Environmental and Health Risk Management for Road Transport of Hazardous Material

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Abstract
A methodology is produced for environmental and health risk assessment for road transports of hazardous material. The general risk management process with focus on health and environment is described briefly. Management systems, risk communication and uncertainty in the risk management process are also discussed in this context. The produced methodology is implemented in a case study in Iceland. The case study considers risks related to gasoline and diesel transports past a water protection area and a popular leisure fishing and recreational area. The endpoint for health is the water quality and for the environment effects on the game fish.

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Summary

A fundamental objective has been to produce a suitable method to systematically analyze and evaluate the health and environmental risks of hazardous material transports on road. Extensive literature studies have been carried out in an attempt to capture the broad spectrum of the present methods and tools of environmental and health risk analysis.

In order to systematically describe methods, definitions and praxis the report is divided into two main parts:

Part I: General methods in risk management with focus on health and environment

Part II: Case study - Health and environmental risk assessment for transport of hazardous material

Part I:

The focus of risk management is often on three main areas; Safety (S), Health (H) and Environment (E). These have a general risk management process in common with important concepts and definitions. Therefore great efficiency benefits may be gained from treating these in an integrated framework. These areas are described in part I.

Different levels of risk analyses are described and how the results can be evaluated in terms of tolerability. Emphasis is also on important parts of the overall risk management process that lie outside the risk analysis, e.g.:

- Handling uncertainty
- Communication and Risk Communication
- Management systems
- Risk control options

The main objective of the first part is to produce a method for environmental and health risk assessment of road transports of hazardous material. The first steps of the methodology are Problem Formulation, Data Collection/Evaluation and Hazard Identification. Here it is crucial to have appropriate *endpoints*, and to assimilate enough information and knowledge on the area and chemicals. In order to identify the major risks and to decide whether time-consuming quantitative methods are motivated, a rough analysis should be applied (e.g. an index method). If the risk is substantial, scenarios can be selected based on the first steps of the methodology. The quantitative analysis should contain three estimations:

1. Frequency/probability estimation of accident.
2. Exposure estimation.
3. Effect estimation.

} Consequence estimation (2. and 3.)

In order to evaluate the three estimations they need to be transformed to a quantifiable risk value. This is often difficult due to the complexity of health and, especially, environmental risks. One possibility is to calculate a quota of predicted concentration (exposure estimation) and a highest no adverse effect concentration (effect estimation). This quota is a measure of consequence. But in order to measure risk, frequency/probability estimation is also needed.

It is often quite straightforward to calculate a frequency for an accident resulting in a chemical spill, but the probability that the specific environment or individual is exposed is always a challenge. This takes expertise from different fields. The uncertainty in the final risk characterization is substantial, but the scenarios can nevertheless be placed in a risk matrix. The advantage of placing the scenarios in a risk matrix is that it helps the risk control discussions. Actually getting the control measures implemented is very important. When several stakeholders

participate in the risk management process, it is important that the communication works and that there are functioning SHE management systems. These systems also aid risk control.

Part II:
A case-study constitutes the second part of the report where a stretch of the road Sudurlandsvegur (in Iceland) is analyzed using the methodology from part I. Along the road there are vulnerable areas consisting of a water protection area, a Salmon (salmo salar) river and a lake with Brown Trout (salmo trutta) and Arctic Char (salvelinus alpinus) fishing. Effects on these species constitute the endpoints of the environmental risk assessment.

The health endpoint is the water quality of the water protection area that supplies all the drinking water in Reykjavík. Reykjavík Energy delivers the water so they are stakeholders in this analysis. At the end of the line the consumers are also stakeholders. The chemicals in the analysis are gasoline and diesel. These were chosen partly because they are the most commonly transported chemicals on the stretch and partly because they are the only chemicals that any transport data was available on.

Risk identification of the area is partly conducted with a qualitative hazard estimation method (an index method). Based on this rough analysis the environmental and health hazards are substantial. Therefore more quantitative methods are motivated. The identification step also aids in the selection of scenarios.

Frequency and probability estimation is conducted, e.g. by collecting data on the transports through contacts with distribution company and actual counting of trucks. An event tree is constructed with three possible sizes of release for hazardous material transports and one for common heavy transports (equal to small hazardous material release). Due to lack of data, frequencies cannot be calculated for all scenarios, but rough estimates are possible.

The frequency calculations themselves do not consider the exposure probability, i.e. the probability of estimated effects in case of spill.

The exposure estimation consists mainly of two chemical distribution calculations, one via the groundwater predominantly for the health assessment and one via surface water for the environmental assessment.

The health effect estimation assumes that the water quality is adversely affected if the concentration exceeds 0.1 mg/l. This value has been proposed by experts, and is further motivated by reference values presented by the Swedish environmental protection agency. The environmental effect estimation is more complex, and since no appropriate effect values could be found for any of the endpoint species, the estimation becomes more qualitative as it must be based on the data available. But even qualitative estimates can be basis for risk management strategies. At the very least they can imply the need for further investigations.

As far as possible a quotient is created of the results from the exposure estimation and the effect estimation to form a consequence measure. This is then combined with the frequency estimation in risk matrices of different levels.

The risk exceeds the set criteria for both health and environment. The reason is mainly the extent of the consequences. It is left to the stakeholders to decide whether the set criteria are the right ones to ratify the judgments, and in that case which measures to take. Some recommendations are nevertheless given in the end of the report.

Sammanfattning (Summary in Swedish)

Ett övergripande mål i rapporten har varit att ta fram en lämplig metod för att på ett systematisk sätt kunna analysera och utvärdera miljö- och hälsoriskerna vid vägtransport av farligt gods. Omfattande litteraturstudier har genomförts för att försöka fånga in det breda spektret av dagens metoder och analysverktyg för miljö- och hälsorisker.

För att på ett systematiskt sätt kunna beskriva metoder, definitioner och tillämpning är rapporten uppdelad i två större delar:
Del I: Generella metoder i riskhantering med fokus på hälsa och miljö.
Del II: Case study – Hälso- och miljöriskbedömning för transport av farligt gods

Del I:
Riskhantering delas ofta in i tre huvudområden, säkerhet (S), hälsa (H) och miljö (M). Gemensamt har dessa en generell riskhanteringsprocess med viktiga begrepp och definitioner, och stora samordningsvinster kan göras genom att hantera dessa i ett integrerat system. De olika blocken beskrivs i del I.

Olika nivåer på riskanalyser beskrivs liksom hur resultatet från analyserna kan värderas i termer av tolerabel risk och ej tolerabel risk. Stor vikt läggs också vid viktiga delar av riskhanteringsprocessen som ligger utanför själva riskanalysen, bland annat diskuteras:

- Osäkerhetshantering genom processen
- Kommunikation och riskkommunikation
- Ledningssystem
- Olika åtgärdsstrategier

Första delens huvudmål är dock att ta fram en miljö- och hälsoriskbedömningsmetod för vägtransport av farligt gods. De första momenten i metodiken går ut på att göra en problembeskrivning, datainsamling samt en faroidentifiering. Viktigt i dessa moment är att finna rätt ”endpoints” samt att få in tillräckligt med information och kunskap om område och kemikalier. För att identifiera de största riskerna samt bedöma om fallet är aktuellt att analysera med mer kvantitativa metoder bör någon form av grovanalys tillämpas (ex. index-metod). Om risken är påtaglig kan scenarios väljas utifrån de första stegen i metodiken. Den kvantitativa analysen bör innehålla tre bedömningar:

1. Frekvens/sannolikhetsbedömning för olyckshändelse
2. Exponeringsbedömning.
3. Effektbedömning.

} Konsekvensbedömning (2–3)

För att kunna värdera de tre olika bedömningarna behöver de formas till ett mätbart riskmått. Detta är dock mycket svårt eftersom hälso- och framförallt miljöriskbedömningar är mycket komplexa. Ett möjligt tillvägagångsätt är att beräkna en kvot mellan beräknad koncentration i aktuell miljö (exponerings bedömning) och den högsta koncentrationen då inga negativa effekter uppstår (effektbedömning). Denna kvot bildar ett konsekvensmått. Men för att få ett riskmått krävs även en frekvens/sannolikhets bedömning.

Det är oftast relativt lätt att beräkna fram en frekvens för olycka med läckage av aktuell kemikalie, kvar står dock sannolikheten för att just den utvalda miljön eller individen exponeras. För att detta ska vara möjligt krävs kompetens från flera olika områden. Osäkerheten blir därför väldigt stor i den slutliga riskkarakteriseringen men det är ändå möjligt att placera varje scenario i en riskmatris. Fördelen med att få in scenarierna i en riskmatris är att man sedan lättare kan

diskutera lämpliga åtgärder. Ännu viktigare är dock att verkligen få åtgärderna utförda. Då flera intressenter är med i riskhanteringsarbetet är det viktigt att kommunikationen är god samt att det finns utarbetade ledningssystem på SHM området.

Del II:
Andra delen av rapporten utgörs av en ”case study” där området längs en sträcka på vägen Sudurlandsvegur (på Island) analyseras med hjälp av den framtagna metodiken i rapportens första del. Längs sträckan finns sårbara områden i form av en vattentäkt, en å med laxfiske (salmo salar) och en sjö med röding (Salvelinus Alpinus) och öring (salmo trutta). Effekter på dessa arter utgör endpoints för miljöriskanalysen.

Endpoint för hälsa är vattenkvaliteten i vattentäktsområdet som försörjer hela Reykjavik med dricksvatten. Reykjavik Energi står för leveransen av dricksvatten och är därmed en av risktagarna i analysen. I slutändan är förstås konsumenterna även risktagare. Kemikalierna i analysen är bensin och diesel. Dessa kemikalier välj dels för att de är vanligast på sträckan och dels för att de är de enda kemikalierna som någon transportinformation kunde tas fram om.

Identifiering av riskerna på den aktuella sträckan görs med bland annat en kvalitativ faro-bedömning, en indexmetod. Utifrån denna grovanalys kan faran för miljö och hälsa anses påtaglig och därför bör mer kvantitativa riskanalyser tillämpas. Ur identifieringen kan också lämpliga scenarion väljas ut.

Frekvens- och sannolikhetsbedömning görs genom insamling av data för aktuella transporter, via kontakter med distributionsbolag och räkning av transporter. Händelseträd byggs upp där tre olika storlekar på spill är möjliga för trafik med farligt gods transport och en för vanlig tung transport (lika med litet farligt gods utsläpp). På grund av bristande indata är det inte möjligt att få fram frekvenser för alla scenarion, men grova uppskattningar är möjliga.

Frekvensberäkningarna tar ej hänsyn till exponeringssannolikheten, dvs sannolikheten för beräknad effekt vid spill.

Exponeringsbedömningen består till stor del av två spridningsberäkningar, en via grundvattnet som i första hand är för hälsoriskerna och en för spridning via ytvatten för miljörisker.

Effektbedömning för hälsa förutsätter att vattenkvalitén börjar försämras vid ca 0,1 mg/l. Detta värde har föreslagits av experter, och motiveras med hänsyn till Naturvårdsverkets riktlinjer. Effektbedömningen för miljön är mer komplicerad och eftersom inga direkt passande effektvärden hittades för lax, röding eller öring blir bedömningen i dessa fall mer kvalitativ då den får grundas på tillgänglig data. Men även kvalitativa resultat kan utgöra grund för riskhanteringsstrategier. De kan åtminstone visa på behov för vidare arbete.

I möjlig mån kan nu en kvot mellan exponeringsbedömningen och effektbedömningen bildas till ett konsekvensvärde och kopplas ihop med frekvensbedömningen i olika nivåer av riskmatriser.

Riskerna överskrider satta kriterier för både hälsa och miljö. Detta beror främst på konsekvensernas omfång. Det är upp till berörda parter att bestämma om de satta kriterierna är de rätta att basera beslut på, och i så fall vilka åtgärder som skall väljas. Vissa rekommendationer har dock lyfts fram i slutet av rapporten.

Contents

PART II: CASE STUDY - HEALTH AND ENVIRONMENTAL RISK ASSESSMENT FOR TRANSPORT OF HAZARDOUS MATERIAL

1 Introduction

1.1 Background

Since January 1st 2001, a new law for fire protection in Iceland states that it is the responsibility of the fire departments to respond to accidents (on land) that threaten the environment. Therefore the fire authority and the fire departments in Iceland have an interest in assessing the environmental risk picture in Iceland.

During the last few years petroleum transports on land have increased radically in Iceland since it in most cases has become more economic to use that route than transport by ship. This means that the risk of accident on land has increased and the authorities would like an indication of the magnitude of these risks and/or the increased vulnerability of society as a consequence. As a result of this project the oil distribution companies, as well as the authorities, have a new tool at their disposal besides economic considerations, when deciding how the transports should be performed in the future.

When this project was initiated it's goal and demarcations were somewhat uncertain, but the object of the analysis gradually developed (see section 6.1). When consideration of the water protection area of Reykjavík emerged in the project, a meeting was held with Reykjavík Energy concerning the project and the project has been carried out in cooperation with them.

Early in the project it was clear that a single stretch of road would be analyzed in a case study, while the methodology produced to achieve this analysis could possibly be used later on for other stretches.

1.2 Objectives

The main objective of this report is to illuminate the health and environment issues of Safety, Health and Environmental (SHE) risk management in regard to road transports of hazardous material (in Iceland).

To achieve this a methodology will first be produced, or gathered from various sources. Then a case study using that methodology will be performed on a stretch of road near Reykjavík. In the case study the health aspects will be exemplified by contamination of a water protection area and the environmental aspects by adverse effects on salmon (salmo salar), arctic char (Salvelinus Alpinus) and brown trout (salmo trutta) populations affected by a petroleum spill, see figure 1-1.

It is important to illuminate the present situation in the area, the organization and communication between the relevant parties; fire authorities, fire department, oil transport companies and Reykjavík Energy. When deemed necessary, improvements will be suggested as to how the risk management process could function better between and within the stakeholders' organizations. Contradictions between the stakeholders are a threat to effective risk management. The first step towards solving these is illuminating them. This can only be attained by comprehensive, clear and straightforward communication on each stakeholders risk perception, goals and motives.

1.3 Structure of the report

The report is divided in two parts. First some general methods in risk management are described with focus on health and environment. A suitable methodology for health and environmental risk assessment for transport of hazardous material on roads is the goal of the first part. In this part the importance of risk communication is also discussed. The second part is a case study where the methodology from the first part is utilized on an object in Iceland. In this part it is also important to shed some light on the responsibility of different stakeholders concerning the hazardous transports in question. Therefore the organization and communication between the relevant parties is discussed.

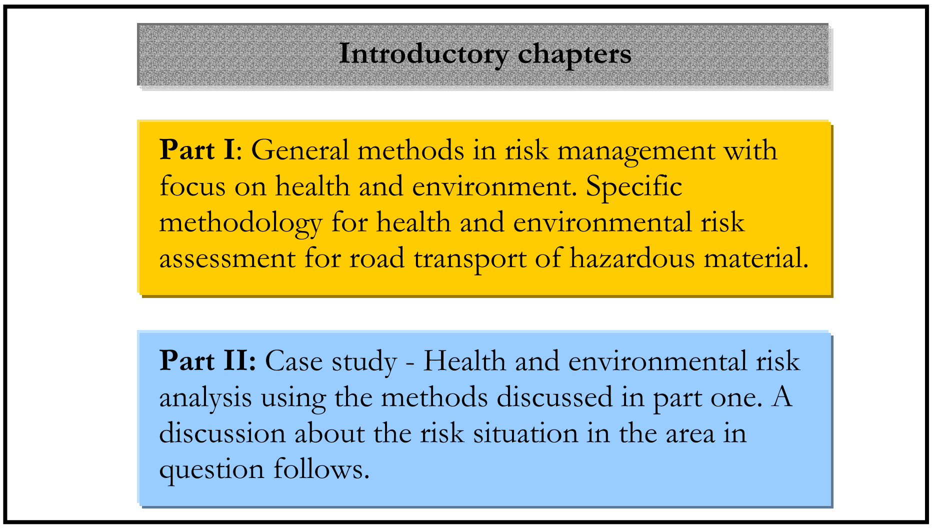


Figure 1-1 An illustration of the structure of the report

1.4 Demarcations

The most fundamental demarcation is that safety issues are not considered, and therefore the possibility of petroleum ignition is ignored. The ramification of this for the case study is that since safety issues constitute the overwhelming risk in urban settings the transport through Reykjavík is not considered and the stretch of road that is analyzed starts outside of Reykjavík's urban areas. The only substances covered in the assessment in the case study are gasoline and diesel (see chapter 6).

Since health and environmental risk analysis is a relatively new discipline a lot of energy must be spent on probing the field and describing methods and procedures used internationally. Therefore the depth of the analysis in the case study is limited. The possible depth of the analysis depends greatly on available scientific data on the area in question and we must rely on information already gathered for other purposes. The result is a certain discrepancy between the general methodologies described in part one and the case study in part two. This is a flaw that can be expected in pioneer work, and points out the need for further development in the area.

The endpoints of the health risk assessment are whether or not the concentration of petroleum products in the wells of Reykjavík Energy (Orkuveita Reykjavíkur) may exceed a certain level. It may be argued that water quality risk assessment is a more proper denomination than health risk assessment, but degraded water quality is likely to give adverse health effects. Further, since petroleum products are considered, their potency to aromatize water is likely to render water

unsuitable for drinking before serious health risks arise. Nevertheless we choose to keep using the term health risk assessment because it fits the nomenclature of SHE.
The endpoints of the environmental risk assessment are rather narrow, i.e. direct (fatality and failure to reproduce) effects on salmon, char and trout in lake Ellidavatn and the river Ellidaár. These are popular leisure fishing species in the area, so whether the fish will remain edible is also a concern.

1.5 Acronyms & abbreviations

ALARP	As Low As is Reasonably Practical
BCF	Bio Cumulating Factor
ECx/EDx	Effect concentration/dose
EMAS	Environmental Management and Audit Scheme
EPA	U.S. Environmental Protection Agency
EPI	Exposure/ Potency Index
ETA	Event Tree Analysis
EU	European Union
HazOp	Hazard an Operability studie
HI	Hazard index
HRA	Human readability analysis
HSE	Human and safety Executive (United Kingdom)
HQ	Hazard quotient
ISRS	International Safety Rating System
K_{oa}	n-octanol air partition coefficient
K_{oc}	Organic carbon sorption coefficient
K_{ow}	n-octanol water partition coefficient
LCx/LDx	Lethal concentration/dose. The concentration or dose at which x percent of test organisms die when exposed to the substance for a specified time period.
LD_{lo}	Lethal doses low. The lowest dose to cause death in the specimen.
LOAEL	Lowest observed adverse effect level.
MF	Modifying factor
MOE	Margin of Exposure
MOS	Margin of Safety
NOAA	American National Oceanic & Atmospheric Administration
NOAEC/NOAEL	No observed adverse effect concentration/level. An exposure concentration/level at which there are no statistically significant increases in the frequency or severity of adverse effects.
NOLC	No observed lethal concentration.
NRC	National Research Council (United States)
PDCA	Plan-Do-Check-Act
PEC	Predicted environmental concentration
PNEC	Predicted no effect concentration
ppm	Part per million (mg/kg)
PRA	Probabilistic Risk Analysis
OHSAS	Occupational Health and Safety (British Standards Institution)
OECD	The Organization for Economic Cooperation and Development

QI	Quotient Index
QRA	Quantitative Risk Assessment/Analysis
RfD/RfC	Reference dose/Reference concentration. An estimate of a daily exposure to the human population, including subgroups, that is likely to without appreciable risk of deleterious effect during a lifetime.
SHE	Safety, Health and Environment
SF	Safety Factor
TDI	Tolerable Daily Intake
TGD	Technical Guidance Document
UF	Uncertainty Factor

1.6 Glossary of Risk management concepts

Assessment endpoint: The adverse or undesired environmental or human health event that is the objective of the assessment (e.g., local extinction, decreased reproduction, occurrence of an illness); the decision criteria for selecting among risk management alternatives.
Bioaccumulation - The total uptake in the living organism through all routes of exposure (bioconcentration through food and environmental exposure via air, water, soil, sediment etc.). Bioaccumulation factors (BAF) describe the steady-state concentrations and may be referenced to any exposure medium.
Deterministic Risk Assessment - A risk assessment that expresses risk as a point estimate for an endpoint, usually as the ratio of exposure and effects (e.g. PEC/PNEC)
Hazard - source of potential harm or situations with a potential for causing harm, in terms of human injury, damage to health, property, the environment, and other things of value, or some combination of these.
Hazard Identification - the process of recognizing that a hazard exists and defining its characteristics.
Measurement endpoint: What can actually be quantified or measured in the environment/human health analysis (e.g., counting organisms, measuring changes in habitat, increased frequency of an illness).
Risk - the chance of injury or loss as defined as a measure of the probability and severity of an adverse effect to health, property, the environment, or other things of value.
Risk Analysis - the systematic use of information to identify hazards and to estimate the chance for, and severity of, injury or loss to individuals or populations, property, the environment, or other things of value.
Risk Assessment - the overall process of risk analysis and risk evaluation.
Risk Communication - any (ideally two-way) communication between stakeholders about the existence, nature, form, severity, or acceptability of risks.
Risk Control Option - an action intended to reduce the frequency and/or severity of injury or loss including a decision not to pursue the activity.
Risk Estimation - the activity of estimating the frequency or probability and consequence of risk scenarios in numerical terms, often by using models.
Risk Evaluation - the process by which risks are examined in terms of costs and benefits, and evaluated in terms of tolerability of risk considering the needs, issues, and concerns of stakeholders.
Risk Management - the systematic application of management policies, procedures, and practices to the tasks of analyzing, evaluating, controlling, and communicating about risk issues.
Risk Matrix – a way to visualize risks by placing them in a matrix. This matrix is most often two-dimensional with frequency/probability on one axis and consequence on the other.
Risk Perception - the significance assigned to risks by stakeholders. This perception is derived from the stakeholders' expressed needs, issues, and concerns.

Part I: General methods in risk management with focus on health and environment

2 Risk management process

In risk management we look at a situation or scenario and ask these types of questions:

- What can go wrong and why?
- How likely is it?
- How bad can it be?
- What can we do about it?

2.1 Definitions

2.1.1 Risk and hazard

Hazard is commonly defined as the potential to cause harm. A hazard can be defined as a property or situation that in particular circumstances could lead to harm. Risk is a function of the nature of the hazard, accessibility or avenue of contact i.e. the exposure potential, characteristics of the exposed population (receptors), the likelihood of occurrence, and the magnitude of exposures and consequences, as well as public values.

Risk = f (frequency or probability , consequence)

Consequence in terms of acute effects result from single exposure, generally in high concentrations over a short period, and the effects are evident in a short time. Chronic effects result from continuous or repeated exposures over a significant part of a receptor's lifetime, and the effects may not manifest themselves for long time after initial exposure. These definitions and more can be found in /Kaplan 1997/, /Kolluru et al 1996/ and /McColl et al 2000/.

2.1.2 Risk management and assessment

Risk management (see figure 2-1 below) is a process of evaluating and, if necessary, controlling sources of exposure and risk. Risk assessment is the process within risk management where risks are identified, analyzed and evaluated. While risk assessment provide estimates of risk, they do not answer such questions as "how clean is clean?" and "how safe is safe?", i.e. what is tolerable and what is not. These kind of questions need to be answered in a separate context of democratic society evaluation, where criteria for the risk evaluation in risk assessment are created, because the risk tolerability of a society is a political question and must be answered in a democratic way. /Kolluru et al 1996/

Risk management decisions that are anchored in risk assessments as well as cost-benefit analyses, technical feasibility and public values, are far more effective and more enduring than decisions that stem from isolated analyses.

Sound risk assessment, whether voluntary or regulated by law, means weighing many different attributes of the available alternatives and thereafter reaching a decision. The scientific information provided by risk assessment is but one input to the process. Other criteria include politics, economics, competing risks, and equity and other social concerns. Although the number of factors gives risk assessment a somewhat arbitrary nature, it's structure and how it is conducted must be rooted in science. It must be planned rigorously in advance, if the objective of illuminating the risks is to be obtained. Unfortunately, too many risk assessments prove to be of little value to risk managers because of inadequate planning. /McColl et al 2000/

2.2 The general risk assessment and management model

The risk assessment and analysis is only one part of the more extensive risk management process. Figure 2-1 presents an overview of safety, health and environmental risk management and assessments including major process steps, outcomes of interest, and typical applications.

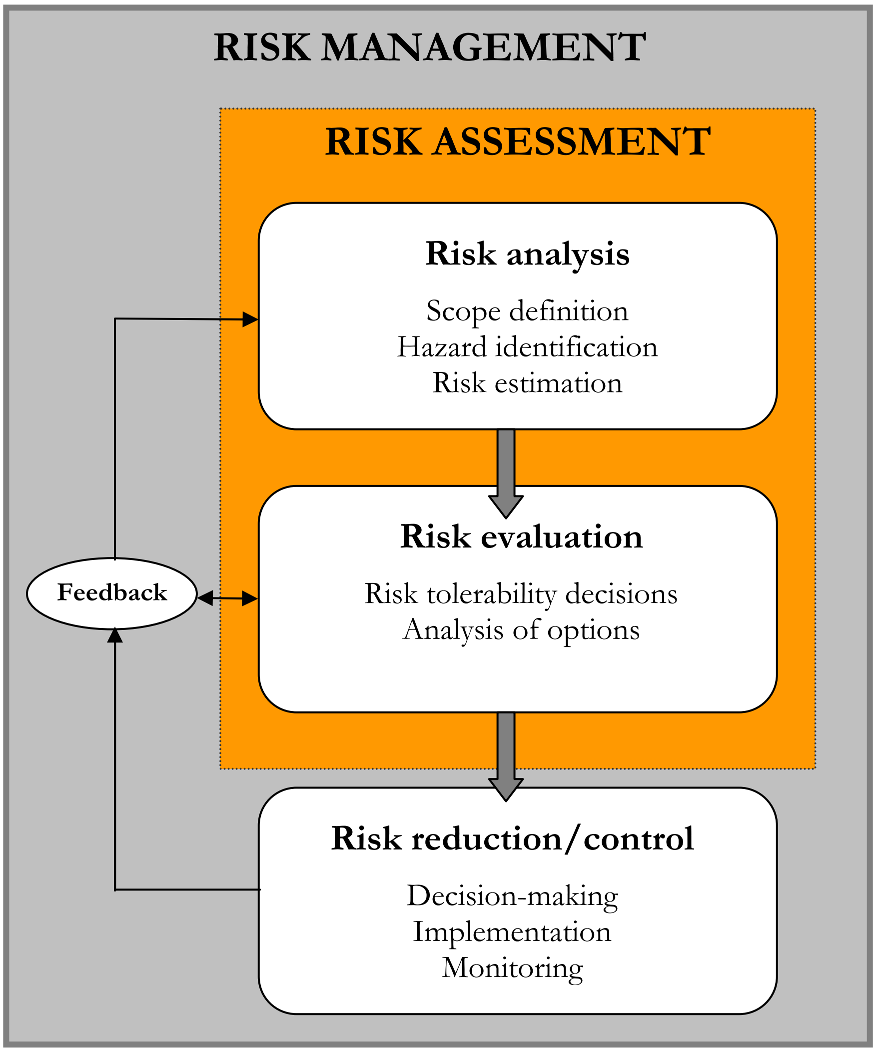


Figure 2-1 Generalized risk assessment and management model. /IEC 1996/

The three activities that constitute the essential decision-making steps in the risk management process are each involved in examining different aspects of risk problem.

- ***Risk analysis***
  The use of science-based risk information and analytical methods to analyze and characterize the nature and extent of safety, health and environmental risks.
- ***Risk evaluation***
  Consideration of the economic, social, political and legal factors that influence a decision to adopt a particular course of action to reduce the risk. In some risk frameworks the quantitative economic analysis of the benefits and cost of risk reduction is combined with results of the risk estimation process so that a risk assessment may subsume part or all of risk evaluation.
- ***Risk reduction/control***
  The selection of options and initiation of actions intended to reduce risk to a tolerable level. This activity is often referred to as risk management but the term risk control is more

specific and reflects the objectives of the activities it denotes. By using this term the problem of risk management being a subset of itself is also avoided.

These core processes are conventionally arranged in an ordered sequence of steps, so risk analysis is typically thought to come first, risk evaluation second and risk control third. This stepwise arrangement is intended to ensure that the source of information in risk decision-making flows primarily from well-validated scientific studies, before moving onto the more value-laden considerations of socioeconomic factors and technical control options. Nevertheless each of the steps should be intimately connected to the others by continuous two-way communication occurring in an interactive manner, as is represented by the feedback loop in figure 2-1.

The general risk management process should not be conceived as a closed and isolated system, instead should it be open and flexible. The process should adapt to the actual assumptions and it should also be possible to make amends underway.

2.3 Risk analysis methods

Risk analysis is an important step in the risk management process and there are a number of analyses to select from with different levels. But all of them have the same goal; to systematically use information to identify hazards and to estimate the probability for, and severity of, injury or loss to individuals or populations, property, the environment, or other things of value.

The selection of the analyses depends a great deal on the situation and some of them are developed for specific applications. Various people and organizations throughout the field of risk management have given several different definitions of the scope risk analysis at the different levels. Generally these can be divided into qualitative, semi-quantitative and quantitative analysis. Short descriptions of each are given below in section 2.3.2. To understand the different levels of risk analysis it's necessary to know the difference between deterministic and probabilistic methods. A short description is given in section 2.3.1.

2.3.1 Qualitative and/or quantitative analysis

One way to distinguish between different risk analyses is to divide them up by whether they quantify the risk or not. Usually a risk analysis is either qualitative or quantitative, but sometimes the analyst chooses something in the middle. Then the analysis is called semi-quantitative. The figure 2-2 describes some frequently used analysis at different levels of quantification.

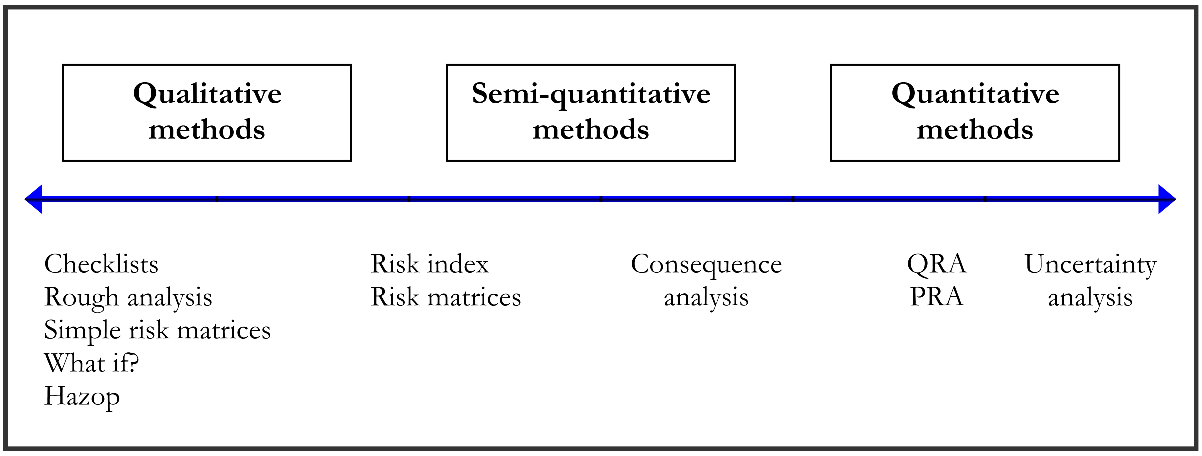


Figure 2-2 Different Levels of Risk Analysis. /Nystedt 2000/

Qualitative
The qualitative methods are often considered to be the first step of a risk analysis, i.e. the Hazard Identification step, to determine whether further analysis is needed, and in what area the resources should be concentrated to provide the greatest efficiency. They are often used as a tool by management to determine where to allocate the resources on more precise evaluation techniques. They are also useful in systems that present a relatively low risk. Usually some sort of ranking system is used to determine what aspects of a technical system need further investigation and what parts or sub-systems can be considered ”safe enough”. Simple risk matrices are often used where frequencies and consequences are divided into categories such as high, medium and low.

Qualitative risk analysis results are mainly derived from deterministic hazard analyses combined with qualitative evaluations of frequencies and consequences of a specific event. Typical qualitative analysis is rough analysis, checklist, HazOp (Hazard an Operability studies) and What If analysis. These methods are very useful and they are often sufficient when the analysis is rather uncomplicated. /Nilsson 2001/

Semi-quantitative
In a semi-quantitative analysis events are identified and ranked on some sort of predetermined risk scale. The risk scales can be divided into various categories and the event is categorized depending on the risk level that is associated with it. The event can also be placed in a risk matrix like in the qualitative methods but with more consideration of quantities. This approach combines qualitative methods with established risk assessment techniques and it is a relatively simple and effective approach.

This form of analysis gives decision-makers more information regarding where to spend resources on risk preventive measures, and allows a crude ranking of risks. It is also important as a screening tool, or filter, for further analysis. Other semi-quantitative analyses are index methods and rough consequence analysis. /Nilsson 2001/

Quantitative
A quantitative risk analysis (QRA) is totally numerical and can generally be considered as being the most objective of the alternatives. Frequencies and consequences are quantified and can thus relatively easily be compared and ranked. This gives much better possibilities to compare risks

and evaluate the effectiveness of different risk reducing measures, which is a necessity when the budget for such measures is limited (i.e. always).

Quantitative risk criteria can be used and thus the quantified risks can be classified as tolerable or intolerable. Of course there are different quantitative risk analyses suited for different risk problems. A strength of quantitative methods of risk analysis is the possibility to propagate uncertainty through the model. Quantitative analysis is usually the most detailed and is therefore very time and resource demanding.

Qualitative methods are usually incorporated into quantitative analysis as early steps in the process.

Widespread methods in a quantitative analysis are Event Trees Analysis, Quantitative Risk Analysis (QRA) and Probabilistic Risk Analysis (PRA). /Nilsson 2001/ /Kolluru et al 1996/

2.3.2 Deterministic or probabilistic methods

Deterministic or consequence based methods set out from an accident that physically can occur and render consequences.
Probabilistic or risk based methods set out from both probability and consequence for an accident.

Both categories are common in the estimation of risk and in many risks analyses both are simultaneously applied. The risk-based method is often abbreviated PRA (Probabilistic Risk Analysis).

2.4 The risk evaluation

A risk analysis will make it easier to make decisions in risk related question. Examples of questions in this context are:

- Should the activity be allowed at all?
- What kind of other activities should be allowed in the vicinity of the risk source?
- Is it necessary to take any frequency reducing measures?
- Is it necessary to take some consequence reducing measures, e.g. for the environment?
- Should some other kind of measures be chosen to manage the risk?

The answers to the questions above are further specified and concretized in the risk reduction/control part, described in section 2.6 below. Evaluation of risk is often a subjective statement and implies to calculate or in some way estimate the risk. Evaluation of risk can be done on individual, organization and society level.

A number of principles or general starting points to risk evaluation can be used:

- **Reasonableness principle**
  An operation shouldn't involve risks if this can be avoided or if the risk level can be decreased using some reasonable resources. This means that risks should always be eliminated or reduced, if this can be done with reasonable technical and economical resources, regardless of risk level.
- **Proportionality principle**
  The total risk an operation involves should not be disproportionately large in relation to the benefit the operation results in.
- **Distribution principle**

The risks should be reasonably distributed in a society in relation to the advantage the operation admits. This means that individual persons and groups shouldn't be exposed to disproportionately large risks in relation to the advantage the operation gives them.

- **The principle to avoid a catastrophe**
  Risks should rather result in accidents, with circumscribed consequences that can be managed by available rescue resource in the society, than a large catastrophe. That means that risk reduction methods should rather be taken against catastrophes than smaller scale accidents, even though the expected value of risk reduction is equal in both cases.

In practice is it often impossible to apply all the general principles. The evaluation principles should therefore be used as support and guidelines in decision-making. /Haeffler et al 2000/ /Strömgren 1997/

2.4.1 Acceptable risk and/or tolerability

Arriving at consensus decisions on the question of acceptable risks in society is not a simple matter. At minimum, one might ask of any hazard, to whom might it be acceptable or unacceptable, when and under what circumstances? In practical terms, individuals, organizations and governments are constantly faced with the necessity to make decisions involving actual or foreseeable hazards, and consequently face the problem: what is acceptable? Several methods have evolved for the resolution of acceptable risk problems.

A fundamental question in risk evaluation is whether any risk can be considered acceptable or unacceptable. It might be better to consider whether the risk is tolerable or intolerable. As a result of the Layfield inquiry the UK Health and Safety Executive (HSE) produced a report in which tolerable risk is defined as follows:

> *Tolerability does not mean acceptability. It refers to the willingness to live with a risk to secure certain benefits and in the confidence that is being properly controlled. To tolerate a risk means that we do not regard it as negligible or something we might ignore, but rather as something we need to keep under review and reduce still further if and as we can. (HSE 1988a p. 1)* /Royal Society Study group 1992/

In the HSE's approach this definition of tolerability is taken to imply that risks should be monitored against possible benefits, and reduced to "As Low As is Reasonably Practical" (the ALARP principles). The ALARP principle divides risks into three territories. Figure 2-3 shows a framework for risk criteria.

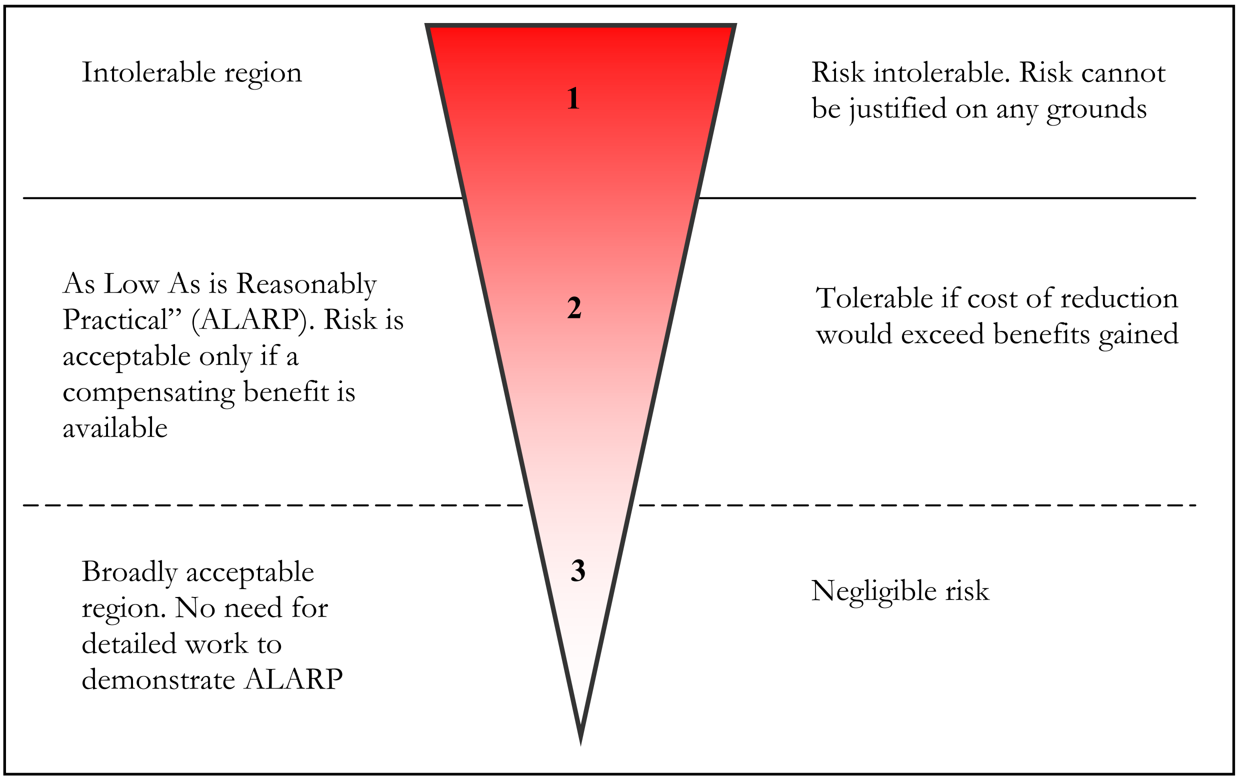


Figure 2-3 Recommended framework for risk criteria /McColl et al 2000/

The use of such a definition to guide regulatory decision-making is clearly a significant development. It implicitly bridges technical and social science considerations of risk by acknowledging that it is individuals and groups in society who must live with hazards, and therefore may be granted a role in making decision about risk. In this respect the HSE is correct in stating that the judgment on what is tolerable is not a scientific but a political matter.

2.5 Risk reduction/control

The risk reduction/control step focuses on choosing a particular course of preventive or remedial action from an array of possible control options, all of which are intended to reduce risks through various strategies identified by the stakeholders and the risk management team. The control options can be divided into the following categories:

- **Inherent safety:** intensification, substitution, attenuation
- **Accident prevention measures:** decrease probability or frequency
- **Preventive injury restriction measures:** measures before an accident occurs that aim to decrease the consequences
- **Emergency management:** prepare rescue efforts, team practice etc.
- **Acute injury restriction:** carrying out rescue efforts
- **Post-accident measures:** evaluating the accident; its causes and the effectiveness of the mitigating measures taken.

It is important to understand that stakeholders sometimes are interested in other risk control strategies than reducing the risk through decreasing the probability or consequence. Some different strategies to mitigate risks are described in table 2-1.

Strategy	Example
Transfer (remove)	*A different method may be chosen for the transport of hazardous material, or it may be substituted for a less hazardous material.*
Trade (insurance)	*The stakeholder may find it convenient to buy an insurance against consequences.*
Eliminate	*Cost-benefit analysis may show that the transport of hazardous material is not worth the risk. Then the transports may be terminated.*
Reduce	*Decreasing the risk through decreasing the probability or the consequence of an accident.*
Accept	*No strategy to decrease the risk is cost-efficient so the stakeholders accept the risk.*
Neglect	*The stakeholders neglect the risks, due to ignorance or nonchalance.*

Table 2-1 Strategies to control risk with some examples

It is important that the risk management team discusses the different strategies in a serious manner, weighing pros and cons with each one. The view of what is the right way to control the risks may (and usually does) differ considerably from one stakeholder to another. A discussion between the stakeholders is therefore crucial here.

In contrast to the apparent objectivity of the previous analytical steps, the risk reduction/control step will need to consider a myriad of inherently subjective economic, social, and political issues, as well as carefully reviewing the critical scientific findings contained in the risk characterization report. Thus, it is important that risk reduction/control deliberations take place within an open and transparent participatory process that involves continual consultations with all stakeholder groups, as well as the general public, employing the full spectrum of available risk communication and consensus building tools.

The basic objectives of the risk reduction/control step will include consideration of the following major issues:

- Determining whether a hazard represents a level of risk greater than society, as represented by the participating stakeholders, is willing to accept.
- Developing and considering what risk minimization actions are available.
- Selecting an effective and feasible course of action to reduce or eliminate intolerable risks.

/McColl et al 2000//Haeffler et al 2000/

2.5.1 Decision-making in risk management

We often incur risk as the inevitable consequence of making decisions with incomplete and uncertain information. It's relatively easy to make decisions about risk in situation where reliable information is at hand, and the uncertainty is low enough so that the robustness of the decision is not compromised. In these circumstances there is little likelihood of making a wrong decision, i.e. a decision that fails to obtain a low risk level with acceptable sacrifices (economic and otherwise).

Unfortunately, decisions about many aspects of risk must be made under conditions of considerable urgency, where there is insufficient time to completely investigate a problem and perform an exhaustive analysis of available options. So it is not uncommon for risk assessors and risk managers to find themselves in situations where quick responses to rapidly unfolding threats must be made with minimal information and a large degree of uncertainty. Even in situations where time is available for further investigations, the necessary information will never be entirely complete or totally unambiguous.

Risk managers must always be prepared to make decisions under uncertainty. A maxim in risk management states that: *"not to decide is to decide"* /Kolluru 1996 et al/, i.e. postponed decisions constitute implicate acceptance of the status quo, including the risks and adverse outcomes that may result from the decision not to act. On the other hand, rash action may introduce new hazards as the result of substitution of an agent with known risks by another agent with uncharacterized, potentially greater, risks. This dilemma is exemplified by the tragic outcomes of the HIV blood transfusion problem. Another one is the seemingly pervasive health problems associated with environmental contaminants for example, asbestos, heavy metals such as mercury and lead, or organochlorine compounds such as PCBs and dioxins. /Kolluru 1996 et al//McColl et al 2000/

Where the criteria are exceeded, a range of frequency and/or consequence reducing measures will have to be investigated to achieve a suitable result. Risk management is the detailed process of selecting which set of mitigation measures is to be implemented and which can be neglected. As discussed before, decision-making can be a hard step in risk management. There are different ways to arrive at the right decision. Below some aids for decision-making are presented:

Relative risk rankings

This method is applicable either for individual or societal risk analyses. The risk assessor ranks top event of failure cases in sequence of risk contribution, with the most significant first. Typical, on a site modeled with 100 events, the top 20 events will contribute the majority of the risk. The list will not be identical for different risk analysis and particularly for large toxic releases, which may pose low individual risk, bur high societal risk. Decision-makers need to focus on the higher-risk-ranking events if the mitigation measures are to achieve significant risk reduction. /Kolluru et al 1996/

Cost-Benefit Tabulations

In this step type of tabulation, each mitigation measure or accumulation of measures is listed with the risk reduction obtained and the cost of the measures. Often the cost is well out of line with the benefit, and the decision will be obvious for adoption or rejection. Where this is not obvious, there is a range of value-of-a-life estimates in use, both in governmental organs and in industry, to aid in the decision-making. The test is sometimes simply pass-fail against a fixed value. /Kolluru et al 1996/

Bar Charts and Pie Charts
These display aids are frequently used for comparison of risk index values. The bar chart would be used to demonstrate risk reduction for each measure. Pie charts would be used to show how the distribution of risk contributors was changing. /Kolluru et al 1996/

2.6 Three major types of risk management and assessment

Three general compartments in risk management; Safety, Health and Environment (SHE) are often considered together. A current question is how far we shall, or can, take integration of these three compartments. In this report we focus on health and environment. There are many steps that risk management within Safety, Health and Environment has in common and therefore there are many ways in which resource efficiency is improved by handling these in an integrated framework. This is best achieved by integrating the management systems for the SHE areas. Figure 2-4 gives a general picture of the disciplines of SHE and their overlap.

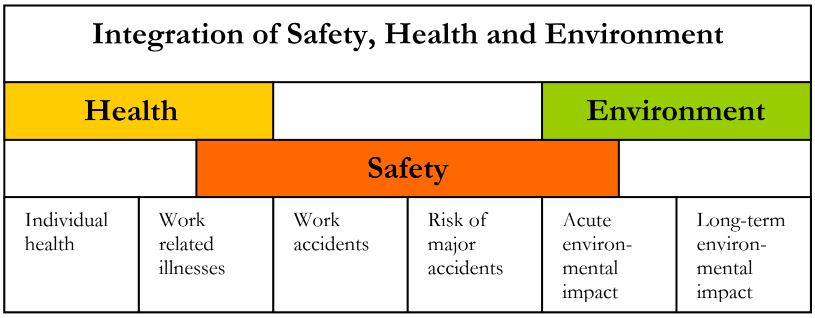


Figure 2-4 A general picture of the disciplines of SHE and their overlap /Jacobsson 2001/

But there are nevertheless some important differences, e.g. in the way risks can be quantified. Another important difference is the difference in scope. Safety risks are usually much more confined in time and space than environmental and health risks. Safety risks mostly deal with the risk object itself and it's immediate vicinity, and only direct and acute local effects are considered. Health and, especially, environmental risks have a much broader scope with regional, and even global considerations. Further, the indirect and chronic effects for time periods up to decades must be considered here.

Safety risk analyses tend to be more probabilistic, incorporating the likelihood of initiating events, as well as the likelihood of exposures and the rank of consequences. Human health and environmental risk assessments are typically deterministic and use single point estimates where valuable information remains hidden from risk managers. This implies that the need for uncertainty analysis is even more prominent within the H and E areas.

These three types of risk assessment all follow the same logic (figure 2-1) but have different emphasis. Figure 2-5 presents an overview of safety, health and environmental risk assessments including the major steps, outcomes of interest and typical applications. The risk assessments for health and environment are discussed in more detail in a separate chapter.

Safety	Human health	Ecological/environmental
Major steps		
1. Hazard identification	1. Data analysis/hazard identification	1. Problem formulation (hazard screening)
- *Materials, equipment, procedures, inventories size and location, flammable, reactivate or acutely toxic materials, and initiating events, equipment malfunction, human error, containment failure.*	- *Quantities and concentrations of chemical, physical, and biological agents in environmental media at site or study area; selection of chemicals of concern.*	- *Resident and transient flora and fauna, especially endangered or threatened species; aquatic; and terrestrial surveys; contaminants and stress of concern in study boundary.*
2. Probability/frequency estimation of causes	2. Exposure assessment	2. Exposure assessment
- *Likelihood of initiating/propagating events and accidents from internal and external cause.*	- *Pathways and routes, potential receptors including sensitive subgroups, exposure rate, and timing.*	- *Pathways, habitats, or receptor populations, especially vaulted and protected species; exposure point concentrations.*
3. Consequence analysis	3. Dose-response or toxicity assessment	3. Toxicity effects assessment
- *Nature, magnitude and probability of adverse effects, fires, explosions, sudden release of toxic materials; meteorology; receptors.*	- *Relationship between exposure or dose and adverse health effects.*	- *Aquatic, terrestrial, and microbial tests, LC_{50}, field studies.*
4. Risk evaluation	4. Risk characterization	4. Risk characterization
- *Integration of probabilities and consequences for quantitative expression of safety risks; review of tolerable system.*	- *Integration of toxicity and exposure data for qualitative or quantitative expression of health risks; uncertainty analysis.*	- *Integration of field survey, toxicity and exposure data for characterizing significant ecological risks, casual relationship, uncertainty.*
Typical endpoints		
Fatalities, injuries (worker and public safety) Economic loss	Individual and population cancer risks, noncancer hazards	Ecosystem or habitat impacts, population abundance, species diversity; global impacts.
Typical applications		
Chemical and petrochemical process safety Hazardous materials transport OSHA Process safety Management EPA and state risk management programs	Hazardous-waste sites (Superfund, RCRA) Air, water, land permitting Food, drugs, cosmetics Facility expansion or closure	Environmental impact statements Natural Resource Damage Assessments (NRDA) Superfund/RCRA sites Facility placement, wetland studies. Pesticide registration

Figure 2-5 Overview and comparison of the tree major types of risk assessments /Kolluru et al 1996/

3 Uncertainty in risk management

Risk management is inevitably associated with uncertainty. This can directly influence the quality of decision-making. Therefore is it important to judge to which extent the uncertainty can lead to wrong decisions. Sensitivity analysis, i.e. analyzing which factors contribute the greatest to uncertainty and results, is an important aid here.

There is much research on this subject and the ways to handle uncertainty. In this chapter we only shortly describe uncertainty in risk management. We don't look at so many methods to handle uncertainty. Instead we focus on how to find the uncertainty problems, i.e. the situations where uncertainty may affect the accuracy, or rather the correctness, of the results. The discussion about uncertainty in this chapter is general for all kinds of risk management but in some steps it is specific for environmental and human health risk management.

Uncertainty can be found in all steps in the risk management process. Some important problems concerning uncertainty are presented below.

3.1 Risk analysis

3.1.1 Hazard identification

Uncertainty in the identification of events is connected to which approach is used in the hazard identification. It depends on how detailed the identification is and how competent the risk team is. The consequence can be that some important events are overlooked and they never get analyzed.

The hazard identification is also continually confronted with the difficult problem of proving a negative. It is a relatively straightforward task to verify the positive assertion that a contaminant manifests a toxic property, but proving the opposite is a big challenge.

Already in the modeling of the hazard identification step some serious decisions have to be made that can bring uncertainty. Often the modeling tends to focus on technical components and machines while the influence of operator action and other human behaviors is often overlooked. The main reason for this is that human behavior is hard to predict, but maybe that is where the big risk lays. /Suter II. 1993//McColl et al 2000/

3.1.2 Risk estimation

One of the gravest errors in any type of risk management process is the presentation of risk estimates which convey a false impression of accuracy and confidence - disregarding the uncertainties inherent in basic understanding, data acquisition and statistical analysis. In the past, ritualistic risk estimation reporting has been widely criticized as too restrictive in its methods for calculating risk, too simplistic in its reporting of risk estimates, too narrow in its explanation of critical underlying assumptions and sources of evidence, and uninformative in describing the sources of uncertainty and their potential impact on risk estimation results.

The history of data can be erroneous, incomplete or unsuitable for the specific situation that is investigated. Often is it necessary to rely on expert estimates to complete the data basis, resulting in subjective probability.

Four major sources of uncertainty in environmental and human health risk estimation have been identified by Adam Finkel and Granger Morgan /McColl 2000/:

- Model uncertainty
- Parameter uncertainty } *Type-B*
- Decision-rule uncertainty
- Natural variability *Type-A*

Model uncertainty reflects the limited ability of mathematical models to accurately represent the real world. Misspecification of model form and the functional relationships between critical variables often is the result of lack of sufficient theoretical knowledge to adequately define the structural and operational characteristics of the model.

Parameter uncertainty is attributable both to statistical uncertainty arising in the estimation of model parameters due to measurement error and sampling error, or alternatively from systematic errors arising from biased sampling or flawed experimental design.

Decision-rule uncertainty takes the form of imprecise or inappropriate operational definitions for desired outcome criteria, value parameters, and decision variables. These include the selection of particular types of summary statistics for outcome measures (e.g. lifetime mortality risk versus annual mortality risk), and the choice of variables that express subjective value judgments in the form of utility functions (e.g. the monetary value attributed to loss of life). These three sources of uncertainty are, in principle, reducible to more precise quantities or specifications by gathering and analyzing additional scientific data. These **reducible** uncertainties are collectively termed type-B uncertainties.

Natural variability arises from many inherently random factors that must be considered in a risk assessment. These include demographic factors such as age and sex distributions in the exposed population, or individual variability in terms of susceptibility to health risks. This last type of uncertainty differs from the others, and is termed Type-A uncertainty, because it reflects the inherent unpredictability of complex processes that occur in nature. No amount of additional data collection or analysis can reduce the degree of variability found in natural processes, but the variability can be better understood and more thoroughly quantified through careful observational studies.

3.2 Risk evaluation

The scientific conclusions of the hazard identification and risk estimation steps inform the risk decision process by appraising scientific evidence, but they do not compel adoption of a particular course of action by decision-makers. This choice is left to the discretion of risk managers at the subsequent risk evaluation step, where the scientific findings of the risk assessment and societal norms such as precautionary principle are considered jointly in preparation for the option selection.

In practice, the basic philosophy of risk assessment has several inherent contradictions that seriously compromise its claim to scientific consistency and objectivity. Scientists are human, and so they carry their own inherent biases related to their professional training, past experiences, and personal views. Often they are unaware of their personal biases and do not fully realize the extent to which prejudices can influence professional judgment. Moreover, scientists typically show a poor understanding of risk problems outside of their immediate sphere of professional expertise. /Suter II. 1993//McColl et al 2000/

3.3 Risk reduction/control

Increasing reliance on the application of the precautionary principle in risk control is often invoked by many governmental organizations in their risk control deliberations. To make this possible it is important that the presentation of the risk assessment is clear and easy to understand. All stakeholders, and eventual external decision makers, must have fundamental information about the risk problem. /Suter II. 1993//McColl et al 2000/

3.4 Risk communication

The way, in which uncertainty is communicated during risk decision-making among stakeholders, and in the risk messages provided to the general public, can have a major influence on the effectiveness and credibility of the risk management effort.

For example, it is still common practice for many risk estimation documents to communicate a single numerical estimate of risk (e.g. one in a thousand) to decision-makers and interested and affected parties. These point estimates are often misinterpreted and convey a false sense of accuracy in the absence of qualitative information about the nature of the risk and about the weight of evidence that supports it. Without a discussion of uncertainty, it is difficult for risk managers to determine the underlying conservatism of a risk estimate provided by risk assessors. /Suter II. 1993//McColl et al 2000/

4 Risk communication

4.1 The importance of risk communication

Risk communication includes many activities that aim to increase the general public's knowledge of risk-related questions and participation in risk management. It could e.g. be warning labels that give information about existing risks, establishment of common databases where dangerous circumstances are described or public hearings on risk questions. An example is the orange sign on hazardous transports. Risk communication is often a regulatory demand, i.e. the Seveso II directive, the ADR-regulations etsc.

Risk communication is defined as any (ideally two-way) communication between stakeholders about the existence, nature, form, severity, or acceptability of risks /McColl 2000/. But regardless of the definition, the communication is regrettably often only one way. It is very important to understand the basic concepts of risk communication and to ensure that communication among stakeholders is integrated in the risk management process.

"Inherent in risk management decisions are uncertainties and value assumptions about the nature and significance of the risk. Stakeholders may bring information and perspectives to the table that is critical to the decision process. Academics, practitioners and citizen leaders agree that the process by which agencies make decisions is critical, in fact, often more critical than the eventual decision outcome. Ongoing exchange of information and ideas between risk managers and the affected publics is fundamental to the overall risk management process. It is critical to building trust in the decision process and therefore ensuring a successful outcome. Experience increasingly shows that decisions made with the involvement of interested and effected parties are more effective and more durable.

The risks associated with ineffective risk communication include irreplaceable loss of management credibility, unnecessary and costly conflicts with government, difficult and expensive approval process for project sites, bitter and protracted debates and conflicts with stakeholders, diversion of management attention from important problems to less important problems, non-supportive and critical employees, and unnecessary human suffering due to high levels of anxiety and fear." (/McColl 2000/)

4.2 A historic perspective on risk communication

"Risk communication has its roots in risk perception, a field that dates back to the seminal work of *Gilbert White* in the 1940s. White's work in natural hazards and the work of *Baruch Fishoff, Paul Slovic* and others on technological hazards in the 1970s showed that the public perceive some risks differently than others for a series of reasons such as degree of control, catastrophic potential, and familiarity. Whilst risk communication cannot be defined as an independent discipline, it is perhaps best described as:

The flow of information and risk evaluations back and forth between academic experts, regulatory practitioners, interest groups, and the general public" (/Leiss 1996/ p86)

This definition by Leiss is good in the sense that it proposes that the different stakeholders communicate their own risk perceptions and evaluations amongst themselves. In order for this to be a comprehensive definition the *interest groups* must be interpreted broadly to include actors like industry and logistics companies. The understanding that risk communication is extremely important has been growing among politicians and in academic circles, as well as within the industry. From the 80's and to date research in the field of risk communication has been both extensive and interdisciplinary.

4.3 The nature of risk communication

To date the outcomes of the various risk communication programs relating to environmental hazards implemented in Europe and the United States have largely been ineffective. The public tends to remain hostile to the local placing of waste incinerators and nuclear waste dumps, a reaction that has not been significantly influenced by the repeated implementation of risk communication programs. Whilst in part such responses might be attributable to the practical problems associated with the need of funding of risk communication programs and, from this, failure to conduct proper evaluations to learn why programs failed, due account must also be taken of inability of practitioners to understand that they have to work together with the public rather than simply educate them.

Researchers, frustrated by the need of both practical and academic success of the various risk communication initiatives, have tried to identify underlying conceptual reasons for the repeated failures. What they have realized is the immense value, and role, of trust. The risk communicators must build up, and earn, the trust of the other parties (e.g. the puplic) in order for the risk communication efforts to be effective./Lofstedt 2001/

The tendency to employ one-way communication when two-way communication is needed is a reoccurring problem of experts in all fields, not just risk management. The public is not keen on getting dictates from above without the opportunity of discussing their feelings on the matter, especially when these dictates concern potential sources of hazard in their environment. Very few persons have a totally objective risk perception, which means that even if they would believe the experts when they claim that the risks involved in a certain project are under control they still might have objections to said project in their vicinity. Being afraid of hazards is instinctive in all living creatures and it seldom helps to merely claim that the worries are unwarranted.

The focus of risk communication has evolved since the mid 1980´s, from concern about how best to inform the public about the technical aspects of risk assessments to a process of early and ongoing dialogue among stakeholders.

Risk communication is not a sender-receiver form of communication from expert to the lay public, but rather a constructive dialogue between all those involved in a particular debate about risk. While guidelines for risk communication have been prepared by various agencies, putting principles into practice is a long-term process requiring considerable resources, time, and effort.

4.4 The role of risk communication in the risk management process

The schematic risk communication model, figure 4-1 shows the necessary steps and interactions involved in the risk communication process.

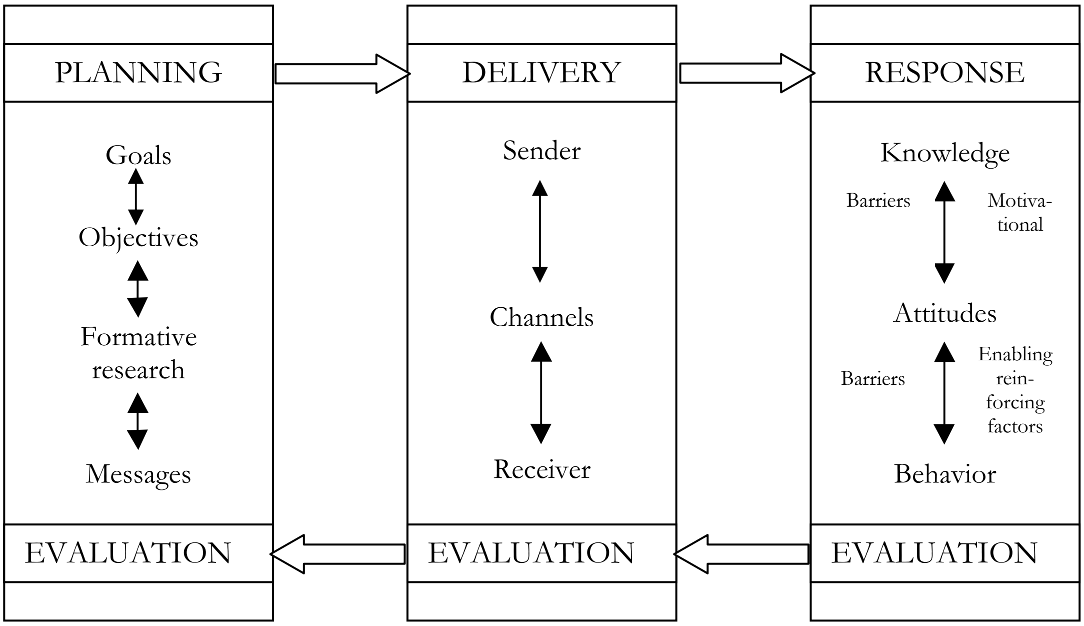


Figure 4-1 A schematic risk communication model /Kolluru 1996 (p 16.3)/

The more complex the problem, the more communication is needed to develop consensus on the solution. Often, risk management fails from a deficiency of public and political acceptability. When this happens, risk assessment and technical uncertainties may be falsely cited as the reason. In designing programs to influence behavior, communication research is seldom given sufficient attention, particularly where communication is not the primary program component. Also, the links between the communication component and other program activities are frequently handled ineffectively, contributing to program failure. /Kolluru 1996/
According to Rossi and Berk, 1988, the three main reasons for program failure are:

- The program structure incorporates a misunderstanding of the problem
- The program is improperly designed
- The program cannot be delivered by "your ordinary governmental agency" with sufficient fidelity and the proper "dosage"

If the risk communication program designer misunderstands the problem, the approach is unlikely to be effective. This error usually results from lack of attention to the formative research necessary to understand the target audiences and the leverage points that will be effective with those audiences.

Program design problems are often a result of lack of formative research and a tendency to focus efforts on one particular approach (e.g., a public service advertising campaign) rather than a comprehensive communication strategy that the recognizes the role of the full rank of channels and sources in achieving and maintaining behavior change in the target audience. The selection of communication channels should be based on understanding the target audience.

Finally, either insufficient financial resources or technical support can lead to the failure of program implementers to administer a "therapeutic dose" to the target audience when innovative programs are being implemented. Later adopters may underestimate the recourses required to produce an effect with a broader audience and may require more support to sustain communication efforts because they lack the deep understanding of the developers of a particular approach. A systematic approach to risk communication is the best antidote to these common problems. /Kolluru 1996/

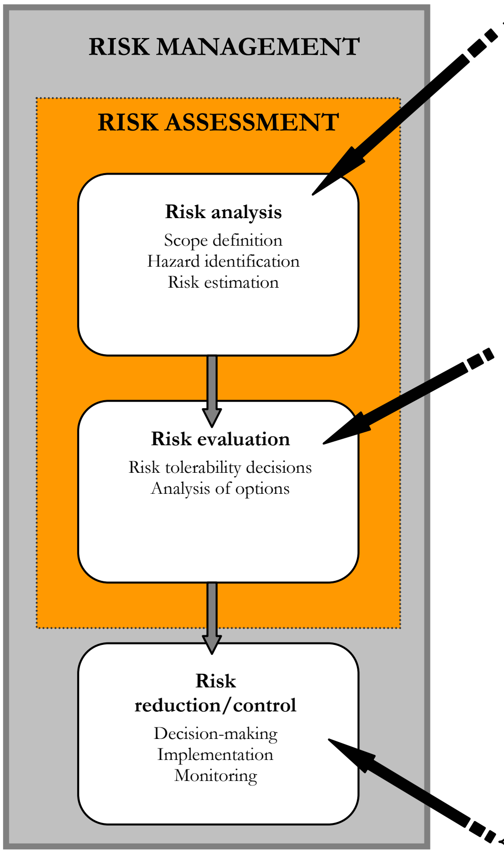
As discussed earlier it is very important to achieve and maintain a well-working risk communication in order to have good risk management. It has been noted that while most firms and agencies that need to be implementing good risk communication practices are not yet doing so, the situation is slowly changing, as there is a growing awareness that good risk communication is essential to good risk management.

4.5 Risk communication tasks in the risk management process

This chapter describes some ideas on how to work with risk communication in the different steps in the risk management process. The view of risk communication described in figure 4-3 is reflected in a Canadian risk management framework, CAN/CSA-Q850-97 (a Risk management guideline for decision-makers) where risk communication among stakeholders is deemed integral to all stages of the risk management process.

The need and role of risk communication is greatly elevated in situations when there are discrepancies in decisions, costs of measures, risk exposure and due benefits between stakeholders. In situations like these exceptional risk communication is the sword that may chop the knot of mistrust and disbelief between the stakeholders, and pave the way for efficient risk management despite the differences.

Figure 4-2 describes different tasks of risk communication in the risk management progess.



Step in risk Management	Job in risk communication
Scope definition	• Identify stakeholders • Consult with stakeholders in defining scope of issue
Hazard identification	• Develop stakeholder analysis for ongoing verification and refinement
Risk estimation	• Discussion of source, exposure issues • Communication of results with stakeholders • Assess changes in knowledge /perception in light of new information
Risk evaluation	• Elicit stakeholder perceptions of the risks and benefits, and the reasons for these, if possible • Assess stakeholder tolerability of the risk
Risk control	• Consult with stakeholders to gain input into identifying and evaluating control options • Inform stakeholders of chosen risk control and financing strategies • Inform stakeholders of benefits, costs, and any new risks associated with proposed control options • Evaluate acceptance of control options and residual risks • Determine if risk trade-offs might be possible
Implementation	• Communication of risk control decision and implementation
Monitoring	• Ensure implementation of communication • Strategies • Monitor changes in needs, issues • Concerns of existing or new stakeholders

Figure 4-2 Risk communication tasks in the risk management process /McColl 2000 modified/

4.5.1 Scope definition

During the Initiation step, the risk communication tasks include identifying stakeholders and assessing stakeholder perspectives on the risk issue for the purpose of defining the scope of the issue to be addressed. Stakeholders include groups that are affected or potentially affected by the risk, risk managers, and groups that will be affected by any efforts to manage the source of the risk. Stakeholders may include the decision-maker(s), community groups, local governments, public health agencies, businesses, labor unions, the media, individuals and groups, advice organizations, and provincial and federal government agencies. The appropriate level of stakeholder involvement is situation specific.

Organizing appropriately broad deliberation presents significant challenges including managing scarce resources, setting realistic expectations, identifying all the parties that should be involved and nurturing the process. The NRC *(U.S. National Research Council)* recommends that under situations when the stakes are high and trust in the organization is low, the organization may need to make special efforts to ensure that the interested and affected parties accept the key underlying assumptions about the risk-generating processes and risk estimation methods as reasonable. Stakeholders may also be consulted during the Initiation phase of the risk management process to gather information to assist in defining or validating the scope of the risk issue. /McColl 2000/

4.5.2 Hazard identification

The risk communication activity of the Hazard identification (or Preliminary Analysis) step of risk management focuses on developing a stakeholder analysis. A stakeholder analysis provides the decision-maker with a profile of potential stakeholders for consideration in decision-making and communication processes. The stakeholder analysis includes the following information for each stakeholder group: needs, issues and concerns and underlying values; risk perceptions; level of interest and knowledge on the issue(s); knowledge gaps and misconceptions; trusted information sources and communication preferences. The profile is verified and updated through dialogue with stakeholders throughout the risk management process (for example through group meetings, focus groups, and telephone interviews). Ideally all major stakeholders have their own representation in the group that performs the actual risk analysis. /McColl 2000/

4.5.3 Risk estimation

During the risk estimation step of risk management, the frequency and consequences associated with each risk scenario are estimated and communicated with stakeholders. Stakeholders may have important knowledge of sources and patterns of exposure that analysts will need to integrate into a risk assessment. However conflict is most likely to arise at this step, as stakeholders are not typically involved in the risk estimation process, and the uncertainties and value assumptions associated with the methods may not be clearly communicated.

During the risk estimation stage, stakeholder's knowledge and perceptions are assessed in light of receiving new information resulting from the risk estimates and the stakeholder analysis is updated. Review by third party experts and explicit communication of the methods, assumptions and uncertainties will contribute to credibility and trust in the technical analyses. /McColl 2000/

4.5.4 Risk evaluation

Communication is central to the risk evaluation step, in which the risks, costs and benefits of the activity are estimated and integrated to determine stakeholder acceptability of the risk associated with the activity. This is where an understanding of stakeholder perceptions of risk and benefits and the influences on these perceptions is critical. The following steps are part of the risk communication process at this stage: /McColl 2000/

- Discuss with stakeholders the purpose of the risk evaluation step
- Discuss with stakeholders the benefits of the activity, as well as any other information pertinent to their decision-making
- Elicit stakeholder perceptions of the risks, and the reasons for these, if possible

- Assess stakeholder acceptability of the risk

4.5.5 Risk control

The purpose of risk communication during the risk control step is to evaluate the proposed risk control options and assess stakeholder tolerability of the residual risk. The risk communication tasks are as follows: /McColl 2000/

- Consult with stakeholders to gain their input into identifying and evaluating feasible control options for reducing risk
- Inform stakeholders of chosen risk control and financing strategies
- Inform stakeholders of benefits, costs, and any new risks associated with proposed control options
- Identify as a result of implementing control measure, any new stakeholders, or new issues
- Evaluate acceptance of control options
- Evaluate acceptance of residual risks and determine if risk trade-offs might be possible

4.5.6 Implementation and Monitoring

The risk communication tasks of this step are associated with stakeholder outreach to communicate the risk control decision and its implementation involving contacts developed through the risk management process. The Monitoring program includes ensuring implementation of the communication strategies, and monitoring for changes in the needs, issues and concerns of existing or new stakeholders. /McColl 2000/

5 Management systems

A very important tool to achieve success when working with risk management is to work with a management system. Today it is an established fact that management factors and organizational factors have a vital importance for safety in fundamental functions. This has led to an increased interest of many risk managers in different companies and it is also reflected in many public rules and regulations. One example is the revised version by the EU of the Seveso directive (Seveso II 96/82/EG).

There are also formal demands for management systems for internal control according to some international standards. Examples:

- ISO 9001 Quality management system
- ISO 14001 Environmental management system
- The EU's EMAS (Environmental Management and Audit Scheme)
- OHSAS 18001 (Occupational Health and Safety) management system (British Standards Institution; not official standard)
- In Sweden Kemikontoret (a chemical supervisory agency) has produced a guidance for an integrated management system for safety, health and the environment.

By creating a management system, the organization documents it's management procedures to guarantee that conditions, activities and tasks that can adversely affect the environment, health or safety of it's employees or neighbors; are planned, organized, carried out and controlled according to the rules and regulations that are applicable.

A well-designed and implemented management system not only creates a better safety management but also a more successful company management. The fundamental idea of most management systems is the Demings cycle, also called the PDCA cycle (Plan-Do-Check-Act). Figure 5-1 describes the structure for a well-functioning management system.

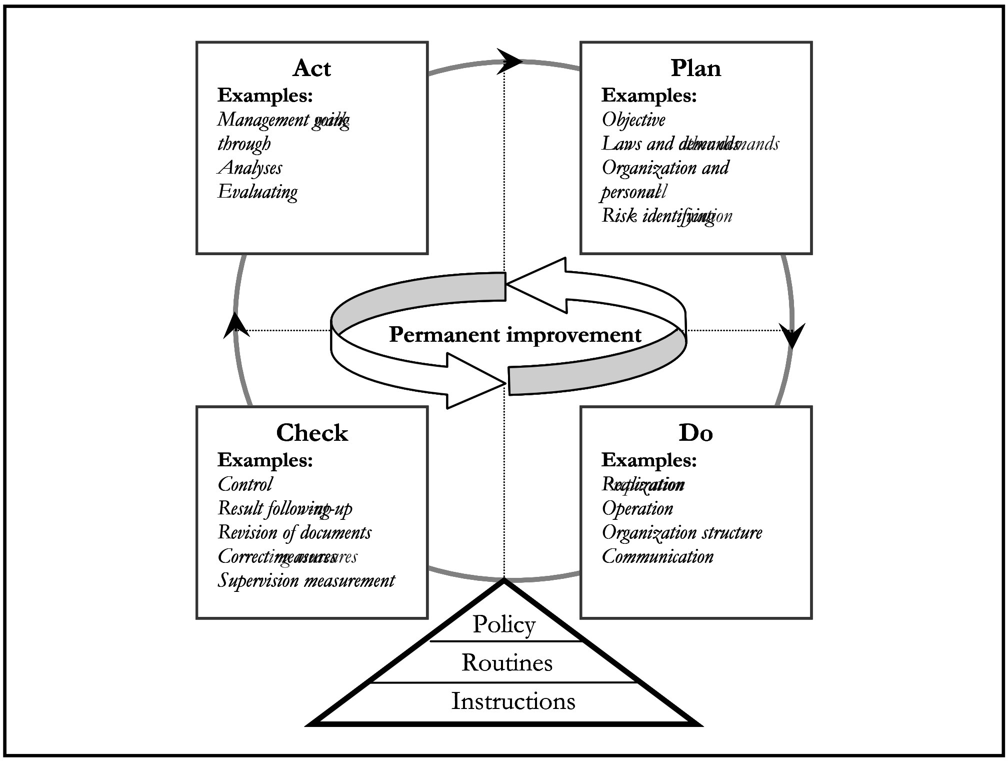


Figure 5-1 Example of the PDCA cycle in environmental, health and safety management system with basic elements, instructions, routines and policy. /Kemikontoret 1997/

The content in the different guidelines for management system varies in some moments/ headings. This depends mostly on the aim of the guideline. Table 5-1 presents as an example the ISRS (International Safety Rating System) comprehension of what should be included in a safety management system.

Basic elements in a safety and health management system ISRS ® (International Safety Rating System)	
1. Leadership and program administration	*11. Private protection equipment*
2. Leadership training	*12. Control of health and hygiene*
3. Planned inspection and maintenance	*13. System evaluation (internal revision)*
4. Analysis and procedures for critical tasks	*14. Control of construction and change*
5. Investigation of accidents and narrow escapes	*15. Personal communication*
6. Work observation	*16. Group communication*
7. Preparedness	*17. Information and internal marketing*
8. Certainty rules	*18. Recruiting and placing;*
9. Analysis of accidents and narrow escapes	*19. Control of goods and service*
10. Theoretical and practical personnel training	*20. Protection of employees on spare time*

Table 5-1 General elements in a program for management of safety and health. /Haeffler et al 2000/

The importance and relevance of the present elements in table 5-1 varies depending on fundamental complexity, risk level, etc.

Table 5-2 discusses some important managerial, organizational and administrative factors for SHE management systems.

Factor	Examples of important managerial, organizational and administrative factors
Management attitude and approach	- Wholehearted involvement is needed. - Responsibility to create and maintain the administrative system - See to that the quality of the personnel is high - SHE is established as a specific goal among other company goals
Organization	- Simple and clear structure - Clear delegation - Line- and staff functions - Formal responsibility always in the line - Specific function for SHE with status and mandate
Competent personnel	- High requirements on management and key persons - Good training
System and procedures	- Formalized written system and procedures - Personal and collective disciplines - Learn from mistakes and experiences - Formal checks - Risk identifications and assessments - Instructions for normal and emergency situations - Modifications procedures - Inspection of equipment - Emergency planning - Accident /incident reporting and follow-up
Technical standards and norms	- Basic requirements in legislation etc. - Owen engineering standards
Maintaining integrity of plan	- Preventive maintenance - Own control procedures
Documentation	- Adequacy - Updating - Accessibility - Well structured filing
Review of system	- Regular assessment as principle
Independent checks	- Independent assessment as principle

Table 5-2 Some important factors in SHE management system. /Jacobsson 2001/

6 Environmental and health risk management for road transport of hazardous material

In this chapter we are going to focus on methodologies for risk assessment and management for transport of hazardous material. The general methodology already described in section 2.2 applies here but the aim of this chapter is to describe some methodologies specifically fitting the health and environmental risk management for hazardous transports on roads. In many ways the methodologies are the same whether the focus is on human health or the environment.

In contrast to safety risk analysis there is today a shortage of methods and instruments to analyze environmental effects following an accident. The developed methods for safety risk analysis cannot be directly transferred to environmental risks. One reason for this is that the external environment as an affected recipient is so much more complicated and variable. The spreading through ground, water and air must e.g. be estimated. It is also hard to estimate the effects and importance of an individual species to the whole ecosystem. Another problem in this analysis is that the chronic effects are, when appropriate, hard to estimate.

6.1 Methodology for risk assessment

The risk assessment in environmental and health issues should be performed stepwise and follow a defined timeline. A recommended approach is described in figure 5-1. The SHE risk analysis can as described in section 2.4 be performed on different ambition levels. Usually the analyst begins with a qualitative analysis method, some form of hazard identification or rough estimation. An example of qualitative methods for health and the environment are index methods.

If the rough method indicates that there is a substantial hazard the work should continue by utilizing some more quantitative methods. In the quantitative risk analysis for health and environment, quantitative calculation for exposure, effects and frequency are performed. This methodology constitutes the quantitative analysis of: frequency and probability assessment for hazard/event, exposure assessment and toxicity or dose-response assessment, see figure 5-1.

The way to carry out the quantitative risk analysis proposed in this chapter is similar to a Technical Guidance Document (TGD), a guideline from the European Chemicals Bureau /European Chemicals Bureau, 1996/. One difference is that in the proposed methodology the analysis ends in an absolute risk measure since the frequency for the hazardous event will be included. The reason for this is that the proposed methodology is intended for analysis of transports, and possible accidents related to these.

The flow diagram in figure 6-1 describes where in the general risk management methodology this methodology for health and environmental fits, what it should contain and also whether the methods are qualitative or quantitative.

The different elements of the flow diagram (figure 6-1) are described further in sections 6.2 through 6.10.

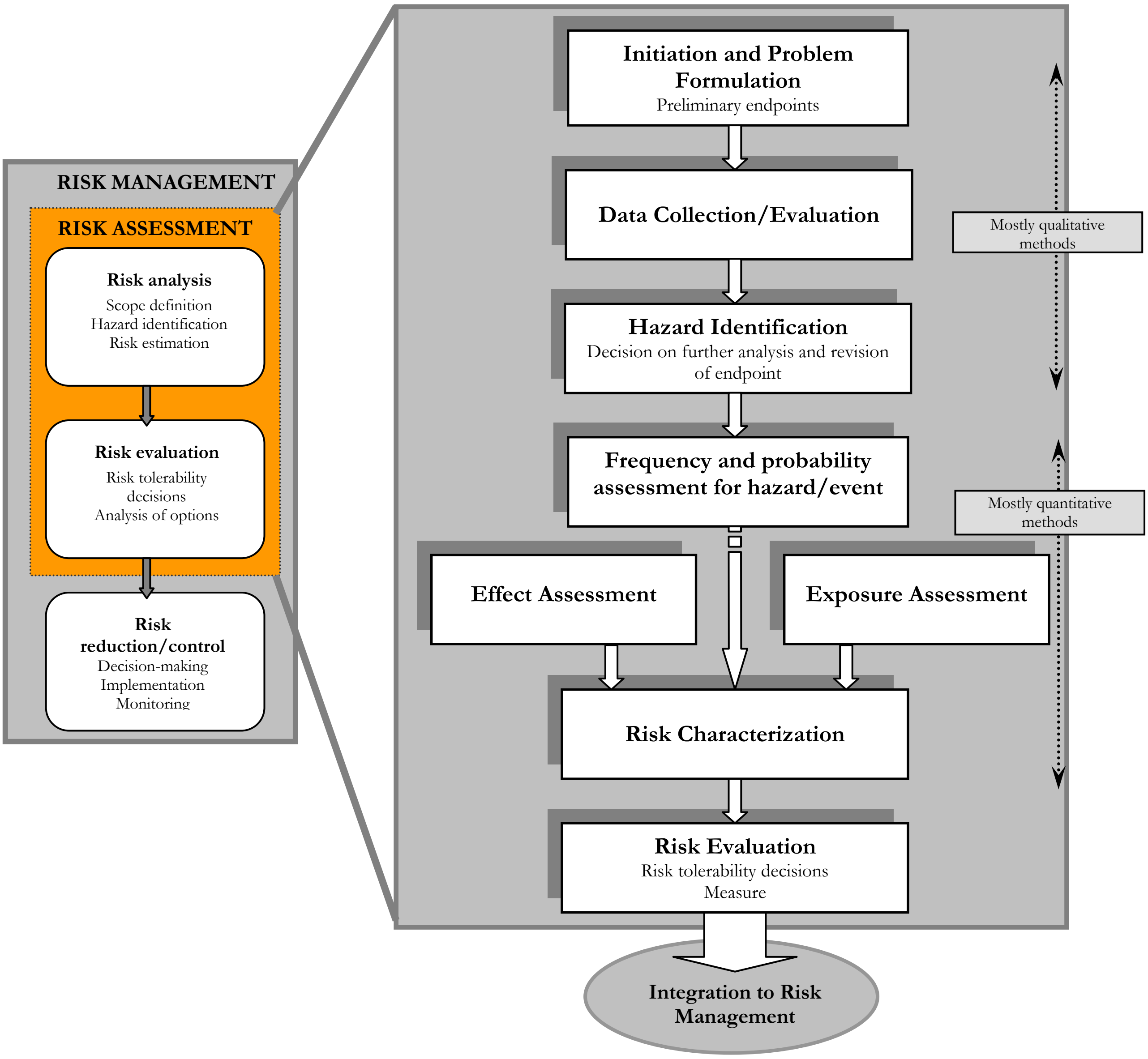


Figure 6-1 Flow diagram for environmental and health risk assessment (modified from /Dyck et al 1999//Suter II 1993/)

6.2 Initiation and Problem Formulation

The purpose of the Initiation and Problem Formulation step is to define a specific environmental or health problem and its associated risk issues within an appropriate decision-making context. Within this step, the key risk issues must be defined, the risk analysis team established, and prospective stakeholders identified.

Critical administrative factors for planning the risk management process will include the envisaged time frame, the reporting requirements, the institutional resources necessary to carry out the risk management tasks, and the risk communication strategy for maintaining ongoing linkages between all concerned stakeholders.

In the Problem formulation the principal goals and focus are established, an initial scoping is carried out, data gaps are identified, and a strategy for conducting a risk assessment is developed. Problem formulation is an iterative process, and can be updated when necessary as additional information is gathered during the assessment. /McColl et al 2000/

If a problem is formulated too narrowly, or incorrectly, risk managers and stakeholders will invest their resources in exploring and implementing control strategies that will be inadequate, less effective, or more costly for reducing risk than they might have been. If a problem is characterized too broadly, the complexity of the associated issues may overwhelm the risk managers capacity to assess and evaluate the enormous quantities of information, so that the ability of stakeholders and decision-makers to achieve an informed decision may be seriously impaired.

Already in this first step a discussion should take place concerning assessment and measurement endpoints (see section 6.4.1). A set of preliminary endpoints should be determined, although these might change somewhat at later revisions. Human health endpoints are frequently more clearly defined and understood than environmental endpoints, simply because the human body and its function has been investigated moreby science than any other aspect of nature.

Some important phase tasks in this step are:

- Overall investigation/feasibility scope
- Identify potential stakeholders and begin to develop consultation process
- Contact with governmental agencies
- Form and organize risk analysis team, or risk management team if the authority is of such a nature
- Define problem or opportunity and associated risk issue(s).

6.3 Data Collection/Evaluation

In order to achieve a good analysis it is important to have a lot of data and information concerning the actual area, chemical(s), frequency of transports, etc. But quantity is not everything, especially in this kind of a situation. The relevancy and quality of the data is crucial to the analysis. The risk managers can easily drown in irrelevant or only partly relevant data if the collection is not cautiously prepared. The result will then inevitably suffer, bad in ⇒ bad out.

Also, information is not always readily available, especially not in the wake of the incidents in the USA on 9/11 2001. The right pathways must often be localized and followed in order to receive the data in question.

Data collection can be maintained goal-oriented by the following help-points:

- Background data
- Modeling needs
- Work plan development
- Sort data by medium
- Evaluate data quality
- Compare site to background
- Develop data set to use

6.4 Hazard Identification

The purpose of the Hazard Identification (or preliminary analysis) is to define the basic dimensions of the risk problem, and then to undertake a review of the potential risks. The Hazard Identification step involves the gathering, organizing, and appraisal of the scientific and technical information necessary to decide whether a particular environmental contaminant is likely to constitute a significant hazard. Therefore all relevant information about a hazard should be assembled in a risk information library, which can be updated whenever necessary, as the risk management process continues.

Hazard Identification represents a qualitative type of risk analysis. It deals principally with weight-of-evidence judgments for inferring that an environmental or health hazard may or may not exist, but it does not attempt to quantify the degree of risk. It involves the systematic review of all relevant evidence by scientific experts, decision-makers, and stakeholders, in order to decide whether or not the risk management process should continue forward toward the subsequent steps within the risk framework that deal with quantitative measures of risk. It also includes identifying the circumstances surrounding the release of a hazard (risk scenarios) and any expected harmful consequences. /McColl et al 2000/

As already discussed in the opening of this chapter there is a lack of worked out methods for analyzing health and environmental risks. A fitting qualitative analysis in this step can be some index method, which is a type of hazard estimation. Index methods are suitable to start with as a rough identification. With the help of this qualitative analysis a decision can be made whether a more quantitative analysis is necessary and it also helps in the process of choosing descriptive scenarios. One index method is described in *Appendix II – Hazard estimation* and applied later in the case study.

The reason that this index method is called hazard estimation is that the probability for a hazardous event is ignored. Therefore it is not risk estimation.

It is also important to look at frequency and probability for an accident in the Hazard Identification step. No exact analysis is necessary but a comprehension can be achieved by rough on-site study of the actual area/road. The stakeholders can also give some input concerning frequency and probability.

It’s important to realize that the Hazard Identification step, by itself, cannot provide a meaningful numerical estimate of the actual level of risk.

Typical phase tasks in this step are:

- Selection of chemicals of concern or indicator chemicals
- Preliminary exposure assessment
- Comparative methods
- Structured question
- Risk screening through qualitative assessment, index methods etc.
- A priority-setting scheme

At the end of the Hazard Identification step some important decisions are required:

1. If the hazard identification shows that the risk is important enough, or if the uncertainty is too large, further analysis (quantitative) is needed.
2. Scenarios are chosen.
3. A revision of preliminary endpoints is conducted.

The endpoint revision is needed here because of the crucial significance of proper endpoints to the success of the analysis. Endpoints are needed from the beginning to direct the assessment, but before the hazard identification has been completed the optimal endpoints may elude the risk managers.

6.4.1 Endpoints

Any risk analysis must have defined endpoints. An assessment endpoint is a formal expression of the environmental/health values to be protected. A clear statement of its endpoint is as important to an assessment as a clear statement of hypothesis is to a scientific research project. Within environmental risk management it is especially difficult, and therefore important, to seek and utilize appropriate endpoint, due to the lower level of scientific understanding in this field. The endpoints for health (and safety, for that matter) risk analysis are often quite obvious, although risk managers should be wary of being nonchalant when defining these. They still have to be very precise.

Assessment endpoints: *The adverse or undesired environmental or human health event that is the objective of the assessment (e.g., local extinction, decreased reproduction, occurrence of an illness); the decision criteria for selecting among risk management alternatives.*
Measurement endpoints: *What can actually be quantified or measured in the environment/human health (e.g., counting organisms, measuring changes in habitat, increased frequency of an illness).*
/Kolluru et al 1996 (p.10.18 modified)/

Defining an assessment endpoint involves two steps.

- Identifying the valued attributes of the environment and/or human health that are considered to be at risk.
- Defining these attributes in operational terms, i.e. so that they are measurable and predictable.

Suter (/Suter II 1993/) accounts five criteria that any endpoint should comply with:

1. Societal relevance
2. Biological relevance
3. Unambiguous operational definition
4. Accessibility to prediction and measurement
5. Susceptibility to the hazardous agent

In choosing assessment endpoints, two general questions must be answered:
What valued components of the environment or human health are considered to be at risk (i.e. an entity and a property of the entity) and how should the effect be defined. The process of answering the first question is often referred to as hazard identification. As discussed earlier the selection of assessment endpoints is constrained by legal mandates, regulatory policy, and public

concerns. In addition, the process of hazard identifications is often constrained by habits and preconceptions.

6.5 Frequency and Probability Assessment

This report focuses on road transport of hazardous materials, so the hazard/event in figure 5-1 constitutes a road accident involving a hazardous material transport. The frequency of hazardous transport accidents on the analyzed stretch must be produced if a quantitative risk is to be calculated. This is done by combining general accident frequencies from several areas with site-specific frequencies. If this is implausible for practical reasons (lack of data) then an effect or consequence analysis may still be valuable. But even if site-specific frequency data is missing, such data can sometimes be estimated (with added uncertainty of course) using data from similar stretches and/or from expert judgments.

The probability of release in case of an accident depends on the nature of the accident but databases exist that allow for estimating the probabilities of different sizes and rates of release if an accident occurs.

6.6 Effect Assessment

The purpose of the effect assessment is to estimate the potential of selected chemicals to cause adverse effect in exposed population or environment and to provide an estimate of the effects, i.e., the dose-response relationship.

Obviously, not all contaminants or chemicals are created equal in their capacity to cause adverse effects. Further, receptors of the same species may respond differently to a certain pollution, due to natural variability. The toxicity data are derived largely from animal experiments where the animals are the exposed species. This can pose a problem when the results are to be interpreted to human effects. Even if the tested species is in itself the endpoint of the analysis, the results of laboratory tests must be cautiously transferred to their natural environment, since factors present there may influence the effects. A substantial level of uncertainty is invariably linked to this step.

Dose is normalized as milligrams of substance ingested, inhaled, or absorbed through the skin per kilogram of body weight per day (mg/kg x day). Response or effects can vary widely, from no observable effect to temporary and reversible to permanent injury to organs, to chronic functional impairment and finally to death.

The effect assessment and the exposure assessment are described as parallel in the flow diagram in figure 6-1. In reality the exposure assessment can often be more efficiently performed if results of the effects assessment are available, e.g. target concentrations for diffusion and dilution simulations can be taken from the exposure assessment.

Figure 6-2 sheds some light on the problems and the uncertainty in the effect assessment.

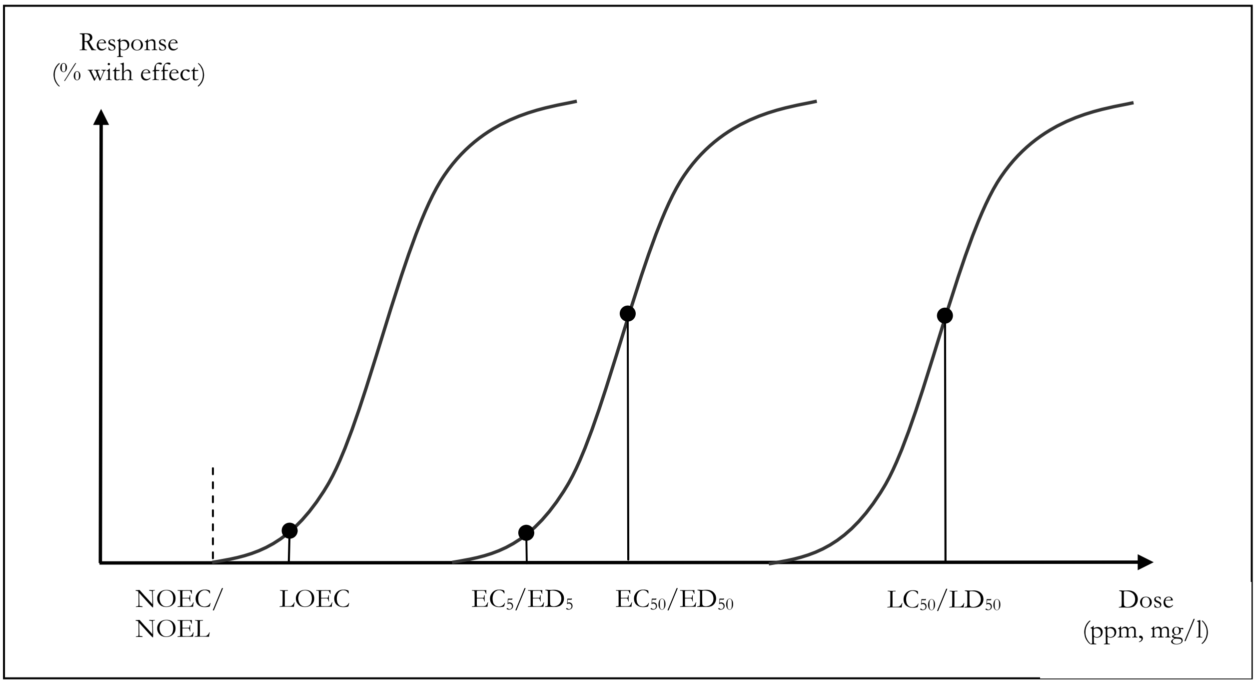


Figure 6-2 Theoretical dose-response curve for different effects that can arise at exposure for a toxicant material /Edling 2000/

Observe that the effect in the three curves designates three different effects.

NOEC:	No Observed Effect Concentration
NOEL:	No Observed Effect Level
LOEC:	Lowest Observed Effect Concentration
ED:	Effect Dose (e.g. ED_{50}: the dose that causes measurable effects in 50% of the test group)
EC:	Effect Concentration
LD:	Lethal Dose
LC:	Lethal Concentration

In figure 6-2 some endpoints are suggested (see discussion below) but deciding which of these, or some other, to use is a difficult task that requires much thought.

The acute effects arise usually after only a few hours or days. The results from studies for acute toxicity records are often given as a LC_{50}- value or LD_{50}- value, which means the concentration or dose of the chemical that causes 50 percent of test organisms to die when exposed a specified, relatively short, time period. The Swedish National Chemicals Inspectorate (Kemikalie-inspektionen) uses the following reference values for environmental hazard assessment of acute toxicity to water living organisms, see table 6-1.

LC_{50} (mg/l = ppm)	Toxicity
<1	Very toxic
1-10	Toxic
10-100	Harmful

Table 6-1 Acute toxicity for water living organisms

But it is important to remember that these values are not limit values. Mortality often occurs already at lower concentrations.

The chronic effects appear after long-term exposure (months, years). The limit values regarding chronic toxicity are often categorized as NOEC values. Naturally a NOEC value must be from a long-term study to be applicable in chronic assessment, acute NOEC values cannot be assumed to have no chronic effects. The chronic effects are generally less studied, due to the complications of long-term studies. If chronic effects have not been studied sufficiently the BCF (Bio Cumulating Factor) can indicate whether the chemical is likely to have long-term effects.

Bio cumulating is when the rate of chemical uptake by an organism through gills, skin or intestines exceeds the rate of chemical excretion, i.e. the chemical is concentrated in the receptor. This gives delayed, but often serious, symptoms e.g. reduced or impaired fertility, especially in organisms higher up in the food chain (bio magnification). The BCF value can be deduced from the distribution coefficient octanol/water, K_{ow} (most often expressed as log K_{ow}). A higher K_{ow} (little or negligible solubility in water) renders a larger BCF-value.

These concepts are more commonly used for water living organisms. Kemikalieinspektionen uses the BCF values to do accumulation hazard assessment of chronic effects, see table 6-2.

BCF (Bio Cumulating Factor)	**Chronic effects**
> 1000	Very high
100 - 1000	High
30 -100	Moderate
< 30	Low

Table 6-2 Chronic effects from the Bio Cumulating Factor/FOA 1998/

The effect (dose-response) assessment for human health focuses only to one species, the human being. The largest uncertainty in this assessment is the variation of how sensitive different people are. Some limit value is often used to determine if a chemical will have effects or not, but there may still be some percentile (e.g. 1% or 0.1%) where effects are possible even if the limit value is not exceeded.

As already commented in earlier chapters there are larger theoretical difficulties with handling uncertainty in environmental risk assessment. One big problem in environmental effect assessment is the large number of species with different sensitivity. Simplifications are necessary, like deciding to focus on a few species. This decision is often difficult and it's further complicated by the fact that direct effects on one species usually lead to indirect effects on others.

Another source of uncertainty, and a general complication, are possible additive effects. This is especially problematic when assessing chronic effects as different chemicals present in the environment can neutralize each other, add to each other's effects or even synergistically magnify each other's effects.

6.7 Exposure Assessment

The goal here is to describe the environmental chemistry, transport, and fate of the chemical; estimate chemical exposure profile and subsequent exposure or dose.

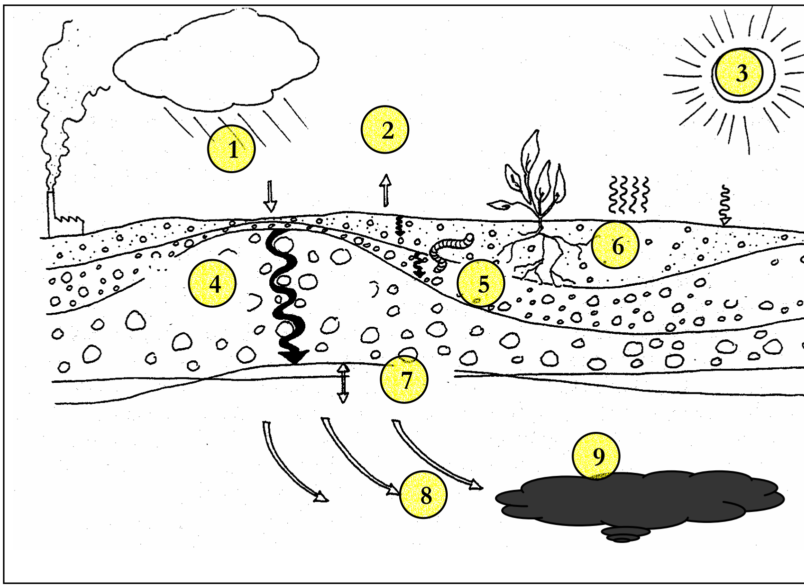
Exposure assessment is the process of measuring or estimating the intensity, frequency, and duration of human or other living creatures' exposure to a contaminant present in the environment, or estimating hypothetical exposure that might arise from the release of alien chemicals into the environment. Exposure or access is what bridges the gap between a hazard and risk. A hazard becomes a risk if, and only if, somebody or something can be exposed to it.

Contaminant sources, release mechanisms, and transport and transformation characteristics, as well as the nature, location, and activity patterns of the exposed population (receptors), are important aspects of exposure assessment. Because of the difficulty in identifying the receptors, exposure point concentrations, exposure timings, and so on, exposure assessment is often called "the Achilles heel of risk assessment" within health and environment.

Exposure assessment should consider both current and future land use, including possible residential use. As can be expected, the level of cleanup will depend in part on whether the land would be restricted to industrial use or developed into a commercial or residential property. The key steps in exposure assessment are identification of potential receptor population, evaluation of exposure pathways and routes, and quantification of exposures. /Kolluru et al 1996/ /McColl et al 2000/

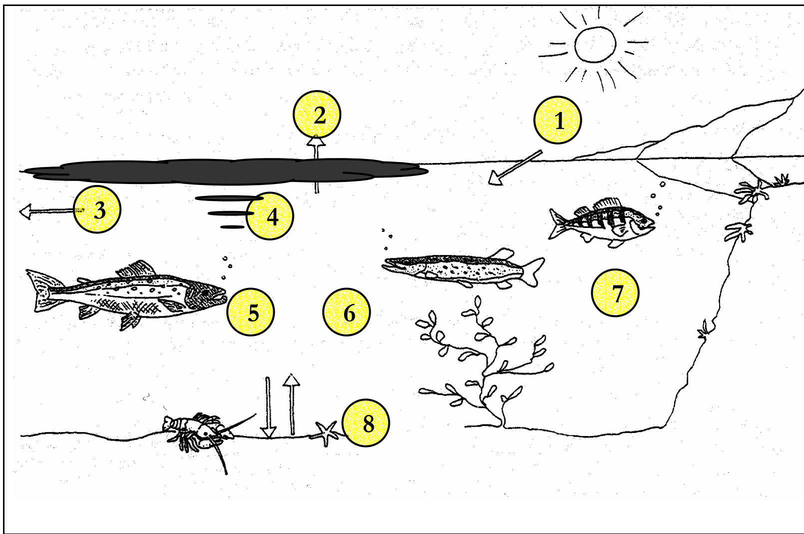
The way to right exposure assessment depends on the kind of risk analysis. The transports of a hazardous material can generally be divided into three pathways; spreading through ground, spreading through air and spreading through water. Figures 6-3 through 6-5 show important aspects/parameters to be decided for each of the three.

For chronic effect assessment it is important to assess exposure of all relevant chemicals if additive effects are to be illuminated. This is regrettably often too large a task to be practically plausible.



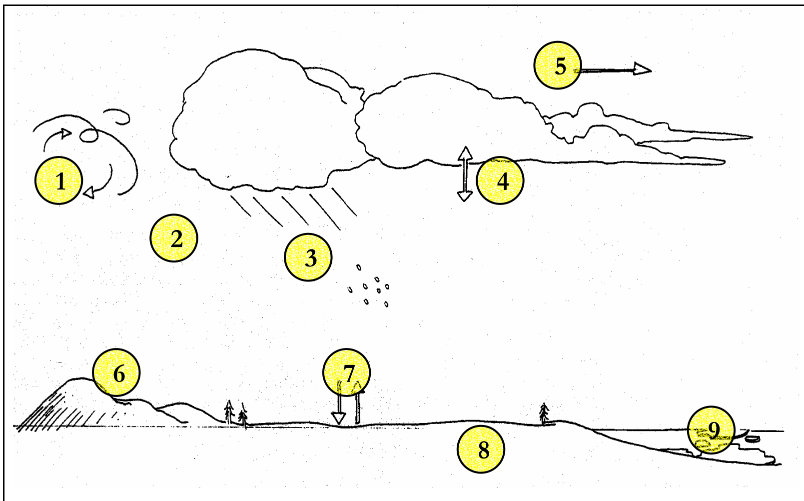
1. Precipitation
2. Evaporation
3. Photolysis
4. Earth deposit/Infiltration
   Effective porosity
   Organic content
   pH etc.
5. Biodegradation
6. Uptake in plants, Bio-accumulation
7. Groundwater variation
8. Groundwater flow and direction.
9. Solubility in water, difference in density, dispersion

Figure 6-3 Some important factors that influence spreading in the ground



1. Photolysis
2. Evaporation
3. Transport
4. Solubility in water
5. Bio-accumulation
6. Hydrolysis
7. Biological activity: season etc.
8. Sorption, complex-formation, oxidation, reduction, biodegradation etc.

Figure 6-4 Some important factors that influence spreading in water



1. Turbulence
2. Temperature
3. Precipitation
4. Stratum
5. Wind speed
6. Topography
7. In/out radiation
8. Ground conditions: ground frost, snow, etc.
9. Open water

Figure 6-5 Some important factors that influence spreading in the air

Some important components of exposure assessment:

- Nature of the source
- Pathways of transport and accumulation
- Chemical form and location, e.g., air, soil, surface water, groundwater, sediments
- Exposure concentration, e.g., magnitude, frequency, duration, timing
- Uncertainties associated with exposure estimation

The uncertainty in the exposure assessment is often substantial. Usual reasons for this are lack of information about the emission-factor and difficulties in assessing the quantity to reach the receptors. The large geographic variations concerning climate, hydrological factors, geology and structures in the ecosystem also cause large uncertainty. As showed in the figures above many important parameters need to be decided in an exposure assessment.

In exposure assessment for human health different exposure pathways are often integrated to consider the Tolerable Daily Intake (TDI) (mg/kg body weight).

Ecological exposure assessment is often hindered by large theoretical uncertainties. Simplifications are usually necessary, e.g. when deriving PEC (Predicted Environmental Concentration) and PNEC (Predicted No-effect Environmental Concentration) for specific environments or species.

More about how to assess exposure can be found in section 6.8 (Risk Characterization).

6.8 Risk Characterization

The final summation in the risk assessment for human health and environment is risk characterization. This step is an estimation and representation of the analysis. Risk characterization combines the most critical findings obtained from dose-response estimation and exposure assessment, providing a description of the nature of the hazard and an explicit account of the estimated degree of risk. The risk characterization process must both summarize and explain the methods used to compute estimates of risk.

In this step the frequency and probability for the event should also be integrated. The flow diagram in figure 6-1 shows that there are three inputs in the last step risk characterization, exposure assessment, toxicity or dose-response assessment and frequency assessment for the event. These three are now the foundation to build a risk characterization on.

The exposure and the dose-response assessment can be combined into a consequence assessment by weighing together the two parameters to a quotient, the exposure assessment divided with the dose-response (effect) assessment. This is a common way to judge how extensive the consequences are. The quota can then be combined with the frequency assessment in a risk matrix. It's also possible to make a three-dimensional matrix where a third parameter can aid the risk characterization. This third parameter can for example be time, cost-benefit or uncertainty.

There are a lot of methods/names used to form the quotient between exposure and dose-response (effects) but they all aim at the same goal, the size of the quotient. A common criterion to evaluate the quotient is whether or not it is larger than one. Safety factors are a common approach to compensate for the uncertainties. The larger the uncertainty, the more pronounced the need for safety factors. Since safety factors are already included in the calculations, a ratio of less than one can usually be considered safe. Nevertheless, the total risk picture must always be taken into consideration, especially if the ratio is close to one.

Some quotients are especially designed for human health assessment and some for environmental assessment. Some well-known international methods to estimate the ratio between exposure and effect (dos-response) are presented in table 6-3.

Name and Source	Numerator, Espouse	Denominator, Effect (dose-response)	Safety, Uncertainty, Modifying Factors	Quotient
PEC/PNEC *Technical Guidance Document (TGD) /European Chemicals Bureau, 1996/ and The Organization for Economic Cooperation and Development (OECD)*	PEC (Predicted Environmental Concentration) PEC is most often deter-mined by through computer Simulations.	PNEC (Predicted No Effect Concentration) $PNEC_{acute} = LC_{50}/SF$ $PNEC_{chronic} = NOEC/SF$ The lowest LC_{50} and NOEC values should be used.	SF: Safety Factor SF for acute: 100-1000 SF for chronic: 5-100 Dependent of available toxin data.	PEC/PNEC > 1, risk for toxic effects. Not tolerable. PEC/PNEC < 1, little risk for toxic effects. Tolerable.
Quotient Index (QI) *(Suter, 1991; SENES, 1994; Cardwell et al., 1993)* /Kolluru et al 1996 (p.10.31)/	Exposure concentration	Toxicity benchmark		Quotient Index (QI) QI = Exposure concentration / Toxicity benchmark QI > 1, interpreted as indication of an ecological risk.
Hazard Quotient (HQ) *Margin of Safety (MOS) or Margin of Exposure (MOE)* /McColl et al 2000/	Predicted exposure	Exposure limit		Hazard Quotient (HQ) HQ = predicted exposure / exposure limit HQ > 1, large probability of producing toxic effects HQ< 1 harmful effects are unlikely to occur in most of the exposed population
Hazard Quotient (HQ) *Noncancer Hazards* /Kolluru et al 1996 (p.4.27)/	Exposure or intake [mg/(kg day)]	RfD [mg/(kg day)] (Reference dose) or RfC [mg/m3 in ambient] (Reference concentration) RfD = (NOAEL or LOAEL) / (UF x MF)	UF: Uncertainty factor MF: Modifying factor UF between 1-10 MF between 1-10 Dependent of available toxin data.	Hazard Quotient (HQ) HQ = exposure or intake/ (RfD or RfC) HQ < 1, hazards are not considered to pose a threat to public health, including sensitive subgroups. HQ ≈ 1, there may be concern for potential noncancer effects.
Hazard Index (HI) *Noncancer Hazards* /Kolluru et al 1996 (p.4.27)/	E_i = Exposure (average or intake or dose) for the i:th toxicant mg/(kg day)]	RfD_i = Reference Dose for i:th toxicant[mg/(kg day)]		Hazard Index (HI) $HI = \Sigma E_i / RfD_i$ If the sum of the ratios is greater than 1, a more detailed and specific judgment is necessary
Exposure/ Potency Index (EPI) *CEPA Priority substance by Health Canada* /McColl et al 2000/	Exposure level	TD_{05}: Tumorigenic Dose measured in test animals as the dose inducing a 5% increase in the incidence of tumors or other disease endpoints.		If the ratio between exposure and the TD_{05} is less than 2×10^{-6} there is little need for further action. If the ratio is 2×10^{-4} or greater there is a high priority for further action.

Table 6-3 Some ratios between exposure and dos-response (effect) for risk characterization in human health and environmental risk assessment.

When a proper quotient is selected the scenarios can be characterized. But this characterization only says whether the consequences are large enough to consider (no absolute risk measure). To get a complete risk characterization the frequency for accident/release rate must be integrated into the risk characterization.

In the EU, the method described at the top of table 6-3 (PEC/PNEC), is used for risk characterization in environmental risk assessments. The abovementioned Technical Guidance Document describes a procedure for the risk assessment of new and existing chemicals in the EU. As discussed earlier, this procedure has many parallels to the methodology presented in this report.

A common risk characterization problem, especially pronounced in the environmental area, is expressing the risks, or the consequences, in monetary terms. One simplification is to consider the costs of sanitation following an accident, but this is only a part of the damage. It can nevertheless by itself motivate a discontinuation/relocation/alteration of transports, if the expected value of sanitation costs exceeds the expected value of the transports.

Other approaches to measure the environment in monetary terms have had limited success, but further work in this field is necessary if the environmental risks are to be successfully treated in the same context as other risks with more clear-cut economic aspects. This is discussed further in the Risk evaluation step in section 6.9.

6.8.1 Development of risk characterization

The result from the risk characterization can be presented in a risk matrix, as mentioned above. The risk matrices should not be interpreted as totally correct; instead they should aid the discussion about which risk reduction measure to choose and which scenarios attribute the largest risks.

The figures 5-6 to 5-10 show a possible development of risk characterization and estimation. When research makes the necessary progress in judging probability/frequency, exposure and effects a more advanced model can be chosen.

1. On the first level the risk assessor has no information about the probability and can therefore only assess the consequences. The inherent uncertainties should cause extra skepticism as to the accuracy of any result close to one. In the following figures green means tolerable and red not tolerable. The consequences can be measured in various units, i.e. PEC/PNEC.

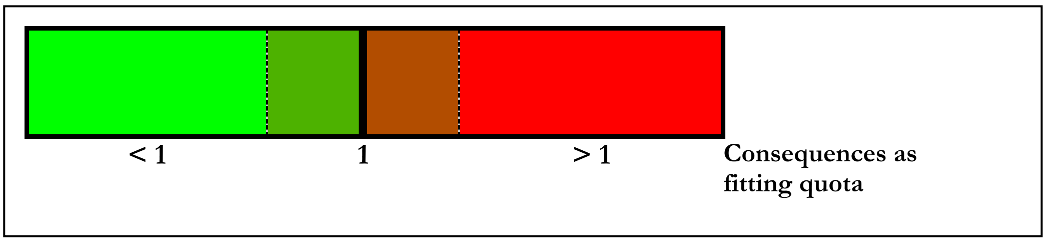


Figure 6-6 Level 1, consequence analysis

2. A risk matrix with classes, but only two classes and quite qualitative. The category definitions and values used in within the matrices in figures 5-7 through 5-10 are illustrative only. The magnitude of risk to be tolerated depends on the context. When discussing a unique scenario with no similar scenario possible; a PEC/PNEC quotient of 1 may be tolerable every 1000 years. But if the scenario is a common one, with hundreds or maybe thousands of similar possible scenarios in the country, that kind of frequency of PEC/PNEC quotients of 1 is obviously unacceptable. In that case the tolerable frequency perhaps lay's in the once every million years region.

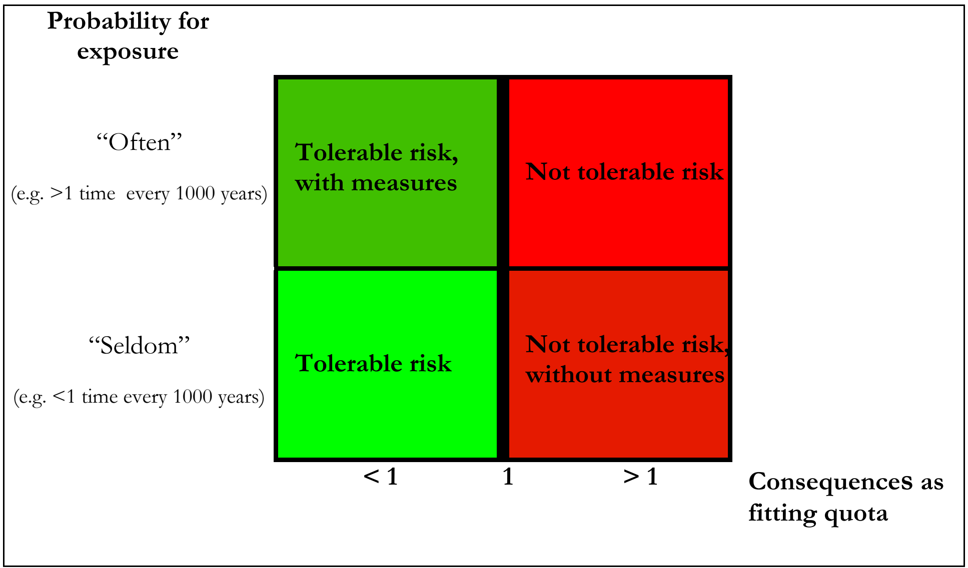


Figure 6-7 Level 2, a qualitative risk matrix, rough judgment of both probability and consequences

3. A risk matrix arranged in classes. The classes for probability/frequency are now several which allows for a semi-quantitative judgment. The consequences are still only divided in to two classes but the yellow field around one implies that there is uncertainty around a quotient close to one.

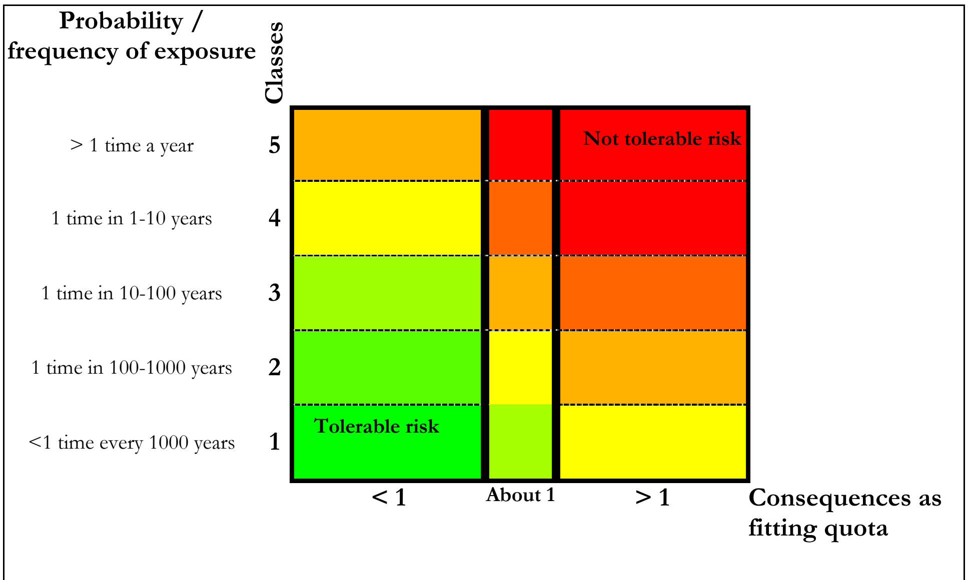


Figure 6-8 Level 3, a risk matrix arranged in classes; especially for probability/frequency.

4. A risk matrix arranged in classes. But research in exposure and effects in environmental and health fields have lead to a more quantitative judgment. The growing number of classes allows for a more precise characterization. This makes it possible to focus on the right scenarios and also aids the process of reaching a tolerable level. Risk criterion can be expanded in the risk characterization to create a yellow ALARP area (see also figure 2-3 in section 2.4 The risk evaluation).

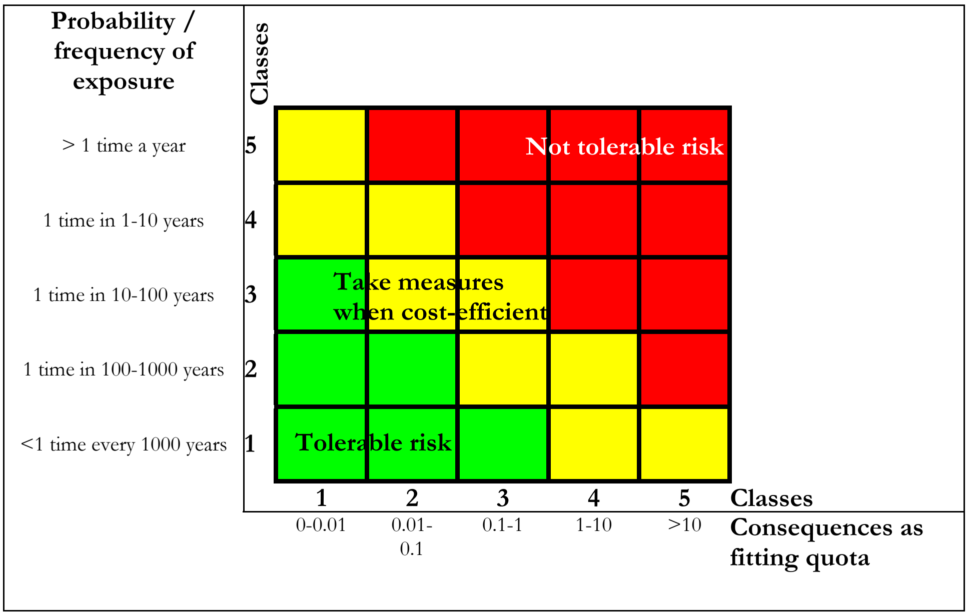


Figure 6-9 Level 4, risk matrix with several classes for both consequences and probability/frequency

5. It is preferable to leave classes for both probability and consequences when possible, and change to exact values. The characterization or estimation is then completely quantitative, but to reach that point a lot of research and experience feedback is needed.

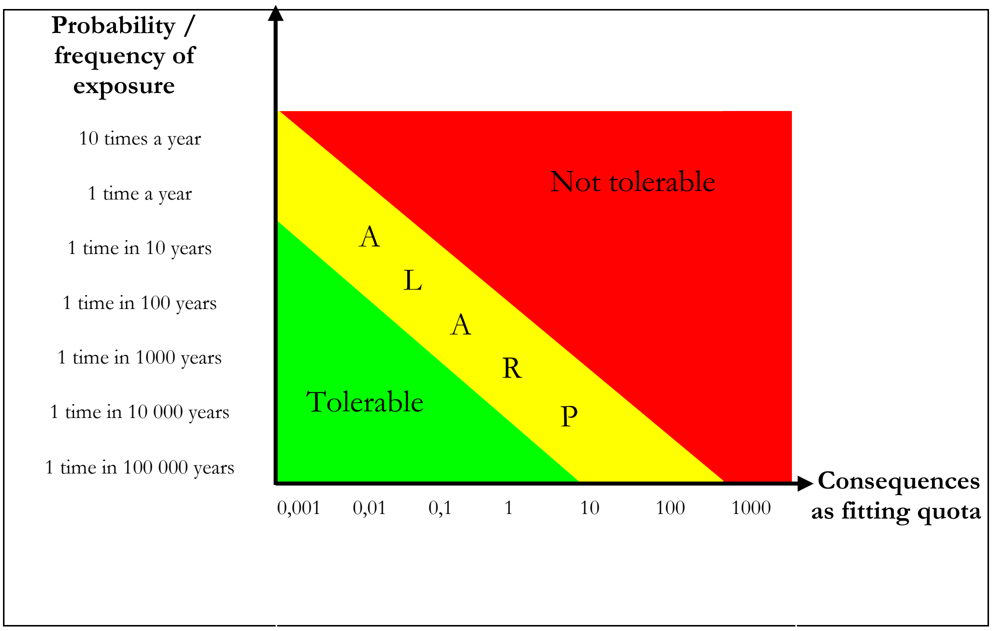


Figure 6-10 Level 5, risk-estimation diagram, with criteria for tolerable risk

6. 3D-Matrix. It is also possible to make a three-dimensional matrix where a third parameter can aid the risk characterization. This third parameter can for example be time, distribution or uncertainty.

One important property of the consequences that is difficult to visualize in a diagram but must not be overlooked is whether or not they are reversible. Irreversible effects are by definition much more serious than reversible effects and must be avoided at practically any cost. If the effects are deemed reversible it is preferable to estimate a timeframe in which they can be expected to be reversed

6.9 Risk Evaluation

The Risk evaluation step examines the economic and social issues influencing the selection of control options intended to ensure tolerable levels of risk. In many areas of risk management these are fairly straightforward questions of economic optimization, but in the context of environmental and health risks these considerations deal extensively with individual and societal values, and thus they go far beyond the scientific notion of objective analysis of "empirical" (measurable) physical quantities. Instead, risk evaluation techniques focus on the exploration of normative issues related to what ought to happen in a society that seeks to provide effective protection of the health of its citizens and the integrity of its environment in an equitable, but affordable, manner.

The complexities of dealing with environmental and health risks cause scientific risk estimates to have little intuitive meaning to non-experts. This is partly because people tend to focus on the severity of consequences for a given risk rather than the numerical probability of its occurrence. We often evaluate risks according to our subjective perception of the threatening characteristics of a particular hazard that most stand out in our minds as memorable and menacing. In order to compensate for such distortions in public perception of risk, decision-makers and stakeholders must rely, in part, on a systematic review of the economic and social dimensions of risk to provide a more pragmatic approach to the identification and selection of effective risk reduction strategies.

Two major classes of normative societal issues are considered in the Risk evaluation step /McColl et al 2000/:

Economic evaluation: (Cost-Effect Analysis) Estimating the expected health/environmental benefits and anticipated costs of control associated with varying degrees of reduction in risk, using monetary criteria which are amenable to quantitative economic analysis. If the benefits can be wholly quantified in monetary terms then this becomes a Cost-Benefit Analysis (CBA).

Social evaluation: Characterizing the social issues that reflect value judgments and societal preferences that are not amenable to formal economic analysis, as well as the factors that influence political perceptions of equity and fairness.

6.10 Integration into Risk Management

The results from the risk assessment must then be integrated in risk management. As described in section 2.2 risk management is an integral of several important tasks where risk assessment is one. The results from the risk assessment are the basis for risk reduction and control. Some general strategies for risk reduction and risk control (for SHE-assessment) is presented in section 2.6.

Some important steps in the risk reduction/control process are:

- Identify feasible risk control options.
- Evaluate risk control options in terms of effectiveness, cost, and risks.
- Evaluate options for dealing with residual risk.
- Assess stakeholder acceptance of residual risk.
- Develop an implementation plan.
- Implement chosen control, financing, and communication strategies.
- Evaluate effectiveness of risk management decision process.
- Establish a monitoring process, terminate if applicable.

/McCall et al 2000/

A risk assessment usually results in several recommended ways to reduce or control risks. The proposed risk reduction measures are often technical in nature and the implementation and follow up is scarcely addressed.

In order to effectively implement risk control in the risk management process, the optimal tool is a well designed, -structured and –functioning management system, see chapter 5.

Part II: Case study - Health and environmental risk assessment for transport of hazardous material

7 Introduction to case study

7.1 Background

In Iceland there are three major actors that provide petroleum products. These are Esso, Olís and Shell. Esso and Olís cooperate concerning distribution through the jointly controlled (Esso 60%, Olís 40%) distribution company Olíudreifing. Shell distributes its products themselves. Therefore there are only two major actors on the petroleum distribution market: Olíudreifing and Shell.

There is some friction between the fire department in Reykjavík on one hand and the oil companies on the other due to the placement of the major petroleum storage area in Reykjavík at Örfirisey peninsula by Reykjavík harbor (see figure 6-1). This localization means that oil truck transports out of Reykjavík to any part of Iceland have to pass through a big portion of Reykjavík's urban areas.

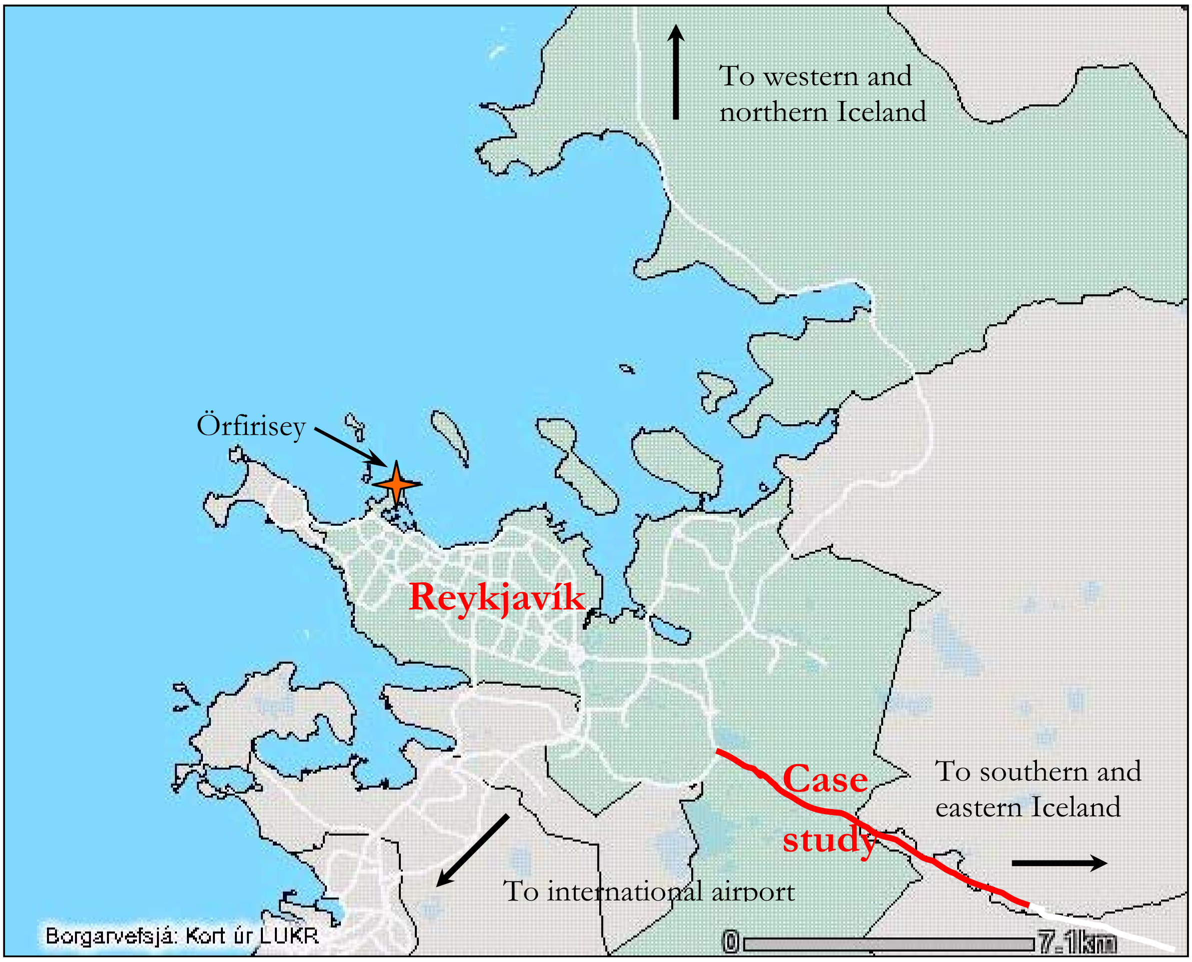


Figure 6-1 Reykjavík with surrounding roads.

The road transports of petroleum products have increased greatly in last years, as transports by ship around the island have decreased. This is due to changes in the economic climate that have favored road transports. This change in logistics has inevitably shifted risks from coastal areas around Iceland to the roads, especially in Reykjavík and vicinity. This increase in transports through Reykjavik has led to concerns on the behalf of the Reykjavík Fire Department and the Iceland Fire Authority, that the risk picture may be unnecessarily grave in and around Reykjavík.

7.2 The choice of object

The object of analysis in the case study was originally supposed to be fuel transports from Reykjavík to Keflavík international airport. The focus of this report is risk management within the fields of human health and the environment. The focus has been on safety aspects in many master's theses from the Risk Management and Safety Engineering Program in Lund. Therefore these aspects are excluded here. That means that possible ignition of the hazardous cargo is ignored here, since that would mainly constitute safety risks.

On the stretch between Reykjavík and Keflavík, wildlife is scarce. The road runs mostly through barren lava fields and appears to have little to offer as relevant endpoints in environmental risk analysis. Marine risks should nevertheless be considered, as the road runs close to the coastline. The health aspects are not much more prominent as the only water-protection area in danger along the stretch is that of the tiny village of Vogar. In case of an accident there, a new well could swiftly and cost-efficiently be drilled upstream from the road.

Preliminary risk identification reveals that the major risk associated with these transports is in the urban areas at the beginning and the end of the stretch. In these areas the prevailing risk is in the field of safety, in case of fire and/or explosion. Therefore an exclusive health and environment risk analysis does not appear to be motivated here.

A new object was chosen, a stretch of road going from Reykjavík to the south of Iceland (Sudurlandsvegur). Here the environmental risks are more prominent, with a popular recreational area, a lake renowned for its trout fishing and a salmon river. The health aspects were even more interesting as the water-protection area of Reykjavík, supplying more than half the population of Iceland with water, is in the imminent vicinity of the road.

To begin with, the analysis was supposed to include other hazardous material transports, besides fuel. After meetings with the authorities of environment and the agency for safety and health at work the problems of this approach began to reveal themselves. Even though Iceland is a member of the ADR-cooperation, no central agency has any comprehensive statistics for transports of hazardous materials on the roads of Iceland. This is probably due to the fact that there is no transit of hazardous materials through Iceland on route to a third country, and therefore no international demand for these data. Therefore this safety culture is not as developed in Iceland as in many other countries.

The best available tip was to contact customs, get records for total import of individual substances to Iceland, and then multiply by the population in southern Iceland divided by total population. This seemed rather far-fetched since many substances are probably not used at all in southern Iceland, where there is hardly any industry besides agriculture. Further, contact with customs proved somewhat problematic so a decision was made to focus on gasoline and diesel. These were the two most likely candidates as serious sources of risk anyway.

Other chemicals that are indeed transported on this stretch (quantities and frequencies unknown to the authors) include ammonia, hypochlorides and isocyanates. Besides there is a large gravel mine on the other side of the stretch which implies extra heavy transports. This on the other hand is included in the analysis.

Even though the object of the case-study is motivated for a risk assessment, it is by no means the only object in the vicinity of Reykjavík where a risk assessment is warranted. And even though safety risks are omitted in this report, they still very much need to be studied. The increase of road transports through Reykjavík inevitably increases the risk. Assessing how large this increase in risk is, and from what initial level, is definitely an important task for the future.

Regardless of the findings of future risk analyses, it is difficult to justify this placement of the petroleum storage at Örfirisey from a risk minimizing point of view. This placement makes sense from a logistical perspective with regard to the needs of the petrol station within Reykjavík, but it can hardly be motivated with regard to transports to areas outside of Reykjavík. These transports should not have to go through urban Reykjavík.

7.3 Method

This case study began with a visit to Reykjavík, Iceland, from May 20th to June 17th 2002. During this time it was decided which road section to analyze and the work to gather as much information about the actual area as possible started. Many contacts were made to receive information from oil companies, authorities and landowners (mainly Reykjavík Energy).

The methodology that is presented in chapter 5 was produced through literature studies on human health and environmental risk assessment. This methodology is a general method for health and/or environmental risk assessment on a road stretch. The aim is to fully utilize this methodology in this case study, but due to limitations in available data and time, some shortcuts must be made.

7.4 Demarcations

The most fundamental demarcation is, as mentioned before, that safety issues are not considered, and therefore the possibility of petroleum ignition is ignored. The ramification of this for the case study is that since safety issues constitute the overwhelming risk in urban settings the transport through Reykjavík is not considered and the stretch of road that is analyzed starts outside of Reykjavík's urban areas. The only substances covered in the assessment in the case study are gasoline and diesel (see section 7.2).

The endpoints of the health risk assessment are whether or not the concentration of petroleum products in the wells of Reykjavík Energy can exceed a certain level. It may be argued that water quality risk assessment is a more proper denomination than health risk assessment, but degraded water quality is likely to give adverse health effects. Further, since petroleum products are considered, their potency to aromatize water (especially diesel) is likely to render water unsuitable for drinking before serious health risks arise. Nevertheless we choose to keep using the term health risk assessment because it fits the nomenclature of SHE.

The endpoints of the environmental risk assessment are rather narrow, i.e. direct (fatality and failure to reproduce) effects on salmon, char and trout in lake Ellidavatn and the river Ellidaár. These are popular leisure fishing species in the area, so whether the fish will remain edible is also a concern.

7.5 Laws, regulations and responsibility

In January 2001 a new law (law #75/2000) for fire protection in Iceland states that it is the responsibility of the fire departments to respond to accidents (on land) that threaten the environment.

The European Union (EU) passed a directive 9th of December 1996 (96/82/EG) about measures to prevent and restrict the consequences of serious accidents with dangerous chemicals involved. This directive is commonly called the Seveso-II directive and it has great importance for the risk management community since it demands safety reports or risk analysis of major chemical industries. The directive has been integrated into both Icelandic and Swedish law. In Iceland it is regulation #263/1998 and in Swedish law SFS 1999:381. But both in Iceland and Sweden transports of hazardous materials outside of the industrial compounds are excluded in the Seveso laws and regulations. Although other laws and regulations cover the transports in both Iceland and Sweden the strict demands for reporting, risk communication and in depth analysis are missing in these. Therefore industries that the Seveso regulations apply for have two sets of rules to follow, one for the industrial compounds and one for the transports. A major drawback of this is that the information about the transports is much less readily available for governmental stakeholders.

Other Icelandic laws and regulations that address the handling and transports of petroleum products, especially from health and environmental impact aspects, include the following:

1988 #52:	Law on Toxic and otherwise Dangerous Substances.
1994 #103	Law on Leveling the Costs of Oil Product Transports.
1998 #7	Law on Health and Pollution Prevention.
1999 #44	Law on Nature Preservation.
2000 #106	Law on Environmental Impact Assessment.
2001 #784	Regulation concerning Liquid Fuels.
2002 #90	Law on Environmental Protection Agency.

The English names of laws and regulations above are the authors' own translation, i.e. *not* official translations.

As mentioned above, the UN-directive regarding transports of hazardous material (ADR) also applies in Iceland.

8 Initiation and Problem Formulation

The main stretch of road to be analyzed is a part of Sudurlandsvegur, the main road connecting Reykjavík and the south of Iceland. This stretch is 10,5 km but the assessment also includes the road from Sudurlandsvegur to Bláfjöll (Reykjavík's skiing area) and a part of a small road inside the water protection area, see figure 8-1.

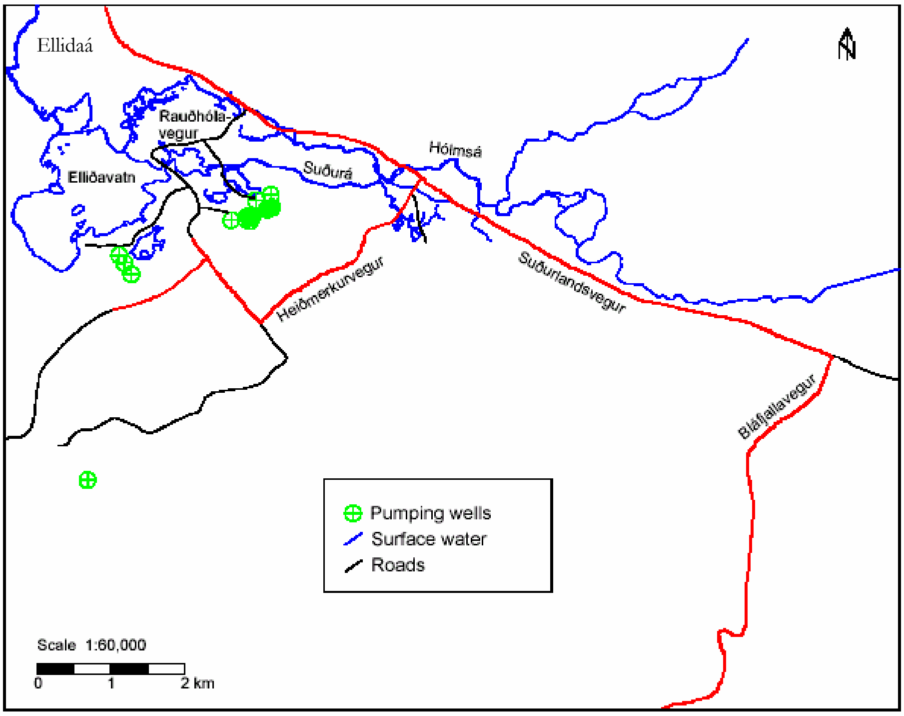


Figure 8-1 The stretch of road (red) to be analyzed (base map provided by Vatnaskil Consulting Engineers)

The reason that these smaller roads are included is their position in relation to the groundwater currents (see figure 8-2) to the wells in the water protection area.

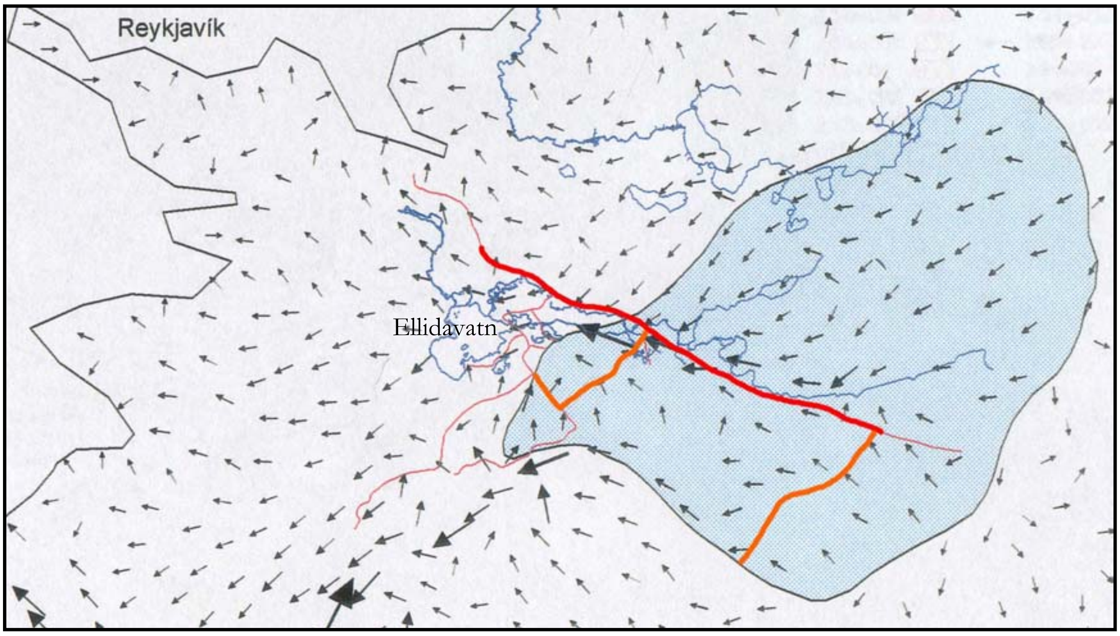


Figure 8-2 Groundwater flow to the water protection area. (Vatnaskil, 2002)

As mentioned above the road transports of petroleum have increased greatly in Iceland during the last few years. Therefore it is important do determine if the roads and their surroundings meet tolerable safety standards. Alongside many roads there are areas that are extremely sensitive to spill of hazardous material (in this case gasoline and diesel). One of these areas is the surrounding of where Sudurlandsvegur enters Reykjavík. In this area all the drinking water to the citizens of Reykjavik (and surroundings) is collected. There are also two rivers that meander along this road, Hólmsá and Sudurá. These rivers discharge in lake Ellidavatn, wherefrom the popular salmon-fishing river Ellidaá originates. Lake Ellidavatn is in its own right a popular trout-fishing area. Accordingly whether or not the fish will remain edible is a concern, beyond the obvious ecological concerns.

Therefore this area is important for the authorities, oil companies, fire department, oil transport companies, Reykjavik Energy and of course in the end the citizens of Reykjavik and Iceland. All of these are stakeholders in this risk assessment.

The objectives of this environmental and health risk assessment for transport of gasoline and diesel are to discuss and seek answers to the following (figure 8-3):

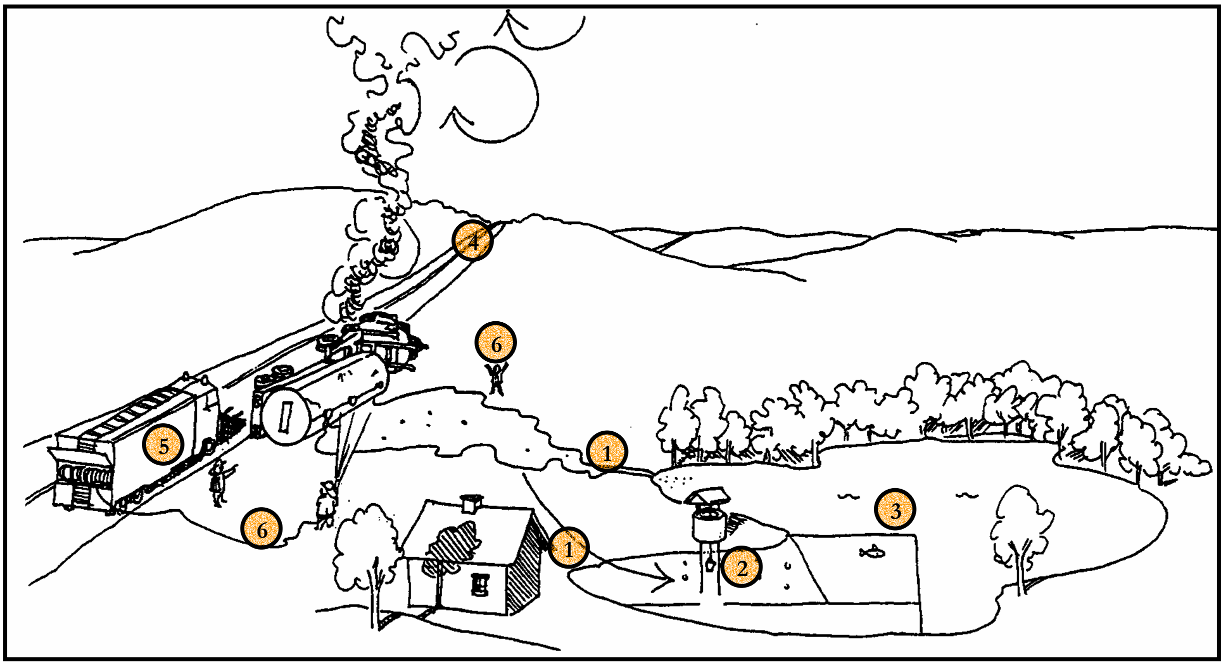


Figure 8-3 A schematic illustration of the problem formulation /(modified from) Räddningsverket 1998/

1. What happens if gasoline or diesel spill reaches the groundwater or an open watercourse?
2. Can a spill foul the water in the water protection area?
3. How will salmon, char and trout in lake Ellidavatn and surrounding rivers be affected?
4. How probable is an accident?
5. Who has the responsibility for clean up and consequence mitigation when an accident already has happened?
6. How does the risk communication function between the stakeholders?

Already in this first step of the risk assessment is it clear that the endpoints in this work should be the water quality in the health assessment, and the effects on salmon, char and trout in the environmental assessment. Of course we return to the endpoints later but for now we can assert this much.

9 Data Collection/Evaluation

This step is one of the most important and often time arduous tasks in health and environmental risk assessment. As much relevant data as possible should naturally be found and evaluated before the analysis goes too far. But this case study had to start from scratch because no truly comparable investigation has been done before, at least not any that the authors are aware of. Therefore the data collection extended itself right to the end of the project, which obviously limits the possibility of critical evaluation. This is of course undesirable and if the project had e.g. been a consultant project it would have been hard to accomplish within set financial and temporal limits.

Missing data is quite common in risk assessment for health and environment, so the assessment must often be adapted to available data. In this case study the missing data is a large problem and the data collection/evaluation step has taken an unreasonably large part of the total time spent.

Some of the tasks in this step have been to investigate and collect the following:

- Hazardous material transport: kind of chemicals, how often transported and how much.
- Statistics for accidents on the road.
- The properties of gasoline and diesel, as well as some of their constituents.
- The properties of the surroundings, mostly lava with thin or nonexistent vegetation.
- Effects, dose-response values etc. for the endpoint species salmon, char and trout.
- Etc. etc.

In isolated aspects however we have been lucky, like e.g. concerning the chemical distribution via the groundwater flow. Vatnaskil Consulting Engineers have produced and, improved for many years, a groundwater model for the area. Vatnaskil ran the necessary simulations according to our specifications, which gave us high quality results with little time invested.

10 Hazard Identification

Through investigation and data collection concerning the transport of hazardous material a first identification of hazards is achieved. On the actual stretch transports include for instance petroleum products, Ammonia, Hypochloride, Isocyanides etc. For reasons discussed in section 7.1 the analysis is focused on Gasoline and Diesel. These chemicals are also the most common on this road, about 5 to 10 transports each day according to one of the two distributing companies in Iceland. This frequency was later confirmed by visual counting.

Inspection of the actual stretch showed that there were no risk reducing measures alongside the road, no protective barriers and no ditches to trap spill. In several places the road crosses the two small rivers in the area and barriers to prevent transports from driving off the bridges are sometimes missing. The only observed risk reducing measures for the water protection area were fences around the inner parameter of the wells and pumping stations and some warning signs for liquid hazardous material transports by the smaller roads around the area.

The infiltration to the groundwater, and subsequent transport with it, can be expected to be really fast since the vegetative cover and soil above the lava is very thin, if it can be found at all, and because of cracks in the lava. The analyzed chemicals also have very low viscosity, which also hastens the infiltration.

Figure 8-2 clearly shows that an accident with a fluid release on Sudurlandsvegur can affect the water protection area and lake Ellidavatn. This figure gives a good understanding of how a spill can be distributed.

10.1 Hazard estimation method – an Index method

To get an understanding of the consequence of an accident with leakage of gasoline or diesel, a qualitative method should be used. In this case an index method is a fitting hazard estimation tool. The aim of the index method is to quickly show how big the consequences can be expected to become, and whether or not it is necessary to analyze the risks with a more quantitative method.

The index method considers several parameters, which must be graded, and the added sum from the different parameters gives an indication of the consequences. Since some of the parameters in the index vary a lot depending on circumstances alongside the analyzed stretch, one worst case scenario and one best case scenario are calculated to get the full span of consequences. The method is produced by /FOA 1998/ and since the model is designed for Swedish circumstances the model has been modified somewhat to fit the stretch on Iceland.

More information on index method and the hazard estimation can be found in *Appendix II – hazard estimation method.*

The guidelines for how to judge the environmental accident index sum are described in table 10-1.

Index sum	Necessary depth of analysis
1-100	Hazard estimation
100-500	At least the first steps of a further investigation (semi quantitative/quantitative risk analysis)
> 500	Further investigation (semi quantitative/quantitative risk analysis)

Table 10-1 Criteria for further analysis necessity /FOA 1998/

The results from the two calculations, a worst possible accident site and a best possible accident site in Appendix II give the following environmental index sum with recommendation on investigation necessity.

Calculation 1 & 2	Sum environmental accident index Index = To x Qu x [Vi + So + Su]	Necessary depth of analysis
Worst possible passage	6 x 5 x [4 + 1 + 10] = 450	Further investigation with a more quantitative method
Best possible passage	6 x 5 x [4 + 1 + 3] = 240	Further investigation with a more quantitative method

Table 10-2 The result from the index method, hazard estimation

The index method clearly shows that this environmental hazard should be analyzed with a more quantitative method. But as discussed above it is important to also weigh in the probability of an accident.

10.2 Decisions on further analysis and revision of preliminary endpoints

The results of the investigations so far show that the hazards motivate further analysis.

10.2.1 Revision of preliminary endpoints

The endpoint for the health analysis, whether or not the water can become undrinkable following an accident resulting in a petroleum release, remains a key endpoint. However it is made more precise, i.e. whether or not the pollutant concentration will exceed 0.1 mg/l in any of the drinking water wells within the water protection area (see section 4.1 in Appendix I – *Chemical description*).

Lack of toxicological data on salmon, char and trout lead to lowered expectations on answering question 3 in chapter 8 fully, but this and remaining questions will be answered to the best of the authors' capacity.

In the first risk inventory, the rivers Hólmsá and Sudurá where primarily seen as hypothetical pollutant transporters. Their importance as a nursery for juvenile trout was not realized until late in the data collection phase. If the trout population of these rivers suffered a serious pollution accident it would greatly affect the trout population of the water system.
/Antonsson 2002/

10.2.2 Chosen scenes of accident with scenarios from the hazard identification

The information gathered already in the hazard identification can now be of help in choosing descriptive scenarios, see figure 10-1 and table 10-3.

Some of the accident sites are especially chosen for the environmental assessment (sites 1, 2 and 3), the remaining for the health assessment. This can be more easily understood by examining figure 8-2, *Groundwater flow to the water protection area.* The sites chosen for the health assessment can naturally also give rise to environmental risks, but these will only be considered qualitatively, when addressed at all.

The order in which the accident sites are labeled may be confusing. The reason is that sites 8, 9 and 10 were added since the results of the first simulations motivated them.

Table 10-3 explains the scenes of accident more closely and it also explains the different scenarios for each scene of accident with level of frequency estimation.

Scenarios outside the main road Sudurlandsvegur are represented with S1-S3. A quantitative frequency analysis of these was impossible due to total lack of accident statistics. Every scene of accident on Sudurlandsvegur is divided up in different scenarios that are represented with P1-P7 (see chapter 10). All the scenarios fall between the worst case and the best case scenarios calculated above. Therefore further investigation is motivated for them all. These scenarios are quantitatively, or at least semi-quantitatively, frequency estimated in chapter 11.

Location of hypothetical oil spills

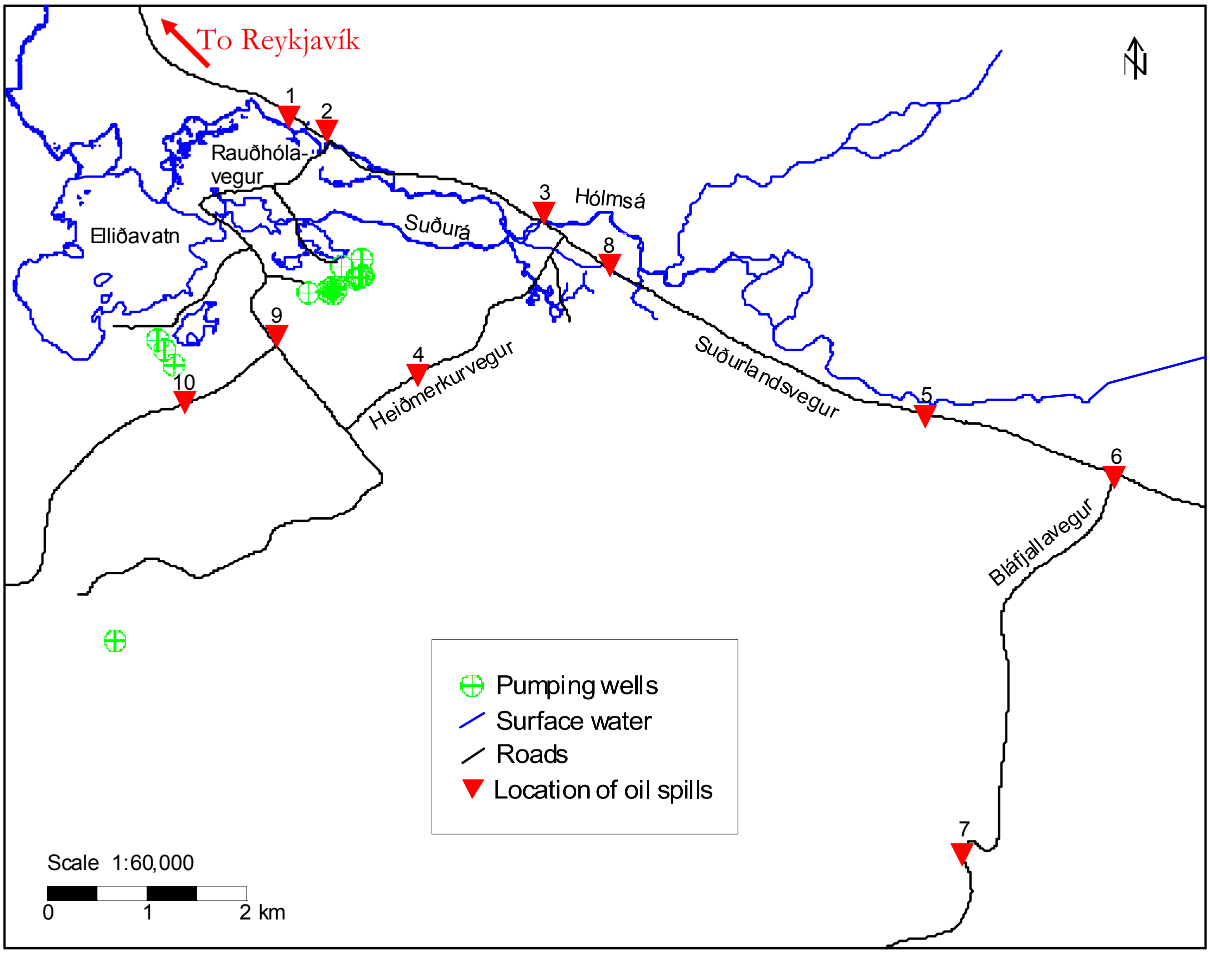


Figure 10-1 Chosen scenes of accident (1-10)

Scenes of accident	***Location:***	***Spill recipient:***	***Scenario (P or S) with amount of spill (ton):***	***Level of frequency estimation***
1	Sudurlandsvegur, 500 m NW of Raudhólavegur-intersection	Ground	P1: 32 tons P2: 4 tons P3 & P5: 0.2 ton	Semi-Quantitative *(Appendix-III)*
2	Sudurlandsvegur, bridge by Raudhólavegur-intersection	River	P1: 32 tons P2: 4 tons P3 & P5: 0.2 tons	Semi-Quantitative *(Appendix-III)*
3	Sudurlandsvegur, bridge by Hraunslód-intersection	River	P1: 32 tons P2: 4 tons P3 & P5: 0.2 tons	Semi-Quantitative *(Appendix-III)*
4	Heidmerkurvegur, 2 km from eastern intersection	Ground	S1: 50 kg S2: 100 kg	Qualitative
5	Sudurlandsvegur, 2 km W of Bláfjallavegur-intersection	Ground	P1: 32 tons P2: 4 tons P3 & P5: 0.2 tons	Quantitative *(Appendix-III)*
6	Sudurlandsvegur, Bláfjallavegur-intersection	Ground	P1: 32 tons P2: 4 tons (P3 & P5: 0,2 tons)	Quantitative *(Appendix-III)*
7	Bláfjallavegur, 4 km from Sudurlandsvegur-intersection	Ground	S3: 3 tons	Qualitative
8	Sudurlandsvegur, 700 m east of Heidmerkurvegur-intersection	Ground	P1: 32 tons P2: 4 tons P3 & P5: 0.2 tons	Quantitative *(Appendix-III)*
9	Heidmerkurvegur at intersection between the main clusters of wells	Ground	S1: 50 kg S2: 100 kg	Qualitative
10	Heidmerkurvegur due south of western cluster of wells	Ground	S1: 50 kg S1: 100 kg	Qualitative

Table 10-3 Chosen scenes of accident (1-10) with explanations of scenarios.

11 Frequency and probability Assessment

For most of the scenes of accident (1-10) it is possible to calculate the frequency of an accident with different sizes of spill. As described in *Appendix – III Frequency calculation* these scenarios are denominated by P1-P7. On the smaller roads Bláfjallavegur and Heidmerkurvegur only a qualitative estimation is possible since basic accident data is missing. These scenarios are denominated by S1-S3 and will be discussed more in the risk characterization.

The calculations are carried out in appendix III. The calculations concerning hazardous material transport accidents principally use values from the Iceland Road Authorities and from a Swedish publication jointly produced by the road and rescue authorities:

Vägverket (VV) *Publ 1998:064, Förorening av vattentäkt vid vägtrafikolycka,* which is a continuation from Räddningsverkets (SRV) (1996) guidelines *"Farligt gods –riskbedömning vid transport", Statens väg- och transportforskningsinstitut, VTI – model.*

Since the model and inputs contain a lot of uncertainty, and in order to get an acceptable final result, an uncertainty analysis has been carried out in the end of Appendix III.

11.1 Basis for the calculations

The described scenes of accident (1, 2, 3, 5, 6 and 8) in section 10.2.2 for the road Sudurlands-vegur are divided up into different scenarios (P1-P7) that lead to different sizes of spill.

Petroleum accidents in this report can arise from either hazardous material transport with gasoline or diesel, or from any heavy transport with a larger motor fuel tank. The two different sources to a petroleum accident are abbreviated according to the following:

Hazardous Material Transport (with gasoline or diesel):	**HMT**
Heavy Transport (with larger motor fuel tank):	**HT**

These two sources to a petroleum spill can be described in an Event Tree according to figure 11-1.

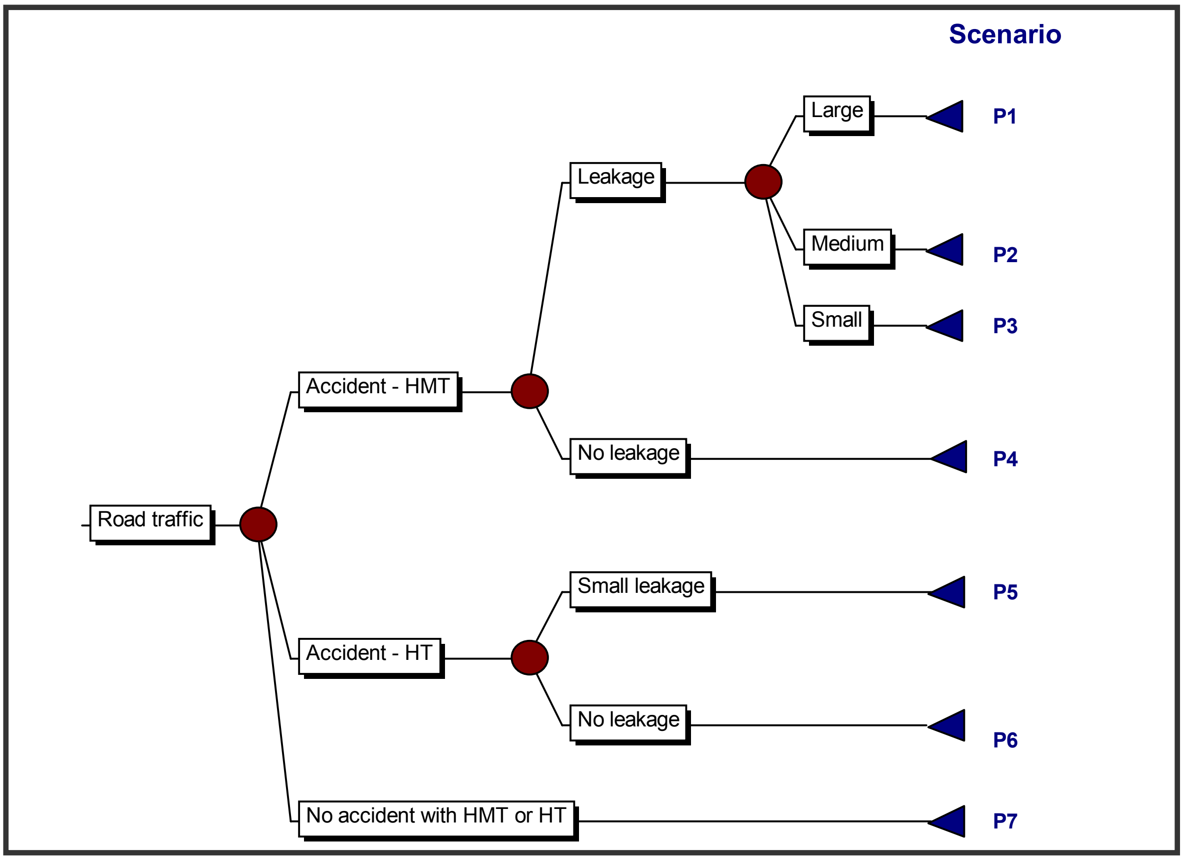


Figure 11-1 Event tree for accidents with petroleum products from HMT or HT

11.2 Result

The calculations in Appendix III give the frequency for each scenario, P1-P7, see table 11-2 below.

Scenario (end events)	Probability for accident P_0	Probability for spill, P_u	Probability for size, P_s	Final frequency for end event
P1: large	0,019	0,28	0,25	1,3 x 10^{-3}
P2: medium	0,019	0,28	0,25	1,3 x 10^{-3}
P3: small	0,019	0,28	0,50	2,7 x 10^{-3}
P4: no spill	0	0	0	0
P5: small	1,96	0,028	1	5,5 x 10^{-2}
P6: no spill	0	0	0	0
P7: no accident	0	0	0	0

Table 11-1 Calculated probabilities and final frequencies.

11.3 Uncertainty in the calculations

Some of the inputs in the frequency calculations for accident with hazardous material transport or any heavy truck accident are very uncertain. Therefore an uncertainty analysis has been carried out in Appendix III. The uncertainty analysis has been done in the simulation program @Risk. The simulation also contains a sensitivity analysis, see Appendix III.

When distributions are introduced for the input parameters distributions emerge for the different scenarios P1, P2, P3 and P5, see figures 11-2 to 11-3. Observe that the distributions for scenarios P2 and P3 are the same since they have same inputs.

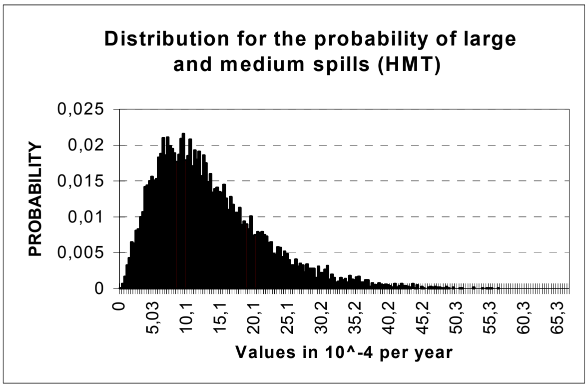
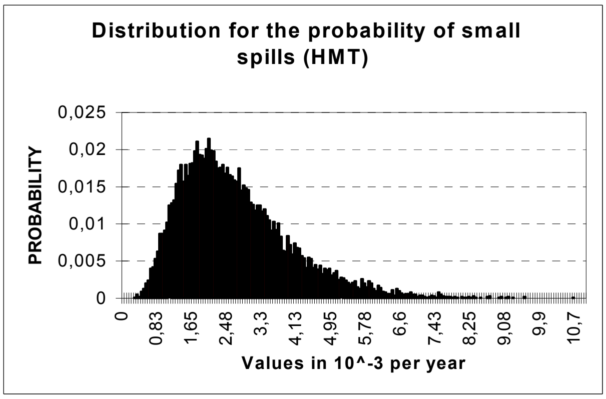


Figure 11-2 Distribution for the probability of large and medium spills with hazardous material transport, scenario- P1 and P2



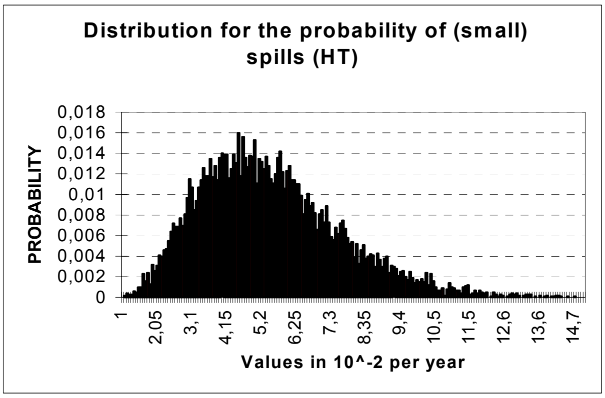


Figure 11-3 Distributions for probabilities of small spills with hazardous material transport and with any heavy transport, scenario-P3/P5

12 Effect Assessment

The effect assessment is mainly carried out in *Appendix – I Chemical description*. There tables with the physical properties and some toxicological information can be found.

12.1 Effect assessment for health

The criteria for the exposure assessment is whether or not the concentration in any of Reykjavík Energy's pumping wells, which supply the citizens of Reykjavík with their drinking water, exceeds 0.1 mg/l. This is a limit where the water is likely to get fouled by smell and/or taste of the petroleum product spilled. The water in the wells is groundwater so it is the chemical distribution via groundwater that is of interest here.

12.2 Effect values for environmental assessment

12.2.1 Gasoline and diesel in general

When it comes to the environmental assessment the difference in evaporation rates between the chemicals becomes very important. In this project the environmental risks are almost exclusively considered when the chemicals are distributed with the surface water. Gasoline is much more prone to evaporate (more volatile) than diesel, as is clearly implied by the difference in boiling points and vapor pressures in the tables above. Therefore diesel will be around to have effects long after the gasoline is "gone with the wind".

Sedimentation is unlikely to be a major factor for any of the two chemicals due to their low density compared to water. Adhesion to suspended fine sediment particles and subsequent sedimentation with these is possible but will only account for the fate of a fragment of the release.

The low viscosity of both chemicals means that they are readily dispersed into the water in turbulent circumstances, i.e. in lake Ellidavatn when winds exceed 3 m/s or in the more turbulent parts of the rivers. The low viscosity also implies that adhesion to the river/lake banks will not be a dominant factor.

These chemicals have a tendency to be retained by organic material in the soil. In the area in question there is almost no topsoil and below is just lava. Therefore the retention will not be a significant factor.

Petroleum products are not among the most acutely toxic chemicals that man utilizes, but the sheer volumes transported are unique in our chemical handling. Diesel is relatively toxic to aquatic life forms, one of the most potent oils. This fact, in combination with the fact that it remains in the water for a much longer time than gasoline, makes diesel the larger environmental hazard of the two.

Studies have shown that fish can be tainted and rendered inedible after being exposed to diesel in their environment for some weeks. This is due to the fact that several components of diesel have high BCFs and are readily bioaccumulated. /NOAA, (factsheet on small diesel spills)/

No specific values of toxicity were found for salmon, char or trout, but in general the concentration of hydrocarbons has to exceed 10 mg/l to be acutely toxic for adult fish.

Acute fatalities in juvenile fish and larvae occur when the concentration exceeds 1 mg/l.

If the concentration exceeds 0.01 mg/l (10 ppb) abnormal fish spawns are produced and hatching can be delayed.

Already at 0.1 µg/l (0.1 ppb) chromosome abnormalities have been experimentally demonstrated in laboratory conditions, but there is no evidence of similar genetic damage to natural fish populations affected by oil spillages./O'Sullivan et al 1998/

12.2.2 Specific components of gasoline and diesel

In this effect assessment three characteristic components are chosen to represent diesel and gasoline.

These are:

- Anthracene
- Benzene
- MTBE

These three have been chosen since they give rise to harmful effects and they are also common chemicals in gasoline and diesel.
Anthracene: up to 0.02% in diesel
Benzene: up to 1 % of gasoline
MTBE: up to 10 % of gasoline

Aquatic toxicity for these three chemicals is presented in table 12-1.

Anthracene		Benzene		MTBE	
PNEC (EU):	0.000019 mg/l	PNEC (EU):	0.017 mg/l	NVV RRV:	0.05 mg/l

Table 12-1 PNEC and RRV values for selected components. /Klein et al 1999/

13 Exposure assessment

Before any effect analysis can be conducted the fate of the release must be assessed. A pollutant will only have direct effects in the locations where it actually occurs. In order to assess effects one first has to determine where, and in what concentration, the chemical will end up after a given time. The exposure assessment is mainly presented in *Appendix – IV Exposure assessment.*

There are two distinct ways of exposure modeled in this report; via groundwater (mainly health risk assessment) and via surface water (mainly environmental risk assessment). Section 11.1 and appendix I discuss effect values for water quality and conclude that a petroleum concentration of 0.1 mg/l can be enough adversely affect smell and/or taste of drinking water. So for the water quality aspects this is the criterion for the exposure assessment via ground water. The environmental aspects are more complex. In fact they are too complex to be thoroughly investigated here. But the effect assessment above has given some possibilities and the results here will be a mixture of semi-quantitative and qualitative ones.

13.1 Exposure via groundwater

Vatnaskil Consulting Engineers in Reykjavík have been building and improving their groundwater-model of the surroundings of Reykjavík since the 1980's, which makes their model quite outstanding when assessing transport via the groundwater in the area.

The model environment is Vatnaskil's own software *AQUA 3D,* which solves three-dimensional groundwater flow and transport problems using the Galerkin finite element method. It is designed to simulate both homogeneous isotropic aquifers and inhomogeneous anisotropic aquifers. /Vatnaskil 1998/

The main reason why this approach was chosen is not the software but the groundwater model itself of the area that Vatnaskil have been updating and improving for numerous years. Any modeling work done specifically for this project would have been extremely rudimentary in comparison.

Eight of the ten hypothetical scenes of accident, with different scenarios, result in a release to the groundwater (see figure 12-1). Accidents at these sites can harm both health and environment.

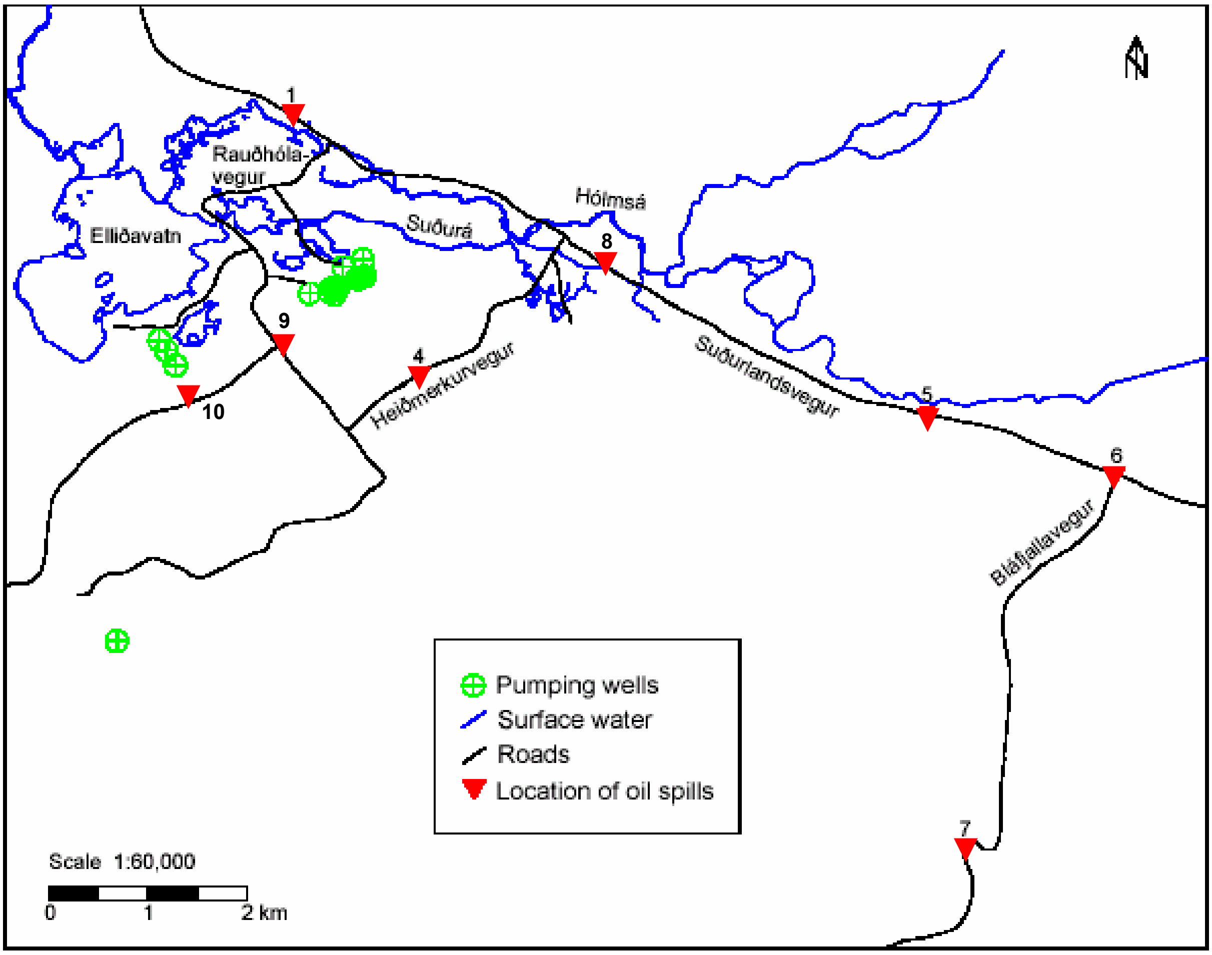


Figure 13-1 Hypothetical scenes of accident where spill infiltrates into groundwater.

13.1.1 Result from exposure assessment via groundwater

The scenes of accident are divided up in different scenarios (P:x or S:x) that lead to different size of spill and exposure. The P scenarios are related to accidents on the main road, Sudurlandsvegur. The S scenarios are related to accidents on the smaller roads. In appendix IV some of the scenarios are presented in figures. The total number of figures produced by Vatnaskil exceeds one hundred and a selection of the most informative ones is presented in the appendix. One example is presented below, figure 13-2. Reading appendix IV is quite fundamental in order to get a feel for the results.

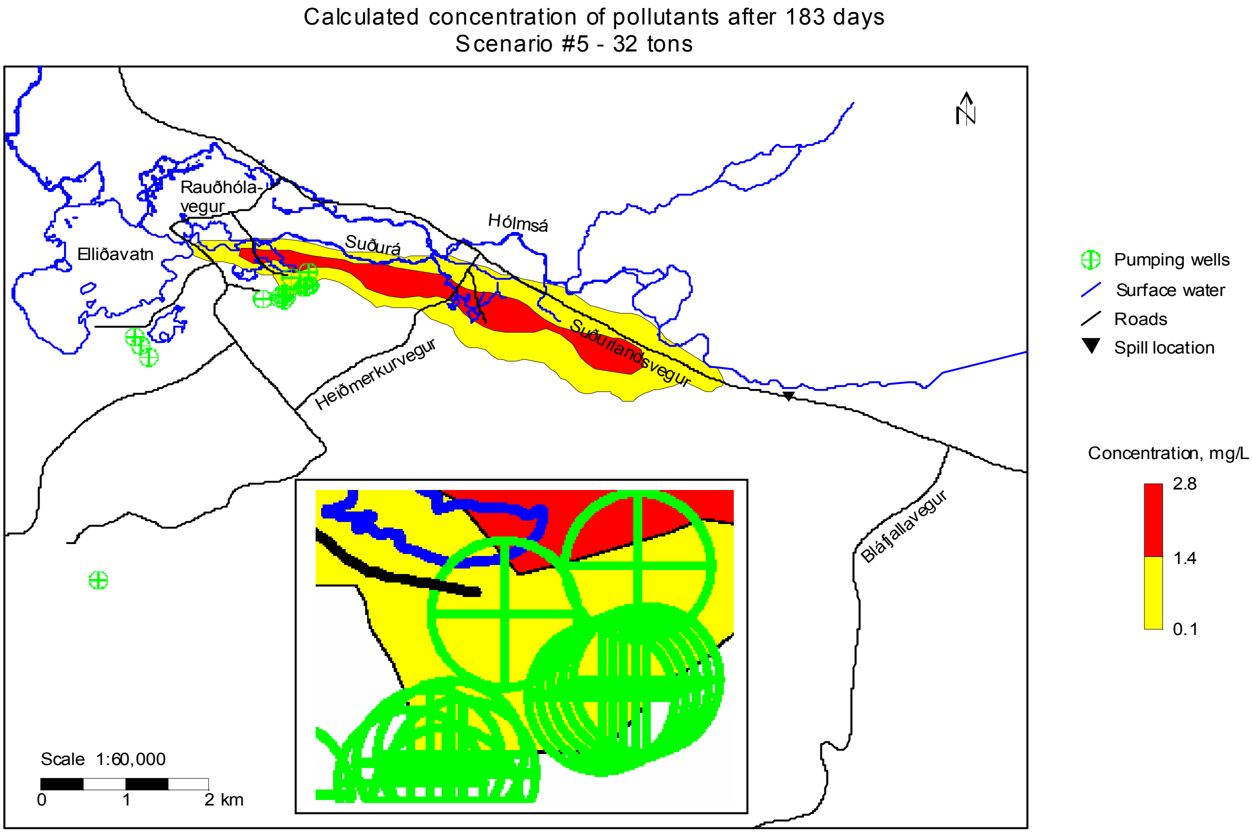


Figure 13-2 An example of the results from the distribution via groundwater (see appendix IV)

As mentioned above the criterion for the health exposure assessment is whether or not the concentration in any of Reykjavík Energy's pumping wells, which supply the citizens of Reykjavík with their drinking water, exceeds 0.1 mg/l. This is a limit where the water is likely to get fouled by smell and/or taste of the petroleum product spilled.

The environmental exposure assessment is mostly qualitative here since the model does not calculate the concentrations in the rivers. But if the drop in concentration in the model is relatively high, the rivers are receiving more pollutants.

In table 13-1 the results are summarized.

Scenes of accident:	Scenario (P or S) with amount of spill:	Days to reach the concentration 0.1 mg/l in wells
1	P1: 32 tons	**n.a.**
1	P2: 4 tons	-
1	P3 & P5: 0.2 ton	-
4	S1: 50 kg (0,5 ton)	-
4	S2: 100 kg (1 ton)	-
5	P1: 32 tons	Yes after 90 days
5	P2: 4 tons	Yes after 180 days
5	P3 & P5: 0.2 ton	**n.a.**
6	P1: 32 tons	Yes after 720 days
6	P2: 4 tons	**n.a.**
6	P3 & P5: 0.2 ton	-
7	S3: 3 tons	No but see Appendix IV
8	P1: 32 tons	Yes after 7 days
8	P2: 4 tons	**n.a.**
8	P3 & P5: 0.2 ton	-
9	S1: 50 kg (0,5 ton)	-
9	S2: 100 kg (1 ton)	-
10	S1: 50 kg (0,5 ton)	No but see Appendix IV
10	S2: 100 kg (1 ton)	No but see Appendix IV

Table 13-1 A summary of the results from the exposure assessment via groundwater

The common heavy transports (HT) do not appear to threaten the drinking water as none of the scenarios with a release of 0.2 tons cause the limit of 0.1 mg/l to be exceeded in any of the wells.

13.2 Exposure via surface water

The model of Vatnaskil does not simulate surface water flow and transport; it simply treats surface flow as sinks of groundwater and possible pollutants. Therefore another method had to be found to estimate exposure when the release of petroleum products hit the rivers directly.

Due to the low density (700-850 kg/m^3) of the petroleum products in question, evaporation was considered to be the main way of removal of petroleum from the system. A computer program, *Adios II,* was downloaded from the American National Oceanic & Atmospheric Administration (NOAA). This program was mainly designed for marine releases but it allows for fresh water settings. For more information about the simulation see *Appendix IV - Exposure estimation.*

Two accident scenes (figure 13-3) have been placed at bridges over the river Hólmsá to cover the extreme case when the release hits a river directly.

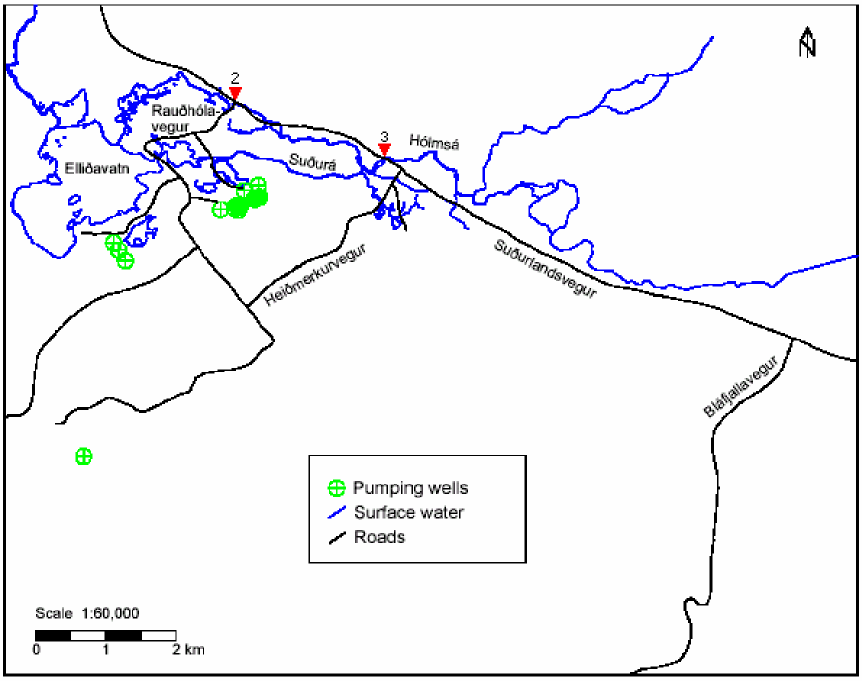


Figure 13-3 The two accident scenes where release occurs directly into the river Hólmsá

13.2.1 Result from exposure assessment via surface water

The scenarios where the release is small (0.2 tons) were included in this report to see if the drinking water is threatened by the usual heavy transports (HT). These are not included in the environmental assessment since any such release would probably only have very local effects. Assuredly there are locations where such local effects would be tragic, but this assessment does not go to such a depth as to point out the most ecologically vulnerable or valuable locations along the stretch.

The release rates were calculated in AdiosII, see appendix IV. The large release is over in two minutes, the smaller one in just under 9 minutes. The releases rates are approximately constant during the first half of the release, to smooth out towards zero during the latter half (see appendix 4; 3.1.1.) Given the calculated release rates the initial concentrations of diesel or gasoline in the river Hólmsá become:

Scenario (P) with amount of spill	Initial concentration in Hólmsá
P1: 32 tons (large release):	1.5 x 10^5 mg/l
P2: 4 tons (medium release):	5050 mg/l

Table 13-2 Initial concentration in Hólmsá downstream accident.

This means the following initial concentration of the constituents discussed in section 12.2.2 and presented in table 12-1:

Scenario (P)	Anthracene	Benzene	MTBE
P1 (large release)	30 mg/l	1500 mg/l	1.5 x 10^4 mg/l
P2: (medium release)	1.01 mg/l	50.5 mg/l	505 mg/l

Table 13-3 Initial PEC values of selected chemicals downstream of release point.

With assumptions described in appendix IV a spill at site 2 would reach lake Ellidavatn in a little over 40 minutes, and a spill from site 3 in a little under 1½ hours. During those times the evaporation would be as described in table 13-4.

Chemical:	Accident site and scenario:	Percent evaporated
Diesel	Site 2, P1 (large)	**0%**
-	Site 2, P2 (medium)	**1%**
-	Site 3, P1 (large)	**0%**
-	Site 3, P2 (medium)	**1%**
Gasoline	Site 2, P1 (large)	**19%**
-	Site 2, P2 (medium)	**47%**
-	Site 3, P1 (large)e	**32%**
-	Site 3, P2 (medium)	**71%**

Table 13-4 Evaporation of pollutants in the river Hólmsá, before lake Ellidavatn is reached.

When the pollution plumes reach lake Ellidavatn the evaporation increases as the oil can spread out over a larger surface. Table 13-5 shows the evaporation from lake Ellidavatn.

Scenario	% evaporated after:						Scenario	% evaporated after:			
Diesel	**1h**	**2h**	**6h**	**12h**	**24h**	**48h**	**Gasoline**	**1h**	**2h**	**3h**	**6h**
P2: (medium spill)	3	8	33	49	60	63	P2: (medium spill)	88	95	99	99
P1: (large spill)	11	25	47	56	62	64	P1: (large spill)	66	90	96	99

Table 13-5 Evaporation in lake Ellidavatn

Observe that these percentages are relative to the concentration that reaches lake Ellidavatn, not to the initial concentration.

When lake Ellidavatn is reached it is safe to assume that the chemicals will most probably be diluted in most of the lake before the salmon fishing river Ellidaá gets any high concentrations. Ellidaá is the river that runs into the upper left corner of figure 12-3, and even though it is quite close to the outlet of Hólmsá, it is in the counterclockwise direction. The Coriolis force will for the most part force the water to take the long way around the lake before reaching the river Ellidaá. If there was a strong wind blowing due NW then the spill would probably reach Ellidaá quickly, but on the other hand if a strong wind is blowing then the evaporation would also be a lot faster (see appendix IV; 3.2). /Horne et al 1994/

The part of the water system that is hit the hardest following accidents at sites 2 or 3, the river Hólmsá, is dominated by juvenile trout (see appendix IV; 3.3).

The uncertainties in this chapter are huge, and further work is needed here, and accordingly also in chapter 14.

14 Risk Characterization

The final summation in this case study is the risk characterization. In this step an estimation of the risks is presented in an appropriate way. It is not possible to do one common risk characterization for all scenes of accident. One reason for this is that the assessment contains both scenarios for health and the environment and they need different judgments and different evaluations. Another one is the lack of data in some scenarios. The risk characterization in this study is an attempt to apply some of thelevels discussed in section 6.8.1.

14.1 Risk Characterization for the health scenarios

The actual scenes of accident with different scenarios have been assessed with respect to frequency, effect and exposure. The consequence is often presented as a quota between the exposure concentration and effects concentration. In this case the question is whether the exposure (concentration of inflow to the wells) exceeds the effect level (0.1 mg/l). Table 14-1 presents the scenarios with results from the different assessments. If no values for the frequency are available the judgment becomes semi-quantitative. Since only accidents on a part of the main road, Sudurlandsvegur, give consequences for the water quality, the frequencies for the scenario have to be reduced by 6.5/10.5 (part that gives rise to adverse effects/total stretch), see figure 8-2. The results that have frequency attached have been collected in a matrix, see figure 14-1.

Scenes of accident:	*Scenario (P) with amount of spill:*	Is the limit of 0.1 mg/l exceeded (intolerable)?	Frequency:
4	S1: 50 kg (0,5 ton)	**No**	-
4	S2: 100 kg (1 ton)	**No**	-
5	P1: 32 tons	**Yes**	8×10^{-4}
5	P2: 4 tons	**Yes**	8×10^{-4}
5	P3 & P5: 0.2 ton	**No**	$1{,}7 \times 10^{-3}$ & $3{,}4 \times 10^{-2}$
6	P1: 32 tons	**Yes**	8×10^{-4}
6	P2: 4 tons	**No**	8×10^{-4}
6	P3 & P5: 0.2 ton	**No**	$1{,}7 \times 10^{-3}$ & $3{,}4 \times 10^{-2}$
7	S3: 3 tons	**No**	-
8	P1: 32 tons	**Yes**	8×10^{-4}
8	P2: 4 tons	**No**	8×10^{-4}
8	P3 & P5: 0.2 ton	**No**	$1{,}7 \times 10^{-3}$ & $3{,}4 \times 10^{-2}$
9	S1: 50 kg (0,5 ton)	**No**	-
9	S2: 100 kg (1 ton)	**No**	-
10	S1: 50 kg (0,5 ton)	**No**	-
10	S2: 100 kg (1 ton)	**No**[1]	-

Table 14-1 Risk characterization of health scenarios

[1] See the discussion in appendix IV. This scene of accident would almost certainly have resulted in the concentration exceeding the 0.1 mg/limit had it only been placed a little bit differently.

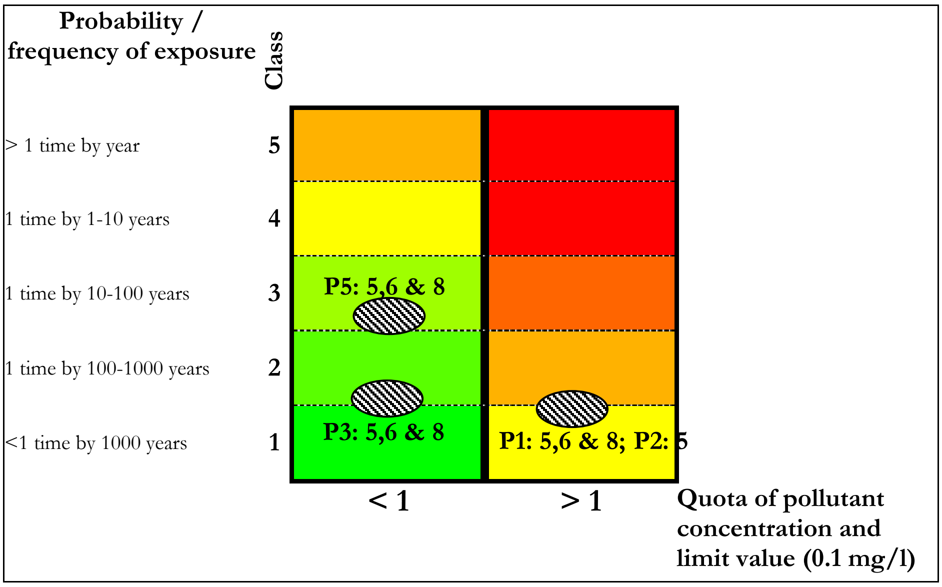


Figure 14-1 Alternative characterization of health risks (matrix)

14.2 Risk Characterization for the environmental scenarios

The quotients of the PEC and PNEC values from chapters 12 and 13 constitute the basis of the environmental risk characterization. Some qualitative discussions follow later.

14.2.1 PEC/PNEC

The first relevant results are the information from tables 12-1 and 13-3, summarized below in table 14-2.

Scenario	Anthracene	Benzene	MTBE
P1: (large release)	30 mg/l	1500 mg/l	1.5 x 10^4 mg/l
P2: (medium release)	1.01 mg/l	50.5 mg/l	505 mg/l
PNEC/RRV:	0.000019 mg/l	0.017 mg/l	0.05 mg/l
Quotients			
P1: (large release)	1.58 x 10^6 (1)	8.82 x 10^4 (2)	3.00 x 10^5 (3)
P2: (medium release)	5.32 x 10^4 (4)	2970 (5)	10100 (6)

Table 14-2 Initial PEC/PNEC quotients.

These are very high quotients indeed, and even though the concentration of benzene and MTBE drops somewhat due to evaporation during the transport in the river Hòlmsá, all fish in the plumes' path can be assumed to perish.

Figure 14-2 shows these results in a matrix.

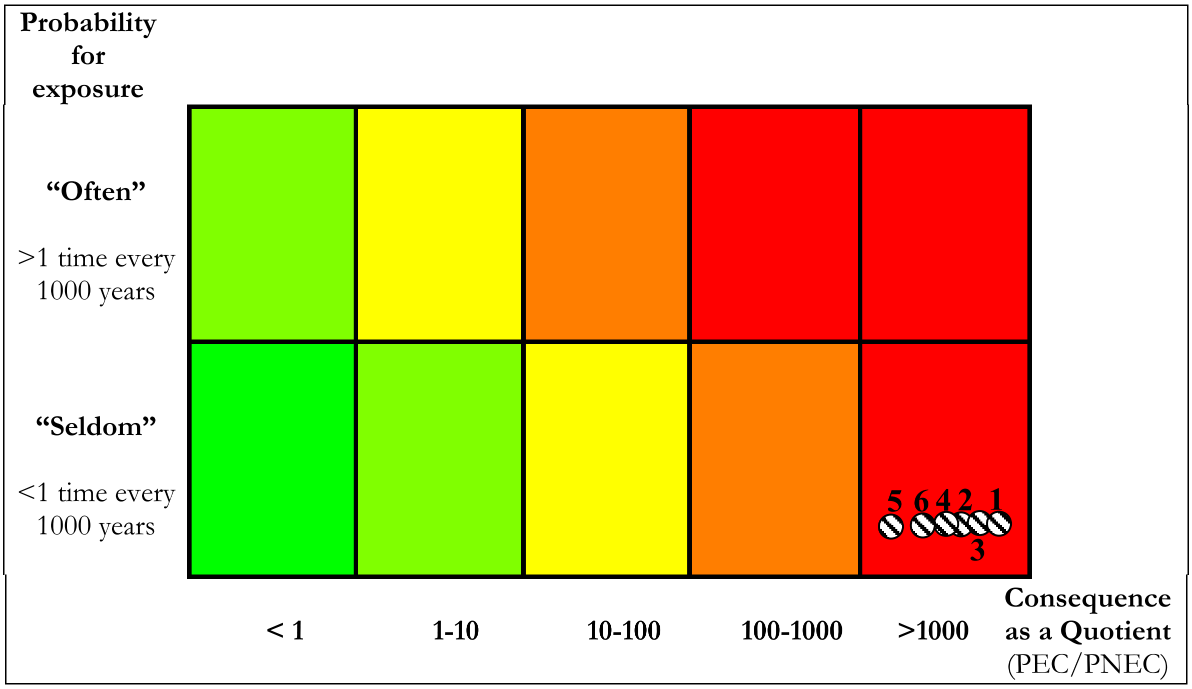


Figure 14-2 An environmental risk matrix for initial phase, qualitative frequency, quantitative effects.

14.2.2 Qualitative effect discussion

The matrix in figure 14-2 only applies to the river Hólmsá, but the concentration in parts of lake Ellidavatn can be assumed to exceed 100 mg/l for some hours after a large diesel release. The upper layers in a large part of the lake can be assumed to have concentrations of 10-100 mg/l for up to 24 hours and the entire lake (at least the upper layers) can be assumed to have concentrations between 1 and 10 mg/l for days, even weeks (see appendix IV). Comparing these to the effect intervals given at the end of section 12.2.1. reveals that most of the juvenile fish in the lake are likely to perish following this scenario and also some of the adult fish.

This would be a huge blow to the trout and char populations, quite possibly irreversible (without human interaction), at least for the char. The salmon population would probably not be hit as hard, their juvenile are mostly found in the river Ellidaá that runs from lake Ellidavatn, through Reykjavík, to the sea. Ellidaá is not likely to receive much higher concentrations than 1 mg/l. This may nevertheless be too much. Both salmon and trout have considerable stocks higher up in the rivers Hólmsá and Sudurá. The stocks in upper Hólmsá are not threatened by an oil truck accident, since they are upstream of the main road Sudurlandsvegur.

A gasoline spill would probably only affect Hólmsá and a smaller fraction of Ellidavatn since the evaporation is so fast.

The abovementioned scenarios are related to accidents at sites 2 and 3. These constitute a very small part of the entire stretch so the frequency is quite low. These accidents also pretty much assume that the oil truck drives off one of the bridges and lands in the rivers. This would be even more improbable were it not for the fact that one of the bridges lacks protective rails.

But as can be seen from discussions about accident site 8 in appendix IV, large, and even medium, accidents at other locations on Sudurlandsvegur can also have serious effects.

15 Risk Evaluation

The Risk evaluation step examines the economic and social issues influencing the selection of control options intended to ensure tolerable levels of risk. The result of the risk characterization is evaluated in this step. Whether or not a specific risk reduction method should be implemented must be an agreement between all affected stakeholders. Therefore this step must mainly be performed by the stakeholders after this report has been produced and distributed among the stakeholders.

In some risk assessments, time and resources may be allocated to evaluate different risk mitigating methods, but that is not the case here. Some risk reduction proposals will nevertheless be presented in section 16.2.

The risk characterization shows that there are clear and present risks. It is up to the stakeholders to decide how to manage these risks; whether they can be tolerated, whether some of the mitigating proposals in chapter 16 are attractive or whether some other measures are to be taken.

16 Integration into risk management

The results from the assessment in this case study must now be integrated into the risk management process. The results from the risk assessment provide the basis for risk reduction and control. Some general strategies for risk reduction and risk control (for SHE-assessment) were presented in section 2.6.

In this case study no deep or advanced analysis is performed of risk reduction measures, see chapter 15. But some proposals to risk reduction measures without consideration to economic aspects are presented in section 16.2. Cost-effect analysis is recommended to the stakeholders before implementation.

But it's important to remember that the most important step towards facilitating effective risk reduction and control is probably an improvement of the communication and organizational factors between the stakeholders, see section 16.1.

16.1 Communication between stakeholders

To optimize protection against accidents on the studied stretch of road, it is important that communication and organizational factors between the relevant parties work well. The involved stakeholders in an accident involving gasoline or diesel on this road are the fire department of Reykjavík (and police), oil transport companies, oil companies and Reykjavik Energy. Especially important now with the new fire protection law (law #75/2000) is the new responsibility of the fire department to respond to environmental hazards following an accident.

There are interdependent expectations from the different parties that can be complicated by the differences in work-culture and behavioral patterns between them:

- The fire department employees are used to working under time pressure, in operative situations and with objective targets. To handle these acute situations they have to think and act fast, ignoring anything that seems irrelevant at first glance.
- The other stakeholders routinely have a more relaxed and analytical work situation.

Therefore a scene of an accident can become something of a cultural collision. To avoid possible complications following this it is vital that the parties begin their cooperation in joint emergency planning at a much earlier stage. Question like the following should be answered well in advance

- Who should be first on the scene of the accident?
- How should the priorities be when it comes to protecting different values?
- Who pays for the rescue work and clean-up?
- Who should have the necessary equipment for treating a discharge of petrol or diesel?
- Who should be responsible for bringing equipment to the scene of an accident?
- Who should/can lead the rescue work?
- Where is the necessary know-how?
- Do the stakeholders possess the right knowledge?
- When should the main responsibility change hand to/from the oil transport company, fire department or Reykjavik Energy?
- Etc.

For a well functioning risk management in this case it is as earlier discussed (sections 5.10 and 15) very important that all parties have a functioning management system and that the individual management systems have been synchronized between the stakeholders in the relevant areas.

To lead the work forward it is necessary for the involved parties to have meetings so they learn more about respective knowledge and preferences. Some examples of what should be discussed:

- Liabilities
- Planning
- Emergency management
- Suitable opportunity for practice
- Equipment
- etc.

A good manner to discuss these points is to work with an accident in five phases along a time-line. Different types of measures (see section 2.5) are connected to different phases and the responsibility in the different phases can be distributed between involved parties. Figure 16-1 describes the five phases, which are divided up in before, during and after an accident.

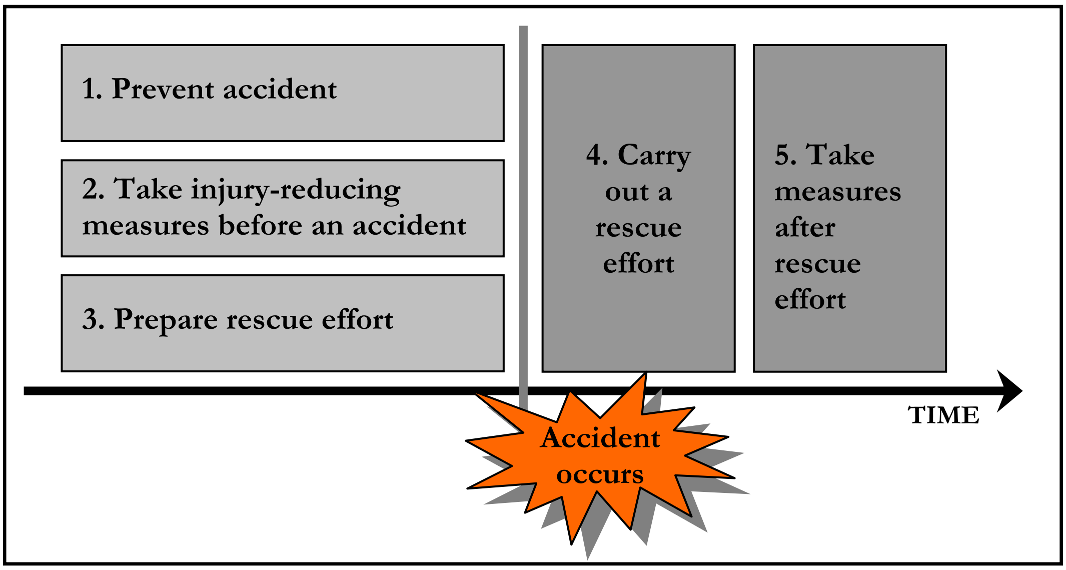


Figure 16-1 Accident's five phases, a way to structure work with protection against accidents /Räddningsverket 1999/

The three first phases can be at work parallel and these phases should be well planned. Experience shows that it is very cost-efficient to allot large resources to prevention of accidents.

A combination of well-planned protective measures in all five phases is necessary in order to maintain an adequate level of protection.

Table 16-1 explains the five phases with some examples for the actual situation.

Phase	Description	Support words	Example of measure
1. Prevent accident	Measures that aim to decrease the probability for an accident	Eliminate, isolate, separate, modify, instruct, plan, act, cooperate and construct	Management system, chauffeur training, road improvements, continuous maintenance of trucks, decrease quantity of transports, etc.
2. Take injury-reducing measures before an accident	Measures that aim at decreasing the consequences of an accident	Isolate, separate, modify, instruct, plan, organize, construct, and detach	Protection barriers, tightening of ditches, way-barrier, right rescue equipment
3. Prepare rescue effort	Measures that aim to facilitate for private persons, owner and/or possessor, rescue service or other organ to realize a rescue effort	Equip, train, plan construct, dimension, modify, instruct and cooperate	Contribution planning, cooperation agreement, liabilities, equipment, suitable opportunity for practice, warning system, etc.
4. Carrying out a rescue effort	Measures carried out by owner, possessor, and rescue service, which aim to interrupt an ongoing accident, reduce harm and consequences	Rescue, warn, alarm, extinguish, restrict and cut off	Stop or decrease the discharge. Confine, pump up, control the flow, etc. If ignited it may be best to allow a controlled burning to decrease health & environmental damage
5. Take measures after rescue effort	Measures taken after a finished rescue effort in order to clear up, restore and prevent a new accident.	Relieve, restore, evaluate and collect knowledge	Sanitation for acute and chronic effects, guard the area and the water, accident investigation, etc.

Table 16-2 The five phases of an accident with some examples for the actual situation /Räddningsverket 1999/

The management systems are mentioned in the table 16-2 in the prevention of accidents phase. They are assuredly important in this phase but they are equally important in the later phases, especially that the different stakeholders' management systems are synchronized so that the efforts of the different stakeholders can be smoothly coordinated.

16.2 Proposal to risk reduction measures

As mentioned above we only present some proposals of risk reduction measures without considerations to economic aspects. Some of the factors below may already be satisfactory, rending improvements superfluous. Many of the measures have already been mentioned in the assessment, e.g. in table 16-2, so this section is partly a summary.

Below follow some examples of measures to reduce the probability and/or consequences of an accident.

- Synchronized and individually well designed (and implemented) management systems in the SHE field for all stakeholders.
- Protective rails/barriers on road, especially on bridges
- Make threatened wells redundant, in order to reduce vulnerability of water supply system
- Forbid all heavy transports on Heidmerkurvegur and adjacent small roads upstream of wells, unless pre-approved
- Road diversion, see e.g. new road proposed in figure IV-2, appendix IV
- Clearer signs when entering sensitive area and water protection area, with relevant information on how to report an accident.
- Similar signs on the part of Sudurlandsvegur that can affect the water protection area
- Increasing information to the distributors and chauffeurs about the risks with transports through sensitive areas
- Modify the area around the road so that a spill can be halted and collected before infiltrating the groundwater
- Continuous maintenance of trucks
- Broaden road
- Chauffeur training and awareness

At last, the most important and effective measure is improved communication between the stakeholders, establishing of trust and finally cooperation and coordination of management systems.

One example is the material question. The fire department has only recently been given the responsibility of responding to environmental threats following accidents. They therefore lack the necessary material to facilitate this. The oil companies have most of the necessary material but they have no training, or authority, for swift response. Some sort of cooperation, and joint training operations, are obviously recommendable.

Regardless of possible cooperation concerning oil transport accidents, the fire departments must have constant access to material for absorbing, capsulating and pumping (spark-free) liquid hazardous material, since accidents where the oil distribution companies have no responsibility are quite possible. This could also partly be solved through improved cooperation and lending/leasing of material.

17 Discussion and conclusions

17.1 Part I: Methodogy

Much time has been spent on how to present and estimate the risks, which is presently an underdeveloped discipline in the fields of risk analysis for health and environment. This work is hopefully a step in the right direction for to decide how health and environmental risks can best be estimated. To make progress more assessments of this kind need to be performed, so that comparison can be done. The methodology in chapter 6 has according to the authors' opinion worked quite well.

The framework of the methodology, and the case study, shows that other aspects than economical can be included in operational decisions, e.g. whether oil transports should be performed by truck or boat.

The general methodology is produced considering hazardous material transports on roads, but it is nevertheless quite general, and can easily be modified to apply to a wide range of risks of any kind of accident.

Some points:

- The methodology works rather well in this kind of risk assessment.
- Accidents involving hazardous material transports demand a well working communication between stakeholders.
- The knowledge of the health and environmental risks following accidents needs improvement.
- Coordination of management systems is the best way to go for efficient risk management.

17.2 Part II: Case Study

Since the case study is very extensive, the depth of some moments in the assessment became regrettably small. When we now look back on the case study, it would probably have been wise to focus on either health or environmental risks for the analyzed stretch. But the objective was to fully apply the methodology in chapter 5 on an object, which led to this broad approach.

When the project started we had no presentiment that the data collection on how petroleum products effects health and environmental would prove so difficult. This was naturally not the only problem, we have had to introduce or accept several restrictions during the process that where not foreseen at the beginning.

One restriction concerns the simulations of pollutant distribution via ground water. Since the simulation had to be carried out by other party (Vatnaskil Consulting Engineers in Reykjavík), the adaptation possibilities were severely restricted. Another difficult problem was how to calculate the correct frequency/probability for exposure. A third problem was the lack of data (at least experienced by the authors) on similar accidents, especially in Iceland with its tiny population.

The case study may very well be helpful to someone else, both the successful, and maybe just as importantly, the less successful parts. Some aspects of the assessment have to be adjusted for future objects since the circumstances in Iceland are rather unique, but the headlines in the methodology should remain relatively intact.

Despite the overgrown scope and other problems in this case study, it is possible to arrive at some conclusions:

- The frequency calculations for environmental risks are incomplete; this is a field that warrants further work. But the consequences, combined with qualitative frequency estimations, nevertheless justify some mitigating measures.
- The health (water quality) risks on the analyzed stretch are not negligible.
- Concerning the water-quality issue the conclusion is rather obvious: The risk that an irredundant well is fouled must be kept as close to zero as possible.
- Given the fact that the populations of salmon and char are already on a down slope, the risk that irreversible damage can follow an oil transport accident is apparent.
- The economic and social consequences can be large if the water protection area is badly damaged by an oil spill. For the surface water (environmental risks) the consequences are probably less in monetary valuation, but the effects may be irreversible.
- The stakeholders' communication, and in some cases trust, need improvement.
- Their management systems, especially emergency plans, need improvement and coordination with each other.

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Appendix I – Chemical description

- with toxicological data

1. Introduction

In this appendix a description of the chemicals analyzed in this report is given. Tables describe the physical and chemical properties and this information is used in several moments in this report. This appendix also presents toxicological data for the effects assessment in the case study.

The chemicals in this report are gasoline and diesel. Since these two chemicals are complex mixtures of different carbohydrate compounds with different chemical and physical properties it is necessary to choose some specific elements of gasoline and diesel to study.

The choice of elements is made in consideration of a report from Naturvårdsverket (the Swedish environmental protection agency) and the Swedish Petroleum Institute: *Förslag till riktvärden för förorenade bensinstationer*. Material from the oil companies and the oil distribution company (ODR) has also been helpful in the choice of elements, as well as in the actual effect assessment. Discussions with several experts have also been important in this subject.

The toxicity data for the specific elements are the foundation for the effect assessment. More about the effect assessment can be found in chapter 5.4 in the report.

1.1 Sources

To find exact data about gasoline and diesel is hard because the mixture of elements can vary a lot depending on the origin of the crude oil and the differences in refining processes. Regardless of these differences, the sheer complexity of these chemicals makes comprehensive data scarce. Different sources have been used to get a sufficient number of information.

In the following tables information has been gathered from:

/1/ Räddningsverket, *Räddningsverkets informationsbank, RIB, Version 3.4.00,* Statens räddningsverk, Sweden, 2001

/2/ Svenska Brandförsvarsföreningen, *Farligt Gods Version 2001:6*, Stockholm, Sweden, 2001

/3/ Prevent AB*, Om kemiska ämnen, Version 8.0*, 2001

/4/ Product paper, Identification of the substance/preparation, ESSO, Belgium, 1996-11-06

2 Gasoline

Gasoline is a complex mixture of hydrocarbons with several different functional groups, see chapter 4 below.

Table I-1 presents some useful information about gasoline and the most important physical and chemical data. Several of the properties like e.g. the viscosity are highly temperature dependent, although the sources often only give a point estimate.

Appearance:	Clear, green or red liquid	/4/	**Fire class**	1	/3/
Smell:	Pungent petroleum odour	/4/	**ADR-class**	3, 3 b)	/4/
Melting point:	< -60 ^{0}C	/2/	**Hazard nr:**	33	/3/
Boiling point:	25-215 ^{0}C	/4/	**UN-nr:**	1203	/4/
Limits of flammability:	1 to 7 vol %	/4/	**CAS-nr:**	86290-81-5	/2/
Flash point:	-40 to -30 ^{0}C	/1/	**EG-nr:**	289-220-8	/2/
Auto ignition temp. :	450 ^{0}C	/4/	**Customs-nr:**	2710	/3/
Density:	700-800 kg/m^3	/2/	**Index-nr:**	649-378-00-4	/2/
Viscosity:	Ca 1 cSt	/2/			
Vapor pressure:	90 kPa (38°C)	/4/			
Solubility:	Sparingly soluble in water (0,006 weight %). Soluble with many organic solvents	/2/			

Table I-1 Physical and chemical data for gasoline

Table I-2 presents some toxicological data for gasoline.

Hygienic limit (NGV, exposure during one workday):	250 mg/m^3	/3/
Hygienic limit (KTV, expusure during fifteen minutes):	300 mg/m3, ca 70 ppm	/2/
Perceptibility limits:	300 ppm	/2/
Bluegreenalgae (Anabaena sp) LOEC:	2,9 mg/l	/2/
Crayfish (Daphnia sp.) (2d): LC_{50}:	4,9 mg/l	/2/
Guldid LC_{50}:	40 mg/l	/3/
Fish (96h) LC_{50}:	82 mg/l	/3/
Daphnia (48h) EC_{50}:	170 mg/l	/3/
Algae (72h) IC_{50}:	19 mg/l	/3/
Toxicity for inhalation (4 h), rat LC_{50}:	10 mg / l	/1/
Toxicity for oral intake, rat LD_{50} :	92 000 mg/kg (body weight)	/1/
Toxicity for dermal absorption, rabbit LD_{50}:	5 000 mg / kg	/1/
Biochemical oxygen consumption (BOD):	0,08 g BOD / g	/1/
Carcinogenic:	Yes	/3/

Table I-2 Toxicity data for gasoline

3 Diesel

Diesel is also a complex mixture received through distillation of crude oil. Diesel contains more heavy hydrocarbons than gasoline, especially C9 to C20. Diesel contains several substances that are, or are suspected to be, carcinogenic e.g. benzene, Polynuclear Aromatic Hydrocarbons and formaldehyde.

Table I-3 presents some useful information about diesel and the most important physical and chemical data. Once again temperature dependency is not always accounted for.

Appearance:	Clear light coloured liquid	/4/	**Fire class**	3	/3/
Smell:	Petroleum hydrocarbon odour	/4/	**ADR-class**	3, 31 c)	/4/
Melting point:	-		**Hazard nr:**	30	/3/
Boiling point:	180 - 390^{0}C	/4/	**UN-nr:**	1202	/4/
Limits of flammability:	0,5 to 5,0 vol %	/4/	**CAS-nr**	68334-30-5	/3/
Flash point:	55 ^{0}C	/4/	**EG-nr**	269-822-7	/3/
Auto ignition temp. :	250 ^{0}C	/4/	**Customs-nr:**	2710	/3/
Density:	Ca 833 kg/m3	/2/	**Index-nr:**	649-224-00-6	/3/
Viscosity:	2 cSt	/2/			
Vapor pressure:	< 0,3 kPa (20°C)	/4/			
Solubility:	10 mg/l	/3/			

Table I-3 Physical and chemical data for diesel

Table I-4 presents some toxicological data for diesel.

Hygienic limit (NGV):	350 mg/m^3	/3/
Pronounced odor:	100 ppm	/1/
TEEL 1: (Temporary Emergency Exposure Limit, feel slightly ill at ease)	100 mg/m3	/1/
TEEL 2: (Temporary Emergency Exposure Limit, no grave injury arises)	500 mg/m3	/1/
TEEL 3: (Temporary Emergency Exposure Limit, no fatality)	500 mg/m3	/1/
Fish (96h) LC_{50}:	100 mg / l	/1/
Fish (96h) LC_{50}:	54 mg/l	/3/
Algae (72h) IC_{50}:	20 mg/l	/3/
Toxicity for oral intake, rat LD_{50} :	7 500 mg / kg	/3/
Toxicity for dermal absorption, rabbit LD_{50}:	4 150 mg / kg	/1/
Carcinogenic:	Yes	/3/

Table I-4 Toxicity data for gasoline

4 Effects values for water quality (health assessment)

In the effect assessment for health and environment it is necessary to look at some specific elements in gasoline and diesel.

Naturvårdsverket (Environmental Protection Agency) in Sweden (NVV) has produced recommended reference values for contaminated groundwater in the vicinity of gas stations. These values are presented in table I-5.

Substance	Recommended Reference Value, RRV (mg/l)
Nonpolar aliphatic hydrocarbon	0,1
Total extraction of aromatic compounds	0,1
Benzene	0,01
Toluene	0,06
Ethyl benzene	0,02
Xylene	0,2
Carcinogenic PAH (benzanthracene, benzpyrene, etc)	0,0002
Remaining PAH (naphthalene, acenaphylene, anthracene etc)	0,01
MTBE (Methyl Tert-Butyl Ether)	0,05
Lead	0,01
1,2 – dichloroethane	0,03
1,2 – dibromomethane	0,001

Table I-5 Recommended reference values from Naturvårdverket in Sweden

Several of the experts that have been consulted concerning at which concentration diesel or gasoline can be expected to damage water quality have claimed that 0.1 mg/l is a reasonable limit. Any concrete references for this opinion have regrettably not been given, but considering e.g. the RRV of MTBE (table I-5) and the fact that the MTBE content of at least gasoline can be up to 10%, the RRV of 0.05 mg/l divided by 0.1 motivates 0.5 mg/l. This reference value is for water in the environment in large, not for water actually intended directly for human consumption. From conservatism standpoint 0.1 mg/l is reasonable, but ideally further motivation would have been found.

5 Effect values for environmental assessment

5.1 Gasoline and diesel in general

When it comes to the environmental assessment the difference in evaporation rates between the chemicals becomes very important. In this project the environmental risks are almost exclusively considered when the chemicals are distributed with the surface water. Gasoline is much more prone to evaporate (more volatile) than diesel, as is clearly implied by the difference in boiling points and vapor pressures in the tables above. Therefore diesel will be around to have effects long after the gasoline is "gone with the wind".

Sedimentation is unlikely to be a major factor for any of the two chemicals due to their low density compared to water. Adhesion to suspended fine sediment particles and subsequent sedimentation with these is possible but will only account for the fate of a fragment of the release.

The low viscosity of both chemicals means that they are readily dispersed into the water in turbulent circumstances, i.e. in lake Ellidavatn when winds exceed 3 m/s or in the more turbulent parts of the rivers. The low viscosity also implies that adhesion to the river/lake banks will not be a dominant factor.

Petroleum products are not among the most acutely toxic chemicals that man utilizes, but the sheer volumes transported are unique in our chemical handling. Of the oils, diesel is considered among the most toxic to aquatic life forms. This fact, in combination with the fact that it remains in the water for a much longer time than gasoline, makes diesel the larger environmental hazard of the two.

Studies have shown that fish can be tainted and rendered inedible after being exposed to diesel in their environment for some weeks. This is due to the fact that several components of diesel have high BCFs and are readily bioaccumulated./NOAA, (factsheet on small diesel spills)/

No specific values of toxicity were found for salmon, char or trout, but in general the concentration of hydrocarbons has to exceed 10 mg/l to be acutely toxic for adult fish.

Acute fatalities in juvenile fish and larvae occur when the concentration exceeds 1 mg/l.

If the concentration exceeds 0.01 mg/l (10 ppb) abnormal fish spawns are produced and hatching can be delayed.

Already at 0.1 µg/l (0.1 ppb) chromosome abnormalities have been experimentally demonstrated in laboratory conditions, but there is no evidence of similar genetic damage to natural fish populations affected by oil spillages.
/O'Sullivan et al 1998/

5.2 Specific components of gasoline and diesel

In this effect assessment three characteristic components are chosen to represent diesel and gasoline.

These are:

- Anthracene

- Benzene
- MTBE

These three have been chosen since they give rise to harmful effects and they are also common chemicals in gasoline and diesel.
Anthracene: up to 0.02% in diesel
Benzene: up to 1 % of gasoline
MTBE: up to 10 % of gasoline

Aquatic toxicity for these three chemicals is presented in table I-6.

Anthracene		Benzene		MTBE	
PNEC (EU):	0.000019 mg/l	PNEC (EU):	0.017 mg/l	NVV RRV:	0.05 mg/l

Table I-6 PNEC and RRV values for selected components. /Klein et al 1999/

These PNEC values have actually been produced with crustaceans as the target organisms, but in lack of other data they are utilized here.

Appendix II – Hazard estimation method

- index-method for hazard identification

1 Introduction

This appendix describes a method for hazard identification. The method is an index method for environmental accidents. It is a very rough tool for analysis but it is a good starting point for qualitative analysis to see whether it is motivated to continue the risk assessment using a more quantitative method. This method can also indicate which scenarios that should be chosen in the further analysis.

This concern is mainly acute effects on the aquatic and terrestrial environments. The probability of an accident is not considered in this index method. Of course the probability of an accident is a concern in the hazard identification and should therefore be involved in the choice of further analysis and scenarios.

The index methodology in this appendix is from /FOA 1998/. Since the model is designed for Swedish circumstances, some modifications must be made to adapt to Icelandic circumstances. The method has many simplifications but they are necessary in order to get a reasonably quick answer.

2 Framework for environmental accident index

Data for the following categories needs to be entered into the index method:

1. Acute toxicity for water-living organisms [To]
2. Transported quantity of chemical [Qu]
3. Viscosity [Vi]
4. Water-solubility [So]
5. Surrounding's characteristics [Su]

Through combining points from the different categories a summarized indication of the chemical's potential to harm the environment is achieved. How the different parameters result in points is described below. The environmental accident index utilizes the following equation:

$$\text{Index} = \text{To} \times \text{Qu} \times [\text{Vi} + \text{So} + \text{Su}] \qquad \text{[equation II-1]}$$

2.1 Acute toxicity for water-living organisms [To]

The point contribution for the chemical's acute toxicity is described in table II-1 below.

Acute toxicity (LC_{50} or EC_{50})	Points
< 1 mg/l	10
1-6 mg/l	8
6-30 mg/l	6
30-200 mg/l	4
200-1000 mg/l	2
>1000 mg/l	1

Table II-1 Points for the chemical's acute toxicity

2.2 Transported quantity of chemical [Qu]

The point contribution for the transported quantity of the chemical is described in table II-2 below.

Transported quantity of chemical	Points
>500 ton	10
50-500 ton	7
5-49 ton	5
0,5-4,9 ton	3
<0,5 ton	1

Table II-2 Points for the transported quantity of chemical

2.3 Viscosity [Vi]

The point contribution for viscosity is described in table II-3 below.

Viscosity	Points
<0,5 cSt	10
0,5-4,4 cSt	7
4,4-4,7 cSt	5
47-300 cSt	3
>300 cSt	1
solid material	0
unknown viscosity	4

Table II-3 Points for the viscosity

2.4 Water-solubility [So]

The point contribution for water-solubility is described in table II-4 below.

Water-solubility	Points
>90 weight-%	5
25-90 weight-%	4
5-25 weight-%	3
1-5 weight-%	2
<1 weight-%	1
Dissolves in water	5

Table II-4 Points for the water-solubility

2.5 Surrounding characteristics [Su]

The surrounding characteristics consist of four parameters:

P1: Distance to nearest well, lake or watercourse *table II-5*
P2: Depth to groundwater *table II-6*
P3: Direction and flow of groundwater *table II-7*
P4: Hydraulic conductivity *table II-8*

To obtain an index for the surrounding's characteristics these four parameters must be determined and summed up (P1+P2+P3+P4 => [Su]). How this is done is explained in the following tables; II-5 to II-8.

The first parameter, distance to nearest well, lake or watercourse, is estimated according to table II-5.

Meters	0-10	10-20	20-35	35-50	50-75	75-150	150-300	300-1000	1000-2000	>2000
Points	9	8	7	6	5	4	3	2	1	0

Table II-5 Points for the distance to nearest well, lake or watercourse

The second parameter, depth to the groundwater, is estimated according to table II-6.

Meters	0-0,2	0,2-1	1-3	3-5	5-7	7-12	12-20	20-30	30-60	>60
Points	9	8	7	6	5	4	3	2	1	0

Table II-6 Points for the depth to groundwater

The third parameter, direction and flow of the groundwater, is estimated according to table II-7.

Terms	The groundwater flows into a well, lake or watercourse	Horizontal groundwater surface	No well, lake or watercourse within 1 km in the direction of the groundwater flow.
Points	5	1	0

Table 7 Points for the direction and flow of the groundwater

The fourth parameter, hydraulic conductivity, is estimated according to table II-8.

Thickness	**Points**					
	Cracked rock or gravel	**Sand**	**Moraine**	**Silt**	**Clay**	**Frozen ground**
> 30 m	9	8	6	4	0	0
25-30 m	9	7-8	5-6	3-5	0-1	0
20-25 m	9	7-8	5-6	3-5	0-2	0
15-20 m	9	7-8	5-7	3-6	0-3	0
10-15 m	9	7-9	5-8	3-7	0-4	0
3-10 m	9	7-9	6-8	4-8	1-6	0
<3 m	9	7-9	6-9	4-8	2-8	0

Table II-8 Points for the hydraulic conductivity

The point from these four tables II-5, II-6, II-7 and II-8 (P1,P2,P3,P4) are added together and the point contribution for the surrounding's characteristics is estimated as table II-9 below describes.

Surrounding's characteristics *(the sum from tables II-5 through II-8)*	Points
> 25	10
25-20	7
20-15	5
15-10	3
<10	1

Table II-9 Points for the surrounding's characteristics (the sum from table II-5 to II-8)

2.6 Evaluation of index-number

The final index-number (from eq. II-1) is compared to guidelines, which assert whether it is motivated to continue the analysis using some more quantitative method. The table below shows how the index-number should be interpreted.

Index sum	Necessary depth of analysis
1-100	Hazard estimation
100-500	At least the first steps of a further investigation (semi quantitative/quantitative risk analysis)
> 500	Further investigation (semi quantitative/quantitative risk analysis)

Table II-10 Evaluation of environmental accident index

3 Application of environmental accident index on case study

In chapter 9 of the case study, Hazard identification, it is necessary to first conduct a rough analysis. In the case study the methods described in this appendix are used.

The aim of this index method is to quickly see how big the consequence can be and whether it is necessary to analyze the risks with a more quantitative method. Since some of the parameters in the index vary a lot depending on which part of the analized stretch is considered, it is wise to calculate one worst case and one best case scenario.

The information on the chemical properties of gasoline and diesel is taken from *Appendix I - Chemical description*. This gives the following parameter values:

Parameter		Petrol		Diesel	
Acute toxicity	**[To]**	IC_{50} Algae 72h: 19 mg/l	**6**	IC_{50} Algae 72h: 20 mg/l	**6**
Transported quantity	**[Qu]**	32 tons	**5**	32 tons	**5**
Viscosity,	**[Vi]**	1 cSt	**4**	2 cSt	**4**
Water-solubility	**[So]**	0,006 weight %	**1**	10 mg/l	**1**

Table II-11 calculation of parameters; To, Qu, Vi and So

Surrounding's characteristics [Su] are determined from the four parameters and they vary a lot depending on were the accident occurs. Table II-12 describes the surrounding's characteristics for a worst case and a best case scenario.

Parameters		Worst case		Best case	
Distance to nearest well, lake or watercourse	**P1:**	0 m	**9**	1000 m	**2**
Depth to the groundwater	**P2:**	0 m	**9**	20 m	**3**
Direction and flow of the groundwater	**P3:**	Towards wells	**5**	Towards wells	**5**
Ground infiltration tendency	**P4:**	Cracked Lava	**9**	Uncracked lava	**0**
P1+P2+P3+P4		**32**		**10**	
Surroundings condition	**[Su]**	**10**		**3**	

Table II-12 Calculation of surrounding's characteristics, worst and best case scenario

Since gasoline and diesel have the same values in table II-11 it is not necessary to perform the calculations for both chemicals. The environmental accident index is calculated according to [equation II-1].

The results from the two calculations, a worst case and a best case scenario, are presented in table II-13 with recommendations on analysis necessity.

Calculation 1 & 2	**Sum environmental accident index** Index = To x Qu x [Vi + So + Su]	**Necessary depth of analysis**
Worst possible passage	6 x 5 x [4 + 1 + 10] = 450	Further investigation with a more quantitative method
Best possible passage	6 x 5 x [4 + 1 + 3] = 240	Further investigation with a more quantitative method

Table II-13 Results from the index method, hazard estimation

The index method clearly shows that this environmental hazard should be analyzed with a more quantitative method.

Appendix III – Frequency calculation

- for spill of gasoline/diesel from hazardous material transport or any heavy transport with larger motor fuel tank

-with uncertainty analysis using @Risk

1 Background

To understand how frequent or how probable an accident is on the road going from Reykjavík to the south of Iceland (Suðurlandsvegur) some calculations have to be made. In order to perform these calculations, some data from different local authorities and companies are needed.

The calculations concerning hazardous material transport accidents principally use values from the Iceland Road Authorities and from a Swedish publication jointly produced by the road and rescue authorities:
Vägverket (VV) *Publ 1998:064, Förorening av vattentäkt vid vägtrafikolycka,* which is a continuation from Räddningsverkets (SRV) (1996) guidelines *" Farligt gods –riskbedömning vid transport", Statens väg- och transportforskningsinstitut, VTI – model.*

2 Restrictions

The accident frequency is calculated for the road going from Reykjavík to the south of Iceland (Sudurlandsvegur). The smaller roads to Bláfjöll and the small road in the water protection area in are not calculated, because it was not possible to find any relevant documentation of accidents. When data is incomplete or missing, pattern values are used from VV Publ 1998:064 and the VTI-model.

The accuracy in this calculation depends partly on the possibility to gather appropriate information. The VTI – model has many uncertain assumptions and therefore the calculations should some times be adapted to the actual problem. One way to do this is to use the VV Publ *1998:064,* which is a continuation of the older VTI – model.

Since the model and inputs contain a lot of uncertainty, and in order to get an acceptable final result, an uncertainty analysis has been carried out in the end of this appendix.

When new material becomes available it is possible to update the frequency calculation.

3 Analyzed stretch

The main stretch of road to be analyzed is a part of Sudurlandsvegur, the main road connecting Reykjavík and the south of Iceland, from the end of urban Reykjavík to the Bláfjallavegur-intersection. This stretch is 10,5 km, see figure 7-2 in the report.

4 Basis for the calculations

The described scenes of accident (1,2,3,5,6 & 8) in the report for the road Sudurlandsvegur are divided up in different scenarios that lead to different end events.

Petroleum accidents in this report can arise from either hazardous material transport with gasoline or diesel, or from any heavy transport with a larger motor fuel tank. The two different sources to a petroleum accident are abbreviated according to the following:

Hazardous Material Transport (with gasoline or diesel): **HMT**
Heavy Transport (with larger motor fuel tank): **HT**

These two sources to a petroleum spill can be described in an Event Tree according to figure III-1.

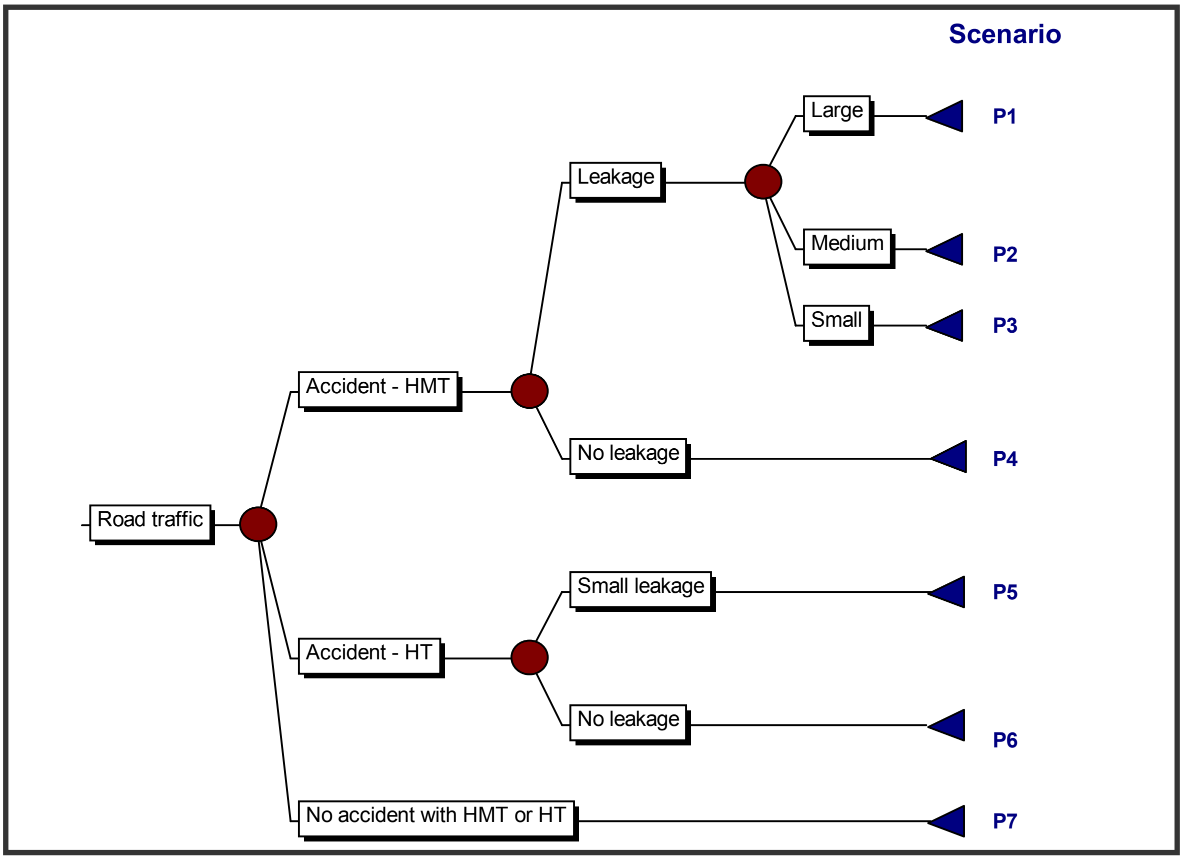


Figure III-1 Event tree for accidents with petroleum products from HMT or HT

The size of the spills in the scenario P1-P7 are as already described in the report in chapter, 9.2.2 Chosen scenarios from the hazard identification. Table III-1 presents the different amount of spill for the different scenarios.

Scenario:	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
Metric tons:	32	4	0.2	0	0.2	0	0

Table III-1 Amount of spill for the different scenarios

The rest of the basic information and statistic's necessary for the estimation are gathered from the following sources:

- Nr:1613 III-Reykjavik, Accident analysis 1996-1999 , Road Authorities in Iceland.
- Interviews with Gestur Gudjonsson at ODR and confirming frequency investigation in cooperation with the fire department in Reykjavík *(number of HMT).*
- Räddningsverket, *Farligt Gods- Riskbedömning Vid Transport- Handbok för riskbedömning av transporter med farligt gods på väg eller järnväg*, Statens räddningsverk, Risk och Miljö avdelningen, Karlstad, Sweden, 1996.
- Räddningsverket, Vägverket, *Förorening av vattentäkt vid vägtrafikolycka, Hantering av risker vid petroleumutsläpp*, Publikation 1998:064, Statens räddningsverk, Risk och Miljö avdelningen, Karlstad, Vägverket, Borlänge, Sweden, 1998

5 Probability calculation for road traffic accident with spill

The methodology to calculate the frequency for each scenario according to the precision tree in figure III-1 follows the methodology in the publication, VV Publ 1998:064.

5.1 Probability of road traffic accident

Probability of road traffic accident with hazardous material transport, $P_{0,\ HTM}$ alternative heavy truck in general, $P_{0,\ HT}$ is calculated according to following formula:

$$P_0 = N \times Q \times L \times 365 \times F \times 10^{-6} \qquad \text{[equation III-1]}$$

Where:

N :	number of transports with petroleum products - or motor fuel tanks on average during 24 hours.
Q :	accident quota [number/ million vehicle kilometers]
L :	length of analyzed stretch of road [km]
F :	average number of vehicles involved in an accident

The calculations are carried out according to the following framework:

N: Number of transports with petroleum products - or heavy transports (motor fuel tanks) on average every twenty-four hours. $\mathbf{N}_{HMT}$: *number of Hazardous material transports with gasoline or diesel during 24 hours* and $\mathbf{N}_{HT}$: *heavy transports during 24 hours.*

In an interview with Gestur Gudjonsson at ODR an estimate of 4-8 HMTs a day was given for the stretch in question. A frequency investigation performed in cooperation with the fire department in Reykjavík resulted in the count of 5 HMTs one day and 7 HMTs another day. This supports an average of 6 HMTs a day. But the transports are almost exclusively performed during the weekdays so this number has to be reduced by a factor of 5/7. To maintain some conservativism the result is rounded upwards to 5 HMTs a day.

The Icelandic Road Authorities estimate that 9 % of the total traffic on the stretch is heavy transports. The total traffic during 24 hours is estimated from data during the years 1996-1999. Medium value for these years is 5658 vehicles a day.
This gives the following values:

$\mathbf{N}_{HMT} = \mathbf{5}$ /24 h

$\mathbf{N}_{HT} = \mathbf{510}$ /24 h

Q: To get the accident quota Q, we use an accident map (Nr: 1613 III-Reykjavik) for the stretch from the years 1996-99, provided by the Iceland Road Authorities. Q is the number of accidents during one year divided with the number of million kilometers driven that year.
Between the years 1996 - 1999 there occurred 58 accidents on the stretch (excluding accidents with pedestrians, bicyclists and animals). This gives an average accident frequency of 14.5 accidents/year

An average for the number of vehicles during a year between 1996 and 1999 is 5658 vehicles/24h according to figures from the road authorities.
The length of the road stretch is measured to 10.5 km.
This gives the number of million vehicle kilometers to (5658 x 365 x 10,5 x 10^{-6} =) 21,68 million vehicle kilometers/year.
Finally the quota Q can be estimated:

Q = (14,5 / 21,68) = **0,67** accidents per million vehicle kilometers

L: The length of the analyzed road stretch [km] is measured to **L = 10,5 km**

F: We had no data available for the number of vehicles per accident so F is taken from pattern values in VV Publ 1998:064. There one value is given for urban areas and one for rural areas. Since our area is rural F becomes: **F = 1,5**

P_0: Finally the probability each year of a road traffic accident involving hazardous material transport or heavy truck can be calculated according to *[equation III-1]*.

$$P_{0,\,HMT} = 0{,}019$$
$$P_{0,\,HT} = 1{,}96$$

This means that one accident with gasoline or diesel can expected to occur in 50 years and about 2 accident with heavy trucks can expected to occur during one year on this stretch of road.

5.2 Probability of spill following a road traffic accident

The probability of a spill of gasoline or diesel in connection with an accident involving a hazardous material transport or with heavy trucks are estimated with pattern values from VV Publ 1998:064, p17. The values for a spill in event of an accident on a 90-km/h road in a rural area are presented in table III-2:

Types of spill	*Probability of spill,* P_u
Accident with HMT	**0,28**
Accident with HT	**0,028**

Table III-2 Probability of spill in event of an accident on a 90 km/h road in a rural area

In this step is it important to realize that probability of a spill is dependent of the area alongside the road. A determining factor for how big the consequences become is the size of the spill. In this case the spill is assumed to be small, medium or large, se figure III-3. In an accident with heavy trucks, only a small spill can arise since the amount of petroleum is limited to the vehicles fuel tanks. Different probabilities are calculated for different sizes of spill. To estimate the probability of a spill of a certain size some kind of approximations must be done. The foundation for this approximation is the VTI model with the knowledge that the road transport of petroleum products is performed in thin-wall tanks. These calculations use values according to table III-3.

Type of spill (tons)	*Probability (%)*
Small spill of diesel or gasoline: 0,2 tons	**50**
Medium spill of diesel or gasoline: 4 tons	**25**
Large spill of diesel or gasoline: 32 tons	**25**

Table III-3 Probabilities for different sizes of spill in case of a release following a HMT accident

The estimation of the probability of a spill in the event of an accident is laden with uncertainty but the result is best presented and understood as a discrete value. Later in this appendix an uncertainty analysis with sensitivity analysis is performed, which clearly points out the probabilities given for different sizes of spill as a highly sensitive parameter (see chapter 6.2 Sensitivity analysis using @RISK)

5.3 Final probability of scenarios

The calculations above give the frequency for each scenario, P1-P7. See table III-4 below.

Scenario (end events)	*Probability of accident P_0*	*Probability of spill, P_u*	*Probability of size, P_s*	*Final frequency for end event*
P1: large	0,019	0,28	0,25	$1,3 \times 10^{-3}$
P2: medium	0,019	0,28	0,25	$1,3 \times 10^{-3}$
P3: small	0,019	0,28	0,50	$2,7 \times 10^{-3}$
P4: no spill	0	0	0	0
P5: small	1,96	0,028	1	$5,5 \times 10^{-2}$
P6: no spill	0	0	0	0
P7: no accident	0	0	0	0

Table III-4 Calculated probabilities and final frequencies.

5.4 Discussion

Apparently some hundreds of years should elapse between larger spills of petroleum products while 200 liters or so can be expected to be spilt approximately every 20 years. Whether or not this is tolerable depends on several factors, but mainly on the consequences.

The choice of P_s may seem arbitrary and intuition may imply that the probability of a large spill should be lower considering that the tanks are divided up into individual cells. Nevertheless, P_s has actually been toned down a notch for the large spill event from the recommendations in VV Publ 1998:064. If further data can be found somewhere concerning this probability, this may be a good choice for further research.

6 Uncertainty and sensitivity analysis for frequency

Some of the inputs in the frequency calculations for accident with hazardous material transport or any heavy truck accident are very uncertain. An uncertainty analysis has been carried out on the variables with distributions according to following simulation in @Risk. In headlines 6.2 Sensitivity analysis, a sensitivity investigation is performed for the parameters in each scenario.

6.1 Uncertainty analysis using @RISK

In the uncertainty analysis is interesting to see how much the results in table III-4 vary when the distributions alter the input parameters.

Table III-5 below presents the inputs with assigned distributions. Every input receives an expected value and from the distribution picks out the 5, 50 and 95 % percentiles. The (Monte Carlo) simulations are performed with 10 000 iterations. The shaded fields in table III-4 are the result from the uncertainty analysis.

Monte Carlo analysis in @Risk

Inputs:

		Distribution	Expected -value	5 perc%	50 perc%	95 perc%
N_{HMT}	Number of hazardous material transports with petroleum	RiskUniform (3;7)	5,000	3,2	5,0	6,8
N_{HT}	Number of heavy transports (fuel tanks)	RiskUniform (400;620)	510,0	411,0	510,0	609,0
Q	Accident quota [accidents/ million vehicle kilometers]	RiskTriang (0,34;0,67;1)	0,670	0,44	0,67	0,90
L	Length of the analyzed road stretch [km]		10,50	10,5	10,5	10,5
F	Number of vehicles per accident	RiskTriang (1;1,5;2)	1,50	1,158	1,500	1,842
$P_{u, HMT}$	Probability of petroleum spill from HMT	RiskTriang (0,1;0,28;0,46)	0,28	0,157	0,280	0,403
$P_{u, HT}$	Probability of petroleum spill from HT	RiskTriang (0,01;0,028;0,046)	0,03	0,016	0,028	0,040
$P_{s, large}$	Probability of large spill	RiskTriang (0,01;0,25,0,49)	0,25	0,086	0,250	0,414
$P_{s, medium}$	Probability of medium spill	RiskTriang (0,01;0,25,0,49)	0,25	0,086	0,250	0,414
$P_{s, small}$	Probability of small spill	RiskTriang (0,25;0,5,0,75)	0,50	0,336	0,500	0,664

Simulating setting:

Number of iterations	10 000
Model	Latin Hypercube
Random number, Generator seed:	150

Calculation & Result

Probability of road traffic accident with HMT containing petroleum	$P_{0, HMT} = N_{HMT} \cdot Q*L*365*F*10^{-6}$	0,0193	0,0100	0,0185	0,0312
Probability of road traffic accident with HT fuel tank	$P_{0, HT} = N_{HT} \cdot Q*L*365*F*10^{-6}$	1,96	1,16949	1,91711	2,93618
Probability of large spill, with HMT	$P1 = P_{0, HMT} * P_{u, HMT} * P_{s, large}$	**1,35E-03**	**3,37E-04**	**1,18E-03**	**2,98E-03**
Probability of medium spill, with HMT	$P2 = P_{0, HMT} * P_{u, HMT} * P_{s, medium}$	**1,35E-03**	**3,37E-04**	**1,18E-03**	**2,98E-03**
Probability of small spill, with HMT	$P3 = P_{0, HMT} * P_{u, HMT} * P_{s, small}$	**2,70E-03**	**1,03E-03**	**2,46E-03**	**5,27E-03**
Probability of spill, with HT	$P5 = P_{0, HT} * P_{u, HT}$	**5,50E-02**	**2,52E-02**	**5,24E-02**	**9,38E-02**

Table III-4 Uncertainty analysis in @RISK, inputs and results

The uncertainty in scenarios P1, P2, P3 and P5 are presented in distributions in figures III-2 to III-4. Observe that the distributions for scenario P1 and P2 are the same since they have same intervals in the input distributions.

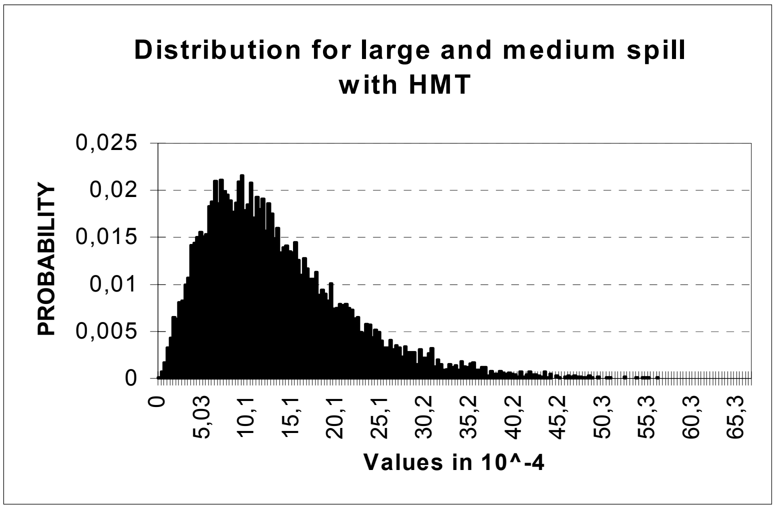


Figure III-2 Distribution for large and medium spill with hazardous material transport, scenario- P1 and P2

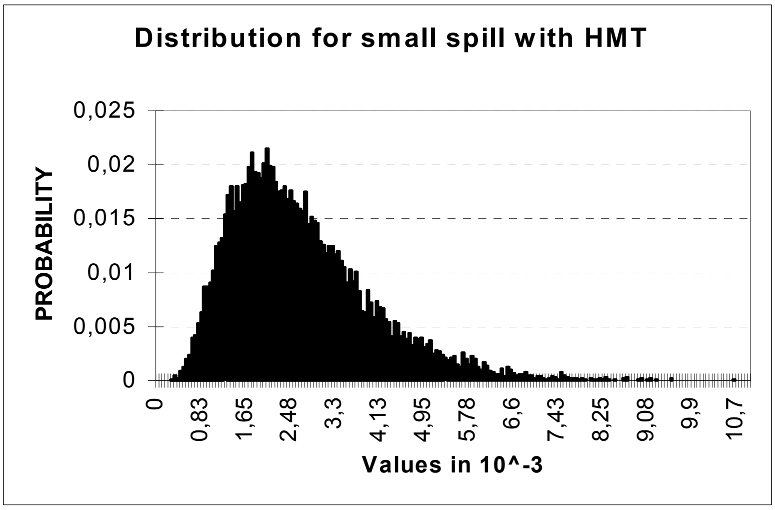


Figure III-3 Distribution for small spill with hazardous material transport, scenario-P3

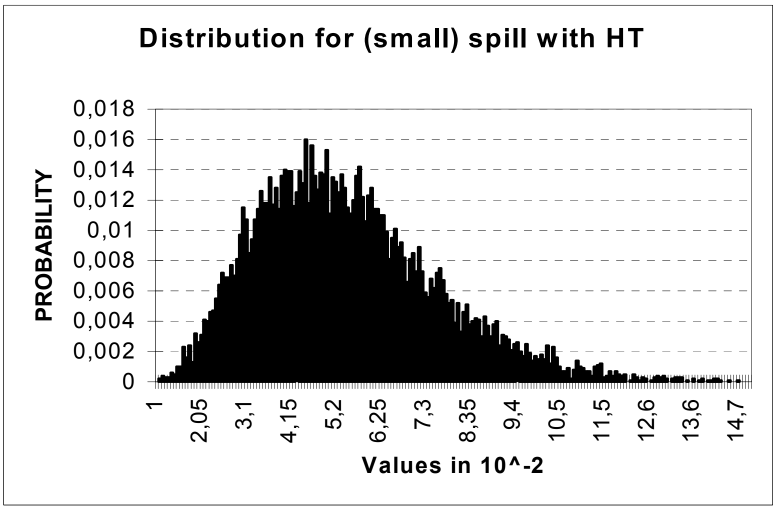


Figure III-4 Distribution for spill with any heavy transport, scenario-P5

6.2 Sensitivity analysis using @RISK

Tables III-5 through III-8 are a sensitivity-analysis for the parameters involved. The size of spill and the probability of spill has generally a large influence on the result. When no values are presented for a specific parameter, they are not involved in the scenario.

Simulation Sensitivities for Expected value of Probability of large spill with HMT			
(From @RISK Simulation of 1a körn.xls- Run on 2002-11-01 at 13:09:09, Simulations= 1, Iterations= 10000)			
Rank	**Parameters**	**Sensitivity (RSqr=0,891525)**	**Rank Correlation Coefficient**
#1	$P_{s, large}$	0,634503	0,680143
#2	$P_{u, HMT}$	0,428839	0,429454
#3	N_{HMT}	0,373331	0,369682
#4	Q	0,328598	0,319465
#5	F	0,224002	0,215641
#6	N_{HT}	-	-
#7	$P_{u, HT}$	-	-
#8	$P_{s, medium}$	-	-
#9	$P_{s, small}$	-	-

Table III-5 Simulation Sensitivities for Expected value of Probability of large spill with HMT

Simulation Sensitivities for Expected value of Probability of medium spill with HMT			
(From @RISK Simulation of 1a körn.xls- Run on 2002-11-01 at 13:09:09, Simulations= 1, Iterations= 10000)			
Rank	**Parameters**	**Sensitivity (RSqr=0,891525)**	**Rank Correlation Coefficient**
#1	$P_{s, medium}$	0,634503	0,680143
#2	$P_{u, HMT}$	0,428839	0,429454
#3	N_{HMT}	0,373331	0,369682
#4	Q	0,328598	0,319465
#5	F	0,224002	0,215641
#6	N_{HT}	-	-
#7	$P_{u, HT}$	-	-
#8	$P_{s, large}$	-	-
#9	$P_{s, small}$	-	-

Table III-6 Simulation Sensitivities for Expected value of Probability of medium spill with HMT

Simulation Sensitivities for Expected value of Probability of small spill with HMT			
(From @RISK Simulation of 1a körn.xls- Run on 2002-11-01 at 13:09:09, Simulations= 1, Iterations= 10000)			
Rank	**Parameters**	**Sensitivity (RSqr=0,9208134)**	**Rank Correlation Coefficient**
#1	$P_{u, HMT}$	0,536329	0,549651
#2	N_{HMT}	0,469495	0,493418
#3	Q	0,410887	0,404182
#4	$P_{s, small}$	0,396313	0,404726
#5	F	0,274605	0,271531
#6	N_{HT}	-	-
#7	$P_{u, HT}$	-	-
#8	$P_{s, large}$	-	-
#9	$P_{s, medium}$	-	-

Table III-7 Simulation Sensitivities for Expected value of Probability of small spill with HMT

Simulation Sensitivities for Expected value of Probability of spill with HT			
(From @RISK Simulation of 1a körn.xls- Run on 2002-11-01 at 13:09:09, Simulations= 1, Iterations= 10000)			
Rank	**Parameters**	**Sensitivity (RSqr=0,9539333)**	**Rank Correlation Coefficient**
#1	$P_{u, HT}$	0,677467	0,682442
#2	Q	0,523045	0,50865
#3	F	0,351539	0,330236
#4	N_{HT}	0,324952	0,318263
#5	N_{HMT}	-	-
#6	$P_{u, HMT}$	-	-
#7	$P_{s, large}$	-	-
#8	$P_{s, medium}$	-	-
#9	$P_{s, small}$	-	-

Table III-8 Simulation Sensitivities for Expected value in Probability of spill with HT

Appendix IV – Exposure estimation

- distribution via groundwater and surface water

1 Introduction

There are two distinct ways of exposure modeled in this report; via groundwater (mainly health risk assessment) and via surface water (mainly environmental risk assessment). Before any effect analysis can be conducted the fate of the release must be assessed. A pollutant will only have direct effects in the locations where it actually occurs. In order to assess effects one first has to determine where, and in what concentration, the chemical will end up after a given time.

1.1 Exposure via groundwater

Vatnaskil Consulting Engineers in Reykjavík have been building and improving their groundwater-model of the surroundings of Reykjavík since the 1980's, which makes their model quite outstanding when assessing transport via the groundwater in the area.

The model environment is Vatnaskil's own software *AQUA 3D,* which solves three-dimensional groundwater flow and transport problems using the Galerkin finite element method. It is designed to simulate both homogeneous isotropic aquifers and inhomogeneous anisotropic aquifers.

As such, this program is similar to a range of other software using finite element methods to solve flow and transport equations, e.g. FEMLAB and ModFlow. The fact that it is designed with Icelandic circumstances in mind makes it extra suitable when dealing with unusual situations like flow over fault lines etc.

The main reason why this approach was chosen is not the software but the groundwater model itself of the area that Vatnaskil has been updating and improving for numerous years. Any modeling work done specifically for this project would have been extremely rudimentary in comparison.

The model could regrettably, but understandably, not leave the offices of Vatnaskil so we defined the scenarios and Vatnaskil ran the simulations in the model. This limited the options of optimizing the choice of accident scenes and simulation times through iteration, but relevant results where nevertheless obtained during the two rounds of simulations that were ordered.

Retention of the chemicals is neglected in the model. This would be a mistake in most parts of the world since the hydrophobic nature of the chemicals would result in substantial retention by organic carbon compounds. In the analyzed area however the groundwater flows in lava surroundings, practically void of any organic material.

1.2 Exposure via surface water

The model of Vatnaskil does not simulate surface water flow and transport; it simply treats surface flow as sinks of groundwater and possible pollutants. Therefore another method had to be found to estimate exposure when the release of petroleum products hit the rivers directly.

Due to the low density (700-850 kg/m^3) of the petroleum products in question, evaporation was considered to be the main way of removal of petroleum from the system. A computer program, *Adios II,* was downloaded from the American National Oceanic & Atmospheric Administration (NOAA). This program was mainly designed for marine releases but it allows for fresh water settings.

2 Exposure via groundwater

Eight of the ten hypothetical scenes of accident result in a release to the groundwater (see figure IV-1). What sizes of release are simulated, and for how long, is described in chapter 9 of the report.

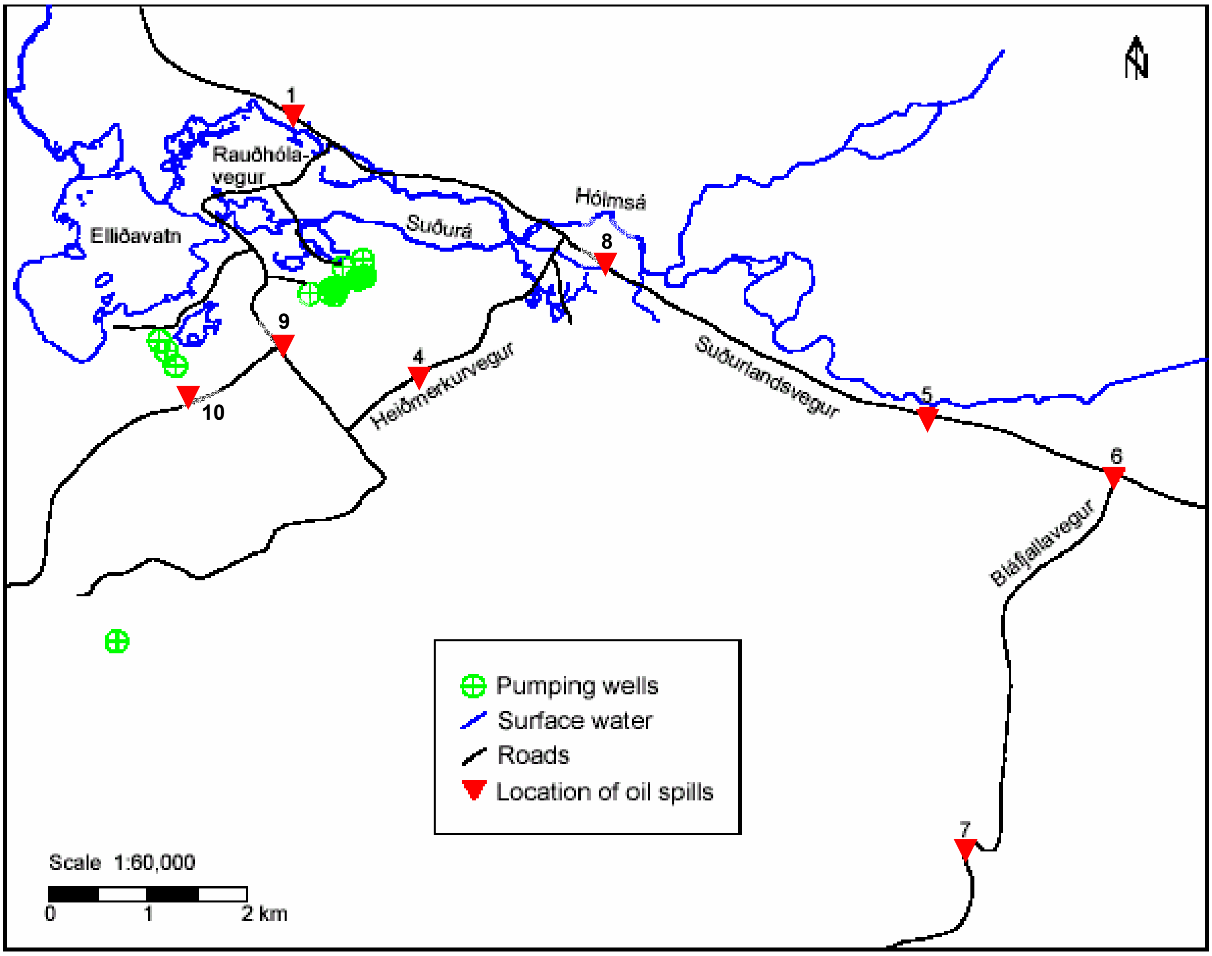
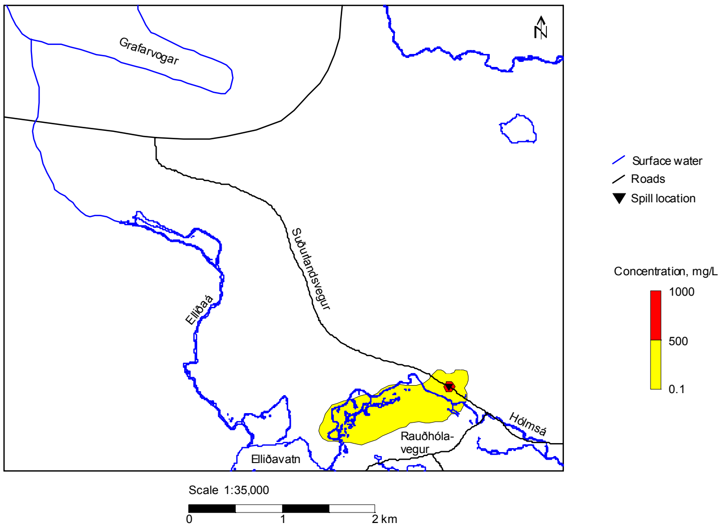


Figure IV-1 Hypothetical scenes of accident where spill infiltrates into groundwater.

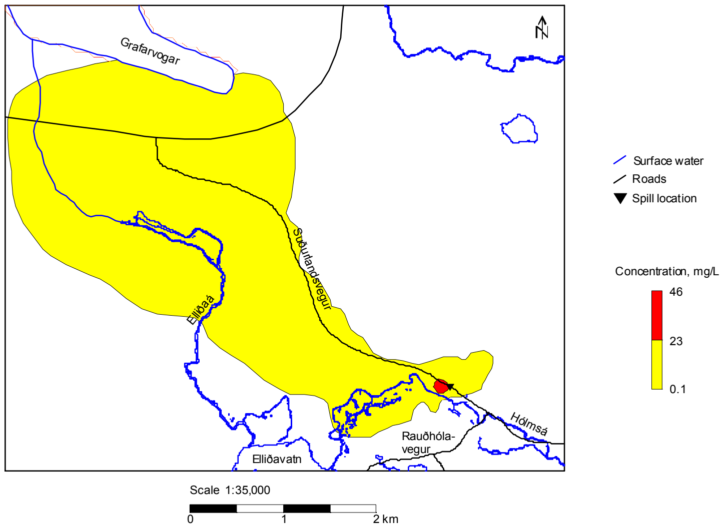
The criteria for the exposure assessment is whether or not the concentration in any of Reykjavík Energy's pumping wells, which supply the citizens of Reykjavík with their drinking water, exceeds 0.1 mg/l. This is a limit where the water is likely to get fouled by smell and/or taste of the petroleum product spilled.

Following are selected graphs from the simulation results with comments. The order in which they are presented (1, 4, 9, 10, 8, 5, 6 and 7) may seem random, but it makes sense geographically since the sites are located further and further away from Reykjavík.

Calculated concentration of pollutants after 7 days
Scenario #1 - 32 tons

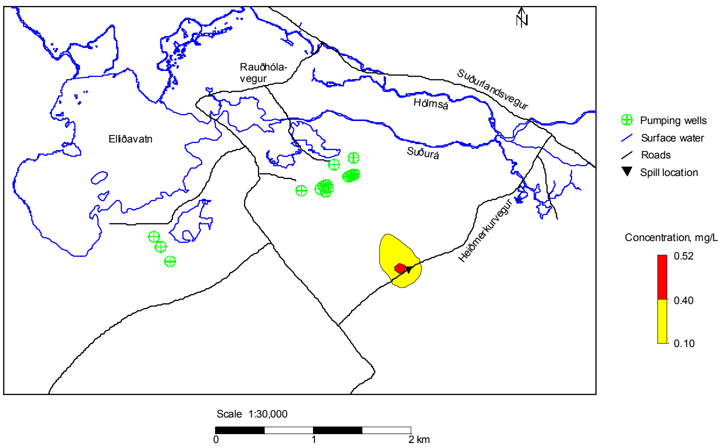


Calculated concentration of pollutants after 365 days
Scenario #1 - 32 tons

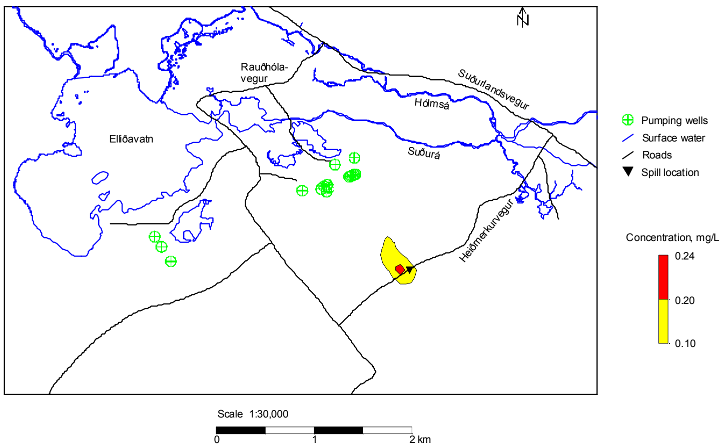


Accident **site 1** does not cause water quality risks for the pumping wells, but adverse environmental effects are probable, especially in the lower parts of the river Hólmsá where the concentration is elevated for at least a full year after the accident. This is likely to at least cause chronic effects, eventually acute effects as well.

Calculated concentration of pollutants after 91 days
Scenario #4 - 0.1 tons

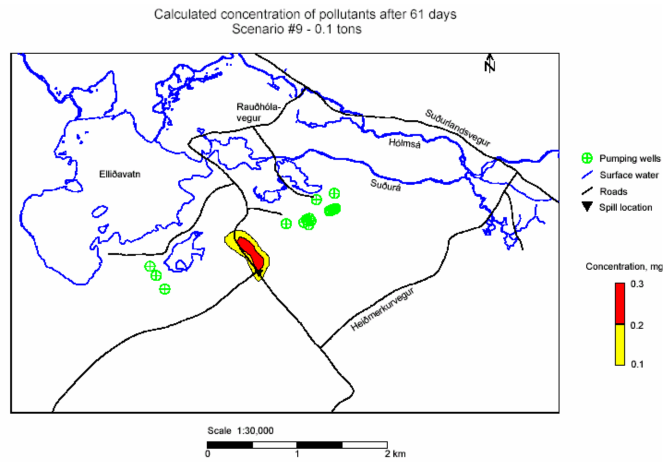


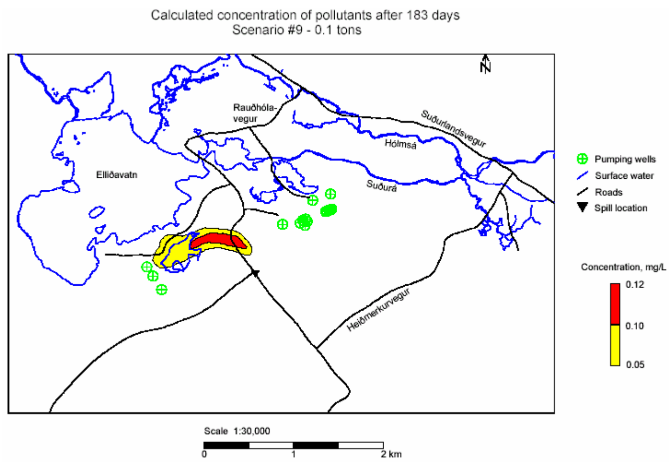
Calculated concentration of pollutants after 183 days
Scenario #4 - 0.1 tons



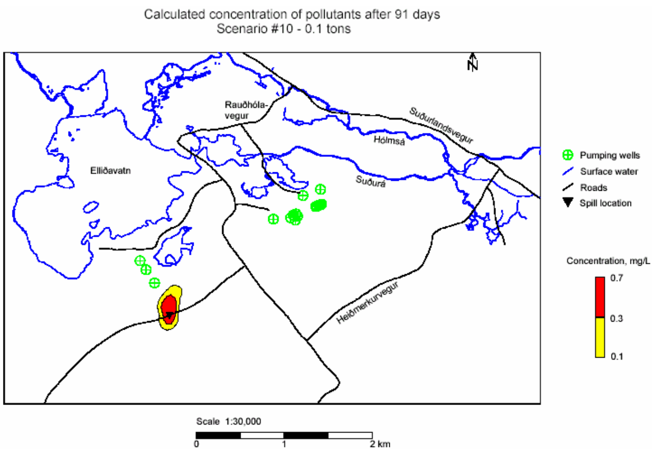
Accident **site 4** does not cause water quality risks, at least not when the release is confined to 100 kg of petroleum (the fuel tank of a large jeep). After three months the dilution is so great that the 0.1 mg/l plume starts shrinking.

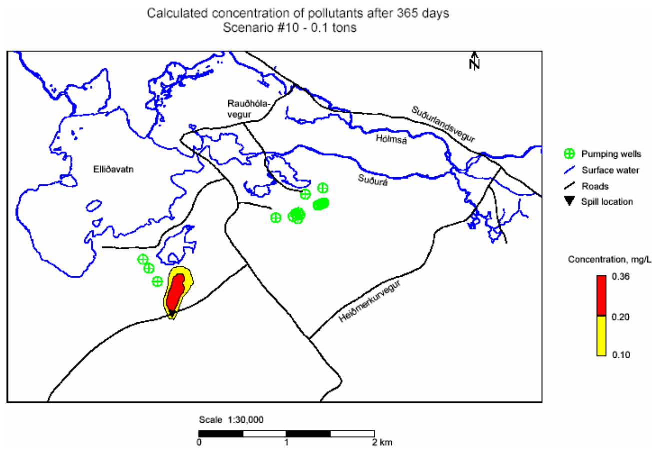
Hazardous liquid transports are not allowed on this road. But when Sudurlandsvegur is blocked by a car accident, traffic tends to redirect itself onto these small gravel roads and there is no guarantee that heavy transports do not follow. We advice that stricter warning signs against all heavy transports be placed at the start of these roads.





At accident **site 9** the graph after two months implies that the plume will pass by the wells. Then after 6 months the plume has turned sharply to the west and heads straight for some of the wells. But by then the dilution has taken its toll, so it is actually the smaller red plume that represents the limit of 0.1 mg/l. If the release is no larger than 100 kg the concentration in the wells will hardly reach the limit value for an accident at this location according to the simulation.





At accident **site 10** the hypothetical accident has regrettably not been placed in the optimal location. The simulation nevertheless indicates that if an accident were to occur a few hundred meters west of position 10, the wells directly south of lake Ellidavatn would indeed be exposed to concentrations above 0.1 mg/l. Further the concentration can be expected to be above the limit for quite some time since the frame on the left is after three months and the one on the right after twelve months.

A possible risk reduction measure is proposed in figure IV-2. But all amplifications of the new road (including during the construction phase) must be considered beforehand.

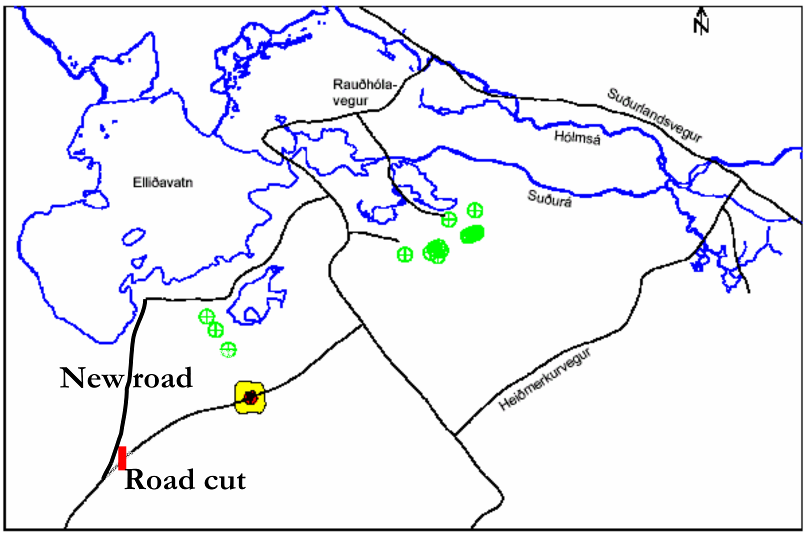
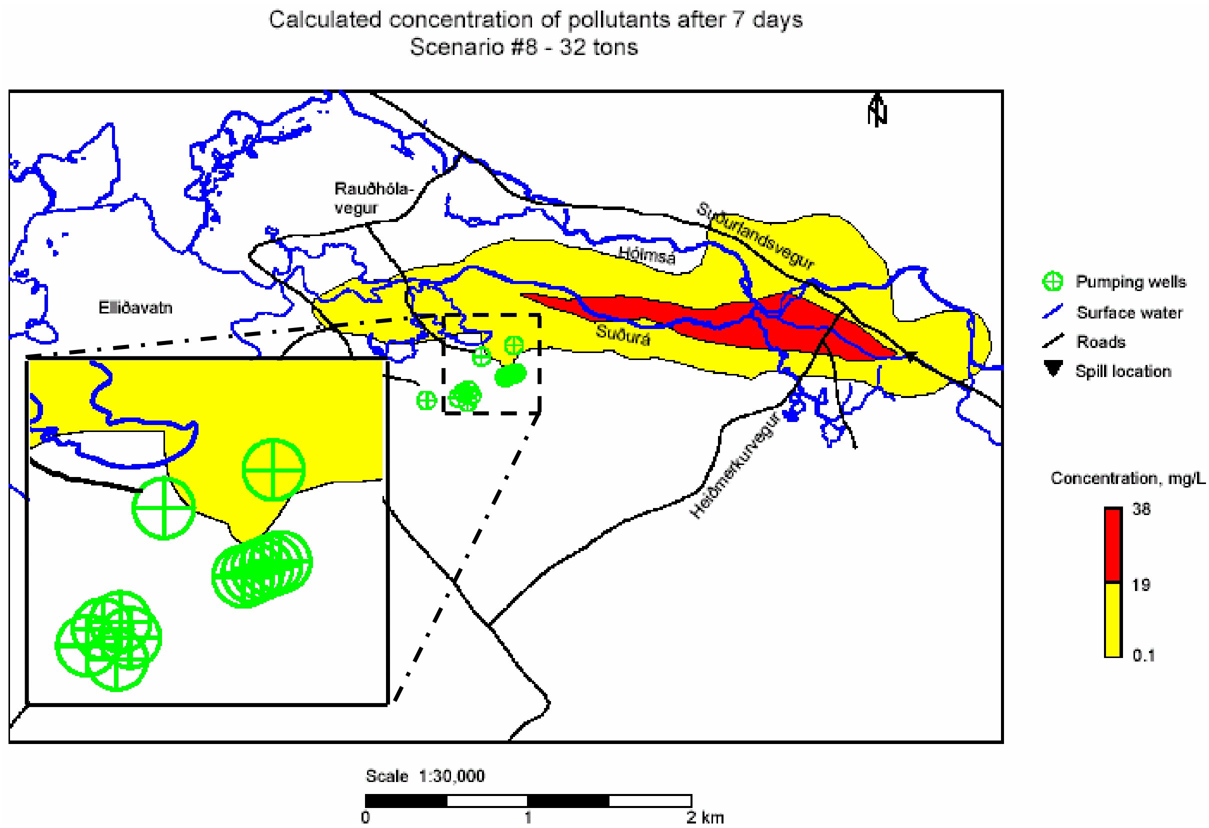


Figure IV-2 A possible risk reduction measure.

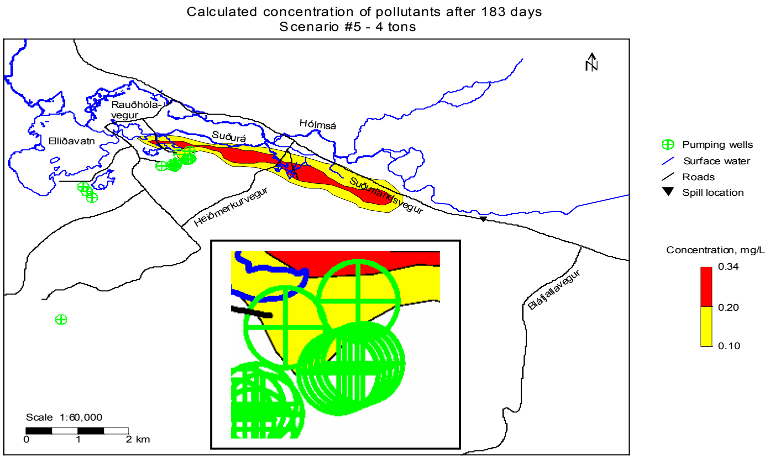


At accident **site 8** the wells are threatened a week after an accident resulting in a large release (32 tons). The only well that definitely falls within the 0.1 mg/l parameter is one of the old ones that is not currently in use. But a cluster of the newer wells is clearly threatened. After a month the dilution has taken its toll and the 0.1 mg/l frontier has receded to a few hundred meters from the wells. A simulation for two weeks was regrettably never performed but the probability is high that the concentration frontier temporarily engulfed the aforementioned cluster before it receded. Regardless this scenario poses a substantial threat.

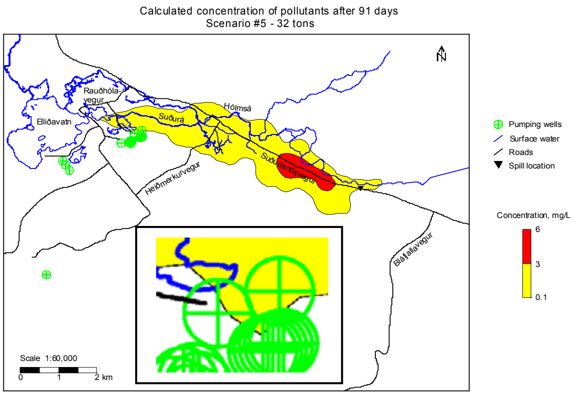
When the results of the simulation at this site are compared to the results at other sites along Sudurlandsvegur the drop in concentration is unusually fast. The model has a number of spring nodes where groundwater is assumed to enter the rivers at a given rate. The quick drop in concentration implies a high number of spring nodes in the area, resulting in elevated concentrations in the rivers. The concentration in the rivers is not accounted for, but both the rivers Hólmsá and Sudurá receive large quantities of polluted water following this scenario.

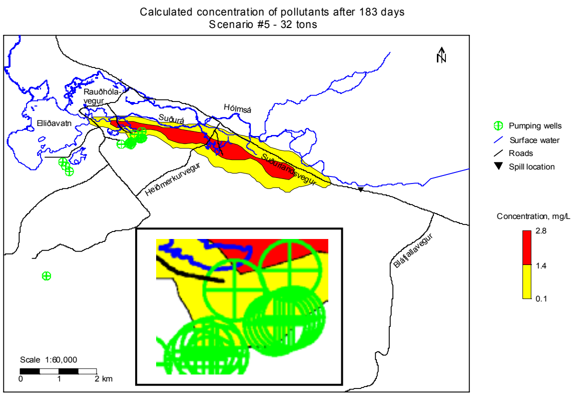
To get an idea as to the concentration in the rivers following this scenario a rough calculation can be made. After the first month more than 95% of the spill has left the simulated system. The drain of the spill is almost exclusively the rivers Hólmsá and Sudurá. These rivers have a combined average flow of 3.5 m^3/s. For a large spill that means 0.95*32 tons divided by (3.5 m^3/s*2.59 x 10^6 s/month) = 3.35 x 10^{-6} tons/m^3 = 3.4 mg/l.

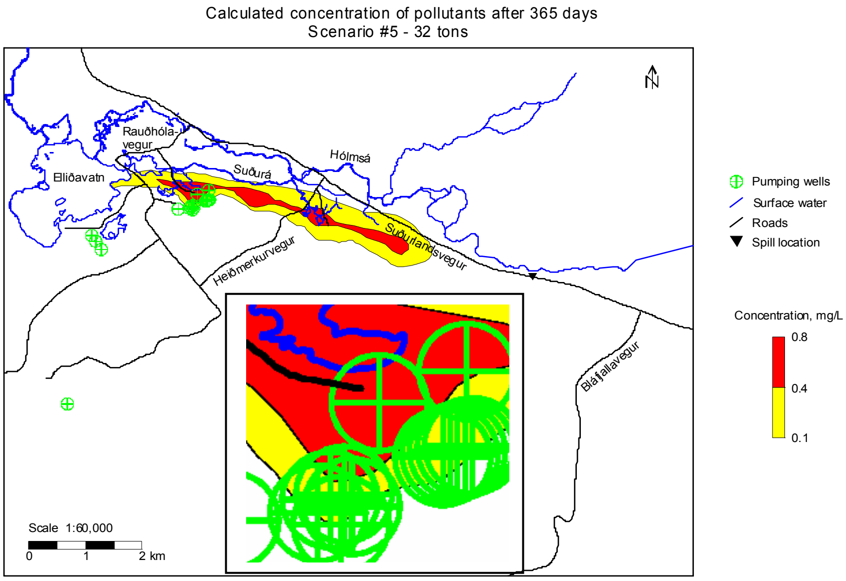
These calculations show that the average concentration of chemicals in the rivers Hólmsá and Sudurá, at least in the vicinity of the release point, will probably be in the range 1-10 mg/l during the first month after the accident.



At accident **site 5** even a medium release (4 tons) is sufficient to threaten the wells. According to the simulation the 0.1 mg/l concentration frontier engulfs the two older wells but stops just short of the main clusters of wells after six months time. This is of course much too close for comfort and must be treated as a serious risk, even if the older wells are assumed to be redundant.

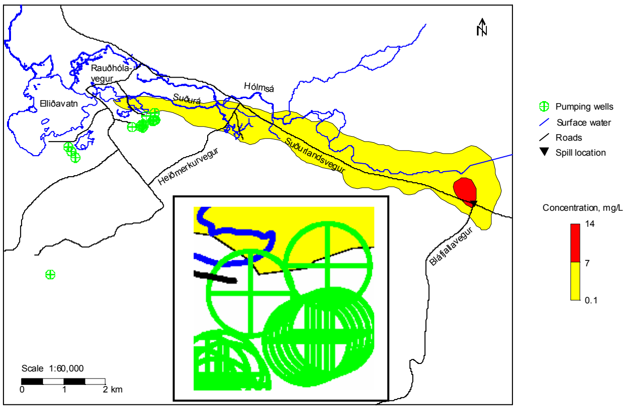




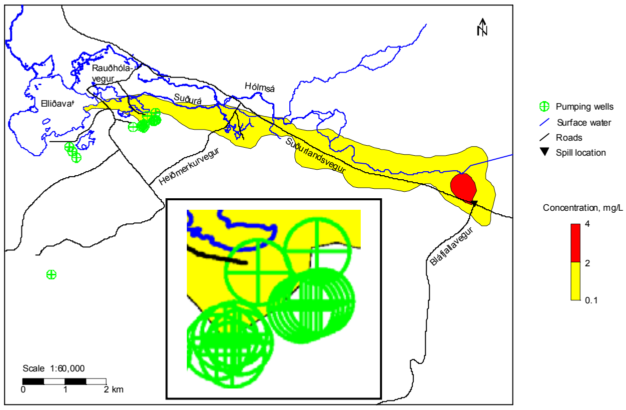


When the large release (32 tons) is modeled at site 5 the consequences are huge. Already after three months the 0.1 mg/l frontier is close to the wells, after six months most of the wells are within the polluted parameter and still after a year the feed to all but one well in the main area is above the limit.

Calculated concentration of pollutants after 365 days
Scenario #6 - 32 tons

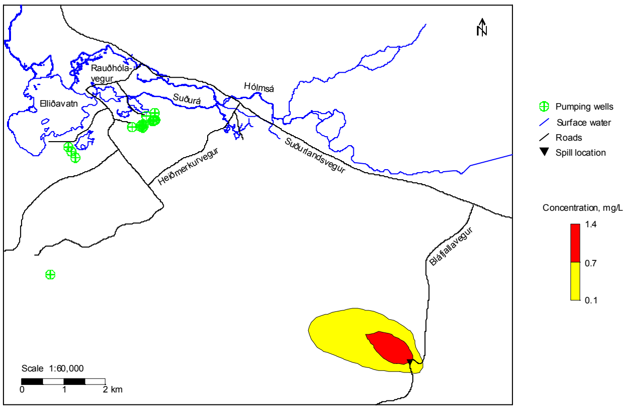


Calculated concentration of pollutants after 730 days
Scenario #6 - 32 tons

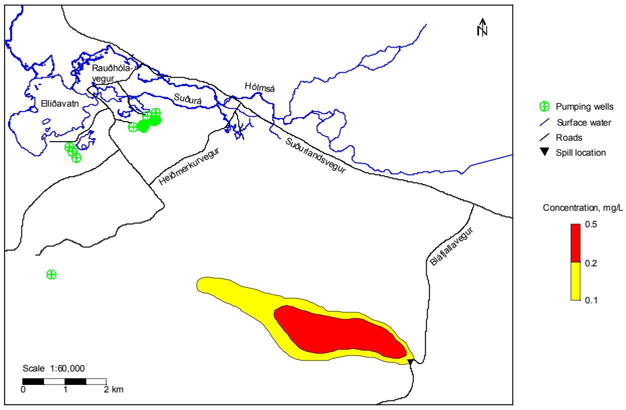


Accident **site 6** is so far from the wells that the 0.1 mg/l frontier does not reach the wells during the first year after release. But during the second year it does reach the wells and in case of a large release the dilution is not sufficient to bring the concentration beneath the limit. This means that even an accident this far up in the system poses a threat to the wells of Reykjavík Energy.

Calculated concentration of pollutants after 365 days
Scenario #7 - 3 tons



Calculated concentration of pollutants after 730 days
Scenario #7 - 3 tons



Accident **site 7** is also far from the wells. Since a release here cannot exceed 3 tons it appears that dilution probably will bring the concentration beneath 0.1 mg/l before the plume reaches the wells. The maximum concentration sinks from 1.4 to 0.5 mg/l during the second year after the release. A simulation after three or maybe four years is nevertheless advisable to see the further evolution of the plume and to see whether the well in the southwest corner is threatened.

3 Exposure via surface water

Two accident scenes (figure IV-3) have been placed at bridges over the river Hólmsá to cover the extreme case when the release hits a river directly.

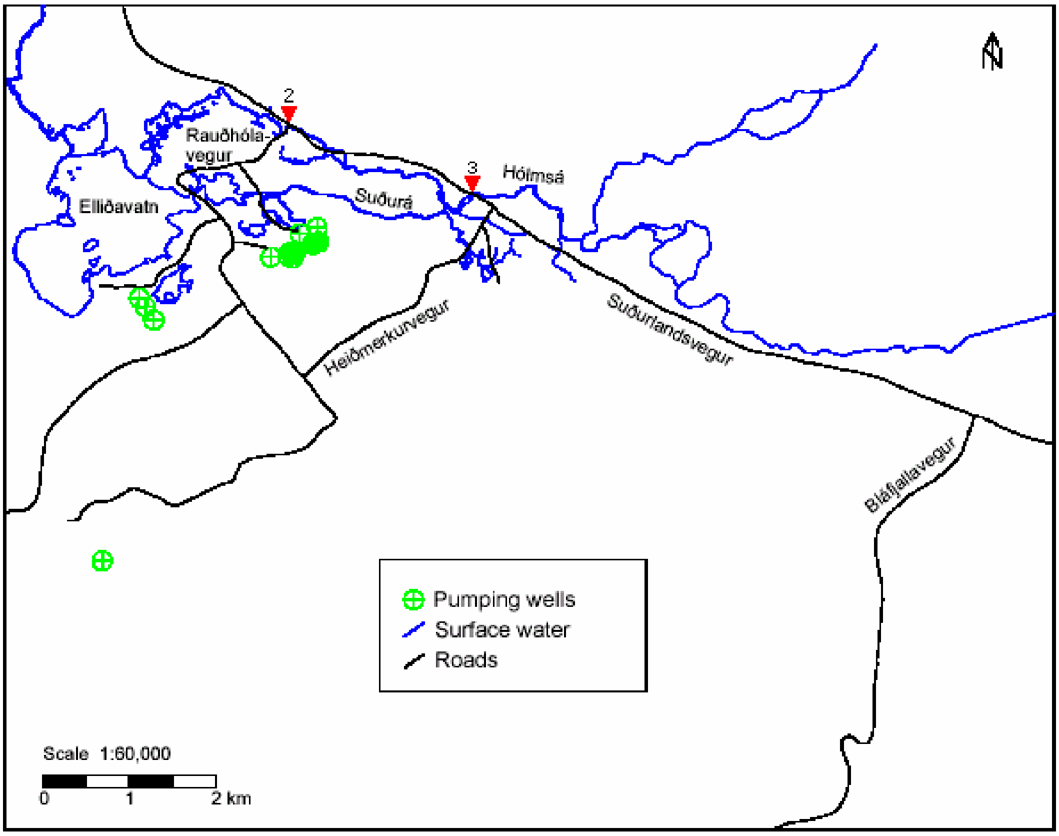


Figure IV-3 The two accident scenes where release occurs directly into the river Hólmsá

The release, as well as the evaporation, is modeled using AdiosII in the following chapter.

3.1 AdiosII simulation

AdiosII is a program designed by the Hazardous Materials and Response Division of the NOAA. Although it is designed for marine modeling, it can be used for freshwater conditions by adjusting the salinity and sediment content parameters.

3.1.1 The release phase

Simulating the release from an oil truck tank can be done by any of a number of methods, including calculations by hand. Since AdiosII includes a ruptured tank release model, especially produced for petroleum products, the simplest way to proceed is to utilize this.

The large trailer tanks are approximately 45 m^3 and they are divided into 9 individual sections. In order for all the petroleum to be spilled a gash has to occur throughout the side of the tank. To model this (see figure IV-4) an 8-meter by 2 centimeter gash is assumed. A gash of this magnitude is probably likely to be broader, but the spilling process is fast even for such a narrow opening. The gash is assumed to be located close to the bottom of the tank (with the trailer on its side) above water level.

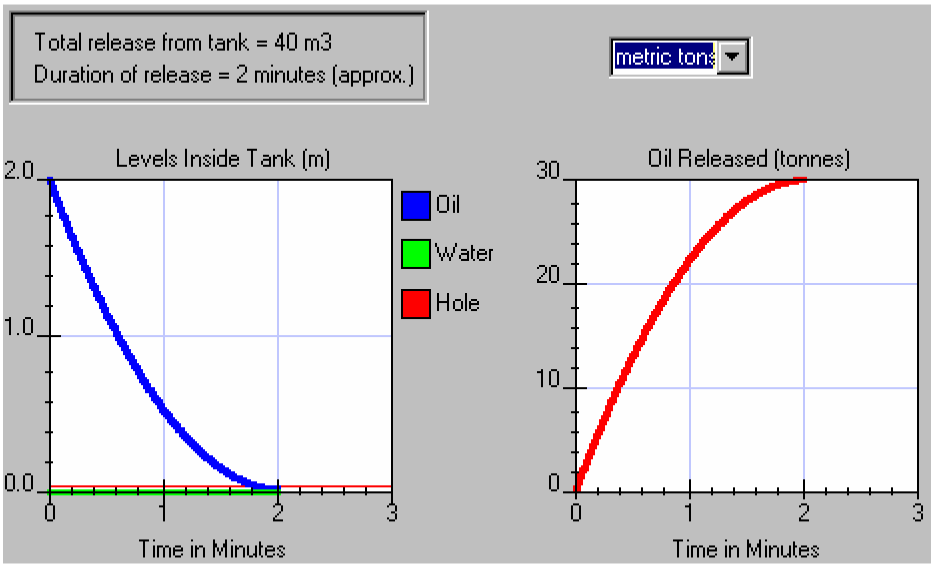


*Figure IV-4 Release of gasoline when hole is 8*0.02 m²*

When diesel is the released substance the course of events is almost identical, except that the higher density of diesel results in a larger amount (approximately 32 metric tons) released. The flow velocity is similar for both fluids, as they both have very low viscosity. Figure IV-5 shows the course of the release when only one section (1.1*2*2 m^3) of a tank is punctured by a rectangular hole measuring 0.2*0.02 m^2.

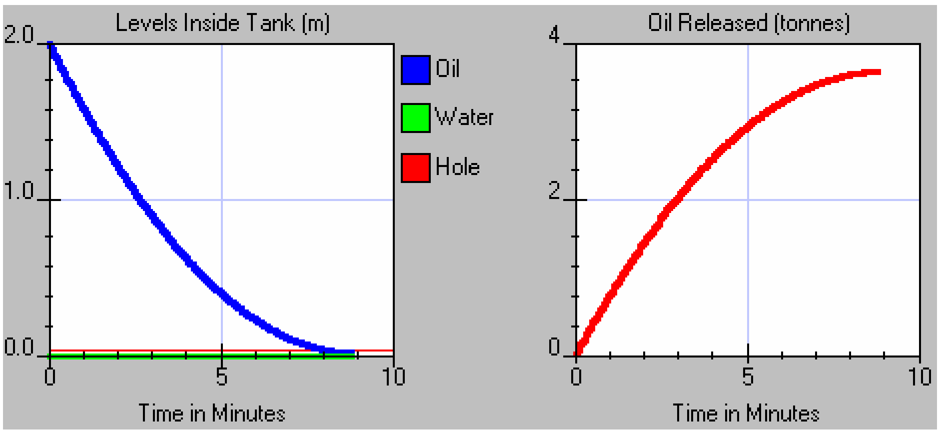


*Figure IV-5 Release of diesel when hole is 0.2*0.02 m²*

Once again, release of gasoline is practically identical.
Following are calculations for the initial concentrations of petroleum in the river Hólmsá, given the above depicted rates of release result in the following initial at the point of release, assuming average flow, i.e. 2.2 m^3/s:

In the case of the large hole (entire tank release) the rate of release can be assumed to be constant during the first minute of the release, in which 75 % the tank content, 24 tons or 30 m^3, is released. This means a release rate of 400 kg/s or 0.5 m^3/s. Accordingly the concentration will become:

$$\frac{400}{(2.2+0.5)} = 148\ \text{kg/m}^3 = 148\ \text{g/l} \approx \mathbf{1.5\ x\ 10e^5\ mg/l}$$

For the smaller hole (one section release) the rate can be assumed to be constant during the first three minutes, in which 2 tons or 2.5 m^3 are released. That means a release rate of 11.1 kg/s or 13.9 l/s (negligible for the total flow). 11.1 kg/s divided by 2.2 m^3/s results in a concentration of 5.05 kg/m^3 or **5050 mg/l** during the initial 3 minutes.

In reality any number of sections could be punctured, so these two scenarios really only indicate the scale. Further, neither of these characterizing scenarios is the ultimate in each end. The small hole could be smaller, and the large hole could be larger. But these two point estimates suffice to characterize the specific event that the release hits the rivers directly.

According to the oil companies, as well as Icelandic regulation #2001/784, benzene constitutes up to 1% of gasoline, anthracene up to 0.02% of diesel, and MTBE up to 10% of high-octane gasoline.

Therefore the initial predicted environmental concentration (PEC) of these chemicals downstream of the point of release becomes:

Scenario (P)	Anthracene	Benzene	MTBE
P1 (large release)	30 mg/l	1500 mg/l	1.5 x 10^4 mg/l
P2: (medium release)	1.01 mg/l	50.5 mg/l	505 mg/l

Table IV-1 The initial PEC values of selected chemicals downstream of release point.

The low content of anthracene is somewhat puzzling since anthracene is supposed to be (at least among) the most common PAH in diesel and the PAH content of diesel can and may be up to 11%.

3.1.2 The evaporation

Most constituents of gasoline are extremely volatile so the evaporation of gasoline is very fast. This constitutes a problem in AdiosII since the resolution of the evaporation output data is very low (a calculation every hour or two). This is due to the fact that the typical release that AdiosII is designed to simulate is crude oil, which is less volatile than gasoline. This problem is "solved" by simple linear interpolation when necessary. Diesel is less volatile than gasoline and therefore constitutes less of a problem for AdiosII.

The river Hólmsá has an average flow of **2.2** m^3/s, an average width of approximately **5** m and the average depth is assumed to be half a meter. Assuming approximately homogeneous flow velocity the average flow velocity is approximately **1** m/s.

In the case of the large hole the entire release only takes about two minutes. During that time the front of the pollution is carried through convection about 120 m from the point of release. There will be some small distribution in the axial direction due to diffusion and perhaps some dispersion, but for practical purposes the oil can be assumed to be a 120 m long and 5 m wide plume traveling along the river towards Ellidavatn at the constant rate of 1 m/s.

In the case of the small hole the release time is longer, approximately 8.5 minutes, so the plume is also longer, approximately 500 m.

In AdiosII the evaporation in the river is simulated by a confined release of 600 m^2 for the large release and 2500 m^2 for the smaller release.

Assumptions:		Comments:
Water temperature:	**4°C**	Spring water
Salinity:	**0%**	Fresh water
Wind:	**3 m/s**	Conservative (high wind, high evaporation)
Sediment load:	**20 g/m^3**	Relatively clean river

Table IV-2 Assumptions for AdiosII runs.

The simulations were made with petroleum sold in Canada since weather conditions are often similar in Iceland and in Canada.

From accident site 2 the plume has approximately 2500 m (2500 s) to lake Ellidavatn, and from site 3 approximately 5000 m (5000 s).

The results from the simulations for the evaporation in the river Hólmsá are summarized in table IV-3:

Chemical:	Accident site and scenario:	Percent evaporated
Diesel	Site 2, P1 (large)	**0%**
-	Site 2, P2 (medium)	**1%**
-	Site 3, P1 (large)	**0%**
-	Site 3, P2 (medium)	**1%**
Gasoline	Site 2, P1 (large)	**19%**
-	Site 2, P2 (medium)	**47%**
-	Site 3, P1 (large)e	**32%**
-	Site 3, P2 (medium)	**71%**

Table IV-3 Evaporation of pollutants in the river Hólmsá, before lake Ellidavatn is reached.

Apparently the evaporation in the river is negligible for diesel, but not for gasoline. This means that the fish are exposed to the same concentration of diesel all the way from the point(s) of release to lake Ellidavatn. In the case of gasoline, especially in the case of the smaller release, the fish closest to lake Ellidavatn are exposed to a lower concentration.

When lake Ellidavatn is reached the confinement factor is all but eliminated and the evaporation becomes much faster. Figure IV-6 shows the fate of a large release of diesel after lake Ellidavatn is reached (simulation start at noon 18th of November).

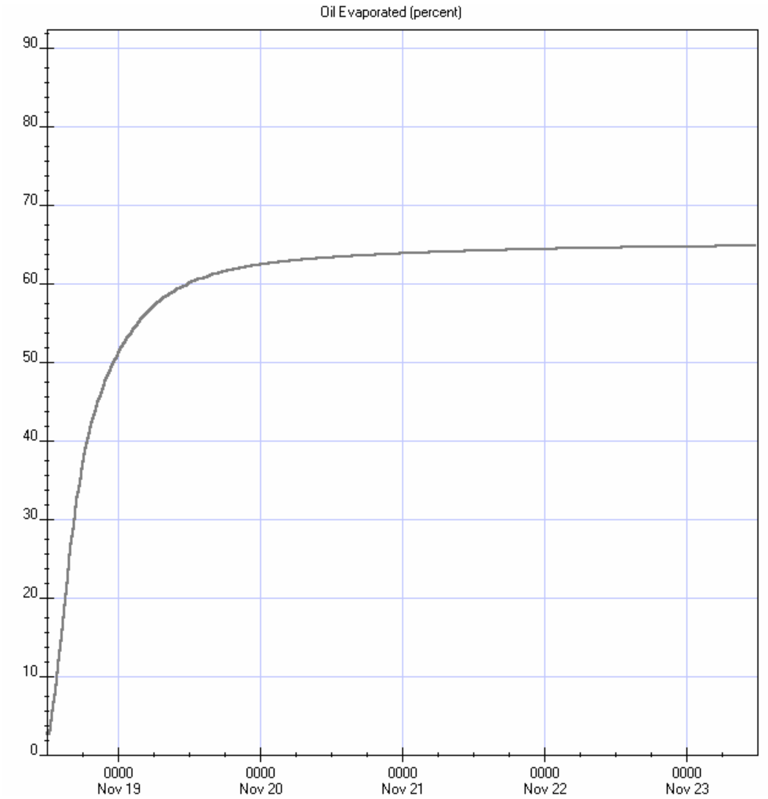


Figure IV-6 Evaporation of large diesel spill in lake Ellidavatn.

An evaporation graph of a small diesel spill looks similar. In table IV-4 the evaporation from the time the spill reaches lake Ellidavatn is summarized:

Scenario	% evaporated after:						Scenario	% evaporated after:			
Diesel	**1h**	**2h**	**6h**	**12h**	**24h**	**48h**	**Gasoline**	**1h**	**2h**	**3h**	**6h**
P2: (medium spill)	3	8	33	49	60	63	P2: (medium spill)	88	95	99	99
P1: (large spill)	11	25	47	56	62	64	P1: (large spill)	66	90	96	99

Table IV-4 Evaporation in lake Ellidavatn

Observe that these percentages are relative to the concentration that reaches lake Ellidavatn, not to the initial concentration.

3.2 What happens in lake Ellidavatn?

When lake Ellidavatn is reached it is safe to assume that the chemicals will most probably be diluted in most of the lake before the salmon fishing river Ellidaá gets any high concentrations. Ellidaá is the river that runs into the upper left corner of figure IV-1, and even though it is quite close to the outlet of Hólmsá, it is in the counterclockwise direction. The Coriolis force will for the most part force the water to take the long way around the lake before reaching the river Ellidaá. If there was a strong wind blowing due NW then the spill would probably reach Ellidaá quickly, but on the other hand if a strong wind is blowing then the evaporation would also be a lot faster. /Horne et al 1994/

The lake is about 2 km^2 and has an average depth in the vicinity of 2 meters (/Björnsson 2001 (II)/), which gives a volume of approximately 4 million m^3. So hypothetically if an entire oil trailer is emptied directly in the lake (or in the case of diesel anywhere in Hólmsá) and total mixing is assumed then the concentration would be $32 \times 10^9 / 4 \times 10^9 = 8$ mg/l.

Now this is not quite going to happen. Wind and wave action will distribute the chemicals in the vertical direction also, but hardly to a uniform concentration since they are significantly lighter than the water.

Since the flow from Ellidavatn averages just over 4 m^3/s the turnover time of lake Ellidavatn is approximately 10 days. Therefore it is unlikely that any gasoline spill would reach the river Ellidaá in significant concentration. A diesel spill is also unlikely to raise the concentration of oil in Ellidaá far above 1 mg/l. The greatest effects on salmon, char and trout would accordingly be in the river Hólmsá and in lake Ellidavatn.

3.3 Where is the fish?

The adult salmon can be just about anywhere, depending on the time of year. They may not be in the water system at all. Therefore the effects on the adult population of salmon depends greatly on what time of year an accident occurs. The juvenile fish is much less mobile, and can mostly be found in the river Ellidaá and the uppermost parts of the rivers Sudurá and Hólmsá.

Adult Char, as well as adult trout, is mostly found in lake Ellidavatn itself. A relatively high number of juvenile trout is found all over Hólmsá and Sudurá. It is usually so that where trout is common, salmon is not, and vice-versa.

It should be noted that the numbers of both salmon and char have been falling for the last decades, while the population of trout seems stable. Several hypotheses exist as to why this reduction is occurring, but man-related environmental effects cannot be ruled out. Urban Reykjavík creeps closer and closer to the lower parts of the water system. /Antonsson 2002/