National Institute for Public Health
and the Environment
Ministry of Health, Welfare and Sport

Reference Manual Bevt Risk Assessment

Guidelines for calculating external risk for transporting hazardous substances by road, rail and water

RIVM report 2022-0168

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Synopsis

Reference Manual Bevt Risk Assessment

Guidelines for calculating external risk for transporting hazardous substances by road, rail and water

The Dutch government has defined standards for the transportation of hazardous substances by road, rail and water. These standards are laid down in the External Safety of Transport Routes Decree (Besluit externe veiligheid transportroutes) and Basic Transport Network Regulation (Regeling Basisnet). The Regulation stipulates risk ceilings for transports as well as spatial planning restrictions for areas surrounding transport routes with a view to limiting the consequences of potential accidents.

The government commissions consultancy firms to perform risk calculations to verify that transports do not exceed these risk ceilings. They also perform calculations to substantiate the permissibility of any new spatial planning initiatives in the vicinity of transport routes and to assess risks arising from new or modified transport routes. The risks of transporting hazardous substances are calculated using the Reference Manual Bevt Risk Assessment (Handleiding Risicoanalyse Transport) and the RBM II software.

The Reference Manual Bevt Risk Assessment sets out the method for calculating the risk to the surrounding area of transporting hazardous substances by road, rail or water. The main document summarises legal and regulatory aspects of environmental safety, insofar as relevant to the calculation method, and defines the model parameters and input data needed to perform risk calculations. The annex provides basic rules and a description of the models.

The calculation method was updated in 2020 and 2022. The new calculation method, incorporating the latest insights, is available on the RIVM website. The Reference Manual Bevt Risk Assessment and RBM II are not suitable for calculating risks on waterways of which more than 10% is maritime.

Publiekssamenvatting

Handleiding Risicoanalyse Transport

Richtlijnen voor het berekenen van externe-veiligheidsrisico's van het vervoer van gevaarlijke stoffen over weg, spoor en water

Voor het transport van gevaarlijke stoffen via weg, water en spoor heeft de Nederlandse overheid normen bepaald. Deze staan in het Besluit externe veiligheid transportroutes (Bevt) en de Regeling Basisnet. Het Basisnet geeft de risicoplafonds aan waaraan het transport moet voldoen. Ook legt het beperkingen op aan de ruimtelijke ordening in de omgeving van transportroutes, zodat de gevolgen van een eventueel ongeval beperkt blijven.

Adviesbureaus voeren in opdracht van overheden risicoberekeningen uit om te bepalen of het transport binnen de risicoplafonds blijft. Dit gebeurt ook om nieuwe ruimtelijke ontwikkelingen in de omgeving van transportroutes te verantwoorden. Verder worden risicoberekeningen gemaakt om risico's te bepalen bij nieuwe of gewijzigde transportroutes. De risico's van het vervoer van gevaarlijke stoffen worden berekend met de Handleiding Risicoanalyse Transport (HART) en het rekenprogramma RBM II.

HART beschrijft de methode om het risico voor de omgeving te berekenen van het vervoer van gevaarlijke stoffen over de weg, het spoor en het water. Het hoofddocument beschrijft kort de wet- en regelgeving over omgevingsveiligheid, voor zover dat van belang is voor het gebruik van de rekenmethode HART, en de benodigde modelparameters en invoergegevens voor risicoberekeningen. In de bijlage staan onder andere vuistregels en worden de modellen beschreven.

Het rekenvoorschrift is in 2020 en in 2022 bijgewerkt. Het nieuwe rekenvoorschrift is beschikbaar op de website van RIVM en bevat de meest recente inzichten. Verder zijn HART en RBMII niet geschikt om het risico te berekenen van vaarwegen met meer dan 10 procent zeevaart.

Contents

Introduction

1.1 Background

In the external safety policy, a quantitative risk assessment (hereinafter referred to as QRA) is used to calculate the risks to local residents resulting from the transport of hazardous substances. To put it in simple terms, the result of a QRA is the probability of dying at a specific location as a direct consequence of an incident involving hazardous substances and the probability of a specific-sized group of people dying. The risk is determined by the transport route, the substances being transported and the nature of the environment.

A QRA should be transparent, verifiable, robust and valid [1]. It is therefore extremely important that every QRA is carried out based on the same models and basic principles. The information needed to carry-out a QRA for ES risks of transporting hazardous substances is bundled with this document.

1.2 Aim, target group and demarcation

The aim of this reference manual is to provide an unambiguous framework for carrying out quantitative risk assessments for the carriage of hazardous substances as well as providing the necessary background and basic information. The reference manual does not aim to provide a reference manual for the use of specific risk assessment software, such as RBM II, nor for subjects that do not directly relate to the quantitative risk assessment itself, such as societal risk accountability.

This reference manual is intended for anyone who is involved to any extent in external safety relating to transport networks and who carries out or evaluates a quantitative risk assessment within that framework.

This reference manual specifies how the risks of transporting hazardous substances should be analysed in accordance with the applicable policy. Deviation from this is only permitted in special, properly justified cases. Any change in the calculation method must be validated and approved [2]. For example, additional safety measures must be rated based on case studies, analogous cases or based on expert judgement.

The use of this reference manual in combination with the RBM II risk assessment package is legally anchored in 'Basisnet' (Rbn).
The risk approach is used in environmental decisions (such as land-use plans and environmental permits) and infrastructure decisions (routing decisions, infrastructure decisions such as planning procedure orders).
The rules for environmental decisions are contained in the External Safety of Transport Routes Decree {*Besluit externe veiligheid transportroutes*} (Bevt). The ES Policy - evaluation of infrastructure decisions (ES Policy) applies when dealing with external safety in planning procedure orders.

1.3 Changes since 01 November 2011

Version 1.0 has been fully modified to the 'Basisnet' Act, the External Safety of Transport Routes Decree, the 'Basisnet' Regulation and the policy rules for evaluation of external safety for infrastructure decisions.

In version 1.1, some textual changes had been made, including the removal of information about the national population data service and a clarification of the substance classification (in particular substance category D4). Version 1.2 also contains some textual changes. This concerns a different classification of the substance category for LNG (see section 5.1.1) and the description of three mitigating measures (see section 9.4.1).

1.4 Report structure

This Reference Manual consists of three modules. Module A explains the legal framework. Module B contains the generic model parameters and aspects applicable to all modalities, such as modelling the population in the vicinity of a transport route, modelling the transport route and scenario modelling. Finally, Module C covers model parameters that apply specifically to certain transport modalities (road, rail or inland waterway). The first chapter of Modules B and C further elaborates the structure of those modules.

1.5 Information

In practice, situations may arise in which use of this reference manual leads to queries. Queries and remarks can be sent to RIVM using the e-mail address rbmii@rivm.nl.

Module A Legal framework

2 Legal framework

The requirement to carry-out a risk assessment and the requirements in relation to the input, basic principles, assumptions and working method are based on various legal frameworks. These frameworks are referred to in broad outline in this chapter, insofar as they are relevant to carry-out a QRA. The relationship between the relevant laws and regulations is illustrated in Figure 2-1.

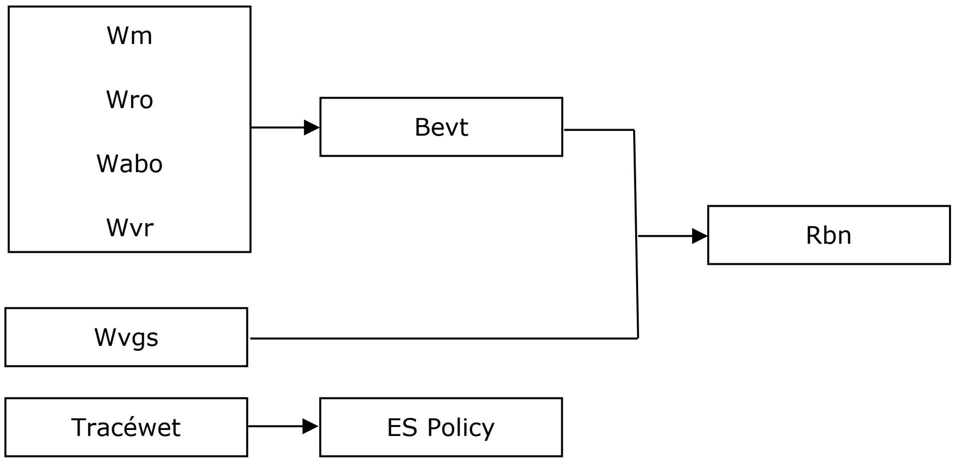

Figure 2-1 Relationship between external safety of transport laws and regulations

The abbreviations are explained below:

Wm	Environmental Management Act
Wro	Spatial Planning Act
Wabo	Environmental Law (General Provisions) Act
Wvr	Safety Regions Act
Wvgs	Carriage of Dangerous Goods
Bevt	External Safety of Transport Routes Decree
Rbn	'Basisnet' Regulation
ES Policy	ES Policy - evaluation of infrastructure decisions

2.1 External Safety of Transport Routes Decree {*Besluit externe veiligheid transportroutes*}

The External Safety of Transport Routes Decree (Bevt) [3] contains the environmental quality requirements for external safety. In a specific number of named decisions the competent authority should:

- Take account of the threshold value for the individual risk
- Take account of the target value for the individual risk
- Justify the societal risk (decisions within 200 m of the transport route and societal risk greater than the orientation value or societal risk greater than 10% of the orientation value and more than 10% increase).
- Consider the options for preparing to combat and limit the scale of a disaster (decisions within the transport route's area of influence).

- Consider the options for individuals to reach a place of safety if a disaster occurs (decisions within the transport route's area of influence).
- Further justify permitting the construction of (moderately) sensitive objects in a pool fire area for special attention[1], given the possible consequences of an accident involving flammable liquids.

This relates to decisions where the construction, establishment or development of moderately sensitive objects is permitted.

The Bevt is aimed at competent authorities (the Government, provincial authorities and local authorities) in the field of spatial planning. This Decree formulates environmental quality requirements in relation to the Individual Risk (IR). The standards for the individual risk are arranged in the form of a statutory threshold value (for sensitive objects) and a target value (for moderately sensitive objects). For the 'Basisnet' routes, instead of calculating a risk value for testing a spatial planning decision, a distance specified by the Minister of Infrastructure and the Environment ('Basisnet' Distance) applies.

At this distance, the individual risk resulting from the transport of hazardous substances is allowed to be maximum 10^{-6} per annum. The competent authority must take account of this distance in spatial decisions that permit new, sensitive objects in the vicinity of a 'Basisnet' Route. If new, moderately sensitive objects are permitted, then the competent authority must take this distance into account. The 'Basisnet' Distance is measured between a reference point on the route and a measurement point at the spatial destination. Both points are documented in the Rbn.

The locations where the individual risk due to the transport of hazardous substances along a 'Basisnet' Route is allowed to be maximum 10^{-6} per annum is designated as the 'IR ceiling'. The position of the IR ceiling is included in the Appendices of the Rbn as a distance in relation to the reference point on the route. The individual risk concerning a spatial decision about an area alongside the 'Basisnet' Route is not calculated, but taken from tables that are included in the appendices of the Rbn.

The competent authority is subject to accountability for the societal risk. The competent authority should cover the options for preparing to combat and limit the scale of a disaster and the self-protection possibilities in the explanatory notes for a land-use plan within the area of influence of a route [3].

In the explanatory notes for a land-use plan within 200 m of a route, the competent authority should also cover the height of the societal risk for the current and expected population density in the planning area, the options for taking measures to reduce the societal risk and the options for spatial alternatives with a lower societal risk. The latter can be omitted if the societal risk is relatively low (smaller than 10% of the

[1] Pool fire areas of attention (PFAA) are designated alongside and above certain 'Basisnet' routes in the appendices to the 'Basisnet' Regulation (Rbn)

orientation value) or if the increase in the societal risk is relatively small (less than 10%). If the societal risk is higher than the orientation value, the competent authority should always consider all of the aforementioned external risk aspects.

The level of the societal risk and the increase of it stem from a risk calculation. The representative kilometre section for the societal risk is used to evaluate the societal risk. This is the 1 kilometre section where the societal risk is the highest. This is determined automatically by the prescribed calculation program RBM II. The increase in the societal risk is evaluated at the point on the FN curve at which the societal risk is the highest. This is also determined automatically by the calculation program.

Rules of thumb can be used in simple cases. Rules of thumb which indicate whether the societal risk is smaller than the orientation value or smaller than 10% of it are included in the Appendix 1 to this reference manual.

The duty of accountability is further elaborated on in, among others, the Societal Risk Accountability Guidelines [4].

2.2 'Basisnet' Regulation

The 'Basisnet' Act, which is an act amending the Transport of Hazardous Substances Act, implements a maximum usable space for the designated infrastructure, in the form of a risk ceiling. Developments on the transport side must not lead to the ceiling being exceeded. The risk ceiling is a line next to the infrastructure where the individual risk has a specified maximum value.
To this end, the 'Basisnet' Regulation (Rbn) [5] specifies:

- The height of the risk ceilings in 'Basisnet'.
- The geographical location of the risk ceilings in 'Basisnet'.
- A report obligation for the infrastructure managers on the number of transports of hazardous substances.
- An obligation on the Minister to analyse and report the risks.
- The calculation method comprising RBM II and this reference manual, and the transport numbers that must be used in calculating the transport risks.
- The geographical location of the pool fire areas of attention.
- The reference points and the measurement points between which the 'Basisnet' Distances in the Bevt should be measured.

2.3 ES Policy - evaluation of infrastructure decisions

The Bevt establishes how the competent authority should evaluate the effects of environmental decisions on external safety. The ES Policy - evaluation of infrastructure decisions (hereinafter referred to as ES Policy [6]) gives the Minister for I&M a framework for evaluating the effects of infrastructure decisions for which he is the competent authority on external safety. Municipal authorities and Provincial authorities are also asked to apply this evaluation to decisions with an external safety component where they are the competent authority. Examples are a Municipal Authority routing regulation and a Provincial integration plan with the aim of constructing or changing infrastructure.

The ES Policy provides guidelines for evaluating external safety for:

- Changes to roads that are part of 'Basisnet'.
- Constructing or changing roads that are not part of 'Basisnet'.
- Diversions over roads that are part of 'Basisnet'.
- Diversions over roads that are not part of 'Basisnet'.
- Changes to main railway lines that are part of 'Basisnet'.
- Constructing main railway lines.
- Changes to main waterways that are part of 'Basisnet'.
- Constructing or changing main waterways that are not part of 'Basisnet'.

Whether and the way in which the societal risk and/or the individual risk has to be calculated is determined for each case. The concrete consequences for the risk calculation differ per modality and are discussed in Module C.

2.4 Relationship to other documents

In addition to the legal framework described above there are various relevant documents that have been developed by certain parties and which have or have not been approved by an umbrella steering group. Although these documents have no legal basis they could well achieve such status through jurisprudence. Examples are the Calculation Protocol for the Transport of Hazardous Substances by Rail [7][2] and the Societal Risk Accountability Guidelines [4][3][3]. The elements of these documents that are relevant for carrying out a quantitative risk assessment relating to transport routes have been included in this reference manual.

[2] Applicability confirmed in Council of State's {Raad van State} judgement 200406607/1 of 15 June 2005 concerning DSM's environmental permit
[3] Applicability confirmed in, among others, Council of State's judgement 200704460/1 of 11 June 2008 concerning revision permit for MPM International Oil Company B.V.

Module B General principles and model parameters

3 Overview of Module B

This Module B deals with the various steps in a risk assessment for the carriage of hazardous substances. Module B describes the general basic principles of the model and the parameters that are required for carrying out a QRA regardless of modality. The modality-specific elaboration and way of modelling is described in Module C.

The structure of Module B is as follows:

- Chapter 4. Population modelling.
- Chapter 5. Modelling transport routes.
- Chapter 6. Scenario modelling.
- Chapter 7. Reporting requirements.

3.1 Rules of thumb: indication of level of individual risk and societal risk

The Explanatory Notes for the Bevt and the Explanatory Notes for the ES Policy state that the calculation of the individual risk and the societal risk can be omitted in some cases. To this end, rules of thumb in the form of threshold values for transport numbers have been formulated which give the user an indication of the level of the individual risk or the societal risk. The rules of thumb can be used to estimate whether the transport numbers, building distances and/or presence densities are too small to lead to the threshold value or target value for the individual risk being exceeded or to the orientation value being exceeded by 0.1 times the orientation value for the societal risk.

The rules of thumb for the various transport modalities are included in Appendix 1. This appendix also elaborates on the limitations and preconditions that are considered when applying the rule of thumb.

3.2 Transport risk calculation: what to compare?

A QRA for a transport route is usually used as an instrument to support a decision and thereby improve the quality of the decision. The relevant laws and regulations describe the requirements for a QRA depending on the administrative embedding of the decision. These requirements are described in this reference manual insofar as they relate to the calculation or the reports.

The QRA provides insight into the level of the external risks of a transport route. The consequences of the decision concerned become apparent from a comparison of the situation before the decision and the situation after the decision. In addition to the risk level, the increase or decrease in the risk as a result of the decision can also be evaluated.

The risk for a transport route is determined by the combination of the transport, spatial planning and the development of both through time (in relation to numbers and safety).

The planning period and land-use plan is ten years. This is also the relevant period for spatial decisions. Infrastructure decisions often have consequences for a much longer period of time. A QRA within the framework of an EIA study concentrates on comparing alternatives for periods of 25 or 30 years or even longer.

The options are shown in table 3-1. The situations that are compared with each other depend on the type of decision that is supported by a QRA. In some cases, it is required to calculate more than two situations.

Table 3-1 Overview of possible situations

Situation	**Route**	**Transport**	**Space**
Current			
Autonomous development			
Future			

The route characteristics (location, design), the transport numbers and the spatial development that have to be incorporated in the calculation are discussed in Chapter 4 (population modelling) and the modality-specific chapters 9, 10 and 11. Two examples of the completion of the schema are shown in Table 3-2 and Tabel 3-3.

Table 3-2 Land-use plan alongside a 'Basisnet' road

Situation	**Route**	**Transport**	**Space**
Before planning decision	Actual location	Rbn 'Basisnet' table	Current
After planning decision	Actual location	Rbn 'Basisnet' table	Future

Variant: if during a planning procedure, a planning procedure order for a road diversion exists, the external risk of the new spatial development for the situation after the planning decision should be calculated, using the new planned route.

Table 3-3 EIA study for new infrastructure

Situation	**Route**	**Transport**	**Space**
Current	Actual location	Current	Current
Autonomous development	Actual location	Future prognosis	Future
Future	Future (more variants)	Future prognosis	Future

4 Population modelling

4.1 General

The societal risk is the probability distribution for the number of fatalities as a result of the release of hazardous substances from the risk source, in this case a transport unit loaded with a hazardous substance. The societal risk is calculated based on the presence of people in the area of influence. In this regard, the calculation of transport risks does not differ from the calculation of the societal risk for static establishments. The societal risk presents an image of the social disruption as a result of accidents involving hazardous substances.

The question now is how the number of people can be determined for the calculation. This can differ, depending on the framework within which the risk assessment is carried out.

Risk assessments are carried out with and without a legal basis. When feasibility studies are carried out for alternative designs of a building plan, the client determines the relevant number of people for their question. This also applies when a safety region wants to carry out a risk assessment to gain more insight into the request for assistance that may be expected.

A risk assessment is carried out on a legal basis:

- As an element of societal risk accountability for a spatial decision (adoption of a land-use plan, integration plan or environmental permit with deviation from the current plan).
- As an element of the societal risk accountability for granting an environmental permit.
- As an element of the societal risk accountability for a planning procedure order.

In these cases, the legislation requires that the result of the societal risk calculation is compared to the orientation value.

In a risk assessment for a decision, two or more situations are compared with each other: the situation before the decision, the situation after the decision and any more variants. This also quantifies the increase or decrease in the societal risk. In addition to the orientation value, in certain cases the legislation couples consequences to the increase of the societal risk [3]. The inventory of people should be based on the same principles to make a sound comparison between before and after.

If the risk assessment is carried out within a legal framework, there are two basic rules for determining the number of people for the risk assessment. Outside of these rules, there are also descriptions of 'good practices' where the risk analyst can find practical tips for the inventory of numbers of people [4, 8]. This chapter summarises them.

The principle rule is that the number of people used, reflects the possibilities provided by the land-use plan. This is also designated as 'the number of people that can reasonably be expected' [3, 6]. How these numbers are determined depends on the level of detail in the land-use plan, the land-use main group and the capacity already realised. There is no fixed rule for this. A 'good practice' is described in [8]. The approach is further elaborated in section 4.2.7.

Because a fixed rule cannot be given, the risk analyst must make choices here. This concerns the number present in a specific property, the indicators to be used for presence per m^2 GFA or per hectare and suchlike. The competent authority leads here.

For a QRA, the quality aspect includes that the choices should be substantiated, be reproducible and must be reported, please refer to the reporting requirements in Chapter 7 also. The text of the QRA is usually an appendix to the explanation of the plan. The QRA should be filed with the decision, including the calculation files. The QRA, with the basic principles for the inventory of people included, is then the calibration point for a within-plan change or elaboration, for renewal of the decision and for a decision for a neighbouring area with an overlapping area of influence.

The second rule is that traffic participants (users of the public highway and those present on a passenger platform) and users of public spaces (such as a park or square) are not included in the societal risk calculations where the result has to be compared with the orientation value. If desired, the competent authority can always use a societal risk calculation that also includes all of those present in their evaluation [4].

The remainder of this chapter contains a discussion of a number of practical aspects of the inventory of the number of people for a societal risk calculation. Section 4.1 shows four options for tackling the inventory of people. The risk analyst can use these, or a combination of them, provided the choices are reported with justification and are reproducible. The two most important source publications drawn upon are in references [4] and [8].

4.2 The population inventory in practice

The aim of the population inventory is to obtain a true and complete picture of the population that is legally present. The latter means that the population file must reflect the number of people that could be found in the area of influence at any time given the opportunities presented by the land-use plan.

4.2.1 The area within which the population must be inventoried

The legislation [3] prescribes that the population within the area of influence must be included in the QRA. The inventory area is bounded by the 1% lethality distance, measured from the centre of the through tracks or from the centre of the road or waterway.

In practice, very large areas of influence are possible on this basis, where entire villages or towns could be included in the area of influence.

However, this does not mean that a smaller area of influence will suffice in those cases.

It does mean though that the smaller the distance between a population area and the route, the larger the area's contribution to the societal risk. In practice, LPG is the substance that determines the risk for road and rail. This means that the inventory of the number of people within the effect distances for the most significant LPG scenarios should be as accurate as the available data permits. This is known as the societal risk primary zone. Outside of these distances larger, uniform population areas will suffice where the density (people per hectare) is based on the actual presence. Table 4-1 shows the distances from which a broad interpretation of population numbers provides sufficient accuracy. Figure 4-1 illustrates this approach.

Table 4-1 Societal risk primary zone per modality

Modality	**Societal risk determinative substance**	**Societal risk primary zone**	**Inventory distance**
Road	Flammable gas (GF3)	Up to 355 m	Up to 1% fatality
Railway	Flammable gas (GF3)	Up to 460 m	Up to 1% fatality
Inland waterway	Toxic gas (GT3)	Up to 600 m[4]	Up to 1% fatality

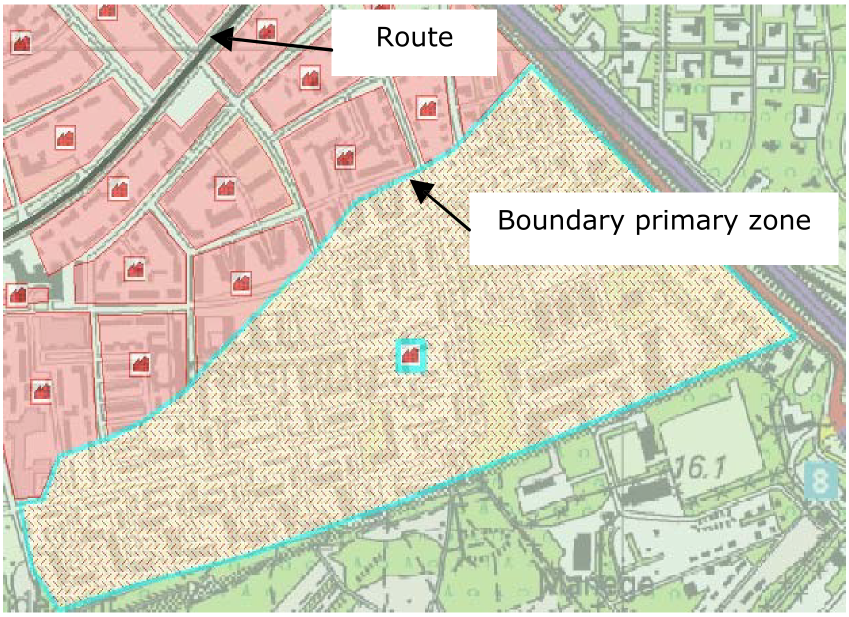

Figure 4-1 Example of more detail in the primary zone of the societal risk

The areas of influence per substance category (see Chapter 5 for clarification) are shown in table 4-2.

[4] Here we must understand that a societal risk above 10% of the orientation value is only possible in inland waterways transport with very high transport numbers and people densities, see the rules of thumb in Appendix 1 to the HART.

Table 4-2 Area of influence per substance category and modality

Substance category		**Area of influence 1% lethality distance (m)**		
Road, water	**Railway**	**Railway**	**Road**	**Water**
LF1			45[1]	35[1]
LF2	C3	35	45	35
LT1	D3	375	730	600
LT2			880	880
LT3	D4	>4000	>4000	N/A[2]
LT4			N/A[2]	N/A[2]
GF1			40	N/A[2]
GF2			280[3]	65
GF3	A	460[3]	355[3]	90
GT2			245	N/A[2]
GT3	B2	995	560	1070
GT4	B3	>4000	>4000	N/A[2]
GT5	B3	>4000	>4000	N/A[2]

1. LF1 transports are modelled as 1/13 LF3 transports.
2. This substance category is not (or hardly ever) transported in bulk on waterways or the road.
3. These distances are associated with the instantaneous release, delayed ignition, explosive combustion of the cloud in weather class D5 scenarios, death of people in a building (indoors). In theory, a greater distance is achieved for weather class D9. Because population areas outside of 355 m only affect the societal risk with unrealistically high numbers of people, the stated distance is amply sufficient in practice.

The QRA report should contain a justification of how the population file has been filled and the basic principles that were used.

4.2.2 *Inventory general*

RBM II distinguishes the following population types:

- Residential building, between 08:00 hours and 18:30 hours (meteorological day) and between 18:30 hours and 08:00 hours (meteorological night).
- Companies (day shift).
- Companies (continuous shift).
- Events (on working days).
- Events (during the weekend).

The presence of people differs per time of day: in offices for example, people are usually only present in the daytime. To this end a distinction is made for quantitative risk assessments between the presence during the annual average meteorological day (08:00 to 18:30 hours) and night (18:30 hours to 08:00 hours) [9, 10].

Events are characterised by the number of people present, the number of events per year, the duration of each event during the day and/or night and the fraction of the population outside during the daytime and at night.

4.2.3 *Inventory methods*

A number of data sources, in varying levels of detail, are available for inventorying people in the vicinity:

- Competent authority (municipal authority) inventory.
- BAG.
- Land-use plans.

In all situations, a check should first be made of whether the development that is to be evaluated has been the subject of previous investigation, or is situated within the inventory zone of a neighbouring development that has been investigated. If this is the case, then the population data used in the QRA that formed the basis for the decision that has already been made, can be used. The RBM II file used for this is then the starting point for the inventory. Naturally, these data will have to be checked and supplemented with more recent data where necessary.

In practice, the ultimate building file will comprise a combination of the data sources mentioned above. Section 4.2.7 describes a possible working method for a population inventory.

4.2.3.1 Competent authority (municipal authority) inventory

The competent authority (municipal authority) usually has detailed knowledge of the local situation. In addition to the building occupation, this concerns for example the frequency and duration of events. Where possible you can build on data collections that have already been created within the framework of previous studies.

4.2.3.2 BAG

The BAG is a publicly accessible online geographic information system (GIS) that can be used to access information from the Key Register of Addresses and Buildings {*Basisregistratie Adressen en Gebouwen*} (www.pdok.nl). The BAG comprises polygons with information linked to them at building level, including the status (e.g. 'in use') and usable area. In addition, it contains information at address level (as a point and as a polygon) such as residential function.

When combined with indicator numbers as mentioned in Section 4.2.4, an estimate can be made of the number of people present during the day and night periods per building. The BAG can be referenced as a WMS layer (Web Map Service) but it has to be downloaded as a WFS layer (Web Feature Service) in order to process the data and perform analyses. When this is done, the information visible on screen plus the underlying information are locally saved as files. Under certain conditions, a country-wide geodatabase can be downloaded.

To use this feature, it is necessary to have access to GIS software. In addition to professional programs, there are numerous applications available for free on the Internet.

4.2.3.3 Land-use plans

Just like the BAG, land-use planning information is available online. All kinds of land-use planning information can be viewed or downloaded via www.ruimtelijkeplannen.nl. This concerns, for example, the visual impression, planning regulations and the environmental studies such as external safety, that formed the basis for the plan. It should be noted that not all decisions are equally well documented. Moreover, the level of detail of the available data is highly dependent on the nature of the land-use plan.

Combined with the indicator numbers as mentioned in Section 4.2.4, for each building or area type an estimation can be made of the number of people present during the day and night periods.

4.2.4 Use of indicator numbers

Indicator numbers will have to be used when there is no information available about the number of people present. These indicator numbers can also be used to detail the presence that can reasonably be expected in applicable land-use plans, as mentioned in Section 4.2.5. This is covered in more detail later in this chapter.

4.2.4.1 Indicator numbers at object level

These should primarily be based on the indicators in Table 4-3 [4].

Table 4-3 Indicator numbers for number of people present per function from [4]

Function[1]	**Number of people**	**Unit**
Living	2.4	Per dwelling
Working (industry/business)	1	Per 100 m^2 GFA[1]
Working (offices)	1	Per 30 m^2 GFA
Shops[2]	1	Per 30 m^2 GFA
Schools[3]	1.1	Per student

1. GFA: gross floor area
2. The indicator for shops comprises staff and shoppers.
3. In the case of schools, the capacity of the school should be used, not the student file.
4. Unnamed functions, such as hospitals usually differ from each other significantly and should be evaluated individually. When doing so, the assumptions and basic principles in [11] can be used for a number of these functions.

Traffic participants are not included in the societal risk calculation but can be included in an additional calculation for fire brigade preparations [4].

4.2.4.2 Indicator numbers at area level

The basic principles in Table 4-4 [4] can be used when a plan is only functionally completed at area level. These basic principles can simplify the population inventory because a single assumption is used for a larger area.

Table 4-4 Additional population indicator numbers for large, homogeneous areas [4]

Area type		**Density (people/ha)**
Residential area	Nature area	0
	Outdoor area	1
	Incidental residential building	5
	Peaceful housing estate	25
	Busy housing estate	70
	Urban development with high-rise buildings	120
Industrial areas (production, distribution, etc.)	Low personnel density	5
	Average personnel density	40
	High personnel density	80
Office area	Offices (high-rise building)	200
Recreational area	Campsite, bungalow park	60-200[1]

1. The density stated applies to the summer season and must not be averaged across the entire year. The density that should be selected depends on the precise function; e.g. a spaciously laid-out campsite 60 people/ha, other campsites 130 people/ha, bungalow parks 180 people/ha, caravan sites 200 people/ha [11]

4.2.4.3 Differences in presence in day and night time

Table 4-5 shows the percentages for distributing the people across the meteorological day and night. The factors have been taken from [4]. These correction factors must also be used in determining the number of people that can reasonably be expected when the stated generic indicator numbers are used as the basis. If the land-use plan permits fully continuous operations, this should be included in the calculation, even if employees are only present during the day in the current situation; this could, after all, change if another company opens there.

Table 4-5 Distribution across day and night [4]

Object	**Day**	**Night**
Dwellings	0.5	1
Educational establishments (day)	1	0
Offices and businesses (day)	1	0
Fully continuous business[1]	See point 1	
Recreation and events[2]	See point 2	
Other[3]	See point 3	

1. Businesses that operate fully continuously often comprise a combination of an office, where employees are only present during the day, and a production department where people are present day and night in shifts. This can be entered as a separate office occupation (presence factor 1 for the day and 0 for the night) plus an occupation for shifts. The same approach can also be applied for, for instance, healthcare facilities and prisons.
2. People in recreational areas must be included in the calculation. This is done by defining different time periods with different numbers of people present, taking account of the desired accuracy. Events where large numbers of people are present for a short period of time, in stadiums for example, are also included in this way. As a guideline, the presence of large groups of people does not have to be included in the societal risk calculation if the product of the sum of the frequencies for the relevant scenarios and the fraction of the time in which a group of people is present is less than 10^{-9} per year [4].
3. For other specific situations, such as large shopping centres, hotel and catering industry and evening education, the applicable calculation method, either day presence and/or night presence or an event with peak attendance, should be

considered on a case by case basis. For an event with peak attendance, there should be a time correction using the duration of the presence and not the number of people present [4].

4.2.5 *Presence that can reasonably be expected*

The inventory of the population should be based on the actual situation of the people already present in that area and this should be supplemented by the number of people reasonably expected to be present, based on the applicable land-use plans. The reason for this is that the current plans allow for new building objects. In those cases, the planned capacity is greater than the population that is currently present. This means that information about the land-use plans within the area of influence and especially within the primary zone of the societal risk (see Table 4-1) are essential base information for a risk assessment.

When evaluating the presence that can reasonably be expected, it does not only concern new projects that have not yet been developed or undeveloped sites with development plans. It could also concern no yet determined capacity in existing, urban areas [4]. In this way the presence that can reasonably be expected in old land-use plans is often far too large, because in those days few restrictions were included in relation to the possible land-uses in the area. In this case, existing buildings (and thus population) are present, but the presence that could be expected is larger. The development plan therefore permits more people than are currently being taken up by the existing buildings. This presence that can reasonably be expected should also be taken into account, because a building permit (integrated environmental permit) cannot easily be refused and new objects can be developed without problems.

It is however not expected that existing developments in inner-city areas will be topped up to the maximum possible presence.

It is also possible for objects to exist that do not fit into the land-use plan. These objects could have been built illegally or are 'planned-out' in the new land-use plan, with the intention of realising a different function once the current owner departs. These objects should be included in the population inventory because, in general, they are now considered to be legally present.

If the situation, including the presence to be expected, differs significantly from the actual situation this could be reason for performing two calculations: one based on the possibilities presented by the plan and one on the basis of the population actually present. Only the former is mandatory.

4.2.6 *Current and future situation*

The buildings file must be compiled for both the current situation and the future situation. The buildings file for the current situation models all of those currently present plus the people who could reasonably be expected to be present in the area of influence on full realisation of the development opportunities in the current land-use plan (presence that can reasonably be expected)[4]. In the future buildings file the presence is adapted for the planning area to which the decision relates.[5]

In both cases, it is not only the people who are registered in the Municipal Personal Records Database but all of those people who could reasonably be expected to be present.

4.2.7 *Example of an inventory plan*

One possible working method for the environment inventory is shown in [8] in which various inventory methods are described and evaluated. The conclusion is that the combination of methods produces the most effective inventory method. This combination is shown in the flowchart below.

A detailed land-use plan includes the precise surface areas of building parcels per building object. In a flexible land-use plan an area may well have a functional purpose but the building parcels are still large and the building heights generic.
For example, many types of activities are possible in the industrial estate main group. Other examples can be found in [8].

This also includes indicator numbers that, in broad outline, match those in Table 4-3 and Table 4-4. Table 4-6 summarises them. The land-use plan is leading for the environment inventory.

4.2.7.1 Base on actual presence

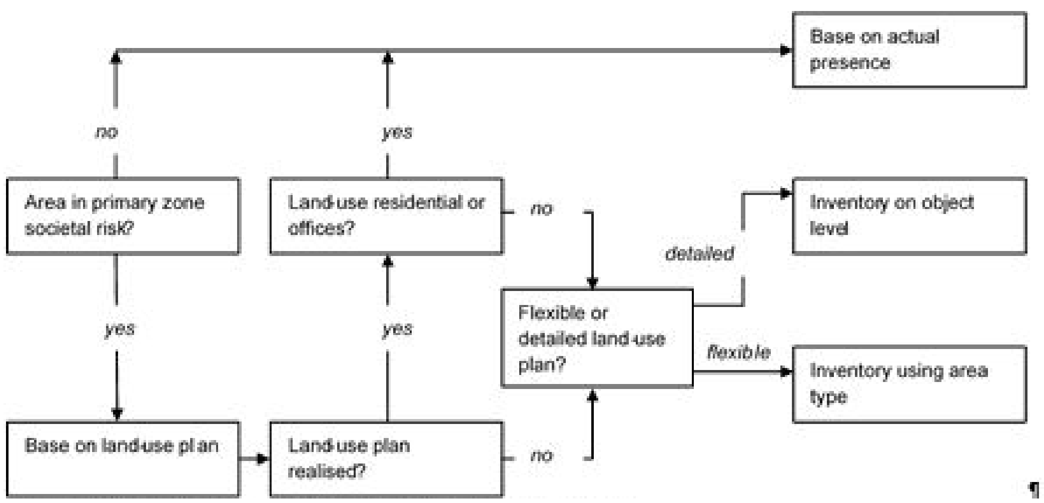

Figure 4-2 Flow-chart for population inventory, taken from [8]

[5] Environment decisions should therefore be based on land-use plans that have already been identified. For infrastructure decisions it is good practice to always include the (draft) land-use plans that have been submitted for inspection.

Table 4-6 Population indicator numbers (Dutch abbreviations) [8]

Land-use		**Area type**	**Object level**
B	Company	N/A	Offices: 1/30 m^2 GFA Company: 1/100 m^2 GFA
BT	Industrial estates	5, 40 or 80 people/ha	N/A
C	Centre	120 people/ha	Offices: 1/30 m^2 GFA Retail: 1/40 m^2 GFA
CO	Culture and leisure	N/A	Specific
DH	Retail - Large scale	120 people/ha	1/40 m^2 GFA 1/100 m^2 GFA
DV	Services	N/A	1/30 m^2 GFA
GD	Mixed	Specific	Offices: 1/30 m^2 GFA Retail: 1/40 m^2 GFA
H	Hotel and catering	N/A	Specific
K	Office	200 people/ha	Offices: 1/30 m^2 GFA
M	Social	N/A	Specific
R	Recreation - With overnight stay	25 people/ha 200 people/ha	N/A
S	Sport	25 people/ha	Specific
W	Living	N/A	2.4 people / dwelling unit
WG	Residential area	25, 70 or 120 people/ha	N/A

4.3 Special situations in the population

4.3.1 Population above a tunnel

The way in which calculations should be performed in situations where the population is in buildings above a tunnel is explained in Section 5.2.7. The population is inventoried and modelled as described above.

4.3.2 Population above a transport route

The population above a transport route is inventoried as described earlier in this chapter.

4.3.3 Population in mixed functions or multiple functions at the same location

Some land-use plans permit different functions. The different functions must be modelled in separate layers.

4.4 Evaluation of SP measures

In environmental decisions, it may be the case that changes to the spatial plan have to be calculated to limit the societal risk. These adjustments could relate to the function, building height, built-up surface area, building density and distance to the route. In order to see these adjustments properly reflected in the calculation results it is important that the population is inventoried and modelled in sufficient detail and matches the possibilities offered under the plan. It is worth mentioning that some adjustments relate to the movement of functions or buildings; if this leads to an increase or decrease in the population density elsewhere this should also be modelled in that (those) location(s). In other words, anything added to one side could be subtracted from the other side.

5 Modelling transport routes

This chapter describes which hazardous substances have to be considered in the risk assessment and how the transport route should be modelled.

5.1 Substances being transported

5.1.1 Substance categories and representative substances

The variety of substances transported along transport routes is so large that a risk assessment per substance would be extremely labour intensive. Due to practical considerations, the substances are included in a limited number of substance categories and a representative substance per substance category is used in the risk assessment. The classification of the substance categories and representative substances has been chosen in such a way that they are sufficiently representative and conservative and match the substances transported most frequently to the largest possible extent [12]. The representative substances to be used in the risk calculation are included in Table 5-1 [13]. Background information on the differences is included in [14, 15]. According to method II [12], LNG is classified in substance category GF0. To do justice to the risks of LNG, it should be treated provisionally as a GF3/A substance and calculated with the example substance propane.

Table 5-1 Representative substances per substance category and modality [13]

Substance category		**Representative substance**
Road/waterways Method II	**Rail Method I**	
GF1		Ethylene oxide
GF2		n-Butane
GF3	A	Propane
GT2		Methyl mercaptan
GT3	B2	Ammonia
GT4/GT5	B3	Chlorine
LF1		Heptane
LF2	C3	Pentane
LT1	D3	Acrylonitrile
LT2		Propylamine
LT3	D4	Acrolein
LT4		Methyl isocyanate

The classification of hazardous substances into substance categories under Method I (rail) is based on the GEVI code of the substance, see Table 9-1.

The classification of hazardous substances into substance categories under Method II (road, water) is based on the aggregation status (L = liquid, G = gas), flammability (F = flammable), toxicity (T = toxic) and volatility of the substance. A higher number (1, 2, etc.) after the letter code indicates a higher danger, so in this way a substance in substance category GT3, for instance, is a more toxic gas than a substance in substance category GT2. For transport on water a number of additional substance properties are used in the classification: the solubility, reactivity with water and density in relation to water [12].

Some substances are both toxic and flammable. The QRA must pay attention to both aspects. In principle, these substances must be modelled based on their toxicity as long as the cloud has not been ignited and based on their flammability properties once the cloud ignites. For transport on the road and on water this has already been incorporated in the annual intensities, because the substance has initially been classified in a combined substance category (e.g. LF1/LT2). In converting the recorded transports in substance categories into annual intensities these combination categories are included for 100% in the flammable category[6] and included for (1-immediate probability of ignition)x100% in the toxic category [16]. In the case of rail, this is incorporated to a limited extent in the annual intensities. The substance most transported by rail that is both flammable and toxic is acrylonitrile. The toxic liquid D3 substance category comprises this substance only. Only the toxic aspect of this substance is considered. The flammable aspect is only included in the determination of the probability of a hot BLEVE (see Section 9.5.4).

5.1.2 *Other hazardous substances*

The risk calculation only considers the bulk transport (road tankers, tank wagons, tank containers, fixed ship tanks, etc.) of flammable and/or toxic pressurised liquefied gases and flammable and/or toxic liquids. Transport of explosive substances and radioactive substances are not currently included in the calculations.

5.2 Modelling the transport route

5.2.1 *Length of the transport route*

When performing a risk calculation it is important that the length of the transport route that is entered is at least the same as the area of interest (planned area or new planned route). The minimum length for an infrastructure decision is the length of the transport route in the decision plus one kilometre either side. The minimum length of the transport route for a spatial planning decision is the length of the new spatial development plus one kilometre on either side[7]. So when the spatial development or new planned route that has to be examined has a length of 400 metres, a total of 2400 metres of transport route must be modelled. This is depicted schematically for an spatial planning decision in Figure 5-1.

The area of influence is equal to the modelled transport route plus the maximum 1% lethality distance around this route for the substance categories being transported along the transport route. So when the transport route in Figure 5-1 is a road over which LF1, LF2, GF3 and LT2 are transported (LT2 has the largest 1% lethality distance of 880 metres, see Table 4-1), then the area of influence becomes 1760 by 4140 metres.

[6] The probability of ignition is taken into account in the risk analysis itself.
[7] The background is that the kilometre with the highest societal risk is determined and that this kilometre also relates to the new spatial development.

When a risk assessment has to be carried out for an area of influence that is larger than the calculation program can handle, then the calculation area must be split up into subareas in such a way that there is always an overlap the size of the 1% lethality distance of the risk determinative substance category between successive subareas[7].

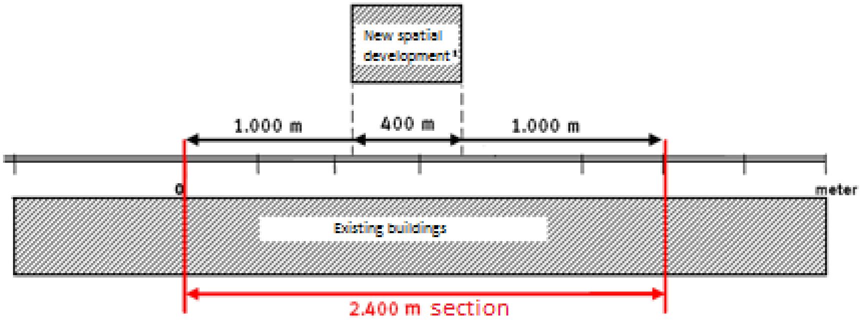

Figure 5-1 Example of determining the minimum length of the transport route to be modelled for a spatial planning decision

5.2.2 *Width of the transport route*

The width of the transport route is significant for modelling the outflow locations over the width of the route (see Section 5.2.5). The width is based on the distance between the two edges of the planned route.[8]

In the case of a railway this means that the width of the rail tracks is delineated to the space between the outermost rail tracks for the trough traffic. This width is included for the Railway 'Basisnet' routes in the appendices to the Rbn [5]. In the case of roads the outermost edge markings for the through carriageways is determinative for the width of the route to be modelled. In the case of waterways the width is indicated by the bounding lines for the waterway as included in the Public Works Ledger, accessible via Rijkswaterstaat.nl (see Section 11.2.2 also).

5.2.3 *Wide unused space between both directions*

Situations exist on roads where there is an area between the two traffic directions that is not used for the transport of hazardous substances. An example of this could be a central reservation. When this unused space between the two traffic directions is greater than 25 metres[9] each traffic direction must be modelled as separate sections.

5.2.4 *Location of the transport route*

The default situation in the QRA relates to a fully open through transport route at ground level with an equal distribution of the transports in both transport directions.
The (limited) option to model different situations or estimate them in relation to the effect on the risk, such as elevated or sunken situation, is

[8] If the maximum 1% lethality distance is used for the substance categories being transported this could lead to an unrealistically large overlap. The calculations for the railway 'Basisnet' indicate that an overlap of 500 metres is workable for RBM II.
[9] The choice of 25 m is based on the mutual distance between the outflow points. To avoid accidents being modelled on the central reservation, carriageways that are separated by more than 25 m must be modelled individually, see [14] also.

explained per modality in Module C, see Section 9.6 for rail, 10.6 for road and 11.6 for waterways.

5.2.5 *Outflow points*

This risk along transport routes is calculated by distributing the outflow points across the length and width of the transport route. To this end, outflow points (accident spots) are distributed across the transport route in such a way that both the individual risk and the societal risk are calculated as accurately as possible without the calculation time being unnecessarily long. Because of the characteristic differences in the routes for modalities the distance between the outflow points differs per modality [13].

For road and rail the distance between the outflow points when calculating the individual risk is a maximum of 10 metres. (So for a width up to 10 m a single outflow point is used, and for a width between 10 and 20 metres 2 outflow points are used, and so on. These are modelled every 10 metres along the length of the route; see Figure 5-2 also). When calculating the societal risk, outflow points with a mutual distance of maximum 25 metres are used.

For waterways, a maximum distance of 25 m between outflow points is used for calculating the location-specific risk; a maximum distance between outflow points of 50 m is used to calculate the societal risk.

The accident frequency that is assigned to each outflow point is the same as the accident frequency associated with the transport route, multiplied by the length of the transport route divided by the total number of outflow points modelled on the transport route.

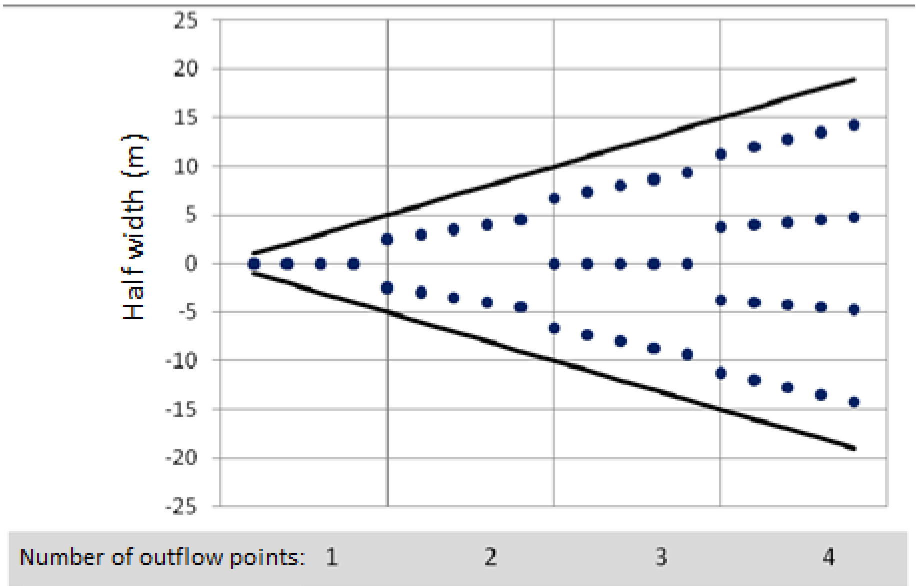

Figure 5-2 Distribution of outflow points across the width of the transport route for calculating the individual risk (road, rail)

5.2.6 *Subsections*

The transport route that is to be evaluated on the road, railway or waterway is known as a route. This route is modelled using one or more sections. The risk determinative characteristics of a section must not vary within a section, so each section has a fixed transport composition, accident frequency, width, etc. The section can however be entered using a multitude of coordination points so that the actual situation of the transport route is modelled as accurately as possible. The characteristics of the routes and sections are further elaborated in Module C, Chapter 9 for the railway, 10 for roads and 11 for waterways.

5.2.7 Tunnels/roofing

An enclosed tunnel is a special case because the tunnel has a shielding effect and the effects of some outflows in the tunnel will move through the tunnel and exit at the tunnel portals. Therefore, the risks could be lower at (alongside) the tunnel and could be higher at/in the extension of the tunnel portals.

In this chapter tunnels are understood to mean: structures, as defined in the Safety of Road Tunnels Act Supplementary Rules {*Wet aanvullende regels veiligheid wegtunnels*} (Warvw, 2013) and the comparable structures on the railways, both with a minimum length of 250 metres. This only applies to fully enclosed structures longer than 250 metres (so without ventilation openings and suchlike for example). The method proposed below does not apply to structures that do not match the description above.

TNO conducted research into how accidents involving hazardous substances in tunnels affect the environment [17]. Subsequently, AVIV researched the contribution to the ES risk in a consequence analysis [18].

This analysis demonstrated that the additional risks as a consequence of flammable gases (and flammable liquids) at the tunnel and at the tunnel portals are negligible.

As far as toxic substances are concerned, these substances could well lead to an increase in the risk contours at the tunnel portals with large numbers of transports of toxic liquids (or gases). These risks are negligible for small numbers of these transports.
In tunnels where a high amount of transport of toxic substances takes place, the additional risk at the tunnel portals as a result of accidents in the tunnel involving toxic substances is not negligible.

When establishing ‘Basisnet’, the presence of tunnels has been taken into account but the vicinity of the tunnel was not. Given the protective effect of the tunnel, the External Safety of Transport Routes Decree includes, that the IR ceiling does not has to be taken into account for the area parallel to a tunnel.

This reference manual therefore proposes the following method for tunnels that match the aforementioned description:

- In the calculation, set the number of transports in the tunnel section to 0.
- For flammable liquids and gases the effects at the tunnel portals can be ignored.

- Customisation is required when large amounts of toxic substances are transported. HART and the RBM II software currently do not provide for this as the necessary insight is lacking. The extent to which a quantitative approach is required and/or possible will be investigated in consultation with RIVM.

For lighter structures, such as roofing in railways or other structures and tunnels that do not match the aforementioned definition of a tunnel, the effects on the environment cannot be ignored. They must therefore be calculated as open road.

6 Modelling scenarios

Various types of accidents could occur when transporting hazardous substances. If more than 100 kg of hazardous substance flows out, effects could occur outside of the transport route and the outflow could contribute to the external safety risk. To prevent the calculation time becoming unnecessarily long only possibly relevant outflows, so outflows of more than 100 kg, are modelled in a limited number of representative default scenarios. These default scenarios must be used for the QRA calculation.

Section 6.1 contains a general description of the default scenarios per modality and Section 6.2 shows the subsequent events per substance category. The modality-specific parameters and a detailed description of the developments and effects to be considered by default are given in Module C, Chapter 9 for the railway, Chapter 10 for roads and Chapter 11 for waterways.

The effect and damage models that are described in Appendix 3 are to be used for modelling the effects and risks in relation to outflows of hazardous substances. These methods and models are mostly taken from the coloured books [10, 11, 19]. Section 6.3 contains an overview of the generic model parameters that do not differ per modality.

6.1 Scenarios

When transporting hazardous substances on transport routes, various causes can lead to various types of accidents, in which not all of the contents of the means of transport can flow out. An outflow of more than 100 kg is considered relevant for external safety [20, 21].

All possible outflows are modelled per modality using two default scenarios, a 'major' scenario and a 'minor' scenario. A third scenario is only relevant to rail, the hot BLEVE, also known as domino-BLEVE. The relevant scenarios in the QRA are therefore:

- Major scenario: Instantaneous release (the release of the entire contents at once as a result of the catastrophic failure of the tank).[10]
- Minor scenario: The continuous release of the contents of the tank through a hole in the tank. Here there could be, in principle, major diversity in the size of the hole and the amount that flows out which is modelled for the various modalities using representative hole sizes, flow rates or quantities (see also Module C).
- Hot BLEVE. The hot BLEVE domino scenario is possible with the simultaneous presence of flammable liquid and flammable or toxic gas in one train (mixed train). As a result of an incident where the outflow and ignition of flammable liquid occurs, a tank

[10] Instantaneous failure of a cargo tank is not considered realistic for the waterways modality [23]. In the case of liquid tankers (single or dual walled) a collision or damage to a vessel could lead to the outflow of part of the cargo tank in a certain period of time, depending on the location of the hole (above or below the waterline). A collision or damage to a vessel in the case of a gas tanker could lead to the pressurised tank moving followed by a pipe breaking off. The continuous outflow resulting from this is modelled as a two-phase outflow.

wagon containing flammable or toxic gas could be irradiated and at some time after the initial incident this tank wagon could fail as a result of increased temperature and pressure, whereby the entire contents of the tank could be released instantaneously at the increased temperature and pressure.[11] See Section 9.5.4 also.

The scenarios that can be distinguished per modality are shown in Table 6-1 (rail), Table 6-2 (road) and Table 6-3 (waterway).

Table 6-1 Rail scenarios [20]

Type of wagon	**Sub-stance cat**	**Scenario**	**Description of outflow**
Liquid	C3, D3, D4	Major	Release of the entire contents of the tank.
Liquid	C3, D3, D4	Minor	Release of some of the contents of the tank.
Gas	A, B2, B3	Major	Instantaneous release of the entire contents of the tank.
Gas	A, B2, B3	Minor	Continuous outflow of a liquefied gas through a hole with an effective diameter of 75 mm and contraction coefficient C_d=0.62 (see the model description appendix).
Gas	A, B2	Hot BLEVE	Instantaneous release of the entire contents of the tank at increased temperature and pressure.

Table 6-2 Road scenarios [21]

Type of wagon	**Sub-stance cat**	**Scenario**	**Description of outflow**
Liquid	LF, LT	Major	Release of the entire contents of the tank.
Liquid	LF, LT	Minor	Release of some of the contents of the tank.
Gas	GT, GF	Major	Instantaneous release of the entire contents of the tank.
Gas	GT, GF	Minor	Continuous outflow of a liquid through a hole with an effective hole diameter of 50 mm and contraction coefficient C_d=0.62.

[11] This escalation is no longer considered possible if the distance between a tank containing flammable gas and a tank with a highly flammable liquid is greater than 18 m or if the tank with the flammable gas is separated from a tank of highly flammable liquid by two 2-axle wagons or by a 4-axle wagon. The probability of this type of escalation is included per track section in the appendix to the Rbn as 'hot/cold BLEVE ratio'.

Table 6-3 Waterway scenarios [23]

Type of vessel	Sub-stance cat	Scenario	Description of outflow
Liquid, single walled	LF	Major	Release of 75 m^3 in 1800 seconds.
Liquid, single walled	LF	Minor	Release of 30 m^3 in 1800 seconds.
Liquid, dual walled	LF, LT	Major	Release of 75 m^3 in 1800 seconds.
Liquid, dual walled	LF, LT	Minor	Release of 20 m^3 in 1800 seconds.
Gas	GT, GF	Major	Continuous two-phased outflow through a 150 mm hole (maximum 1800 sec.) contraction coefficient C_d= 0.62.
Gas	GT, GF	Minor	Continuous two-phased outflow through a 75 mm hole (maximum 1800 sec.) contraction coefficient C_d= 0.62.

6.2 Event tree per substance category

An outflow of hazardous substances (Loss Of Containment, LOC) can have a number of subsequent events. The release of toxic liquids and gases leads to exposure to a toxic gas cloud. Various subsequent effects are possible on release of flammable liquids and gases, namely, a BLEVE, jet fire, pool fire, vapor cloud explosion and flash fire. The occurrence of these phenomena depends on the substance, the conditions and the scenario. This can be presented in an event tree. The event trees for the default scenarios are shown per substance category in the paragraphs below. The initial probabilities and subsequent probabilities in the event trees are completed differently per modality (see Module C).

6.2.1 Flammable liquid (LF, C3)

The outflow of a flammable liquid leads to the formation of a liquid pool on the ground or the water. When an ignition source is present a pool fire could occur which leads to heat being radiated to the vicinity.

In the event of immediate ignition, the liquid that has flowed out ignites resulting from, for instance, sparks created during the accident. In the event of delayed[12] ignition, the cloud formed by evaporation could ignite, a flash fire occurs which burns back, resulting in a pool fire. The effect distances for both scenarios are comparable for the assumed pool sizes and (representative) substances. These scenarios have therefore been combined into a single scenario where the effects are calculated as a pool fire [24].

[12] Delayed ignition occurs when, some time after the start of the outflow, the flammable substance that has flowed out is ignited by an open flame, hot surface, etc.

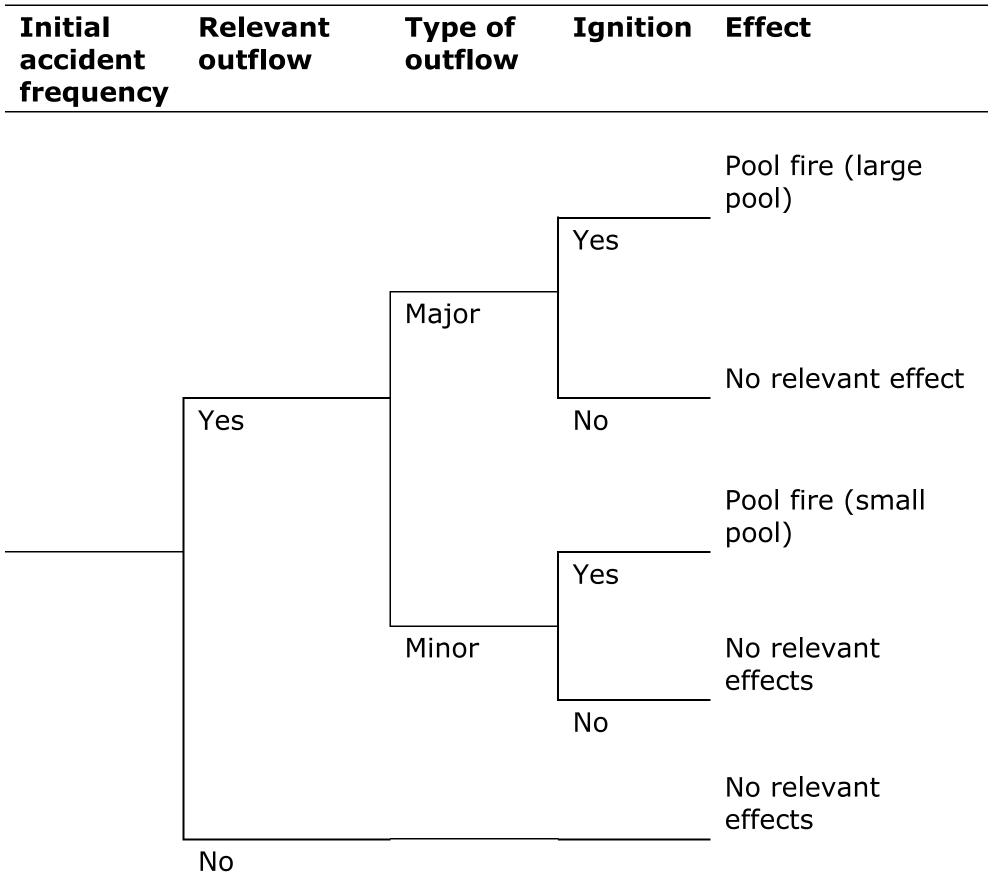

Figure 6-1 Event tree for flammable liquids

6.2.2 *Flammable gas (GF, A)*

Only flammable gases that are pressurised liquefied gases are considered because the bulk transport of a flammable gas that is cooled into liquid form does not or hardly ever takes place. Various effect scenarios are possible for flammable gas.

If immediate ignition occurs, a so-called jet fire (continuous outflow) or a BLEVE (instantaneous outflow) occurs with thermal radiation as the effect. If the gas that is flowing out is not ignited immediately, a flammable gas cloud forms with drops of liquid that disperse into the surroundings. Depending on the substance properties, some of the liquid drops will rain down and form a pool. The contribution of evaporation of the rained down liquid drops in the pool is ignored in the effect calculations. In the event of delayed ignition of the gas cloud that has formed, there is an event with the characteristics of both a flash fire and an explosion. This is modelled as two separate events, namely as a pure flash fire and as a pure explosion.

For rail, the domino scenario of a hot BLEVE is also possible if the tank wagon fails as a result of increased temperature and pressure resulting from the radiation.
There is no instantaneous outflow of flammable gas on waterways, only a major and minor continuous outflow. The event tree for gas tankers is shown in Figure 11-3.

Initial accident frequency	Relevant outflow	Instantaneous outflow	Ignition	Explosion	Effect
Irradiation through pool fire (rail)					BLEVE at increased temperature and pressure (rail)

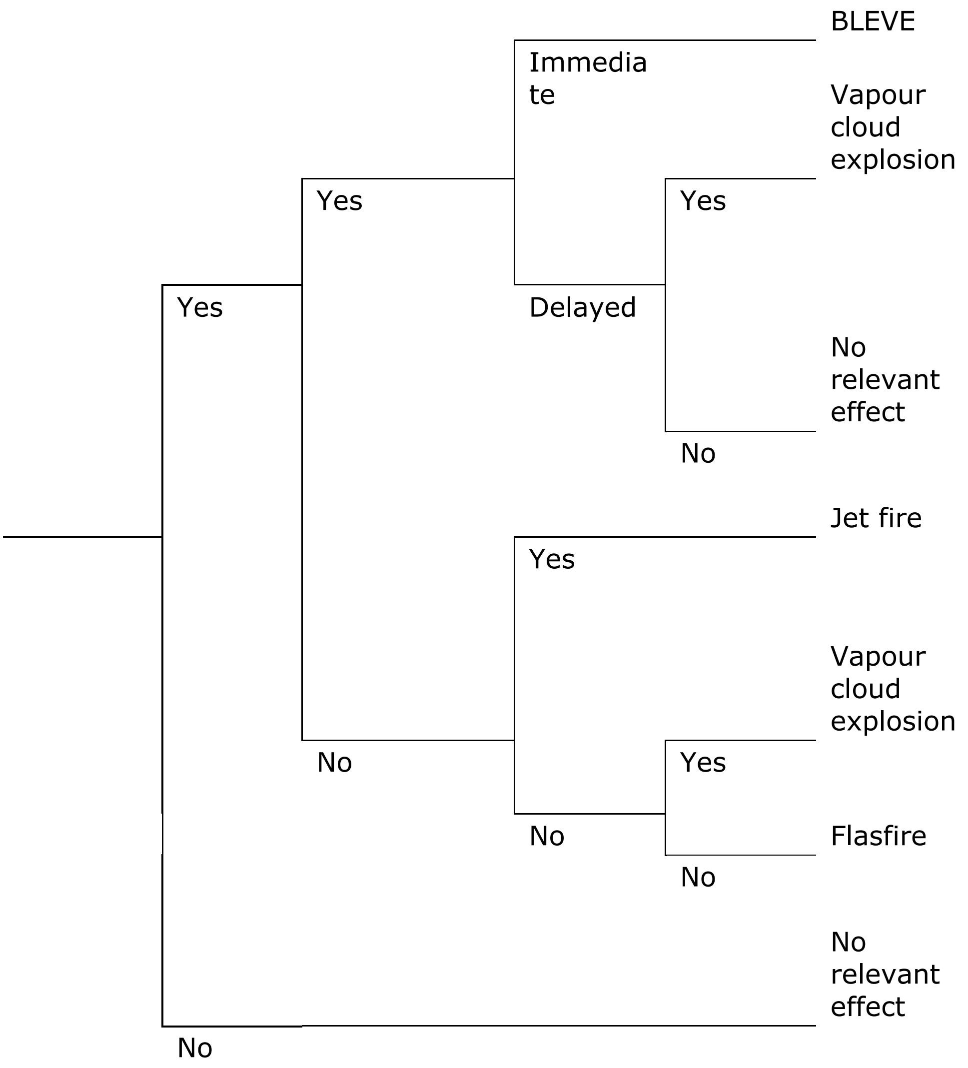

Figure 6-2 Event tree for flammable gases (road, rail)

6.2.3 *Toxic liquid (LT, D)*

A pool forms on the outflow of a toxic liquid. As a result of evaporation a toxic cloud forms which disperses into the surroundings.

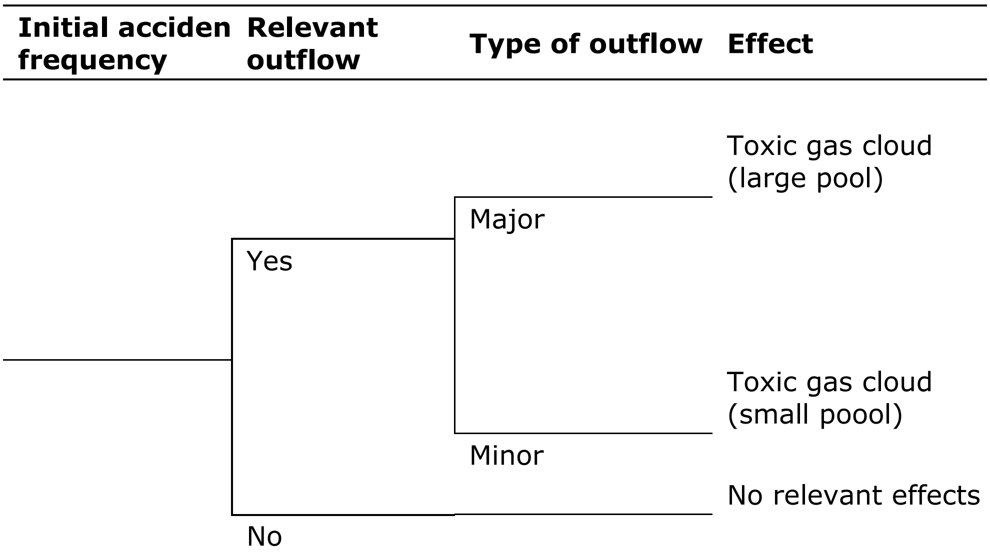

Figure 6-3 Event tree for atmospheric pressure toxic liquids

6.2.3.1 Toxic gas (GT, B)

Only gases that are pressurised liquefied gases are considered because the bulk transport of toxic gas that is cooled into liquid form does not or hardly ever takes place. Immediately after outflow, a toxic gas cloud with liquid drops forms, which disperses into the surroundings. Depending on the substance properties some of the liquid drops will rain down and form a pool. The contribution of evaporation of the rained down liquid drops in the pool is ignored in the effect calculations.
For rail, the domino scenario of a hot BLEVE is also possible if the tank wagon fails as a result of increased temperature and pressure resulting from the radiation.

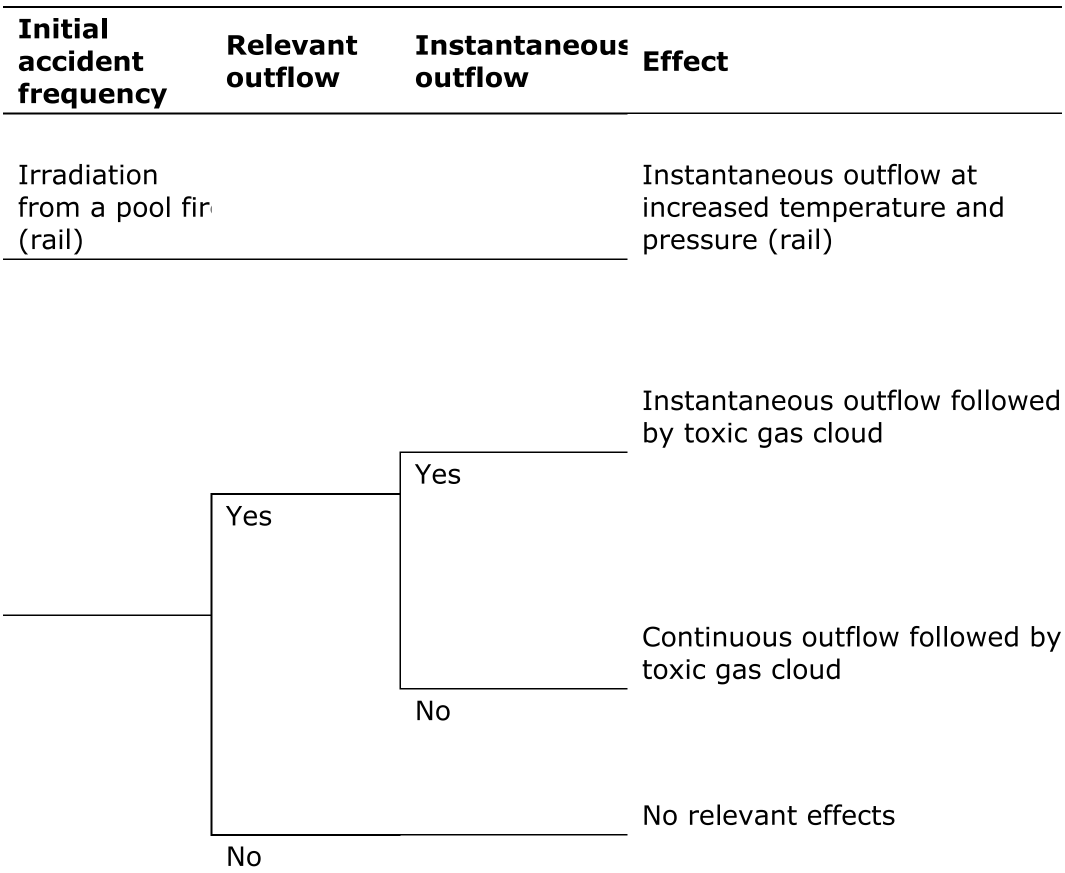

Figure 6-4 Event tree for toxic gases (road, rail)

6.3 Generic model parameters

This chapter contains an overview of the generic model parameters that do not differ per modality. Please refer to Module C for parameters that are specific per modality.

This chapter covers:

- Outflow and evaporation parameters
- Meteorological parameters
- Environmental parameters
- Substance-specific parameters and damage modelling

6.3.1 Outflow and evaporation parameters

By default the direction of the continuous outflow of pressurised liquefied gases is modelled horizontally with the wind. When doing so it is assumed that the outflow is not blocked (unhindered outflow) by the ground surface and objects in the immediate vicinity.

The outflow is modelled at ground level. Concentrations are also calculated at ground level. The (limited) height of the liquid column in the tank is not included in the calculation of the outflow.

By default, the continuous outflow through a hole in the tank is modelled with a constant outflow rate that is equal to the outflow rate at the start of the outflow.

When liquid flows out onto the road, the waterway or the tracks the liquid spreads evenly in all directions. A circular liquid surface area with fixed dimensions (see Module C) is assumed for rail and road transport. In the case of water, in the situation where the diameter of the pool is larger than the width of the waterway, a rectangular pool is assumed with a width matching the width of the waterway and a length equal to the quotient of the pool surface area with the width of the waterway. When doing so, the calculation of the pool size takes account of a balance between the outflow rate and for flammable liquids the combustion flow rate or for toxic liquids the evaporation flow rate from the pool. No time dependent temperature effects (cooling of the pool due to the evaporation) are taken into account in the event of evaporation.

6.3.2 *Meteorological parameters*

The weather station that is representative for the meteorological situation on the transport route must be selected. This should be based on the weather station in Table 6-4 that is closest to the transport route; it may be necessary to take account of several weather stations for very long transport routes. By default the meteorological conditions of each weather station is modelled with six weather classes (a combination of Pasquill class and wind speed) and twelve wind directions; these are shown in Appendix
2. This relates to processed data from [9].

Table 6-4 Overview of weather stations

Name					
Beek	Eelde	Hoek van Holland	Rotterdam	Twente	Volkel
Deelen	Eindhoven	IJmuiden	Schiphol	Valkenburg	Woensdrecht
Den Helder	Gilze-Rijen	Leeuwarden	Soesterberg	Vlissingen	Ypenburg

6.3.3 *Environmental parameters*

Default values for generic parameters are included in Table 6-5. No distinction into day/night or season is made for these parameters.

Table 6-5 Default values for a number of parameters

Parameter	**Default value**
Ambient temperature	282 K
Temperature at ground level	282 K
Water temperature	282 K
Atmospheric pressure	101.550 N/m^2
Relative humidity	83%
Roughness length	0.3 m
Averaging time constant	600 sec.

The values for meteorological parameters are annual averages [9].

The roughness length is a measure that indicates the effect of the urban and natural environment on the wind speed / turbulence and thereby indicates the dispersion of substances. The averaging time constant (for concentrations) is used in the Gaussian dispersion model for neutral gas to calculate the concentration and the plume width of the gas cloud.

6.3.4 *Substance specific parameters and damage modelling*

The probability of death P-lethal depends on overpressure, concentration of the toxic substance, thermal radiation and the exposure time to this effect and the possible direct exposure to fire. The calculation of the individual risk does not take account of protection factors (indoor stay), this is taken into account for the SR.

The model is explained in more detail in Appendix 3. The minimum value for P-lethal that is included in the calculation per scenario is 0.01 (1% lethality distance) [3].
The probability of death is calculated using so-called 'probit relationships' among other things. For flammable substances the probit relationship for thermal radiation gives the relationship between thermal radiation, exposure time and the probability of death of the people present.
For toxic substances the probit relationship is substance-specific and gives the relationship between the concentration, length of exposure and the lethality to humans after exposure to the substance. The probit relationships for the various representative toxic substances is given in Table 6-6.[13]

Table 6-6 Probit relationships for the representative toxic substances (C in mg/m3, t in min)

Substance categories		**Substance**	**Cas No.**	**a (C in mg/m^3)**	**b**	**n**
Road, water	**Rail**					
GT2		Methyl mercaptan[14]	74-93-1	-16.04	1	2
GT3	B2	Ammonia	7664-41-7	-15.60	1	2
GT4, GT5	B3	Chlorine	7782-50-5	-6.35	0.5	2.75
LT1	D3	Acrylonitrile	107-13-1	-8.60	1	1.3
LT2		Propylamine[15]	107-10-8	-15.00	1	2
LT3	D4	Acrolein	107-02-8	-4.10	1	1
LT4		Methyl isocyanate	624-83-9	-1.20	1	0.7

[13] New probit relationships are tested by RIVM's independent Probit Relationships Management Group.
[14] The probit relationship for methyl mercaptan is different from the relationship in the Reference Manual Bevi Risk Assessments [26]. When evaluating the available toxicity data the Probit Relationships Management Group found 1 suitable animal experiment (1981) to form the basis for a probit relationship for human death (Probit function technical support document 20110715). The probit relationship derived from this differs from both RBM and HRB. It has an interim status for the time being. The probit relationship used in RBM II is such that methyl mercaptan is a representative substance for the GT2 category, i.e. the results of the risk calculation for the GT categories are transitive (GT1<GT2<GT3). Furthermore, the contribution of the GT2 category to the risk is very small in practice.
[15] The origin of the constants for the probit relationship for propylamine is explained in [16].

7 Reporting requirements

This chapter describes the information that must be included in the risk assessment report in order to be able to properly evaluate the substance of the risk assessment.

The risk assessment must be documented in such a way that the competent authority has enough information to be able to effectively assess the substance of the risk assessment and reproduce it if necessary. This means, among other things, that all input details must be clearly described.

The most important elements are summarised in this section. Therefore, if requested to do so, the input file should also be sent to the competent authority, including the population data that was used. The competent authority may request a printout of the report from RBM II (without population data to limit the number of pages if necessary).

It is worth mentioning that the report must provide insight into all of the elements mentioned. Naturally, deviation from the layout in this section is permitted if this improves legibility.

Reporting requirements

General report information
Administrative information:
Reason for drawing up QRA (and if applicable the contracting party, contractor, etc.).
Method used:

- Computer model used with version numbers
- Reference Manual Transportation Risk Assessment with version number
- Weather station used
- Any additional guidelines
- QRA reference data (year of the prevailing situation/prevailing QRA and the investigated/future situation)
- Date QRA submitted (if this differs from the date of submission of the environmental permit or land-use plan)

General description of the transport route
Location and layout of the transport route, based on map(s) at a suitable level of detail. Showing the following:

- Location and name of the transport route(s)
- The name in accordance with the Rbn if a 'Basisnet' Route is involved
- North arrow and scale indication
- Risk heightening aspects (switches, connecting waterway, prescribed speed, etc.)

Traffic details, showing at least the following:

- Annual intensity used per substance category per section of the transport route, including citing the source. (In the case of

environmental decisions for 'Basisnet' routes: transport quantities from [5]; in the case of infrastructure decisions and environmental decisions for non 'Basisnet' routes: realisation figures and prognosis figures).
- Distribution of transport across day/night
- Distribution of transport across week/weekend
- If used: the growth figures used for the transport of hazardous substances
- Source citation

The data from the appendix of the Rbn will suffice for spatial decisions along 'Basisnet' routes.
For infrastructure decisions: Possible dangers around the section, which could have an effect on the probability of an accident occurring (companies/activities, windmills, combined/adjacent transport modalities).

Specific for rail transport:
The data from the appendix to the Rbn will suffice for spatial decisions along 'Basisnet' routes. For new routes this data must be described in accordance with the information in the Rbn, based on the new design.

Specific for road transport:
- The failure frequency used
- Width of the road (outermost edges of right carriageways)
- Location of slip roads, if relevant for the QRA (for example: because the slip road is part of the road modification)
- Location of intersections: if relevant for the QRA (for example: because part of the junction is part of the road modification)

The data from the appendix to the Rbn will suffice for spatial decisions along 'Basisnet' routes.
- 'Special situations', see Section 10.6.

Specific for waterways:
- Location-specific failure frequency used
  - Source citation and/or derivation stating the underlying data
  - If the necessary data is not available: navigability class and generic failure frequency
- Width of the waterway

The data from the appendix to the Rbn will suffice for spatial decisions along 'Basisnet' routes
- 'Special situations', see Section 11.6.

Description of the environment/population
Inventory area for the population. Where the relevant parameters for determining the inventory area are shown:
- Section length
- Size of the area of influence based on the 1% lethality distance for the most far-reaching substance category transported

A description of the population distribution around the transport route where fatalities could still occur, stating the way in which the description came about, and stating the functions that occur (living, events, etc.).
- The population variants used (current, future or other)

- The information sources used (competent authority, land-use plans, BAG, etc.)
- Additions/changes made to the information sources used
- Population as used for the risk calculation including the basic principles upon which the numbers are based.
- Presentation of numbers present in areas or grid cells by RDM coordinate.
- Depiction on current topographic map or aerial photograph

Description of possible risks to the surrounding area
Summary overview of the results of the QRA which includes at least the following:

For individual risk
- Map of the calculated individual risk, with contours for 10^{-5}, 10^{-6}, 10^{-7} and 10^{-8} (if present), which also shows the sensitive objects within the 10^{-6} risk contour
- Distance from the middle of the transport route to the 10^{-6} contour for the individual risk
- Description of the sensitive objects and moderately sensitive objects within the individual risk 10^{-6} contour

For societal risk
- The FN curve for the kilometre with the highest societal risk for the variants considered (current, future or other). The horizontal axis of the graph of the FN curve shows the number of fatal casualties, starting at 10 casualties. The vertical axis shows the cumulative probability up to 10^{-9} per annum.
- The figures which include an indication of the height of the societal risk in relation to the orientation value and the location of the kilometre with the highest societal risk.
- Tables with the relationship to the orientation value of the highest societal risk per kilometre.

If a societal risk justification is required: Explanation of the risk determinative scenarios for the societal risk.

For a recalculation of the risk for an in-hand environmental or infrastructure decision, for example because the input data or agreements about the risk assessment have changed, the additional report should clearly indicate whether agreements have changed in relation to the earlier study.
Here, if a number of factors have led to a changed risk, the effect per factor individually as well as the effect as a consequence of the combination of all factors should be illustrated.

When using the calculated intervals or contours, it is important that the accuracy of the mapping material is in accordance with the intended use. Given the fact that these intervals or contours could be significant at land-use planning level in the case of environmental decisions, the use of Key Register Large Scale Topography {*Basisregistratie Grootschalige Topografie*} (BGT) is recommended. This can be accessed via the Dutch National Spatial Data Infrastructure {*Publieke Dienstverlening op de Kaart*} (PDOK).

Module C Modelling specific modalities

8 Introduction

This module describes the way in which the modality-specific elements of the risk assessment must be implemented for the specific transport modalities. This relates to the rail, road and waterways modalities.

The module has the following structure:

- Elaboration per modality: rail (Chapter 9), road (Chapter 10) and waterways (Chapters 11 and 12).
- Per modality:
    - Scope and field of application;
    - Transport details;
    - Scenarios;
    - Accident frequency;
    - Subsequent probabilities and event trees;
    - Special situations.

9 Rail

This chapter contains the basic principles that should be used when assessing the risks associated with the carriage of hazardous substances by rail. The chapter is divided into six paragraphs, namely:
9.1 Scope and field of application
9.2 Transport details
9.3 Scenarios
9.4 Accident frequency
9.5 Subsequent probabilities and event trees
9.6 Special situations

9.1 Scope and field of application

Based on Figure 9-1 it is easy to determine which part of the reference manual is applicable to a specific rail situation. The basic principle behind Figure 9-1 is that substances relevant to external safety could be transported in the distinguished rail situations.

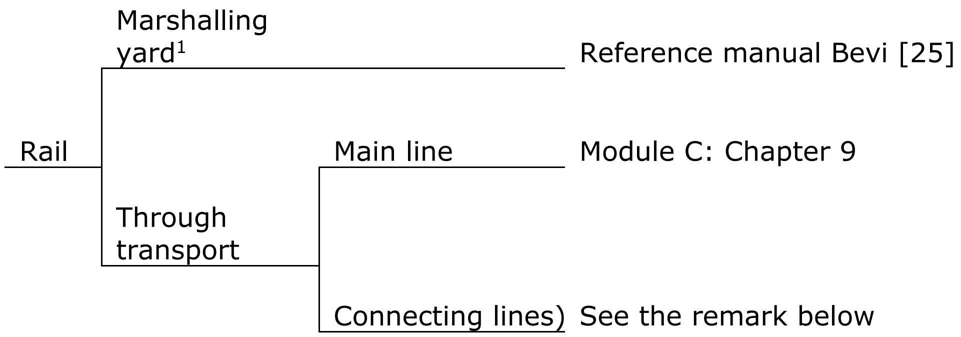

Figure 9-1 Flowchart for selecting the various rail categories
1) Environmental Management Act establishment designated in Appendix 3 to the Revi.

This chapter focuses on the risks that are associated with the transport of hazardous substances on the main line.

- Connecting lines (also known as branch lines) are dedicated railway lines/connections between industrial zones and the main line or marshalling yards. The marshalling yards are not handled separately in this reference manual because an established calculation method is not yet available for this. If a risk assessment has to be carried out on track sections that are always considered to be branch lines in the legislation you should contact the RBM II helpdesk (rbmii@rivm.nl) for advice.
- Railway marshalling yards for which the risk from activities involving hazardous substances has to be calculated within the framework of environmental or spatial permits should be calculated as specified in Appendix 3 of the External Safety Order. The calculation method for marshalling yards is described in [7] and is included in the Reference Manual Bevi Risk Assessments [25].

9.2 Transport details

9.2.1 Introduction

Hazardous substances are transported in various ways. The following are distinguished for the calculations:

- Gas tank wagons for transporting pressurised liquefied gases or highly cooled liquefied gases
- Liquid tank wagons for transporting liquids or molten substances
- Container wagons for transporting tank containers, among others

In the QRA you should assume the use of transport with tank wagons. In the risk assessment tank containers are counted as railway tank wagons, this is because there is no known specific accident data (failure frequencies and scenarios) for tank containers. Transport figures are expressed in tank wagon equivalents (TWE). One gas and/or liquid tank wagon is the same as one TEW and 2 containers of flammable substance or 3 containers of toxic substance equate to one tank wagon equivalent.

The number of substances allowed to be transported per track is of such a magnitude that a risk calculation per substance type can be very labour intensive. For practical considerations it is therefore useful to categorise the substances and use a representative substance in the calculation. Table 9-1 shows the substance categories from Table 5-1 that must be included in the risk calculation for rail, the substance category and the representative substances [12].

Table 9-1 Substance categories for relevant hazardous substances [13]

Substance category		**Representative substance**	**Applicable for GEVI**
A	Flammable gas	Propane	23, 263, 239
B2	Toxic gas	Ammonia	268, 26, 265
B3	Highly toxic gas	Chlorine	265 (UN 1017)
C3	Highly flammable liquid	Pentane	33, 33*, X33*, 336 (excl.UN 1093), X323
D3	Toxic liquid	Acrylonitrile	UN No. 1093
D4	Highly toxic liquid	Acrolein**	66, 663, 668, 886, (X88, X886)

* Indicates a third figure in the GEVI code for the substance. This is used to indicate that this third figure (if present, e.g. in methanol 336) is irrelevant.

** The original reference [12] gives hydrogen fluoride as an example substance for substance category D4. However, in [7] it was proposed to replace this example substance by acrolein, except when hydrofluoric acid is transported.

Substance category D4 (highly toxic liquid) is limited to liquids with GEVI codes 66, 663, 668, 886, X88 or X886 that are inhalation toxic in gas or vapour form at certain concentrations. There are also substances with these GEVI codes that pose no or other environmental risks. These substances are not included in the D4 category. You can check which substances these are on the RIVM website.

In addition to the hazardous substances mentioned in Table 9-1, less relevant hazardous substances are transported, for example substances with GEVI number 30 or 60 but which are included in the risk assessment for road and water.

There may be incidental transport activity of substances in UN Hazard Class 1 (explosive substances) or UN Hazard Class 7 (radioactive substances). Substances in UN Hazard Classes 1 and 7 are not included in the QRA.

9.2.2 *Evaluation of Individual Risk and Societal Risk*

The 'Basisnet' Act and associated legislation prescribes when the individual risk or the societal risk should be calculated. In a general sense, calculation of the societal risk is only necessary in specific cases (see Figure 9-2).

Table 9-2 Cases in which calculation of the societal risk is required (shaded boxes)

		Societal risk level		
		< 0.1 times ov	0.1-1.0 times ov	>1 times ov
Increase in societal risk	< 10%		See note 1	
	> 10%			

1. A calculation can be omitted when the increase in the societal risk as a result of the decision is smaller than 10% of the orientation value (ov). The increase is smaller than 10% in, for example, a preservational land-use plan in which no new developments are made possible.

A specific transport flow of hazardous substances is used in the calculation depending on the situation. The situations are summarised below. Please refer to the text of the Act for the exact requirements.

1. Spatial development within 200 m of a main railway (Bevt Sect. 3.1, 8.1)

IR: do not calculate, use distance from Appendix 2 to Rbn.
SR: calculate using numbers per substance category from Table 2 in Rbn (Rbn Sect. 14)
N.B. only required in the shaded cases in Figure 9-2.
N.B. do not calculate (Rbn Sect. 14.3) for other main railway lines (see definition, Rbn Sect. 1).

2. Changes to a main railway line (ES Policy para. 3.1)

IR:

a) Report IR ceilings from Appendix 2 to Rbn (ES Policy Sect. 25).
b) Report whether an increase in transport or change in risk determinative variables can be expected (ES Policy Sect. 26.1b and 26.1c).
c) Report the consequences of the changes on the completion of the IR ceilings (ES Policy Sect. 26.2).

SR:

a) Report SR ceilings from Appendix 2 to Rbn (ES Policy Sect. 27).
b) Report whether an increase in transport or change in risk determinative variables can be expected (ES Policy Sect. 27).

c) Report the consequences of the changes on the completion of the SR ceilings (ES Policy Sect. 27).

If the change concerns:

a) a widening of a main railway line on a single side, where the middle of the through track moves more than 6 m and the population density on the side of the expansion is higher than on the other side or
b) the installation of one or more switches, except in the case where the new switches are positioned between two existing switches which have a mutual distance of less than 1000 metres or
c) the rail section speed on one or more tracks is to be increased from less than 40 km/hour to more than 40 km/hour,
d) in the shaded cases in Figure 9-2, perform the calculations using the numbers from Appendix 2 to Rbn (ES Policy 28).

3. Construction of a main railway line (ES Policy para. 3.2)

IR Perform calculations using numbers per substance category estimated based on numbers for the railways situated within the study area in Appendix 2 to Rbn (ES Policy Sect. 33).

SR Perform calculations using numbers per substance category estimated based on numbers for the railways situated within the study area in Appendix 2 to Rbn (ES Policy Sect. 34).

9.2.3 *Geographical location of a 'Basisnet' Railway Route*

The coordinates of the railway section that is to be calculated have been determined to be the geographic centre of the outermost tracks of the set of tracks that is used for through traffic [5]. The start and end points as well as the width of the 'Basisnet' sections are included in the appendix to Rbn [5]. The location of the tracks are available as a web service (www.pdok.nl).

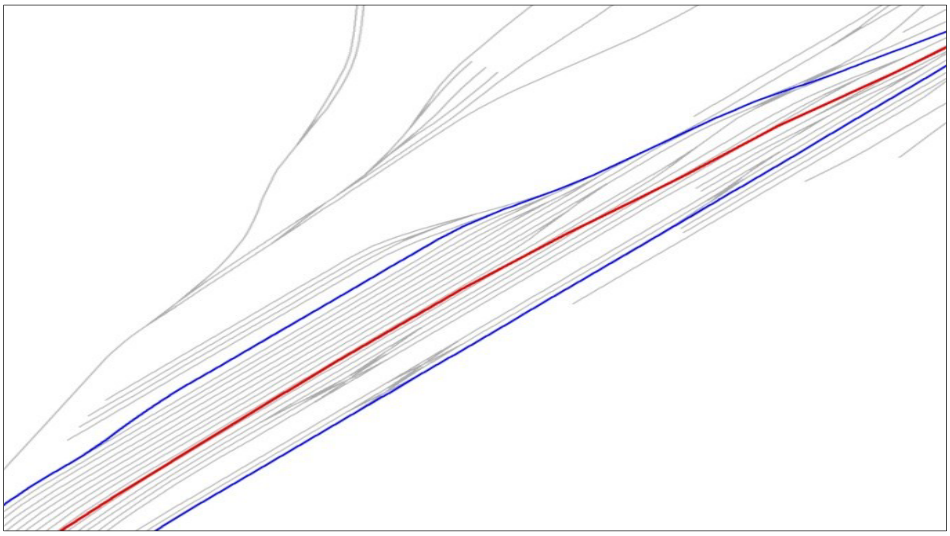

Figure 9-2 Determining the geographic centre (red) of the outermost through tracks (blue)

9.2.4 *Related parameters*

The following default ratio applies for distributing the transports over day/night and week/weekend [7]:

day : night = 1/3 : 2/3
week : weekend = 5/7 : 2/7

The day/night distribution for the rail process is based on the period 07:00-19:00 hours and 19:00-07:00 hours. This differs slightly to the definitions for the meteorological day and night (08:00-18:30 and 18:30-08:00 hours). For the meteorological day/night ratio, a ratio of 0.29 / 0.71 then applies.

N.B. The highly toxic gas category (occasional chlorine trains) is only transported at night and not during the weekend.

9.3 Scenarios

Various types of accidents could occur when transporting hazardous substances on the main line. The relevant outflows are modelled using two default scenarios:

1. Instantaneous release (the release of the entire contents at one time).
2. The continuous release of the contents of the tank through a hole in the tank.

When a flammable liquid and a flammable or toxic gas are simultaneously present in a train (mixed train), a hot BLEVE must also be taken into account. This is the instantaneous release of the entire contents of the tank at an increased temperature and pressure as a consequence of the irradiation of a tank wagon containing flammable gas A or toxic gas B2 as result of a pool fire causing the pressure in this wagon to rise so high that it fails (see Section 6.2 and 9.5.4). In the case of toxic gases in substance category B3 (chlorine) the probability of hot BLEVE is considered to be negligible due to the various preventative measures such as minimising the quantities and transporting in block trains. The default scenarios stated in Table 9-3 have been defined for rail [7].

Table 9-3 Overview of rail outflow scenarios

Type of tank wagon	Sub-stance category	Scenario	Description of outflow	Pool (m^2), radius (m)
Liquid	C3, D3, D4	Major	Release of the entire contents of the tank.	600, 14
Liquid	C3, D3, D4	Minor	Release of some of the contents of the tank.	300, 10
Gas	A, B2, B3	Major	Instantaneous release of the entire contents of the tank.	-
Gas	A, B2, B3	Minor	Continuous outflow of a liquid through a hole with an effective hole diameter of 75 mm and C_d=0.62.	-
Gas	A, B2	Hot BLEVE	Instantaneous release of the entire contents of the tank at increased temperature and pressure.	-

For the transport that is relevant to the risk, the tank content of a tank wagon for each substance category has been established and should be used in the calculations. The standard content of a gas tank wagon is:

- flammable gas 50 tonnes
- highly toxic gas 55 tonnes
- toxic gas 50 tonnes.

The tank content of a liquid tank wagon can be approximately 80 m3 but this is of lesser importance when modelling the scenarios as the calculation uses fixed pool surface areas, namely 600 m^2 for a major outflow[16] and 300 m^2 for a minor outflow, see [27, 28] also.

The probability of these default scenarios occurring is included in Section 9.4 and 9.5.

9.4 Accident frequency

Rail related failure frequencies are expressed per kilometre per wagon. Therefore, the term 'wagon kilometre' will be used in the text of this document. The term track kilometre is, for example, applicable to the additions for switches because this is related to the infrastructure and is used for the kilometre around the switch.

The following formula applies for calculating the failure frequencies for the main line [7, 20]:

$$F_{main\ line} = (F_{basic} \times C_{speed}) + C_{switch}$$

$F_{main\ line}$	failure frequency for the main line (per wagon kilometre)
F_{basic}	basic failure frequency for the main line (2.2×10^{-8} per wagon kilometre)
C_{speed}	correction factor for the rail section speed = 0.62 (track section speed < 40km/h) = 1.26 (track section speed > 40km/h)
C_{switch}	correction for the presence of switches: + $3.3.10^{-8}$ per track kilometre

A level crossing addition is no longer included [29].

The section for which the correction for switches applies runs from 500 meters before the switch to 500 metres after the switch. This correction is only applied once for a route section irrespective of the number of switches. The switch is the point at which the switch legs come together. The determination of the failure frequency is visualised in Figure 9-3.

The accident probability for chlorine trains is 5 times lower. This is due to the additional safety measures that are taken for these transports [20, 30].

[16] A pool surface area of 600 m2 with instantaneous outflow equates reasonably well to the results of outflow tests on the Betuwe Route [29].

Failure frequencies Betuwe Route, Port Rail Link
Different failure frequencies should be used for the Betuwe Route and Port Rail Link, due to the safeguards that have been implemented, namely [31]:

Port Rail Link:	1.66 x 10^{-8} per wagon kilometre (without switches, > 40 km/hour)
Port Rail Link:	3.64 x 10^{-8} per wagon kilometre (with switches, > 40 km/hour)
Betuwe line:	1.50 x 10^{-8} per wagon kilometre (without switches, > 40 km/hour)
Betuwe Line :	3.28 x 10^{-8} per wagon kilometre (with switches, > 40 km/hour)

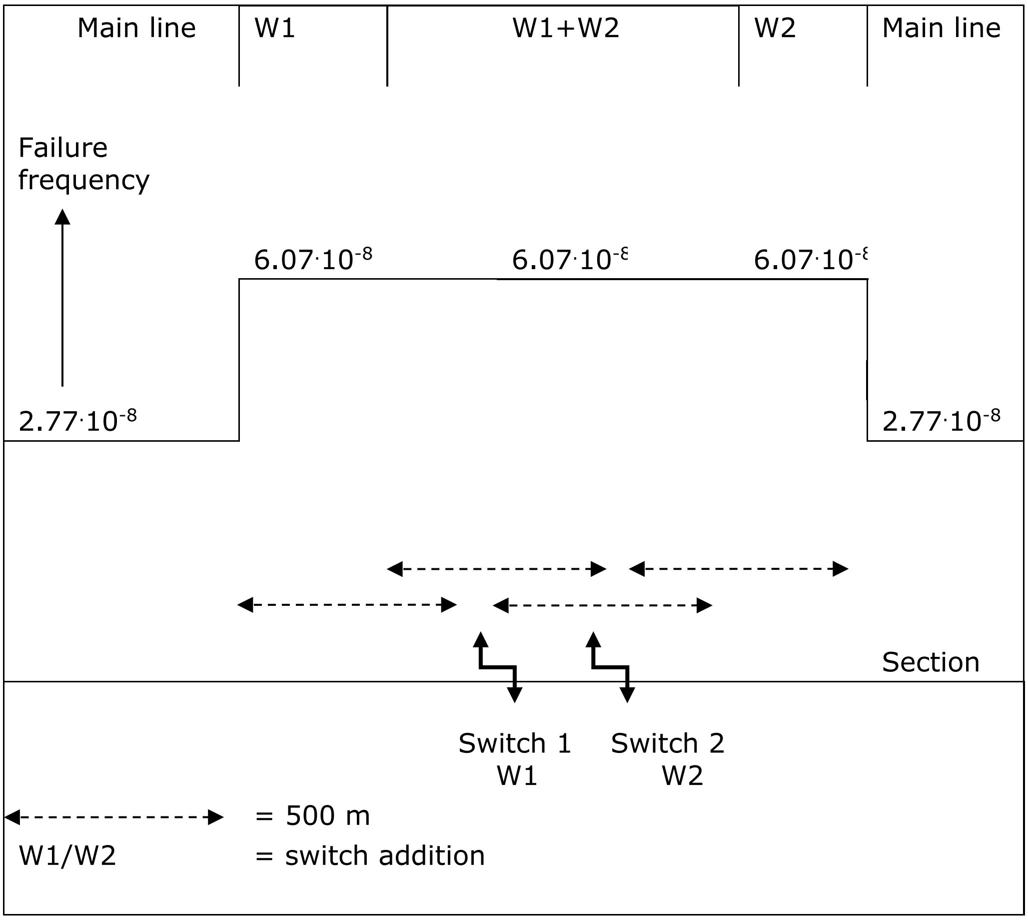

Figure 9-3 Example for the progression of failure frequency along a specific section with high track section speed and switches

9.4.1 *Assessment of safety measures*
The standard failure frequencies for the main line do not take into account the presence of additional safety measures. For a number of safety measures a reduction factor on the standard failure frequencies has been derived after research. This concerns the following safety measures..

ETCS (ERTMS)
The train protection system ETCS (European Train Control System), which is part of the broader ERTMS (European Rail Traffic Management System), is considered safer than ATB-EG. For ETCS (level 1), a risk reduction factor of 0.14 is applied, i.e. a correction factor on the failure frequency for the main line of 0.86. This factor was derived on the basis of an estimate made by a number of experts as to which accidents could have been prevented by ETCS [46]. This correction factor does not apply to the Port Rail Link and the Betuwe line, because the correction factor is already factored into the lower failure frequency.

This correction factor is also not applicable to complex situations because it is assumed that the increased accident frequency for complex situations will be compensated by the introduction of ETCS (see also Section 9.4.2).

Hotbox detection
Hotbox detection systems in the infrastructure measure the temperature of an axle bearing and a wheel tyre with an infrared detector. This is used to detect defective rolling stock, hot axle bearings and seized brakes in good time and prevent derailments. ProRail has calculated that this results in an estimated 11.6% reduction of the derailment frequency [47]. Based on a collision:derailment ratio of 65.4:34.6, this results in a reduction in the failure frequency of 0.08 (rounded off). Although further substantiation is required for a number of points, a correction factor of 0.92 can be assumed for the basic failure frequency for the main line.

This correction factor does not apply to the Port Rail Link, the Betuwe line and complex situations, because the correction factor has already been factored into the lower failure frequency.

Crash buffers and climb-up protection
Crash buffers absorb part of the crash energy and climb-up protection prevent a wagon from sliding upwards after a crash ('climbing up'), which could damage the tank wall. In an expert judgement study, this measure was rated with a risk reduction factor of 0.08 [48]. If the wagons are equipped with this provision, a correction factor of 0.92 is applied to the failure frequency for the main line.

This correction factor is not applicable to complex situations. In addition, the correction factor may only be applied to wagons equipped with these facilities, namely wagons carrying toxic/flammable gases and toxic liquids.

9.4.2 *Complex situations*
Complex situations[17] are defined as the locations where the main line is combined with a station environment with a bundle of tracks larger than 25 m, reduced speeds and many switches and/or many options to interact with other train traffic. There are often through trains, which are sometimes stationary for some time. The accident probabilities in complex situations will be higher than for the normal main line due to the increased probability of interactions (collisions).

[17] Complex situations are also known as junctions.

The accidents, train collisions, at complex situations are generally preceded by passing a signal at danger (Signal Passed at Danger). To reduce the incidence of signals passed at danger and the risk arising from them an addition to the ATB-EG {*Automatic Train Protection System - First Generation*} has been introduced, the so-called ATBvv {*Automatic Train Protection System - advanced version*} or a similar protection system such as flank protection. This has been done on all usual / obvious routes for goods trains. The Rail 'Basisnet' Working Group has proposed that the addition factor to the accident frequency for complex situations is compensated by a reduction factor following the introduction of ATBvv.

Within the framework of the development of the 'Basisnet' Rail Network, based on the aforementioned, it has been decided to not use the accident frequencies based on [32] or [33] in the calculations for complex situations.

This reference manual is in line with this decision. There is therefore no difference in failure frequencies for through train traffic on the main line or in complex situations.

9.5 Subsequent probabilities

9.5.1 Outflow probability

The subsequent probability of outflow at low speed is different to high speed. There is therefore a distinction between low speed (< 40 km/hour) and high speed (> 40 km/hour).

Table 9-4 shows the subsequent probabilities of an outflow where more than 100 kg flows out, applicable to a track section speed < 40 km/hour [7, 20]. For toxic and highly toxic liquids a factor 10 reduction applies and for pressurised tank wagons a factor of 100 applies in relation to the subsequent probability for flammable liquids based on agreements and experts estimates in relation to the stronger construction of wagons for these substances.

Table 9-4 Overview of subsequent probabilities of an outflow of more than 100 kg at low track section speeds (< 40 km/h) [20]

Substance category		**Subsequent probability**
C3	Flammable liquids	0.079
D3	Toxic liquids	0.0079
D4	Highly toxic liquids	0.0079
A	Flammable gases in tank wagons	0.00079
B2 and B3	Toxic gases in tank wagons	0.00079

Table 9-5 shows the subsequent probabilities of an outflow with an outflow in excess of 100 kg, applicable to a track section speed > 40 km/hour [7, 20]. For toxic and highly toxic liquids a factor 10 reduction applies here also and for pressurised tank wagons a factor 200 reduction applies in relation to the subsequent probability for flammable liquids.

Table 9-5 Overview of subsequent probabilities of an outflow in excess of 100 kg at high speed track sections (> 40 km/h) [20]

Substance category		**Subsequent probability**
C3	Flammable liquids	0.56
D3	Toxic liquids	0.056
D4	Highly toxic liquids	0.056
A	Flammable gases in tank wagons	0.0028
B2 and B3	Toxic gases in tank wagons	0.0028

In the default scenarios, there is a subsequent probability of 0.6 for continuous (minor) outflow and 0.4 for instantaneous (major) outflow [7, 20].

9.5.2 *Developments and probability of ignition*

In the case of toxic substances, the subsequent event is dispersion and toxic pollution. In the case of flammable substances, a distinction can be made into immediate and delayed ignition. The probabilities of ignition for the flammable gas and highly flammable liquid categories are shown in Table 9-6 [7, 20].

Table 9-6 Overview of probabilities of ignition [7, 20].

<table>
<tr><th colspan="2">Substance category</th><th>Outflow (ignition)</th><th>Probability of ignition</th><th>Effect</th></tr>
<tr><td rowspan="4">A</td><td rowspan="4">Flammable gas</td><td>Instantaneous (immediate)</td><td>0.8</td><td>Cold BLEVE</td></tr>
<tr><td>Instantaneous (delayed)</td><td>0.2</td><td>Flash fire, Gas explosion</td></tr>
<tr><td>Continuous (immediate)</td><td>0.5</td><td>Jet fire</td></tr>
<tr><td>Continuous (delayed)</td><td>0.5</td><td>Flash fire, Gas explosion</td></tr>
<tr><td>C3</td><td>Highly flammable liquid</td><td>Pool</td><td>0.25[18]</td><td>Pool fire</td></tr>
<tr><td>A or B2 and C3</td><td>Flammable or toxic gas + highly flammable liquid</td><td></td><td>See Section 9.5.4</td><td>Hot BLEVE</td></tr>
</table>

9.5.3 *Event trees*

Figures 9-4 through Figure 9-6 show the event trees and all subsequent probabilities. The failure frequency $F_{main\ line}$ is determined using the method shown in Section 9.4. The probability of this type of outflow is obtained by multiplying the subsequent probability in Table 9-4 or Table 9-5 by the subsequent probability of a minor (0.6) or major (0.4) outflow.

In the case of toxic and highly toxic liquids, a factor 10 reduction applies to the subsequent probability for flammable liquids.

[18] CPR 18/PGS3 [10] contains the various probabilities of ignition for flammable liquid. The base documents [21] have established that the probability should be 0.25.

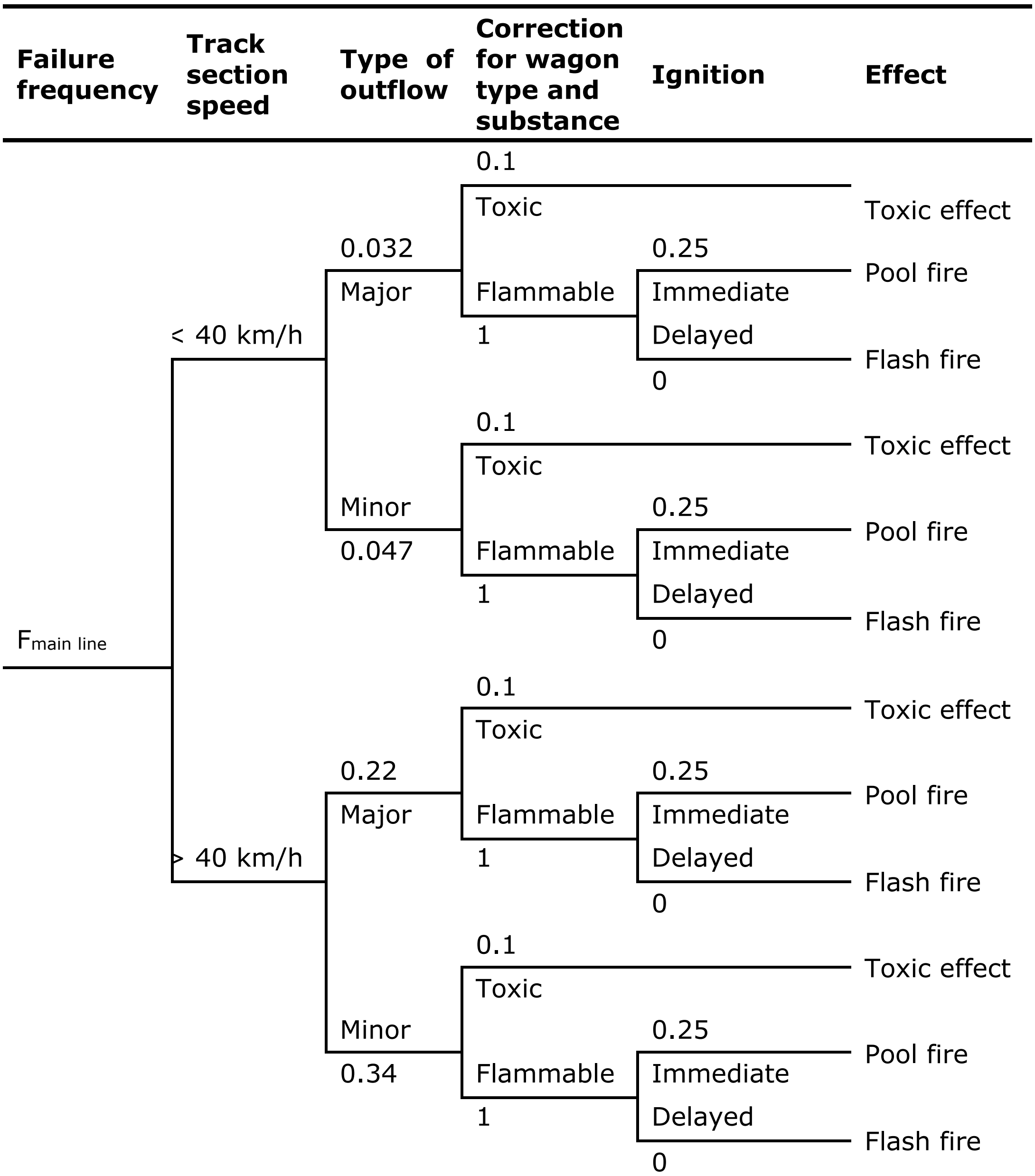

Figure 9-4 Event tree for a flammable or toxic liquid under atmospheric conditions (substance category C3, D3 and D4) [20]

As mentioned in Section 6.2.1 immediate ignition (pool fire) and delayed ignition (flash fire followed by pool fire) lead to comparable effect distances. These individual effects are therefore combined and calculated as a pool fire.

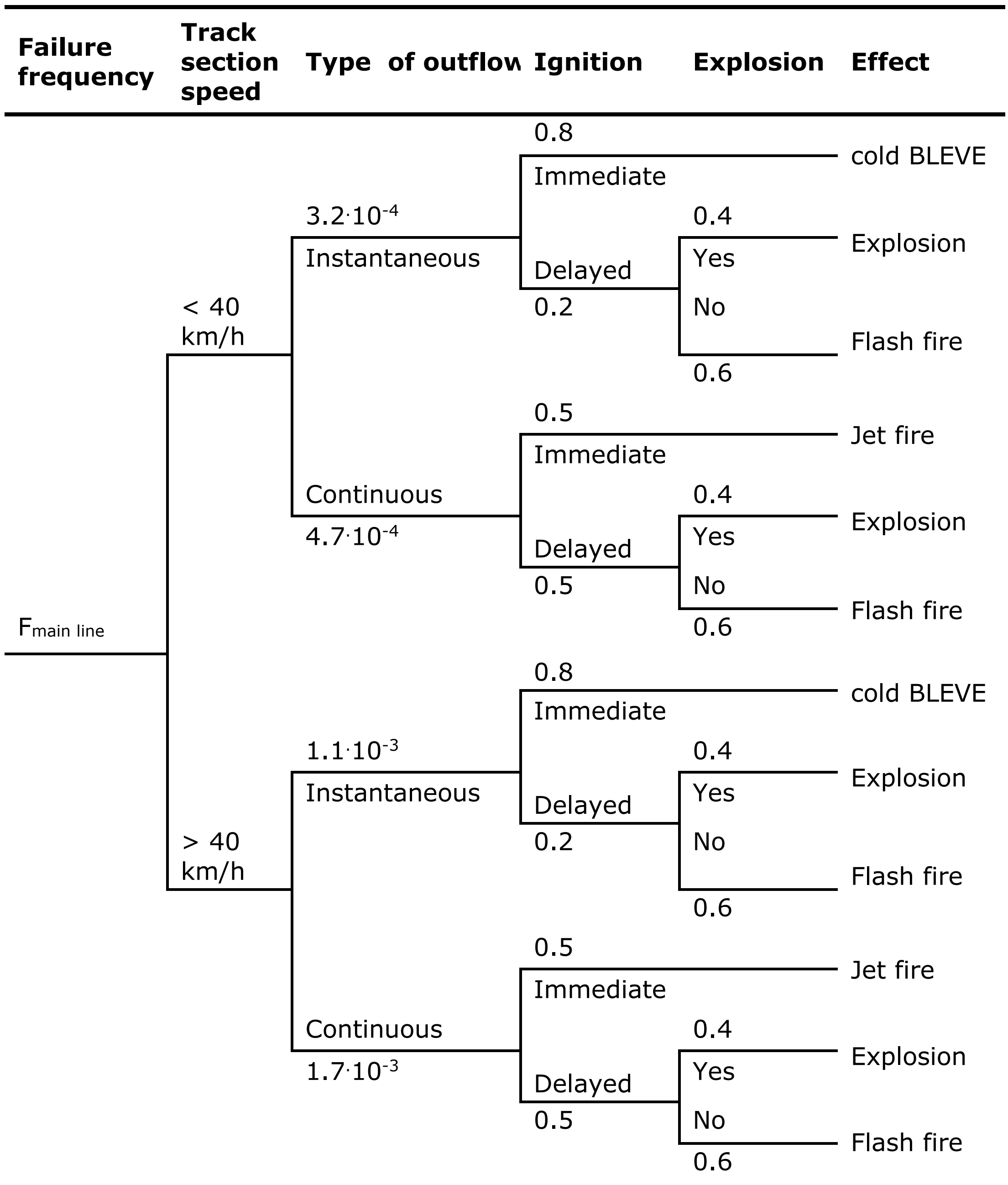

Figure 9-5 Event tree for a flammable gas (substance category A), excluding hot BLEVE [20]

After the delayed ignition of the gas cloud that has formed, effects occur with the characteristics of both a flash fire and an explosion. Two separate events are modelled, namely a pure flash fire (subsequent probability 0.6) and a pure explosion (subsequent probability 0.4) [10].

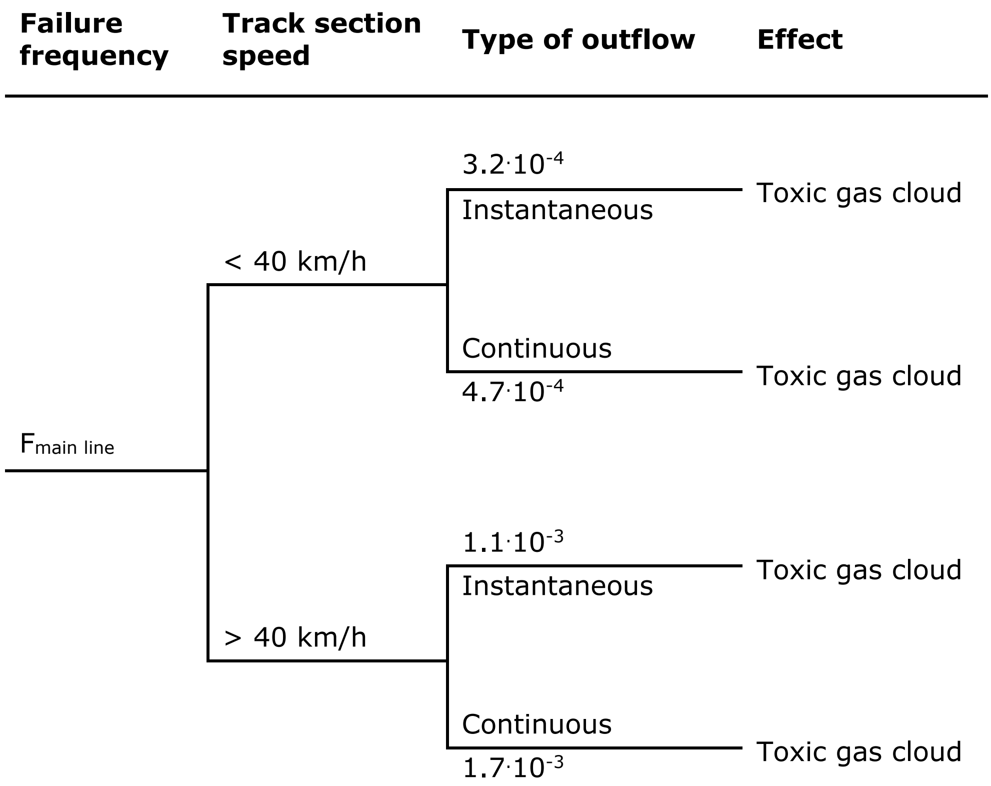

Figure 9-6 Event tree for a toxic gas (substance category B2 and B3), excluding hot BLEVE. There is a 5 times lower accident probability and no hot BLEVE for chlorine trains (B3).

9.5.4 *Subsequent probability of hot BLEVE*

The abbreviation BLEVE is short for Boiling Liquid Expanding Vapour Explosion. This means that, in the event of failure under pressure, a pressurised liquefied flammable gas or toxic gas explosively[19] expands into a vapour cloud. If the instantaneous failure of the tank wagon occurs under the storage conditions, as the result of mechanical failure of the tank wagon for example or from an external impact, this known as a 'cold' BLEVE. If the substance being stored is flammable and is ignited, a fireball forms.

A so-called 'hot' BLEVE occurs as the result of domino effects. Here we must consider in particular the irradiation of a tank wagon containing flammable or toxic gas by a pool fire, whereby the tank wall weakens and the pressure in the wagon rises to such an extent that it collapses in the course of time. The tank wagon fails at higher pressure and temperature than in a mechanical failure or external impact. This is then known as a hot BLEVE. If the substance being stored is flammable, it is ignited and a hotter fireball occurs than is the case for a cold BLEVE. In the case of toxic substances the entire contents of the tank are released at an increased temperature and pressure.

[19] For explosive evaporation of the liquid to occur, the temperature of the liquid must be higher than the homogeneous nucleation temperature (superheat limit) of the substance concerned. If this is the case, various authors refer to this as a hot BLEVE. Blast effects when the tank wagon fails are not considered in HART.

The probability of a hot BLEVE is determined from the probability of a cold BLEVE and the hot/cold BLEVE ratio.

$F_{hot\ BLEVE} = F_{cold\ BLEVE} x\ (F_{hot\ BLEVE}/F_{cold\ BLEVE})$

The ratio $F_{hot\ BLEVE}/F_{cold\ BLEVE}$ has been established for each track section within the framework of the 'Basisnet' Rail Network and is included together with the transport quantities in the appendix to Rbn [5].

Explanation
It is assumed that a hot BLEVE can only occur if the same train has wagons loaded with flammable or toxic gases placed immediately adjacent to wagons containing flammable liquids (so in the case of a mixed train)[21]. The probability of a 'hot' BLEVE occurring as a result of a jet fire from flammable gas (so-called cutting torch scenario) is considered to be so less probable that this scenario is not considered in the risk assessments. The same applies to a hot BLEVE as the result of a fire involving a flammable substance not being a hazardous substance (e.g. a wagon carrying wood).

9.6 Special situations

The calculation methods described above are suitable for the default situation, through rail routes at ground level. There are, however, special situations that could affect the probabilities of failure and spread of substances. These are:

- Sunken situation
- Elevated situation

The risk calculations for 'Basisnet' routes assumes that the default calculation is still representative, or slightly conservative, in these situations. All mainlines are designated as part of 'Basisnet'. The risk calculations for the existing 'Basisnet' do not, therefore, take account of these special situations. Naturally, these are highly relevant when considering the options for preparations for combating and limiting the scale of a disaster in accordance with Bevt Sect. 7.

The approach to the risk calculation at tunnel and roofing locations is outlined in Section 5.2.7.

10 Road

This chapter contains the basic principles that should be used when assessing the risks associated with the transport of hazardous substances by road.

This chapter is divided into six paragraphs, namely:

10.1 Scope and field of application

Within the road modality 3 types of roads are distinguished, namely:
1. Motorways
2. Rural roads
3. Urban roads

The type of road determines the accident frequency (Section 10.4) and the width of the road. Urban roads are roads with a maximum speed of 50 km/hour. Rural roads usually have a maximum speed of 80 km/hour and there is no physical separation between the two directions (so head-on collisions could occur). Motorways and dual carriageways usually have a maximum speed of 100 km/hour or more and a physical separation between the two directions [21].

10.2 Transport details

10.2.1 Introduction

The risk calculation only considers the bulk transport (road tankers, tank wagons, containers, ship tanks, etc.) of flammable and/or toxic pressurised liquefied gases and flammable and/or toxic liquids. The transport of break bulk is not considered relevant to external safety. Tank containers on trucks also have orange signs and are therefore recorded during counting and thereby form part of the transport figures for bulk transport. Transport of explosive and radioactive substances is not included.

Table 10-1 shows the category and substance classifications for the transport of hazardous substances by road [12, 13].

Table 10-1 Substance categories and representative substances [12, 13]

Category	Name	Representative substance
GF1	Flammable gas	Ethylene oxide
GF2	Flammable gas	n-Butane
GF3	Flammable gas	Propane
GT2	Toxic gas	Methyl mercaptan
GT3	Toxic gas	Ammonia
GT4	Toxic gas	Chlorine
GT5	Toxic gas	Chlorine

Category	Name	Representative substance
LF1	Flammable liquid	Heptane (diesel)
LF2	Flammable liquid	Pentane (petrol)
LT1	Toxic liquid	Acrylonitrile
LT2	Toxic liquid	Propylamine
LT3	Toxic liquid	Acrolein
LT4	Toxic liquid	Methyl isocyanate

The following characteristic tank quantities have been established per main category; they should be used for calculations in the QRA [21].

Table 10-2 Characteristic tank quantities [21]

Main category	Contents	Unit
Flammable gases (GF1 through GF3)	50	m^3
Toxic gases (GT2 through GT5)	16	tonnes
Flammable liquids (LF1, LF2)	23	tonnes
Toxic liquids (LT1 through LT4)	23	tonnes

10.2.2 *Evaluation of Individual Risk and Societal Risk*

The ‘Basisnet’ Act and associated legislation prescribes when the individual risk or the societal risk should be calculated. In a general sense, calculation of the societal risk is only necessary in specific cases (see Table 10-3).

Table 10-3 Cases in which calculation of the societal risk is required (shaded boxes)

		Societal risk level		
		< 0.1 times ov	0.1-1.0 times ov	>1 times ov
Increase in societal risk	< 10%		See note 1	(shaded)
	> 10%		(shaded)	(shaded)

1. A calculation can be omitted when the increase in the societal risk as a result of the decision is smaller than 10%. The increase is smaller than 10% in any case in
   a. a preservational land-use plan in which no new developments are made possible or
   b. a widening of the road where the geographical centre of the road remains in the same location, the transport remains below the reference values in the table in Appendix 1 to Rbn and the width of the road remains in the same class (e.g. less than 25 meters, from 25 to 50 metres, etc.; see Chapter 5.2.5)

A specific transport flow of hazardous substances is used in the calculation, depending on the situation. The situations are summarised below. Please refer to the text of the Act for the exact requirements.

1. Spatial development within 200 m of a ‘Basisnet’ Route (Bevt Sect. 3.1, 8.1)

IR: do not calculate, use distance from Appendix 1 to Rbn.

SR: calculate using numbers of GF3 transport from Table 1 in Rbn; on slip roads half the GF3 numbers on the road that the slip road branches off (Rbn Sect. 14). N.B. only required in the shaded cases in Table 10-3.

2. Spatial development within 200 m of a non 'Basisnet' Route (Bevt Sect. 4.1, 8.1)

IR: calculate using numbers per substance category in accordance with the most recent insights (Sect 15 of Rbn).

SR: calculate using numbers per substance category in accordance with the most recent insights (Sect. 15 of Rbn).
N.B. only required in the shaded cases in Table 10-3.

3. Changes to roads that are part of the 'Basisnet' (ES Policy para. 2.1)

IR:

a) Report IR ceilings from Appendix 1 to Rbn for all roads situated within the study area (ES Policy Sect. 5.1a).
b) Report whether an increase in transport or accident frequency can be expected (ES Policy Sect. 5.1b).
c) Report the consequences of the increase on the completion of the IR ceilings (ES Policy Sect. 5.2 and explanation).

SR:

a) Report SR ceiling from Appendix 1 to Rbn for all roads situated within the study area (ES Policy Sect. 6), if present.
b) Report whether an increase in transport or accident frequency can be expected (ES Policy Sect. 5.1b).
c) Report the consequences of the increase on the completion of the SR ceilings.

If the change concerns:

a) a road widening with two or more carriageways on a single side or
b) a road widening with two or more carriageways on both sides or
c) a modification where existing or projected (moderately) sensitive objects lie within 50 m of the new reference point
d) in the shaded cases in Table 10-3, calculate using the GF3 numbers from Appendix 1 to Rbn (ES Policy Sect. 7).

4. Constructing or changing roads that do not form part of the 'Basisnet' (ES Policy para. 2.2)

IR:

a) If it concerns the construction of a new road, calculate using numbers estimated on the basis of the numbers in Appendix 1 to Rbn and the appendix to ES Policy for the connecting roads in the study area (ES Policy Sect. 12.2b).
b) If it concerns a change to a road, calculate using numbers per substance category in accordance with the most recently available data (ES Policy Sec. 12.3).

SR:

a) If it concerns the construction of a new road, calculate using numbers estimated on the basis of the numbers in Appendix 1 to Rbn and the appendix to ES Policy for the connecting roads in the study area (ES Policy Sect. 13.2).
b) If it concerns a change to a road, calculate using numbers per substance category in accordance with the most recently available data (ES Policy Sec. 13.2).

N.B. only required in the shaded cases in Table 10-3.

5. Diversions on roads that are part of the 'Basisnet' (ES Policy para. 2.3)

IR:

a) Report IR ceilings for the diversion routes from Appendix 1 to Rbn (ES Policy Sect. 16.1a).
b) Provide insight into the scale of transport on the road that is closed based on the most recently available data (ES Policy Sect. 16.1b).
c) Provide insight into the expected increase in transport on the diversion routes (ES Policy Sect. 16.1c).
d) Report the consequences for the completion of the IR ceilings for the diversion routes (ES Policy Sect. 16.2 and explanation).

SR:

a) Report SR ceilings for the diversion routes from Appendix 1 to Rbn (ES Policy Sect. 16.1a).
b) Provide insight into the scale of transport on the road that is closed based on the most recently available data (ES Policy Sect. 16.1b).
c) Provide insight into the expected increase in transport on the diversion routes (ES Policy Sect. 16.1c).
d) Report the consequences for the completion of the SR ceilings for the diversion routes (ES Policy Sect. 16.2 and explanation).

Only required if the restriction of the traffic on the existing routes lasts longer than four months (Decision on Administrative Provisions Relating to Road Traffic Decree {*Besluit administratieve bepalingen inzake het wegverkeer*}, Sect. 37).

6. Diversions on roads that are not part of the 'Basisnet' (ES Policy para. 2.4)

IR: Calculate using numbers per substance category per year in accordance with the most recent figures for the road used for the diversion **PLUS**
the numbers per substance category per year in accordance with the most recent figures for the section of road that is to be closed. If the closure period is shorter than one year, the numbers should be multiplied by the fraction of the year that the closure lasts (ES Policy Sect. 20 and explanation).

SR: Calculate using numbers per substance category per year in accordance with the most recent figures for the road used for the diversion **PLUS** the numbers per substance category per year in accordance with the most recent figures for the section of road that is to be closed. If the closure period is shorter than one year, the numbers should be multiplied by the fraction of the year that the closure lasts (ES Policy Sect. 21).

N.B. only required in the shaded cases in Table 10-3.
Only required if the restriction of the traffic on the existing routes lasts longer than four months (Decision on Administrative Provisions Relating to Road Traffic Decree {*Besluit administratieve bepalingen inzake het wegverkeer*}, Sect. 37).

The following applies in general:
When a societal risk calculation is required, the substances transported by road other than those in substance category GF3, have to be taken into account since these substances also affect the size of the area of influence and the measures to be considered in the societal risk justification.

Where necessary the annual intensity should be increased to the year of the situations to be examined. The existing prognoses can be used for this.

10.2.3 Related parameters

A default day/night division of 70% for transport during the day and 30% in the night period applies for calculations of the road transport. This is 61%/39% for the meteorological day/night division. By default the transport takes place during the working week, so from Monday through Friday [34]. This distribution over the week can be refined if necessary based on the detailed data on transport and population [35].

10.3 Scenarios

Various types of accidents could occur when transporting hazardous substances on the road. The probability of these accidents occurring and the associated effects can differ from each other significantly. All possible outflows are modelled using a limited number of accident scenarios that are presented in a so-called event tree.

The scenarios, taken from [21], are defined in Table 10-4. The outflow of liquids leads to pool formation. The pool sizes stated must be used. A pool will not be formed when smaller quantities (approximately 0.5 m^3) are released from an atmospheric pressure transport unit. This scenario mentioned in [21] is no longer included because the effects of this type of pool alongside the road are negligible.

Table 10-4 Road transport scenarios [21]

Scenario	Description	Pool radius (m)	
		Toxic	Flammable
Atmospheric pressure tank wagons			
Major	Instantaneous release of the entire contents of the tank	23	23
Minor	Minor outflow	10	10
Gas tank wagons			
Major	Instantaneous release of the entire contents of the tank	-	
Minor	Liquid outflow through a hole with an effective hole diameter of 50 mm	-	

10.4 Accident frequency

The default values for the generic outflow frequency for pressurised and atmospheric pressure tank wagons has been established for three road types in [21], these are the averages per road type for the outflow frequencies applicable to the Netherlands. They are shown in Table 10-5.

The Update of road transport outflow frequencies study [37] has concluded that, based on an analysis of more recent accident data, an adjustment of these outflow frequencies is not necessary. It further concluded that the method described in [21] using local correction factors based on accidents with injuries to differentiate outflow frequencies for a road type is insufficiently robust and reliable.

Table 10-5 Outflow frequencies per road type

Road type	Outflow frequency (/veh/km)	
	Pressurised tank wagon	Atmospheric pressure tank wagon
Motorway	$4.3 \cdot 10^{-9}$	$8.4 \cdot 10^{-9}$
Rural roads	$1.2 \cdot 10^{-8}$	$2.8 \cdot 10^{-8}$
Urban roads	$3.8 \cdot 10^{-9}$	$1.2 \cdot 10^{-8}$

The outflow frequency is equal to the product of the initial accident frequency and the subsequent probability of an outflow of more than 100 kg. The subsequent probabilities of an outflow of more than 100 kg is covered Table 10-7 in Section 10.5. The initial accident frequency is known as the motor vehicle injury accident frequency and is defined as the probability of a motor vehicle becoming involved in an accident with injury without slow moving traffic per kilometre travelled. The motor vehicle injury accident frequency per road type is given in Table 10-6 and must be used in combination with the subsequent probability of an outflow, Table 10-7, as the accident frequency in the risk assessment.

Table 10-6 Motor vehicle injury accident frequency (without accidents in slow moving traffic) [21]

Road type	Motor vehicle injury accident frequency (vehkm)
Motorway	$8.3 \cdot 10^{-8}$
Rural roads	$3.6 \cdot 10^{-7}$
Urban roads	$5.9 \cdot 10^{-7}$

10.5 Subsequent probabilities and event trees

10.5.1 Outflow probability

The fixed outflow frequencies in Table 10-5 can be interpreted as the product of the motor vehicle injury accident frequencies (Table 10-6) and the corresponding subsequent probabilities of an outflow of more than 100 kg as included in Table 10-7 [21, 37].

Table 10-7 The subsequent probability of outflow of more than 100 kg

Road type	Probability of outflow > 100 kg	
	Pressurised tank wagon	Atmospheric pressure tank wagon
Motorway	0.052	0.101
Rural roads	0.034	0.077
Urban roads	0.006	0.021

10.5.2 Subsequent probability per scenario

Not all outflows of more than 100 kg are relevant to the external risk [21]. In addition, a distribution across the separate default scenarios, major and minor, is used. This is shown in Table 10-8.

Table 10-8 Subsequent probabilities for the scenarios [21]

Substance category	Fraction of the relevant outflow	Scenario fraction	
		Major	Minor
Flammable gas (GF)	0.3	0.35	0.65
Toxic gas (GT)	0.3	0.35	0.65
Flammable liquid (LF)	0.75	0.2	0.80
Toxic liquid (LT)	0.75	0.2	0.80

10.5.3 Probability of ignition

The following probabilities of ignition apply to flammable substances:

Table 10-9 Probabilities of ignition [24, 36]

Substance category	Probability of ignition	
	Immediate	Delayed
Flammable liquid LF 1	0.01	-
Flammable liquid LF 2	0.065	0.065
Flammable gases (GF1 t/m GF3)	0.8	0.2

In the event of delayed ignition of the flammable liquid, a flash fire will occur that will ignite the evaporating, flammable pool. Because the effect distance for a flash fire is comparable with that of the pool fire itself, the subsequent probability of a pool fire can be set to match the sum of the immediate and delayed probabilities of ignition in the model [36]. The probability of immediate ignition with LF1 (diesel) is 0.01. The probabilities of ignition for flammable gas have been used since 1995 [24].

After the delayed ignition of a gas cloud of flammable gases that have flowed out, there is an effect with the characteristics of both a flash fire and an explosion. This is modelled as two separate events, namely as a pure flash fire and as a pure explosion. The fraction that is modelled as an explosion or flash fire is equal to 0.4 or 0.6 respectively [10].

10.5.4 *Event trees*

Figure 10-1 shows the event tree for flammable liquids. Figure 10-2 shows the event tree for flammable gases. In these figures 'urban' means 'urban road' and 'rural' means 'rural road'; the subsequent probabilities of relevant outflow are the product of outflow of more than 100 kg in Table 10-7 and the fraction of relevant outflow in Table 10-8.

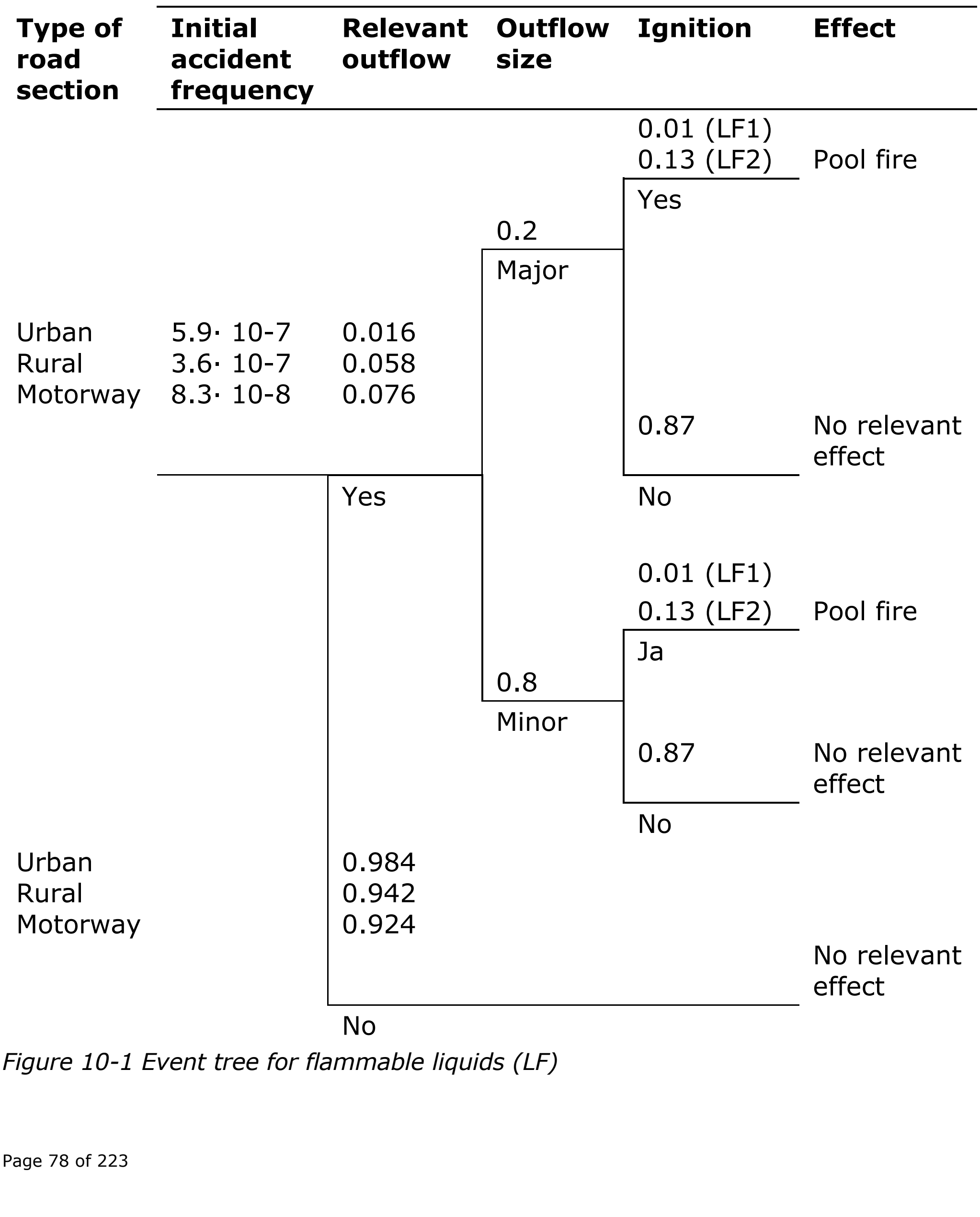

Figure 10-1 Event tree for flammable liquids (LF)

The event tree for toxic liquids (LF) is up to and including the 'outflow size' development the same as that of the flammable liquids and results in both the minor and major scenario in the 'toxic gas cloud' effect.

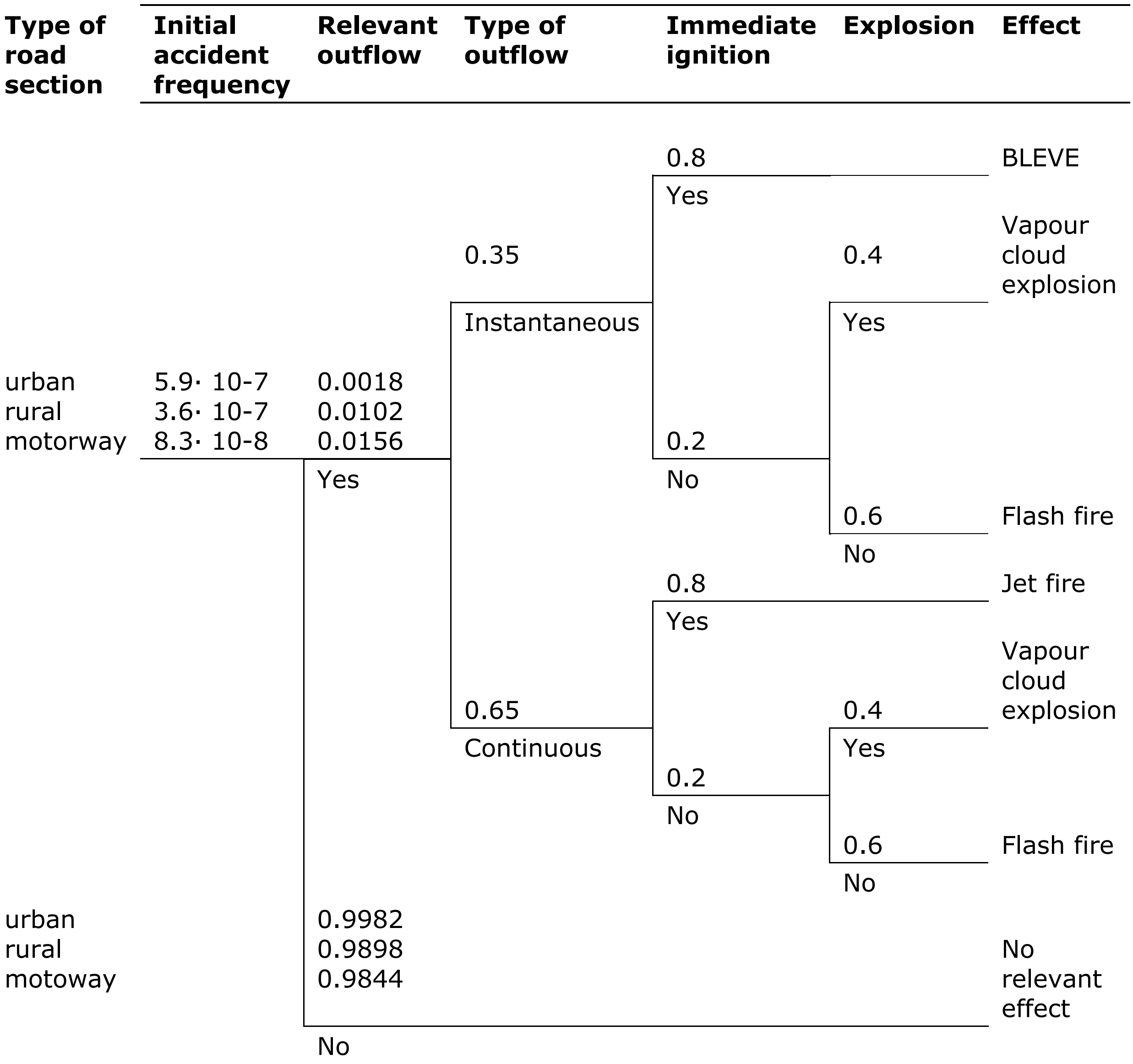

Figure 10-2 Event tree for flammable gas (GF)

The event tree for toxic gases (GT) is up to and including the 'outflow type' development the same as that of the flammable gases and results in both the instantaneous and continuous scenarios in the 'toxic gas cloud' effect.

10.6 Special situations

A special situation is all infrastructure that deviates from the default situation: a fully open through transport route at ground level, with equal distribution of the transports across the transport directions. The method prescribed in the paragraph above appears to be applicable in almost every case. For most special situations, such as elevated or sunken situation, the results are representative or slightly conservative.

The approach to tunnels and roofing has already been outlined in Section 5.2.7. Only the approach to roads with an exceptionally wide central reservation is covered here. In addition, the modelling of junctions, crossroads and intersections is explained.

10.6.1 *Wide central reservation between both directions*

When both carriageways of a road are separated from each other by more than 25 metres, both carriageways must be modelled as separate sections to prevent outflow points being mathematically situated in the central reservation.
First of all, the individual risk, the societal risk of the total and the location of the kilometre with the highest societal risk can be determined by calculating the risks of both sections. Then, only the parts of the sections on which the kilometre with the highest societal risk lies, is modelled and the societal risk is calculated once again. That total societal risk that is now calculated is the same as the societal risk for the kilometre with the highest societal risk [14].

10.6.2 *Junctions and crossroads*

In order to gain insight into the societal risk of the various sections of a junction, all possible combinations of the road should be calculated one by one (minimum 1 kilometre of road per combination) which then establishes the highest applicable societal risk for the junction or crossroads. Figure 10-3 and Figure 10-4 are schematic depictions of a junction and crossroads respectively. The text underneath explains the combinations of roads for which the societal risk must be calculated.

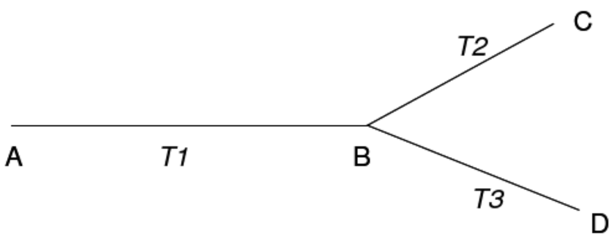

Figure 10-3 Schematic depiction of a junction

The following sections must be used to calculate the societal risk for a junction (Figure 10-3):

- Section A-B-C with transport numbers T1 (road section A-B) and T2 (road section B-C).
- Section A-B-D with transport numbers T1 (road section A-B) and T3 (road section B-D).
- Section C-B-D with transport number T2 (road section B-C) and T3 (road section B-D).

These three calculations must be used to check which combination has the highest societal risk.

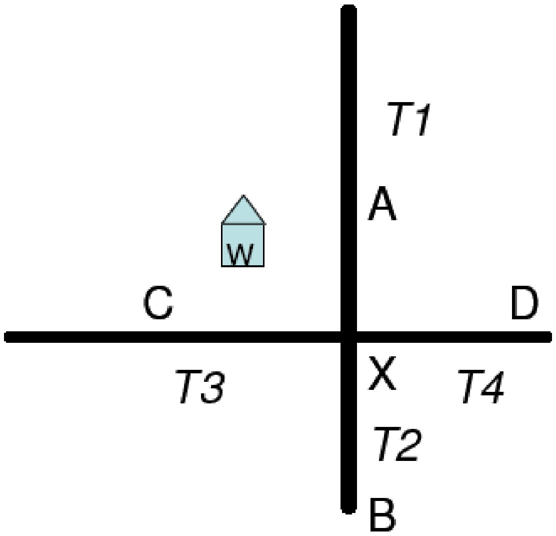

Figure 10-4 Schematic depiction of a crossroads

The following sections must be used to calculate the societal risk for a crossroads (Figure 10-4):

- Section A-x-B with transport numbers T1 (road section A-X) and T2 (road section B-X.)
- Section A-x-C with transport numbers T1 (road section A-X) and T3 (road section C-X).
- Section A-x-D with transport numbers T1 (road section A-X) and T4 (road section D-X).
- Section C-x-D with transport numbers T3 (road section C-X) and T4 (road section D-X).
- Section B-x-D with transport numbers T2 (road section B-X) and T4 (road section D-X).
- Section B-x-C with transport numbers T2 (road section B-X) and T3 (road section C-X)

These calculations can be used to check which subsection has the highest societal risk.

If the prime interest is in the effect of buildings on the societal risk for a junction or crossroads, the available data in relation to transport intensities, the building densities and the distance to the routes can be used as the basis for an advanced reduction of the combinations to be calculated by, in particular, examining those routes where the societal risk is affected by the buildings.

10.6.3 *Intersections (cloverleafs)*

For spatial planning decisions in the vicinity of an intersection it is only the societal risk that requires calculation. The number of transports on the slip roads must be based on half of the GF3 transport intensities stated in the appendix to Rbn for the road section where the slip road branches off [5].

In the risk assessment for the infrastructure decisions, the roads are modelled as a normal through road up to (or as through road at the site of) the intersection and the individual risk and societal risk are calculated from this based on transport intensities for the current situation, autonomous development and the future situation.

In addition, the intersection itself, including the slip roads has to be modelled. In each case, the individual risk for the intersection, including the slip roads has to be calculated. A societal risk calculation for the intersection, including the slip roads, is only necessary when:

- a relatively high or a significant increase in the individual risk is calculated (both in the calculation of the through route and in that of the intersection including the slip roads), and
- the societal risk in the calculation of the through route at the intersection is relatively high or is increasing, and
- as a result of the road modification the slip road comes closer to the buildings and the population density of these buildings is so high that an increase in the societal risk can be expected as a consequence of the road modification.

When the societal risk for the intersection has to be calculated in accordance with the conditions above, this calculation must be performed for the 'through' routes via the slip roads over the intersection that form part of the road modifications. If a societal risk calculation is not required, the report should state why the calculation is not required.

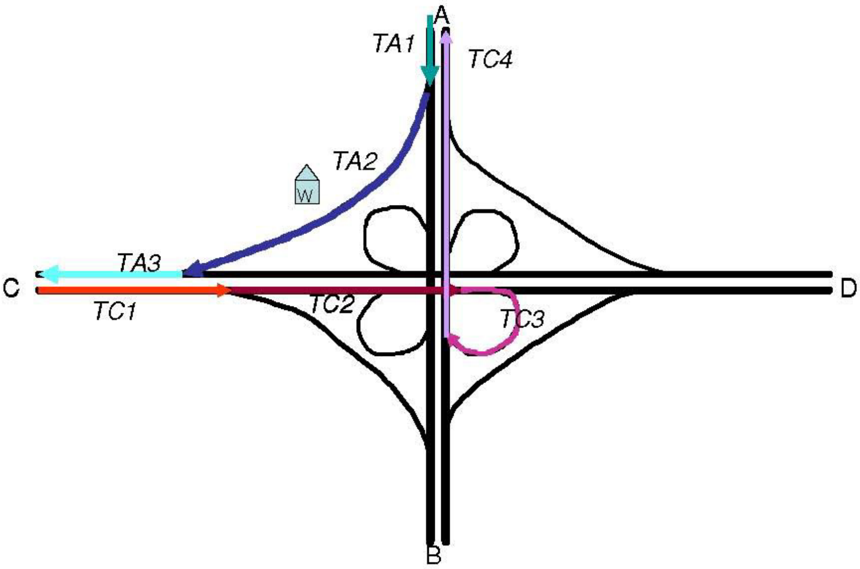

Figure 10 5 Schematic depiction of a cloverleaf including slip roads (with transport A-C highlighted)

To prevent the number of calculations being unnecessarily large the following approach has been chosen for the societal risk calculation for the intersection: only perform a calculation for the routes over the slip roads that form part of the road modification or along which new buildings are planned.

If we are primarily interested in the route A-C, see Figure 10-5, then the road sections from A to C and from C to A have to be modelled as separate sections in the risk assessment. For the traffic travelling from A to C this then concerns the road sections where the quantities TA1, TA2 and TA4 are transported and for the route from C to A it concerns the road sections where the quantities TC1, TC2, TC3 and TC4 are transported. Calculate the societal risk for both these sections for a section length of one kilometre; the societal risk of the total route is then equal to the societal risk of both directions.

Where necessary, a number of routes on the intersection can be calculated in this way.

The following figures give examples of the determination of the start and end of a road section for the calculation at the site of a crossroads or intersection [5].

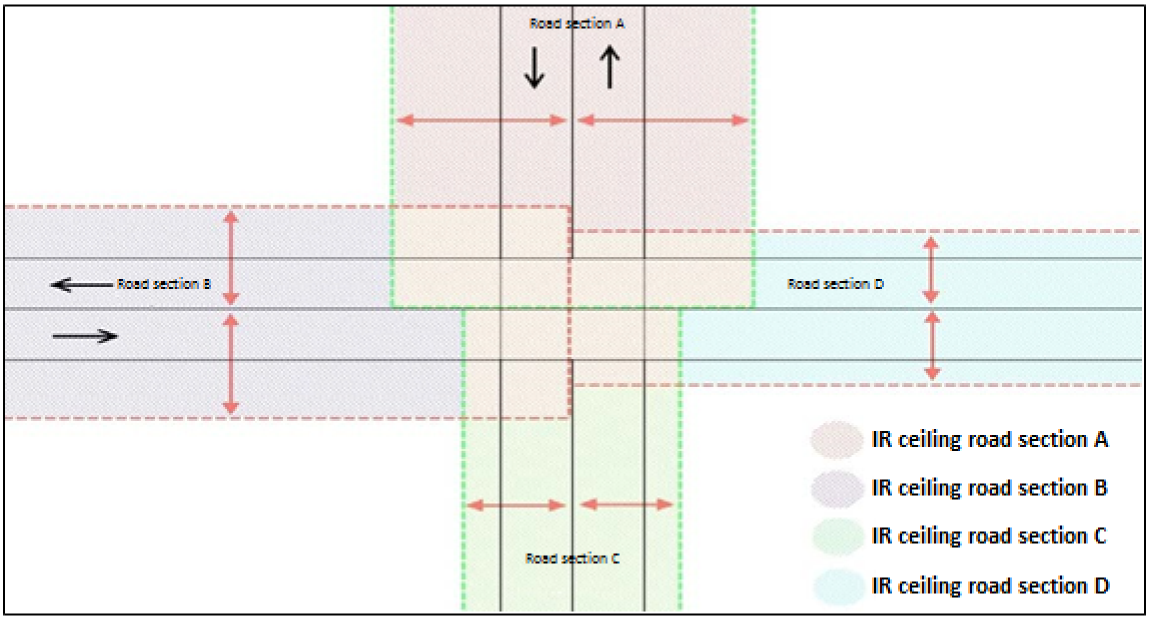

Figure 10-6 Start and end for a road section at a crossroads with crossing carriageways

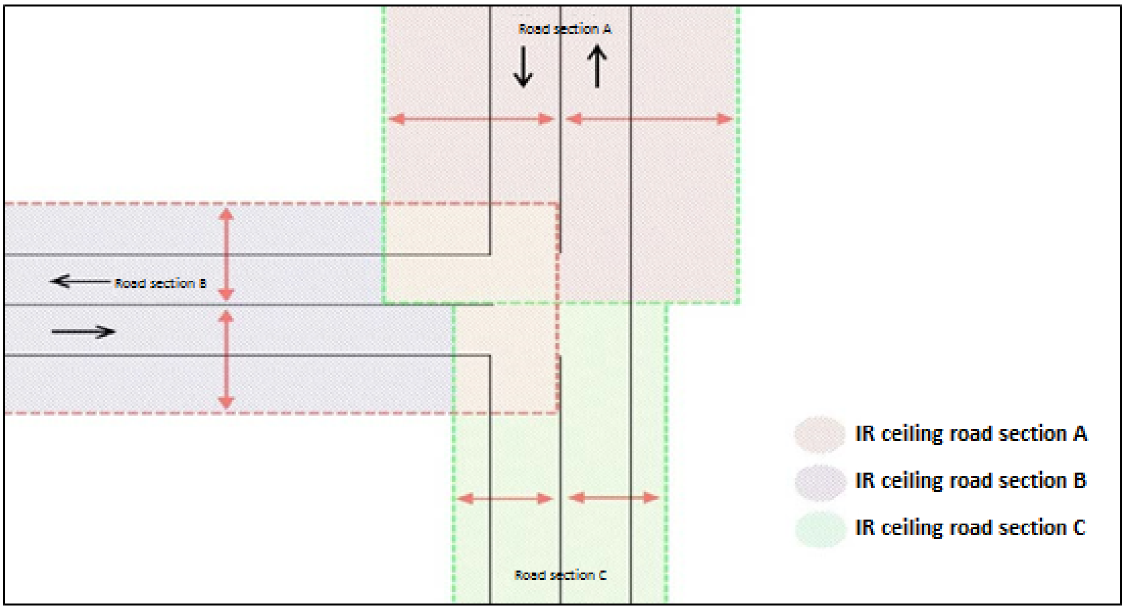

Figure 10-7 Start and end for a road section at a junction with splitting carriageways

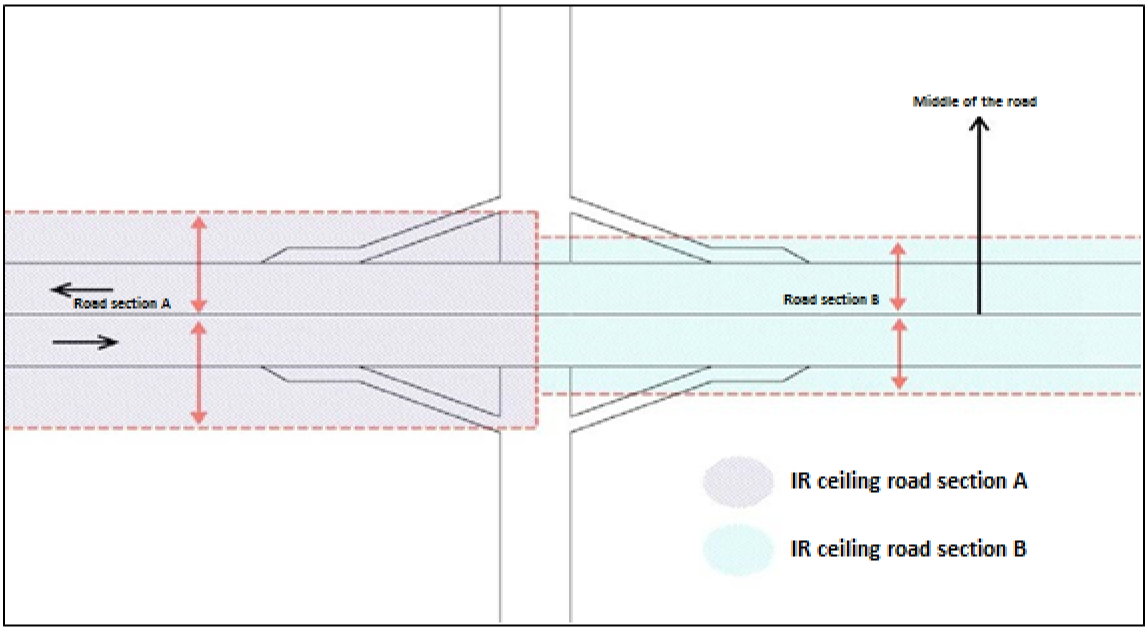

Figure 10-8 Start and end of a road section at slip roads

11 Waterways with less than 10% maritime shipping (inland waterways)

This chapter is divided into six paragraphs, namely:
11.1 Scope and field of application
11.2 Transport details
11.3 Scenarios
11.4 Accident frequencies
11.5 Subsequent probabilities and event trees
11.6 Special situations

11.1 Scope and field of application

This chapter contains the basic principles that should be used when assessing the risks associated with the transport of hazardous substances on waterways with less than 10% maritime shipping.
It concerns the transport of hazardous substances using inland waterway vessels only. The waterways with less than 10% maritime shipping (inland waterways), just like the waterways with more than 10% maritime shipping (maritime routes) are summarised in Appendix 3 of the ‘Basisnet’ Regulation.

11.2 Transport details

11.2.1 Introduction

A risk assessment relating to the transport of hazardous substances on water only concerns transport in tankers. Transport in (tank) containers is not included as the probability of hitting a container and causing a leak is so small that it does not contribute substantially to the external safety risk [40, 41].

Table 11-1 shows the category and substance classifications for the transport of hazardous substances on inland waterways.

Table 11-1 Substance category classification for inland waterways [12, 13]

Category		Representative substance	Vessel type
GF1	Flammable gas	N/A[1]	-
GF2	Flammable gas	n-Butane	Gas tanker
GF3	Flammable gas	Propane	Gas tanker
GT2	Toxic gas	N/A[2]	-
GT3	Toxic gas	Ammonia	Gas tanker/semi-cooled[3]
GT4	Toxic gas	N/A[2]	-
GT5	Toxic gas	N/A[2]	-
LF1	Flammable liquid	Heptane (diesel)[4]	Single/dual walled[5]
LF2	Flammable liquid	Pentane (petrol)	Single/dual walled[5]
LT1	Toxic liquid	Acrylonitrile	Dual walled
LT2	Toxic liquid	Propylamine	Dual walled
LT3	Toxic liquid	N/A[2]	-
LT4	Toxic liquid	N/A[2]	-

1 Ethylene oxide is flammable and toxic. This representative substance assignment relates to the flammable properties only. Substance category GF1 is falling away in

terms of numbers and effects in relation to GF2 and GF3. It is therefore not included as a category in the RBM II program.
2 These substance categories are not currently transported in tankers on the waterway.
3 Substance category GT3 is transported both semi-cooled (5 ºC) and pressurised (ambient temperature).
4 LF1 transports are modelled as 1/13th LF2 transport (so add the number of LF1 transports divided by 13 to the number of LF2 transports); this is because the effects of the pool fire for the LF1 and LF2 substance categories are almost the same and it is only the probability of ignition of LF1 substances that is 13 times lower than that of LF2 substances.
5 Table C in Chapter 3.2.3 of the ADN [42] prescribes which substances are allowed to be transported in tankers. Up until 2018, transitional rules apply to existing vessels (para. 1.6.7.4.2). After, 2018 a very limited number of substances are still allowed to be transported in single walled containers. It is expected that it will not be economically viable to keep a single walled vessel in service for this limited range of substances. The proportion of hazardous substances that will be transported in dual walled ships will therefore increase to 100% in the period up to 2020. For the 2011 situation, it is assumed that 60% of the transport of hazardous substances in the LF2 category is in single walled inland waterway vessels.

11.2.2 *Evaluation of Individual Risk and Societal Risk*

The 'Basisnet' Act and associated legislation prescribes when the individual risk or the societal risk should be calculated. In a general sense, calculation of the societal risk is only necessary in specific cases (see Table 11-2).

Table 11-2 Cases in which calculation of the societal risk is required (shaded boxes)

		Societal risk level		
		< 0.1 times ov	0.1-1.0 times ov	>1 times ov
Increase in societal risk	< 10%		See note 1	(shaded)
	> 10%		(shaded)	(shaded)

1 A calculation can be omitted when the increase in the societal risk as a result of the decision is smaller than 10%. The increase is smaller than 10% in, for example, a preservational land-use plan in which no new developments are made possible.

A specific transport flow of hazardous substances is used in the calculation depending on the situation. The situations are summarised below. Please refer to the text of the Act for the exact requirements. In the case of multiple shipping channels, the calculations must model each shipping channel separately. When doing so, the distribution of the transport across the various shipping channels must be taken into account. The assumptions that are made must be substantiated in the report.

IR risk ceilings for waterways are established differently to roads and railways. In principle, they lie on the bounding lines for the waterway as recorded in the ledger meant in Section 5.1 of the Water Act[20]. These lines usually correspond to the division between water and land. For

[20] In deviation from this, the reference points are located at:
a) the Westerschelde with its mouths; the boundaries of the shipping channels;
b) the Hartel canal and the Beer canal: on the bounding lines as shown on the map in Appendix III to the Water Regulations.

wide waters such as the Oosterschelde and the IJsselmeer these bounding lines are not on the banks. The line is somewhere on the water, depending on the location of the shipping channels. The bounding lines can be viewed on the website of Rijkswaterstaat {Directorate-General for Public Works and Water Management} (use the search term Rijkswaterstaatwerken).

1. Spatial development within 200 m of the Amsterdam-Rijn canal or Lek canal (Bevt Sect. 3.1, 8.1)

IR: Coincides with the waterway bounding line.

SR: Calculate using numbers per substance category from Appendix 3 to Rbn.
N.B. only required in the shaded cases in Table 11-2.

2. Spatial development within 200 m of the other inland waterways that are included in 'Basisnet' (Bevt Sect. 3.5, Rbn Sect. 13)

IR: There is no requirement to test the IR ceiling. There are, however, additional building requirements.

SR: Calculate using numbers per substance category from Appendix 3 to Rbn.
N.B. only required in the shaded cases in Table 11-2.

3. Spatial development within 200m of the inland waterways not included in 'Basisnet'

IR: There is no requirement to test the IR.

SR: There is no requirement to test the SR.

4. Changes to waterways that are part of 'Basisnet' (ES Policy para. 4.1)

IR:

a) Report IR ceiling for the waterways situated within the study area (ES Policy Sect. 37.1a).
b) Report whether or not there are changes to the location of the reference points and the increase in the transport that can be expected (ES Policy Sect. 37.1b and 37.1c).
c) Report the consequences of this on the completion of IR ceilings (ES Policy Sect. 37.2).

SR: In the shaded cases in Table 11-2 calculate using the numbers per substance category from Appendix 3 to Rbn (ES Policy Sect. 38).

5. Construction or change to waterways that are not part of the 'Basisnet' (ES Policy para. 42)

IR:

a) If it involves the construction of a new waterway, calculate using numbers per substance category estimated on the basis of the numbers for the waterways situated within the study area in Appendix 3 to Rbn (ES Policy Sect. 42).
b) If it concerns a change to a waterway, calculate using numbers per substance category in accordance with the most recently available data (ES Policy Sect. 42).

SR:

a) If it involves the construction of a new waterway, calculate using numbers per substance category estimated on the basis of the numbers for the waterways situated within the study area in Appendix 3 to Rbn (ES Policy Sect. 43).
b) If it concerns a change to a waterway, calculate using numbers per substance category in accordance with the most recently available data (ES Policy Sect. 43).

N.B. only required in the shaded cases in Table 11-2.

11.2.3 Related parameters

For calculations of the waterway transport, a uniform distribution of the transport over the 24-hour period is applied by default, which leads to a meteorological day/night ratio of 0.44/0.56. 71.4% of the transport takes place during the working week (Monday through Friday) and 28.6% in the weekend.

11.3 Scenarios

Various types of accidents could occur when transporting hazardous substances on inland waterways. The probability of these accidents occurring and the associated effects can vary significantly. In this respect we speak in terms of accident scenarios, which are presented in an event tree (see Module B, Section 6.2 also).

The representative system sizes are given in Table 11-3: the outflow scenarios are given in Table 11-4.

Table 11-3 Characteristic tank contents [43]

Substance category	Contents	Unit
Single walled	150	m^3
Dual walled or cooled	150	m^3
Gas tanker	180	m^3

Table 11-4 Outflow scenarios [43]

Vessel type (substance category)	Scenario	Hole size (mm)	Volume (m^3)	Outflow time(s)
Single walled (LF)	Major		75	1,800
	Minor		30	1,800
Dual walled (LF, LT)	Major		75	1,800
	Minor		20	1,800
Gas tanker (GT, GF)	Major	1501		Max 1,800
	Minor	751		Max 1,800

1 The outflow is modelled as a two-phase outflow. So with inland waterway vessels there is no instantaneous outflow, only major and minor continuous outflow, see Section 6.1 also. The scenario is rupture of a line connected to the tank [23]. Toxic gases (ammonia) can be transported pressurised at ambient temperature or cooled. In the latter case, the transport temperature is incorporated in the source calculation of the outflow model. In RBM II this is dealt with under the 'semi cooled vessel' means of transport.

11.4 Accident frequency

11.4.1 Location-specific failure frequency

The location-specific vessel damage frequency has to be used in the risk calculation for a waterway. The vessel damage frequency is included in the Risk Atlas for Main Waterways in the Netherlands [44] and is shown in Appendix 5. If the waterway is not included in the Risk Atlas, the external safety support point of Rijkswaterstaat (servicedesk-data@rws.nl) should be contacted to ask for advice. A more detailed classification of the waterway may be required for special nautical situations (incl. locks, dams and ports, see para. 11.6.1). The method for calculating location-specific failure frequencies is included in Appendix 6.

11.4.2 Default vessel damage frequency

If the location-specific accident frequency is not known, it must preferably be derived based on the incident and intensity record (all shipping apart from recreational shipping). The method for this is described in Appendix 6. If this is not possible, then the generic accident probability for the navigability class (CEMT class) may be used.

The navigability class is based on the normative vessel for the waterway (type, length, width, laden deep draft and air draft). Transport of hazardous substances in such quantities that there is a possibility of external risks occurring [39] only takes place on waterways in navigability class IV, V and VI.

The generic accident frequency for vessel damage with extremely severe damage (minimum of a hole in the hull) per navigability class is given in Table 11-5 [45].

Table 11-5 Default vessel damage frequency per waterway type [45]

Waterway type (CEMT)[21]	Default vessel damage frequency (/vslkm)
Navigability class 4	$8.67.\ 10^{-8}$
Navigability class 5	$1.32.\ 10^{-7}$
Navigability class 6	$4.14.\ 10^{-7}$

11.5 Subsequent probabilities

11.5.1 Outflow probability

The subsequent probabilities (conditional probabilities) of the outflow scenarios in Table 11-4 after vessel damage with extremely severe damage (at least a hole in the hull) are included in Table 11-6 [45].

[21] In Europe, inland navigation is divided into CEMT classes. This harmonizes the dimensions of waterways in Western Europe. The maximum dimensions for the vessel are laid down per class. The classification runs from 0 through VII. See the RBM II Default Vessel Damage Frequency for more information.

Table 11-6 Subsequent probabilities of outflow per vessel type [45]

Substance category	Scenario	
	Major	**Minor**
LF or LT in a single walled tanker	0.22	0.44
LF or LT in a dual walled tanker	0.005	0.02
GF or GT in a gas tanker	0.00006	0.0125

Navigability class corrected outflow probability
On the smaller, narrower waterways (navigability classes 4 and 5) the navigation speeds are lower and possible collision angles smaller than on waterways in navigability class 6. Therefore, the outflow probabilities for navigability classes 4 and 5 are corrected using the factor in Table 11-7. This correction factor only applies to dual walled tankers and gas tankers. After all, for single walled tankers a hole in hull is the same as a hole in the cargo zone.

Table 11-7 Correction factors for the outflow probability for dual walled tankers and gas tankers [45]

Waterway type (CEMT)	Correction factor
Navigability class 4	0.44
Navigability class 5	0.59

11.5.2 Probabilities of ignition

The probabilities of ignition that apply to flammable substances are included in Table 11-8 [13].

Table 11-8 Probabilities of ignition per flammable substance category [22]

Substance category	Scenario	Probability of immediate ignition	Probability of delayed ignition
Flammable liquid LF 1	All	0.01	0
Flammable liquid LF 2	All	0.13	N/A[1]
Flammable gases (GF1 through GF3)	Major	0.7	0.3
Flammable gases (GF1 through GF3)	Minor	0.5	0.5

1 In the event of delayed ignition of the flammable liquid a flash fire will occur that will ignite the flammable pool. The probability of a pool fire is therefore equal to the probability of immediate ignition (0.065) plus the probability of delayed ignition (0.065) which is included here as the probability of immediate ignition.

11.5.3 *Event trees*

Figure 11-1 shows the event tree for single walled tankers containing flammable liquids. Figure 11-2 shows the event tree for dual walled tankers containing liquids. Figure 11-3 shows the event tree for pressurised gas tankers [25, 45].

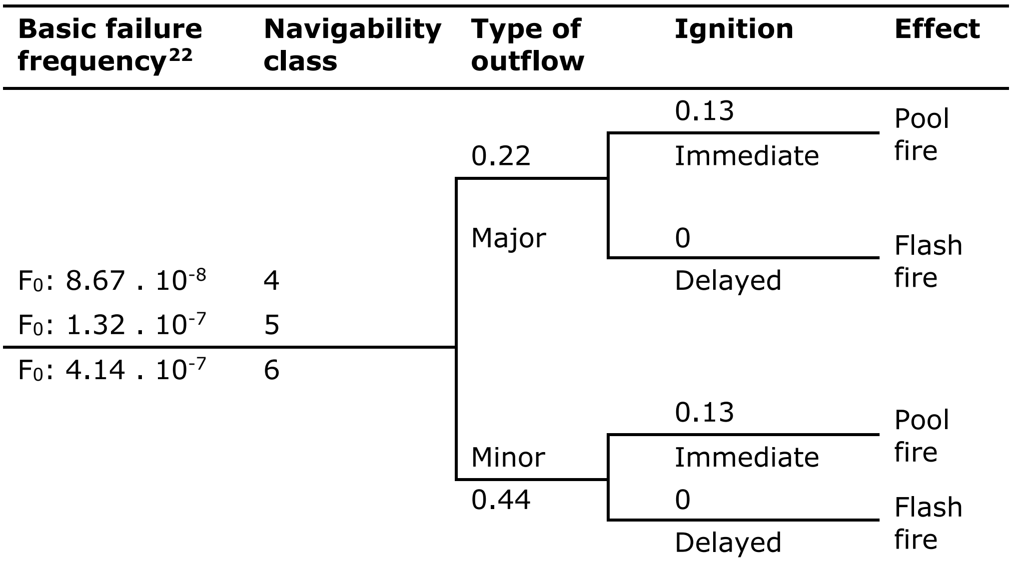

Figure 11-1 Event tree for single walled tankers [13]

When transporting substance category LF1, the probability of ignition is 0.01 instead of 0.13. Single walled tankers are only used for transporting flammable liquids. Moreover, single walled inland waterway vessels for hazardous substances are being slowly phased-out, see note 4 to Table 11-1.

[22] The recommended method is not to use the default failure frequency that is shown, but to use the location-specific frequency

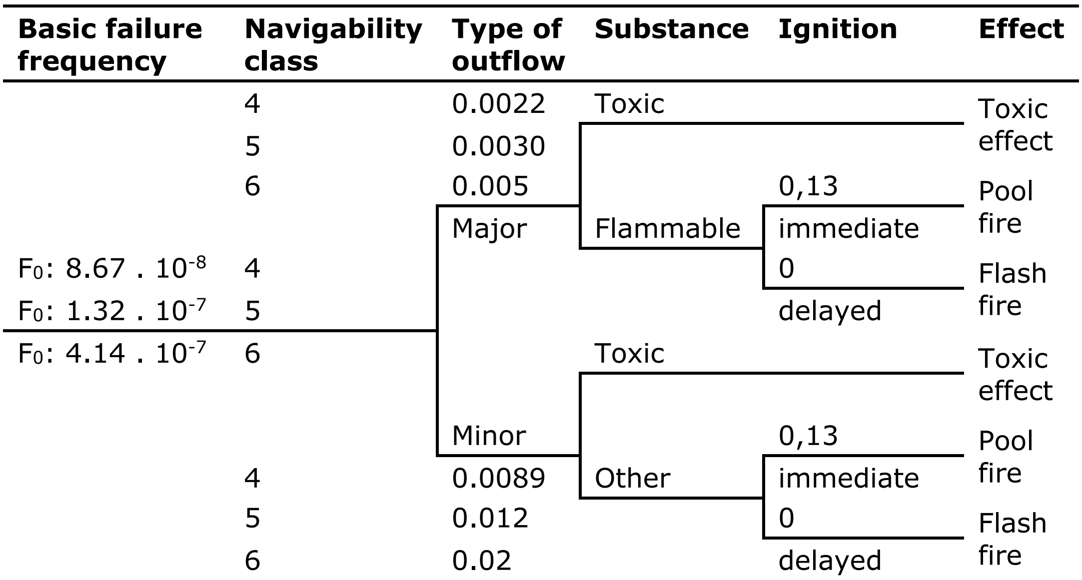

Figure 11-2 Event tree for dual walled tankers (LF and LT) [25, 45] (subsequent probabilities of type of outflow are the product of Table 11-6 and Table 11-7)

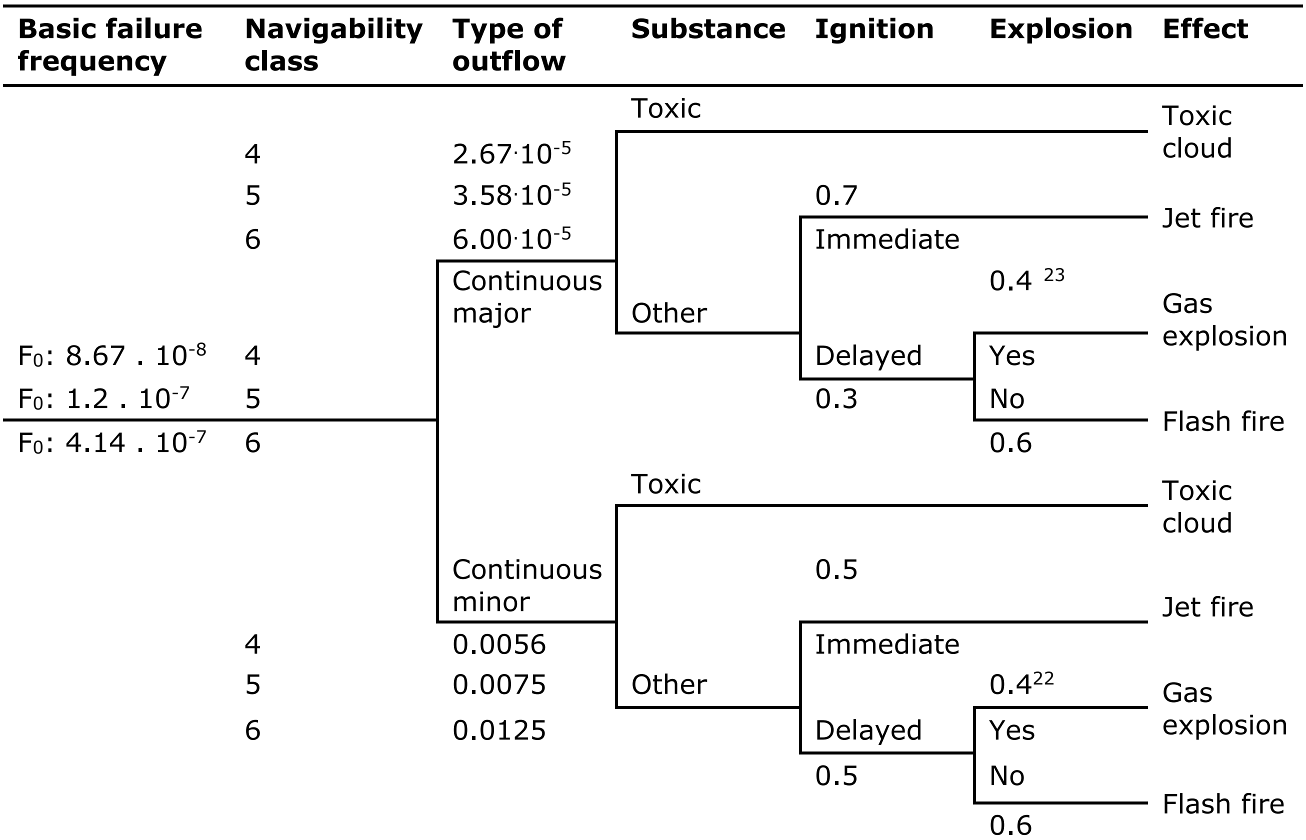

Figure 11-3 Event tree for gas tankers (GF and GT) [13] (subsequent probabilities of type of outflow are the product of Table 11-6 and Table 11-7)

11.6 Special situations

The calculation methods described above are suitable for the default situation, waterways at ground level. There are, however, special situations which could affect those probabilities of failure or the dispersion of substances. These are:

- Locks, dams and ports
- Elevated or sunken situation
- Intersections and crossings
- Viaducts, bridges, etc
- Unequal distribution of transports across the width

The risk calculations for 'Basisnet' routes assumes that the default calculation is still representative, or slightly conservative, in these situations. If these situations have an effect on the probability of severe vessel damage this appears in the location-specific accident frequency, see Section 10-4.

The risk calculation of the 'Basisnet' Waterways does not take separate account of these special situations. Naturally, these are highly relevant when considering the options for preparations for combating and limiting the scale of a disaster in accordance with Bevt Sect. 7.

[23] The 40% probability of explosive ignition is taken from [26], [14]

12 Waterways with more than 10% maritime shipping (maritime routes)

The risks of transporting hazardous substances in maritime vessels cannot currently be calculated using RBM II. As long as the models required for this have not yet been included in RBM II a qualitative estimate of the risks should be drawn up for waterways where the proportion of maritime vessels is greater than 10% to make clear that the risks are not unacceptably high. The following aspects should be covered when doing so:

- Previous external safety risk assessments
- Expert judgement
- (Changes in) the total maritime and inland navigation intensity
- (Changes in) the masses and speeds of the maritime shipping
- (Change in) the number of vessels bulk transporting substance categories that are relevant to external safety for both inland and maritime shipping
- (Changes in) the people present in the vicinity of the waterway
- The effect of the changes to be made on/to aspects/components of the waterway for all of the aforementioned points

13 Glossary

Term	Meaning
1% lethality distance	The maximum effect distance from the source at which 1 in 100 of those exposed will suffer fatal consequences from an outflow of a hazardous substance.
ADN	Accord europeén relatif au transport international des marchandises dangereuses par voie de navigation intérieure {European Agreement concerning the International Carriage of Dangerous Goods on Inland Waterways}
Area of influence	Area on either side of a road, railway or inland waterway where a maximum of 1% of the people present in that area could die as a direct consequence of an unusual event involving a hazardous substance transported on that route. The size of the area is determined by the 1% lethality distance of the most far-reaching substance transported and the length of the transport route being studied.
ATB-EG	Automatische Trein Beïnvloeding - Eerste Generatie {Automatic Train Protection System - First Generation}.
ATBVv	Automatische Trein Beïnvloeding – Verbeterde versie {Automatic Train Protection System -Improved Version}.
‘Basisnet’ (Rail, Road and Waterway)	‘Basisnet’ is a network of routes for transporting hazardous substances on the railways, waterways and (national) roads, in which a clear choice between the tensions of transport, the economy and spatial planning is applied. To this end, a risk ceiling for the individual risk and the societal risk together with the transport ceiling is assigned to each route/section.
‘Basisnet’ Distance	Distance between reference point and IR ceiling.

Term	Meaning
Bevi	Besluit externe veiligheid inrichtingen Stb. 2004, 250 {*External Safety (Establishments) Decree, Bulletin of Acts & Decrees 2004, 250*.}
Bevt	Besluit externe veiligheid transportroutes Stb. 2013, 465 {External Safety of Transport Routes Decree, Bulletin of Acts & Decrees 2013, 465.}
BLEVE	Boiling Liquid Expanding Vapour Explosion
Block train	Train with wagons containing substances in a single substance category only.
CEMT class	Classification of waterways into navigability classes by the Conference of Ministers of Transport {*Conférence Europeén de ministres de transport European (CEMT)*} 1992. The CEMT class lays down the maximum dimensions permitted for a vessel on a specific waterway.
Competent authority	Body that decides on a land-use plan, grants an environmental permit or decides on a planned route or road modification decision.
Conditional probability	Contingent probability of Y given X. If we already have foreknowledge that an event X has taken place, this affects the probability of Y. For example, the probability of outflow in a subset of accidents with injury involving high-speed traffic is greater than when the subsequent probability of outflow is determined for all accidents, including slow-speed traffic.
Connecting lines	These are railway lines that usual form a connection between industrial estates and the main line or a goods marshalling yard.
Damage class	The level of damage
Dispersion	The mixing and spreading of substances in the air.

Term	**Meaning**
Domino effect	The effect that an outflow from a single installation or means of transport leads to an outflow from another installation or means of transport.
Dose	A measure for the integral exposure; the function of concentration and exposure duration or the thermal radiation and exposure duration.
Effect distance	The distance up to which a disaster has a specific effect (death, injury) on a person who is not protected, given the scenario and the weather class.
Event tree	A diagram in which success and failure combinations are used to identify event sequences leading to all possible consequences of a given initiating event.
Explosion	A sudden release of energy that creates a pressure wave.
Explosive substances	Explosive substances are understood to mean: a. Firstly, substances and preparations that present a danger of explosion as a result of shock, friction, fire or other ignition causes (risk phrase R2); secondly, pyrotechnic substances. Pyrotechnic substance is understood to be a substance or mixture of substances with the purpose of producing heat, light, sound, gas or smoke or a combination of these phenomena by means of non-explosive, self-propagating exothermic chemical reactions; thirdly, explosive or pyrotechnic substances and preparations that are contained in objects; b. substances and preparations that present a serious danger of explosion as a result of shock, friction, fire or other ignition causes (risk phrase R3).
External Safety (ES)	The risks for the people present in the vicinity occasioned by, for instance, the transport of hazardous substances on water, a road or a railway.

Term	**Meaning**
Extremely severe damage	Major damage, e.g. dents deeper than 40 cm, holes or splits exceeding 100 cm^2, breaking of the hull or the ship being gutted by fire.
Fireball	A fire, burning rapidly enough for the burning mass to rise into the air as a cloud or ball.
Flash	Part of a super-heated liquid that evaporates quickly due to a relatively quick reduction of pressure in the tank to ambient pressure, where the vapour/liquid mixture that is created cools to below boiling point.
Flash evaporation	See Flash.
Flash fire	The rapid combustion of a flammable vapour and air mixture in which the flame passes through the mixture at a rate less than sonic velocity so that negligible damaging overpressure is generated.
FN curve	The double logarithmic graph of the societal risk: the X axis gives the number of fatalities and the Y axis the cumulative frequency of accidents where the number of fatalities is equal to or greater than N.
Frequency	The number of times an outcome is expected to occur in a given period of time (see probability also).
GEVI	Hazard identification code {*Gevarenidentificatie code*.} This code is shown on the orange sign, the display of which is mandatory when transporting hazardous substances.
HART	Reference Manual Transportation Risk Assessment {*Handleiding Risicoanalyse Transport*}.

Term	**Meaning**
Hazardous substance	'Hazardous substances' are understood to mean, with the exception of transport through pipelines, those substances that must be considered hazardous within the framework of Section 1(1), Part b, Point (1) through (9) of the Carriage of Hazardous Substances Act {*Wet vervoer gevaarlijke stoffen (WVGS)*}. More particularly, they are those substances, preparations and objects that are designated pursuant to Section 3 of the *WVGS*. These substances can be found in the appendices to the treaties that have been concluded for the various transport modalities, specifically the ADR (road transport) the ADN (inland navigation) and the RID (rail transport). These appendices are also included as appendix I to the various Dutch regulations, specifically the Regulation on the carriage of hazardous substances by land {*Regeling vervoer over land van gevaar*lijke stoffen (VLG)}, The Regulation on the carriage of hazardous substances on inland waterways {*Regeling vervoer over de binnenwateren van gevaarlijke stoffen (VBG*)} and the Regulation on the carriage of hazardous substances by rail {*Regeling vervoer over de spoorweg van gevaarlijke stoffen (VSG)}.*
HRB	Reference Manual Bevi Risk Assessments {*Handleiding Risicoberekeningen Bevi*}.
Ignition source	A thing able to ignite a flammable cloud, e.g. due to the presence of sparks, hot surfaces or open flames.
Individual Risk contour	A graphic depiction of the individual risk where points with the same individual risk are joined together.
Instantaneous release	The release of the entire contents of a transport unit in one go in a short period of time.
IR	Individual Risk (see Location-specific risk).

Term	**Meaning**
IR ceiling	Location where the individual risk is a maximum of 10^{-6}.
IVS-90	Shipping Information and Tracking System {*Informatie- en Volgsysteem voor de Scheepvaart}.*
Jet fire	The combustion of materials emitted from an opening with great force.
Location-specific risk	Risk at a location along, on or above a transport route expressed as a value for the probability per year of a person staying in that location continuously for a year without protection would die as the direct consequence of an unusual event on that transport route in which a hazardous substance is involved.
Loss of Containment (LOC)	An event that leads to the release of material into the atmosphere.
Main road network	Roads that are part of the national main infrastructure as defined in the SW-lI (Structuurschema Verkeer en Vervoer (Tweede Kamer 1990-1991 20922 nr. 114).
Maximum effect distance	See 1% lethality distance.
Mixed train	Train with wagons containing multiple types/categories of hazardous substances.

Term	Meaning
Moderately sensitive object	Object as intended in Sect. 1.1. under b. of the External Safety (Establishments) Decree. a. 1st low density housing, houseboats and caravans belonging to third parties with a maximum density of two houses, houseboats or caravans per hectare, and 2nd lodgings and company housing belonging to third parties. b. Office buildings, insofar as they are not designated as sensitive. c. Hotels and restaurants, insofar as they are not designated as sensitive. d. Shops, insofar as they are not designated as sensitive. e. Sports halls, sports fields, swimming baths and playgrounds. f. Campsites and other sites intended for recreational purposes, insofar as they are not designated as sensitive. g. Industrial buildings, insofar as they are not designated as sensitive. h. Objects comparable with those listed under e through g arising from the average length of time per day during which people are present there, the number of people that are usually present there and the opportunities for self-protection in the event of an accident, insofar as those objects are not sensitive objects, and i. objects with a high infrastructure value, such a telephone exchange or power station or a building containing air traffic control equipment, insofar as those objects deserve protection against the consequences of an accident considering the nature of the hazardous substances that could be released in the event of such an accident.
Navigability Class	International Waterway Classification. The navigability is sub-divided into six classes that provide information about the capacity of the waterway (see CEMT class) based on the cargo capacity and the dimensions of the vessels.
NWB-vaarwegen	National Road File - Waterways {*Nationaal wegenbestand-Vaarwegen*

Term	Meaning
Orientation value	This term is used in setting the external safety standards for the societal risk. The orientation value for the societal risk is determined per km-route or planned route by $10^2/N^2$, i.e. a frequency of 10^{-4}/yr for 10 victims, 10^{-6}/yr for 100 victims, etc.
Outflow frequency	The probability per vehicle kilometre (or per year) of an accident involving an outflow of more than 100 kg occurring.
Outflow point	The point on the transport route where the outflow of hazardous substances is modelled.
Pasquill class	Classification for the stability of the atmosphere, indicated by the letters A through F, where A represents very unstable and F represents stable.
PGS	Hazardous Substances Publication Series {*Publicatiereeks Gevaarlijke Stoffen*}.
Pool fire	The combustion of material evaporating from a layer of liquid (pool).
PRE	Presence that can reasonably be expected.
Pressurised liquefied gas	Gas compressed to a pressure that is equal to the evaporation pressure at storage temperature, such that the bulk of the gas is condensed into the liquid phase.
Pressurised tank wagon	Wagon with a pressurised storage tank within which the maximum permitted pressure is higher than 0.5 bar overpressure.
Probability	Measure of the likelihood of an occurrence, expressed as a dimensionless number between 0 and 1.
Probit	A number directly related to probability by a numerical transformation.

Term	**Meaning**
Probit relationship	A probit relationship indicates the relationship between the dose (as a function of the concentration of the liquid/thermal radiation and the exposure time) and the response (the fraction of the exposed population displaying a specific effect). A probit relationship can thus be used to determine the mortality rate for any arbitrary concentration/thermal radiation and exposure time.
ProRail	ProRail is responsible for the rail network in the Netherlands: construction, maintenance, management and safety.
QRA	See Quantitative Risk Assessment.
Quantitative Risk Assessment	Systematic investigation of the probabilities of the consequences of accidents for activities involving hazardous substances. Probability and consequence are combined into the term risk.
RBM II	RisicoBerekeningsMethodiek II. A software package for determining the risks of transporting hazardous substances, developed and maintained on behalf of the Ministry of Infrastructure and the Environment.
Rbn	‘Basisnet’ Regulations {*Regeling basisnet*}, Government Gazette. 2014, 8242.
Reference point	A point on the Transport Route ‘Basisnet’ from which the ‘Basisnet’ Distance is measured, as defined in Rbn Sect. 3 through 6.
RID	Regulations Concerning the International Carriage of Dangerous Goods by Rail {*Règlement concernant le transport international ferroviaire des marchandises dangereuses*}.

Term	Meaning
Risk	Risk is defined as the probability of an unwanted effect occurring within a fixed time period, usually one year. Consequently, risk is expressed as a dimensionless number. However, risk is often expressed in units of frequency, 'per year'. In this Reference Manual, the frequency is used to indicate the risk of (sudden) death as a consequence of an accident involving hazardous substances.
Risk assessment	See Quantitative Risk Assessment.
Risk contour	See Individual Risk contour.
RIVM	National Institute for Public Health and the Environment.
Roughness length	Artificial length scale appearing in relationships describing the wind speed over a surface and characterising the roughness of the surface. The roughness length of the environment determines the wind speed at ground level.
Scenario	Assumed course of events. Description of the release of a hazardous substance based on the quantity and outflow duration.

Term	Meaning
Sensitive object	Object as intended in Sect. 1.1 under l. of the External Safety (Establishments) Decree a. Houses, houseboats and caravans, not being dwellings, houseboats or caravans designated as moderately sensitive. b. Buildings intended for occupation, whether or not during part of the day, by minors, the aged, infirm or handicapped, such as: firstly, hospitals, old people's homes and hospitals, old people's homes and nursing homes, secondly, schools, or thirdly, buildings or parts thereof intended for the day-care of minors. c. Buildings in which large numbers of people are usually present for a large part of the day, which in any event includes: Firstly, office buildings and hotels with a gross floor area of more than 1500 m2 per object, or secondly, complexes housing more than 5 shops and for which the joint gross floor area is greater than 1000 m2 and shops with a total gross floor area of more than 2000 m2 per shop, insofar as a supermarket, hypermarket or department store is housed in those complexes, and d. camping and other recreation sites intended for occupation by more than 50 people during multiple consecutive days.
Severe damage	Considerable damage, e.g. dents from 25 to 40 cm, holes or splits with a surface area from 15 to 100 cm^2, considerable fire damage and explosion damage.
Societal risk	The frequency (per year) with which a group of at least 10 people become fatalities as the result of an accident involving hazardous substances. The societal risk is usually shown using an FN curve.
Societal risk population file	The societal risk population file is a national, generic population file, developed to obtain clarity on the population inventory and societal risk calculations for external safety studies.

Term	Meaning
SOS database	Rijkswaterstaat manages a central Vessel Accident Database {*Scheepsongevallendatabase} (SOS-database)*}. This contains details about vessel accidents and other events on the water that have taken place within the Dutch nautical and economic management area.
SP	Spatial Planning.
SR	Societal risk (see societal risk).
SR ceiling	Location where the individual risk is a maximum of 10^{-7} or 10^{-8}.
Study area	The area surrounding the main road, main railway line or main waterway that is to be constructed or modified, within which main roads, main railway lines or main waterways, or parts thereof, are situated, in relation to which, in the opinion of Our Minister, it can reasonably expected that the transport flows of hazardous substances will change as a result of the construction or modification concerned.
Substance category (classification)	Specific classification of substances into a limited number of categories which provide a comparable risk for external safety and allow modelling using a single, representative substance. The basic principle behind this classification is the substance properties relevant to external risk, such as volatility, flammability and toxicity.
Track section speed	The maximum speed valid on the track section.
Transport route	The road, railway or waterway to be evaluated. The transport route is modelled using one or more sections.
TWE	Tank wagon equivalent.
Vapour cloud explosion	An explosion resulting from ignition of a cloud of flammable vapour, gas or spray mixed with air, in which flames accelerate to significantly high velocities to produce significant overpressure.

Term	Meaning
ViN	Characteristics of Waterways in the Netherlands {*Vaarwegkenmerken in Nederland*}, file managed by Rijkswaterstaat.
VN-number	International substance identification number. This is used to indicate a specific substance of substance group. This number is shown on an orange sign, the display of which is mandatory for transports carrying hazardous substances.
Weather class	A combination of the Pasquill class and the wind speed. Weather class D5 means Pasquill category D and wind speed 5 m/s.

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Annex

15 Rules of thumb for external risks when transporting hazardous substances

15.1 Introduction

The Explanatory Note with the Bevt [1] indicates that in some cases the calculation of the individual risk and the societal risk can be omitted. To this end, rules of thumb, in the form of threshold values for transport totals have been developed, which give the user an indication of when a risk calculation is meaningful. The rules of thumb can be used to estimate whether the transport numbers, development distances and/or presence densities are too small to lead to the threshold value or target value for the individual risk being exceeded or to the orientation value being exceeded by 0.1 times the orientation value for the societal risk.

The threshold value of 0.1 times the orientation value for the societal risk gives an indication that a societal risk calculation certainly should be carried out.

This appendix gives an elaboration of these rules of thumb. The rules of thumb for the individual risk and the societal risk, calculated using version 1.3 of RMB II, are given below per modality and route type.

15.2 Rules of thumb for transport by road

15.2.1 Introduction

The rules of thumb were formulated for the individual risk and the societal risk.
For the individual risk, the threshold value and target value are 10^{-5} and 10^{-6} per annum, respectively, and for the societal risk, the orientation value and a factor of 0.1 times the orientation value are used.

The numbers will be used often in the remainder of this section. For road transport, this mainly concerns numbers of LPG road tankers in both directions per annum over a road section. LPG is one of the pressurised liquefied gases, substance category GF3 (see below). When the rules of thumb mention a substance category, such as GF3, this means the number of loaded passages per annum in both directions.

The numbers encountered in real life were used as a reference when formulating the rules of thumb. There is not much point in indicating that 4000 road tankers per annum are required to exceed the threshold value for the individual risk in the highly toxic liquids category when the maximum number observed was 183. The camera counts by Rijkswaterstaat {Directorate-General for Public Works and Water Management} in 2006 and 2007 provided information from 510 counting points. The summary has been supplemented with approximately 100 hand-counted points (in Flevoland and Friesland in particular) so that a file containing 610 counting points has been used for reference. The rules of thumb have been formulated to a factor of 2 above the observed maximum. Larger numbers of transports are not expected in the coming years.

Substance categories
The risks from transporting hazardous substances depend on, among other things, substance properties, such as volatility and toxicity. There is a wide range of substances that are being transported. It includes solid substances, liquids and gases, flammable, toxic or both. The substances have been assigned to categories to keep the calculations workable. Substances that have little 'hazard potential', due to the combination of their properties, are placed in the 'irrelevant to external safety' category. The risk is calculated using the other categories. These categories are listed in Table 1-1.

Table 1-1 Substance categories and associated representative substances

Category	**Name**	**Representative substance**
GF1	Flammable gas	Ethylene oxide
GF2	Flammable gas	n-Butane
GF3	Flammable gas	Propane
GT2	Toxic gas	Methylmercaptan
GT3	Toxic gas	Ammonia
GT4	Toxic gas	Chlorin
GT5	Toxic gas	Chlorine
LF1	Brandbare liquid	Heptane (diesel)
LF2	Brandbare liquid	Pentane (gasoline)
LT1	Toxic liquid	Acrylonitrile
LT2	Toxic liquid	Propylamine
LT3	Toxic liquid	Acrolein

A higher number denotes a higher hazard potential. When the transports are counted, the results are also provided in these categories. The classification system is described in 'System for classifying substances for risk calculations for the carriage of hazardous substances', Ministry of Transport, Public Works and Water Management 1999 [9].

Development area and presence density
The societal risk is determined by four variables:

- The distance from the development area to the axis of the road.
- The presence density in the development area.
- The nature of the transported substances.
- The number of transported substances.

In practice, it is usually sufficient to inventory the population in the area within the 10^{-8} contour of the individual risk. An RMB II calculation can be used to check if the result of the societal risk calculation is sensitive to the population outside of the 10^{-8} contour.
The societal risk is determined by GF3 in almost all cases. It is then sufficiently accurate to inventory the population density up to 300 m from the axis of the road for the result of the societal risk calculation, in other words, adding the population outside of 300 m does not produce any significant change in the result.

N.B. Naturally, the maximum effect distances for major toxic liquid and gas scenarios, are bigger than 300 m. Table 1-2 gives the maximum distances to a 1% probability of lethality per substance category.

Table 1-2 Maximum effect distance (1% probability of lethality) per substance category

Substance category	**Max effect [m]**
LF1	45
LF2	45
LT1	730
LT2	880
LT3	> 4000
LT4	> 4000
GF1	40
GF2	280
GF3	355
GT2	245
GT3	560
GT4	> 4000
GT5	> 4000

The rules of thumb have been derived for population areas that are uniformly populated with a specific presence density per hectare, see Figure 1-1. In a specific case, the choice should therefore be conservative, i.e. the smallest distance between the development area to be considered and the axis of the road and the highest presence density that occurs.

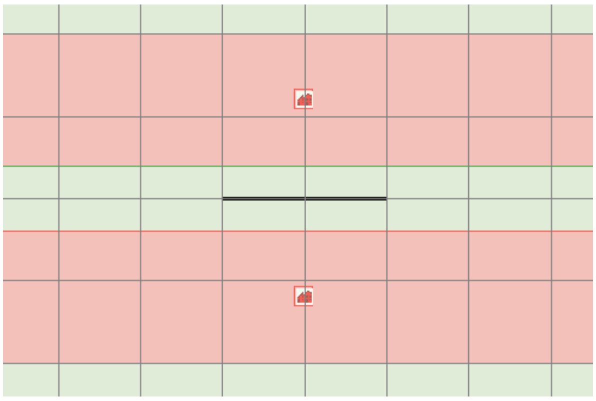

Figure 1-1 Modelling population and route

Field of application
As stated in the introduction, the rules of thumb are an initial filter: they select those situations in which there is absolutely no question of a spatial, external safety problem. They are coarse and do not take account of the details of the situation that has to be evaluated such as local variations in the development density. Local variations in accident frequency, 'black spots', cannot be incorporated in the calculation. The available accident case studies make it impossible to make sufficiently reliable and valid subdivisions into road sections or other road characteristics [2].

The user should take these limitations into account, every time the rules of thumb are used. In many cases, a number of points to note are highlighted.

For orientation purposes Table 1-3 shows, per substance category, the numbers that are required per category to generate a 10-6 contour at the edge of the road. The table also shows the observed maxima.

Table 13 Threshold values for 10-6 contour and observed maxima

	MWAY[24]		**Rural**[25]		**Urban**[26]	
Substance categories	**10^{-6} Threshold**	**NL max**	**10^{-6} Threshold**	**NL max**	**10^{-6} Threshold**	**NL max**
GF1 (flammable gases)	101711	1120	17045	629	35998	33
GT2 (toxic gases)	81269	20	23108	0	76961	0
GT3 (toxic gases cat. 3)	60827	535	17645	394	60736	65
GT4 (toxic gases cat. 4)	8741	399	3000	131	10370	33
GF2 (flammable gases)	19677	2913	6210	1130	21029	367
GF3 (highly flammable gases)	10308	26637	3379	14146	11404	1707
GT5 (toxic gases cat. 5)	8741	66	2999	35	10370	0
LF1 (flammable liquids)	>1000000	57746	>200000	15941	>400000	11185
LF2 (highly flammable liquids)	98918	92463	16803	17512	35562	32569
LT1 (toxic liquids)	20423	3719	4265	486	9282	364
LT2 (toxic liquids cat. 2)	10964	5206	2536	1870	5571	2008
LT3 (toxic liquids cat. 3)	3796	183	1054	215	2375	0
LT4 (toxic liquids cat. 4)	1220	0	356	0	802	0

The rules of thumb for individual risk and societal risk per route type are shown below.

15.2.2 Route type: motorway

15.2.2.1 Checking individual risk

A motorway is considered a road on which a maximum speed of 100 km/hour or higher applies under normal traffic flows.

Rule of thumb 1: A motorway does not have a 10^{-5} contour.

Rule of thumb 2: A motorway does not have a 10^{-6} contour when the number of GF3 transports per annum is less than 4000.

Rule of thumb 3: If the number of GF3 transports per annum is greater than 4000, a motorway does not have a 10^{-6} contour if $0.0001*(0.1*LF2+GF3+0.5*LT1+LT2+3*LT3+GT4+GT5)<1$.

N.B.

1. All rules of thumb apply in the order shown.
2. If a rule of thumb indicates that a 10-6 contour is possible then use RBM II.

[24] MWAY: motorway
[25] Rural: rural road
[26] Urban: urban road

15.2.2.2 Checking societal risk

Checking orientation value

Rule of thumb 1: If the transport flow of hazardous substances in road tankers (bulk transport) comprises categories LT3, GT4 or GT5 (irrespective of numbers) then use RBM II.

Rule of thumb 2: The orientation value for the societal risk is not exceeded if GF3 is less than 10 times the threshold value in Table 1-4 (single sided development) or 10 times the threshold value in Table 1-5 (2-sided development).

Checking 10% of the orientation value

Rule of thumb 1: If the transport flow of hazardous substances in road tankers (bulk transport) comprises categories LT3, GT4 or GT5 (irrespective of numbers) then use RBM II.

Rule of thumb 2: If GF3 is less than the threshold value shown in Table 1-4 (single sided development) or in Table 1-5 (2-sided development), then 10% of the orientation value is not exceeded.

N.B.

1. All rules of thumb apply in the order shown.

Table 1-4 GF3 transport threshold values for exceeding 10% of the motorway orientation value, single sided development
-: more than twice the maximum observed number of transport units per annum required

Density/ha	**Distance to the axis of the road (m)**												
	20	30	40	50	60	70	80	90	100	125	150	175	200
10	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-
30	23330	-	-	-	-	-	-	-	-	-	-	-	-
40	13130	19440	-	-	-	-	-	-	-	-	-	-	-
50	8400	12440	18990	20330	22670	25270	-	-	-	-	-	-	-
60	5830	8640	13180	14120	15740	17550	19570	21810	26170	-	-	-	-
70	4290	6350	9690	10370	11560	12890	14370	16030	19230	-	-	-	-
80	3280	4860	7420	7940	8850	9870	11010	12270	14720	22090	-	-	-
90	2590	3840	5860	6270	7000	7800	8700	9700	11630	17450	-	-	-
100	2100	3110	4750	5080	5670	6320	7040	7850	9420	14130	24310	-	-
200	530	780	1190	1270	1420	1580	1760	1960	2360	3530	6080	11470	22040
300	230	350	530	560	630	700	780	870	1050	1570	2700	5100	9790
400	130	190	300	320	350	390	440	490	590	880	1520	2870	5510
500	80	120	190	200	230	250	280	310	380	570	970	1840	3530
600	60	90	130	140	160	180	200	220	260	390	680	1270	2450
700	40	60	100	100	120	130	140	160	190	290	500	940	1800
800	30	50	70	80	90	100	110	120	150	220	380	720	1380
900	30	40	60	60	70	80	90	100	120	170	300	570	1090
1000	20	30	50	50	60	60	70	80	90	140	240	460	880

Table 1-5 GF3 transport threshold values for exceeding 10% of the motorway orientation value, two sided development

Density/ha	**Distance to the axis of the road (m)**												
	20	30	40	50	60	70	80	90	100	125	150	175	200
10	-	-	-	-	-	-	-	-	-	-	-	-	-
20	9500	16360	-	-	-	-	-	-	-	-	-	-	-
30	4220	7270	13690	21060	-	-	-	-	-	-	-	-	-
40	2370	4090	7700	11850	16010	16830	18770	24540	-	-	-	-	-
50	1520	2620	4930	7580	10250	10770	12010	15710	18700	-	-	-	-
60	1060	1820	3420	5270	7120	7480	8340	10910	12990	19630	-	-	-
70	780	1340	2520	3870	5230	5500	6130	8010	9540	14420	24810	-	-
80	590	1020	1930	2960	4000	4210	4690	6140	7310	11040	18990	-	-
90	470	810	1520	2340	3160	3330	3710	4850	5770	8730	15010	-	-
100	380	650	1230	1900	2560	2690	3000	3930	4680	7070	12160	22950	-
200	90	160	310	470	640	670	750	980	1170	1770	3040	5740	11020
300	40	70	140	210	280	300	330	440	520	790	1350	2550	4900
400	20	40	80	120	160	170	190	250	290	440	760	1430	2750
500	20	30	50	80	100	110	120	160	190	280	490	920	1760
600	10	20	30	50	70	70	80	110	130	200	340	640	1220
700	10	10	30	40	50	50	60	80	100	140	250	470	900
800	10	10	20	30	40	40	50	60	70	110	190	360	690
900	4	10	20	20	30	30	40	50	60	90	150	280	540
1000	4	10	10	20	30	30	30	40	50	70	120	230	440

-: more than twice the maximum observed number of transport units per annum required

15.2.3 Route type: rural road (80 km/hour)

15.2.3.1 Checking individual risk

Rule of thumb 1: A rural road does not have a 10^{-5} contour.

Rule of thumb 2: A rural road does not have a 10^{-6} contour when the number of GF3 transports per annum is less than 500.

Rule of thumb 3: If the number of GF3 transports per annum is greater than 500 a rural road does not have a 10^{-6} contour if 0.0003*(GF3+0.2*LF2+LT1+LT2+3*LT3+GT4+GT5) <1.

N.B.
1. All rules of thumb apply in the order shown.
2. If a rule of thumb indicates that a 10^{-6} contour is possible then use RBM II contour.

15.2.3.2 Checking societal risk

Checking orientation value

Rule of thumb 1: If the transport flow of hazardous substances in road tankers (bulk transport) comprises categories LT3, GT4 or GT5 (irrespective of numbers) then use RBM II.

Rule of thumb 2: The orientation value for the societal risk is not exceeded if GF3 is less than 10 times the threshold value in Table 1-6 (single sided development) or 10 times the threshold value in Table 1-7 (2-sided development).

Checking 10% of the orientation value

Rule of thumb 1: If the transport flow of hazardous substances in road tankers (bulk transport) comprises categories LT3, GT4 or GT5 (irrespective of numbers) then use RBM II.

Rule of thumb 2: If GF3 is less than the threshold value in Table 1-6 (single sided development) or in Table 1-7 (2-sided development), then 10% of the orientation value is not exceeded

N.B.
1. All rules of thumb apply in the order shown.

Table 1-6 GF3 transport threshold values for exceeding 10% of the orientation value, rural road, single sided development

Density/ha	Distance to the axis of the road (m)													
	10	20	30	40	50	60	70	80	90	100	125	150	175	200
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	9580	-	-	-	-	-	-	-	-	-	-	-	-	-
30	4260	6340	9800	-	-	-	-	-	-	-	-	-	-	-
40	2400	3570	5510	9660	11030	11030	12300	13710	-	-	-	-	-	-
50	1530	2280	3530	6190	7060	7060	7870	8780	9790	12160	-	-	-	-
60	1060	1580	2450	4300	4900	4900	5470	6090	6800	8450	12230	-	-	-
70	780	1160	1800	3160	3600	3600	4020	4480	4990	6210	8990	-	-	-
80	600	890	1380	2420	2760	2760	3070	3430	3820	4750	6880	12400	-	-
90	470	700	1090	1910	2180	2180	2430	2710	3020	3750	5440	9800	-	-
100	380	570	880	1550	1770	1770	1970	2190	2450	3040	4400	7940	-	-
200	100	140	220	390	440	440	490	550	610	760	1100	1980	3680	6340
300	40	60	100	170	200	200	220	240	270	340	490	880	1630	2820
400	20	40	60	100	110	110	120	140	150	190	280	500	920	1580
500	20	20	40	60	70	70	80	90	100	120	180	320	590	1010
600	10	20	20	40	50	50	50	60	70	80	120	220	410	700
700	10	10	20	30	40	40	40	40	50	60	90	160	300	520
800	10	10	10	20	30	30	30	30	40	50	70	120	230	400
900	5	10	10	20	20	20	20	30	30	40	50	100	180	310
1000	4	10	10	20	20	20	20	20	20	30	40	80	150	250

-: more than twice the maximum observed number of transport units per annum required

Table 1-7 GF3 transport threshold values for exceeding 10% of the orientation value, rural road, two sided development

Density/ha	**Distance to the axis of the road (m)**													
	10	20	30	40	50	60	70	80	90	100	125	150	175	200
10	8660	13190	-	-	-	-	-	-	-	-	-	-	-	-
20	2170	3300	5680	10740	-	-	-	-	-	-	-	-	-	-
30	960	1470	2520	4770	7160	9170	10390	11590	13590	-	-	-	-	-
40	540	820	1420	2680	4030	5160	5850	6520	7640	8520	13760	-	-	-
50	350	530	910	1720	2580	3300	3740	4170	4890	5450	8810	-	-	-
60	240	370	630	1190	1790	2290	2600	2900	3400	3790	6120	10300	-	-
70	180	270	460	880	1310	1680	1910	2130	2500	2780	4490	7570	-	-
80	140	210	360	670	1010	1290	1460	1630	1910	2130	3440	5790	11490	-
90	110	160	280	530	800	1020	1150	1290	1510	1680	2720	4580	9080	-
100	90	130	230	430	640	820	940	1040	1220	1360	2200	3710	7360	12670
200	20	30	60	110	160	210	230	260	310	340	550	930	1840	3170
300	10	10	30	50	70	90	100	120	140	150	240	410	820	1410
400	10	10	10	30	40	50	60	70	80	90	140	230	460	790
500	3	10	10	20	30	30	40	40	50	50	90	150	290	510
600	2	4	10	10	20	20	30	30	30	40	60	100	200	350
700	2	3	5	10	10	20	20	20	20	30	40	80	150	260
800	1	2	4	10	10	10	10	20	20	20	30	60	110	200
900	1	2	3	10	10	10	10	10	20	20	30	50	90	160
1000	1	1	2	4	10	10	10	10	10	10	20	40	70	130

-: more than twice the maximum observed number of transport units per annum required

15.2.4 *Route type: urban road (50 km/hour)*

15.2.4.1 Checking individual risk

Rule of thumb 1: An urban road does not have a 10^{-5} contour.
Rule of thumb 2: An urban road does not have a 10^{-6} contour.

15.2.4.2 Checking societal risk

Checking orientation value

Rule of thumb 1: If the transport flow of hazardous substances in road tankers (bulk transport) comprises categories LT3, GT4 or GT5 (irrespective of numbers) then use RBM II.

Rule of thumb 2: The orientation value for the societal risk is not exceeded if GF3 is less than 10 times the threshold value in Table 1-8 (single sided development) or 10 times the threshold value in Table 1-9 (2-sided development).

Checking 10% of the orientation value

Rule of thumb 1: If the transport flow of hazardous substances in road tankers (bulk transport) comprises categories LT3, GT4 or GT5 (irrespective of numbers) then use RBM II.

Rule of thumb 2: If GF3 is less than the threshold value in Table 1-8 (single sided development) or in Table 1-9 (2-sided development), then 10% of the orientation value is not exceeded.

N.B.
1. All rules of thumb apply in the order shown.

Table 1-8 GF3 transport threshold values for exceeding 10% of the orientation value, urban road, single sided development

Density/ha	**Distance to the axis of the road (m)**													
	10	20	30	40	50	60	70	80	90	100	125	150	175	200
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-	-	-	-	-	-
70	2640	-	-	-	-	-	-	-	-	-	-	-	-	-
80	2020	3010	-	-	-	-	-	-	-	-	-	-	-	-
90	1600	2380	-	-	-	-	-	-	-	-	-	-	-	-
100	1290	1930	2980	-	-	-	-	-	-	-	-	-	-	-
200	320	480	740	1300	1490	1490	1660	1850	2060	2570	-	-	-	-
300	140	210	330	580	660	660	740	820	920	1140	1650	2980	-	-
400	80	120	190	330	370	370	420	460	520	640	930	1670	3100	-
500	50	80	120	210	240	240	270	300	330	410	590	1070	1990	-
600	40	50	80	140	170	170	180	210	230	290	410	740	1380	2380
700	30	40	60	110	120	120	140	150	170	210	300	550	1010	1750
800	20	30	50	80	90	90	100	120	130	160	230	420	780	1340
900	20	20	40	60	70	70	80	90	100	130	180	330	610	1060
1000	10	20	30	50	60	60	70	70	80	100	150	270	500	860

-: more than twice the maximum observed number of transport units per annum required

Table 1-9 GF3 transport threshold values for exceeding 10% of the orientation value, urban road, two sided development

Density/ha	**Distance to the axis of the road (m)**													
	10	20	30	40	50	60	70	80	90	100	125	150	175	200
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	3250	-	-	-	-	-	-	-	-	-	-	-	-	-
40	1830	2780	-	-	-	-	-	-	-	-	-	-	-	-
50	1170	1780	3070	-	-	-	-	-	-	-	-	-	-	-
60	810	1240	2130	-	-	-	-	-	-	-	-	-	-	-
70	600	910	1570	2960	-	-	-	-	-	-	-	-	-	-
80	460	700	1200	2270	3400	-	-	-	-	-	-	-	-	-
90	360	550	950	1790	2680	-	-	-	-	-	-	-	-	-
100	290	450	770	1450	2170	2780	3160	-	-	-	-	-	-	-
200	70	110	190	360	540	700	790	880	1030	1150	1860	3130	-	-
300	30	50	90	160	240	310	350	390	460	510	830	1390	2760	-
400	20	30	50	90	140	170	200	220	260	290	460	780	1550	2670
500	10	20	30	60	90	110	130	140	170	180	300	500	990	1710
600	10	10	20	40	60	80	90	100	110	130	210	350	690	1190
700	10	10	20	30	40	60	60	70	80	90	150	260	510	870
800	1*	10	10	20	30	40	50	60	60	70	120	200	390	670
900	1*	10	10	20	30	30	40	40	50	60	90	150	310	530
1000	1*	1*	10	10	20	30	30	40	40	50	70	130	250	430

-: more than twice the maximum observed number of transport units per annum required
1*: number is less than 1

15.2.5 Practical example

Road: A4

Situation: Densities in the blocks per hectare. Distances to the axis of the road in metres

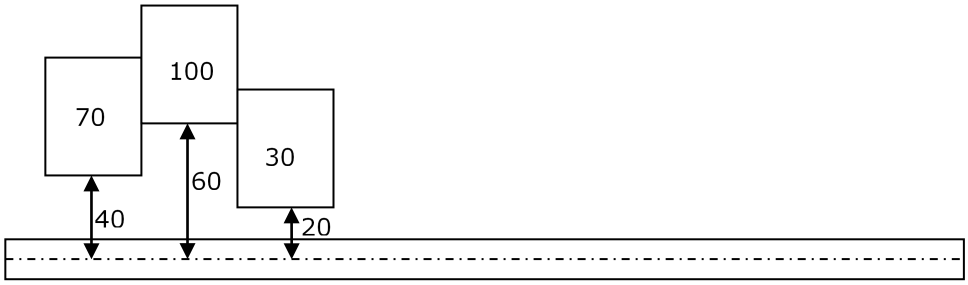

Figure 1-2 Schematic presentation of population

Table 1-10 Transport flow

Substance cat.	**Number**	**Substance cat.**	**Number**
LF1	12794	GT2	1
LF2	17364	GT3	251
LT1	1872	GT4	135
LT2	1338	GF0	881
LT3	66	GF1	445
		GF2	1094
		GF3	2573

Use of rules of thumb

This concerns a motorway with single sided development. Paragraph 1.2.2 above thus applies.

The first check is for the individual risk. These rules of thumb are in paragraph 1.2.2.

Rule of thumb 1: A motorway does not have a 10^{-5} contour.

Self-explanatory.

Rule of thumb 2: A motorway does not have a 10^{-6} contour when the number of GF3 transports per annum is less than 4000.

GF3 is 2573. This is less than 4000 so no 10^{-6} contour.

The second check is on the societal risk. These rules of thumb are in paragraph 1.2.2.2.

Rule of thumb 1: If the transport flow of hazardous substances in road tankers (bulk transport) comprises categories LT3, GT4 or GT5 (irrespective of numbers) then use RBM II.

LT3 and GT4 are present in the transport flow. RBM II should therefore be used. One more check on GF3:

Rule of thumb 2: If GF3 is less than 10 times the threshold value in Table 1-4 (single sided development) or 10 times the threshold value in Table 1-5 (2-sided development) the orientation value for the societal risk is not exceeded.

The number of GF3 is 2573. The minimum distance is 20 m, the maximum density is 100/ha. Table 1-4 gives 2100 GF3 transports to exceed 10% of the orientation value, 21000 to exceed the orientation value. Ten percent of the orientation value could thus be exceeded. The orientation value itself is not exceeded by GF3 on its own, but it could be in combination with LT3 and GT4. RBM II should therefore be used, a conclusion that was already drawn from rule 1.

15.2.6 Explanatory notes for rules of thumb for transport by road

This paragraph provides the background to the calculations that form the basis for the rules of thumb for external safety for transport by road.

15.2.6.1 Individual risk

The individual risk is calculated for a route section with a length of 5 kilometres. The other variables are shown in Table 1-11.

Table 1-11 Values used in calculating the individual risk

Variable	**Value**
Software	RBM 1.3.0 build 247 dated 30/10/2008
Road type	Motorway (MWAY), rural road (Rural), urban road (Urban)
Road width	Default
Accident frequency	Default
Weather	RIVM homogeneous
Substance	GT1..5, GF1..3, LT1..4, LF2

Table 1-12 shows, per substance category, the numbers that are required per category to generate a 10^{-6} contour at the edge of the road and the observed maxima. The count results published on the Internet (status as of November 2008) are incorporated into a database. The results of 610 counting points are used as reference.

Table 1-12 Threshold values for 10-6 contour and observed maxima

Substance categories	**MWAY**		**Rural**		**Urban**	
	10^{-6} threshold	**NL max**	**10^{-6} threshold**	**NL max**	**10^{-6} threshold**	**NL max**
GF1 (flammable gases)	101711	1120	17045	629	35998	33
GT2 (toxic gases)	81269	20	23108	0	76961	0
GT3 (toxic gases cat. 3)	60827	535	17645	394	60736	65
GT4 (toxic gases cat. 4)	8741	399	3000	131	10370	33
GF2 (flammable gases)	19677	2913	6210	1130	21029	367
GF3 (highly flammable gases)	10308	26637	3379	14146	11404	1707
GT5 (toxic gases cat. 5)	8741	66	2999	35	10370	0
LF1 (flammable liquids)	>1000000	57746	>200000	15941	>400000	11185
LF2 (highly flammable liquids)	98918	92463	16803	17512	35562	32569
LT1 (toxic liquids)	20423	3719	4265	486	9282	364
LT2 (toxic liquids cat. 2)	10964	5206	2536	1870	5571	2008
LT3 (toxic liquids cat. 3)	3796	183	1054	215	2375	0
LT4 (toxic liquids cat. 4)	1220	0	356	0	802	0

Table 1-12 shows that, in relation to the observed numbers, categories LF2, GF3 and LT2 determine the location of the 10-6 contour.

When the number of GF3 transports per annum is less than 4000, it is highly improbable that a combination of numbers in the other substance categories would achieve the level of 10^{-6} per annum. Above this number a summation rule has been formulated which indicates when a 10^{-6} contour arises. The rule is a linear combination of the contributions per transport unit.

15.2.6.2 Societal risk

The societal risk is calculated for a one kilometre road length with an occupied population area on one side or on both sides of the road as shown in Figure 1-3. The other variables are shown in Table 1-13.

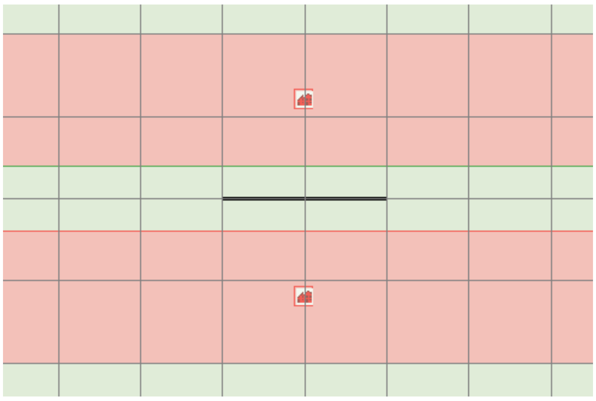

Figure 1-3 Modelling population and route

The base calculation assumes 1000 transports per annum. The norm value (NW) for the calculated societal risk curve in relation to the orientation value is:

$$NW = \frac{MAX\left(FN^2\right)}{0.01}$$

The result of this determines the number per annum that is sufficient to reach the orientation value if:

$$DR_{1000} = \frac{1000}{NW}$$

The threshold values for other presence densities are based on the following formula, where ad is the requested presence density.

$$DR_{ad} = DR_{1000} * \left(\frac{1000}{ad}\right)^2$$

These calculations have been performed for distances from the development to the axis of the road between 10 and 200 m. The results have been used to formulate a contingency table that shows the number of transports per annum at which the orientation value is exceeded at a specific distance and density.

Table 1-13 Values used in societal risk base calculation

Variable	**Value**
Software	RBM 1.3.0 build 247 dated 30/10/2008
Road type	Motorway (MWAY), rural road (Rural), urban road (Urban)
Road width	Default
Accident frequency	Default
Weather	RIVM homogeneous
Substance categories	GT3..5, GF2..3, LT1..2
Number per annum	1000
Population type	Residential development
Distance to the axis of the road	10, 20… - 200 m
Depth of area	To 1 km from the axis of the road
Presence density	1000/ha
Proportion present in daytime	50%
Proportion present at night	100%
Proportion outside in daytime	7%
Proportion outside at night	1%

Table 1-14 shows the norm value for the substance categories in relation to GF3 for three distances to the axis of the road. The table shows that GF3 dominates the societal risk unless LT3, GT4 or GT5 are present in the transport flow. GF2 and GF3 always have a combined presence in the transport flow. This means that GF3 is always determinative in relation to GF2.

If LT3, GT4 or GT5 are present in the transport flow, only small numbers are needed for (10% of) the orientation value to be exceeded. Table 1-15 gives the threshold values for a rural road as an example. When the required numbers are more than twice the maximums observed in the Netherlands, a dash has been used. When 1 transport is counted in a weekly-count this means approximately 35 transports on an annual basis. This is a number that, at higher presence densities, quickly leads to the orientation value being exceeded or which, in any case, significantly 'tilts-up' the FN curve. There are no, GT4, GT5 or LT3 transports on approximately 65% of the road sections.
It has therefore been decided not to choose a (complex) combination rule for various substance categories for the rules of thumb, but for a calculation if LT3, GT4 or GT5 are present.

The previous approach of the rules of thumb [3], to also provide threshold values for an average composition across the Netherlands, is no longer used. The composition of the road sections is so diverse that an average has little meaning for a concrete case in which the rules of thumb are used.

Table 1-14 Norm values in relation to GF3 (Motorway, 2-sided)

	Distance [m]		
	20	100	200
Substance category	**Norm value regarding GF3**		
LT1 (toxic liquids)	<0.01	<0.01	<0.01
LT2 (toxic liquids cat. 2)	<0.01	0.02	0.07
LT3 (toxic liquids cat. 3)	0.61	5.13	30.36
GF3 (highly flammable gases)	1.00	1.00	1.00
GF2 (flammable gases)	0.10	0.17	0.02
GT3 (toxic gases cat. 3)	<0.01	0.01	0.02
GT4 (toxic gases cat. 4)	1.66	15.76	113.59
GT5 (toxic gases cat. 5)	1.66	15.76	113.59

Table 1-15 GT4 and GT5 transport threshold values for exceeding 10% of the orientation value, rural road, two sided development

Density /ha	**Distance to the axis of the road (m)**													
	10	20	30	40	50	60	70	80	90	100	125	150	175	200
10	-	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-	-	-	-	-	-
60	220	220	220	220	240	250	250	-	-	-	-	-	-	-
70	160	160	160	160	170	180	190	190	200	210	220	230	250	-
80	120	120	120	120	130	140	140	150	150	160	170	170	190	210
90	100	100	100	100	110	110	110	120	120	130	130	140	150	170
100	80	80	80	80	90	90	90	90	100	100	110	110	120	140
200	20	20	20	20	20	20	20	20	20	30	30	30	30	30
300	10	10	10	10	10	10	10	10	10	10	10	10	10	20
400	5	5	5	5	5	6	6	6	6	6	7	7	8	9
500	3	3	3	3	3	4	4	4	4	4	4	4	5	5
600	2	2	2	2	2	2	3	3	3	3	3	3	3	4
700	2	2	2	2	2	2	2	2	2	2	2	2	3	3
800	1	1	1	1	1	1	1	1	2	2	2	2	2	2
900	1	1	1	1	1	1	1	1	1	1	1	1	2	2
1000	1	1	1	1	1	1	1	1	1	1	1	1	1	1

-: more than twice the maximum observed number of transport units per annum required

15.3 Rules of thumb for rail transport

15.3.1 Introduction

The numbers will be used often in the remainder of this section. For rail transport, this mainly concerns the numbers of LPG tank wagons in both directions per annum over a track section. LPG is one of the pressurised liquefied gases, substance category A (see below). When the rules of thumb mention a substance category, such as A, this means the number of loaded passages per annum in both directions.
The rules of thumb were formulated for the individual risk and the societal risk.
This is a threshold value and a target value, 10^{-5} and 10^{-6}, per annum for the individual risk, and the orientation value and a factor of 0.1 times the orientation value for the societal risk.

The numbers encountered in real life were used as a reference when formulating the rules of thumb. There is not much point in indicating that 4000 tank wagons per annum are required to exceed the threshold value for the individual risk in the highly toxic liquids category when the maximum number observed was 183. The 2007 realisation figures [4] and the market expectation [5] have been used for reference. The rules of thumb have been formulated to a factor 2 above the observed maximum or the expectation. Larger transport numbers are not expected in the coming years.

Substance categories
The risks from transporting hazardous substances depend on, among other things, substance properties, such as volatility and toxicity. There is a wide range of substances that are being transported. It includes solid substances, liquids and gases, flammable, toxic or both. The substances have been assigned to categories to keep the calculations workable. Substances that have little 'hazard potential', resulting from the combination of their properties, are in the 'irrelevant to external safety' category. The risk is calculated using the other categories. These categories are:

Table 1-16 Substance categories for rail transport

Substance category		**Representative substance(s)**	**Applicable for GEVI**
A	Flammable gas	Propane	23, 263, 239
B2	Toxic gas	Ammonia	265 (excl. UN 1017), 26,
B3	Highly toxic gas	Chlorine	268 (UN 1017)
C3	Highly flammable liquid	Hexane	33, 33*, X33*, 336 (excl. UN
D3	Toxic liquid	Acrylonitrile	Acrylonitrile (UN No. 1093)
D4	Highly toxic liquid	Hydrogen Fluoride or Acrolein	66, 663, 668, 886, (X88, X886)

When the transports are reported, the results are also given in terms of these categories. The classification system is described in 'System for classifying substances for risk calculations for the carriage of hazardous substances', Ministry of Transport, Public Works and Water Management 1999 [9].

Development area and presence density
The societal risk is determined by three variables:

- The distance from the development area to the axis of the track section.
- The presence density in the development area.
- The nature and the numbers of substances transported.

In practice, it is usually sufficient to inventory the population in the area within the 10^{-8} contour of the individual risk. An RMB II calculation can be used to check if the result of the societal risk calculation is sensitive to the population outside of the 10^{-8} contour.
In almost all cases, the societal risk is determined by substance category A. It is then sufficiently accurate to inventory the population density up to 400 m from the axis of the railway for the societal risk calculation or, in other words, adding the population outside of 400 m does not produce any significant change in the result.

N.B. Naturally, the maximum effect distances for major toxic liquid and gas scenarios, are bigger than 300 m.

Table 1-17 gives the maximum distances to a 1% probability of lethality per substance category.

Table 1-17 Maximum effect distance (1% probability of lethality) per substance category

Substance category	**Max effect [m]**
A	460
B2	995
B3	>4000
C3	35
D3	375
D4	> 4000

The rules of thumb have been derived for population areas that are uniformly populated with a specific presence density per hectare, see Figure 1-4. In a specific case, the choice should therefore be conservative, i.e. the smallest distance between the development area to be considered and the axis of the road and the highest presence density that occurs.

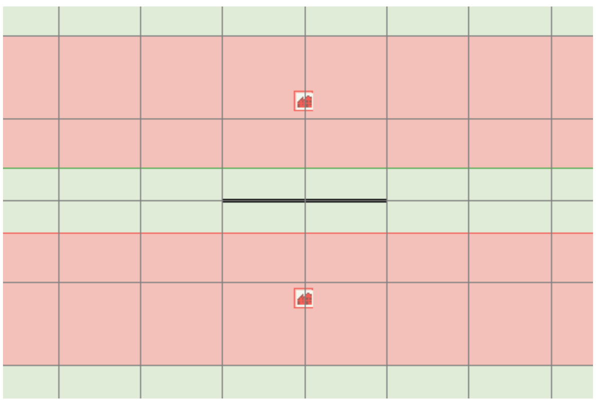

Figure 1-4 Modelling population and route

Field of application

As stated in the introduction, the rules of thumb are an initial filter: they select those situations in which there is absolutely no question of a spatial, external safety problem. They are coarse and do not take the details of the situation that has to be evaluated into account, such as local variations in the development density or the accident frequency. The user should take proper account of these limitations every time the rules of thumb are used. In many cases, a number of points to note are highlighted.

Table 1-18 shows, per substance category, the numbers that are required per category to generate a 10^{-6} contour at the edge of the track section and the observed and forecast maxima also.

Table 1-18 Threshold values for 10-6 contour and observed maxima.

Substance category	**Train type**	**10-6 Threshold**	**NL max 2007**	**Market expectation 2020**
A (flammable gases)	Mixed	22743	13550	24990
A (flammable gases)	Block	86794		
B2 (toxic gases)	Mixed	>100000	3950	10620
B2 (toxic gases)	Block	>100000		
B3 (highly toxic gases)	Block	> 100000	50	200
C3 (highly flammable liquids)		16964	21200	59280
D3 (toxic liquids)		62403	3600	7210
D4 (highly toxic liquids)		14147	1800	2140

The rules of thumb have been formulated for two route types: a high-speed track section and a low-speed track section. They apply to the main line. They do not apply to complex situations such as station locations.
The rules of thumb for individual risk and societal risk per route type are shown below.

15.3.2 *Route type: high-speed rail section*

15.3.2.1 Checking individual risk

At a high-speed track section, a track section speed of more than 40 km per hour applies.

Rule of thumb 1: A high-speed track section does not have a 10^{-5} contour.

Rule of thumb 2: A high-speed track section has a 10^{-6} contour when the number of C3 transports per annum is higher than 17000.

Rule of thumb 3: If the number of C3 transports per annum is less than 17000, a high-speed track section does not have a 10^{-6} contour if $0.00006*(C3+A+0.3*D3+D4)<1$.

N.B.

1. All rules of thumb apply in the order shown.

2. If a rule of thumb indicates that a 10^{-6} contour is possible then use RBM II.
3. These rules of thumb only apply to the main line and must be used with caution. Risk assessments on the railway are carried out using the generic accident frequencies, but the generic accident frequency for the through main line railway, is corrected for the presence of switches and level crossings. The resulting accident frequencies used in a calculation, could be higher than the accident frequency used as the basis for deriving these rules of thumb. If a higher accident frequency is assumed than the default frequency, RBM II has to be used at even lower transport numbers.

15.3.2.2 Checking societal risk

Checking orientation value

Rule of thumb 1: If the transport flow of hazardous substances in tank wagons (bulk transport) comprises substances in the B3 category (irrespective of numbers) then use RBM II.

Rule of thumb 2: If A is less than 50 and D4 or B2 are present in the traffic flow then use RBM II, if the presence densities are higher than 200 per hectare within 200 m of the track section.

Rule of thumb 3: The orientation value for the societal risk is not exceeded if A is less than 10 times the threshold value in Table 16 (single sided development) or 10 times the threshold value in Table 17 (2-sided development).

Checking 10% of the orientation value

Rule of thumb 1: If the transport flow of hazardous substances in tank wagons (bulk transport) comprises substances in the B3 category (irrespective of numbers) then use RBM II.

Rule of thumb 2: If A is less than 50 and D4 or B2 are present in the traffic flow then use RBM II, if the presence densities are higher than 70 per hectare within 200 m of the track section.

Rule of thumb 3: If A is less than the threshold value in Table 1-19 (single sided development) or in Table 1-20 (2-sided development), then 10% of the orientation value is not exceeded.

N.B.

1. All rules of thumb apply in the order shown.
2. If a rule of thumb indicates that 10% of the orientation value for the societal risk could be exceeded then use RBM II to calculate the level of the societal risk, if a risk assessment is being carried out for a transport or spatial planning decision.

3. These rules of thumb only apply to the main line and must be used with a degree of caution. Risk assessments on the railway are carried out using the generic accident frequencies, but the generic accident frequency for the through main line railway is corrected for the presence of switches and level crossings. As a result of this the accident frequencies used in a calculation could be higher than the accident frequency used as the basis for deriving these rules of thumb. If a higher accident frequency is assumed than the default frequency, RBM II has to be used at even lower transport numbers.

Table 1-19 Threshold value for the transport of flammable pressurised liquefied gases (A) in mixed trains for exceeding 10% of the orientation value, high speed track section, single sided development

Den-sity /ha	**Distance to the axis of the road (m)**												
	20	30	40	50	60	70	80	90	100	125	150	175	200
10	11410	14140	17530	21800	27090	33680	41800	-	-	-	-	-	-
20	2850	3530	4380	5450	6770	8420	10450	14470	19960	-	-	-	-
30	1270	1570	1950	2420	3010	3740	4640	6430	8870	29200	-	-	-
40	710	880	1100	1360	1690	2100	2610	3620	4990	16430	-	-	-
50	460	570	700	870	1080	1350	1670	2320	3190	10510	-	-	-
60	320	390	490	610	750	940	1160	1610	2220	7300	46110	-	-
70	230	290	360	440	550	690	850	1180	1630	5360	33880	-	-
80	180	220	270	340	420	530	650	900	1250	4110	25940	-	-
90	140	170	220	270	330	420	520	710	990	3240	20490	43100	-
100	110	140	180	220	270	340	420	580	800	2630	16600	34910	-
200	30	40	40	50	70	80	100	140	200	660	4150	8730	13490
300	10	20	20	20	30	40	50	60	90	290	1840	3880	5990
400	10	10	10	10	20	20	30	40	50	160	1040	2180	3370
500	5	10	10	10	10	10	20	20	30	110	660	1400	2160
600	3	4	5	10	10	10	10	20	20	70	460	970	1500
700	2	3	4	4	10	10	10	10	20	50	340	710	1100
800	2	2	3	3	4	10	10	10	10	40	260	550	840
900	1	2	2	3	3	4	10	10	10	30	200	430	670
1000	1	1	2	2	3	3	4	10	10	30	170	350	540

-: more than twice the maximum observed number of transport units per annum required

Table 1-20 Threshold value for the transport of flammable pressurised liquefied gases (A) in mixed trains for exceeding 10% of the orientation value, high speed track section, two sided development

Density/ha	**Distance to the axis of the road (m)**												
	20	30	40	50	60	70	80	90	100	125	150	175	200
10	3120	3480	4300	5350	6640	8220	11360	14120	21550	-	-	-	-
20	780	870	1070	1340	1660	2060	2840	3530	5390	15940	-	-	-
30	350	390	480	590	740	910	1260	1570	2390	7080	44430	-	-
40	200	220	270	330	420	510	710	880	1350	3990	24990	-	-
50	120	140	170	210	270	330	450	560	860	2550	15990	-	-
60	90	100	120	150	180	230	320	390	600	1770	11110	48490	-
70	60	70	90	110	140	170	230	290	440	1300	8160	35630	-
80	50	50	70	80	100	130	180	220	340	1000	6250	27280	42150
90	40	40	50	70	80	100	140	170	270	790	4940	21550	33300
100	30	30	40	50	70	80	110	140	220	640	4000	17460	26970
200	10	10	10	10	20	20	30	40	50	160	1000	4360	6740
300	3	4	5	10	10	10	10	20	20	70	440	1940	3000
400	2	2	3	3	4	10	10	10	10	40	250	1090	1690
500	1	1	2	2	3	3	5	10	10	30	160	700	1080
600	1	1	1	1	2	2	3	4	10	20	110	480	750
700	1	1	1	1	1	2	2	3	4	10	80	360	550
800	1	1	1	1	1	1	2	2	3	10	60	270	420
900	1*	1*	1	1	1	1	1	2	3	10	50	220	330
1000	1*	1*	1*	1	1	1	1	1	2	10	40	170	270

-: more than twice the maximum observed number of transport units per annum required
1*: number is less than 1

15.3.3 *Route type: low speed track section*

15.3.3.1 Checking individual risk

A track section speed lower than 40 km per hour applies to a low speed track section.

Rule of thumb 1: A low speed track section does not have a 10^{-6} contour.

N.B.

1. This rule of thumb only applies to the main line and must be used with a degree of caution. Risk assessments on the railway are carried out using the generic accident frequencies, but the generic accident frequency for the through main line railway is corrected for the presence of switches and level crossings in the section. As a result of this the accident frequencies used in a calculation could be higher than the accident frequency used as the basis for deriving these rules of thumb. If a higher accident frequency is assumed than the default frequency, RBM II has to be used at even lower transport numbers.

15.3.3.2 Checking societal risk

Checking orientation value

Rule of thumb 1: The orientation value for the societal risk is not exceeded if A is less than 10 times the threshold value in Table 1-21 (single sided development) or 10 times the threshold value in Table 1-22 (2-sided development).

Checking 10% of the orientation value

Rule of thumb 1: If the transport flow of hazardous substances in tank wagons (bulk transport) contains substances in the B2, B3 or D4 categories (irrespective of number) then use RBM II, if the presence densities are greater than 200 per hectare within 200 m of the track section.

Rule of thumb 2: 10% of the orientation value is not exceeded if A is less than the threshold value in Table 1-21 (single sided development) or in Table 1-22 (2-sided development).

N.B.

1. All rules of thumb apply in the order shown.
2. These rules of thumb only apply to the main line and must be used with a degree of caution. Risk assessments on the railway are carried out using the generic accident frequencies, but the generic accident frequency for the through main line railway is corrected for the presence of switches and level crossings. As a result of this the accident frequencies used in a calculation could be higher than the accident frequency used as the basis for deriving these rules of thumb. If a higher accident frequency is assumed than the default frequency, RBM II has to be used at even lower transport numbers.

Table 1-21 Threshold values for the transport of flammable pressurised liquefied gases (A) in mixed trains for exceeding 10% of the orientation value, low speed track section, single sided development

Density/ha	**Distance to the axis of the track section (m)**												
	20	30	40	50	60	70	80	90	100	125	150	175	200
10	-	-	-	-	-	-	-	-	-	-	-	-	-
20	16460	20400	25290	31440	39080	48580	-	-	-	-	-	-	-
30	7310	9060	11240	13970	17370	21590	26800	37120	-	-	-	-	-
40	4110	5100	6320	7860	9770	12150	15070	20880	28790	-	-	-	-
50	2630	3260	4050	5030	6250	7770	9650	13360	18430	-	-	-	-
60	1830	2270	2810	3490	4340	5400	6700	9280	12800	42130	-	-	-
70	1340	1660	2060	2570	3190	3970	4920	6820	9400	30950	-	-	-
80	1030	1270	1580	1970	2440	3040	3770	5220	7200	23700	-	-	-
90	810	1010	1250	1550	1930	2400	2980	4120	5690	18720	-	-	-
100	660	820	1010	1260	1560	1940	2410	3340	4610	15170	-	-	-
200	160	200	250	310	390	490	600	840	1150	3790	23950	-	-
300	70	90	110	140	170	220	270	370	510	1690	10640	22390	34590
400	40	50	60	80	100	120	150	210	290	950	5990	12590	19460
500	30	30	40	50	60	80	100	130	180	610	3830	8060	12450
600	20	20	30	30	40	50	70	90	130	420	2660	5600	8650
700	10	20	20	30	30	40	50	70	90	310	1950	4110	6350
800	10	10	20	20	20	30	40	50	70	240	1500	3150	4860
900	10	10	10	20	20	20	30	40	60	190	1180	2490	3840
1000	10	10	10	10	20	20	20	30	50	150	960	2010	3110

-: more than twice the maximum observed number of transport units per annum required

Table 1-22 Threshold values for the transport of flammable pressurised liquefied gases (A) in mixed trains for exceeding 10% of the orientation value, low speed track section, two sided development

Density/ha	**Distance to the axis of the track section (m)**											
	20	30	40	50	60	70	80	90	100	125	150	175	200
10	18020	20090	24810	30840	38340	47450	-	-	-	-	-	-	-
20	4510	5020	6200	7710	9580	11860	14700	20380	31090	-	-	-	-
30	2000	2230	2760	3430	4260	5270	6530	9060	13820	40880	-	-	-
40	1130	1260	1550	1930	2400	2970	3680	5090	7770	23000	-	-	-
50	720	800	990	1230	1530	1900	2350	3260	4970	14720	-	-	-
60	500	560	690	860	1060	1320	1630	2260	3450	10220	-	-	-
70	370	410	510	630	780	970	1200	1660	2540	7510	47090	-	-
80	280	310	390	480	600	740	920	1270	1940	5750	36050	-	-
90	220	250	310	380	470	590	730	1010	1540	4540	28490	-	-
100	180	200	250	310	380	470	590	820	1240	3680	23070	-	-
200	50	50	60	80	100	120	150	200	310	920	5770	25180	38910
300	20	20	30	30	40	50	70	90	140	410	2560	11190	17290
400	10	10	20	20	20	30	40	50	80	230	1440	6300	9730
500	10	10	10	10	20	20	20	30	50	150	920	4030	6230
600	10	10	10	10	10	10	20	20	30	100	640	2800	4320
700	4	4	10	10	10	10	10	20	30	80	470	2060	3180
800	3	3	4	5	10	10	10	10	20	60	360	1570	2430
900	2	2	3	4	5	10	10	10	20	50	280	1240	1920
1000	2	2	2	3	4	5	10	10	10	40	230	1010	1560

-: more than twice the maximum observed number of transport units per annum required

15.3.4 *Explanatory notes for rules of thumb for transport by rail*

15.3.4.1 Individual risk

The individual risk is calculated for a route section with a length of 5 kilometres. The other variables are shown in Table 1-23.

Table 1-23 Values used in calculating the individual risk

Variable	**Value**
Software	RBM 1.3.0 build 247 dated 30/10/2008
Road type	High speed track section, low speed track section
Width	Default
Accident frequency	Default, switches: default, level crossing: none
Weather	RIVM homogeneous
Substance categories	C3, A-mixed[27], A-block, B2-mixed, B2-block, B3, D3, D4

Table 1-24 shows, per substance category, the numbers that are required per category to generate a 10^{-6} contour at the edge of the track section and the observed and forecast maximums also.

Table 1-24 Threshold values for 10-6 contour and observed maxima

Substance category	**Train type**	**10-6 Threshold**	**NL max 2007**	**Market expectation 2020**
A (flammable gases)	Mixed	22743	13550	24990
A (flammable gases)	Block	86794		
B2 (toxic gases)	Mixed	>100000	3950	10620
B2 (toxic gases)	Block	>100000		
B3 (highly toxic gases)	Block	> 100000	50	200
C3 (highly flammable liquids)		16964	21200	59280
D3 (toxic liquids)		62403	3600	7210
D4 (highly toxic liquids)		14147	1800	2140

Table 1-24 shows that, in relation to the observed numbers, the C3 and A categories in mixed trains determine the location of the 10^{-6} contour.

When the number of C3 transports per annum is less than 17000, the level of 10-6 per annum could be achieved by a combination of numbers in the other substance categories. A summation rule has been formulated which indicates when a 10^{-6} contour arises. The rule is a linear combination of the contributions per transport.

15.3.4.2 Societal risk

The societal risk is calculated for a one kilometre track section length with an occupied population area on one side or on both sides of the track section as shown in Figure 1-5. The other variables are shown in Table 1-25.

[27] Mixed: train for various customers, which has both rail tank wagons containing flammable liquids and wagons with pressurised liquefied gases. Block: train usually for a single customer and a single substance category.

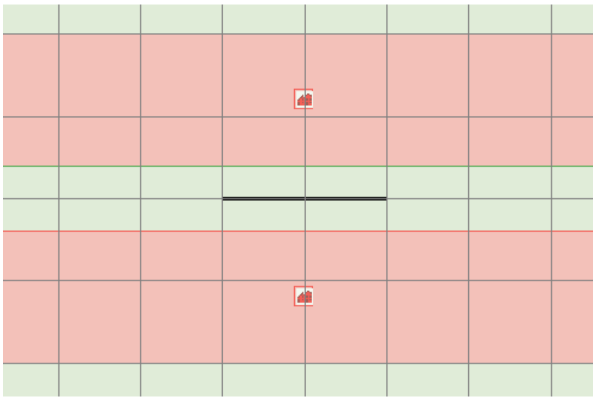

Figure 1-5 Modelling population and route

The base calculation assumes 1000 transports per annum. The norm value for the calculated societal risk curve in relation to the orientation value[28] has been determined to be:

$$NW = \frac{MAX\left(FN^2\right)}{0.01}$$

The result of this determines the number per annum that is sufficient to reach the orientation value if

$$DR_{1000} = \frac{1000}{NW}$$

The threshold values for other presence densities are projected backwards using the relationship:

$$DR_{ad} = DR_{1000} * \left(\frac{1000}{ad}\right)^2$$

where ad is the requested presence density.

These calculations have been performed for distances from the development to the axis of the track section between 20 and 200 m. The results have been used to formulate a contingency table that shows the number of transports per annum at which the orientation value is exceeded for a specific distance and density.

[28] This is a mathematical formula. The norm value is the ratio between the calculated societal risk and the orientation value. To put it more precisely: the maximum ratio between the probability of a number of victims and the probability associated with the orientation value, or 0.01/N^2. A norm value of 1 therefore means that the calculated societal risk curve touches the orientation value. At a norm value greater than 1 the calculated curve intersects the orientation value.

Table 1-25 Values used in societal risk base calculation

Variable	**Value**
Software	RBM 1.3.0 build 247 dated 30/10/2008
Track section type	High speed track section, low speed track section
Width	Default (10)
Accident frequency	Default, switches: default, level crossing: none
Weather	RIVM homogeneous
Substance categories	A-mixed, A-block, B2-mixed, B2-block, B3, C3, D3, D4
Average number of C3 wagons	Default (2)
Daytime transport	33%
Working week transport	71.4%
Transport unit	Rail tank wagon
Number per annum	1000
Population type	Residential development
Distance to the axis of the track section	10, 20…..200 m
Depth of area	To 1 km from the axis of the track section
Presence density	1000/ha
Percentage present in daytime	50%
Percentage present at night	100%
Percentage outside in daytime	7%
Percentage outside at night	1%

Table 1-26 shows the norm value for the substance categories in relation to A-mixed for four distances to the axis of the track section. The table shows that A-mixed dominates the societal risk when the distance to the development is less than 125 m. It also shows that the transport of substance category A in block trains instead of mixed trains produces a significant reduction in the societal risk and the relative contribution of the substance categories to the societal risk changes. Figure 1-8 illustrates the dominance of substance category A in determining whether or not the orientation value is exceeded. This is broadly the case for numbers of A greater than 50 per annum. If it is the case, then it is sufficient for a rule of thumb just to check for the substance category A-mixed. It is only in very atypical environments, such as development starting outside of 150 m from the railway that this does not apply. Figure 1-7 illustrates the shift in the exceedance point depending on the distance of the development from the track section for pure A and pure D4.

Table 1-26 Norm values in relation to A in mixed trains

Substance category	**Distance [m]**			
	20	100	125	200
	Norm value in relation to A-mixed			
A-mixed	1.00	1.00	1.00	1.00
A-block	0.04	0.04	0.12	1.00
B2-mixed	0.00	0.00	0.01	0.12
B2-block	0.00	0.00	0.01	0.12
B3	0.04	0.20	0.66	10.69
D3	0.00	0.00	0.00	0.00
D4	0.02	0.11	0.35	6.43

The other categories that contribute to the societal risk are B2, B3 and D4. The societal risk for B3 depends little on the distance from the development to the track section (see Figure 1-6). Although B3, partly due to the small numbers on an annual basis, will not quickly lead to the orientation value being exceeded on its own, this category could raise the entire curve. For the rule of thumb, it has therefore been decided to always perform a calculation in the case of B3 in the transport flow. D4 reaches the orientation value earlier than B2. D4 usually appears in a specific ratio to A (0.5 is a typical value but the ratio varies significantly). The contribution to the societal risk is then masked by A. However, when very little or no A is transported (<50), D4 and/or B2 can determine the value being exceeded. In this case, the rule of thumb states that a presence density of more than 70 per hectare must exist to enable the exceedance of 10% of the orientation value (see Table 1-27).

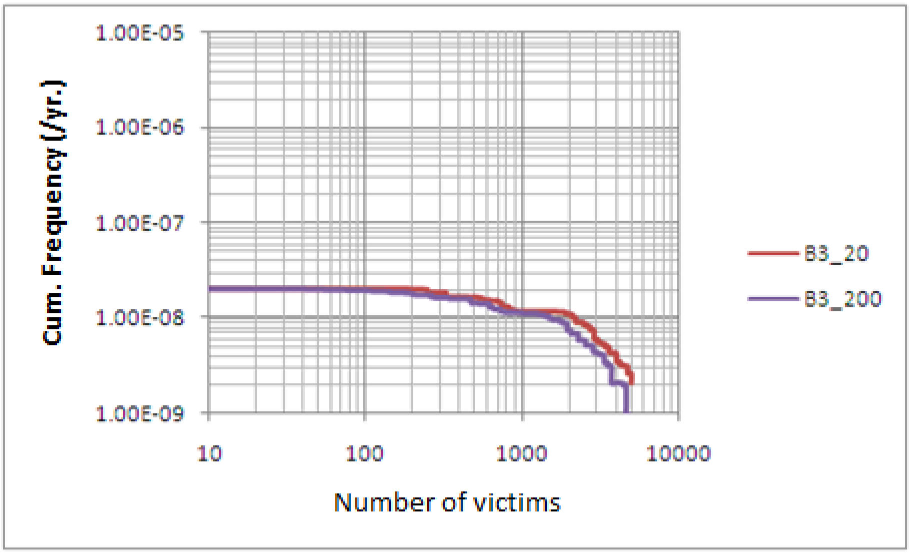

Figure 1-6 Effect of distance to development on B3 (distance 20 and 200 m)

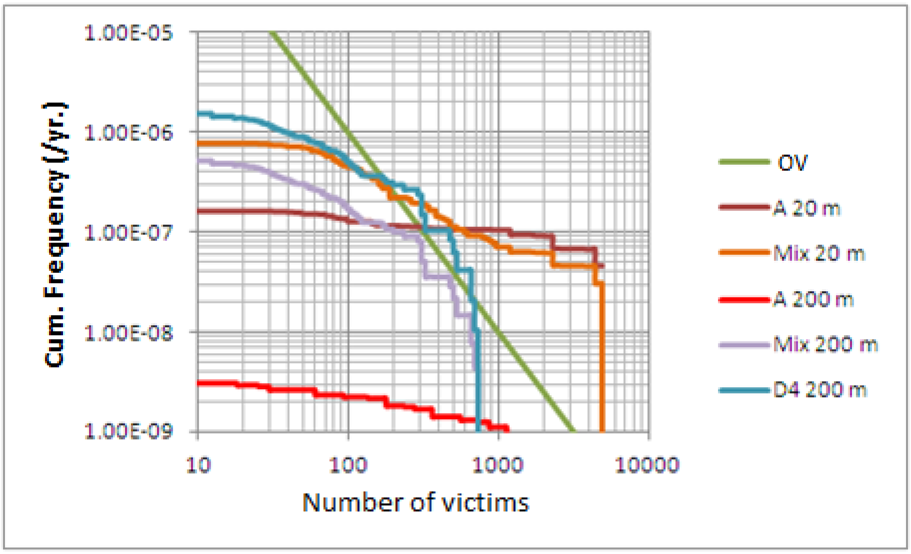

Figure 1-7 Effect of distance to track section on the shape of the societal risk curve (the 'Mixed' flow has the ratio D4/A=0.5, distances 20 and 200 m, OV is the orientation value)

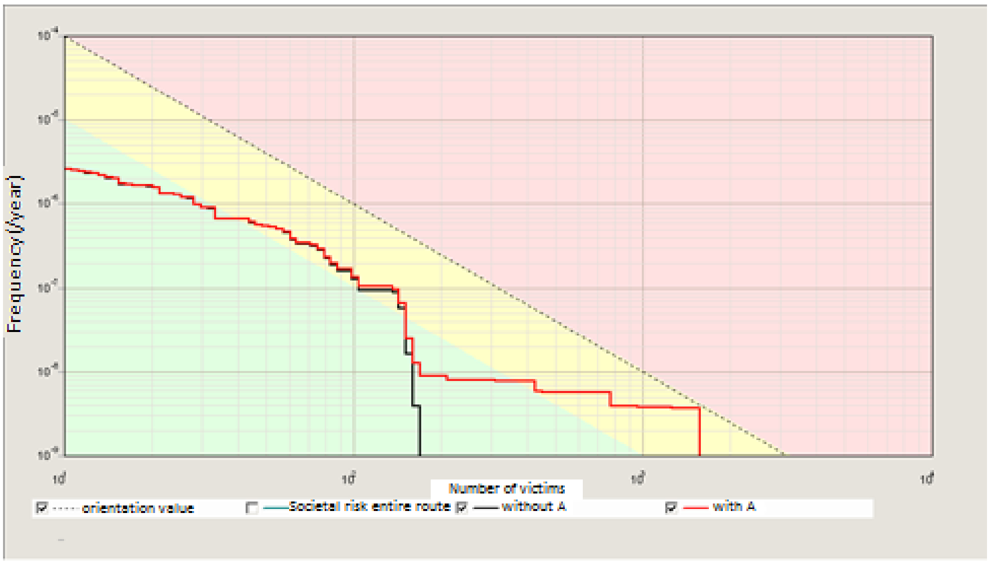

Figure 1-8 Typical societal risk profile: 50 wagons of A determine the point at which the orientation value is exceeded (in addition to 900 D4 and 250 B2)

The approach in the previous version of the rules of thumb [3] to provide threshold values for an average composition across the Netherlands is no longer used. The composition of the track sections is so diverse that an average has little meaning for a concrete case in which the rules of thumb are used. One source of diversity is the value for the average number of C3 wagons.

This determines the ratio between the frequency of a BLEVE at increased pressure in relation to a BLEVE at ambient temperature. In practice, this can vary between 0.2 and 3 per direction. The default value is therefore on the conservative side. Normally, this value is not available flow-specifically and the default value is chosen.

Table 1-27 D4 transport threshold values for exceeding 10% of the orientation value, high speed track section, two sided development

Density /ha	**Distance to the axis of the track section (m)**											
	20	30	40	50	60	70	80	90	100	125	150	175	200
10	-	-	-	-	-	-	-	-	-	-	-	-	-
20	-	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-	-
50	-	-	-	-	-	-	-	-	-	-	-	-	-
60	-	-	-	-	-	-	-	-	-	-	-	-	-
70	-	-	-	-	-	-	-	-	-	-	-	-	-
80	3800	4000	4090	4090	4240	-	-	-	-	-	-	-	-
90	3000	3160	3230	3230	3350	3470	3600	3930	4020	4190	-	-	-
100	2430	2560	2620	2620	2720	2810	2920	3180	3250	3390	3900	3950	4200
200	610	640	650	650	680	700	730	790	810	850	980	990	1050
300	270	280	290	290	300	310	320	350	360	380	430	440	470
400	150	160	160	160	170	180	180	200	200	210	240	250	260
500	100	100	100	100	110	110	120	130	130	140	160	160	170
600	70	70	70	70	80	80	80	90	90	90	110	110	120
700	50	50	50	50	60	60	60	60	70	70	80	80	90
800	40	40	40	40	40	40	50	50	50	50	60	60	70
900	30	30	30	30	30	30	40	40	40	40	50	50	50
1000	20	30	30	30	30	30	30	30	30	30	40	40	40

-: more than twice the maximum observed number of transport units per annum required

15.4 Rules of thumb for transport on inland waterways

15.4.1 Introduction

The numbers will be used often in what follows. In the case of transport on inland waterways, it mainly concerns the numbers of petrol or ammonia loaded tankers in both directions per annum on a waterway. Petrol is one of the flammable liquids, substance category LF2, (see below). When the rules of thumb mention a substance category, such as LF2, this means the number of loaded passages per annum in both directions.

The rules of thumb were formulated for the individual risk and the societal risk.
This is a threshold value and a target value, 10^{-5} and 10^{-6}, per annum for the individual risk, for the societal risk it is the orientation value and a factor of 0.1 times the orientation risk.

The numbers encountered in real life were used as a reference when formulating the rules of thumb. There is not much point in indicating that 20,000 tankers per annum are required to exceed the threshold value for the individual risk in the highly toxic liquids category when the maximum number observed was 7700. The transport in the years 2004-2007 has been used as a reference [6]. The rules of thumb have been formulated to a factor of 2 above the observed maximum. Larger numbers of transports are not expected in the coming years.

Substance categories
The risks from transporting hazardous substances depend on, among other things, substance properties, such as volatility and toxicity. There is a wide range of substances that are being transported. It includes solid substances, liquids and gases, flammable, toxic or both. The substances have been assigned to categories to keep the calculations workable. Substances that have little 'hazard potential', resulting from the combination of their properties are in the 'irrelevant to external safety' category. The risk is calculated using the other categories. These categories are:

LF1: Flammable liquid, e.g. diesel
LF2: Highly flammable liquid, e.g. petrol
LT1: Toxic liquid e.g. acrylonitrile
LT2: Toxic liquid e.g. propylamine
GF2: Flammable pressurised liquefied gas e.g. butane
GF3: Flammable pressurised liquefied gas e.g. propane
GT3: Toxic pressurised liquefied gas e.g. ammonia

A higher number denotes a higher hazard potential. When the transports are counted, the results are also given in terms of these categories. The classification system is described in 'System for classifying substances for risk calculations for the carriage of hazardous substances', Ministry of Transport, Public Works and Water Management 1999 [9].

Development area and presence density
The societal risk is determined by three variables:

- The distance from the development to the waterway
- The presence density in the development area
- The nature and the numbers of substances transported

In practice, it is usually sufficient to inventory the population in the area within the 10^{-8} contour of the individual risk. An RMB II calculation can be used to check if the result of the societal risk calculation is sensitive to the population outside of the 10^{-8} contour.

The societal risk is determined by substance categories GT3 or LT2 in almost all cases. It is then sufficiently accurate to inventory the population density up to 500 m from the waterway for the result of the societal risk calculation, i.e. adding the population outside of 500 m does not lead to any significant changes in the result.

N.B. Naturally, the effect distances for the major scenarios are (much) bigger than 500 m.
Table 1-28 gives per substance category the maximum distances to a 1% probability of lethality.

Table 1-28 Maximum effect distance (1% probability of lethality) per substance category

Substance category	**Max effect [m]**
LF1	35
LF2	35
LT1	600
LT2	880
GF2	65
GF3	90
GT3	1070

The rules of thumb have been derived for population areas that are uniformly populated with a specific presence density per hectare, see Figure 1-9. In a specific case, the choice should therefore be conservative, i.e. the smallest distance between the development area to be considered and the axis of the road and the highest presence density that occurs.

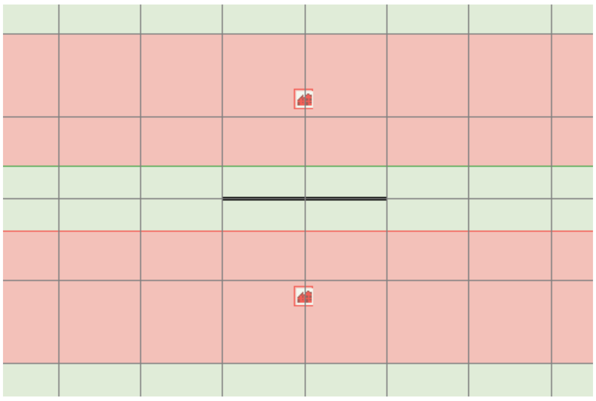

Figure 1-9 Modelling population and route

Field of application
As stated in the introduction, the rules of thumb are an initial filter: they select those situations in which there is absolutely no question of a spatial, external safety problem. They are coarse and do not take the details of the situation that has to be evaluated into account, such as local variations in the development density or the accident frequency. If the accident records show that there is a higher probability of an incident at waterway crossings, bridges, unloading quays, harbour entrances etc., than the average on the waterway section then that waterway section should be incorporated into the calculation with a higher accident frequency. The procedure for this is described in Appendix 6.

The user should take proper account of these limitations every time the rules of thumb are used. In many cases a number of points to note are highlighted.

Table 1-29 shows, per substance category, the maximum number of loaded tankers per category that were observed in the period 2004-2007 [6]. In all cases, more than 10,000 vessels are required per annum for a 10^{-6} contour on the bank. Substance category LF1 (flammable liquids with a flashpoint above 21 °C) has not been included in the table. The threshold values for LF1 are a factor of 13 higher than those of LF2, which results in unrealistically high numbers of tankers which would be required to achieve an individual risk of 10^{-6}.

Table 1-29 Observed maximum numbers of tankers per annum per substance category [6]

Substance cat.	**NL max (2004-2007)**
LF2 (highly flammable liquids)	7709
LT1 (toxic liquids)	258
LT2 (toxic liquids)	251
GF2 (flammable gases)	600
GF3 (flammable gases)	1707
GT3 (toxic gases)	217

Three route types are distinguished in the analyses of the waterways. The waterways are classified into navigability classes or CEMT classes. The CEMT class lays down the maximum dimensions of a vessel that is permitted on the waterway. Table 1-30 gives the CEMT class for a number of main waterways.

Table 1-30 Navigability classes (CEMT) for a number of main waterways

Waterway	**CEMT-class**	**Waterway**	**CEMT-class**
Eems canal	5	Waal	6
v. Starkenborgh canal	5	Beneden Merwede	6
Prinses Margriet canal	5	Noord	6
IJssel	5	Hollandsch Diep	6
Nederrijn	5	Scheldt-Rhine	6

Waterway	CEMT-class	Waterway	CEMT-class
Lek	6	Maas	5
Amsterdam-Rhine canal	6	Juliana canal	5
Oude Maas	6	Ghent-Terneuzen canal	6
Nieuwe Maas	6	Hollandsche IJssel	5

The rules of thumb for the individual risk and societal risk per route type are shown below.

15.4.2 *Route type: Navigability class 6*

15.4.2.1 Checking individual risk

Rule of thumb 1: A navigability class 6 waterway does not have a 10^{-6} contour.

N.B.

1. The rule of thumb applies to the average waterway situation. A rule of thumb may not be suitable in a nautically complex situation (crossing traffic, current, bend, etc.). The vessel damage frequency should then be established based on the number of accidents that have occurred, see note in paragraph 4.1. RBM II should be used if possible.

15.4.2.2 Checking societal risk

Checking orientation value

Rule of thumb 1: Alongside a navigability class 6 waterway, the orientation value for the societal risk is not exceeded.

N.B.

1. The rule of thumb applies to the average waterway situation. A rule of thumb may not be suitable in a nautically complex situation (crossing traffic, current, bend, etc.). The vessel damage frequency should then be established based on the number of accidents that have occurred (see Appendix 6). RBM II should be used if possible.

Checking 10% of the orientation value

Rule of thumb 1: Alongside a navigability class 6 waterway, 10% of the orientation value for the societal risk is only exceeded if within 200 m of the river bank, the presence densities are higher than 500/ha and LT2+GT3>1000 a year.

N.B.

1. The rule of thumb applies to the average waterway situation. A rule of thumb may not be suitable in a nautically complex situation (crossing traffic, current, bend, etc.). The vessel damage frequency should then be established based on the number of accidents that have occurred (see Appendix 6). RBM II should be used if possible.

15.4.3 *Route type: Navigability class 5*

15.4.3.1 Checking individual risk

Rule of thumb 1: A navigability class 5 waterway does not have a 10^{-6} contour.

N.B.

1. The rule of thumb applies to the average waterway situation. A rule of thumb may not be suitable in a nautically complex situation (crossing traffic, current, bend, etc.). The vessel damage frequency should then be established based on the number of accidents that have occurred (see Appendix 6). RBM II should be used if possible.

15.4.3.2 Checking societal risk

Checking orientation value

Rule of thumb 1: The orientation value for the societal risk is not exceeded alongside a navigability class 5 waterway.

N.B.

1. The rule of thumb applies to the average waterway situation. A rule of thumb may not be suitable in a nautically complex situation (crossing traffic, current, bend, etc.). The vessel damage frequency should then be established based on the number of accidents that have occurred (see Appendix 6). RBM II should be used if possible.

Checking 10% of the orientation value

Rule of thumb 1: 10% of the orientation value for the societal risk is not exceeded alongside a navigability class 5 waterway.

N.B.

1. The rule of thumb applies to the average waterway situation. A rule of thumb may not be suitable in a nautically complex situation (crossing traffic, current, bend, etc.). The vessel damage frequency should then be established based on the number of accidents that have occurred (see Appendix 6). RBM II should be used if possible.

15.4.4 *Route type: Navigability class 4*

15.4.4.1 Checking individual risk

Rule of thumb 1: A navigability class 4 waterway does not have a 10^{-6} contour.

N.B.

1. The rule of thumb applies to the average waterway situation. A rule of thumb may not be suitable in a nautically complex situation (crossing traffic, current, bend, etc.). The vessel damage frequency should then be established based on the number of accidents that have occurred (see Appendix 6). RBM II should be used if possible.

Checking societal risk Checking orientation value

Rule of thumb 1: The orientation value for the societal risk is not exceeded alongside a navigability class 4 waterway.

N.B.

1. The rule of thumb applies to the average waterway situation. A rule of thumb may not be suitable in a nautically complex situation (crossing traffic, current, bend, etc.). The vessel damage frequency should then be established based on the number of accidents that have occurred (see Appendix 6). RBM II should be used if possible.

Checking 10% of the orientation value

Rule of thumb 1: 10% of the orientation value for the societal risk is not exceeded alongside a navigability class 4 waterway.

N.B.

1. The rule of thumb applies to the average waterway situation. A rule of thumb may not be suitable in a nautically complex situation (crossing traffic, current, bend, etc.). The vessel damage frequency should then be established based on the number of accidents that have occurred (see Appendix 6). RBM II should be used if possible.

15.4.5 Explanatory notes for rules of thumb for transport on inland waterways

15.4.5.1 Individual risk

The individual risk is calculated for a route section with a length of 5 kilometres. The other variables are shown in Table 1-31.

Table 1-31 Values used in calculating the individual risk

Variable	**Value**
Software	RBM 1.3.0 build 247 dated 30/10/2008
Type of waterway	Navigability class 6, 5 and 4
Width	200, 100 and 50 m
Accident frequency	Default
Weather	RIVM homogeneous
Substance category / vessel types	LF2: sw and dw[29], GF2 pressurised gas, GF3 pressurised gas, GT3: pressurised and semi cooled gas, LT1: dw, LT2: dw

Table 1-32 shows per substance category, the maximum number of tankers per category, observed in the period 2004-2007 [6]. In all cases, more than 10,000 vessels are required per annum for a 10^{-6} contour on the bank.

[29] sw: single walled, dw: dual walled.

Table 1 32 Observed maximum numbers of tankers per annum per substance category [6]

Substance category	**NL max (2004-2007)**
LF2 (highly flammable liquids)	7709
LT1 (toxic liquids)	258
LT2 (toxic liquids)	251
GF2 (flammable gases)	600
GF3 (flammable gases)	1707
GT3 (toxic gases)	217

Table 1-32 shows that, given the numbers observed, an individual risk level of 10^{-6} per annum is under normal conditions not reached alongside waterways.

15.4.5.2 Societal risk

The societal risk is calculated for a one kilometre length of waterway with an occupied population area on one side or on both sides of the waterway as shown in Figure 1-10. The other variables are shown in Table 1-33.

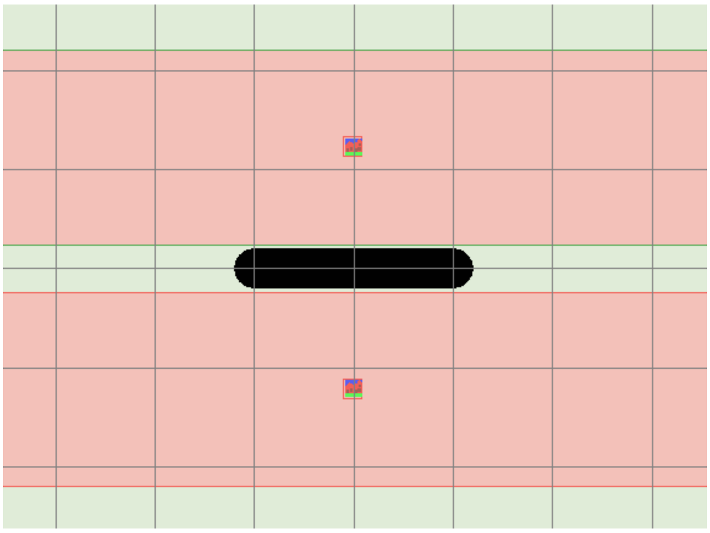

Figure 1-10 Modelling population and route

The base calculation assumes 1000 transports per annum. The norm value for the calculated societal risk curve in relation to the orientation value has been determined to be:

$$NW = \frac{MAX\left(FN^2\right)}{0.01}$$

The result determines the number per annum that is sufficient to reach the orientation value if

$$DR_{1000} = \frac{1000}{NW}$$

The threshold values for other presence densities are calculated using the relationship:

$$DR_{ad} = DR_{1000} * \left(\frac{1000}{ad} \right)^2$$

where ad is the requested presence density.

These calculations have been performed for distances from the development to the waterway bank between 10 and 200 m.

Table 1-33 Values used in societal risk base calculation

Variable	**Value**
Software	RBM 1.3.0 build 247 dated 30/10/2008
Type of waterway	Navigability class 6, 5 and 4
Width	200, 100 and 50 m
Accident frequency	Default
Weather	RIVM homogeneous
Substance category / vessel types	LF2: sw and dw, GF2: pressurised gas, GF3 pressurised gas, GT3: pressurised and semi cooled gas , LT1: dw, LT2: dw
Number per annum	1000
Population type	Residential development
Distance to the bank of the waterway	10, 20, 30 … - 200 m
Depth of area	1 km
Presence density	1000/ha
Proportion present in daytime	50%
Proportion present at night	100%
Proportion outside in daytime	7%
Proportion outside at night	1%

Only when GT3 or LT2 are present in the transport flow, there is a possibility that the societal risk approaches 10% of the orientation value. Table 1-34 shows that in the order of 1000 tankers per annum and a density in the order of 500/ha close to the bank are required to reach this level. The societal risk for LT2 and GT3 is comparable.

Table 1-34 GT3 transport threshold values for exceeding 10% of the orientation value, navigability class 6, two sided development

Density/ha	**Distance to the bank of the waterway (m)**							
	10	20	30	40	50	60	70	80
10	-	-	-	-	-	-	-	
20	-	-	-	-	-	-	-	
30	-	-	-	-	-	-	-	
40	-	-	-	-	-	-	-	
50	-	-	-	-	-	-	-	
60	-	-	-	-	-	-	-	
70	-	-	-	-	-	-	-	
80	-	-	-	-	-	-	-	
90	-	-	-	-	-	-	-	
100	-	-	-	-	-	-	-	
200	10930	12430	13780	15360	18610	-	-	
300	4860	5520	6120	6830	8270	9230	11470	12790
400	2730	3110	3440	3840	4650	5190	6450	7190
500	1750	1990	2200	2460	2980	3320	4130	4600
600	1210	1380	1530	1710	2070	2310	2870	3200
700	890	1010	1120	1250	1520	1690	2110	2350
800	680	780	860	960	1160	1300	1610	1800
900	540	610	680	760	920	1030	1270	1420
1000	440	500	550	610	740	830	1030	1150

16 Meteorological data

Meteorological data, such as wind direction, wind speed and stability are often expressed as frequencies or numbers of observations. To reduce the calculation time required in the QRA, it is advisable to classify the data into a limited number of representative weather categories, defined by the stability and wind speed.

The tables below give the classification into the wind direction and weather class (wind speed and Pasquill stability class) for the meteorological day and night per weather station. The probabilities have been taken from PSG 3 (CPR 18, Purple Book, pages 4.21 through 4.40) [7]. This relates to processed data from [8].

Table 2-1 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Beek

Beek							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	2.01	0.99	2.01	0.72	0.00	0.00	5.73
016-045	2.39	0.69	1.96	1.13	0.00	0.00	6.17
046-075	3.33	0.80	2.21	1.91	0.00	0.00	8.26
076-105	2.25	0.64	1.66	2.21	0.00	0.00	6.76
106-135	0.97	0.49	0.64	0.28	0.00	0.00	2.38
136-165	0.96	0.54	0.92	0.56	0.00	0.00	2.97
166-195	1.91	0.88	2.67	2.78	0.00	0.00	8.24
196-225	3.03	1.53	5.88	7.10	0.00	0.00	17.54
226-255	3.49	2.27	7.89	6.31	0.00	0.00	19.96
256-285	2.29	1.82	4.54	2.45	0.00	0.00	11.11
286-315	1.20	1.19	2.44	1.25	0.00	0.00	6.07
316-345	1.28	0.99	1.80	0.76	0.00	0.00	4.84
Total	25.11	12.83	34.61	27.46	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	0.88	1.33	0.39	0.60	1.04	4.24
016-045	0.00	0.79	1.84	0.77	1.06	1.21	5.67
046-075	0.00	0.94	2.00	1.15	1.79	1.83	7.69
076-105	0.00	0.77	1.87	1.22	1.76	1.61	7.23
106-135	0.00	0.72	1.13	0.26	0.96	1.49	4.56
136-165	0.00	0.93	1.50	0.64	1.11	1.89	6.07
166-195	0.00	1.41	5.01	3.64	2.51	2.32	14.88
196-225	0.00	2.14	7.38	6.99	2.56	2.11	21.18
226-255	0.00	2.49	5.46	3.80	1.08	1.61	14.44
256-285	0.00	1.78	2.66	1.06	0.45	1.15	7.10
286-315	0.00	1.13	1.36	0.40	0.25	0.77	3.91
316-345	0.00	0.84	0.98	0.19	0.25	0.80	3.05
Total	0.00	14.80	32.51	20.48	14.38	17.83	100.00

Table 2-2 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Deelen

Deelen							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.17	1.18	1.51	0.84	0.00	0.00	4.70
016-045	2.09	1.49	1.39	0.65	0.00	0.00	5.62
046-075	3.21	1.57	2.14	1.64	0.00	0.00	8.55
076-105	2.89	1.17	1.92	1.63	0.00	0.00	7.61
106-135	2.07	0.91	1.41	0.77	0.00	0.00	5.16
136-165	1.88	1.27	2.07	1.23	0.00	0.00	6.44
166-195	1.36	1.53	2.67	2.07	0.00	0.00	7.63
196-225	1.60	1.89	4.64	4.48	0.00	0.00	12.60
226-255	1.66	1.76	4.87	6.39	0.00	0.00	14.67
256-285	1.09	1.39	3.63	5.01	0.00	0.00	11.12
286-315	1.20	1.26	3.07	3.42	0.00	0.00	8.95
316-345	1.32	1.20	2.13	2.30	0.00	0.00	6.95
Total	21.54	16.61	31.44	30.43	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	1.37	0.71	0.19	0.30	2.35	4.91
016-045	0.00	1.50	1.10	0.47	0.64	2.76	6.47
046-075	0.00	1.84	2.68	1.45	2.18	3.35	11.50
076-105	0.00	1.38	2.27	1.01	1.73	3.49	9.88
106-135	0.00	1.66	1.51	0.41	1.23	4.20	9.01
136-165	0.00	1.54	1.88	1.04	0.62	2.39	7.47
166-195	0.00	1.72	2.28	1.75	0.45	1.53	7.73
196-225	0.00	2.12	3.76	3.49	0.87	2.13	12.36
226-255	0.00	1.97	3.74	4.26	0.80	1.69	12.45
256-285	0.00	1.60	2.55	2.26	0.61	1.38	8.40
286-315	0.00	1.37	1.32	0.99	0.29	1.20	5.16
316-345	0.00	1.33	0.92	0.42	0.21	1.78	4.66
Total	0.00	19.39	24.71	17.74	9.92	28.25	100.00

Table 2-3 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Den Helder

Den Helder							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.52	0.25	1.10	4.81	0.00	0.00	6.68
016-045	0.71	0.28	1.02	4.34	0.00	0.00	6.36
046-075	1.80	0.37	1.69	5.01	0.00	0.00	8.87
076-105	1.43	0.36	1.93	3.38	0.00	0.00	7.10
106-135	0.96	0.40	1.43	1.37	0.00	0.00	4.15
136-165	0.73	0.52	1.36	0.49	0.00	0.00	3.10
166-195	1.21	0.71	2.59	3.26	0.00	0.00	7.77
196-225	0.73	0.46	1.98	11.30	0.00	0.00	14.47
226-255	1.17	0.38	2.32	9.79	0.00	0.00	13.67
256-285	1.29	0.44	1.91	7.28	0.00	0.00	10.92
286-315	1.20	0.37	1.32	5.13	0.00	0.00	8.02
316-345	1.09	0.36	1.43	6.03	0.00	0.00	8.91
Total	12.83	4.90	20.08	62.20	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	0.36	2.01	4.04	0.81	0.47	7.70
016-045	0.00	0.34	1.56	2.85	0.63	0.49	5.86
046-075	0.00	0.20	0.84	3.78	0.30	0.27	5.38
076-105	0.00	0.41	2.36	4.80	1.07	0.49	9.14
106-135	0.00	0.58	2.06	1.67	1.06	0.78	6.15
136-165	0.00	0.95	2.02	0.61	1.04	1.13	5.75
166-195	0.00	1.31	4.66	4.06	2.22	1.39	13.63
196-225	0.00	0.53	2.04	9.04	0.71	0.77	13.08
226-255	0.00	0.30	1.76	7.28	0.46	0.38	10.17
256-285	0.00	0.32	1.56	7.09	0.44	0.31	9.71
286-315	0.00	0.20	0.98	4.89	0.30	0.24	6.61
316-345	0.00	0.24	1.06	4.98	0.28	0.25	6.82
Total	0.00	5.75	22.89	55.08	9.31	6.97	100.00

Table 2-4 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Eelde

Eelde							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.80	0.89	1.80	0.96	0.00	0.00	5.44
016-045	2.38	1.05	1.71	1.11	0.00	0.00	6.25
046-075	2.56	0.97	2.03	1.93	0.00	0.00	7.49
076-105	2.63	1.05	2.09	2.06	0.00	0.00	7.83
106-135	2.15	0.91	1.68	1.46	0.00	0.00	6.20
136-165	1.23	0.83	1.40	0.82	0.00	0.00	4.28
166-195	1.52	1.06	2.54	2.22	0.00	0.00	7.35
196-225	1.67	1.17	3.88	5.47	0.00	0.00	12.18
226-255	1.59	1.10	3.92	7.87	0.00	0.00	14.48
256-285	1.90	1.12	3.57	6.11	0.00	0.00	12.69
286-315	1.52	1.03	2.88	3.41	0.00	0.00	8.84
316-345	1.50	0.91	2.34	2.22	0.00	0.00	6.98
Total	22.43	12.09	29.85	35.63	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	0.91	0.74	0.29	0.33	1.35	3.62
016-045	0.00	1.19	0.99	0.32	0.66	2.25	5.41
046-075	0.00	1.15	2.00	1.43	1.34	2.84	8.76
076-105	0.00	1.22	2.22	1.51	1.54	2.65	9.15
106-135	0.00	1.41	1.77	0.98	0.90	2.22	7.27
136-165	0.00	1.24	1.45	0.74	0.54	1.67	5.63
166-195	0.00	1.49	2.68	2.04	0.94	2.01	9.16
196-225	0.00	1.76	4.59	4.52	1.64	2.55	15.07
226-255	0.00	1.52	3.96	5.15	1.57	2.34	14.54
256-285	0.00	1.71	2.80	2.68	1.12	2.56	10.87
286-315	0.00	1.40	1.53	1.19	0.42	1.84	6.38
316-345	0.00	0.90	1.14	0.64	0.28	1.20	4.15
Total	0.00	15.90	25.87	21.49	11.27	25.47	100.00

Table 2-5 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Eindhoven

Eindhoven							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.76	1.03	1.88	1.39	0.00	0.00	6.06
016-045	2.28	1.28	1.93	1.04	0.00	0.00	6.53
046-075	2.91	0.92	2.08	1.77	0.00	0.00	7.69
076-105	2.41	0.81	1.57	1.55	0.00	0.00	6.34
106-135	1.90	0.81	1.57	1.13	0.00	0.00	5.41
136-165	1.56	1.07	1.36	0.57	0.00	0.00	4.56
166-195	1.43	1.20	2.36	2.07	0.00	0.00	7.06
196-225	1.58	1.41	3.82	6.28	0.00	0.00	13.08
226-255	1.73	1.50	4.86	9.23	0.00	0.00	17.32
256-285	1.24	1.30	3.51	5.76	0.00	0.00	11.81
286-315	1.12	0.86	2.35	3.23	0.00	0.00	7.56
316-345	1.23	0.94	2.10	2.31	0.00	0.00	6.58
Total	21.15	13.14	29.39	36.32	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	0.83	1.00	0.42	0.60	1.84	4.69
016-045	0.00	1.40	1.44	0.60	0.95	2.73	7.11
046-075	0.00	1.14	2.00	1.03	1.53	2.90	8.61
076-105	0.00	0.80	1.47	1.04	1.17	1.83	6.31
106-135	0.00	1.27	1.60	0.80	1.00	2.38	7.05
136-165	0.00	1.54	1.69	0.56	0.81	2.46	7.05
166-195	0.00	1.80	2.56	1.75	0.88	2.47	9.45
196-225	0.00	1.89	4.05	5.10	1.33	2.41	14.77
226-255	0.00	1.76	4.41	6.31	1.22	1.78	15.49
256-285	0.00	1.48	2.54	2.82	0.82	1.68	9.33
286-315	0.00	1.08	1.39	1.04	0.49	1.45	5.45
316-345	0.00	0.87	1.15	0.56	0.39	1.71	4.69
Total	0.00	15.84	25.29	22.04	11.20	25.63	100.00

Table 2-6 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Gilze-Rijen

Gilze-Rijen							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	2.06	1.24	2.11	0.98	0.00	0.00	6.39
016-045	2.90	1.35	2.37	1.51	0.00	0.00	8.14
046-075	2.67	0.94	2.07	2.30	0.00	0.00	7.98
076-105	1.53	0.66	1.33	1.72	0.00	0.00	5.24
106-135	1.46	0.68	1.31	1.06	0.00	0.00	4.51
136-165	1.20	0.81	1.44	0.70	0.00	0.00	4.14
166-195	1.18	0.97	2.50	2.51	0.00	0.00	7.16
196-225	1.74	1.45	4.70	5.71	0.00	0.00	13.60
226-255	2.01	1.67	5.14	7.20	0.00	0.00	16.01
256-285	1.99	1.63	4.02	5.10	0.00	0.00	12.74
286-315	1.55	1.41	3.14	2.24	0.00	0.00	8.34
316-345	1.30	1.05	2.22	1.17	0.00	0.00	5.74
Total	21.59	13.87	32.34	32.20	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	1.36	1.06	0.30	0.96	3.02	6.70
016-045	0.00	1.43	1.62	0.65	1.29	3.47	8.45
046-075	0.00	1.06	1.81	1.32	1.24	2.37	7.79
076-105	0.00	0.72	1.00	0.85	0.62	1.20	4.38
106-135	0.00	0.91	1.30	0.62	0.65	1.47	4.94
136-165	0.00	1.08	1.43	0.66	0.64	1.98	5.79
166-195	0.00	1.43	2.93	2.20	1.06	1.92	9.54
196-225	0.00	2.21	4.58	4.47	1.66	2.87	15.79
226-255	0.00	2.40	4.44	4.96	1.69	3.33	16.81
256-285	0.00	2.02	2.24	1.95	0.81	2.98	9.99
286-315	0.00	1.44	1.37	0.60	0.41	1.88	5.70
316-345	0.00	1.05	0.80	0.25	0.35	1.67	4.13
Total	0.00	17.10	24.56	18.81	11.37	28.16	100.00

Table 2-7 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Hoek van Holland

Hoek van Holland							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	2.36	0.67	2.75	5.01	0.00	0.00	10.79
016-045	1.18	0.49	1.77	2.33	0.00	0.00	5.77
046-075	1.25	0.70	1.71	1.61	0.00	0.00	5.26
076-105	2.86	0.99	2.24	1.77	0.00	0.00	7.85
106-135	1.35	0.60	1.38	1.14	0.00	0.00	4.47
136-165	1.60	0.79	1.81	1.56	0.00	0.00	5.77
166-195	1.00	0.70	2.46	3.77	0.00	0.00	7.92
196-225	0.62	0.47	1.97	6.31	0.00	0.00	9.37
226-255	1.25	0.48	2.42	11.38	0.00	0.00	15.53
256-285	2.01	0.65	2.51	6.12	0.00	0.00	11.29
286-315	1.63	0.69	1.82	3.91	0.00	0.00	8.05
316-345	1.69	0.64	1.85	3.77	0.00	0.00	7.94
Total	18.77	7.87	24.69	48.66	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	0.44	1.48	2.73	0.43	0.49	5.57
016-045	0.00	0.84	1.82	1.58	1.23	1.09	6.57
046-075	0.00	1.32	2.37	1.67	1.82	2.25	9.42
076-105	0.00	1.67	2.92	1.31	2.92	2.77	11.58
106-135	0.00	0.77	1.62	0.90	0.95	1.34	5.56
136-165	0.00	0.87	2.30	1.70	0.85	1.23	6.96
166-195	0.00	1.06	3.37	4.14	1.23	1.26	11.07
196-225	0.00	0.51	2.31	6.55	0.63	0.57	10.58
226-255	0.00	0.39	1.94	8.50	0.54	0.46	11.82
256-285	0.00	0.46	1.80	5.41	0.35	0.38	8.39
286-315	0.00	0.36	1.33	4.41	0.30	0.43	6.82
316-345	0.00	0.37	1.33	3.28	0.32	0.39	5.68
Total	0.00	9.07	24.56	42.18	11.54	12.65	100.00

Table 2-8 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Ijmuiden

IJmuiden							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	0.87	0.48	1.80	3.94	0.00	0.00	7.09
016-045	0.71	0.41	1.57	1.84	0.00	0.00	4.53
046-075	1.15	0.37	1.59	3.10	0.00	0.00	6.21
076-105	2.11	0.54	2.74	4.39	0.00	0.00	9.77
106-135	1.25	0.65	1.62	1.60	0.00	0.00	5.11
136-165	0.86	0.67	1.96	2.04	0.00	0.00	5.51
166-195	0.58	0.58	1.99	2.99	0.00	0.00	6.13
196-225	0.91	0.52	2.31	8.06	0.00	0.00	11.80
226-255	1.65	0.57	2.65	9.95	0.00	0.00	14.82
256-285	1.50	0.55	2.08	7.11	0.00	0.00	11.24
286-315	1.24	0.51	1.83	5.29	0.00	0.00	8.86
316-345	1.41	0.49	2.16	4.85	0.00	0.00	8.91
Total	14.23	6.33	24.29	55.15	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	0.56	1.39	1.69	0.48	0.45	4.58
016-045	0.00	0.73	2.59	1.70	1.35	0.80	7.17
046-075	0.00	0.40	1.76	3.11	1.05	0.69	7.02
076-105	0.00	0.85	3.47	4.35	2.42	1.37	12.45
106-135	0.00	1.09	2.28	1.48	1.33	1.15	7.33
136-165	0.00	1.11	3.05	2.32	1.39	1.23	9.09
166-195	0.00	0.97	2.80	3.62	1.19	0.88	9.45
196-225	0.00	0.36	1.77	6.89	0.53	0.42	9.96
226-255	0.00	0.31	1.55	8.04	0.37	0.40	10.67
256-285	0.00	0.25	1.45	6.91	0.40	0.32	9.32
286-315	0.00	0.26	1.17	5.36	0.30	0.26	7.34
316-345	0.00	0.29	1.14	3.71	0.23	0.27	5.63
Total	0.00	7.18	24.40	49.17	11.03	8.23	100.00

Table 2-9 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Leeuwarden

Leeuwarden							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.42	0.77	2.07	1.87	0.00	0.00	6.13
016-045	1.92	0.84	2.13	2.33	0.00	0.00	7.22
046-075	1.84	0.88	1.88	2.48	0.00	0.00	7.08
076-105	2.23	0.97	1.91	2.58	0.00	0.00	7.69
106-135	1.25	0.74	1.45	1.02	0.00	0.00	4.45
136-165	1.13	0.82	1.74	0.92	0.00	0.00	4.62
166-195	1.77	1.45	2.93	2.56	0.00	0.00	8.70
196-225	1.70	1.50	3.89	5.91	0.00	0.00	13.00
226-255	1.47	1.17	3.37	6.87	0.00	0.00	12.87
256-285	1.49	0.91	2.93	6.75	0.00	0.00	12.09
286-315	1.12	0.69	2.10	4.28	0.00	0.00	8.19
316-345	1.28	0.68	2.35	3.66	0.00	0.00	7.96
Total	18.63	11.42	28.75	41.21	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	0.85	1.17	0.76	0.47	1.23	4.48
016-045	0.00	1.02	1.28	0.72	0.71	1.63	5.36
046-075	0.00	1.15	1.74	1.43	1.27	2.33	7.92
076-105	0.00	1.17	2.19	2.08	1.77	2.48	9.68
106-135	0.00	0.87	1.73	1.05	0.99	1.38	6.03
136-165	0.00	1.08	2.20	1.07	0.82	1.21	6.37
166-195	0.00	1.85	3.52	2.40	1.73	2.74	12.23
196-225	0.00	2.00	4.05	4.84	1.72	3.10	15.71
226-255	0.00	1.40	2.82	3.78	1.03	2.09	11.11
256-285	0.00	1.10	2.10	3.26	0.84	1.55	8.85
286-315	0.00	0.87	1.61	2.40	0.70	1.03	6.60
316-345	0.00	0.90	1.46	1.79	0.44	1.06	5.65
Total	0.00	14.25	25.87	25.57	12.50	21.82	100.00

Table 2-10 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Rotterdam

Rotterdam							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	2.17	0.84	2.26	1.88	0.00	0.00	7.16
016-045	1.97	0.84	1.62	1.42	0.00	0.00	5.85
046-075	2.86	0.85	2.13	2.23	0.00	0.00	8.07
076-105	2.91	0.84	2.02	1.89	0.00	0.00	7.66
106-135	1.58	0.52	1.40	0.93	0.00	0.00	4.43
136-165	1.31	0.88	1.61	0.81	0.00	0.00	4.60
166-195	1.66	1.19	3.26	2.44	0.00	0.00	8.54
196-225	1.64	1.08	3.76	4.86	0.00	0.00	11.34
226-255	2.04	1.31	3.86	7.11	0.00	0.00	14.33
256-285	2.75	1.36	4.09	4.38	0.00	0.00	12.57
286-315	2.40	0.87	2.74	2.88	0.00	0.00	8.90
316-345	1.22	0.61	2.01	2.72	0.00	0.00	6.57
Total	24.50	11.19	30.76	33.55	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	1.19	1.13	0.46	0.54	2.44	5.76
016-045	0.00	1.20	1.30	0.61	0.77	2.66	6.53
046-075	0.00	1.17	2.26	1.67	1.52	2.96	9.58
076-105	0.00	1.22	1.83	1.01	1.20	2.26	7.51
106-135	0.00	0.79	1.30	0.53	0.71	1.42	4.75
136-165	0.00	1.19	2.08	0.80	0.74	1.50	6.31
166-195	0.00	1.55	3.75	2.37	1.15	2.10	10.91
196-225	0.00	1.49	3.62	4.79	1.26	2.50	13.65
226-255	0.00	1.93	3.81	4.76	1.15	3.30	14.96
256-285	0.00	1.66	2.26	1.96	0.88	2.24	8.99
286-315	0.00	0.94	1.51	1.78	0.53	1.45	6.20
316-345	0.00	0.86	1.23	1.13	0.41	1.22	4.86
Total	0.00	15.19	26.06	21.87	10.85	26.04	100.00

Table 2-11 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Schiphol

Schiphol							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.25	0.62	1.84	2.63	0.00	0.00	6.33
016-045	1.23	0.45	1.50	2.44	0.00	0.00	5.62
046-075	2.09	0.62	2.36	4.12	0.00	0.00	9.18
076-105	2.01	0.69	1.86	1.88	0.00	0.00	6.45
106-135	1.32	0.54	1.35	0.95	0.00	0.00	4.15
136-165	1.30	0.76	2.00	1.56	0.00	0.00	5.62
166-195	1.49	0.94	2.85	3.04	0.00	0.00	8.33
196-225	1.19	0.83	3.24	6.26	0.00	0.00	11.51
226-255	1.23	0.78	2.62	9.44	0.00	0.00	14.07
256-285	1.58	0.75	3.01	7.52	0.00	0.00	12.86
286-315	1.21	0.61	2.02	4.46	0.00	0.00	8.31
316-345	1.23	0.60	1.93	3.82	0.00	0.00	7.58
Total	17.12	8.17	26.59	48.12	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	0.83	1.60	1.03	0.83	1.87	6.15
016-045	0.00	0.55	1.24	1.33	0.69	1.04	4.84
046-075	0.00	0.75	2.15	3.11	1.21	1.27	8.49
076-105	0.00	0.90	2.42	2.20	1.63	1.53	8.68
106-135	0.00	0.86	1.60	0.67	0.83	1.36	5.32
136-165	0.00	1.14	2.74	1.81	1.27	1.61	8.57
166-195	0.00	1.51	3.76	2.99	1.31	2.10	11.66
196-225	0.00	1.19	4.14	5.99	1.38	1.36	14.06
226-255	0.00	1.24	2.66	5.28	1.01	1.75	11.94
256-285	0.00	0.96	1.77	3.60	0.67	1.26	8.26
286-315	0.00	0.73	1.35	2.36	0.49	1.03	5.96
316-345	0.00	0.86	1.65	1.48	0.62	1.46	6.06
Total	0.00	11.52	27.07	31.85	11.91	17.65	100.00

Table 2-12 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Soesterberg

Soesterberg							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.99	1.49	2.59	1.53	0.00	0.00	7.60
016-045	3.75	1.74	2.86	1.44	0.00	0.00	9.79
046-075	2.16	1.18	1.67	1.02	0.00	0.00	6.03
076-105	2.33	1.11	1.61	1.20	0.00	0.00	6.25
106-135	1.62	0.98	1.35	0.48	0.00	0.00	4.43
136-165	1.33	1.34	1.76	0.57	0.00	0.00	5.01
166-195	1.51	2.03	3.01	1.19	0.00	0.00	7.74
196-225	1.65	2.45	5.37	3.53	0.00	0.00	13.00
226-255	1.39	1.59	4.70	5.15	0.00	0.00	12.83
256-285	1.51	1.58	3.82	4.84	0.00	0.00	11.76
286-315	1.64	1.25	3.99	2.73	0.00	0.00	9.62
316-345	1.04	1.13	2.16	1.64	0.00	0.00	5.96
Total	21.93	17.85	34.91	25.32	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	1.42	0.98	0.25	0.37	2.24	5.26
016-045	0.00	2.24	1.98	0.52	1.26	4.07	10.07
046-075	0.00	1.44	1.67	0.67	1.13	2.96	7.87
076-105	0.00	1.50	1.66	0.67	1.41	3.27	8.50
106-135	0.00	1.39	0.97	0.21	0.52	2.58	5.67
136-165	0.00	2.00	1.77	0.59	0.54	3.08	7.97
166-195	0.00	3.13	2.72	1.05	0.75	3.57	11.23
196-225	0.00	3.01	4.27	2.67	0.97	3.02	13.93
226-255	0.00	2.04	3.53	3.33	0.74	1.82	11.46
256-285	0.00	1.85	2.15	1.83	0.62	1.90	8.34
286-315	0.00	1.31	1.24	0.68	0.35	1.64	5.22
316-345	0.00	1.17	1.12	0.42	0.21	1.55	4.48
Total	0.00	22.49	24.07	12.88	8.88	31.69	100.00

Table 2-13 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Twente

Twente							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.75	1.38	1.60	0.70	0.00	0.00	5.43
016-045	2.38	1.38	1.64	0.36	0.00	0.00	5.77
046-075	3.19	1.46	2.07	0.86	0.00	0.00	7.59
076-105	3.36	1.50	1.85	0.81	0.00	0.00	7.52
106-135	2.45	1.45	1.29	0.25	0.00	0.00	5.43
136-165	1.67	1.30	1.11	0.20	0.00	0.00	4.29
166-195	1.80	1.63	2.93	1.26	0.00	0.00	7.63
196-225	2.56	2.72	6.86	5.12	0.00	0.00	17.25
226-255	1.97	2.05	5.53	4.90	0.00	0.00	14.45
256-285	1.36	1.51	3.22	3.30	0.00	0.00	9.38
286-315	1.46	1.41	3.02	2.72	0.00	0.00	8.60
316-345	1.63	1.48	2.26	1.30	0.00	0.00	6.67
Total	25.59	19.25	33.38	21.78	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	1.07	0.69	0.18	0.27	1.46	3.66
016-045	0.00	1.48	1.16	0.14	0.61	2.66	6.04
046-075	0.00	1.81	2.00	0.54	1.67	3.39	9.41
076-105	0.00	1.73	1.86	0.61	1.94	3.24	9.39
106-135	0.00	1.71	1.18	0.16	1.25	2.88	7.18
136-165	0.00	1.60	1.15	0.22	0.60	2.49	6.06
166-195	0.00	2.26	3.21	1.13	1.47	3.03	11.10
196-225	0.00	3.19	5.98	4.32	1.73	3.35	18.57
226-255	0.00	2.21	4.09	3.40	0.99	1.99	12.68
256-285	0.00	1.46	2.06	1.57	0.52	1.51	7.12
286-315	0.00	1.38	1.30	0.84	0.35	1.37	5.24
316-345	0.00	1.10	0.88	0.28	0.17	1.12	3.56
7Total	0.00	21.03	25.56	13.37	11.56	28.48	100.00

Table 2 14 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Valkenburg

Valkenburg							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.93	0.65	2.40	4.32	0.00	0.00	9.30
016-045	1.26	0.75	1.59	1.61	0.00	0.00	5.20
046-075	1.93	0.81	2.01	2.87	0.00	0.00	7.62
076-105	1.89	0.72	1.79	1.99	0.00	0.00	6.39
106-135	1.16	0.51	1.26	1.39	0.00	0.00	4.32
136-165	1.44	0.78	1.76	1.57	0.00	0.00	5.56
166-195	1.32	0.96	2.12	2.43	0.00	0.00	6.84
196-225	0.76	0.85	2.74	5.24	0.00	0.00	9.59
226-255	1.00	0.79	3.01	9.86	0.00	0.00	14.66
256-285	2.13	0.99	3.94	6.77	0.00	0.00	13.83
286-315	1.71	0.76	2.38	3.96	0.00	0.00	8.81
316-345	1.58	0.65	2.11	3.55	0.00	0.00	7.89
Total	18.11	9.23	27.10	45.57	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	0.70	1.43	1.63	0.52	1.59	5.86
016-045	0.00	1.33	1.87	1.13	1.14	3.42	8.88
046-075	0.00	1.21	2.07	1.92	1.30	2.72	9.21
076-105	0.00	0.89	1.77	1.66	1.02	2.03	7.36
106-135	0.00	0.61	1.10	0.87	0.38	0.90	3.86
136-165	0.00	1.43	1.95	1.27	0.76	2.69	8.09
166-195	0.00	1.67	2.30	2.26	0.68	3.28	10.20
196-225	0.00	1.30	2.92	5.10	0.71	2.17	12.21
226-255	0.00	1.03	2.67	6.60	0.59	1.56	12.45
256-285	0.00	0.96	2.32	4.45	0.59	1.19	9.52
286-315	0.00	0.62	1.51	3.24	0.35	0.90	6.62
316-345	0.00	0.58	1.42	2.51	0.36	0.88	5.74
Total	0.00	12.34	23.33	32.63	8.38	23.32	100.00

Table 2-15 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Vlissingen

Vlissingen							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	2.10	0.64	2.44	2.80	0.00	0.00	7.98
016-045	2.31	0.76	2.16	2.23	0.00	0.00	7.46
046-075	1.89	0.58	1.86	2.62	0.00	0.00	6.95
076-105	2.28	0.54	1.52	1.49	0.00	0.00	5.82
106-135	1.91	0.58	1.41	0.99	0.00	0.00	4.89
136-165	1.23	0.50	1.36	1.18	0.00	0.00	4.28
166-195	1.19	0.51	2.22	3.99	0.00	0.00	7.91
196-225	1.19	0.54	2.60	6.72	0.00	0.00	11.04
226-255	1.71	0.66	2.47	9.42	0.00	0.00	14.26
256-285	2.84	0.68	3.56	8.42	0.00	0.00	15.50
286-315	1.36	0.56	2.02	2.93	0.00	0.00	6.86
316-345	1.57	0.63	2.19	2.68	0.00	0.00	7.07
Total	21.56	7.18	25.80	45.46	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	0.86	1.57	0.86	0.89	1.62	5.79
016-045	0.00	1.19	2.24	1.47	2.02	2.45	9.37
046-075	0.00	1.02	2.61	2.05	2.12	1.77	9.56
076-105	0.00	0.62	1.55	1.49	0.98	1.22	5.86
106-135	0.00	0.48	1.34	1.09	0.60	0.82	4.34
136-165	0.00	0.54	2.04	1.68	0.73	0.78	5.76
166-195	0.00	0.66	3.10	5.00	0.83	0.81	10.39
196-225	0.00	0.68	3.92	8.58	1.15	1.04	15.38
226-255	0.00	0.58	2.80	7.94	0.92	0.83	13.07
256-285	0.00	0.61	1.72	3.90	0.51	0.81	7.54
286-315	0.00	0.72	1.69	2.63	0.70	1.16	6.89
316-345	0.00	0.94	1.65	1.11	0.69	1.67	6.06
Total	0.00	8.89	26.24	37.79	12.12	14.96	100.00

Table 2-16 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Volkel

Volkel							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	2.11	1.38	1.91	0.94	0.00	0.00	6.34
016-045	2.23	1.22	1.65	1.06	0.00	0.00	6.15
046-075	3.02	1.08	1.95	2.03	0.00	0.00	8.08
076-105	2.50	0.92	1.49	1.41	0.00	0.00	6.31
106-135	1.76	0.76	1.18	0.79	0.00	0.00	4.49
136-165	1.50	1.04	1.45	0.95	0.00	0.00	4.94
166-195	1.60	1.61	2.56	1.91	0.00	0.00	7.68
196-225	2.12	2.18	4.35	4.79	0.00	0.00	13.43
226-255	2.45	2.37	5.90	6.24	0.00	0.00	16.95
256-285	2.00	2.11	4.24	3.97	0.00	0.00	12.33
286-315	1.59	1.48	2.70	1.94	0.00	0.00	7.71
316-345	1.32	1.21	1.94	1.10	0.00	0.00	5.58
Total	24.21	17.36	31.32	27.11	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	1.30	0.86	0.27	0.57	2.88	5.87
016-045	0.00	1.35	1.32	0.61	0.82	3.27	7.37
046-075	0.00	1.20	1.80	1.28	1.41	2.96	8.65
076-105	0.00	1.17	1.45	0.82	1.00	2.52	6.95
106-135	0.00	1.02	0.96	0.35	0.50	1.84	4.67
136-165	0.00	1.26	1.53	0.76	0.57	1.93	6.04
166-195	0.00	2.16	2.59	1.48	0.92	2.41	9.57
196-225	0.00	2.48	4.08	3.72	1.42	3.29	14.98
226-255	0.00	2.61	4.61	4.15	1.43	2.85	15.65
256-285	0.00	1.97	2.42	1.91	0.86	2.73	9.89
286-315	0.00	1.60	1.30	0.59	0.42	2.25	6.15
316-345	0.00	1.14	0.72	0.21	0.31	1.84	4.22
Total	0.00	19.24	23.64	16.13	10.22	30.77	100.00

Table 2-17 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Woensdrecht

Woensdrecht							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.36	1.03	1.88	0.79	0.00	0.00	5.06
016-045	2.09	1.07	2.62	1.34	0.00	0.00	7.11
046-075	3.29	1.21	2.44	1.94	0.00	0.00	8.88
076-105	3.32	1.32	1.78	0.98	0.00	0.00	7.39
106-135	1.01	0.91	0.78	0.18	0.00	0.00	2.88
136-165	1.03	1.39	1.06	0.15	0.00	0.00	3.63
166-195	1.46	2.08	3.15	1.19	0.00	0.00	7.88
196-225	2.16	2.71	7.08	4.06	0.00	0.00	16.01
226-255	1.83	1.99	5.39	5.55	0.00	0.00	14.76
256-285	2.36	1.64	3.63	4.72	0.00	0.00	12.34
286-315	2.17	1.46	3.10	1.86	0.00	0.00	8.59
316-345	1.18	1.05	2.14	1.09	0.00	0.00	5.47
Total	23.24	17.87	35.05	23.83	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	1.16	0.72	0.14	0.28	1.95	4.25
016-045	0.00	1.51	1.55	0.64	1.11	2.93	7.74
046-075	0.00	1.67	2.41	1.38	1.88	4.10	11.44
076-105	0.00	1.81	1.20	0.47	0.95	4.04	8.46
106-135	0.00	1.70	0.58	0.09	0.19	2.30	4.87
136-165	0.00	1.88	0.81	0.08	0.23	2.44	5.43
166-195	0.00	3.02	3.00	1.18	0.76	3.25	11.21
196-225	0.00	3.62	5.80	3.21	1.78	4.00	18.40
226-255	0.00	2.36	4.46	3.18	1.05	2.44	13.48
256-285	0.00	1.14	1.55	1.68	0.40	1.21	5.97
286-315	0.00	1.17	1.20	0.72	0.38	1.38	4.85
316-345	0.00	1.22	0.84	0.25	0.18	1.42	3.91
Total	0.00	22.24	24.12	13.02	9.19	31.44	100.00

Table 2-18 Distribution of wind direction and weather class (wind speed and Pasquil stability class) for meteorological day and night for weather station Ypenburg

Ypenburg							
Day	**B 3.0 m/s**	**D 1.5 m/s**	**D 5.0 m/s**	**D 9.0 m/s**	**E 5.0 m/s**	**F 1.5 m/s**	**Total**
346-015	1.71	0.95	2.41	2.58	0.00	0.00	7.65
016-045	1.65	1.00	1.81	1.33	0.00	0.00	5.78
046-075	2.72	1.14	2.36	2.82	0.00	0.00	9.04
076-105	2.20	0.98	1.66	1.82	0.00	0.00	6.65
106-135	1.74	0.77	1.32	1.06	0.00	0.00	4.90
136-165	0.88	0.73	1.10	0.73	0.00	0.00	3.43
166-195	0.77	0.95	2.19	2.08	0.00	0.00	5.98
196-225	1.10	1.14	3.41	5.11	0.00	0.00	10.75
226-255	1.51	1.26	3.54	7.41	0.00	0.00	13.73
256-285	2.34	1.40	3.76	8.39	0.00	0.00	15.90
286-315	1.42	0.76	2.38	3.35	0.00	0.00	7.90
316-345	1.53	0.88	2.46	3.42	0.00	0.00	8.29
Total	19.56	11.95	28.40	40.09	0.00	0.00	100.00
Night	B 3.0 m/s	D 1.5 m/s	D 5.0 m/s	D 9.0 m/s	E 5.0 m/s	F 1.5 m/s	Total
346-015	0.00	1.22	1.42	0.77	0.67	2.34	6.42
016-045	0.00	1.62	1.67	0.90	1.36	3.05	8.60
046-075	0.00	1.56	2.41	2.00	1.72	3.69	11.37
076-105	0.00	1.22	1.40	0.97	0.75	2.19	6.52
106-135	0.00	1.05	1.15	0.49	0.45	1.49	4.63
136-165	0.00	1.05	1.16	0.73	0.35	1.29	4.57
166-195	0.00	1.30	2.34	2.06	0.61	1.30	7.60
196-225	0.00	1.25	4.16	5.07	1.16	1.64	13.27
226-255	0.00	1.84	3.31	4.88	1.03	2.69	13.74
256-285	0.00	1.49	2.36	4.25	0.56	1.85	10.50
286-315	0.00	0.76	1.54	2.68	0.42	0.97	6.36
316-345	0.00	1.03	1.78	1.86	0.50	1.25	6.42
Total	0.00	15.38	24.69	26.62	9.58	23.74	100.00

17 Models

17.1 Introduction

This appendix describes the models for calculating the consequences of the scenarios described in Module C. These are first the outflow models and evaporation models. These models produced source strengths for the dispersion and effects models. Then, the dispersion models and the links to the effects models and damage models are described.

In the calculation method, the diversity of substances that are transported is reduced to a limited number of substance categories that contain substances with a comparable risk. Substance categories are characterised by a representative substance per transport modality. The categorisation of substances is based on aggregation status, volatility, flammability and toxicity [9]. For transport on water, a number of additional substance properties are used in the classification: solubility, reactivity with water and density in relation to water. The main categories that are distinguished for road, waterway and rail are given in Table 3-1. The substance category considered in the external safety is included in the main report.

Table 3-1 Substance category

Category		**Meaning**	**Description**
Road/water-way	**Rail**		
GF	A	Gas Flammable	Pressurised liquefied flammable gas
GT	B	Gas Toxic	Pressurised liquefied toxic gas
LF	C	Liquid Flammable	Flammable liquid
LT	D	Liquid Toxic	Toxic liquid

17.2 Source strength model: Outflow

The outflow models are described per modality and substance category.

17.2.1 Rail and road

Continuous outflow of pressurised liquefied gases (GF, GT, A, B)

The scenario upon which the continuous release of pressurised liquefied gas through a hole in a road tanker or tank wagon is based, concerns the penetration of the tank wall by another object, the tank wall splitting or from a fitting shearing off. The continuous outflow through the hole (m_{rel}) is calculated as a liquid outflow using the Bernoulli equation [7].

m_{rel} = $C_d \cdot A_h \cdot (2 \cdot \Delta P \cdot \rho_l)^{½}$ [kg/s]

A_h	hole surface area	[m^2]
C_d	contraction coefficient, 0.62	[-]
ΔP	P_1 - P_a	[N/m^2]
P_a	ambient pressure	[N/m^2]
P_1	reservoir pressure	[N/m^2]
ρ_l	liquid density	[kg/m^3]

Instantaneous outflow of pressurised liquefied gases (GF, GT, A, B)
In the event of instantaneous outflow, the entire mass is simultaneously released from the transport reservoir.

Rain-out of pressurised liquefied gases
Some of the instantaneous or continuous amount of pressurised liquefied gas flowing out as a liquid contributes to the vapour cloud, the remainder rains out. It is assumed that the portion that rains out does not participate in the vapour cloud. The mass in the cloud is then equal to:

M_b = (1 - fr) · M_{rel}

M_b = Mass in the cloud [kg] or source strength [kg/s]
f_r = Rain-out fraction
M_{rel} = Released mass [kg, or kg/s]

The rain-out fraction fr is a function of adiabatic flash fraction X as shown in Table 3-2 [7].

Table 3-2 Fraction of mass in the cloud [7]

Adiabatic flash fraction X	**Fraction of mass in the cloud: (1 - fr)**
X < 0.1	2.X
0.1 < X < 0.36	(0.8 X- 0.028)/ 0.26
X > 0.36	1

The adiabatic flash fraction X is calculated as follows:

X = $C_{p,l\text{-}avg} \cdot T_K / H_v \cdot \ln(T_1/T_k)$

T_k	=	boiling point	[K]
T_1	=	storage temperature	[K]
H_v	=	evaporation enthalpy	[J/kg]
$C_{p,l\text{-}avg}$	=	(average) specific heat liquid	[J/kgK]

Liquid outflow on land (LF, LT, C, D)
In the scenarios for the road and rail modalities it is assumed that the outflows result in a pool with a different sized A_{pool}, determined per modality and scenario. In addition, it is assumed that the liquid spreads evenly in all directions. Do not take account of the liquid accumulating in lower parts of the surface (holes) or the liquid running off a sloping surface.

The following applies: $\pi R_{pool}^2 = A_{pool}$

17.2.2 Waterways

Outflow of pressurised liquefied gases (GF, GT)

The scenario upon which the outflow of pressurised liquefied gas is based for shipping concerns the failure of suspension points and/or connections. The continuous outflow is therefore calculated as two phases, vapour and liquid outflow from a short pipe [10], [11] and it is assumed that liquid will rain-out. The total amount flowing out contributes to the vapour cloud.

m_{rel}	$= C_d \cdot A_h \cdot [2 \cdot (P_1 - P_c) \cdot \rho_c]^{½}$	[kg/s]

P_1	= reservoir pressure	[N/m^2]
P_c	= pressure in the outflow opening	[N/m^2]
	$= 0.55 \cdot P_1$	[N/m^2]
C_d	= contraction coefficient, 0.62	[-]
A_h	= hole surface area	[m^2]
ρ_c	= average density of mixture in outflow opening	[kg/m^3]

The following applies for ρ_c:

ρ_c	$= [(x/\rho_v) + ((1-x)/\rho_l)]^{-1}$	[kg/m^3]

where:

ρ_v	= vapour density	[kg/m^3]
ρ_l	= liquid density	[kg/m^3]
x	= vapour mass fraction in the outflow opening	[-]

The following applies for x:

$x = C_{pl} \cdot (T_1 - Tc)/H_v$

where:

C_{pl}	= specific heat of liquid	[J/kgK]
T_c	= equilibrium temperature matching P_c	[K]
H_v	= evaporation enthalpy	[J/kg]
T_1	= reservoir temperature	[K]

Outflow of liquids on water (LF, LT):

The outflow scenarios for liquids on waterways concern a fixed flow rate M_{rel} [kg/s] during a fixed, assumed outflow time. For calculating the pool size, an equilibrium between the outflow and the evaporation is assumed.

$\pi R_{pool}^2 \cdot M_{evap} = M_{rel}$

The calculation of M_{evap} is explained in the paragraph below.

For the effect calculation, the pool is assumed to be square with the outflow point at its centre. If the pool touches the bank then, if multiple outflow points have been defined across the width of the waterway, the outflow point is moved. The maximum length of a side of the (square) pool is equal to the width of the waterway. If the length of the pool is greater than the width of the waterway, the effects are calculated based on a series of square pools over a specific length of the waterway. These are chosen in such a way that the summed lengths of sides of the pools is the same as the calculated length of the pool. For the final pool, the remaining length is not equal to the length of the side. The contribution from the square pool is determined by adjusting probability to the ratio of the remaining length and the length of the side.

Pool evaporation on land and water from liquids that are not boiling (LF, LT, C, D)
The outflow of liquids that are not boiling, substance categories LF, LT, C and D, leads to pools of liquid from which evaporation takes place.

Calculate the pool evaporation using the MacKay and Masugu model [12] as described in the Yellow Book [11].

The source strength of the evaporation is obtained by multiplying the evaporation speed M_{evap} by the pool surface area (= $\pi . R_{pool}^2$).

<u>$P_w > 2.10^4$ [P_a] :</u>
M_{evap} = $k_m \cdot M/RT \cdot P_a \cdot \ln [1 + P_w / (P_a - P_w)]$

<u>$P_w < 2.10^4$ [P_a] :</u>
M_{evap} = $k_m \cdot M/RT \cdot P_w$

M_{evap}	evaporation speed	[kg/ $m^2 \cdot s$]
R	gas constant = 8314	[J/K·kmol]
T	temperature of pool	[K]
P_w	substance vapour pressure at temperature T for the pool [N/m^2]	
M	molecular weight of liquid	[kg/kmol]
P_a	atmospheric pressure	[N/m^2]
k_m	mass transfer coefficient	[m^{-1}]

The following applies for k_m:
k_m = $0.004786 \cdot u^{0.78} \cdot (2.R_{pool})^{-0.11} \cdot Sc^{-0.67}$

where
Sc Schmidt number for air [-]

The following applies for Sc:
Sc = $\mu_a/(\rho_a.D_{ac})$
= v_a/ D_{ac}

where
μ_a dynamic viscosity of air [kg/m/s]
ρ_a atmospheric density [kg/m^3]

D_{ac}	substance-specific diffusion coefficient for air and gas	[m^2/s]
v_a	kinematic viscosity of air = 1.35 10^{-5}	[m^2/s]

The value 0.004786 for the mass transfer coefficient stems from the original publication, after corrections for the Sc number for the investigated substance [12].

The calculation of the Schmidt number Sc is substance-specific. This differs from the Yellow Book where a constant of 0.8 is used. The diffusion coefficient D_{ac} is calculated using correlations given in Reid [13].

The logarithm driving force in the model for substances with a vapour pressure $P_W > 2.\ 10^4$ [Pa] has been taken from Opschoor [14].

The time-dependent temperature effects, such as the pool cooling down as a result of evaporation are not taken into account.

17.3 Dispersion models

Two types of dispersion models for dispersion of gases and vapours are used in calculations, namely the Gaussian neutral gas model and the heavy gas dispersion model. With pool evaporation from a non-boiling liquid, the dispersion of gas is modelled using the standard Gaussian dispersion model. With outflow of pressurised liquefied gases from a reservoir, the heavy gas dispersion model is used until the gas mixture behaves as a neutral gas. After the heavy gas phase, the dispersion is calculated using the Gaussian model.

17.3.1 Natural gas dispersion for pool evaporation (LT, D)

With pool evaporation from a non-boiling liquid, the dispersion of gas is modelled using the standard Gaussian dispersion model for continuous sources with non-negligible measurements [15] in the wind direction and perpendicular to the wind direction. It starts with square pools, represented by a number of line sources, which are placed perpendicular to the wind. Concentrations at location (x, y, z) are calculated by summation of the individual line sources in the wind direction. The standard deviations σ used here are a function of the atmospheric stability, terrain roughness z_0 and the distance x to the source [15].

17.3.2 Heavy gas dispersion of pressurised liquefied gases (GF, GT)

The heavy gas dispersion model that is used for outflow of pressurised liquefied gases is a modified version of Cox and Carpenter's box model [16], [10]. The modification relates to the initial phases of dispersion on the release of pressurised liquefied gases [17].

Four dispersion phases are distinguished in the model:

1. Initial mixing phase (spray release for instantaneous outflow, jet dispersion for continuous outflow)
2. Transition to heavy gas phase
3. Heavy gas phase (Cox Carpenter model)
4. Neutral gas phase (Gaussian model)

The first phase describes the turbulent mixing of air with the released substance. The amount of air mixed in depends on the way in which outflow has taken place.

For continuous outflow, the geometry of the cloud is assumed to be square, with the dimensions L x L. The entrainment relationship for a turbulent jet in a non-stagnant medium used to determine the amount of air mixed in Q_{air} is:

$$Q_{air} = k_1 \cdot (\rho_a \cdot I_0)^{0.5} (v- u_w /v)$$

Q_{air}	amount of air mixed in
I_0	impulse flux in the jet
k_1	0.282
v	velocity of the jet
u_w	wind speed
ρ_a	atmospheric density

For instantaneous outflow, the spray release model [15] is the core of modelling the initial phase. A symmetrically expanding and moving cylindrical cloud is assumed, with a height H equal to 2/3 of the radius R of the cloud. The amount of air mixed in Q per unit of time

$$Q = 9/8 \cdot \rho_a \cdot V^{1/9} \cdot V_{fac}^{8/9}$$
$$V_{fac} = 2\pi/3 \cdot R_{fac}^3$$
$$R_{fac} = k_3 \cdot E_{exp}^{3/16} \cdot V_{go}^{5/24}$$

Q	amount of air mixed in	[kg/s]
ρ_a	atmospheric density	[kg/m^3]
V	volume of cloud	[m^3]
V_{go}	twice the initial volume at 273 K and 1 bar	
k_3	0.4	

E_{exp} is the expansion energy, to be calculated from the thermodynamic change of state on outflow. The advection speed of the instantaneous cloud is determined using an impulse balance.

The initial phase is linked to a heavy gas phase via the second interim phase. The first phase concludes when the change in the radius of the cloud as a result of turbulent mixing is equal to the change in the radius as a result of gravitational spread.

The mixing in the intermediate phase proceeds as in the initial phase. The increase in the radius is given by the gravitational spread [16].

$$dR/dt,\ dL/dt = (k_2 \cdot g \cdot H \cdot (\rho_a-\rho_c)/\rho_c)^{0.5}$$

ρ_a	atmospheric density	[kg/m^3]
ρ_c	density of cloud	[kg/m^3]
H	height of cloud	[m]
g	gravitational acceleration constant = 9.81	[m/s^2]
R	radius	[m]

L	width of cloud	[m]
k_2	1	

As opposed to the first phase, the size of the cloud no longer increases symmetrically. The second phase ends when the amount of air mixed in according to the equations in the first phase is less than the amount of air mixed in according to the heavy gas phase.

In the third, heavy gas, phase the further mixing of the cloud is modelled in accordance with the original Cox and Carpenter model [16]. The box model assumes a uniform contraction profile.

The amount of air mixed in dm/dt is determined using the entrainment speeds ut and ue via the top and edge of the cloud respectively. For example, for an instantaneous cloud, the following applies:

$$dm/dt = \rho_a \cdot (2\pi RH \cdot u_e + \pi R^2 \cdot u_t)$$

Relationships for the entrainment speeds u_t and ue and the entrainment relationships in the case of a continuous cloud are given in [16], [10].

A transition to a Gaussian dispersion model is made if the speed of the gravitational spread dR/dt is less than the speed of the spread by Gaussian dispersion or if the density of the cloud minus the density of the air is less than 0.001.

In this fourth phase, a virtual line source is assumed in the dispersion calculation [17]. The location and dimensions of the virtual line source are determined through a match of the concentration on the axis of the cloud at the transition point. Time-dependent modelling is used for instantaneous outflow. The standard variations σ for Gaussian dispersion are a function of the atmospheric stability, terrain roughness z0 and the distance x to the source. The correlations in [15] are used.

The thermodynamic effects of the mixing with humid air and the heat transfer from the (hot) ground to the (cold) cloud are taken into consideration to determine the cloud conditions (density, temperature, etc.). The maximum for the forced and free convection is taken for the heat transfer from the ground.
Please refer to the description in, for instance, [18], [16].

17.4 Effect models

When a vapour cloud encounters an ignition source, the cloud can catch fire and burn. After the delayed ignition of the vapour cloud that has formed, there is an event with the characteristics of both a flash fire and an explosion. This is modelled as two separate events, namely as a pure flash fire and a pure explosion.

17.4.1 Flash fire

The potential hazards from a flash fire are direct exposure to the flames and hot combustion gases, thermal radiation, smoke and toxic by-products. Use the dispersion models to determine the size of the flammable area of the vapour cloud. This is the area within which a flash fire could occur at any time after the release of gas from the tank. The flammable area is bounded by the lowest explosive limit (LFL) at ground level.

17.4.2 *Vapour cloud explosion*

The speed at which the cloud burns determines the effect. In some situations, the cloud will burn so quickly that this gives rise to a pressure wave. The size and intensity of the explosion depend on, among other things, the type of flammable substance, the way in which it is released, the size of the cloud on ignition and the degree to which the vapour cloud is confined and the ignition method. The primary hazard is overpressure. The secondary fragments that could be formed by the explosion are not considered. Calculate the overpressure effects using the correlation model [10].

The circular effect areas where the incoming pressure waves are 0.3 bar and 0.1 bar, are calculated using the correlation model and the numerically calculated mass M in the cloud above the LFL contour. The midpoint of this effect area lies at a specific distance from the outflow point. This distance stems from the dispersion model. For continuous sources, assume that the centre of the explosion lies at half the distance to the LFL contour in the wind direction. For instantaneous sources, assume that the centre of the explosion is the same as the centre of the vapour cloud when it has reached is largest size (the largest possible surface area of the LFL contour).

$$R_{0.3\ bar} = 0.03 \cdot (0.1\ M \cdot H_c)^{1/3}$$
$$R_{0.1\ bar} = 0.06 \cdot (0.1\ M \cdot H_c)^{1/3}$$

$R_{0.3\ bar}$	distance to overpressure of 0.3 bar	[m]
$R_{0.1\ bar}$	distance to overpressure of 0.1 bar	[m]
M	mass in the cloud above the LFL	[kg]
H_c	combustion enthalpy	[J/kg]

The correlation model is based on an evaluation of three vapour cloud explosions where the vapour cloud can be characterised as partially confined before the explosion[30].

17.4.3 *Pool fire*

A pool fire occurs when a pool of flammable liquid catches fire. Outside of the burning pool, thermal radiation is the most significant hazard from a pool fire. Other effects from a pool fire, such as smoke, toxic by-products and secondary fires or explosions in the surrounding environment are not modelled. In some cases the pool fire could weaken the neighbouring tanks to such an extent that they collapse. This could result in a hot BLEVE. This scenario is only included in the rail modality.

[30] This model produces identical results to the Multi Energy Method [7] if that model assumes the curve with the highest blast strength 10 and a value of 0.08 for the obstruction factor.

The thermal radiation in the vicinity is calculated using the 'solid flame' model for an oblique cylinder [11]. Here the flame is represented by an oblique cylinder with a constant radiation strength E at the surface.

The thermal radiation q (kW/m^2) at a specific location is given by:
q = $\tau \cdot E \cdot F$

Calculate the radiation strength E [kW/m^2] for a soot-forming hydrocarbon fire [11]. This is a function of the diameter D of the pool:
E = $140 \cdot e^{-0.12 \cdot D} + 20 \cdot (1-e^{-0.12 \cdot D})$

The atmospheric transmission τ takes account of the reduction of the thermal radiation by absorption of H_2O in the atmosphere and is therefore dependent on the distance between an object and the concentrations of H_2O in the air. Calculate the atmospheric transmission τ in accordance with Figure 6.4 in [11].

The view factor F between the flame and the irradiated object is determined by geometry: diameter of the pool D, length of flame H, deflection angle for the flame Φ, distance from flame to object and orientation of object in relation to the flame. The calculation of the view factor differs from the Yellow Book and is explained below.

The following applies for the length of the flame H:

$$H = 55 \cdot D \left[\frac{m}{\rho_a \sqrt{g\,D}}\right]^{0.67} (u_*)^{-0.21}$$

$$u_* = u_a \left[\frac{g\,m\,D}{\rho_v}\right]^{-1/3}$$

The following applies for the combustion speed m [kg/m^2.s]:
m = $10^{-3} \cdot H_C \cdot [C_p \cdot (T_k - T_a) + H_v]^{-1}$

The deflection angle Φ follows from:

$$\frac{\tan\phi}{\cos\phi} = 0.666 \cdot (Re)^{0.117} \cdot (Fr)^{0.333})$$

where:

$$Re = \frac{u_a \cdot D}{\nu_a}$$

$$Fr = \frac{{u_a}^2}{g \cdot D}$$

D	pool diameter	[m]
H	length of flame	[m]

ρ_a , ρ_v	air density, vapour [kg/m^3] = 1.20	[kg/m^3]
u_a	wind speed	[m/s]
υ_a	kinematic viscosity = 1.31 10^{-5}	[m^2/s]
g	9.81	[m/s^2]

Assume for the calculation of the pool diameter on water, an equilibrium between the outflow rate constant Mrel and the combustion flow rate m:

$\Pi \cdot R_{pool}^2 \cdot m = M_{rel}$

Calculating the view factor for an oblique cylinder

Thermal radiation effects from a pool fire are calculated using the oblique cylinder model. Figure 3-1 is a schematic depiction of the model. In what follows, the calculation of the view factor is explained for the case without lift-off (in this case the height of the pool is ground level, so L=0).

The view factor is determined for a horizontal and vertical receptor surface both in the wind direction and perpendicular to the wind direction.

$F = (F_v{}^2 + F_h{}^2)^{0.5}$

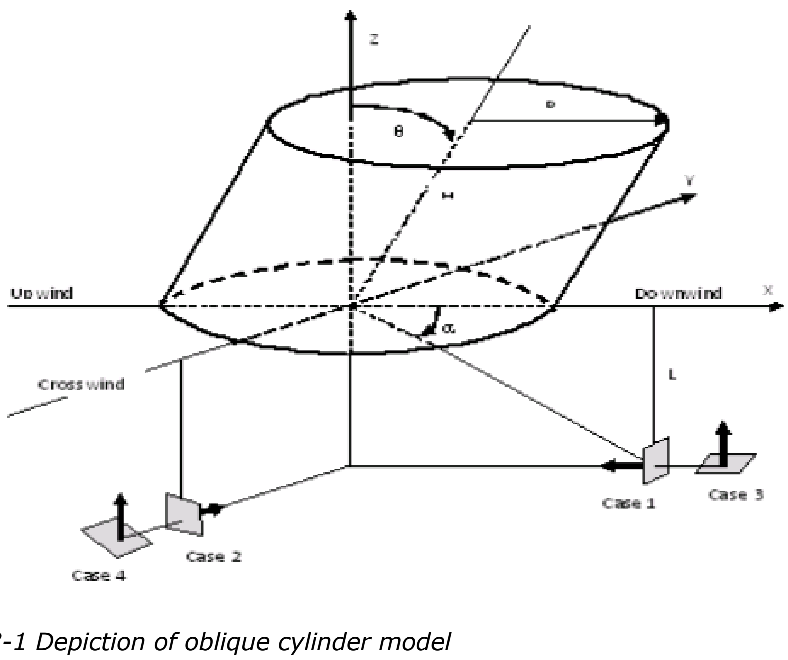

Figure 3-1 Depiction of oblique cylinder model

Definitions

a = h/r,

b = x/r,

$A = \sqrt{(a^2 + (b+1)^2 - 2a(b+1) \cdot \sin\theta)}$

$B = \sqrt{(a^2 + (b-1)^2 - 2a(b-1) \cdot \sin\theta)}$

$C = \sqrt{(1 + (b^2 - 1) \cdot \cos 2\theta)}$

$D = \sqrt{(b-1) / (b+1)}$

E= (a ·cos θ) / (b – a · sin θ)
F = √(b^2 – 1)
G= √(a^2 + b^2 + 1)^2 – 4(b^2 + a^2 ·sin^2 θ)
H= a^2 + (b + 1)^2
I = √(b^2 – sin^2 θ)

Case 1

$$\pi F_v = -E\,tan^{-1} D + E\left[\frac{a^2 + (b+1)^2 - 2b(1 + a \cdot sin\,\theta)}{AB}\right] tan^{-1}\left(\frac{AD}{B}\right) + \frac{cos\,\theta}{C}\left[tan^{-1}\left(\frac{ab - F^2\,sin\,\theta}{FC}\right) + tan^{-1}\left(\frac{F\,sin\,\theta}{C}\right)\right]$$

Case 2

$$2\pi F_v = -\left(\frac{a^2\,sin\,\theta \cdot cos\,\theta}{2(a^2\,sin^2\,\theta + b^2)}\right) ln\left[\frac{a^2 + b^2 - 1 - 2a\frac{F}{b}sin\,\theta}{a^2 + b^2 - 1 + 2a\frac{F}{b}sin\,\theta}\right] + \left(\frac{cos\,\theta}{I}\right)\left[tan^{-1}\left(\frac{\frac{ab}{F} + sin\,\theta}{I}\right) + tan^{-1}\left(\frac{\frac{ab}{F} - sin\,\theta}{I}\right)\right] + \left(\frac{ab \cdot cos\,\theta}{b^2 + a^2\,sin^2\,\theta}\right)\left(\frac{a^2 + b^2 + 1}{G}\right)\left[tan^{-1}\left(\frac{HD - 2a \cdot sin\,\theta}{G}\right) + tan^{-1}\left(\frac{HD + 2a \cdot sin\,\theta}{G}\right)\right] - \left(\frac{2ab \cdot cos\,\theta}{b^2 + a^2\,sin^2\,\theta}\right) tan^{-1} D$$

Case 3

$$\pi F_h = tan^{-1}\left(\frac{1}{D}\right) + \frac{sin\theta}{C}\left[tan^{-1}\left(\frac{ab - F^2 sin\theta}{FC}\right) + tan^{-1}\left(\frac{F sin\theta}{C}\right)\right] - \left[\frac{a^2 + (b+1)^2 - 2(b + 1 + ab \cdot sin\theta)}{AB}\right] tan^{-1}\left(\frac{AD}{B}\right)$$

Case 4

$$2\pi F_h = 2\,tan^{-1}\left(\frac{1}{D}\right) + \left(\frac{F\,sin\,\theta}{I}\right)\left[tan^{-1}\left(\frac{\frac{ab}{F} + sin\,\theta}{I}\right) - tan^{-1}\left(\frac{\frac{ab}{F} - sin\,\theta}{I}\right) - 2\,tan^{-1}\left(\frac{sin\,\theta}{I}\right)\right] - \left(\frac{a^2 + b^2 - 1}{G}\right)\left[tan^{-1}\left(\frac{HD - 2a \cdot sin\,\theta}{G}\right) + tan^{-1}\left(\frac{HD + 2a \cdot sin\,\theta}{G}\right)\right]$$

17.4.4 *Jet fire*

A jet fire occurs when flammable pressurised liquefied gas escapes at high speed through an opening in the tank and ignites almost immediately. Other hazards from a jet fire are smoke, toxic by-products from the fire and the possibility of the jet fire causing secondary fires and explosions in the surrounding area. These effects are not modelled.

It is assumed that the jet fire flows out horizontally and that the most significant hazard is thermal radiation. Use the correlation from LPG Integral [19] for the length of the jet fire L. The jet fire is represented by a horizontal cylinder with a length L and a diameter D equal to the length divided by 8.

L	$= 18.8 \cdot m^{1/3}$	[m]
L/D	= 8	
m	the source strength without rain-out	[kg/s]

The thermal radiation strength E is by default assumed to be 180 kW/m^2 irrespective of the size of the jet fire or the type of gas.

The calculation method for the thermal radiation load q in the surroundings ($q = \tau \cdot E \cdot F$) is performed in the same way as described for the pool fire model.

17.4.5 *BLEVE*

BLEVE is Boiling Liquid Expanding Vapour Explosion. A BLEVE occurs when a tank containing pressurised liquefied gas totally fails in one go. Both flammable gas and non-flammable pressurised liquefied gases can cause a BLEVE. In a BLEVE, a rapidly expanding cloud of vapour and liquid droplets forms. A limited number of fragments are formed which can be found up to several hundred metres into the surroundings. With immediate ignition of a flammable gas, the cloud burns from the outside in the form of an expanding and rising fireball. In addition to thermal radiation, there are also pressure waves due to the relief of pressure in the vapour space in the reservoir, due to the explosive evaporation of the liquid and the combustion of the vapour cloud.
In the case of flammable gases, only consider the risk determinative thermal radiation effect and use the fireball model for this [11]. The thermal radiation covers a greater effect area than the overpressure effect and is therefore determinative for the risk. In the case of toxic gases, the BLEVE is modelled as an instantaneous outflow at the failure pressure.

In the calculation, the thermal radiation from the fireball is assumed to be a spherical heat radiator with a constant radius R, which radiates heat during an effective fire duration t. The centre of the fireball is at height h = 2R.

R	=	$3.24 \cdot M^{0.325}$	[m]
t	=	$0.852 \cdot M^{0.26}$	[s]

Here M is the mass [kg] in the fireball. The fraction of the mass present in the tank that ends up in the fireball is set to 3 times the adiabatic flash at the failure pressure. The maximum fraction is 1 [20].

The heat radiation q at a specific distance is calculated using:

$$q = \tau . E . F \qquad [kW/m^2]$$

The view factor F at distance r from the centre of a fireball with radius R is:

$$F = R^2/r^2 \qquad [-]$$

Calculate the atmospheric transmission τ in accordance with Figure 6-4 in [11].

Calculate the radiation strength E at the surface of the fireball from the fraction Fs of the combustion energy $M.H_C$ which is released as thermal radiation.

$$\pi \cdot D^2 \cdot E \cdot t = F_S \cdot M \cdot H_C$$

The radiation fraction F_S is related to the vapour pressure P [Pa] of the substance at failure.

$$F_S = 0.00325 \cdot P^{0.32}$$

A 'standard' BLEVE ('cold' BLEVE) is based on the vapour pressure at the ambient temperature used by default. In a 'domino' BLEVE ('hot' BLEVE) calculate the failure pressure P [bar] by multiplying the overpressure at 308 K + 1.7 bar by a factor or 1.4.

$$P = 1.4 \cdot [\, P_V(T= 308\ K) +1.7] \qquad [bar]$$

Note:
As far as the BLEVE is concerned, a clear distinction must be made between the causes. The BLEVE can be hot (delayed failure as the result of an external fire) or cold (immediate failure as the consequence of an impact for example). Case studies have made it clear that both scenarios contribute to the risk. The question is, however, to what extent the pressure in the reservoir will rise in a hot BLEVE, because the radiation strength of the fireball depends on the pressure in the tank at the moment it fails. The higher the pressure at failure, the 'hotter' the BLEVE becomes, which results into greater effect distances and increases the consequences of the accident. The pressure at failure cannot, unfortunately, be derived from the case studies. It is assumed that the probability of a significant build-up of pressure is remote for road. For rail, it is assumed that each 'domino BLEVE' will be caused by a build-up of pressure up to the tank's failure pressure.

17.5 Damage modelling

The number of victims as a consequence of exposure to the released toxic substance, direct fire, thermal radiation or overpressure is calculated using dose-effect-relationships that establish a link between the exposure and the probability of lethality.

The following effects are significant here:

- Toxic effects
- Direct fire (flash fire, jet fire, burning pool or the projection from a BLEVE fireball) and thermal radiation effects (pool fire, jet fire, BLEVE).
- Pressure effects (vapour cloud explosion).

The calculation of the individual risk does not take account of protection factors; these are taken into account for the SR.

17.5.1 *Toxic damage*

Probit relationships are used for the probability of lethality, P_{lethal}, as a function of the concentration C and the exposure time t. These have the form:

$$Pr = a + b \ln(\int C^{n}\, dt)$$

Pr	probit associated with the probability of lethality	(-)
a, b, n	constants for the toxicity of a substance	(-)
C	concentration at time t	(mg m^{-3})
t	exposure time	(minutes)

The relationship between the probability of lethality P_{lethal} and the corresponding probit Pr is given by:

$P_{letaal} = 0.5 \times [1 + erf\{(Pr-5)/\sqrt{2}\}]$

where erf is:

$$erf(x) = (2/\sqrt{\pi}) \int e^{-t^2} \times d$$

The probit constants a, b and n for the representative substances in the toxic substance categories are included in Module B.

The probability of lethality for people inside a building is 10% of the probability of lethality outside of a building. Table 3-3 shows the probability of lethality for the two situations distinguished for toxic substances. Probability of lethality of less than 1% is not considered.

Table 3-3 Probability of lethality for the two situations distinguished for toxic effects

Area	**Probability of lethality**	
	Inside	**Outside**
In the area where $P_{lethal} > 0.01$	$0.1 \times P_{lethal}$	P_{lethal}
In the area where $P_{lethal} < 0.01$	0	0

Effective width
In the dispersion model the concentration C is determined as a function of the distance x from the outflow point and the distance y in the width to the axis of the cloud. The probability of lethality P_{lethal} is calculated from this, in combination with the exposure time. For continuous outflow, the concentration at location (x, y) is not time dependent. The exposure time t_b corresponds to an outflow duration with a maximum of 1800 seconds (30 min.). For instantaneous outflows the concentration at location (x, y) is time dependent as a result of the expansion of the cloud and its passing by. The exposure time at location (x, y) matches the passage time for the cloud at location (x, y).

An effective width is determined to simplify the risk calculation.

For **continuous** outflows:

P_{di} (x,0) x effective width = $\sum P_t$ (x,y). dy

Where P_{di} (x,0) is the probability of lethality at the axis of the cloud at a distance x from the source.

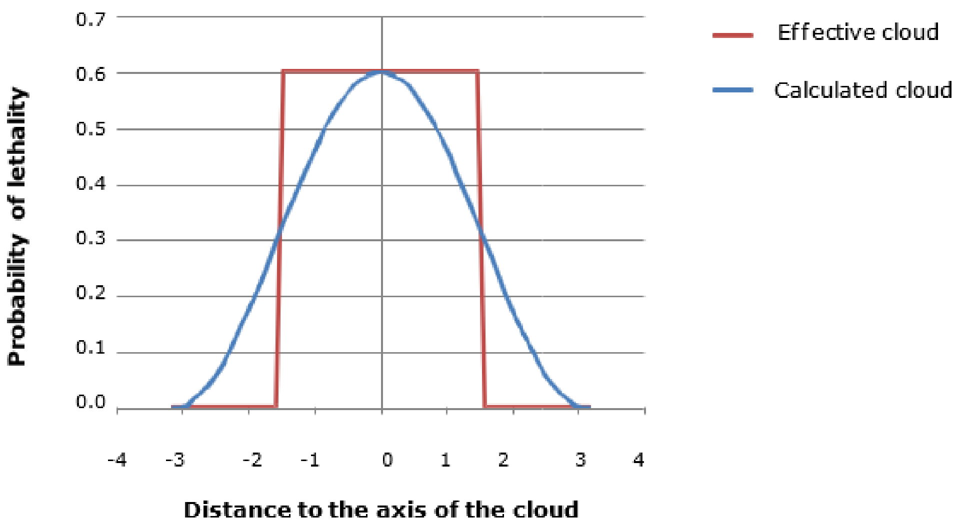

Figure 3-2 Graphic depiction of effective cloud

Figure 3-2 shows the probability of lethality for the calculated cloud as a function of the distance to the axis of the cloud. The effective cloud width is determined where the probability of lethality is the same as the probability of lethality at the axis of the cloud (0.6 here) and the area below the blue curve is the same as the area below the red curve.

With instantaneous outflows the concentration is not constant, it is time dependent. When determining the effective width, the passage time for the expanding and growing cloud at location (x, y) should also be taken into account. This passage time is a function of the distance x to the outflow point and the distance y in the width to the cloud axis and is determined numerically.

17.5.2 *Damage in the event of flash fire*

In a flash fire 100% of those present within the size of the cloud determined by the LFL concentration will die. Outside of this area there are no victims. Therefore, two situations are distinguished for a flash fire, namely inside and outside of the cloud. Table 3-4 shows the probability of lethality for both situations.

Table 3-4 Probability of lethality for flash fire

Area	**Probability of lethality**	
	Inside	**Outside**
Inside the flammable cloud	1	1
Outside the flammable cloud	0	0

17.5.3 *Damage in the event of BLEVE, pool fire, jet fire*

In a fire, 100% of those present within the direct fire (jet fire, burning pool or the projection of the BLEVE fireball) or within the 35 kW/m^2 contour will die. Outside of the fire or the 35 kW/m^2 contour victims will only occur amongst people outside of buildings.

For the individual risk (IR) the probability of lethality from thermal radiation P_{lethal} without protection is determined by the probit relationship below for thermal radiation q in W/m^2 and the exposure time t in seconds.

$$Pr = -36.48 + 2.56 \cdot \ln (q^{4/3} \cdot t)$$

An exposure time of 20 seconds is assumed for a pool fire and jet fire. The exposure time for a BLEVE is set to match the combustion time of the fireball with a maximum of 20 seconds.

The protective effect of clothing is taken into account for the societal risk (SR). The probability of lethality is 14% of the calculated probability of lethality without protection.

Three areas are considered in the calculation. Table 3-5 gives the probability of lethality per area.

Table 3-5 Probability of lethality for the three situations distinguished for a pool fire

Area	**Probability of lethality**		
	SR		**IR**
	Inside	**Outside**	
In the fire (pool, jet fire, BLEVE fireball projection)	1	1	1
In the area where thermal radiation is > 35 kW/m^2	1	1	1
In the area where thermal radiation is < 35 kW/m^2	0	0.14 × P_b	P_b

3.5.4 Damage in the event of explosion

In an explosion 100% of those present within the 0.3 bar overpressure contour will die and 2.5% of those present inside a building in the area between the 0.3 and 0.1 bar overpressure contour will die. There will be no victims outside of the 0.1 bar contour.

Therefore, three areas have been defined for a vapour cloud explosion.

- An area with an overpressure of 0.3 bar overpressure or more.
- An area between 0.3 and 0.1 bar overpressure.
- An area with overpressure lower than 0.1 bar.

The corresponding probability of lethality per area is given in Table 3-6.

Table 3-6 Probability of lethality for a vapour cloud explosion

Area	**Probability of lethality**	
	Inside	**Outside**
Overpressure > 0.3 bar	1	1
Overpressure > 0.1 bar < 0.3 bar	0.025	0
Overpressure < 0.1 bar	0	0

18 Appendix: Calculation of the hot/cold BLEVE ratio

The calculation of the ratio for the hot/cold BLEVE $F_{hot\ BLEVE}/F_{cold\ BLEVE}$ is explained in the draft rail calculation protocol [21]. The ratio depends on the track section speed.

18.1 Calculation method for flammable gas (substance category A)

Low track section speed (< 40 km/hour):

$F_{hot\ BLEVE}/F_{cold\ BLEVE}$ $= 19.5 \times (N_{bvl}/N_g) \times P_{contact}$
$= 1.95 \times N_{bvL}$ (at N_{bvl}, $N_g < 3$)

High track section speed (>40 km/hour):

$F_{hot\ BLEVE}/F_{cold\ BLEVE}$ $= 39.0 \times (N_{bvl}/N_g) \times P_{contact}$
$= 3.9 \times N_{bvl}$ (at N_{bvl}, $N_g < 3$)

N_{bvl} = average number of wagons containing highly flammable liquid in a mixed train
N_g = average number of wagons containing flammable gas in a mixed train.

$$N_{\mathrm{bvl}} = \frac{N_{\mathrm{bvl\ (mixed)}}}{N_{\mathrm{mixed}} \times (100/GS)} \times N_{tot}$$

$$Ng = \frac{N_{\mathrm{bg(bont)}}}{N_{\mathrm{bont}} \times (100/GS)} \times N_{\mathrm{tot}}$$

$N_{bv(mixed)}$ = total number of wagons of highly flammable liquid in mixed trains
= NC3 + 0.1 x ND3
N_{C3} = total number of C3 wagons in mixed trains
N_{D3} = total number of D3 wagons in mixed trains
$N_{bg(mixed)}$ = total number of flammable gas A wagons in mixed trains
N_{mixed} = total number of wagons (A through D4) in mixed trains
N_{tot} = average train length
= 20 wagons [21]
GS = percentage for hazardous substances relevant to external safety[31]
= 5% [25]

$P_{contact}$ is the probability of wagons containing highly flammable liquid and flammable gas being next to each other.

The $P_{contact}$ probability is:

{2/ Ntot x Ng/(Ntot -1) }+ { (Ntot -2)/Ntot x [Ng/(Ntot-1) + (Ntot-Ng-1)/(Ntot-1) x (Ng/(Ntot-2)]}

[31] Track section specific information should be used where possible.

Please note that 10% of the D3 wagons in mixed trains are added to the C3 wagons in mixed trains when determining $N_{bv(mixed)}$ (the number of wagons of highly flammable liquid) [21].

18.2 Calculation method for toxic gas (substance category B2)

The hot/cold BLEVE ratio for toxic gas (B2) is determined in an identical way. The average number of B2 wagons in a mixed train should now be entered in the $P_{contact}$ probability for N_g.

N_g = average number of wagons containing toxic gas B2 in a mixed train

$$N_g = \frac{N_{\mathrm{tg(mixed)}}}{N_{\mathrm{mixed}} \times (100/GS)} \times N_{\mathrm{tot}}$$

$N_{tg(mixed)}$ = total number of wagons of toxic gas B2 in mixed trains.

In addition, a multiplication factor of 0.8 should be applied [21].[32]

Low track section speed (< 40 km/hour):

$F_{hot\ BLEVE}/F_{cold\ BLEVE}$ = 0.8 x 19.5 x (N_{bvl}/N_g) × $P_{contact}$
= 0.8 x 1.95 x N_{bvL} (at N_{bvl}, N_g < 3)

High track section speed (>40 km/hour):

$F_{hot\ BLEVE}/F_{cold\ BLEVE}$ = 0.8 × 39.0 x (N_{bvl}/N_g) x $P_{contact}$
= 0.8 × 3.9 x N_{bvl} (at N_{bvl}, N_g < 3)

18.3 Explanation of the hot/cold BLEVE ratio

The ratio $F_{hot\ BLEVE}/F_{cold\ BLEVE}$ for flammable and toxic gases is determined per track together with the transport quantities in Basisnet.

When doing so the hot/cold BLEVE ratio for flammable gas is first determined in the designated manner per transport route. Then all transport routes are averaged to obtain a more accurate hot/cold BLEVE ratio per track section. It is more accurate because all data for the transport routes (origins-destinations) are used, which contribute to a specific section, such as direction information and information about the transport method (block v mixed). In addition, assumptions are used in relation to the 'hot BLEVE-free composition' of the trains.

[32] The factor 0.8 is the probability of immediate ignition of flammable gas released instantaneously. This factor is missing in the derivation for toxic gas [22].

19 Appendix: Vessel damage frequencies

This appendix gives the individual vessel damage frequencies to be used. They are given per traffic section. Table 5-1 gives the classification of the traffic sections into waterway and kilometre [23].

19.1 Description of traffic sections

The main transport axes and main waterways are subdivided into waterway sections in the National Road File - waterways. Traffic sections are defined by adding together these waterway sections. The kilometre marking, the start and end kilometres, are taken from the National Road File - waterways. For canals, the width of the waterway is the width at canal level. The width as shown on topographic maps is used for rivers.

Table 5-1 Description of traffic sections [23]

No.	Name of traffic section	Water-way no.	Width [m]	Start km	End km	From	To
1	ARK_1	225	105	73.3	61.3	Waal	Lower Rhine
2	ARK_2	225	95	61.3	43.1	Lower Rhine	Lek canal
3	ARK_3	225	87	43.1	35.2	Lek canal	Uranium canal Utrecht
4	ARK_4	225	88	35.2	0	Uranium canal Utrecht	Closed IJ
5	Brabant Waterway	139	500	0	24.0	Scheldt Rhine connection	Oosterschelde
10	Eems canal	1	48	0	26.5	Zeehaven canal	Van Starkenborgh canal
11	Geldersche IJssel_1	84	125	0	43.6	Lower Rhine	Zutphen Enschede canal
12	Geldersche IJssel_2	84	125	43.6	56.3	Zutphen Enschede canal	Inland port in Deventer
13	Geldersche IJssel_3	84	125	56.3	93.0	Inland port in Deventer	Zwolle IJssel canal / Zwarte water
14	Geldersche IJssel_4	84	125	93.0	128.0	Zwolle IJssel canal	Ketelbrug
15	Gouwe	270	50	0	15.0	Old Rhine crossing	Hollandsche IJssel
16	Hartel canal_1	115	166	0	8.1	Oude Maas	Caland canal
17	Hartel canal_2	115	145	8.1	23.7	Caland canal	Hartel harbour
18	Hollandsch Diep	108	1500	0	36.9	Volkerak	Nieuwe Merwede
19	Hollandsche IJssel_1	211	100	3.4	20.3	Juliana lock outer harbour	Nieuwe Maas
20	Hollandsche IJssel_2	211	100	0	3.4	Canalised Hollandsche IJssel	Juliana lock outer harbour
21	IJsselmeer_1	230	500	0	34.5	Closed IJ	Houtrib locks
22	IJsselmeer_2	230	500	34.5	74.1	Houtrib locks	Lemmer
26	Sint Andries canal	101a	65	0	2.1	Maas	Waal
27	Wessem - Nederweert canal	123	28	0	16.1	Canalised Maas	Zuid Willemsvaart
28	Zuid - Beveland canal	137	126	0	10.5	Oosterschelde	Westerschelde
29	Ketelbrug Houtrib	303	500	0	5.6	Ketelbrug	IJsselmeer
30	Lek canal	225e	63	0	4.1	Amsterdam-Rhine canal	Lek
31	Maas_1	150	150	0	5.7	van Ternaaien locks	Connecting canal in het Bossche veld

No.	Name of traffic section	Water-way no.	Width [m]	Start km	End km	From	To
32	Maas_10	150	450	217.7	229.8	Amertak	Hollandsch Diep
33	Maas_2	150	49	5.7	19.7	Connecting canal in het Bossche veld	Stein
34	Maas_3	150	49	19.7	44.7	Stein	Roermond
35	Maas_4	150	90	44.7	52.2	Roermond	Maas power station at Buggenum
36	Maas_5	150	91	52.2	131.2	Maas power station at Buggenum	Maas-Waal canal
37	Maas_6	150	109	131.2	158.7	Maas-Waal canal	Burgemeester Delen canal
38	Maas_7	150	110	158.7	174.6	Burgemeester Delen canal	Sint Andries canal
39	Maas_8	150	110	174.6	186.7	Sint Andries canal	Canalised Dieze
40	Maas_9	150	110	186.7	217.7	Canalised Dieze	Amertak
41	Maas-Waal canal	119	69	0	13.3	Canalised Maas	Waal
42	Margriet canal_1	21	53	0	24.4	Van Starkenborgh canal	Van Harinxma canal
43	Margriet canal_2	21	100	24.4	66.2	Van Harinxma canal	Lemmer
44	Meppelerdiep	88	62	0	11.0	Zwarte Water	Drentsche Hoofdvaart
45	Nieuwe Merwede	108	500	0	23.5	Beneden Merwede	Hollandsch Diep
46	Nieuwe Maas_1	102	365	0	5.0	Lek	Hollandsche IJssel
47	Nieuwe Maas_2	102	365	5.0	20.0	Hollandsche IJssel	2nd Petroleum port
48	Nieuwe Maas_3	102	365	20.0	22.3	2nd Petroleum port	1st Petroleum port
56	Noordzee canal_5	233	270	19.2	22.4	Mercurius harbour	Noordhollandsch Canal
57	Noordzee canal_6	233	270	22.4	25.9	Noordhollandsch Canal	Amsterdam-Rhine canal
58	Oosterschelde	138	800	10.5	11.3	Brabantsch Waterway	Canal through Zuid-Beveland
59	Oude Maas_1	111	300	0	4.3	Noord	Dordtsche Kil
65	Rhine_2	103	101	11.1	59.8	Geldersche IJssel	Amsterdam-Rhine canal
66	Rhine_3	103	135	59.8	80.3	Amsterdam-Rhine canal	Lek canal
67	Rhine_4	103	136	80.3	119.6	Lek canal	North /Nieuwe Maas

No.	Name of traffic section	Water-way no.	Width [m]	Start km	End km	From	To
68	Scheldt-Rhine connection_1	129	187	19.4	38.5	Bergen op Zoom ports	Zandvliet lock
69	Scheldt-Rhine connection_2	129	201	0	19.4	Zuid Vlije	Bergen op Zoom ports
70	Twente canal_1	81	55	0	34.2	Geldersche IJssel	Almelo side channel
71	Twente canal_2	81	55	34.2	43.7	Almelo side channel	Hengelo
72	Twente canal_3	81	50	43.7	49.8	Hengelo	Enschede
74	Volkerak	143	500	0.5	14.9	Volkerak locks	Scheldt-Rhine connection
73	Van Starkenborgh canal	3	54	0	27.4	Ems canal	Prinses Margriet canal
75	Waal_1	101	375	0	9.2	Border	Pannerdensch canal
76	Waal_2	101	375	9.2	28.6	Pannerdensch canal	Maas-Waal canal
77	Waal_3	101	375	28.6	54.8	Maas-Waal canal	Amsterdam-Rhine canal
78	Waal_4	101	375	54.8	67.5	Amsterdam-Rhine canal	Sint Andries canal
79	Waal_5	101	375	67.5	96.2	Sint Andries canal	Merwede canal
80	Waal_6	101	375	96.2	101.3	Merwede canal	Nieuwe Merwede
81	Waal_7	101	375	101.3	116.8	Nieuwe Merwede	Oude Maas
82	Waal_8	101	375	116.8	125.5	Oude Maas	Nieuwe Maas
90	Willemsvaart_1	121	26	0	6.0	Maas	Den Bosch
91	Willemsvaart_2	121	28	6.0	24.6	Den Bosch	New Harbour in Veghel
92	Willemsvaart_3	121	39	24.6	37.8	New Harbour in Veghel	Wilhelmina canal
93	Willemsvaart_4	121	39	67.3	78.9	Wessem - Nederweert canal	Billiton Zink bv. Budel
95	Almelo side channel	82	50	0	17.4	Zutphen Enschede canal	Almelo
96	Zwarte Water	86	75	17.2	48.6	Geldersche IJssel	Ketelmeer

19.2 Vessel damage frequency traffic sections

Table 5-2 gives the individual vessel damage frequencies that are to be used. When a traffic section is shown in cursive script in this table, it means that there are one or more exception kilometres on this traffic section. These are kilometres with a significantly higher or lower individual vessel damage frequency. The individual vessel damage frequencies for the exception kilometres are included in Table 5-3 [23].

Table 5-2 Vessel damage frequencies per traffic section [23]

No.	Traffic section	Severe damage [1/veskm]	No.	Traffic section	Severe damage [1/veskm]
1	ARK_1	2.1E-07	43	Margriet canal_2	1.3E-07
2	ARK_2	2.8E-07	44	Meppelerdiep	1.0E-052)
3	ARK_3	1.5E-07	45	Nieuwe Merwede	3.3E-07
4	ARK_4	1.9E-07	46	Nieuwe Maas_1	3.8E-07
5	Brabant Waterway	2.4E-07	47	Nieuwe Maas_2	2.7E-07
10	Eems canal	1.7E-07	48	Nieuwe Maas_3	2.2E-07
11	Gelderse IJssel_1	1.6E-07	56	Noordzee canal_5	1.2E-06
12	Gelderse IJssel_2	6.7E-08	57	Noordzee canal_6	3.5E-07
13	Gelderse IJssel_3	9.8E-08	58	Oosterschelde	1.3E-07
14	Gelderse IJssel_4	4.7E-07	59	Oude Maas_1	7.0E-07
15	Gouwe	4.6E-07	64	Rhine_1	9.8E-07
16	Hartel canal_1	2.9E-08	65	Rhine_2	1.3E-07
17	Hartel canal_2	1.7E-07	66	Rhine_3	3.0E-07
18	Hollandsch Diep	8.0E-08	67	Rhine_4	1.4E-07
19	Hollandsche IJssel_1	1.4E-07	68	Scheldt-Rhine connection_1	5.5E-08
20	Hollandsche IJssel_2	1.8E-07	69	Scheldt-Rhine connection_2	2.9E-07

No.	Traffic section	Severe damage [1/veskm]	No.	Traffic section	Severe damage [1/veskm]
21	IJsselmeer_1	2.6E-07	70	Twente canal_1	4.9E-07
22	IJsselmeer_2	3.5E-08	71	Twente canal_2	2.3E-07
26	Sint Andries canal	2.0E-07	72	Twente canal_3	2.8E-07
27	Wessem - Nederweert canal	3.6E-07	73	Van Starkenborgh canal	2.7E-07
28	Zuid-Beveland canal	5.2E-07	74	Volkerak	1.6E-07
29	Ketelbrug Houtrib	3.6E-08	75	Waal_1	7.3E-08
30	Lek canal	1.0E-06	76	Waal_2	1.8E-07
31	Maas_1	4.5E-07	77	Waal_3	1.8E-07
33	Maas_2	3.4E-07	78	Waal_4	5.4E-08
34	Maas_3	1.1E-06	79	Waal_5	8.8E-08
35	Maas_4	4.1E-07	80	Waal_6	1.4E-07
36	Maas_5	7.3E-08	81	Waal_7	3.2E-07
37	Maas_6	6.0E-08	82	Waal_8	2.6E-07
38	Maas_7	1.6E-07	90	Willemsvaart_1	3.7E-07
39	Maas_8	7.2E-08	91	Willemsvaart_2	1.9E-07
40	Maas_9	1.4E-07	92	Willemsvaart_3	6.6E-08
32	Maas_10	2.2E-07	93	Willemsvaart_4	1.5E-07
41	Maas-Waal canal	1.7E-07	96	Zwarte Water	9.8E-08
42	Margriet canal_1	2.6E-07			

Table 5-3 Vessel damage frequency per exception kilometre [23]

No.	**Traffic section**	**Subkm**	**Severe damage [1/veskm]**
4	ARK_4	1	2.3E-06
4	ARK_4	12	2.3E-06
4	ARK_4	19	7.1E-07
4	ARK_4	20	6.3E-07
4	ARK_4	31	2.3E-06
10	Ems canal	2	1.4E-06
14	Geldersche IJssel_4	108	4.4E-06
19	Hollandsche IJssel_1	19	2.0E-05
21	IJsselmeer_1	26	1.7E-06
28	Zuid-Beveland canal	2	1.0E-06
41	Maas-Waal canal	11	6.5E-07
42	Margriet canal_1	10	1.6E-06
43	Margriet canal_2	33	1.5E-06
43	Margriet canal_2	36	1.5E-06
43	Margriet canal_2	46	1.2E-06
43	Margriet canal_2	53	1.2E-06
64	Rhine_1	9	3.5E-06
65	Rhine_2	14	2.1E-07
65	Rhine_2	17	2.1E-07
66	Rhine_3	69	2.2E-06
67	Rhine_4	93	5.2E-07
70	Twente canal_1	15	1.5E-06
70	Twente canal_1	28	1.9E-06
73	Van Starkenborgh canal	2	1.7E-06
73	Van Starkenborgh canal	7	6.8E-06

No.	Traffic section	Subkm	Severe damage [1/veskm]
75	Waal_1	7	5.0E-07
75	Waal_1	8	7.1E-07
76	Waal_2	14	5.9E-07
77	Waal_3	45	5.0E-07
77	Waal_3	48	1.4E-06
77	Waal_3	53	4.6E-07
79	Waal_5	69	6.9E-07
79	Waal_5	75	3.8E-07
79	Waal_5	77	3.8E-07
82	Waal_8	120	1.0E-06
96	Zwarte Water	19	3.7E-06

20 Appendix: Determination of individual vessel damage frequency (inland navigation only)

20.1 Introduction

The outflow frequencies, possibly followed by ignition and/or the dispersion of hazardous substance, are calculated using an events tree, see Figure 11-1, Figure 11-2 and Figure 11-3.

The start of the event tree shows an initial frequency, the frequency of an event that could lead to the consequences that are shown. The subsequent probabilities of outflow are linked to the choice of this initial event. In this way the initial frequency of the initial event <a collision in all shipping> will be higher than the initial frequency of the initial event <a collision in all shipping excluding recreational shipping>, while the subsequent probability of an outflow of a hazardous substance given the first initial event will be lower than the second.

Not all vessel damage will lead to outflow of part of the cargo tank. Paint damage, a dent in the hull, a demolished wheelhouse from colliding with a bridge are examples of sometimes severe damage, i.e. expensive damage without impact on the cargo. We are therefore seeking a sub-collection of all vessel damage.

A vessel accident with a hole in the hull and/or a hole in the cargo space is used as the initial event for a possible outflow. Vessel accidents are registered centrally in the Vessel Accident System (SOS) managed by Rijkswaterstaat [Directorate-General for Public Works and Water Management].

The number of vessels passing is important in addition to the accidents. After all, the more ships passing, the higher the probability of an accident. The traffic intensity must relate to vessels that have a potential of causing at least a hole in the hull in a collision with a vessel that is transporting a hazardous cargo. In brief: it is commercial shipping, not pleasure yachts, sailing boats, rowing boats, etc. (comparable with not taking account of motorcycles/bicycles in accident statistics for road transport). The traffic intensity of the commercial shipping is registered in IVS90, Rijkswaterstaat's information and tracking system.

Finally, the distance travelled along the waterway section is also important. After all, the longer the waterway the higher the probability of a vessel accident. The length and other waterway characteristics (width, structural works, unloading quays etc.) are registered in the Vin, the Characteristics of Waterways in the Netherlands file.

The initial frequency in the event trees is derived from these three pieces of information, the number of holes in the hull and/or in the cargo space, the number of passages of commercial vessels and the length of the waterway section: the probability of 'severe' vessel damage per vessel kilometre.

The remainder of this appendix contains a step by step description of how the data is collected and processed.

Step 1 Waterway characteristics
Inventory the characteristics of the waterway in the study area:
- Length
- Hectometre marking (distance marks)
- Width
- Navigability class
- Important origins/destination along the waterway, and possible locations at which a different frequency can apply such as junctions, structural works.

These are included in the ViN and can be obtained from the CIV Service Desk data (servicedesk- data@rws.nl). Familiarise yourself with infrastructure changes over the last 10 years. This could make the representative period for the analysis of vessel accidents shorter, e.g. a lock or bridge becoming defunct could mean a significant change in the accident profile.

Step 2 Divide the waterway into waterway sections
The waterway is divided into nautically homogeneous waterway sections or traffic sections. Nautically homogeneous means:
- A more or less constant traffic intensity and composition.
- A more or less constant width
- A more or less constant waterway profile (current, wind, side channels, crossing manoeuvres).

A division into traffic sections can be found in [23]. Nautical expertise can be used to create your own division for a specific project. This could be important at locks and outer harbours and at bridges with fixed piers in the waterway.

The following steps are carried out per traffic section.

Step 3 Vessel damage incidents
Retrieve the vessel damage incidents over the most recent period of 10 years from the SOS database through the CIV Service Desk data (servicedesk-data@rws.nl). If there are important changes in the infrastructure it may be necessary to base this on a shorter period. It concerns the vessel damage to commercial vessels in damage classes 2 to 5. The geographical location and the distance mark should be copied from the SOS database for each accident.

Step 4 Traffic intensities
Retrieve the traffic intensity for the commercial shipping (see Table 6-1) for a recent period of 10 years from IVS90 through the CIV Servicedesk data (servicedesk- data@rws.nl). If there are important changes in the infrastructure, it may be necessary to base this on a shorter period.

Table 6-1 Definition of commercial shipping

Attribute name in IVS90	Value	Vessel type group
<ste_cod>	1-49	Inland navigation
<ste_cod>	50-69	Maritime shipping

Step 5 Check deviating kilometres
The traffic section is divided into kilometre marked sections. The number of vessel damage incidents in damage classes 2 to 5 are added together. The number of vessel damage incidents for the entire traffic section is N_{tot}. Under the supposition that there are no kilometre marked sections with a different damage frequency, the probability of damage is distributed equally across the kilometre marked sections:

$$p = \frac{1}{L}$$

where:

p probability of vessel damage per km
L length in km

Now the number of damage events in a kilometre marked section can be described using a binomial distribution B(p,Ntot). With a probability of exceeding of 0.025 you can now check if a kilometre marked section is eligible for a vessel damage frequency that differs from the average.

The average number of vessel damage incidents per km is:

$$\overline{N} = \frac{N_{2t/m5}}{L}$$

where:

$\overline{N}$ Average number of accidents per km during the observation period
$N_{2\text{ to }5}$ Number of vessel damage incidents in damage classes 2 to 5 for the entire traffic section
L Length in km

In other words: we are looking for a number of vessel damage incidents for which:

- Upper limit (the marked section is exceptional with more vessel damage incidents):

$$N_{2t/m5,i} = Invbinomdist(0.975, N_{tot}, p)$$

- Lower limit (the marked section is exceptional if there are fewer vessel damage incidents):

$$N_{2t/m5,i} = Invbinomdist(0.025, N_{tot}, p)$$

where:

N_{tot}	Total number of vessel damage incidents in damage classes 2 to 5 on the traffic section.
$N_{2\ to\ 5,i}$	Total number of vessel damage incidents in classes 2 to 5 for km marked section i
p	1/L (per km)
Invbinomdist	Inverse of the cumulative binomial distribution

Step 6 Calculate the vessel damage frequencies

A. For the deviating kilometre marked sections that have been discovered:

$f_i = \frac{N_{4,5,i}}{T \cdot I}$, per veskm,

where:

$N_{4,5,i}$	Number of vessel damage incidents in damage classes 4 or 5 on the kilometre section
T	Number of years considered
I	Commercial shipping traffic intensity (/year)

The following estimate is used if $N_{4,5,i}$=0:

$f_i = \frac{0.061 \cdot N_{2t/m5,i}}{T * I}$, per veskm,

where:

0.061	The average ratio between the number of vessel damage incidents in damage classes 4 and 5 and damage classes 2 to 5 [24] over the Dutch main waterways.
$N_{2\ to\ 5,i}$	Number of vessel damage incidents in damage classes 2, 3, 4 or 5 on the kilometre section
T	Number of years considered
I	Commercial shipping traffic intensity (/year)

The following applies if $N_{2\ to\ 5,i}$ is also equal to 0:

$f_i = \frac{0.061 \cdot 0.69}{T \cdot I}$, per veskm,

where:

0.061	The average ratio between the number of vessel damage incidents in damage classes 4 and 5 and damage classes 2 to 5 [24] over the Dutch main waterways.
0.69	The estimated number of vessel damage incidents in damage classes 2 to 5. This is based on the assumption that the occurrence of vessel damage incidents through time can be described using a Poisson distribution.

The following applies when the probability of 0 vessel damage incidents occurring in the period under consideration is equal to 0.5 (no a priori information available):
$P(\underline{N}=0)=\frac{\lambda^0 e^{-\lambda}}{0!}=0.5$, where λ is the expectation value for the number of damages. From this it follows that λ=0.69.

T	Number of years considered
I	Commercial shipping traffic intensity (/year)

B. For the remaining kilometre marked sections:

$f=\frac{N_{4,5,tot}-\Sigma N_{4,5,i}}{T\cdot I\cdot(L-N_u)}$, per veskm,

where:

$\Sigma N_{4,5,i}$	The sum of all vessel damage incidents in damage classes 4 or 5 on the exception kilometres
$N_{4,5,tot}$	Total number of vessel damage incidents in damage classes 4 or 5 on the traffic section
T	Number of years considered
I	Commercial shipping traffic intensity (/year)
N_u	Number of exception kilometres
L	Length of traffic section (km)

The following estimate is used if $N_{4,5,tot}$ = 0:

$f=\frac{0.061\cdot(N_{2t/m5,tot}-\Sigma N_{2t/m5,i})}{T\cdot I\cdot(L-N_u)}$, per veskm,

where:

0.061	The average ratio between the number of vessel damage incidents in damage classes 4 and 5 and damage classes 2 to 5 [24] over the Dutch main waterways.
$\Sigma N_{2\text{ to }5,i}$	The sum of all vessel damage incidents in damage classes 2 to 5 on the exception kilometres
$N_{2\text{ to }5,tot}$	Total number of vessel damage incidents in damage classes 2 to 5 on the traffic section
T	Number of years considered
I	Commercial shipping traffic intensity (/year)
N_u	Number of exception kilometres
L	Length of traffic section (km)

The following also applies if $N_{2\text{ to }5}$=0:

$f=\frac{0.061\cdot 0.69}{T\cdot I\cdot L}$ per veskm,

where:

0.061	The average ratio between the number of vessel damage incidents in damage classes 4 and 5 and damage classes 2 to 5 [24] over the Dutch main waterways.

0.69 The estimated number of vessel damage incidents in damage classes 2 to 5. This is based on the assumption that the occurrence of vessel damage incidents through time can be described using a Poisson distribution. The following applies when the probability of 0 vessel damage incidents occurring in the period under consideration is equal to 0.5 (no a priori information available):
$P(\underline{N} = 0) = \frac{\lambda^0 e^{-\lambda}}{0!} = 0.5$, where λ is the predicted value for the number of damage incidents. From this it follows that λ=0.69
T Number of years considered
I Commercial shipping traffic intensity (/year)
L Length of traffic section (km)

Step 7 Correction for 'created' vessel damage incidents
When the estimate of the number of severe vessel damage incidents based on the numbers in classes 2 to 5 is used, due to the lack of vessel damage incidents in classes 4 and 5, the calculated vessel damage frequencies predict more severe vessel damage incidents on the traffic section than occurred in the case study period.
The calculated frequencies of all kilometre sections are then multiplied by a factor, to make sure that the predicted number of vessel damage incidents in the damage classes 4 and 5 on the traffic section in the case study period considered, comply with the actual number of incidents that occurred.

The multiplication factor is:

$$CF = \frac{N_{4,5,tot}}{\Sigma f_i \cdot T \cdot I + f \cdot T \cdot I \cdot (L - N_u)}$$

where:

$N_{4,5,tot}$ Total number of vessel damage incidents in damage classes 4 or 5 on the traffic section
$\Sigma f_i \cdot T \cdot I$ Predicted number of vessel damage incidents in classes 4 or 5 on the exception kilometres
$F \cdot T \cdot I \cdot (L - N_u)$ Predicted number of vessel damage incidents in classes 4 or 5 on the other kilometres.

6.2 Practical example

Step 1
For this example only the waterway length is significant. This is 35.19 km.

Step 2
There appear to be no nautical reasons for further dividing the waterway. This length is considered to be the traffic section.

Step 3
The following figures are shown in the SOS database.

Table 6-2 Number of vessel damage incidents per damage class

Damage class	Number of vessel damage incidents in period
2	110
3	24
4	5
5	6

Step 4
The period considered is 10 years. There have been no significant changes to the infrastructure. The traffic intensity for commercial shipping is averaged at 86,483 passages per annum over this 10-year period.

Step 5
The average number of vessel damage incidents per km is:

$$\overline{N} = \frac{N_{2t/m5}}{L} = \frac{145}{35.19} = 4.12$$

$$p = \frac{1}{L} = \frac{1}{35.19} = 0.028$$

A kilometre marked section is considered to deviate if:

$N_{2t/m5,i} = Invbinomdist(0.975{,}145{,}0.028) = 8$ or greater,

and if:

$N_{2t/m5,i} = Invbinomdist(0.025, N_{tot}, p) = 1$ or less.

This appears to be the case for the following kilometre marked sections:

Km marked section	Number of vessel damage incidents	
	Damage classes 2 to 5	Damage classes 4 and 5
1	12	2
12	11	2
19	10	0
20	9	0
31	10	2

Step 6:

Km marked section	Number of vessel damage incidents			
	Damage classes 2 to 5	Damage classes 4 and 5	Frequency /veskm	PRED 4,5
1	12	2	$f_i = \frac{N_{4,5,i}}{T \cdot I} = \frac{2}{10 \cdot 86843} = 2.3.10^{-6}$	2
12	11	2	$f_i = \frac{N_{4,5,i}}{T \cdot I} = \frac{2}{10 \cdot 86843} = 2.3.10^{-6}$	2
19	10	0	$f_i = \frac{0.061 \cdot N_{2t/m5,i}}{T * I} = \frac{0.061 \cdot 10}{10 \cdot 86843} = 7.1.10^{-7}$	0.6
20	9	0	$f_i = \frac{0.061 \cdot N_{2t/m5,i}}{T \cdot I} = \frac{0.061 \cdot 9}{10 \cdot 86843} = 6.4.10^{-7}$	0.5
31	10	2	$f_i = \frac{N_{4,5,i}}{T \cdot I} = \frac{2}{10 * 86843} = 2.3.10^{-6}$	2
Remainder	93	5	$f = \frac{N_{4,5,tot} - \Sigma N_{4,5,i}}{T \cdot I \cdot (L - N_u)} = \frac{145 - 53}{10 \cdot 86843 \cdot (35.19 - 5)} = 1.9.10^{-7}$	5
Totaal		11		12.2

Step 7:

The correction factor is:

$$CF = \frac{11}{12.2} = 0.9$$

The resulting vessel damage frequencies are:

Km marked section	Frequency /veskm
1	$f_i = 0.9 \cdot 2.3.10^{-6} = 2.1.10^{-6}$
12	$f_i = 0.9 \cdot 2.3.10^{-6} = 2.1.10^{-6}$
19	$f_i = 0.9 \cdot 7.1.10^{-7} = 6.4.10^{-7}$
20	$f_i = 0.9 \cdot 6.4.10^{-7} = 5.7.10^{-7}$
31	$f_i = 0.9 \cdot 2.3.10^{-6} = 2.1.10^{-6}$
remainder	$f = 0.9 \cdot 1.9.10^{-7} = 1.7.10^{-7}$

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