the seven annual accidents six are minor accidents and one is a serious accident. For accidents related to DGV, an annual average based on the statistics from the analysed period can be calculated to 44 accidents/year. During this period only one accident has been identified to be connected to a bridge crossing a potential receiving water or within 50 m. When looking into the difference between minor and serious accidents, only serious accidents are estimated to have the potential to contaminate a receiving water. This concludes, in conjunction with the international studies, that these types of accidents are extremely rare.

In 2014 MSB published an event report for the years 2007 - 2012 on the transport of dangerous goods (MSB, 2014). The purpose of the report was to survey the reporting of events that have occurred in conjunction with the transportation of dangerous goods. This has based on accessible data which have been reported to MSB and the Swedish Transport Agency. During the period a total of 233 events regarding road transports were reported. Out of the total events, 130 events resulted in a leakage or a discharge, out of which 17 have caused some form of environmental damage.

3.3 Emergency response time

In case of a spill event with discharge of hazardous substances, the initial phase is crucial in order to contain the discharge. Since the degree of contamination of a receiving water is connected to the amount of discharged substance emergency responders whom are first at the site can affect the environmental outcome of the events. For most spill control management systems, a manual shutoff valve is usually operated to contain the discharge. This makes the emergency response time an important parameter when designing spill control management systems. Consultation with the emergency services considering a capacity increasing project for the highway E6 in Gothenburg in 2010 resulted in an estimated response time of 30-45 minutes (Trafikverket, 2010). This was confirmed during a consultation with the emergency services regarding possible spill management systems on Angeredsbron. 30-45 minutes was suggested to ensure that enough time can be given to prioritize life-saving measures before starting to contain the spill. The response time of 30 minutes is also applied by ODOT, Ohio Department of Transportation, in an American project from 2009, where the reconstruction of two road bridges, crossing a drinking water reservoir, required a spill containment system (NCHRP, 2014). Looking into the containment systems, the emergency services in Gothenburg stated during consultation that portable shutoff equipment is unusual in the emergency responder vehicles thus fixed shutoff devices are preferable (Trafikverket, 2010).

3.4 Discharge of spill

In the most acute introduction phase of a discharge, the diffusion occur from a more or less concentrated substance and a more gradual diffusion often occurs when the substance is diluted in the soil, air or water (Fischer, 1994).

In order to estimate the risk of diffusion it is important to clarify whether the substance occurs in gas, liquid or solid state (Fischer, 1994). A solid substance can occur in a varying degree of atomized form. The degree of atomization affects the dissolution rate in water. If a normally solid substance has been made liquid through heating, the dissolution in water is dependent on how the liquid is spread. If the diffusion occurs directly to the receiving water, the dissolution probably occurs very fast but if the resolution has time to harden, the diffusion occurs much slower. How a discharge is distributed in the environment can mainly be categorised as mobility in soil, mobility in air and mobility in water, where the mobility in water is studied further.

For the initial dispersion, the density of a hazardous substance is crucial when a discharge into water occurs. It either floats on the surface or it sinks to the bottom (Fischer, 1994). When the density is close to the density of water, the substance can act in different ways depending on the water movement e.g. ice conditions. If the substance is easily soluble in water it resolves quickly whilst in contact with water. The density in a long-term perspective can also be of interest when dealing with poorly soluble substances.

The viscosity can also be of interest when assessing the initial dispersion since a reduction of the viscosity often leads to an increase of the substances ability to disperse (Fischer, 1994). The viscosity is however only of interest as long as the substance is undiluted.

Water solubility is important to consider both for the short-term and the long-term dispersion of a substance (Fischer, 1994). The time that the substance is allowed to dissolve in water can be measured in minutes and hours from a short-term perspective and days and years when looking at the long-term perspective. For the short-term perspective it is important to look at the most acute situation when the substance has initially been introduced to the receiving water. The long-term perspective aims to a situation after the short-term perspective where the mobility of the substance is assessed for a longer period of time. This can imply that a substance which is insoluble in a short-term perspective is extensively soluble in a long-term perspective. On the basis of this reasoning, criteria for solubility have been assessed in Table 2.

Table 2 - Solubility criteria (Fischer, 1994)

Water solubility		**Short-term perspective**	**Long-term perspective**
%	grams/litre		
0.00001 -0.0001	<0.001	Insoluble	Very poorly soluble
0.0001 – 0.001	0.001 – 0.01	Very poorly soluble	Poorly soluble
0.001 - 0.01	0.01 – 0.1	Very poorly soluble	Moderately soluble
0.01 – 1	0.1 – 10	Poorly soluble	Freely soluble
1 – 10	10 – 100	Moderately soluble	Freely soluble
10 - 99	100 – 999	Freely soluble	Freely soluble
≥ 100	≥ 1000	Miscible	Miscible

The short-time perspective is most relevant when an outflow in water occurs and here it is primarily interesting to know if the substance is sufficiently insoluble in order to be collected on the surface (Fischer, 1994). For the long-term perspective the substance can end up in the sediments. This is particularly common for substances, such as heavy metals and pesticides that bind to soil particles.

4 Receiving water

Road bridges often cross lakes, streams and rivers and the receiving waters below are often important resources for the society. The water is part of the hydrological cycle which in brief terms means that the sun evaporates the water into steam which rise and gathers into clouds (SGU, 2008). When the clouds release their precipitation, the water either seeps into the groundwater or fills up the bodies of water, which then resumes the hydrological cycle. The amount of available water is fixed and no new water is added to the cycle. Less than one percent of the earth's water is available as drinking water resource. The water is approximately distributed as 97 % salt water, two percent stored as glaciers and one percent as fresh water. From that one percent fresh water, 95 % is stored as groundwater while the remaining five percent is in lakes, rivers and stream. In Sweden about 85 % of the population uses public and often municipal drinking water distribution facilities while the remaining 15 % uses private facilities (SGU, 2007). About half of the water is supplied from surface water and the rest is distributed evenly among groundwater and artificial ground water. This indicates the importance of protecting the surface water since the water source itself is a vital part of the drinking water systems. There are consequently high requirements for caution and protection against activities which can affect the water quality and quantity in a negative way.

4.1 Water Protection Areas

The purpose of the WPAs is to give bodies of water, which serve as resources for drinking water production, sufficient protection to ensure long term access to good quality raw water (Naturvårdsverket, 2011). The protection is directed both towards temporary discharges, such as spill from DGV and HGV, as well as continuous pollution, such as stormwater. By declaring a WPA the protection of the raw water source is increased, the importance of the water source is clearly stated and is included in physical plans and it is stated what is required of the different operators within the area to ensure the sufficient protection of the water source.

The basic level of protection that minimizes hazardous activities within the area of the water sources' proximity is essential (Naturvårdsverket, 2011). In addition to this, different levels of natural barriers are required, often in combination with technical solutions. The purpose is to create a respite before the contaminants may reach the critical areas. The barriers are considered as risk-reducing measures and the technical barriers can vary from treatments techniques within a drinking water plant to diversion of contaminated water. The natural barriers can be dense soil layers and dilution of the pollutants.

To determine the required level of protection for a water source a basis is gathered from the parameters value, vulnerability, risks and consequences (Naturvårdsverket, 2011). The starting point for determining a boundary for a WPA is different depending on the type of water bodies such as surface water, ground water and induced infiltration. For surface water the high velocity of the inflowing water to water bodies has to be taken into consideration as well as the difficulty to remediate a spill event. Therefore it is important to take preventive measures to reduce the probability of a spill event with a discharge of hazardous substances as a result. This is especially important for roads with transportation of dangerous goods in or near a WPA, where it is not possible to create respite before a discharge may reach the critical areas. Complementary systems such as warning and alarm systems can be installed to reduce the risk of contamination in for example in a raw water intake. The protection systems should also be able to handle diffuse pollution from the catchment area. The receiving water should be able to degrade, fix or dilute the pollutants to acceptable levels.

Water is the most essential resource in the society (Naturvårdsverket, 2011). It is therefore essential to estimate the value of a water body, used for drinking water production, when looking to define a WPA. The value can be derived from the available amount of water and its quality, present and eventual future withdrawal and the availability of other raw water sources in the neighbouring area. When specifically looking into surface water, there are other parameters which can be added as well, since the drinking water production and distribution are technical values. Social values such as fishing and recreation also have to be taken into consideration. To determine the value of a receiving water, used for drinking water production, one method is to determine the replacement value of the present water source to an equivalent in case the present becomes unusable. This method is useful to motivate investments in protective measures.

The vulnerability is a way to describe the resilience of an area towards pollution. This is primarily done for groundwater aquifers and there are several methods developed to determine this (Naturvårdsverket, 2011). The most basic versions use only geological parameters while more advanced take hydrogeology and hydrochemistry in account as well. The most important parameters are unsaturated zones thickness, soil composition and permeability. However, when classifying surface water two different pollution scenarios are taken into consideration. The first is direct discharge into the water surface and the second is discharge into the surrounding lands which then transport the pollutants to the receiving water. For direct discharge the vulnerability is extremely high since the pollutants rapidly can reach the water intake. When discharging into the surrounding lands the composition of the soils are important. If the soil is impermeable, for example clays, the vulnerability is high while with permeable soils, such as gravel and sands, the vulnerability is low.

The definition of risk is usually composed as the product of a given impact and the likelihood of its occurrence (Naturvårdsverket, 2011). The risk concept can also contain a subjective component since it is not always feasible to calculate quantitative probabilities for different risk categories or single risk objects. Therefore quantitative estimations can be used when making a risk assessment. Risk inventories should be conducted to identify all risk objects within the investigated area. The identified risks can be assigned to four main categories; water operations, operations and land usage within the catchment areas, sabotage and war, and finally extreme weather conditions and climate change. The operations and land usage are considered most important to this report and consist of HGV and DGV transportations. When the risks are identified a risk assessment regarding pollution type, concentration, way of deposition, time of duration and the possibility of remediation should be carried out. The risk assessment can be used when issuing permits to certain operations within the WPAs. A risk assessment for road operations will be studies in Chapter 5.

Depending on the type of pollutant the consequence for a receiving water can differ. Some pollutants can cause long term or irreversible damage (Naturvårdsverket, 2011). This can for example be different kinds of oil based compositions or chemical pesticides. These pollutants can stay in the water for long periods of time, and continuously affect the water source, before being degraded. The severity of a discharge also affect the consequence. If the water turns unfit for raw water the water source has to be replaced, often resulting in high expenses. If however the water quality is only slightly lowered it can be sufficient to add additional treatment when producing drinking water.

4.2 Discharge regulations

The process of establishing a WPA and the general process of preserving the quality of the water in Sweden is based on several laws and regulations.

4.2.1 EU framework directive

The most comprehensive is the EU framework directive 2000/60/EG, and the modifications and additions made in the Environmental Quality Standard 2008/105/EG, which is used as basis for the national regulation 2004:660 "Environmental Quality Standards for Surface and Groundwater" issued by the Environment and Energy Department (Regeringskansliet, 2004). The national regulation 2004:660 was complemented by the regulation 2007:825 with instructions to the County Administrations in 2007. The EU regulation provides the foundation for a common framework for the protection of inland water, coastal water and groundwater. The regulations provides a basis for interpretation of national conditions and an improved holistic perspective towards protection and usage of water resources, even though the regulations does not directly affect an operator.

4.2.2 National legislation

The Environmental Code controls a large part of the legislation involved around WPAs (Naturvårdsverket, 2011). Here it is stated that the County Administration and municipalities should promote the establishment of WPAs for at least all public, larger private and common water catchments. The Environmental Code's Rules of Consideration provides a number of principles which are generally applied for all operations and measures. The basis of the Rules of Consideration is from the so called Precautionary principle. According to the environmental code the purpose is to prevent not only predictable but also possible damages. Consideration should be taken to the risk of damaging the health of inhabitants and the environment. The obligations to prevent and limit damage begin as soon as it is realised that the measure or operation in focus can counteract the Environmental Code. To the extent that knowledge of the relationship between operations and damage is missing, but there still are reasons to believe that such a relationship exists, the lack of evidence of causation should not exempt the operator from the obligation to take the measures that can be reasonably required. For the WPAs the Precautionary principle is useful, both by authorities when assigning the WPAs as well as when applying rules towards operators within the area with respect to the Rules of Consideration. However it should not result in excessive protected areas to compensate for insufficiently extensive investigations. If however, a thorough investigation is carried out, but it is still unclear if sufficient protection can be established, a larger area should be assigned as WPA. The Environmental Code also states that a land or water area may by the County Administration or the municipality be proclaimed a WPA to ensure a ground or surface water supply which is, or may in the future be, used in drinking water production. This may also be extended to include reserve water supplies.

The parliament has adopted 16 national environmental goals (Naturvårdsverket, 2015). Three of these affect the drinking water supply; living lakes and watercourses, groundwater of good quality and good built environment. These goals are not legally binding but political goals and the Environmental Code should be interpreted with these as a background.

The act on general water operations SFS 2006:412 regulates the responsibility of managing the stormwater (Trafikverket, 2011). Within a municipal's area of operation the operator's responsibility regarding runoff is transferred to the municipality's principal. This area of operations should be connected to urban environment otherwise the road administrator is responsible for the runoff management. The Swedish Transport Administration (TRV) has as road administrator the responsibility for the environmental impact from state road network. Connected to the road administrator's responsibilities for managing stormwater and potential spill from DGV is the Reasonableness article in the Environmental Code. According to the Environmental Code the operator's costs for precautionary measures should not be unreasonably burdensome (Enveco Miljöekonomi AB, 2015). What is considered to be reasonable is assessed in the individual case based on a balance between on one hand the social benefit and on the other the effectiveness of the environmental protection measure. Especially the nature of the inconvenience and the areas sensitivity should be taken into account. The operator has the burden of evidence regarding the costs which cannot be motivated by environmental or health-oriented reasons. Instead, when conducting a reasonableness assessment the conditions within the industry standard should be the basis not the individual operator's solvency. The purpose of the reverse burden of evidence is to ensure that all operators with potentially environmental or health threatening activities are charged to proof that the general Rule of Consideration is fulfilled. This means that the operator is responsible for an eventual damage or inconvenience to the extent the Environmental Code considers it reasonable.

4.2.3 Environmental quality standards

The Swedish Agency for Marine and Water Management, the Water Authorities and the County Administrations have developed a database to improve the management of the water resources in Sweden (Länsstyrelsen i Kalmar, 2016). The database VISS is a water information system for the Swedish lakes, water bodies, ground water and coastal water. The database provides a status classification on the water body with a general assessment on ecological status. It also provides environmental quality standards which govern agencies and County Administrations when applying the legislations. The VISS database can provide information about protected areas and water related environment improving measures. The submitted data is processed to monitor the EU framework directive.

The implementation of the EU framework directive led to the founding of a new administrative organization, the Water Authorities (Vattenmyndigheterna, 2016). One of the main differences is that there now is a comprehensive view towards managing the water resources. Previously the administrative borders between municipalities and a county governed the management procedure but now the natural watersheds govern the work. The Water Authorities consists of five regional authorities; Bothnian Bay, Bothnian Sea, North Baltic, South Baltic and Skagerrak and Kattegat. The 21 county administrative boards in Sweden have been given joint responsibility for the water environment across the country and five are assigned as Water Authorities. In the region of Skagerrak and Kattegat the Västra Götaland County Administrative Board governs the decisions and the coordination. Each Water Authority has a water delegation consisting of expert representatives designated by the Government. The delegation makes decisions on larger issues for the entire water district, for example environmental quality standards, local measure plans and management plans. This means that the water delegation determines the environmental quality standards for each water body found in the database VISS. On local levels the municipalities provide the regulations. In the Gothenburg municipality the Environmental Administration within Gothenburg City has developed environmental protection regulations for the water resource Göta Älv which governs the local operators within the WPA (Länsstyrelsen i Västra Götalands Län, 2004).

4.3 Impact of discharges

The consequence of a discharge, whether it is a discharge from a spill event or continuous discharge of stormwater, is highly depending on the characteristics of the receiving water (Trafikverket, 2011). The total volume, the turnover rate and the expected dilution of the pollutants are important factors when assessing the impacts. In the following chapters the degradation processes of hazardous are described as well as some examples of discharge scenarios. Lastly the environmental impacts of both stormwater and spill events are described.

4.3.1 Degradation processes

The processes of breaking down substances can be spontaneous, chemical or biological (Fischer, 1994). Even very complicated and toxic molecules can be degraded biologically. In the initial stages of a substance discharge the chemical degradation process is dominating. The biological process requires the substance to be diluted to non-toxic levels to the degrading organisms. This can take long time if the substances are solid and poorly soluble. Knowledge of a specific substances biological degradability is therefore important to be able to determine the extension of remediation measures. The degradation processes mainly applies to organic substances. Substances which contain toxic elements such as phosphorous, heavy metals and arsenic can still be toxic when degraded and may even change from being toxic to plants to being toxic to animals.

The degradation process is mainly governed by two factors; temperature and pH (Fischer, 1994). The temperature is the most important factor. This is especially true for extreme temperature changes such as a fire event, where the chemical degradation process is hastened. Normal temperature changes affects as well and the degradation is faster during the summer compared to the winter. In a lake, or stream, the difference between the water temperature on the surface and bottom also affects the degradation rate. At low temperatures the process may come to a complete stop. Especially the biological processes are susceptible to low temperatures. In very acidic or basic environments many stable substances break down. The pH is also affecting the processes in a long-term perspective due to the naturally occurring variations.

The degradability of a certain substance in water is classified into three categories; readily biodegradable, biodegradable and persistent (Fischer, 1994). This classification is mainly designed for treatment plants and for discharges into the nature, where the degradation conditions are less favourable. Some examples of substances within the categories are found in Table 3.

Table 3 - Degradability classification (Fischer, 1994)

Readily biodegradable	Biodegradable	Persistent
Ethanol	Diesel	PCB
Acetic acid	Petrol	DDT
Ethyl acetate	Decane	Quicksilver
Glycerol	Carbon tetrachloride	Arsenic
Toluene	Chlorophenol	Silicone

4.3.2 Discharge scenarios

A couple of scenarios, of a possible substance discharge, are described as examples (Fischer, 1994). The first scenario shows how the volatile liquid mustard gas can act when discharged in a deep lake during sunny and warm weather. From Table 4 the characteristics of mustard gas can be viewed. When exposed to normal temperature, mustard gas is a volatile liquid which sinks in water. At the bottom of a lake in Sweden, including the Baltic Sea, the temperature is normally <10°C. This temperature reduction leads to a solidification of the liquid which is only considered volatile in extremely slow water. This normally volatile substance is therefore going to stay on the bottom of the receiving water for tens of years. Intercepted mustard gas can later become a problem when lifted up from the bottom to warmer climate where it evaporates or during winter conditions where it can remain solid through transportation until exposed to warmer climate.

Table 4 - Mustard gas characteristics (Fischer, 1994)

Characteristics of mustard gas	Substance data
Density (kg/m^3)	1270
Melting point (°C)	14
Boiling point (°C)	217
Water solubility (%)	0,08
Vapour pressure (kPa)	0,012

For the second scenario the behaviour of three substances in liquid state are examined when discharged into water approximately 20-25°C and with a depth of more than 20 m (Fischer, 1994). The behaviour of the substances has been examined based on the properties in Table 5. All three substances are classified as flammable liquids which make them suitable substances for representing a possible discharge since flammable liquids stands for the majority of the transported dangerous goods. It is clear from the table that the high water solubility and density of aniline results in a rapid dispersion in the water. After about eight hours, a maximum value is obtained of which a relatively extensive volume of water has been contaminated. Benzene which has a density lower than water floats on the surface. It has a lower solubility and a higher vapour pressure than aniline causing a slower dissolution in the water and a higher discharge to the atmosphere. The result of this is that a significantly lower volume of water is contaminated after 30 minutes. Hexane has an even lower density and does also float on the surface. It has a significantly lower solubility compared to the other two and even though the vapour pressure only is a bit higher than benzene, it is evaporated within 15 minutes. This example shows that it is important to know if a discharged substance achieves water concentrations high enough to be considered toxic for aquatic organisms. Crucial factors that determine water concentrations are the dissolution rate and the dilution rate. The higher dissolution rate, relative the dilution rate, the higher obtained water concentrations.

Table 5 - Chemical properties (Fischer, 1994)

Characteristic	Aniline	Benzene	Hexane
Density (kg/m^3)	1020	877	660
Vapour pressure (kPa)	0,04	10	16
Solubility (weight %)	3,4	0,18	0,0008
Toxicity (LC_{50}, mg/l)	5	5	5

4.3.3 Road stormwater

Sedimentation is a fundamental process for transportation and immobilisation of pollutants in bodies of water (Folkesson, 1994). The accumulation of pavement particles can cause extensive disruption to benthic fauna. The damage can occur both mechanically, by clogging the pores, or by reduced water flow through the sediments, with reduced oxygenation as a result. In the sediments the highest concentration of heavy metals is found in the top layers. The sedimentation process is affected by several factors and for instance a pH reduction will increase the solubility. Chloride, from maintenance operations, can also increase the solubility for some types of metals such as cadmium.

The road storm water usually increases the turbidity of the receiving water which can alter the light conditions (Folkesson, 1994). This affects the photosynthesis for plants and the general living conditions for animals in the freshwater eco system. Different species of fishes may have the gills blocked by particles. Mud and stone dust can cause an acute toxic reaction.

The oxygen concentration is a crucial factor to all bodies of water (Folkesson, 1994). The concentration is affected by a balance between oxygen-producing and oxygen-demanding processes. Most degradation processes consumes oxygen. Added phosphorous and nitrogen increases the growth of plankton and plants and when these are degraded the oxygen consumptions increase further. The result is often worse than the initial pollution. A low oxygen concentration is one of the most typical disturbances in receiving waters affected by stormwater. Receiving waters affected by stormwater may also suffer from changed species composition, growth disturbances and increased toxicity in the sediments from heavy metal. PAH pollution causes inactivation of vital enzyme systems.

The concentration of heavy metals in the organisms, found in receiving waters, often correspond to the levels in the water or in the sediments (Folkesson, 1994). The correlation is very different depending on species and metals. Supplementation of nutrients from stormwater may have a growth-stimulating effect but if the levels of heavy metals are too high toxicity occurs. In general the balance between the nutrition and the toxic substances will determine whether the stormwater will increase or inhibit the growth but in most cases stormwater causes instability to plants and organisms.

Stormwater which is discharged directly from bridges may cause local pollution of the sediments below (Folkesson, 1994). In some cases the levels of heavy metals such as cadmium, chromium, copper, iron, lead and zinc are doubled.

4.3.4 Spill events

Events resulting in a discharge into a receiving water may under adverse conditions lead to extensive damage to plants and organisms (Folkesson, 1994). If a substance leaks into a receiving water a large number of organisms will be directly exposed (Fischer, 1994). Damage on higher life forms, such as plants and fishes, are often visible. The absence of these signs does not necessarily mean an absence of environmental impact. Damage to non-visible organisms will affect the whole eco-system since the food chain may be disrupted.

The toxicity of a substance is normally divided into acute toxicity and chronic toxicity (Fischer, 1994). The acute toxicity is the effect which occurs within a few hours of exposure where the consequences may be lethal to animals and growth-reducing to plants. The chronic toxicity is the effect of a long-term exposure which usually implicates growth-reduction and inhibited reproduction. While acute effects can be obvious, the chronic effects can be hard to observe. It is important to understand that most species in an eco-system are connected throughout the food chain. Damage to one certain species may lead to unpredictable consequences for the eco-system as a whole.

Bioaccumulation of toxic substances is a possible outcome for organisms in a receiving water after a spill event (Fischer, 1994). This means that organisms, such as algae, will receive a low amount of the toxic substances, maybe within its tolerance, whereas organisms and animals higher in the food chain will receive a much more concentrated dose of the toxic substance, leading to a more severe consequence.

Discharge of substances containing phosphorous and nitrogen can cause over-fertilization (Fischer, 1994). Phosphorous is normally more growth-stimulating in lakes while nitrogen is fertilising in seas. The over-fertilization causes a large amount of algae and microorganism growth. When the biomaterial is degraded large amounts of oxygen is consumed. If the discharge is extensive and the turnover rate is low, the oxygen levels will be close to nothing where the biomaterial is decomposed. Organisms which are not mobile may suffocate. A sign of this could be fishes swimming close to the surface due to the oxygen concentrations being higher there. The over-fertilization can cause long-term damage to the sediments at the bottom due to a reaction which creates hydrogen sulphide. This is lethal to all higher life forms and may severely affect the eco-system of the water body. The risk of over-fertilization is at most during the summer when the temperature is higher, the water turnover rate is lower and the oxygen levels are lower. These factors indicate that a discharge potentially is more severe during the summer compared to the winter.

5 Risk assessment

Risk assessment is about managing uncertainty in terms of unwanted future events (Davidsson, et al., 2003). The purpose of making risk assessments is generally to present sufficient material which can act as decision support when investigating e.g. health and safety issues, product inspections and environmental issues. In order to facilitate the risk assessment it can be suitable to make a collective estimation of the individual risks by classifying them (Räddningsverket, 1989). A traditional risk assessment is generally based on a level of risk which is given as a product of the likelihood of a certain event and the subsequent impact, see Equation 1 (Davidsson, et al., 2003).

$$Risk = Likelihood \times Impact \qquad (1)$$

The following risk assessment is based on a manual developed by TRV, with the intent of helping the assessment of the risk roads, railways and their usage constitutes for surface- and groundwater (Trafikverket, 2013). A common way of conveying a risk assessment is by presenting the combination of the likelihood and impact for an event in a risk matrix, see Figure 1. The likelihood and the impact, that the level of risk is based on, is divided into five levels of severity, here presented as 1-5 for the likelihood and A-E for the impact. In this way it is possible to roughly rank the different levels of risk from the most likely events with the most severe impacts, found in the upper right corner of the matrix, to the most unlikely events with the least severe impacts, found in the lower left corner of the matrix. The method defines five risk levels, represented by different colours in the matrix, where each risk level is connected to a clear decision support regarding the extent of necessary measures.

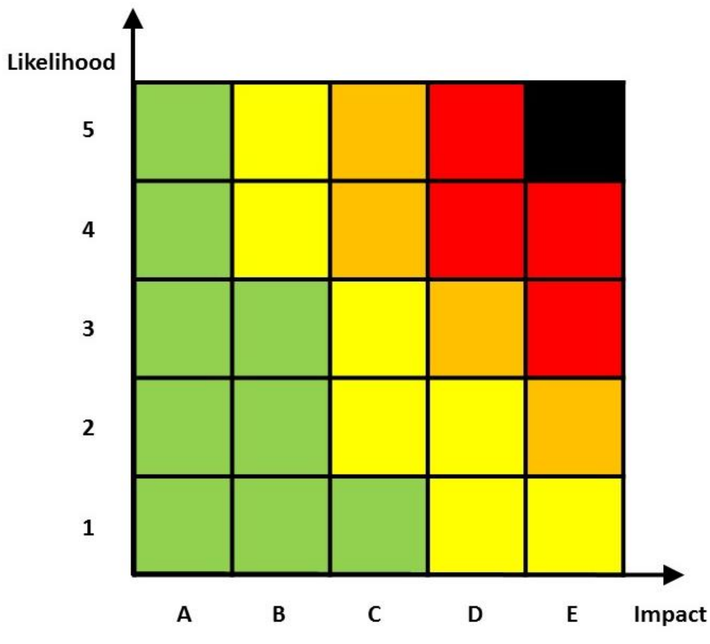

Figure 1 - Risk matrix (Trafikverket, 2013)

The following risk levels are suggested when assessing the risks on roads:

- **5 – Very high risk (black)** – Recurring events, catastrophic consequences if a discharge would reach the protective area. Extensive risk reducing measures are needed; shutdown and relocation of the risk object can be motivated.
- **4 – High risk (red)** – Recurring events, major consequences if a discharge would reach the protective area. Extensive risk reducing measures are motivated, regulation of the traffic should be considered.
- **3** – **Moderate risk (orange)** – Events have occurred within the protective area, consequences of a discharge is extensive. Risk reducing measures are needed, extensive measures can in some cases be motivated.
- **2** – **Increased risk (yellow)** – The consequences of an event is not negligible, for the most potential events the conditions for a successive remediation are however very good. Minor risk reducing preventive measures can be motivated.
- **1 – Low risk (green)** – Low risk of an event and/or necessary remediation operations regarding a discharge claims minor resources. Preventive measures are not motivated.
- **0 – Negligible risk (outside risk matrix)** – Very low risks of an event and/or necessary remediation operations regarding a discharge claim minor resources. It is not motivated to initiate risk evaluations.

5.1 Likelihood

The likelihood of an event can be measured generally in three ways; empirical estimations, logical systems and professional judgments (Davidsson, et al., 2003). Empirical estimations represents the most ideal approach, which are based on previous events e.g. data series which implies that extensive material in the matter is accessible. Logical systems are modelled with the assistance of fault tree analysis or other methods. Combinations of technical and human faults leading to the current event are investigated and the likelihood of an event is then calculated with the assistance of empirical data. The likelihood can also be estimated based on professional judgements from individuals with good knowledge of current conditions. Professional judgements are often based on logical systems. The choice of approach depends on what is accessible and has a great impact on the quality of the likelihood. It is good to have in mind that quantification of the likelihood and impact normally contains subjective estimations and valuations. It is however impossible to take all factors into consideration when calculating the likelihood of an event.

As a first approach it is appropriate to apply a more general likelihood for events. For this case the events which are interesting to evaluate are the likelihood that a discharge of hazardous substances, resulting in an environmental damage, will occur given a traffic incident with HGV or DGV on the Swedish road network. Passenger cars have been neglected for the assessment with the reason that consequences from a HGV or DGV are much more severe from a water protective point of view. It is important to notice that the likelihood of a spill from an event with HGV or DGV are not the same. The likelihood must therefore be divided into two separate events;

- Likelihood of a discharge from a DGV
- Likelihood of a discharge from the fuel tank of a HGV

The overall likelihood (P_0) for the two scenarios is calculated according to Appendix I. The next step is to transfer the overall likelihood (P_0) per driven km to the studied area in order to estimate the site specific likelihood of a discharge causing an environmental damage. This can be done according to Equation 2. The Annual Average Daily Traffic (AADT) for DGV and HGV on the bridge, as well as the length of the relevant road stretch, are needed. By calculating the site specific likelihood (P) according to Equation 2 and by then using Equation 3 it is possible to convert it to a frequency of which the levels for the likelihood is based on found in below.

$$P = P_0 \times N \times L \times 365 \qquad (2)$$

Where:
P_0 = the overall likelihood
N = the number of DGV or HGV per day (AADT)
L = length of the concerned road section in km

It is essential to compare the site specific likelihood (P) with available accident statistics for the specific site (Trafikverket, 2013). If the number of events is below 20, the likelihood is to be considered statistically uncertain. If the observed frequency is significantly lower, in other words less than half of the calculated likelihood, it is conservatively reduced to 75 % of the initially calculated site specific likelihood (P). After the likelihood has been adjusted, the return time (a) can be calculated according to Equation 3.

$$a = \frac{1}{P} \qquad (3)$$

Based on both international and national statistics for events and traffic analysis presented in Chapter 3.2, the likelihood of a discharge resulting in an environmental damage from a DGV can be calculated according to Appendix I. The combination of the parameters given in the appendix gives an overall likelihood (P_0) of 2.8×10^{-8} per DGV driven kilometre. In Gothenburg's municipal general plan from 1999, English and American studies are presented for the likelihood of a discharge with a magnitude of 10^{-8} (Stadsbyggnadskontoret, 1999). Compared to these studies the overall likelihood of 2.8×10^{-8} seems like a reasonable estimation.

In Chapter 3.1 and 3.2 it was found that the total amount of transported kilometres with heavy traffic was three billion in 2014 and the total average number of accidents per year for heavy trucks was 1 217. These statistics combined with a number of other parameters assessed in Appendix I gives an overall likelihood (P_0) of a fuel discharge from a HGV causing an environmental damage to 4.8×10^{-9} per HGV driven kilometre.

When the likelihood of an event has been estimated, it can be assigned to one of the following levels presented below. The return time that the levels have been calibrated against have is based on a time perspective of 50 years which is expected to be a reasonably foreseeable future (Trafikverket, 2013).

- **Likelihood level 5** – The likelihood that at least one event within 20 years will occur is above 95 %. This is a very high level of likelihood which in general is unacceptable not only from a water protective point of view. If a likelihood of this level is identified it should be condemned as soon as possible for all stakeholders and take immediate actions.
- **Likelihood level 4** – The likelihood of at least one event within 50 years is close to 100 %. The likelihood is to be observed as high or very high and strongly indicates that an unacceptable level of risk can exist.
- **Likelihood level 3** – The likelihood of at least one event within 50 years is between 39 % and 92 % which may be considered a high level. The risk costs can be everything between low and high and it is usually appropriate to carry out a thorough risk analysis.
- **Likelihood level 2** – The likelihood of at least one event within 50 years is 39 % or less. The likelihood is significant and can result in a higher level of risk, especially during severe consequences. The risk costs can generally be expected to be low in relation to the costs for preventive measures.
- **Likelihood level 1** – The likelihood of at least one event within 50 years is 6.9 % or less. The likelihood is low enough in order to regard the risk as negligible unless the consequences of an event are major.
- **Likelihood level 0** – The likelihood of at least one event within 50 years is 1 % or less. Likelihood with return times above 5 000 years is categorised as negligible.

5.2 Impact

The impact of an event can be estimated based on e.g. the number of lost lives, injury rates, economical losses or environmental impacts (Davidsson, et al., 2003). According to the Environmental Code, presented in Chapter 4.2.2, it is important to consider the risk of damaging the health of inhabitants and the environment. When assessing the environmental impact due to an event, not only the extents of the discharge and type of substance, but also to the environmental vulnerability and value have to be taken into consideration.

Analysing methods and assessment criteria are mainly focused on the impact of human life and health (Davidsson, et al., 2003). It is therefore difficult to present concrete limits for the environmental impact. Furthermore the numbers of parameters affecting the environmental impact are many thus the impact is usually individual and site specific. The assessment is therefore often a matter of opinions. Factors that can be relevant to assess are:

- Impact on natural resource
- Magnitude of the discharge
- Recovery time
- Transfer to other parts of the ecosystem
- Exceeding allowable threshold values
- Proportion of affected ecosystem
- Possibility to remediate

In this thesis environmental impact of an event resulting in a spill is in focus. The categorisation of the impact, in the risk assessment, is however mostly focused on the receiving water in terms of drinking water quality (Trafikverket, 2013). The levels intend to represent different magnitudes in terms of disruptions and costs of measures, which could occur during an event. An exemplified, but not completely thorough motivation is given in the list below:

- **Impact level E – Catastrophic –** A drinking water resource supplying tens of thousands of persons is permanently wiped out.
- **Impact level D** – **Major** - A drinking water resource supplying tens of thousands of persons is temporarily wiped out, but can be restored.
- **Impact level C** – **Large** – A water resource suffers damage, but can be restored. The functionality remains during restoration although to a limited extent.
- **Impact level B** – **Minor** – A discharge does not constitute to immediate damage, but a threat of damage remains until remediation is completed.
- **Impact level A** – **Very small** – Hydrological conditions exists so that a discharge, in the end, risk to contaminate a valuable water resource. Conditions for remediation is however good both in terms of the extent and temporally.

The level of impact can be assessed by describing the impact as a combination of value and vulnerability (Trafikverket, 2013). The same way as for risk, the impact can be illustrated as a matrix according to Figure 2. Similar to the previous risk matrix the levels of impact are illustrated in different shades of blue. The distribution of the levels of impact in the matrix corresponds to the qualitative categorisations of impact, found above.

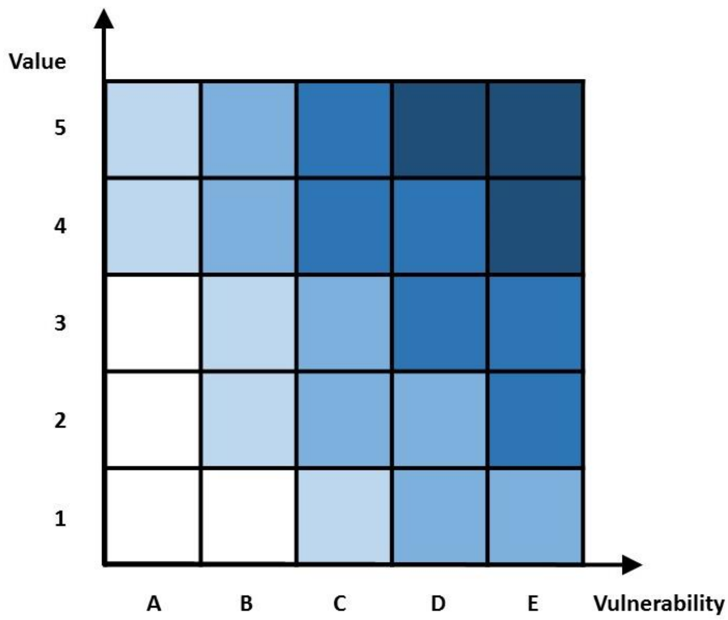

Figure 2 - Impact matrix (Trafikverket, 2013)

5.2.1 Value

The value of a body of water is a parameter that there may be significantly different perceptions of (Trafikverket, 2013). While likelihood and vulnerability often connects to physical, hydrological and logical relations, value is more subjective. This risk assessment takes guidance partly from the EU framework directive for water management, from representatives for the drinking water supply such as municipalities, sewerage system representatives and National Food Agency as well as authorities of the regulatory and supervisory positions such as County Administrations and not least the Geological Survey of Sweden (SGU).

The intention is to primarily evaluate the withdrawal capacity of a water resource (Trafikverket, 2013). Consideration should also be given to potential future use, if the resource is used for drinking water supply and the water resource supplies essential services. Furthermore, a water resource that is used for drinking water supply is valued based on the potential of alternative water supply from a water reserve. The water resource should also be evaluated from a hydrological-ecological perspective in terms of its significance from a larger hydrological context and the natural values.

Determining the status and quality requirements must be considered and constitute important input for assessing the value (Trafikverket, 2013). Classifications for all Swedish water bodies are available through the VISS database. The principle for the valuation of surface water is based on designated values in terms of valuable waters, areas with protected nature or drinking water supply. However, it is important to have in mind that it is not possible to indicate any distinct hierarchy between parameters and each case has to be evaluated individually.

The value of a water body is divided into five different levels as follows:

- **Level of value 5 –** Particularly valuable body of water. An example is a body of water who constitutes a fundamental prerequisite for a designated and specially protected ecological environment. A body of water with a high withdrawal capacity used for supplying a large population with drinking water and where reserve and alternative capacities are lacking.
- **Level of value 4 –** Very valuable body of water. An example is a body of water that is of importance for a designated and specified protected ecological environment.
- **Level of value 3** – Valuable body of water. An example is a body of water used for drinking water supply for a medium-sized population where reserve and alternative capacities are available.
- **Level of value 2** – Moderately valuable body of water. An example is a body of water used for drinking water supply for a smaller population where reserve and alternative capacities are available.
- **Level of value 1** – Remaining bodies of water. An example is a body of water generally considered to have a good withdrawal capacity which is not utilized today and no designations for future use exists.

5.2.2 Vulnerability

The vulnerability must be related to the potential events which are relevant in each individual case (Trafikverket, 2013). Important parameters for how the vulnerability is to be assessed are the time between a discharge, the detection, the type of substance and the volume. Additional considerations needs to be given to the ability to remediate and that traffic disruptions may occur during the time when remediation is needed.

Surface water is generally much less vulnerable from a perspective of drinking water protection (Trafikverket, 2013). However, it can be very vulnerable from an ecological perspective. The turnover time for surface water is crucial and in flowing waters the damage, or disturbance, can be limited to hours or days but at slower turnover times, where the damage generally is more severe, it is reasonable to assume that the receiving water take longer time to recover. From a drinking water perspective it is of interest to be able to estimate the time it takes for a contamination to reach the raw water intake. The shorter transport times, in relation to the expected response times for closing the water intake, the higher the vulnerability. Vulnerabilities need to be determined for each risk object or group of objects and put in relation to the damage that can occur. An evaluation of the difficulty to remediate, as well as the possibility for natural recovery, is also important to have in mind. The following levels of vulnerability are suggested:

- **Vulnerability level 5** – It is practically impossible to prevent a contamination or damage after occurred event. The damage is furthermore such that the protected object ceases to function. For example, a body of water that must be removed from service indefinitely due to the contamination of petroleum products.
- **Vulnerability level 4** – At preparedness and during favourable conditions it is possible to prevent damage on the protected object with remediation operations or it is deemed possible that in the foreseeable future repair the damage caused on the protected object. For example, a polluted ecosystem where the ecology suffered severe damage. However no contaminations remain after remediation and the ecosystem has the ability to recover.
- **Vulnerability level 3** – The dispersion process during a discharge is limited in such a way that acute and subsequent rescue and remediation efforts prevents the damage of the protected object even during less favourable conditions. Alternatively, the damage on the protected object is of such a kind that it can continue to operate, albeit on a reduced scale. For example, a receiving water where de-icing results in increased levels of chloride. The receiving water is usable even if the chloride concentrations exceed the current limits.
- **Vulnerability level 2** – The dispersion process during a discharge is highly limited but will still contaminate the protected object over time unless remediation is not made. For example, a transformer leaking a few hundred litres of oils on fine-grained soils where the calculated vertical transportation time is a few inches per day. Here it is expected that the unsaturated zone have a detention capacity so that the flow essentially ceases. The contamination can be expected to be mobilized during precipitation, especially during more heavy precipitations.
- **Vulnerability level 1** – Dispersion, both vertically and horizontally, is limited to drainage over a smaller area and the penetration is limited to the depth where biological activity is on-going and maintains porosity, usually no deeper than 30 cm. Underlying soils are considered as compact. For example, a fuel tank that leaks into the roadside area on clay in flat terrain.

In this particular case events in focus are discharges of hazardous substances from either DGV or fuel from HGV (Trafikverket, 2013). During acute discharges of hazardous substances the levels of vulnerability is connected on one hand to the time required for necessary actions from the emergency service and on the other hand to the dispersion rate. From Table 1 it can be noted that the most common transported dangerous goods materials in Sweden are flammable liquids.

The most common event of significance is leakage from fuel tanks (Trafikverket, 2013). The fuel tanks of HGV have an exposed position and may be damaged, resulting in a leakage, even during events when in other respects may be considered minor. In Chapter 3.1 it was evaluated that the most common fuel type for HGV is diesel with a tank volume from 500 to 1000 litres. These conditions are to be taken into consideration when assessing the vulnerability.

6 Bridge runoff management systems

Humans have created bridges for as long as we have had the need to move around (Ahlberg & Spade, 2001). Bridge structures represent a challenge in the built environment and provide the most appropriate connection of what nature has divided: a river, a valley, or something that is more or less problematic to reach. In modern times humans have created obstacles in terms of channels, railways, bridges and streets. In able to cross such creations, bridges are either necessary or suitable for safety reasons. There are about 17 500 railway bridges and road bridges, today in Sweden, maintained and operated by TRV.

Runoff management on bridges have not always been a requirement. Road bridges built over bodies of water before around 1990 were not designed to take care of runoff water, or discharge from spill events. It was exclusively discharged uncontrolled to the receiving water. Since the end of the 1990s measures have successively been implemented on existing bridges in order to collect the runoff water and to be able to prevent that spill-related discharge. What measures are needed depends on the discharge demands that the concerned receiving water sets. A result of this is that most solutions are unique.

6.1 Technical design requirements

TRV's task is specified in the parliamentary regulation 2010:185 which states that TRV shall, based on a civil perspective, create conditions for an economically efficient, internationally competitive and sustainable transport system (Regeringskansliet, 2010). In order to fulfil the parliamentary regulations, it is necessary for TRV to ensure that a certain level of quality is obtained. One way of ensuring this is through TRV's documents on technical requirements and advice regarding building engineering.

One of these documents, named TK Avvattning, contains technical requirements for dimensioning and designing runoff systems for roads and railways. This should be used when planning, modelling and constructing drainage systems. It is applied on new constructions and maintenance of public roads and railways where TRV is the administrator (Karlsson & Dittlau, 2014). This document applies for drainage of facilities when roads or railways are in its natural state on land but does not apply for bridges or tunnels. These constructions are instead designed and dimensioned according to TRVK Bro and TRVK Tunnel respectively. For this thesis TRVK Bro is the relevant one to look further into.

TRVK Bro 11 is the current document on technical requirements for how to manage drainage when designing bridges (Karlsson, et al., 2011). In the document it is described how to arrange and place drains, drain pipes and how to connect the pipes to a main pipe. It also includes how to manage and design storage for stormwater. Storage should be designed and dimensioned for an 80 year technical life length and if affected by thaw salt, the storage should be designed for the same resistance as the road environment itself.

TRV have together with the Swedish municipalities and County Administrations developed Vägar och Gators Utformning (VGU). This document includes requirements and advice on how to design roads and streets in Sweden (Trafikverket, 2015). VGU is a voluntary and advisory document for the municipalities. For TRV these requirements are compulsory in case of new constructions or larger reconstructions. The requirements are however not intended for maintenance measures or other types of small improvements. In this document it is stated that a drainage system should be able to collect and drain stormwater from the road surface and road area so that the occurrence of a flood, harmful groundwater lowering or damaging on other sensitive environments does not happen. It is also stated that a particular investigation is needed in order to secure a water supply's future function if a drainage system is constructed close to a body of water. Surface- or groundwater areas that can be important for future water supply shall, if necessary, be protected against infiltration from stormwater and discharges associated with spill. This also includes water bodies with alleged environmental interests.

6.2 Stormwater management systems

Runoff management on bridges can be classified into two general categories; management on the bridge deck or management systems located at the abutment (NCHRP, 2014). Management systems located at the abutment requires a conveyance system to transfer the deck runoff to the abutment area either along the bridge deck or through a pipe system. Systems on the bridge deck do not need a conveyance system but requires maintenance on the bridge structure. In the following chapters bridge specific management solutions are described.

6.2.1 Vegetated surfaces

Vegetated surfaces is a stormwater management system which is most suitable off-bridge e.g. at the abutment or below the bridge. The most common types are filter strips and grassed swells (Butler & Davies, 2000). Filter strips are similar to swales except that they have very low slopes and are designed to promote sheet flow of stormwater runoff.

Swales are used for the conveyance, storage, infiltration and treatment of stormwater by operating as shallow, grass-lined channels. The runoff from a bridge deck is either stored until infiltration takes place, or until the filtered runoff is conveyed elsewhere. Swales provide removal of suspended solids, metals, oil and grease in addition to reducing stormwater peak flow but it is good to have in mind that swales provide a limited volume reduction and removal of nutrients and bacteria (NCHRP, 2014). The width and side slopes should be designed such that flow depths in the swale do not exceed 100 mm. It is therefore required that swales are designed with shallow slopes and soils that drain well (Butler & Davies, 2000). It has been studied that swales of lengths 30-60 m could retain 60-70 % of solids and 30-40 % of metals, hydrocarbons and bacteria.

6.2.2 Dry detention basin

Dry ponds or dry detention basins are storages most suitable as an off-site management system intended to primarily provide peak flow reduction and sedimentation treatment (NCHRP, 2014). For this reason the basins do not have a permanent storage of water between storm events. The function is to detain stormwater for up to about 36 to 48 hours and then to be drained. The bottom and side slopes are typically vegetated and operates with some form of outflow arrangement back into the drainage system e.g. mechanical or fixed hydraulic controls (Butler & Davies, 2000). These basins provide efficient removal of sediments, oil and grease, and particulate-pond pollutants but have a limited ability to remove dissolved pollutants such as nutrients, bacteria and metals (NCHRP, 2014).

6.2.3 Bioretention

Bioretention systems, also called rain gardens, are vegetated shallow depressions filled to temporarily store stormwater prior to infiltration, evapotranspiration, or discharge via an underdrain or surface outlet structure (NCHRP, 2014). This system is most suitable off-site e.g. at the abutment or below the bridge. The fillings are typically an engineered soil mix together with native plants with deep root systems. Removal of contaminants occurs primarily through filtration, shallow sedimentation, sorption and infiltration. Bioretention systems remove suspended soils, metals, oil and grease, bacteria and nutrients, while simultaneously reducing volume and peak flow.

6.2.4 Sand filter

Sand filters treat stormwater runoff by sedimentation, entrapment and straining of solids and is preferably used off-site (NCHRP, 2014). Sand filters are typically constructed with a sand bed that receives runoff though a sedimentation forebay. The treatment pathway is vertical through the sand causing pollutants to be trapped in the small pore spaces between sand grains or being adsorbed to the media surface when stormwater passes through the sand filter bed. A system of underdrain pipes below the sand bed collect and route flows that have percolated through the sand bed to the outlet. Sand filters efficiently remove sediments, oil and grease, bacteria and metals as well are reduce peak flow but provide limited nutrient removal and volume reduction benefits.

6.2.5 Permeable Friction Course

Another possible treatment that is suitable for bridge decks is Permeable Friction Course (PFC). This is a layer of porous asphalt that unlike traditional hot mix asphalt is produced by eliminating the fine aggregates from the asphalt mix (Barret, 2006). The idea is to put an approximately 50 mm thick layer of PFC on top of an existing conventional concrete or asphalt surface. PFC does not encourage infiltration and reduce runoff volume like full depth porous pavements used in parking lots (NCHRP, 2014). Instead, it drains through the porous layer to the underlying impervious road surface for then to be diverted between the asphalt layers to the edge of the pavement.

PFC has been demonstrated to improve water quality compared to traditional hot mix asphalt (NCHRP, 2014). During an 18 months monitoring of a PFC pavement a reduction of about 90 % of the TSS, Total Suspended Solids, has been indicated compared to a conventional pavement (Barret, 2006). The reduction in TSS is comparable to a sand filter (NCHRP, 2014). Other benefits of using PFC are that the removal of water from the road surface improves safety by reducing splashing and hydroplaning. It also reduces the risk that pollutants dissolve from the bottom of the vehicles. The reduction of tire noise, improved visibility and stopping distance during rain events has been observed. Unlike sand filers or other conventional practices, PFC incorporates stormwater treatment into the roadway surface and does not require off-site systems. Maintenance, other than structural maintenance, is not required.

Pollutants from stormwater can be detained in the pores of the PFC and are thereby prevented from leaving the paved area (NCHRP, 2014). In areas where freeze thaw cycles occur, the performance of the PFC overlay appears satisfactory but some durability questions remains. Compared to conventional asphalt, PFC is more expensive but it serves as a compelling choice for stormwater treatment in a high-speed highway environment due to its positive runoff qualifications, combined with the negligible land and maintenance requirements.

6.3 Spill management systems

Spill-related discharge of hazardous substances within bridge environments are of special concern due to the possibility of a rapid leakage of contaminants to receiving waters (Ramböll Sverige AB, 2009). The choice of measure, to prevent this from happening, is assessed based on the consequences of a discharge. The magnitude of a measure is mainly based on the amount spill in combination with the amount of time that the emergency service needs to prevent a discharge. Spill storage methods can, like management systems for stormwater, be installed either on the bridge or off-site e.g. downstream of the bridge deck (NCHRP, 2014). There are four types of hazardous spill management systems that are recommended for bridges;

- Detention basins
- Capacity of bridge-incorporated storage within the superstructure
- Tanks and vaults
- Capacity of the collection and conveyance system

The most common system is excavated detention basins (NCHRP, 2014). These can provide storage, control releases and can be constructed near bridge abutments when adequate open space exists and transportation from the bridge deck to this area is feasible. If adequate storage capacity is accessible in the bridge structure, storage can be incorporated into the bridge structure. A variety of vaults, tanks and conveyance storage in different sizes and materials exist for the purpose of spill containment. The advantage of closed storage facilities is that they can be buried below ground which reduces the potential risk of spilled contaminants to the atmosphere, rainwater or soils. This is one of the main reasons to why closed storage facilities are recommended to use for hazardous spill control. A disadvantage is however that closed system solutions generally cost more per volume unit than detention basins and can be more expensive to maintain.

6.4 Example projects

The following chapters give both national and international examples on how runoff management systems have been implemented in recent projects.

6.4.1 Reconstruction of I-80 in Ohio

In 2009, the ODOT, Ohio Department of Transportation, in USA completed the $87 million reconstruction of Interstate 80 which included to widen and reconstruct two 760 m long bridges (NCHRP, 2014). The bridges span over Meander Creek Reservoir, which supply drinking water to nearby towns. A spill containment system was therefore designed to prevent spills from entering the reservoir. Key components of the spill containment system include the following:

- A bridge profile that crests midway over the reservoir span
- A crowned bridge deck that sheds runoff to 3-4 meter shoulders sized to store and conveys runoff to approach inlets without encroaching on driving lanes.

- Networks of inlets, piping, and roadside ditches and swales
- Two containment basins at low points on opposite sides of the reservoir
- Two control chambers equipped with shutoff valves that prevent hazardous materials from entering the reservoir.

The containment system was designed to collect stormwater runoff on the bridge deck, convey the runoff to off-site basins sized to contain the 100-year event to then be discharged from the basins to the reservoir (NCHRP, 2014). If a spill of dangerous goods would occur, the containment system is designed to contain the spill for a maximum of 30 minutes in order for the emergency responders to close the outflows via shutoff valves located at each respective basin. The contained spill can then be pumped out and disposed in accordance with environmental regulations.

6.4.2 Washington State Route 520

The WSDOT, Washington State Department of Transportation, developed water quality protection measures for the replacement of Evergreen Point Bridge on State Route 520, which is a floating bridge spanning Lake Washington (NCHRP, 2014). The management and treatment of stormwater runoff and spills were developed using the methodology AKART, All Known, Available and Reasonable Technology. AKART represents the most current technology that can be reasonably required for preventing, controlling or abating the pollutants associated with a discharge (WAC, 2016). The study resulted in identification of the following non-structural and structural measures:

- High-efficiency sweeping
- Large, modified catch basins with scheduled cleaning
- Separate, enclosed spill-containment lagoons within supplemental stability pontoons

The new bridge was proposed to use main pontoons for roadway support and additional lateral pontoons, supplemental stability pontoons, for the purpose of stability, stormwater dilution and spill containment (NCHRP, 2014). The drainage system of the bridge was then designed to redirect all stormwater runoff to containment lagoons within the stability pontoons. Regular maintenance includes periodic removal of surface pollutants from the containment lagoons. Dilution of stormwater is as well achieved within the stability pontoons before released into the receiving waters. Although the dilution does not reduce the pollutant load discharges, it does reduce the potential for acute toxic effects to aquatic organisms.

6.4.3 Road 27 Viared - Kråkered

The expansion of Road 27 between Viared and Kråkered, south of Borås in Sweden, has been studied in order to gain information on how bridge runoff can be managed. The aim of this expansion has been to improve the traffic situation in Borås and to redirect DGV from the city centre to Road 27 (Ramböll Sverige AB, 2009). The likelihood of a spill event with a discharge of petroleum from DGV on the new Road 27 has been estimated to one every 50 years. In the area where Road 27 is situated there are no receiving waters used for drinking water today. However the water quality in the river Viskan, which Road 27 crosses, and other nearby receiving waters is not to be impaired according to the EU framework directive. According to this a runoff management system was needed in order to ensure the water quality and the status of Viskan. The critical detention time has been estimated in consultation with the emergency service to be 30 minutes in order to prevent a discharge. This value is used as a design parameter for the runoff management systems.

In order to ensure that there are no direct discharges into receiving waters, a conveyance system with edge girders and curb sides has been constructed. This leads the stormwater and potential discharges away from the structure and receiving water to the abutment (Ramböll Sverige AB, 2009). Beside the bridge, swales with sealed bottom, together with dammed banks with relatively permeable material, have been constructed. Wet detention basins with sealed bottom and with a shutoff valve to cut off the outflow have been constructed in some areas in order to take care of the surface runoff. This has been done in order to prevent infiltration to receiving waters and to increase the possibilities for the emergency service to stop a discharge before reaching the receiving water and thereby reduce the risk of impact.

6.4.4 Road 190 Angereds Storåsväg - Gråbovägen

The project comprised a reconstruction of an existing three-way intersection between the Road 190 and Angereds Storåsväg (Trafikverket, 2012). The purpose of the project was to ensure that the intersection meets future traffic demands and to improve the accessibility. The three-way intersection was previously regulated by traffic signals and the reconstruction made way for a roundabout with three arms. To manage both the stormwater pollution and potential spill events a detention basin was constructed to which a majority of the runoff from the paved surfaces is led. The basin was dimensioned for a 16 000 m^2 runoff area and an initial 15-mm first flush rain. This gave a total volume of 400 m^3 with an included equalization volume of approximately 80 m^3. The basin is a wet detention pond with a permanent water depth of about 1 m (Vectura, 2012). The location of the basin can be seen in Figure 3.

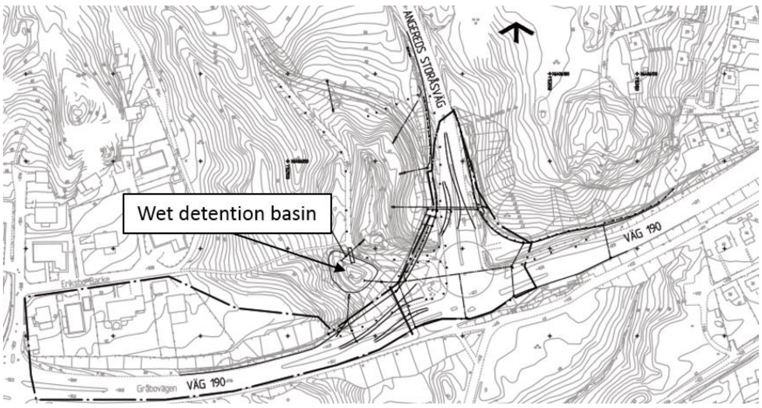

Figure 3 - Area overview (Trafikverket, 2012)

The system includes a shutoff valve that can manage a 10-year-rain event for 60 minutes until its capacity is reached (Trafikverket, 2012). For the treatment of stormwater the basin has a sedimentation function which has an estimated degree of separation for suspended solids of 80 %. The outlet of the pond is also provided with oil-grit separating functions. In case of a spill the shutoff valve can be turned off manually, providing a 60 minutes time margin to start remediation actions. This runoff management system is a combined system since it can manage both stormwater treatment and spill containment.

7 Assessment of management measures

The process of selecting an appropriate measure for managing runoff is governed by several factors including the amount of traffic, the runoff area, the receiving water's value and local environmental regulations. In the following Chapter the national recommendations from TRV and examples of local water protection regulations are described as well as methods based on international studies. These are developed into a combined decision model which is to be evaluated in a case study presented in Chapter 8.

7.1 TRV's general decision method

In the early stages of planning a certain measure TRV has a work strategy called "the four-step principle" (Trafikverket, 2015). The first step, rethink, includes considering measures which can affect the need of transportation and the mode of transportation. The second step, optimize, includes a more efficient usage of the existing infrastructure. The third step, rebuild, includes limited reconstruction of existing infrastructure of fulfil the functional demands. The fourth step, new construction, includes new investments or larger reconstructions. In the context of selecting a suitable runoff management system this could mean for the first steps to decrease the traffic to lower the pollution levels. For the third step to rebuild or complement existing systems into solutions that fulfil the local regulations and in the fourth step to design and construct completely new facilities to manage the runoff.

TRV developed a road technical guidance document in 2011 considering how to select the proper environmental measure (Trafikverket, 2011). This guidance document is to be used in conjunction with the technical requirement documents. With support from the act on general water operations SFS 2006:412 TRV has as road administrator the responsibility for the environmental impact. Four different motifs are identified for managing runoff. Hydraulic motifs to counteract damage on upstream or downstream land and to counteract overloading downstream culverts, piping and drainage systems. Environmental motifs to protect surrounding receiving waters from pollutants in the runoff. Aesthetic motifs to create an attractive and diverse road environment and finally economical motifs to manage the runoff in a cost efficient way. To guide through the decision process a seven-step decision method is presented which can be seen in Figure 4.

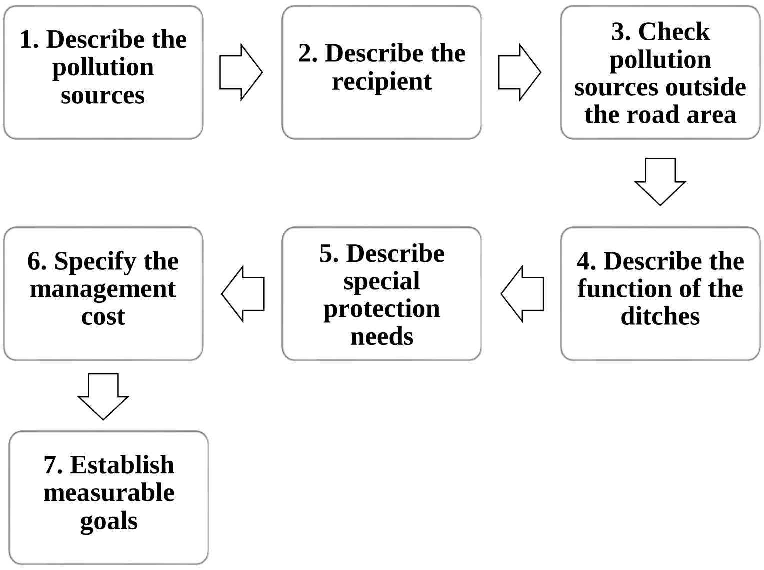

Figure 4 - TRV's decision method for selecting environmental measure

The method is a suggested planning procedure when investigating the need of an environmental measure (Trafikverket, 2011). The first step is to identify the pollutant sources and estimate the amount of traffic on the specified road stretch. It is also important to estimate the percentage of HGV and if the road is an assigned transportation route for DGV. Secondly the receiving water should be analysed. It is important to investigate where the runoff is transported by the ditches and to identify if the receiving water is surface water or a groundwater source. The water turnover should be considered, for the receiving waters, to be able to dilute the pollutants to sufficient levels. The surrounding areas are also of concern. If the drainage systems receive water not only from the road but also from the surrounding area the water may contain agricultural water, which is rich in nutrients. The function of the road ditch is in many cases crucial to treatment process. If properly designed, and maintained, it can manage the infiltration and immobilization of pollutants to sufficient levels and further measures may be redundant. Besides the primary investigation of the receiving water, potential need for special protection measures should be analysed. For example if a receiving water has extra high protection value due to sensitive eco-systems, or usage as a water supply, certain protective measures can be required. The costs should be quantified and compared against the efficiency of the selected measures with the reasonableness in mind. Lastly to be able to follow up and control a facility measureable goals are required. Clearly defined parameters such as a certain metal concentrations, or water flows, from a facility will improve the management.

In areas where the road area allows a substantial vegetated ditch, where the drainage conditions are favourable and where there is no need for special protection against spill, the runoff may be allowed to infiltrate (Trafikverket, 2011). If measures are needed for hydraulic control or spill management, the possibility for treating stormwater should also be assessed. Direct discharge, or direct discharge via piping, is permitted under the condition that an investigation shows that it will not cause acute or long-term damage to the receiving water. Such an investigation should also take additional runoff loading from the surrounding areas into consideration. It is the overall assessment that determines whether or not a treatment action of the stormwater should be taken. The management measures should then be coordinated between the operations which cause the environmental loading. However, direct discharge can be accepted if the total runoff area is limited to a few hundred square meters. A general recommendation for the road administrator is to apply local disposal of the stormwater within the road area. If infiltration is used, treatment as well as limiting and equalizing flows can be achieved to a varying extent.

7.2 Municipal regulations

On a local level it is the receiving waters' regulations which govern how the stormwater and spill events should be managed. In the following Chapter the regulations and recommendations from Stockholm and Gothenburg are investigated.

7.2.1 Stormwater management recommendations

The city of Stockholm developed in the early 2000s a runoff strategy where pollution from roads is taken into consideration (Stockholms Stad, 2002). The stormwater strategy is based on three investigations performed in 2000-2002. The investigations consisted of receiving water classification, stormwater classification and examples of treatment measures and costs. The investigations classify roads with different AADT into different stormwater pollution categories, which can be seen in Table 6 (Stockholm Vatten, 2001).

Table 6 - AADT connected to pollution category (Stockholms Stad, 2002)

AADT	Pollution concentration category
Local streets < 8 000	Low
Roads with 8 000 – 15 000	Low-Moderate
Expressways with 15 000 – 30 000	Moderate-High
Expressways with > 30 000	High

The report also connects the AADT to specific treatment requirements based on the receiving water sensitivity and the pollution concentration, which can be seen in Table 7.

Table 7 - Pollution category connected to receiving water sensitivity (Stockholms Stad, 2002)

Receiving water / Pollution concentration	Very sensitive	Sensitive	Less sensitive
Low	No treatment	No treatment	No treatment
Moderate	Some treatment or divert to another recipient	Some treatment or divert to another recipient	No treatment
High	Treatment	Treatment	Treatment

This concludes that the stormwater on expressways with an AADT of 30 000 or higher should always be treated regardless of the receiving waters' sensitivity. The concentrations levels based on the categories low, moderate and high can be seen in Table 8.

Table 8 - Pollutant concentrations connected to pollutant categories (Stockholms Stad, 2002)

Concentration	Low	Moderate	High
TSS (mg/l)	< 50	50-175	> 175
TotN (mg/l)	< 1.25	1.25-5.0	> 5.0
TotP (mg/l)	< 0.1	0.1-0.2	> 0.2
Pb (µg/l)	< 3.0	3.0-15.0	> 15.0
Cd (µg/l)	< 0.3	0.3-1.5	> 1.5
Hg (µg/l)	< 0.04	0.04-0.20	> 0.20
Cu (µg/l)	< 9.0	9.0-45.0	> 45.0
Zn (µg/l)	< 60	60.0-300	> 300
Ni (µg/l)	< 45	45.0-225	> 225
Cr (µg/l)	< 15	15.0-75.0	> 75
Oil (mg/l)	< 0.5	0.5-1.0	> 1.0
PAH (µg/l)	< 1.0	1.0-2.0	> 2.0

The Environmental Administration in Gothenburg has developed a set of guideline values concerning the most frequently occurring stormwater pollutants (Miljöförvaltningen, 2013). The guideline values are applicable in any point of discharge for an operation. If the operator considers the values to be unreasonable to fulfil the operator may conduct an investigation and suggest concentrations based on the technical, economic and environmental conditions in that individual case. In these cases the Environmental Administration can perform a special review. A prerequisite is that the receiving water is not considered in need of special protection. The guideline values are presented in Table 9 next to the Stockholm Vatten values from Table 8 as a comparison.

Table 9 - Pollutant categories with local Gothenburg pollutant concentration limits

Concentration	Low	Moderate	High	GBG	Category
TSS (mg/l)	< 50	50-175	> 175	25	Low
TotN (mg/l)	< 1.25	1.25-5.0	> 5.0	1.25	Moderate
TotP (mg/l)	< 0.1	0.1-0.2	> 0.2	0.05	Low
Pb (µg/l)	< 3.0	3.0-15.0	> 15.0	14	Moderate
Cd (µg/l)	< 0.3	0.3-1.5	> 1.5	0.4	Moderate
Hg (µg/l)	< 0.04	0.04-0.20	> 0.20	0.05	Moderate
Cu (µg/l)	< 9.0	9.0-45.0	> 45.0	10	Moderate
Zn (µg/l)	< 60	60.0-300	> 300	30	Low
Ni (µg/l)	< 45	45.0-225	> 225	40	Low
Cr (µg/l)	< 15	15.0-75.0	> 75	15	Moderate
Oil (mg/l)	< 0.5	0,5-1.0	> 1.0	1.0	Moderate
PAH (µg/l)	< 1.0	1.0-2.0	> 2.0	0.05	Low

Table 9 shows that the guideline requirements correspond to the low-moderate concentrations from the Table 6. These concentrations originates from the category roads with AADT 8 000 – 15 000 suggesting the AADT of 8 000 as an important indicator of when to start taking measures against stormwater pollution. Management of stormwater is suggested according to Table 10 (Stockholms Stad, 2002).

Table 10 - Stormwater management connected to AADT (Stockholms Stad, 2002)

AADT	Stormwater management suggestion
< 8 000	If the receiving water is sensitive the road administrator needs to show that there is no need for treatment, otherwise no treatment.
8 000 – 15 000	
15 000- 30 000	The road administrator needs to show that there is no need for treatment.
> 30 000	Treatment.

7.2.2 Spill management recommendations

When it comes to spill management on local level both Stockholm and Gothenburg has implemented certain requirements in their environmental protection regulations. In the WPA of Göta Älv the regulations state that stormwater from roads which are assigned routes for DGV should be diverted in such a way that spill can be prevented from reaching Göta Älv (Länsstyrelsen i Västra Götalands Län, 2004). It is also stated that detention basins or similar solutions should be used to be able to collect the pollutants. In Stockholm and for the WPA of Östra Mälaren new or reconstructed paved surfaces should have managements systems which provide a possibility to detain and collect pollutants in case of spill (Länsstyrelsen Stockholms Län, 2008). For existing roads it is stated that discharge is permitted as long as it does not counteract against the current environmental legislation.

7.3 International study

The American NCHRP, National Cooperative Highway Research Program, did in 2014 release a report on bridge stormwater runoff analysis and treatment options. The report is directed to departments of transportations and aims to assist in the process of selecting a cost-efficient strategy for a particular bridge. It is concluded that conventional treatment of stormwater for normal roads have limited effectiveness when applied on bridges and that bridges themselves account for a minor part of the highway systems' runoff.

7.3.1 Runoff management evaluation strategy

The objective of the strategy is to develop a procedure to determine what solutions that should be considered for bridges and when treatment is effective for bridge deck runoff. The strategy presents two general cases which are differentiated by the watersheds' land use. The usage is defined as either rural or urban. For the rural case the treatment of the deck runoff is generally not recommended since the environmental impacts on the receiving waters are usually shown to be minimal. The stormwater assessment procedure found in 7.3.3 can be used to show this. For the urban case the treatment of bridge deck runoff should be governed by local environmental regulations. If a treatment system for a specific bridge is shown to be required the solution should be evaluated from the perspective of obtaining the highest level of treatment possible at the least cost. The evaluation strategy is described in Figure 5.

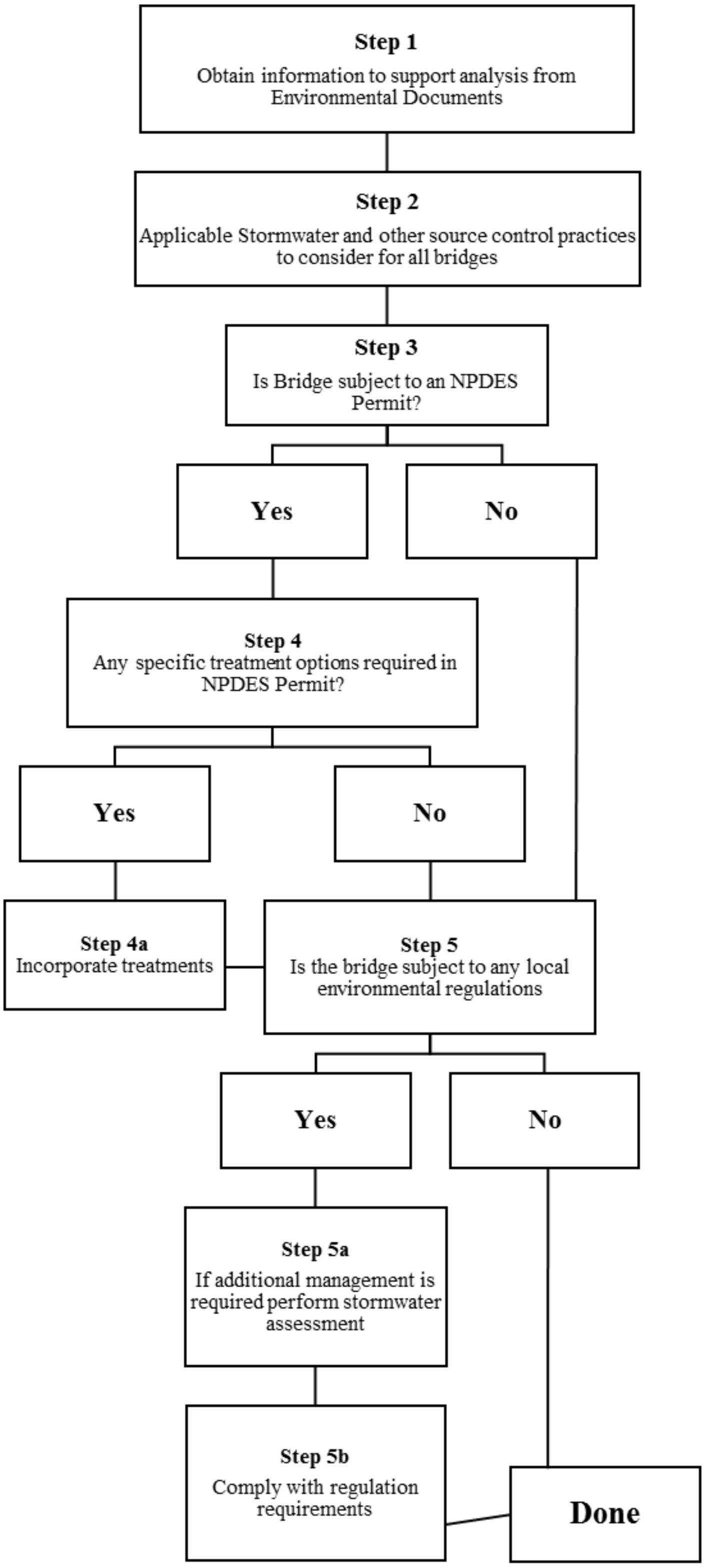

Figure 5 - NCHRP Evaluation strategy modified

- **Step 1**: The environmental documentation should discuss if the receiving water has a special classification such as WPA or is subjected to any nature permits.

- **Step 2**: All bridges should consider applicable stormwater source control and maintenance practices. This includes design and operational provisions to ensure that the bridge and the traffic on the bridge deck do not contribute pollutants to the receiving water to the extent possible.
- **Step 3**: Determine if the bridge is subjected to a NPDES permit, which corresponds to if a watershed is an urban environment of more than 10 000 inhabitants. The permits are divided into different phases based on how urbanized an area is considered. This is closely connected to the number of inhabitants. The different phases have different requirements.
- **Step 4**: If the NPDES permit is connected to specific management solutions these should be implemented. The most cost efficient solution is achieved by treating a comparable roadway section of the same AADT, watershed area and impervious area rather than treating the bridge deck runoff itself. This is due to that the capital, maintenance and operation cost of a deck collection and conveyance system is relatively high and as stated in Chapter 2.2 the effectiveness may be comparatively less.
- **Step 5**: Determine if the bridge is subjected to any local environmental regulations and if needed use the assessment procedure described in Chapter 7.3.3 to demonstrate if the bridge has an impact on the receiving water. The method is based on a calculation of the dilution, showing the change in load concentration of pollutants downstream the bridge.

7.3.2 Overview of the assessment approach

There are three fundamental cases of watershed and receiving waters; rural watersheds, urban watersheds and special situations (NCHRP, 2014). The rural watershed is considered undeveloped and any impairments or degradation of the water quality of a receiving water is not the result of an isolated bridge but rather agriculture or cattle. The runoff impact from road bridges in these watershed areas is considered to be minimal unless any kind of unique or special situation is identified. If there aren’t any stormwater quality requirements for the area further assessment is not warranted. In the urban watershed the main factor affecting the receiving waters is the volume and quality of the runoff from impervious areas and the bridge deck is but one among many. However the accumulated affect from all sources may have a serious impact. Therefore the treatment of the bridge deck runoff should be the same as any other impervious surface within the road area. The third case, unique or special situations, can occur in both rural and urban environments. The special situations include, but are not limited to, WPAs for drinking water supply, receiving water with high environmental or recreational values. These situations require coordination with the appropriate regulatory authority to determine a suitable measure.

7.3.3 Stormwater assessment procedure

The stormwater assessment approach should be used in the case where the regulatory authority requests proof that the water quality is not impaired by the road bridge operations. To demonstrate that the impact usually is minimal a mass balance which determines the percentage of load for any specific pollutant from the bridge can be performed. The US EPA, Environmental Protection Agency, has established a policy that a negligible discharge results in no more than a 10 % decrease in water quality for a single source and for multiple negligible discharges the total limit is 20 % for a water body. The NCHRP does however recommend using a more conservative limit which states that a discharge is negligible if the bridge contributes with less than 1 % of the load in the receiving water downstream the bridge. If the load from the bridge is larger than 1 % a more thorough analysis should be conducted to determine if the impact is large enough to justify treatment. The Load Increase is measured by Equation 4.

$$Load\ Increase = \frac{Bridge\ Load}{Bridge\ Load + Upstream\ Load} \times 100 \qquad (4)$$

Where the Load Increase is the percentage of the load downstream of the bridge contributed by the bridge itself. Bridge Load is the load consisting of the conveyed pollutants by the bridge structure and Upstream Load is the receiving waters load upstream the bridge location. The Bridge Load is defined by Equation 5.

$$Bridge\ Load = Rainfall\ \times Runoff\ Coeff.\ \times Area\ \times Conc. \qquad (5)$$

Where the Rainfall is the average annual rainfall for the specific location, the runoff coefficient is based on the surface but can be assumed to be 1.0 for a conservative value, the area is the runoff area and the concentration can be either measured or derived from tables based on AADT, see Table 11. The Upstream Load is defined by Equation 6.

$$Upstream\ Load = \ Annual\ discharge\ \times Average\ Stream\ Conc. \qquad (1)$$

Where the annual average discharge of the receiving water and average stream concentrations are location specific.

Table 11 - Median concentrations for typical road pollutants (NCHRP, 2014)

Concentration	**Annual Average Daily Traffic**			
	0 – 25K	**25K – 50K**	**50K – 100K**	**100K >**
TSS (mg/l)	43	56	94	108
Tot N (mg/l)	1.44	4.69	2.57	2.73
Tot P (mg/l)	0.12	0.16	0.2	0.24
Pb (µg/l)	6.6	12.7	74	46
Cu (µg/l)	9.3	20	32	50
Zn (µg/l)	60	93	180	270

7.3.4 Recommended spill control criteria

The NCHRP data referred to in Chapter 3.2 indicates that the bridge spill events only represent a very small fraction of the in-transit events with discharge to stormwater drains or waterways and an even smaller subset of events with DGV on highways. The general recommendation is therefore to only apply spill control management when the receiving water has no tolerance towards contamination. These cases correspond to the unique or special cases found in 7.3.2.

7.4 Suggested decision model

The current national decision method mentioned in Chapter 7.1 gives general advice on how to select a suitable environmental measure, but it also promotes an investigation for each individual object. In this Chapter a bridge specific decision model is suggested based on measurable parameters such as watershed area, AADT, AADT HGV, DGV transportation routes and receiving water sensitivity. The aim is to provide a general decision model, regarding how and when to select stormwater and spill management systems on bridges. A visualisation of the model has been developed for urban watershed and rural watershed and is presented in Appendix II as flow charts. The decision model for the urban watershed is also shown in Figure 6.

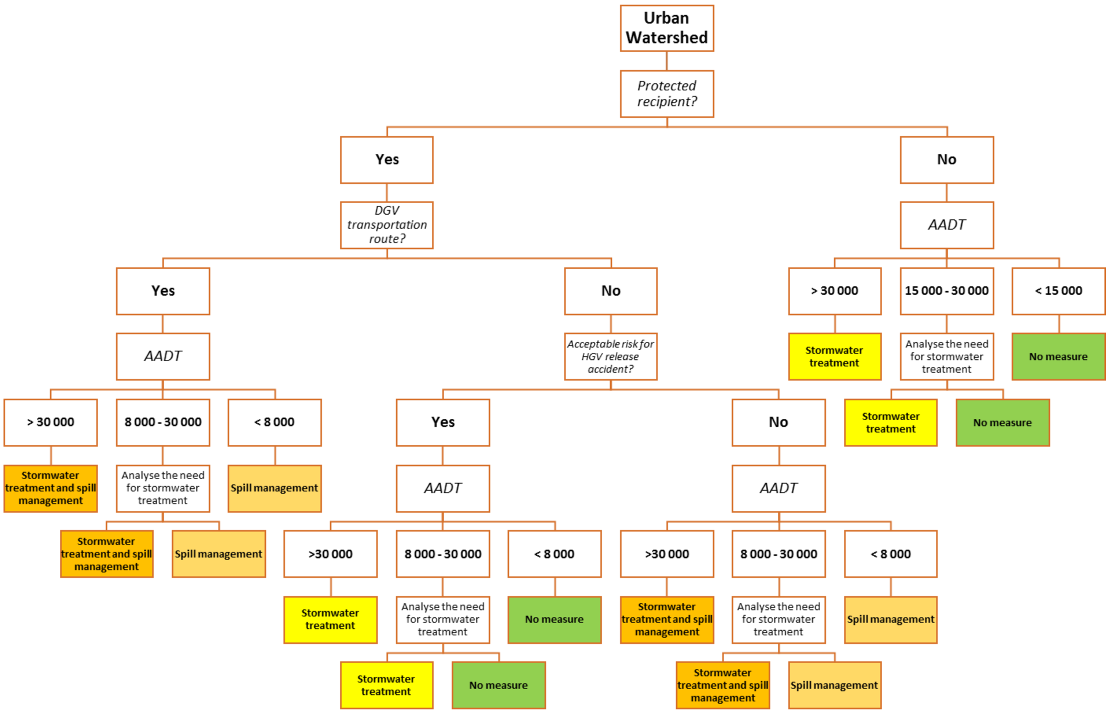

Figure 6 - The decision model for the Urban Watershed

7.4.1 Watershed area

The first step of the model is to define the watershed area that the bridge is located in. This can be either rural or urban. The rural watershed is defined as countryside and less developed areas, where the main contributors of stormwater pollutants are agriculture and livestock farming. The urban watershed is characterized by extensive amounts of paved surfaces which puts the receiving waters under more stress since they are likely to receive polluted stormwater from several different sources. The whole runoff area, for the exposed receiving water, should be analysed to determine the type of watershed.

7.4.2 Protected recipient

The receiving water should be analysed to determine whether or not it is to be considered protected. A protected recipient could be a drinking water source, a WPA, a water body with high natural or recreational values or a water body that is protected with local environmental regulations. The protected recipients are characterized by low tolerance towards contaminating discharges.

7.4.3 DGV transportations

The need for spill management is only considered for protected recipients. This is due to the fact that the risk of a DGV spill event resulting in an environmental damage is negligible, as can be seen in the example further on in this chapter. The same conclusions are drawn by the NCHRP in Chapter 7.3.4. Therefore spill management systems should only be implemented where there is low to minimum tolerance for pollution. This is also a requirement from both the city of Gothenburg and Stockholm in case of roads assigned as DGV transportation routes, described in Chapter 7.2.2.

An example that can be made is by assessing the risk of a discharge of hazardous substances from DGV resulting in an environmental damage on the bridge of Angeredsbron situated in the northern part of Gothenburg, Sweden. The assessment follows the steps according to Chapter 5 and the results are as follows.

In order to evaluate the risk of a discharge the likelihood of such an event has to be evaluated as well as the impact for the exposed receiving water. When the likelihood and impact have been evaluated the level of risk can be assessed according to Figure 1. Starting by assessing the likelihood of a discharge, the overall likelihood (P_0) of a discharge resulting in an environmental damage from a DGV has already been estimated to be 2.8×10^{-8} per DGV driven kilometre according to Chapter 5.1. According to Equation 2, the site specific likelihood (P) can be calculated by multiplying the overall likelihood (P_0) with the AADT of DGV (N) and the length (L) of the concerned road section together with the number of days in a year. In the following Chapters 8.1.1 and 8.1.5 it can be found that the length of Angeredsbron is 902 m long and that the AADT of DGV on the road stretch is about 35 vehicles per day. The product of these factors generates a site specific likelihood (P) of 3.2×10^{-4} events per year seen in Equation 7.

$$P = 2.8 \times 10^{-8} \times 35 \times 0.902 \times 365 \sim 3.2 \times 10^{-4} \qquad (2)$$

The next step is to compare the site specific likelihood to actual accident statistics. According to the following Chapter 8.1.5 accident statistics reveal that no events with DGV have occurred on the bridge. This implies, according to Chapter 5.1, that the calculated likelihood is to be considered statistically uncertain and should be reduced to 75 % of the initially calculated site specific likelihood (P). Furthermore, the return time (a) can be calculated according to Equation 3.

$$a = \frac{1}{0.75\times3.2\times10^{-4}} \sim 4200 \qquad (3)$$

The return time (a) of an event with DGV with a discharge resulting in an environmental damage is about 4 200 years, see Equation 8. Converted to the time perspective of 50 years the likelihood of at least one event within 50 years is about 1.2 %. This estimation can be compared with the levels of likelihood found in Chapter 5.1 where it can be seen that the likelihood of an event with DGV on Angeredsbron is precisely above level 0 which is seen as a negligible likelihood and consequently also a negligible risk. Looking at Angeredsbron as an example it can be considered a worst case scenario due to its extreme length and that it is a primary road for the transportation of dangerous goods. Even so the risk of an event with DGV on Angeredsbron is considered as negligible which indicates that the risk of an event with DGV on the majority of road bridges in Sweden therefore can be regarded as negligible.

7.4.4 Discharge from HGV

In case of a sensitive recipient but no route for DGV, the risk of an event causing a discharge of fuel resulting in an environmental damage from HGV should be evaluated. The recommendation is to evaluate such a risk by doing a risk assessment according to Chapter 5.

An example that can be made is by assessing the risk of a discharge of fuel from HGV resulting in an environmental damage on the bridge of Angeredsbron in Gothenburg, Sweden. The assessment follows the steps according to Chapter 5 and the results are as follows.

In order to evaluate the risk of a discharge the likelihood of such an event has to be evaluated as well as the impact for the exposed receiving water. When the likelihood and impact have been evaluated the level of risk can be assessed according to Figure 1. The overall likelihood (P_0) of a fuel discharge from a HGV causing an environmental damage has already been calculated to be 4.8×10^{-9} per HGV driven kilometre according to Chapter 5.1. According to Equation 2, the site specific likelihood (P) can be calculated by multiplying the overall likelihood (P_0) with the AADT of HGV (N) and the length (L) of the concerned road section together with the number of days in a year. In the following Chapters 8.1.1 and 8.1.5 it can be found that the length of Angeredsbron is 902 m long and that the AADT of HGV on the road stretch is about 1 400. The product of these factors generates a site specific likelihood (P) of 2.2×10^{-3} events per year seen in Equation 9.

$$P = 4.8 \times 10^{-9} \times 1400 \times 0.902 \times 365 \sim 2.2 \times 10^{-3} \tag{4}$$

The next step is to compare the site specific likelihood to actual accident statistics. According to the following Chapter 8.1.5 accident statistics reveal that no events with HGV have occurred on the bridge. This implies, according to Chapter 5.1, that the calculated likelihood is to be considered statistically uncertain and should be reduced to 75 % of the initially calculated site specific likelihood (P). Furthermore, the return time (a) can be calculated according to Equation 3.

$$a = \frac{1}{0.75 \times 2.2 \times 10^{-3}} \sim 600 \tag{5}$$

The return time (a) of a spill event with HGV resulting in an environmental damage is about 600 years, see Equation 10. Converted to the time perspective of 50 years the likelihood of at least one event within 50 years is about 8.3 %. This estimation can be compared with the levels of likelihood found in Chapter 5.1 where it can be seen that the likelihood of an event on Angeredsbron is at level 2 just above level 1.

The impact of the above estimated event can be assessed by evaluating the value of the exposed receiving water as well as the vulnerability of the receiving water if such an event would occur. The receiving water that Angeredsbron crosses is Göta Älv and further necessary information about this receiving water can be found in the following Chapters 8.1.2, 8.1.3 and 8.1.4. Göta Älv have been identified to be a particularly valuable body of water, it has therefore been assigned to have the highest level of value according to Chapter 5.2.1.

The vulnerability of Göta Älv is more difficult to assess and it is important to evaluate the conditions of the estimated event. It has already been stated that the volume of a HGV fuel tank can contain up to 1000 litres and the worst case scenario is that a spill event occur with a full tank and that the whole tank discharge in the receiving water at the same time. A discharge of 1 m^3 into Göta Älv which according to Chapter 8.1.3 has a flow of about 165 m^3/s results in an addition of about 0.61 %, this indicates that remediation efforts may be difficult. On the other hand the dispersion could be of such a large scale in the receiving water that the damage of the protected object is to be considered insignificant. It is also important to have in mind that Angeredsbron does not have a sufficient runoff management system at the time and in case of a spill the discharge is estimated to reach the receiving water within 2-10 minutes. With this in mind the vulnerability of Göta Älv is suggested to be somewhere between level B and C according to Chapter 5.2.2.

With a value level of 5 and a vulnerability level of B or C it can be evaluated, based on Figure 2, that the impact of a HGV discharge is somewhere between C and D indicating that the impact may be large or major in case of an event. The likelihood was estimated to level 2 just above level 1. With these parameters assessed the risk level can be evaluated and according to Figure 7 the risk indicates level 2 meaning an increased risk of an event.

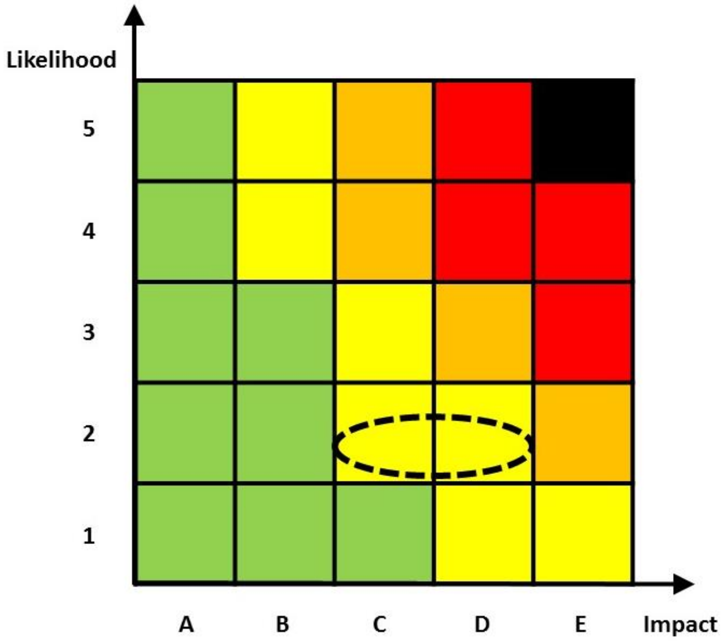

Figure 7 - Assessment of risk factor

7.4.5 AADT pollution levels

The AADT determines the need for stormwater treatment. The general rule is that if the AADT is above 30 000 the stormwater should be treated. For the cases where the AADT is between 8 000 – 30 000 for a sensitive recipient and between 15 000 and 30 000 for other recipients in an urban watershed it is recommended to conduct the assessment procedure found in Chapter 7.3.3 to evaluate if the bridge pollutant contribution is negligible or not. If the AADT is below 8 000 in the case of a sensitive recipient, below 15 000 in the case of an urban watershed non sensitive recipient and below 30 000 for a rural watershed non sensitive recipient it is not recommended to treat the stormwater. Future AADT-prognosis should also be considered for the bridge to ensure long term efficiency for the selected management solution. In this thesis an annual average daily traffic increase of 1.1 % per year until 2030 is used (Trafikanalys, 2015).

7.4.6 Stormwater treatment assessment

In the case of an AADT between 8 000 – 30 000 for a sensitive recipient, or 15 000 - 30 000 for a non-sensitive recipient in the urban watershed, the need for stormwater treatment has to be determined. The recommended procedure is to follow the stormwater assessment procedure found in Chapter 7.3.3. To use the calculation procedure obtaining data for average stream flow, average stream pollutant concentrations, AADT, bridge deck area and annual precipitation is necessary. In Chapter 7.3.3 a quality decrease less than 1 % is considered to be negligible and this value is recommended here as well, though it is important to consider the impact of multiple sources which are consider to be negligible when looked into alone. In case of multiple sources measures for bridges should generally be given lower priority in comparison to roads and highways.

8 Case study

The purpose of the case study is to evaluate an actual bridge which today lacks proper runoff pollution management and to assess the most proper measure by using the decision model developed in Chapter 7. The bridge chosen for the case study is Angeredsbron in Gothenburg, Sweden, which is part of the European highway E6.20, more specifically named Norrleden. In Gothenburg, the river Göta Älv splits the city into two parts. Today there are five connections across the river for road transportation; Älvsborgsbron, Götaälvbron, Tingstadstunneln, Jordfallsbron and Angeredsbron. Norrleden has been pointed out by the city of Gothenburg to be of national interest since it serves as a special use for the road transport system of Gothenburg (Stadsbyggnadskontoret, 2009).

Göta Älv has a variety usage and is partly classified, by the County Administration board in Västra Götaland, as a WPA (Göta Älvs VVF, 2005). Today Angeredsbron lacks proper runoff management meaning that both stormwater and potential discharge from spill events can reach Göta Älv without any detention or treatment. In order to ensure that sufficient protection of Göta Älv is achieved and that regulations are followed, it is essential to investigate Angeredsbron.

8.1 Angeredsbron

Angeredsbron is situated in the northern part of Gothenburg, Sweden, see Figure 8. The construction of the bridge started in 1975 and was completed in 1979 by Skånska Cementgjuteriet AB (Trafikverket, 2016). The bridge links the districts Hisings Kärra with Gårdsten and Angered by crossing the river Göta Älv, the European highways E45 and E6, and the railway track Norge/Vänerbanan. The bridge has a speed limit of 80 km/h and according to TRV’s classification for the bearing capacity, Angeredsbron is categorised as a BK 1, Bearing Class 1, road. In Sweden 95 % of the public road network is categorised as BK1 (Transportstyrelsen, 2015).

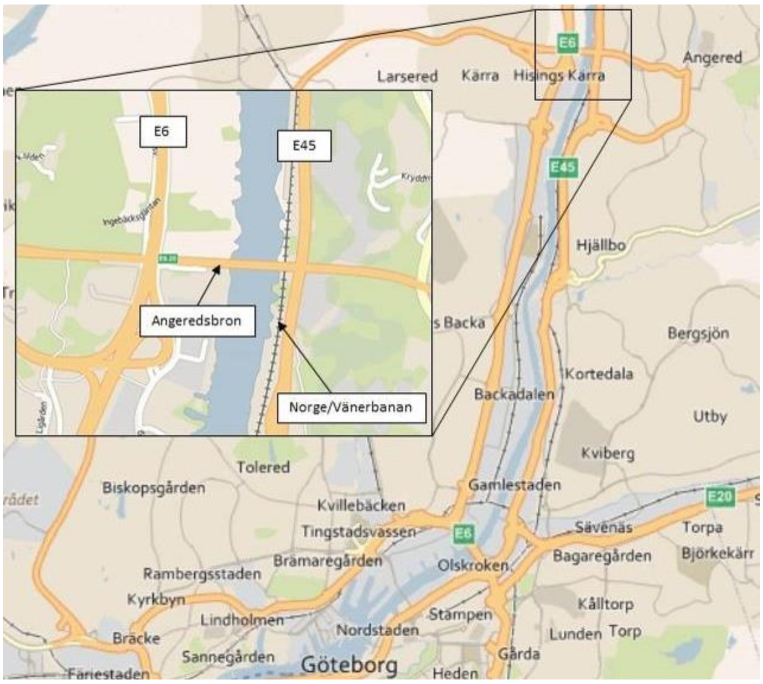

Figure 8 - Location of Angeredsbron

8.1.1 Design specification

Angeredsbron is a girder bridge consisting of pre-stressed concrete (Trafikverket, 2016). The span of the bridge is 902 m and the width is 16.9 m divided into a 14.2 m wide roadway and a 2.6 m wide pavement for pedestrians and bicycles. The roadway is divided into three lanes; two going in the eastern direction and one to the west. The bridge surface is 15 128 m^2 with an inclination of about three percent going from the east to west. The bridge clearance is 47 m and the bridge deck is founded on nine supports; two abutments and seven pillars which are founded on gravel, clay or rock. The life span of a major concrete bridge is about 100 to 120 years (Johansson, 2012), indicating that Angeredsbron theoretically should have more than 60 years left to operate.

8.1.2 Existing runoff management system

The maximum and minimum flow times in case of an accident has been estimated to be 2-10 minutes in a previous DGV spill event study (GF Konsult AB, 2007). The calculations were conducted based on a worst case and a best case scenario, maximizing and minimizing the flow time. On Angeredsbron the runoff is diverted via steel pipes in the bridge pillars from the east side of the bridge to the west side. Two of the pillars are located directly in Göta Älv. This makes for a very short flow time. Four pillars are located on land to where the diverted water is led. This extends the flow time for these areas. Over the green areas below the bridge, as well as over the river, runoff water flows through open steel holes to the ground and is then transported towards the river.

8.1.3 Geology and hydrogeological conditions

The area around Angeredsbron is dominated by the river Göta Älv and the flat areas surrounding it (SGU, 2016). The Göta Älv valley is surrounded by rugged mountains that rise to about a hundred meters from the valley floor. The valley floor soil types consist mainly of fluvial sediments on the western bank and post-glacial fine clays on the eastern bank. Swelling sediments, mostly gravel, can also be found north of the eastern bridge abutment. This is presented in Figure 9. The dense clay layers make Göta Älv susceptible towards discharge in the surrounding lands resulting in surface runoff. The stormwater flow may carry the pollutants towards the river on top of the clay layers. Göta Älv is the largest river in Sweden when looking into the water flow (Göta Älvs VVF, 2005). The average flow is 550 m^3/s. At the city of Kungälv the river is divided into two separate flows; Nordre Älv and Göta Älv. About 70 % of the total flow goes to Nordre Älv leaving the southern Göta Älv part approximately at 165 m^3/s.

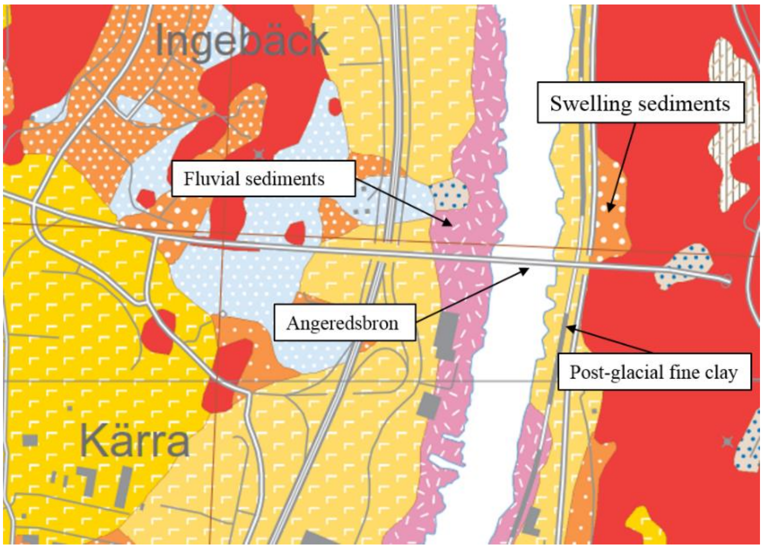

Figure 9 – Angeredsbron geological overview (SGU, 2016)

The average annual precipitation in Gothenburg is estimated to be 952 mm/year from 2000 to 2015 (SMHI, 2016). The evaporation is 400 mm/year based on the average yearly evaporation from 1961 to 1990, which is the currently used normal period (SMHI, 2009). This means that the approximate average annual runoff is 552 mm/year. The runoff area for Angeredsbron is limited to the bridge deck of 15 128 m^2. This is due to the bridge joints which separates the runoff from Gårdstensberget in the east and Kärra in the west. The general runoff area is classified as an urban area.

8.1.4 Local environmental regulations

Angeredsbron is situated in the middle of the Göta Älv WPA, which can be seen in Figure 10 with the WPA marked in blue shading (Göteborg Stad, 2016).

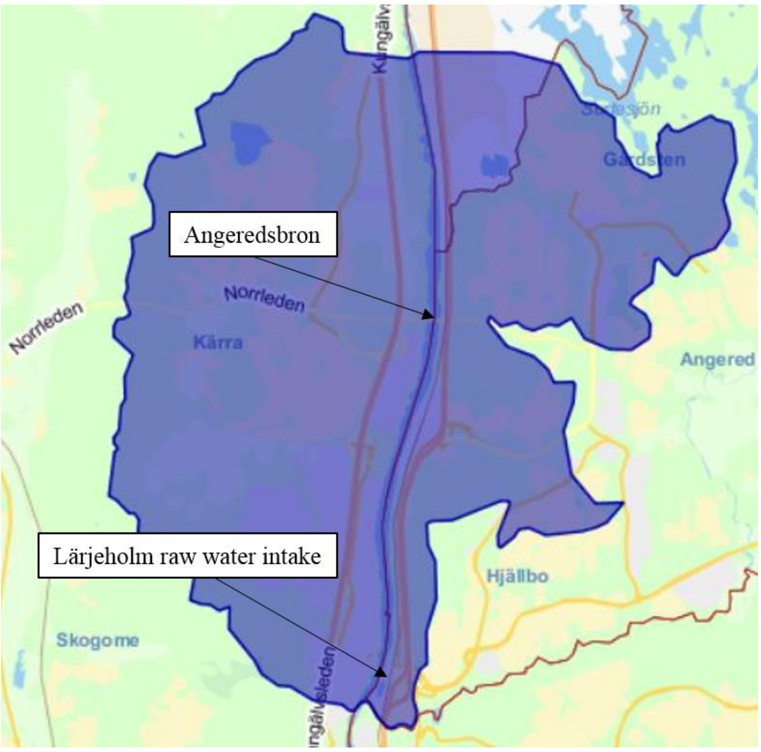

Figure 10 - Göta Älv WPA (Göteborg Stad, 2016)

Göta Älv is a very important river in the region (Göta Älvs VVF, 2005). It is classified as a national resource and has many forms of usage today. About 700 000 inhabitants in the county of Västra Götaland is dependent on Göta Älv for drinking water, for example the municipalities of Gothenburg and Mölndal. It serves as a raw water source with a raw water intake located at Lärjeholm, see Figure 10. About 2 000 l/s are extracted for the drinking water process. Of that amount 50 % is led to the drinking water plant Alelyckan and the rest is pumped to the lakes Delsjöarna to be used as raw water for the drinking water plant Lackarebäck. The two plants produce 170 million litres of drinking water each day. To be able to manage the varying levels of pollutants in the river the raw water intake at Lärjeholm has indicator systems installed along the river's path. The water quality is monitored continuously at seven sites along the river. The monitoring stations measures for example pH, turbidity, conductivity and redox potential. Two monitoring stations are located within the water protection area; Surte and Lärjeholm. For those stations there are direct connections which provide data to the surveillance system in Alelyckan drinking water plant in real time. If a disturbance in the quality of the raw water in Göta Älv is noted the intake can be closed and Delsjöarna used for raw water instead. If the disturbances in quality are of a long-term nature the lake Rådasjön can be used as a secondary reserve raw water source. The water reserves can together manage to supply drinking water for a month. The water from the river is also used for cooling water and process water by industries in the area and it serves as an important marine waterway for transportation of oil and various petroleum products. About 3.1 million tons of cargo is transported on Göta Älv each year and approximately 25 % consists of petroleum products and chemicals.

In 1998 the County Administration board in Västra Götaland determined the area closest upstream the raw water intake in Lärjeholm to a WPA (Göta Älvs VVF, 2005). The protected area spans of 28 km^2 and covers Lärjeholm in the south and Surte harbour in the north. The watershed areas which contribute with stormwater to the river is also included in the WPA. The flow time from the northernmost border to the southernmost of the WPA is estimated to three hours at high water flows. The flow distance between the northern and southern border was estimated by using Google maps distance tool to 7.0 km. This gives an approximate flow velocity of 0.65 m/s. By using the same tool to evaluate the distance between Angeredsbron and the Lärjeholm raw water intake the distance is 4.0 km. From this value and the estimated flow velocity the flow time from Angeredsbron is determined to 100 minutes or more.

In order to ensure the continuous quality of Göta Älv as a raw water source the County Administration of Västra Götaland revised the environmental protection regulations in 2004 (Länsstyrelsen i Västra Götalands Län, 2004). These regulations are applied throughout the whole WPA defined in Figure 10. There are 55 paragraphs controlling a number of different types of operations such as earthworks and management of cattle. For the road administrator a number of paragraphs are relevant when looking into fulfilling the requirements for road runoff:

§1. Within the WPA a general caution according to the Environmental Code should be taken to avoid polluting the river Göta Älv. From that legislation it is determined that anyone who operates or intents to operate or take a measure shall implement protective measures to prevent, hinder and counteract that the operations or measures harm or brings inconvenience to human health or the environment. In the same purpose the best possible technology should be applied in professional operations. These precautionary measures should be taken as soon as there is reason to believe that an operation or measure may bring harm to human health or the environment.

§4. Operators within the WPA shall continuously assess, determine and evaluate the risks the operations poses for the water quality in the river Göta Älv. The assessment should extend to risks for spill of contaminants as well as the possibilities to hinder a discharge of firefighting water in case of an accident. The assessment should be adapted to the nature and the extension of the operations.

§33. During maintenance of roads, railway embankments and railway areas within the water protection area the greatest possible consideration should be taken to avoid contaminating the river Göta Älv.

§36. Stormwater from assigned dangerous goods transportation routes should be diverted in such a way that spill is hindered to reach the river Göta Älv in case of an accident. Stormwater should be diverted to detention basins or similar where the pollutants can be collected.

§44. Sewage, including stormwater, which may contaminate the river Göta Älv, is not to be discharged within the WPA.

There are also paragraphs covering construction operations but §1, §4, §33, §36 and §44 are connected to roads in operation. This means that the roads and bridges, which TRV administer within the WPA, should fulfil these paragraphs.

8.1.5 Traffic

In order to evaluate the risk of a spill event as well as estimations for the amount of polluted stormwater, the AADT for the total amount of vehicles, HGV and DGV have been evaluated. The total AADT is about 14670 (Trafikverket, 2014). The AADT for HGV is about 1 400, see Table 12 (Trafikverket, 2015). This indicates that around 10 % of the total traffic stands for HGV. The AADT of DGV, based on Chapter 3.1 is estimated to be 35.

Table 12 - AADT, AADT HGV and AADT DGV for Angeredsbron, with a margin of error ± 6 %

	AADT Total	**AADT HGV**	**AADT DGV**
Angeredsbron	14670 (±6 %)	1400 (±6 %)	35 (±6 %)

Dangerous goods are daily transported back and forth through Gothenburg and are within the city distributed solely by road vehicles (Stadsbyggnadskontoret, 1999). Transportation of dangerous goods with DGV within the municipality is regulated in the “General local traffic regulations for the city of Gothenburg” published by the Traffic Office. According to these regulations transportation of dangerous goods over a certain quantity is generally prohibited. These quantities are defined by MSB in ADR-S. Excluded from the general prohibition are roads, which act as thoroughfares and main distribution joints for dangerous goods. These are divided into primary and secondary transportation routes. For primary transportation routes all types of dangerous goods are allowed and for secondary routes substances which during a spill event may result in the worst consequences are excluded.

Norrleden is of great importance for transportations to and from Gothenburg, especially for the harbour which serves as the biggest in Scandinavia. The regulations for the transportation of dangerous goods only allow three joints for crossing the river; Jordfallsbron, Älvsborgsbron and Angeredsbron (Länsstyrelsen i Västra Götalands Län, 2013). These bridges are assigned as primary transportation routes.

Looking at accident statistics for Angeredsbron, the STRADA database was analysed from the years 2003 to 2013 and two HGV accidents related to the bridge were found. After using the SWEREF99-coordinates the accidents were found to have taken place outside of the actual bridge deck. It can therefore not be connected to the bridge structure or the runoff area.

8.2 Application of the decision model

In order to suggest a choice of measure the decision support tool for the urban watershed is used since it is suggested in Chapter 8.1.3 that the watershed area is of an urban type. The result can be found in Figure 11.

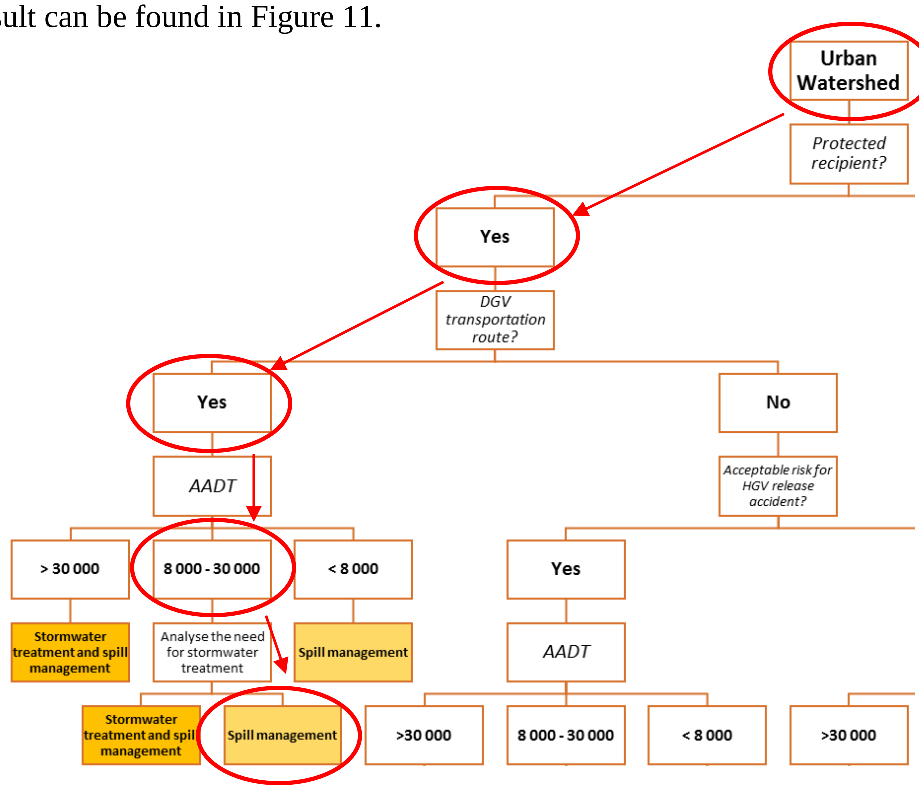

Figure 11 - Application of the decision model

The recipient Göta Älv is protected by a WPA and supplies raw water for the city of Gothenburg. It is therefore classified as a sensitive recipient. Angeredsbron is part of Norrleden and is pointed out as a primary transportation route for dangerous goods. The AADT is measured to be 14 670 and is estimated to increase to 17 285 in 2030 (Trafikanalys, 2015). The decision support tool suggests that a spill management system is implemented and that a further analysis of the consequences of the stormwater pollution is conducted.

8.2.1 Stormwater treatment assessment

To determine the need for stormwater treatment the stormwater assessment procedure, found in 7.3.3, is used. The calculations are presented in Appendix III and the results are found in Table 13. The input data for completing the model was found in published reports regarding the water quality in Göta Älv.

Table 13 - Results from stormwater assessment procedure

Constituent	Annual load in Göta Älv (kg/yr)	Annual load contributed by Angeredsbron (kg/yr)	Increase (%)
Total suspended solids, TSS	31 000 000,00	940	0.003
Total nitrogen, Tot N	3 699 646	26	0.001
Total phosphorous, Tot P	3 700	1,3	0.03
Lead, Pb	1 561	0.08	0.005
Cadmium, Cd	83	0.01	0.009
Quicksilver, Hg	4 891	0.00	0.00002
Copper, Cu	6 921	0.2	0.003
Zinc, Zn	18 212	1.5	0.008
Nickel, Ni	4 267	1.1	0.03
Chromium, Cr	1 405	0.4	0.03
Oil	3 177	6.3	0.2
PAH	52	0.01	0.02

The results show that the annual load contribution is less than one percent for all pollutants and in most cases insignificant. This concludes that stormwater treatment is not needed in this case since the impact on the total loading is negligible.

8.2.2 Combining the results with management system

The decision model support tool suggests that spill management is implemented on Angeredsbron. Examples on runoff management for bridges are found in Chapter 6.3 and include detention basins, tanks and vaults, bridge-incorporated storage within the superstructure and collection and conveyance systems. As can be read in Chapter 8.1.2 the outlets discharge stormwater at several different locations. The first measure would be to connect the pipes to a single discharge point located at the western side of Göta Älv. The runoff from the bridge is limited to the bridge deck itself which makes it easier to control a possible spill event on the bridge. The collected discharge should be further conveyed to a detention pond with shutoff valves which can be closed in case of a spill event, sealing the contaminants in the pond. The suggested placement of the pond can be found in Figure 12. The reason behind this is that it is considered cheaper to construct a pond below the bridge compared to a change in the superstructure with internal storage tanks, it is also easier to access a valve in case of a spill event.

Figure 12 – Pond placement, western side of Göta Älv.

The stormwater assessment procedure indicated that the highest load increase for an individual pollutant was oil. Therefore an oil-grit separator on the pond outlet, as shown in Chapter 6.4.4, would ensure a passive treatment to decrease these levels in case the local environmental administrations does not accept only implementation of spill management. It is also suggested in TRV's decision method found in Chapter 7.1 that if measures against spill from DGV are taken the possibility for treating stormwater should also be assessed.

9 Discussion

In this chapter the decision model will be evaluated and further improvements discussed. This is followed by a discussion around the results from the case study and lastly a discussion about the thesis in general is carried out.

9.1 Decision model

To evaluate the decision model the natural starting point would be to look into whether or not it fulfils the regulations. On national level the water directive governs how the authorities should form local regulations. The directive states that no water can have impaired quality. Comparing this to the model it differs in the case that the directive does not separate water bodies based on the degree of needed protection as the model does. To include all water bodies with for example spill management control would go against the Reasonableness article, described in Chapter 4.2.2, since the cost would be unreasonable if all receiving waters would be protected against discharge events with DGV or HGV. The model does take events with HGV into consideration which is often forgotten in environmental regulations since the major concern is the transportation of dangerous goods. In order to ensure efficient management of financial resources, the model imposes treatment for stormwater but only when it is proven to be harmful.

The decision model provides the user varying options when looking into the five main parameters of the model; watershed area, recipient sensitivity, dangerous goods transportation routes, risk of HGV discharges and AADT. The watershed area is up to the user to define and categorise. The protected recipient criteria require database research or consultation with local environmental authorities. The first approach regarding the sensitivity of a receiving water was to use the VISS portal since it covers most water bodies of interest. However it was not possible to draw any consistent conclusions regarding recipient sensitivity from the database. Due to this the model instead uses existing regulations, e.g. WPAs and local regulations, to define protected receiving waters. This means that which receiving water requires extra protection is already decided by the environmental authorities and agencies.

For the DGV transportation routes the user can often find the information in the municipal administrations webpage or at the road administrator. One example of this is to look at the National Road Database (NVDB) and search for restrictions in DGV transportations. If there aren't any it could indicate a DGV transportation route. When the site specific area does not operate as a dangerous goods transportation route and the affected receiving water is protected, it is recommended that the model user performs a risk assessment for the discharge of hazardous substances from HGV. As have been stated before a risk assessment is about managing uncertainty, in other words an approach to quantify the risk of events so that uncertainties can be assessed in a way as concrete as possible. However, it is important to have in mind that the levels of risk assessed are not definite or self-evident thus a state of criticism and questioning have to be present during the process. The risk of an event is dependent on its conditions thus if the conditions change, the risk of an event can change. The likelihood of an event which has been focused on in this report is based on empirical estimations where previously occurred events found the basis for the calculations. In order to validate the estimations, they have been compared to already estimated values from previous studies. It is however important to have in mind that these studies were published in 1988 and 1992 based on foreign data thus their validity should be questioned. The studies are however believed to give a reasonable reference point when looking at the order of magnitude of the overall likelihood. It is also worth mentioning that the estimations have been presented with an accuracy of maximum two significant figures. The reason for this is that it's practically impossible to be completely accurate with estimations thus an accuracy more refined than two significant figures is unreasonable.

When assessing the impact of an event it is usually more straightforward to assess the level of value of the affected receiving water unlike assessing the vulnerability. In order to assess the vulnerability, variable parameters and aspects need to be taken into account. It is therefore not unreasonable if the vulnerability level cannot be set to one specific level. Due to the risk being dependent on the vulnerability, it implies that the level of risk might also be assigned to more than one level of severity. When the risk is assessed it is up to the user of the model to decide if preventive measures are motivated or not.

The last parameter, the AADT, can also be acquired from the NVDB. There are two results which can be achieved from the AADT parameter, either the model suggests a management solution or further assessment is required. The further assessment requires the user to perform calculations to achieve suggested choice of measure. In the case where stormwater treatment is recommended by the model, it is suggested in Chapter 7.3.1 to treat a corresponding road length, which discharges into the same receiving water, instead of the runoff from the bridge deck. The option to treat a corresponding road length instead of the bridge is not found in Swedish literature and needs to be assessed further. The assessment procedure aims to determine if the load contribution from a bridge is negligible. This will be true in most cases but then the question of multiple negligible pollution sources, in the same watershed area, will have to be determined. This thesis focuses on how and when to manage runoff from bridges and will therefore not go any further into suggesting measures for roads. However it is concluded that in case of many potential pollutant sources the bridge should be given low priority.

9.2 Evaluation of case study

The evaluation of the case study starts by determining how the local regulations are fulfilled by the suggested choice of measure. There are five relevant paragraphs in the local regulations mentioned in Chapter 8.1.4. §1 covers the general caution principle and since the matter is under investigation there is no need to discuss this further. §4 states that continuous assessments are to be conducted and the literature study has shown that several reports, including this thesis, covers the subject. §33 controls maintenance operations and for Angeredsbron mainly reduced de-icing is of concern. This is however not recommended since it might increase the risk of accidents. §36 determine that spill should be hindered to reach Göta Älv. The decision model resulted in spill management and therefore this requirement is fulfilled. The last paragraph to be looked into is §44. This paragraph concerns sewage, including stormwater, which may pollute Göta Älv. In this case an assessment has been conducted which has shown that the stormwater pollution from Angeredsbron is negligible.

Looking into the application of the decision model the AADT and the projected AADT increase led to the assessment procedure. Input data for the load increase calculations was gathered from published scientific reports regarding the water quality in Göta Älv. The accuracy of the input data needs to be evaluated since the used values are not extracted upstream Angeredsbron. The used input data is based on continuous measurements at a site downstream the bridge as well as general values which are considered to be valid for the whole river. These values are estimated to be representative for the present conditions in Göta Älv but for more accurate results on-site measurements should be conducted. However in this case the percentages, as shown in Table 13, are very small and the performed assessment is believed to be accurate enough to draw conclusions regarding the need for stormwater treatment.

As a solution for the technical management system a combined system is recommended even though the decision model only suggests spill management. It is estimated to be considerably cheaper to construct a pond compared to take measures within the bridge structure. Therefore it is suggested that the water should be conveyed from the bridge structure to an exterior treatment facility, e.g. a detention pond, if there is space available near the bridge. At Angeredsbron there is available space which can be seen in Figure 12. A combined solution will provide a passive treatment of stormwater while at the same time functioning as an emergency storage unit for spill with a shutoff valve. It is concluded that this is an efficient solution in comparison to constructing a pond with only spill containing function. The pond is unlikely to ever be used due to the extremely low probability of a discharge event.

9.3 General discussion

Managing runoff systems for bridges solely covers parts of the road administrators' responsibilities. Often there are several facilities operated within an area where pollution is of concern. Therefore it is essential for the road administrators to identify where to spend resources to make sure it is spent efficiently and to make an assessment which covers the whole area of interest.

The Reasonableness article states that the conditions within a certain industry standard should govern the costs spent on environmental protection measures. This article is not easy to apply for road projects since there are very few operators within the area. TRV is by far the largest operator and there seem to be no standardised way to determine how much can be spent on environmental protection measures. This is problematic since it opens for poorly motivated investments if proper investigations are not conducted. However investigations are also costly and since there are no standards, e.g. a percentage of a total project budget dedicated to environmental protection measures, each individual case has to be assessed. This is a very costly cycle and it could be beneficial if the environmental agencies, in cooperation with the road administrators, developed a guideline to determine a minimum level of environmental measures. This can be connected to the national water directive which states that no water can have impaired quality. It is therefore interesting to see that the assessed likelihood of a discharge from both HGV and DGV in a worst case scenario like Angeredsbron is more or less negligible. It is in fact only from a HGV discharge where the likelihood could be seen as significant if the consequences are severe. It can thus be reasonable to question the regulations that the authorities require operators to live up to.

The focus of the report has been to develop a general decision model for suggesting a choice of measure, in terms of runoff management, for bridges in Sweden. It has therefore been essential to develop an overall likelihood for the discharge of hazardous substances causing an environmental damage valid for the whole Swedish road network, as an approach to make the model as user friendly as possible. The disadvantage of this approach could be that no considerations regarding possible different circumstances on bridges have been made. In other words bridges have been seen as any other road stretch. This implies that the estimated site specific likelihood could be either too low or too high depending on the circumstances of the bridge.

As is stated in Chapter 6.1, TRV provides a number of documents with technical requirements and advice regarding building engineering. The document with requirements that is currently used when designing bridges is TRVK Bro 11. In this document there are no requirements on how to manage a potential spill. The only document that TRV provides containing some technical requirements for dimensioning and designing runoff systems for roads which applies to bridges are VGU. Important to notice however is that these requirements are not intended for maintenance measures or other types of small improvements, in other words VGU does not apply for already existing bridges. TK Avvattning does also contain technical requirements for dimensioning and designing runoff systems for roads, however these do not apply for bridges. In conclusion a discussion regarding the reason around why bridges are excluded from TK Avvattning should be held, alternatively include runoff requirements for TRVK Bro.

The general decision model has the intent to make the legislations more accessible and to simplify decision process. An advantage of this approach is that the decision process can be more effective and less time consuming. On the other hand, the simplification can lead to poorly motivated investments if it is used in the wrong way. It is important to keep in mind that there are many different aspects in the decision process thus the model gives an indication of the needed choice of measure.

10 Conclusion

Initially it has been concluded that there is a lack of clear and consistent guidelines regarding when and what type of runoff management system that should be implemented on bridges. The decision model have created a basis for how to manage runoff on bridges and the aim has been to create it as clear and easy to follow as possible, while following regulations to the extent possible. There has been reason to question the reasonableness of the regulations in some cases. It is therefore recommended that TRV, in consultation with concerned authorities and agencies, together looks over and revises current regulations with the purpose of making them easier to interpret. A result could be that the regulations becomes more accessible and the risk for misunderstandings is reduced which could be beneficial for the whole industry.

The literature study has consisted of both national and international studies. Here it has been concluded that there is extensive research done internationally in the field of runoff management on bridges and a holistic approach exists on how and when to act. This is something that should be studied further, and applied on Swedish conditions, since it has been noticed that e.g. experience from already finished projects is not always used.

The conducted risk assessment shows that the risk of a spill event with HGV and DGV are generally to be considered as negligible. This concludes that the risk should not govern the selection of management system, instead the need for protection of the receiving water should be the controlling factor.

For the case study of Angeredsbron the application of the decision model has shown what choice of measure is needed and this has proven to fulfil the local regulations.

11 Further studies

The decision model, in its current state, suggests what choice of measure is needed for management system. To connect the model to specific management designs based on parameters such as available construction space and remaining life length of the bridge would improve the model further. It is also important to implement the economic efficiency and ensure that the cost for an environmental measure does not exceed the cost of a potential remediation.

The protected recipient parameter could be developed by adding more information about recipient sensitivity in the VISS portal. The VISS portal could then provide the needed information about receiving waters in an accessible way. This would add a wider perspective towards the protected recipient parameter since water bodies which do not have pre-defined protected areas could be included as well.

The AADT parameter contains a lot of uncertainties. The model could benefit from a validation of the correlation between pollutant concentrations and AADT.

For the risk assessment, no account has been taken concerning specific circumstances, which could affect the likelihood, for a bridge compared to other road stretches. This could for example be the increased risk of road slipperiness on bridges. Therefore the likelihood of an event occurring on bridges could be further developed.

A GIS study could be carried out to find which bridges that lack proper environmental measures. This could be done by comparing an overlay of bridge locations to an overlay of water bodies so that bridges crossing bodies of water can be identified and analysed further.

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Appendix I – Overall likelihood of a spill event

Below follows an assessment of the overall likelihood of a discharge resulting in an environmental damage for DGV and HGV. The calculations of the overall likelihood is based on a manual developed by Trafikverket with the intent to provide guidance when assessing the risks that roads, railways and their usage constitutes for surface- and groundwater (Trafikverket, 2013).

Dangerous goods vehicles

From the event report published by MSB covering events during 2007-2012 for the transportation of dangerous goods, a total number of 233 events have been reported (MSB, 2014). Looking into the yearly distribution it can be seen, in the table below, that the number of events tends to decrease. It has therefore been concluded to only account for the years 2010-2012 when calculating an annual average of events, in order to get a plausible estimation. The annual average has been set to 28.

Year	Total no. of events
2007	57
2008	40
2009	28
2010	32
2011	29
2012	23
Annual average	**28**

From the report it can be evaluated that a total of 130 events resulted in a discharge out of which 43 occurred in transit (MSB, 2014). Out of the 43 events 17 were identified to have caused some sort of environmental damage. In order to achieve the ratio of events in transit causing an environmental damage, the number of environmental damages in transit has been divided by the total number of events.

$$Ratio\ of\ env.damages = \frac{No.of\ env.damages}{Total\ no.of\ events} = \frac{17}{233} \sim 0.0730$$

The calculation above shows that 7.3 % of the total number of events resulted in a discharge with an environmental damage. So far the calculations have been based on the years 2007-2012. In order to estimate an annual average of events in transit causing an environmental damage, the ratio of environmental damages is multiplied with the previously estimated annual average of events.

$$Ann\ avg\ env.damages = Ratio\ env.damages \times Ann\ avg\ of\ event\ = 0.073 \times 28 \sim 2.043$$

To obtain the overall likelihood of an event in transit causing an environmental damage per DGV driven km it is necessary to divide the annual average of environmental damages with the total number of driven km of DGV. For this purpose it is relevant to look at the number of driven km of DGV in Sweden which was 74 million km during 2014 (Trafikanalys, 2014).

$$Likelihood\ per\ DGV\ driven\ km = \frac{Ann\ avg\ of\ env.damages}{No.of\ driven\ km\ of\ DGV} = \frac{2.043}{74\ 000\ 000} \sim 2.8 \times 10^{-8}/km$$

The overall likelihood of a spill event with a DGV in transit causing an environmental damage is estimated to 2.8×10^{-8} per DGV driven km.

Heavy goods vehicles

The total amount of transported kilometres with HGV was three billion in 2014 and the total average number of events per year for HGV is 1 217.

$$Frequency\ of\ events = \frac{No.of\ events}{Total\ HGVs\ travelled} = \frac{1217}{3 \times 10^9} \sim 4.057 \times 10^{-7}/km$$

The frequency of events does not state if the event results in a discharge of fuel from the tank causing an environmental damage. For DGV the number of events causing an environmental damage was 17 and the total number of discharges in transit was 43. This means that 39.5 % of all discharges from DGV cause an environmental damage.

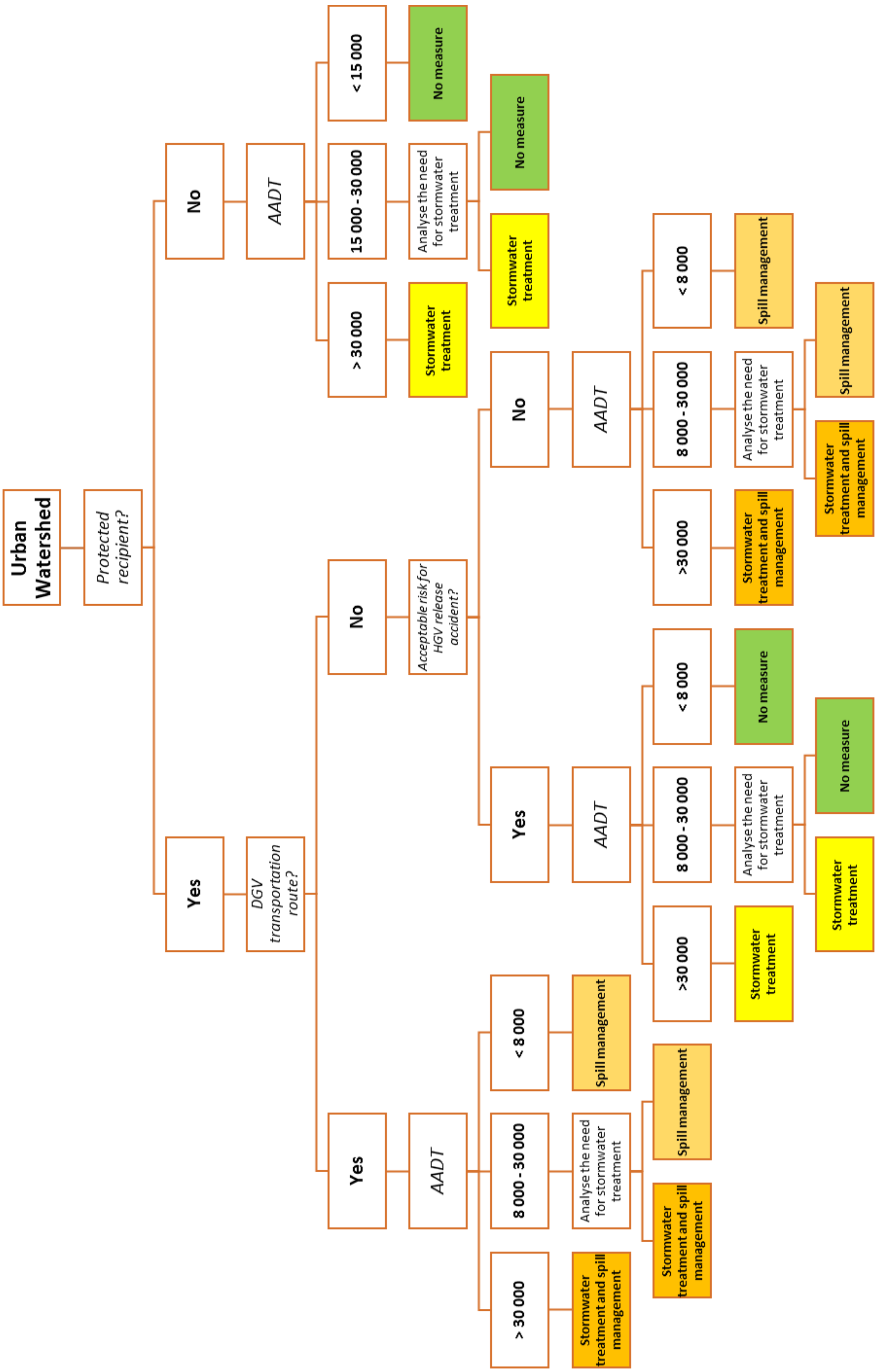
$$Ratio\ of\ release\ causing\ env.damage = \frac{No.of\ env.damages\ (DGV)}{Release\ in\ transit\ (DGV)} = \frac{17}{43} \sim 0.395$$

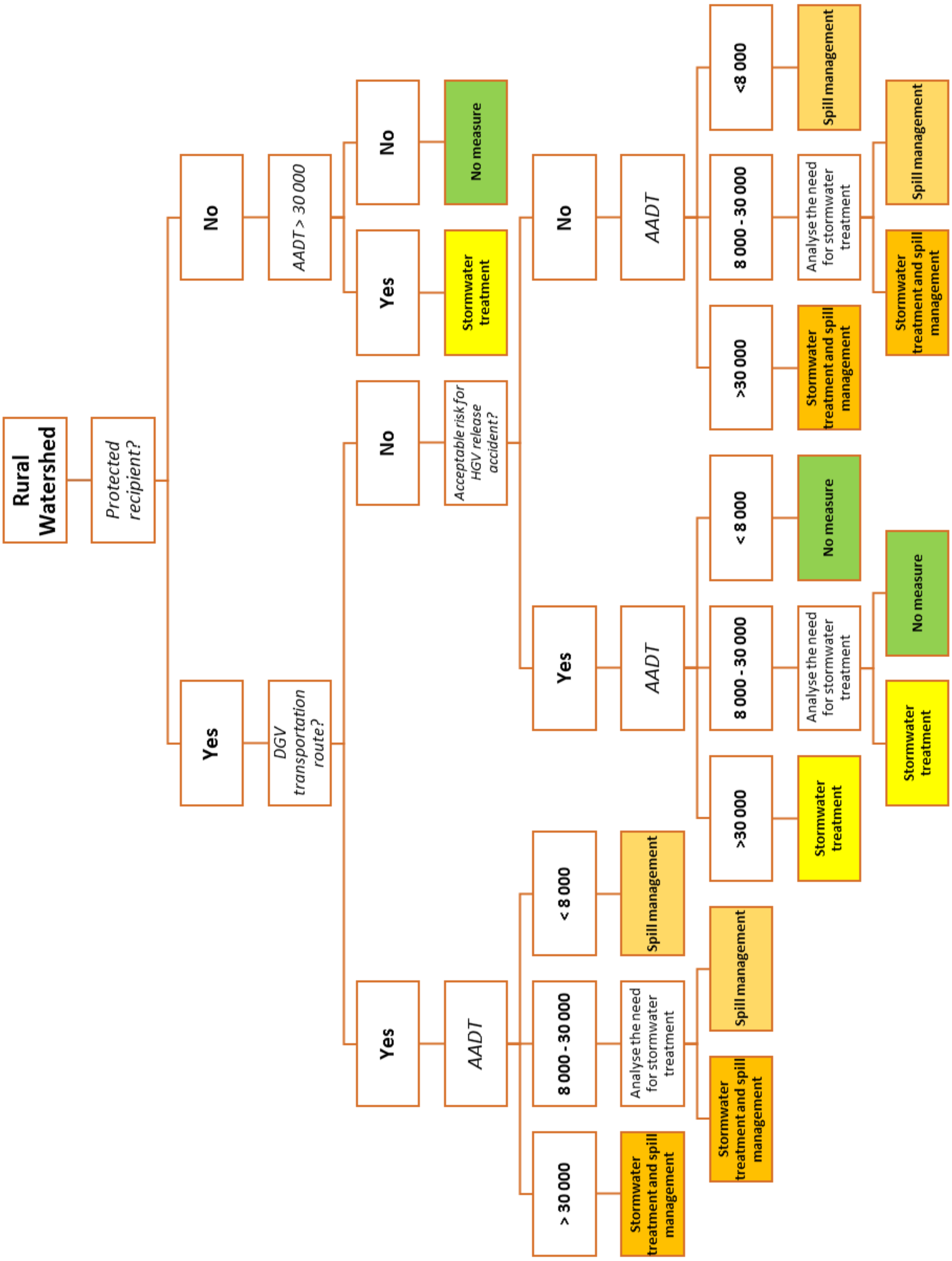
In the manual developed by Trafikverket the likelihood of a discharge during an event is set to 0.03 (Trafikverket, 2013). Even though it might be somewhat conservative the ratio of a discharge causing an environmental damage is estimated to be valid for the discharge of fuel from HGV as well.

$$Likelihood\ for\ HGV = Freq.of\ events \times Likely\ of\ a\ release\ \times Likely\ of\ env.damage$$
$$= 4.057 \times 10^{-7} \times 0.03 \times 0.395 \sim 4.8 \times 10^{-9}/km$$

These parameters combined give an overall likelihood of a discharge from the fuel tank of a HGV causing an environmental damage. The overall likelihood is estimated to 4.8×10^{-9} per HGV driven km.

Appendix II – Decision model





Rural Watershed
Protected recipient?
Yes
No
DGV transportation route?
AADT > 30 000
Yes
No
Yes
No
AADT
Acceptable risk for HGV release accident?
Stormwater treatment
No measure
> 30 000
8 000 - 30 000
< 8 000
Yes
No
Stormwater treatment and spill management
Analyse the need for stormwater treatment
Spill management
AADT
AADT
Stormwater treatment and spill management
Spill management
>30 000
8 000 - 30 000
< 8 000
>30 000
8 000 - 30 000
<8 000
Stormwater treatment
Analyse the need for stormwater treatment
No measure
Stormwater treatment and spill management
Analyse the need for stormwater treatment
Spill management
Stormwater treatment
No measure
Stormwater treatment and spill management
Spill management

Appendix III – Stormwater assessment Angeredsbron

The purpose of the calculation procedure is to determine if the added load from Angeredsbron impacts the total load in the river Göta Älv to any greater extent. Stream load is gathered from various published scientific data sources and used to calculate the annual loading according to the following equation.

$$Upstream\ Load = \ Annual\ discharge\ \times Average\ Stream\ Concentration$$

The bridge load is determined by using the pollutant concentrations found in the report. Mean values for the moderate category of pollutant concentrations are used. The annual bridge load is calculated according to the following equation.

$$Bridge\ Load = Rainfall\ \times Runoff\ Coeff.\ \times Area \times Conc.$$

The various site specific variables as well as conversion factors are found in the table below.

Site specific data	
Stream flow (m3/s)	165
Conversion factor (s/yr)	31 536 000
Conversion factor (l/m3)	1 000
Conversion factor (kg/µg)	0.000000001
Average rainfall (mm/yr)	552
Conversion factor (m/mm)	0.001
Runoff coefficient (-)	1.0
Bridge deck area (m2)	15 128

The results from the annual stream and bridge load concentrations are presented in the following table.

Constituent	**Stream load (µg/l)**	**Stream load (kg/yr)**	**Data source**	**Bridge load (µg/l)**	**Bridge load (kg/yr)**	**Data source**
Total suspended solids, TSS	-	31 000 000	SGI (2011)	112 500	939.45	Table 8
Total nitrogen, Tot N	711.00	3 699 646	Göta Älv VVF (2010)	3 125	26.10	Table 8
Total phosphorous, Tot P	18.00	93 662	Göta Älv VVF (2010)	150	1.25	Table 8
Lead, Pb	0.30	1 561	Göta Älv VVF (2010)	9.0	0.08	Table 8
Cadmium, Cd	0.02	83	Göta Älv VVF (2010)	0.9	0.01	Table 8

Quicksilver, Hg	0.94	4 891	Göta Älv VVF (2010)	0.12	0.00	Table 8
Copper, Cu	1.33	6 921	Göta Älv VVF (2010)	27	0.23	Table 8
Zinc, Zn	3.50	18 212	Göta Älv VVF (2010)	180	1.50	Table 8
Nickel, Ni	0.82	4 267	Göta Älv VVF (2010)	135	1.13	Table 8
Chromium, Cr	0.27	1 405	Göta Älv VVF (2010)	45	0.38	Table 8
Oil	-	3 177	Länsstyrelsen (2003)	750	6.26	Table 8
PAH	0.01	52	Länsstyrelsen (2003)	1.5	0.01	Table 8

The annual load in Göta Älv is compared to the annual load contributed by Angeredsbron according to the following equation.

$$Load\ Increase = \frac{Bridge\ Load}{Bridge\ Load + Upstream\ Load} \times 100$$

The results are presented in the table below. The results are, for all selected constituents, below the recommended 1 % and it is therefore concluded that the stormwater treatment is not needed.

Constituent	**Annual load in Göta Älv (kg/yr)**	**Annual load contributed by Angeredsbron (kg/yr)**	**% Increase**
Total suspended solids, TSS	31 000 000.00	939.45	0.003
Total nitrogen, Tot N	3 699 645.84	26.10	0.001
Total phosphorous, Tot P	3 699.65	1.25	0.034
Lead, Pb	1 561.03	0.08	0.005
Cadmium, Cd	83.26	0.01	0.009
Quicksilver, Hg	4 891.23	0.00	0.000
Copper, Cu	6 920.58	0.23	0.003
Zinc, Zn	18 212.04	1.50	0.008
Nickel, Ni	4 266.82	1.13	0.026
Chromium, Cr	1 404.93	0.38	0.027
Oil	3 177.30	6.26	0.197
PAH	52.03	0.01	0.024