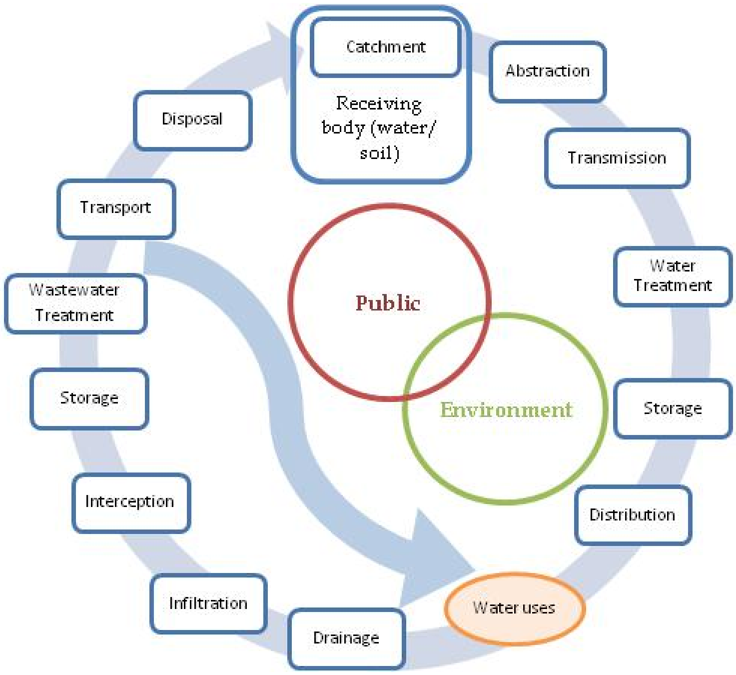
Guidance on RIDB hazard selection and use in the WCSP



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Guidance on RIDB hazard selection and use in the WCSP

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Summary

Potential effects of climate dynamics on the urban water cycle can involve the aggravation of existing conditions as well as occurrence of new hazards or risk factors. The risks associated with expected climate changes have to be dealt with by the society in general and by the water utilities and related stakeholders in particular. For this, an integrated approach for dealing with existing and expected levels of risk is required. In PREPARED Task 2.1.1 a WCSP framework was proposed for such an integrated approach. One of the steps for WCSP application is risk identification.

This document gives guidance for hazard selection and identification and corresponding events to be considered in the WCSP. Plausible hazards identified in the urban water cycle are listed and briefly presented, including information on the consequences of the exposure as well as the potential causes and relevance of specific climate change indicators or effects. Fault trees were constructed for each of the listed hazards to allow identification of potential events, risk sources, risk factors and contributing causes. These were verified together with stakeholder participants and suggestions incorporated.

Three applications (Risk Identification Data Base RIDB; Register of historical hazards; Check list to filter risk sources) developed within PREPARED, intended to facilitate risk identification, are presented.

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Acronyms

CSO	Combined sewer overflow
ENSAD	Energy-related severe accident database
ET	Event tree
ETA	Event tree analysis
FT	Fault tree
FTA	Fault tree analysis
PRA	Probabilistic risk assessment
RIDB	Risk identification database
RRDB	Risk reduction database
SSP	System safety plan
SW	Stormwater
WCSP	Water cycle safety plan
WHO	World health organization
WTP	Water treatment plant
WW	Wastewater
WWTP	Wastewater treatment plant

1 Introduction

1.1 Background

Climate dynamics trends impose important challenges to the urban water sector. Alteration of the range of operation conditions, which may result from atmosphere and sea temperature increase, variation in precipitation quantity and patterns or increase of average sea level, needs to be dealt with proactively by the different stakeholders involved in the urban water cycle.

Potential effects of climate changes on the urban water cycle involve the aggravation of existing conditions as well as occurrence of new hazards or risk factors.

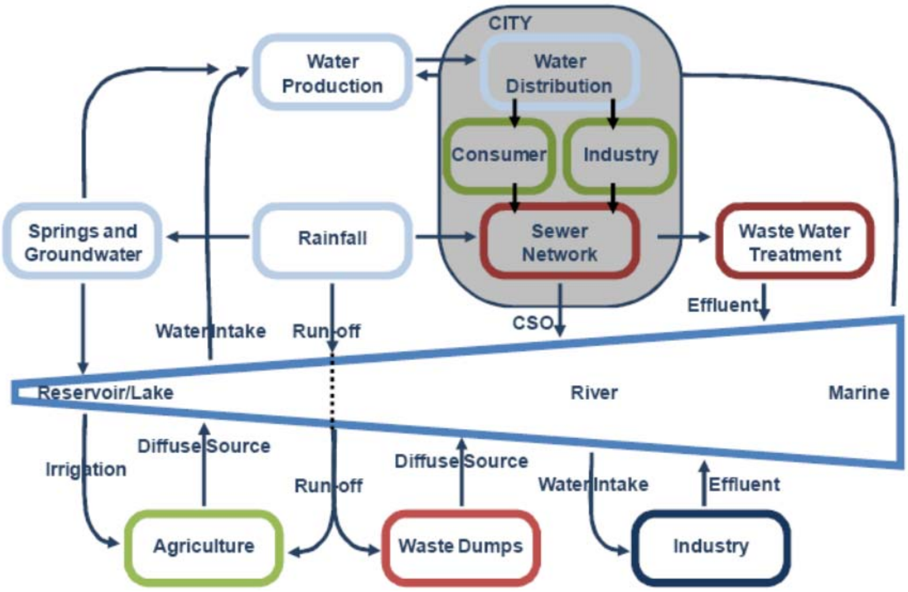

Figure 1 - Water cycle interactions and the city (Extract from PREPARED DoW)

The risks associated with expected climate changes have to be dealt with by the society in general and, in particular, by the water utilities and other stakeholders. It is recognised that these challenges require an integrated approach for dealing with existing and expected levels of risk.

Given the interactions of urban water and natural systems and the effects of climate changes affecting the entire water cycle, adaptation measures should address all water cycle components and their interactions. Therefore, a generic framework to tackle the climate change problematic has been proposed within PREPARED. Important steps of the framework include identification of risks and opportunities in terms of alternative actions.

Climate changes can not only affect probability and consequences of events that may occur in a system in the present climatic situation, but ultimately originate different events not traditionally experienced in a region. The identification of the potential events that should be considered when carrying out risk identification is a challenge to water utilities. The PREPARED risk identification database (RIDB) is intended to be a source of information to facilitate this task (Almeida *et al.*, 2011).

Within the proposed WCSP framework, two main steps deal with risk identification (Figure 2). To ensure continuity in the whole process the RIDB needs to be fully compatible with the WCSP framework. The RIDB is an essential element to support the application of the framework at the different levels. At the integrated level, the RIDB is a tool for supporting step 3. Preliminary risk identification in the water cycle; at system level, for different systems, the RIDB is a tool for supporting step 5.4. Risk identification (Almeida *et al.*, 2010).

The RIDB cannot substitute the comprehensive identification of risks for each application; however, the examples given allow the users to commence the process and draw their attention to some possibilities that should be investigated, when local conditions indicate that it is somehow likely to happen.

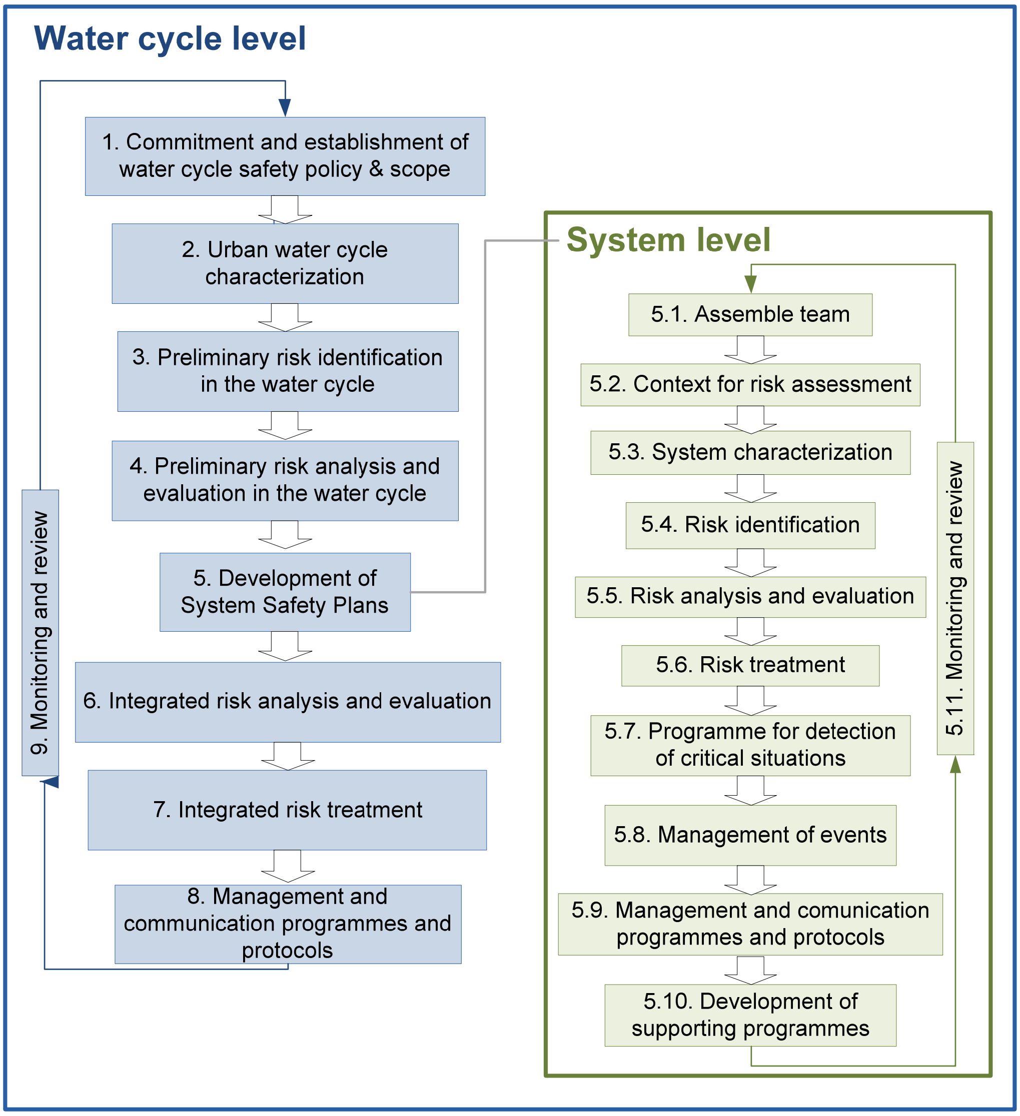

Figure 2 - WCSP framework

The events are only considered for systems in operation; accidents that might occur in other phases of the life cycle of systems and components are not included (e.g. during construction).

At both levels of analysis, WCSP key actions include identification of relevant hazards, risk sources and risk factors, assessment of the potential effect of climate change trends and exploring scenarios and potential events. The RIDB incorporates information intended to facilitate the application of these steps, especially for risk identification (Table 1).

Table 1 – Key actions considered in WCSP risk identification steps

Integrated level: Step 3.	**▸ Identify relevant hazards, risk sources and risk factors** **▸ Assess the potential effect of climate change trends** **▸ Explore scenarios and potential events**
System level: Step 5.4	▸ Identify relevant hazards, risk sources and risk factors ▸ Assess potential effect of climate change trends ▸ Explore scenarios and potential events

At the **water cycle integrated level** issues and interactions are dealt with at a macro scale. Detailed processes analysis is carried out at the **system level**. At water cycle level does not make sense to analyse in detail specific processes or component functioning. These should be dealt with at systems level.

The present report gives guidance for identification of relevant hazards and provides a way to proceed in a structured way, using some recognised approaches in the area of risk assessment and reliability. Other techniques exist that can be useful in specific cases but will not be explored within this report.

1.2 Scope of the WCSP and RIDB

Widening scope of safety plans implies consideration of multiple primary aims when looking at the water cycle. Therefore, the envisaged scope of the water cycle safety plans comprises the **protection of public health**, the **public safety** and the **protection of the environment**. Different exposure modes also need to be considered.

Aspects of water quality as well as water quantity need to be addressed. Numerous examples of interaction between quality and quantity can be given such as the potential effect of water shortages in deterioration of water quality. Insufficient water supply as well as excessive water may cause safety issues (e.g. lack of water for fire fighting, flooding).

The list of potential and relevant events for the whole water cycle can be quite large; therefore, within the scope of PREPARED, the main focus is on those events that may be somehow associated with climate changes. Nevertheless, the approach can be applied for all types of events even if not climate related by those water utilities that prefer to use a broader application.

1.3 Definitions adopted in this report

A number of definitions used in this report are defined in this section to help communication between different partners. Different terms are often used for the same purpose, or the same term is used with different meanings. Thus, the definitions presented in Table 2 are adopted within the present document and are intended to clarify the meaning as used by the authors. Definitions already presented in reports D 2.1.1 and D 2.4.1 are also considered and repeated herein as appropriate.

Table 2 – Definitions adopted in the document

Expression	Definition
consequence	Outcome of an event affecting objectives. An event can lead to a range of consequences. A consequence can be certain or uncertain and can have positive or negative effects on objectives and be expressed qualitatively or quantitatively. Initial consequences can escalate through knock-on effects.
event	Occurrence or change of a particular set of circumstances. An event can be one or more occurrences, can have several causes, can consist of something not happening. An event can be referred to as an "accident" or "incident". The latter is an event without **consequences**.
exposure	Extent to which an organization or individual is subject to an **event**.
hazard	Source of potential harm. A hazard can be a **risk source**.
hazardous event	An event which can cause harm, e.g. a situation that leads to the presence or release of a hazard (Beuken, 2008). The hazardous event is part of the **event** pathway.
risk factor	Something that can have an effect on the risk level, by changing the probability or the consequences of an event. Risk factors are often causes or causal factors that can be acted upon using risk reduction measures. Typically three main categories are considered namely human factors, environmental factors and equipment/infrastructure factors.
risk source	Element which alone or in combination has the intrinsic potential to give rise to risk. A risk source can be tangible or intangible. Risk source is where the hazardous event potentially begins.

1.4 Structure of the document

The main purpose of this report is to provide guidance on hazard selection and identification of events to be considered in the WCSP or SSP, taking into account the developments already presented in previous reports. Applications under development that can be used to deal with the task of risk identification are also briefly presented.

In this introductory chapter, the background, the scope of the WCSP and RRIB, and definitions adopted in this report have been presented.

In chapter 2, the steps for risk identification as a use case approach are presented, including a description of the climate change related hazards considered as relevant in the project and guidelines for the identification of events using fault trees.

Chapter 3 presents applications to support the development of the risk identification steps, concentrating on those developed in this project, such as the RIDB, a register of historical accidents and a check list to filter risk sources.

2 Steps for risk identification

2.1 Risk identification: use case approach

A use case approach is adopted as an exercise to identify relevant hazards and events that put at risk the fulfilment of the main aims (see Almeida *et al.*, 2010 for more detail). Questions arising include:

– What can go wrong in water supply from water source to consumers tap?
– How is public health endangered during recreational uses (also to consider exposure to reclaimed water)?
– How can safety of people be at risk?
– Which negative impacts can result in the environment?

In a first stage of risk identification, recognition of hazards for each of the main aims is necessary, and a table containing most possibilities is an important support, even if not intended as exhaustive (Section 2.2). In a second stage, for each hazard, the user should list the potential events. A second table can illustrate potential events (table with relevant sequences of occurrences). The RIDB and an historical register of events are useful checklists to support this stage.

A further development is building cause-consequence diagrams, such as fault and event trees (Section 2.3). For each event identified, potential underlying causes should also be included to show how the hazard can arise, which are the risk sources and factors based on specific tables for selecting possibilities according to local conditions; the table for risk factors should include the effect on risk of climate changes. Climate changes may affect the hazard or the individual causes that can lead to the occurrence of the hazard. Herein the selected procedure is usage of generic fault trees for each recognised hazard, from which the potential events can easily be identified. Users will need to modify the generic fault trees to adapt to each case, for example using a more detailed description. Event trees were not developed herein but users can consider its application in specific cases.

The historical register of events (having the events described as much as possible depending on available information, including risk sources, risk factors, etc.) can be very useful for the user to understand the possible developments following a triggering occurrence, especially "domino effects".

In further steps of the WCSP, namely risk analysis, the analyst can then proceed with the assessment of the likelihood (P) and consequences (C) for each event, also indicating the deviations expected from the potential climate changes. This is not within scope of this report.

2.2 Identification of hazards for WCSP framework

2.2.1 *Categories of hazards considered*

Taking into account the primary aims of the WCSP, the categories of hazards to consider are (Table 3):

– Hazards having effects in public health, for the exposure modes consumer or user of urban water systems, recreation users, and public spaces use;

– Hazards endangering public safety, for exposure modes such as consumer or user of urban water services, users of public spaces and utility workers exposure in their work environments;

– Hazards having negative impacts on environment, including receiving water bodies and soil, both for quality and impacts on ecosystems.

Table 3 – Hazards list per aim and exposure mode

Primary aim of WCSP	Exposure mode	Hazards
1. Protection of public health	Tap water: consumption (ingestion)	▪ Presence of microbial pathogens in tap water ▪ Presence of cyanotoxins in tap water ▪ Presence of chemical contaminants in tap water ▪ Presence of radiological contaminants in tap water ▪ Extended periods without supply
	Tap water: personal hygiene and other uses (skin contact, inhalation , ingestion,)	▪ Presence of microbial pathogens in tap water ▪ Presence of cyanotoxins in tap water ▪ Presence of chemical contaminants in tap water ▪ Presence of radiological contaminants in tap water
	Recreational or non-recreational: immersion (accidental ingestion, inhalation, skin contact)	▪ Presence of microbial pathogens in water bodies used for recreational activities ▪ Presence of cyanobacteria and cyanotoxins in water bodies used for recreational activities ▪ Presence of microbial pathogens in flooding water ▪ Presence of toxic chemicals in water bodies used for recreational activities
	Recreational or non-recreational: non-immersion	▪ Presence of microbial pathogens in water bodies used for recreational activities ▪ Presence of microbial pathogens in flooding water ▪ Presence of microbial pathogens in water used for irrigation
2. Public safety	Socio-economic activities: public areas or private properties (injuries)	▪ Water infrastructure collapses or bursts potentially causing injuries to public ▪ High velocity runoff in public streets ▪ High depth flooding in public areas or private properties ▪ Collapse of structures, urban equipment or trees due to effect of water ▪ Presence of toxic gases in the atmosphere of locations where public or workers might have access to ▪ Presence of toxic chemicals in locations where public or workers might have access to
3. Environment	Not detailed	▪ Discharge of organics in the water cycle or soil ▪ Discharge of nutrients (P/N) in the water cycle ▪ Discharge of heavy metals and other chemicals in the water cycle or soil ▪ Water scarcity affecting ecosystems

2.2.2 *Hazard list for protection of public health: drinking water consumers*

For the primary aim of protection of public health, in general, considering drinking water consumers exposure modes, the hazards to consider include those presented in Table 4. A general description of the consequence of the exposure as well as the potential causes and relevance of specific climate change effects are also included in this table.

A hazard to public health for drinking water consumers may be **microbiological**, **chemical** or **radiological** in nature and can cause drinking water to be unsafe. Contaminants may occur or be introduced throughout the water system, from catchment to tap. Because of their ability to cause widespread illness, pathogenic microorganisms should be taken into account in risk identification. Consequently, as drinking water supply services work to control all drinking water related risks, measures to control biological risks should not be compromised.

Controlling **microbiological** hazards may often require a balance between public health protection and chemical usage, for example in the usage of chlorine and formation of disinfection by products. Waterborne microbiological hazards include bacteria, virus and protozoa. These organisms are commonly associated with faecal wastes from humans and animals, and some can occur naturally in the environment. Pathogenic bacteria include E. coli O157, Legionella, Salmonella typhi, and Shigella. Viruses of concern include Hepatitis A and Norovirus. Protozoa of concern include Giardia and Cryptosporidium.

Chemical contaminants may occur naturally or may be added or formed during production, transport or storage of treated water. They include: toxic spills, naturally occurring minerals, heavy metals, dissolved gases (e.g. radon), pesticides, fertilizers, endocrine disruptors, personal care products and pharmaceutical residuals, cyanotoxins, flocculants, coagulants, lubricants, copper, iron, zinc and lead from pipes and fittings. Harmful chemicals at high concentrations have been associated with acute cases of waterborne diseases and can be responsible for chronic illness at lower levels of exposure.

Radiological hazards may arise from manmade or natural sources, with naturally occurring chemicals (uranium, radon, etc.) most frequently being found in groundwater. If there is the potential for the accidental release of manmade radiological substances, such as tritium or other radionuclides, these sources should also be considered.

In addition to microbiological, chemical and radiological, the hazards to public health for drinking water consumer can also be related to the unavailability of water.

Table 4 – Hazards to public health for drinking water consumers

Hazard	General description	Potential causes	Potential effect of climate change
Presence of microbial pathogens in tap water	Gastrointestinal diseases are possible (Veldhuis *et al.*, 2010)	▪ Contamination of surface water as result of on-site septic systems, solid waste disposal, land spreading of manure, feedlot runoff, municipal sewage effluent, recreational activities ▪ Contamination of groundwater caused by graveyards, intensive livestock activities, wastewater discharges, agricultural runoff, solid waste disposal ▪ Transport, storage and distribution system contamination caused by pipes cross connections, pipe break, low pressure network, intermittent supply, contamination after component repair, high retention times and inadequate maintenance practices ▪ Backflow at water use devices ▪ Poorly maintained private storage tanks	▪ Increase of precipitation ▪ Increase of temperature ▪ Increase of rainfall extremes
Presence of chemical contaminants in tap water	Harmful chemicals at high concentrations have been associated with acute cases of waterborne diseases and can be responsible for chronic illness at lower levels of exposure	▪ Contamination of surface water as a result of runoff from landfills leachate, wastewater discharges from industrial or public activities, road salt use, highway or railway accidents and spills, pesticides and herbicides runoff from agriculture ▪ Algal toxins originated at reservoir ▪ Incorrect dosing of water treatment chemicals as coagulants, flocculants, chemicals for pH correction, disinfectants ▪ Water treatments chemicals with low purity ▪ Chemicals release from system components	▪ Increase of precipitation ▪ Increase of temperature ▪ Increase of rainfall extremes
Presence of radiological contaminants in tap water	Associated with an exposure dependent risk of some cancers notably leukaemia	▪ Naturally occurring radioactive species in drinking-water sources ▪ Contamination of water from the mining industry ▪ Discharges of radionuclides from medical use ▪ Discharges of radioactive materials from industrial use and power plants	▪ Increase of rainfall extremes ▪ Increase of temperature
Extended periods without supply	Dehydration Disease due to reduced hygiene	▪ Unavailability caused by meteorological drought, overexploitation of sources, supply lower then demand, source water of low quality.	▪ Decrease of precipitation ▪ Increase of temperature

2.2.3 *Hazard list for protection of public health: recreational and other non-consumer exposure modes*

For the primary aim of protection of public health, in general, considering recreational uses and other non-consumer exposure modes, the hazards to consider include those presented in Table 5 and Table 6. A general description of the consequence of the exposure as well as the potential causes and relevance of specific climate change effects are also included.

Table 5 – Hazards to public health from recreational and other non-consumer exposure modes – Immersion activities

Hazard	General description	Potential causes	Potential effect of climate change
Presence of microbial pathogens (bacteria, virus, protozoa) in water bodies used for immersion activities	Respiratory (ear, nose, and throat), skin and gastrointestinal illnesses are commonly associated with recreational bathing in contaminated fresh and oceanic waters (Patz el al., 2008; Hea and Heb, 2008; Ashbolt et al., 2010; Semenza e Menne, 2009).	▪ Stormwater discharges ▪ Discharges of untreated wastewater, e.g. CSO ▪ Exfiltration from sewers ▪ Contaminated discharges from water systems	▪ Increase of rainfall extremes ▪ Increase of temperature
Presence of cyanobacteria and cyano toxins in water bodies used for immersion activities	High numbers of cyanobacteria can cause eye, ear or skin irritation (due to dermal contact and absorption through the skin) and gastrointestinal problems (due to ingestion of water) to water users. Some species of cyanobacteria can also produce toxins that cause nerve or liver problems, allergic reactions (e.g., asthma, eye irritation, and skin rashes) and gastrointestinal problems due to exposure through ingestion, skin contact or inhalation of aerosolized sprays from the water. (WHO, 2003; NHMRC, 2008)	▪ Accumulation of nutrients from discharges of urban wastewater systems contribute to toxic algal blooms	▪ Increase of temperature
Presence of toxic chemicals in water bodies used for immersion activities	High concentrations of certain chemicals may be toxic or irritating to skin or mucous membrane from water users. Exposure routes are direct skin contact and absorption (the most frequent), inhalation of sprays and ingestion. (WHO, 2003; NHMRC, 2008)	▪ Untreated wastewater discharges from industry to public sewer systems ▪ Untreated wastewater discharges from urban systems, e.g. CSO ▪ Accidental spillage of toxic chemicals at components of the water systems where hazardous quantities of chemicals are stored and used	▪ Increase of rainfall extremes
Presence of microbial pathogens (bacteria, virus, protozoa) in flooding water	Pathways similar to immersion activities but resulting from accidental exposure, including swimming or submersion if people are dragged by water. Respiratory and gastrointestinal illnesses are possible (Veldhuis et al., 2010).	▪ Flood from combined sewer systems ▪ Flood from domestic wastewater systems ▪ Flood from stormwater systems contaminated with sewage ▪ Floods from river contaminated with pathogens affecting urban areas	▪ Increase of rainfall (especially intense events) ▪ Increase of temperature

Table 6 – Hazards to public health from recreational and other non-consumer exposure modes – non-immersion activities

Hazard	General description	Potential causes	Potential effect of climate change
Presence of microbial pathogens in water bodies used for non-immersion recreational activities	Pathways similar to immersion activities but resulting from accidental exposure through splashing. Respiratory and gastrointestinal illnesses are possible (Veldhuis et al., 2010).	▪ Stormwater discharges ▪ Discharges of untreated wastewater, e.g. CSO ▪ Exfiltration from sewers ▪ Contaminated discharges from water systems	▪ Increase of rainfall extremes ▪ Increase of temperature
Presence of microbial pathogens (bacteria, virus, protozoa, helminths) in water used for irrigation	A variety of infectious diseases (e.g., gastrointestinal) are associated with water reuse; main exposure modes are inhalation of wastewater aerosols and skin contact with the wastewater.	▪ Insufficient treatment of the water to be reused	▪ Increase of temperature
Presence of microbial pathogens (bacteria, virus, protozoa) in flooding water	Pathways similar to immersion activities but resulting from accidental exposure through splashing while traversing flooded areas. Ear, nose, and throat; respiratory and gastrointestinal illnesses are possible (Veldhuis et al., 2010).	▪ Flood from combined sewer systems ▪ Flood from domestic wastewater systems ▪ Flood from stormwater systems contaminated with sewage ▪ Floods from river contaminated with pathogens affecting urban areas	▪ Increase of rainfall (especially intense events) ▪ Increase of temperature

Herein only hazards deriving or in any way related with the urban water systems are considered; other natural or man-generated hazards are not included.

These hazards were identified considering the following types of exposure in specific situations or uses:

- **Immersion activities** – the user is in direct contact with the water by immersion. This contact may be intentional or accidental. During the contact, the exposure varies with the extent of immersion (full, partial) and contact time (continuous, non-continuous). Considering the components of the water cycle, the immersion can occur in source waters (catchment areas) or receiving waters of any type of discharge from urban water system components (WTP, WWTP, sewers, flushing of water system components). Immersion activities can be further typified in three groups:
  - **Recreational uses with full immersion** (e.g. bathing, diving, surf, swimming) – recreational activities where the user is **fully** immersed for a **continuous** period of time;
  - **Recreational uses with partial immersion** – recreational activities where the user is in direct contact with the water and the pursuit

involves being **regularly**, **partly or fully** immersed in water (e.g. kitesurfing, paddling, windsurfing);

  - **Accidental immersion** – accidental immersion (full or partial) might occur during flooding with sewage contaminated water (Veldhuis *et al.*, 2010).

- **On-water, non-immersion recreational activities** – the user is on a water body and in direct contact with the water but **immersion is not an intended part** of the pursuit (e.g. sailing, canoeing, kayaking);
- **Other activities where sporadic contact with water** might occur – recreational or other activities where the user might accidentally be in contact with water. These activities include:
  - Amenity activities and environmental activities – includes coastal watching or bird watching, fishing with a rod, as well as a variety of conservation and environmental activities related to waters, water sides and wildlife;
  - Leisure or other activities where contact with treated wastewater might occur – activities in public or private areas using treated water for irrigation or for other uses;
  - Activities where contact with water might occur during flooding; contact may occur by splashing.

For these three types of exposure modes (immersion activities, on-water, non-immersion recreational activities, other activities with sporadic contact with water), considering the potential causes and the options to reduce risk, is not essential to quantify or acknowledge a specific organism or substance for reducing the risk in general. Thus, it might not be essential to use detailed lists of pathogens or chemical substances as for tap water. When treatment is an option, then specific removals are relevant for each case. The type and time of exposure to a specific hazard are relevant to the probability and to the consequence of the potential event.

2.2.4 *Hazard list for public safety*

For the primary aim of public safety, hazards to consider are those that result from exposure during activities in urban areas (public or private) and that derive or are related with the urban water systems. Table 7 presents some examples of these hazards. A general description of the consequence of the exposure as well as the potential causes and relevance of specific climate change effects are also included.

Table 7 – Hazards to public safety

Hazard	General description	Potential causes	Potential effect of climate change
Water infrastructure collapses or bursts potentially causing injuries to public	Degradation of underground water infrastructure components can result in structural failure. Often the failure results in ground subsidence or in accidental jets of water that can cause injuries to public.	▪ Poor infrastructural condition	▪ Increase of rainfall and temperature when relevant for the acceleration of deterioration processes
High velocity runoff in public streets	Surface flow in public areas reaching high velocity has potential to drag people and cause injuries.	▪ Flooding of public areas either from sewer systems or from natural systems	▪ Increase of rainfall (especially intense events)
High depth flooding in public areas or private properties	Accumulation of deep water in public or private areas has potential for drowning.	▪ Depressions in public areas without adequate drainage or entrance of water to properties (e.g. basements)	▪ Increase of rainfall (especially intense events)
Collapse of structures, urban equipment or trees due to effect of water	Accumulation of water, poor drainage or erosion can cause the collapse of structures (e.g. walls), urban equipment or trees.	▪ Blockage or inappropriate drainage, erosion of supporting soil due to water motion	▪ Increase of rainfall (especially intense events)
Presence of toxic gases in the atmosphere of locations where public or workers might have access to	The general public and the utility workers may be exposed through skin contact, eye contact or inhalation. Effects of this exposure depend on the specific gas and include skin, eye, nose and respiratory system irritation or burn, headache, nausea, convulsions, inability to breathe, extremely rapid unconsciousness, coma and death (www.osha.org).	▪ Release of stored gases (e.g. chlorine, ozone, chlorine dioxide) ▪ Release of gases produced by biochemical processes in wastewater (e.g. hydrogen sulphide) in open or confined spaces (e.g. sewers, pumping stations, WWTP)	▪ Increase of air and water temperature when relevant for the acceleration of biochemical processes ▪ Increase of rainfall and storms that may cause structural damage
Presence of toxic chemicals in locations where public or workers might have access to	The general public and the utility workers may be exposed to toxic chemicals (liquids or solids) through skin contact, eye contact, inhalation or ingestion. Exposure effects depend on the specific chemical and include skin burns, blisters, eye redness and burns, abdominal pain, liver damage, burns in mouth and throat, irritation to the respiratory tract, nausea and vomiting, shock or collapse. (www.cdc.gov/niosh/)	▪ Spillage/leakage during transport, handling or storage of chemicals (e.g. sodium hydroxide, sulfuric acid, aluminium sulphate, potassium permanganate, polyacrylamides)	▪ Increase of rainfall and storms that may cause structural damage

These hazards were identified considering the following types of exposure in specific situations:

- **Socio-economic activities in public areas** – public involved in activities (e.g. walking in the street, driving a car) in urban public spaces might be injured as consequence of, for instance, collapses/bursts in urban water systems infrastructure or flooding originating from these systems. If public spaces are located nearby treatment facilities or other components of the water system where chemicals are stored or used (e.g. chlorination stations in drinking water systems, oxidation facilities with hydrogen peroxide in wastewater systems, storage tanks during cleaning and disinfection practices), people within those properties might be affected by accidental spillages of liquid and solid chemicals and by the release of toxic gases to the atmosphere. Chemical spillages are, in general, more easily contained than toxic gases release and, thus, have consequences at a local scale. Exposure might occur by skin contact, eye contact, inhalation or ingestion. Release of toxic gases and subsequent transport in the atmosphere may have consequences both at local and regional level. Exposure might occur by skin contact, eye contact or inhalation.

- **Socio-economic activities in private properties** – people in private properties (e.g. businesses, households) can be injured, for instance, during a flooding event originating in urban water systems. If properties are located nearby treatment facilities or other components of the water systems where chemicals are stored or used, people might be affected by chemical spillages and toxic gases release, as explained above.

Consequences of chemicals spillage/release and options to reduce associated risk depend on the specific chemical. The type of exposure (route and concentration of the chemical) and the time of exposure to a specific chemical are relevant to the probability and to the consequence of the potential event. Thus, in order to reduce risk associated with activities in areas located nearby treatment facilities or other components of the water system where chemicals are stored or used, it may be necessary, in each case, to identify/list all chemicals or, at least, groups of chemicals (e.g. acids) that might be a hazard.

2.2.5 *Hazard list for protection of environment*

For the primary aim of protection of the environment the hazards to consider include those presented in Table 8. The hazards in this category are confined to those related to the urban water systems and foreseen climate changes. The scope does not include e.g. hazards such as industrial discharges or pollution derived from agriculture. These may be relevant to the urban water cycle but as risk sources or risk factors for other hazard categories. The same reasoning is applied to sea level rise which will affect the salinity of the ground and the ground water through extended salt water intrusion. Projected sea level rise and excessive groundwater extraction in coastal areas combine to increase the risk of salinity problems in ground water and in the ground (Hetzel, 2008). This is a potential risk source or risk factor for water utilities, especially in abstraction areas.

The hazards to the environment considered are grouped in three groups, namely associated with heavy metals and other harmful chemicals, organics and nutrients which in excessive amounts impact negatively in the environment.

Table 8 – Hazards to environment

Hazard	General description	Potential causes	Potential effect of climate change
Discharge of organics in the water cycle or soil	The discharge of organic matter to receiving waters can cause oxygen depletion that can result in consequences for the stream biota, and alter the characteristics of river bed, rendering it an unsuitable habitat (Lenntech, 2010).	▪ Discharges of untreated wastewater, e.g. CSO or separate storm sewers ▪ Exfiltration from sewers ▪ Untreated wastewater discharges from industry to public sewer systems ▪ Failure in wastewater treatment plant ▪ Overflow from septic systems	▪ Increase of temperature ▪ Increase of precipitation, annual amount, frequency or intensity ▪ Sea level rise
Discharge of nutrients (P/N) in the water cycle	Discharge of flows having high load of nutrients can result in significant water quality problems including harmful algal blooms, hypoxia and declines in wildlife and wildlife habitat (EPA, 2010).	▪ Discharges of untreated wastewater, e.g. CSO or separate storm sewers ▪ Exfiltration from sewers ▪ Industrial water discharges to sewers ▪ Failure in wastewater treatment plant ▪ Overflow from septic systems	▪ Increase of temperature ▪ Increase of precipitation, annual amount, frequency or intensity ▪ Sea level rise
Discharge of heavy metals and other chemicals in the water cycle or soil	Wastewater or spillage from water systems components containing high loads of heavy metals or high loads/concentrations of other chemicals which are harmful to the environment	▪ Discharges of untreated wastewater, e.g. CSO ▪ Exfiltration from sewers ▪ Stormwater runoff from traffic areas with high contents of metals or other toxic chemicals ▪ Untreated wastewater discharges from industry to public sewer systems ▪ Failure in wastewater treatment plant ▪ Spillage/leakage during transport, handling or storage of chemicals	▪ Increase of precipitation, annual amount, frequency or intensity ▪ Sea level rise
Water scarcity affecting ecosystems	Reduction of water available to ecosystems due to excessive abstraction of water from surface or ground water, potentially aggravated by meteorological drought or regional water scarcity	▪ Drought ▪ Increasing water abstraction from surface or groundwater (e.g new developments demand) ▪ Discharges in water bodies causing deterioration of water quality	▪ Increase of air and water temperature ▪ Decrease of precipitation, annual amount, frequency or intensity ▪ Decrease of river flows

Discharge of **heavy metals** to the environment will eventually accumulate in the food chain of people and animals. At lower concentration of dissolved metals in natural water, even smaller alterations in aquatic environment may critically influence the stability of the ecosystem: metals are immobile in soils, thus accumulate in the top soil and endanger crops and vegetables. Besides plants, other items in the food chain may get contaminated (Athar and Vohora, 1995). **Other chemicals** in toxic quantities also have negative impacts in ecosystems (fauna and flora), for instance resulting from discharges of untreated wastewater.

Organic pollution occurs when large quantities of organic compounds, which act as substrates for microorganisms, are released into watercourses. During the decomposition process the dissolved oxygen in the receiving water may be used up by bacteria at a higher rate than it can be replenished, causing oxygen depletion and having severe consequences for the stream biota. Organic effluents also frequently contain large quantities of suspended solids which reduce the light available to photosynthetic organisms and, on settling out, alter the characteristics of the river bed, rendering it an unsuitable habitat for many invertebrates (Lenntech, 2010).

Water bodies require **nutrients**, such as nitrogen and phosphorus, to be healthy, but high nutrient load can be harmful. Excess levels of nitrogen and phosphorus in water bodies can lead to significant water quality problems including harmful algal blooms, hypoxia and declines in wildlife and wildlife habitat. Algal blooms can produce "dead zones" in water bodies where dissolved oxygen levels are so low that most aquatic life cannot survive. This condition in water bodies is referred to as hypoxia (EPA, 2010).

Discharge of pathogens in the water cycle was not considered as a hazard because, within the concentration range in which pathogens are present in urban wastewater, the effects in the environment are not relevant in the scope of WCSP.

Water scarcity affecting ecosystems can result from reduction of water available to ecosystems due to excessive abstraction of water from surface or ground water, potentially aggravated by meteorological drought or regional water scarcity. New developments causing severe increase of water consumption can be a relevant cause. Discharges in water bodies that cause deterioration of water quality will also lead to a decrease of available water to support ecosystems.

2.3 Identification of events using fault trees

2.3.1 *Procedure to identify events*

Identification of events can be a complicated task. Multiple causes and pathways can lead to many different events, each then escalating with different consequences. A systematic procedure to identify the events is recommended to facilitate risk analysis.

An event can be seen as a combination of fault and event trees. The graphical composition of the two trees is sometimes called a ‘bow-tie’ diagram (Figure 3).

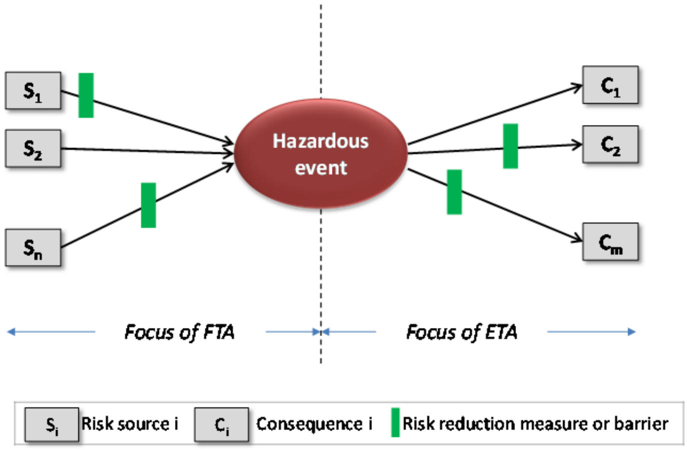

Figure 3 – Bow-tie diagram (adapted from ISO 31010:2009)

Fault trees (FT) can be used to identify the possible ways by which a hazardous event may arise, while the event trees (ET) allow exploring the possible consequences following that hazardous event. Either can be applied qualitatively or, if data are available, quantitatively, the later allowing determination of the likelihood of different events. In annex 1 an explanation of how to develop these trees is given. Both trees can be used to identify and evaluate the effect of existing or potential control measures on risk levels.

Herein, generic fault trees for the WCSP hazards are developed and presented in the next section and in annex 2. Event trees are not developed since they correspond to developments following the appearance of the hazard or hazardous event, and are strongly case dependent.

The process selected to systematically identify the events included in the RIDB results from the identification of the fault or cut sets for each tree. The consequence part is not developed in detail, since it is out of the scope of the project and case dependent are referred to above. The resulting events are included in the RIDB.

2.3.2 *Generic fault trees for WCSP hazards*

In order to facilitate the task of identification of events either at integrated or system level, for each identified hazard, as included in Table 3, a fault tree was constructed. These qualitative fault trees are generic thus the basic events can be more detailed for each specific application. Figure 4 to Figure 8 present examples of simplified versions of the trees (annex 1 explains fault trees' symbols and gives guidelines for FT analysis). These simplified trees are a first systematization and the corresponding complete trees are included in annex 2. Not all possible occurrences (faults, risk factors, risk sources, etc.) are incorporated and often a number of causes are aggregated.

Fault trees consider only aspects related to the urban water systems and, thus, occurrences (faults, risk factors, risk sources, etc.) not relevant from this point of view were not included.

Although adaptation to climate change has been the primary driver for the development of a risk-based framework for the whole water cycle aiming at support decision making by water utilities, the WCSP framework was developed to be applicable to other risks as well. Thus, to assist WCSP application to those risks, it was decided to include in the fault trees other pathways that might be not directly related to climate change.

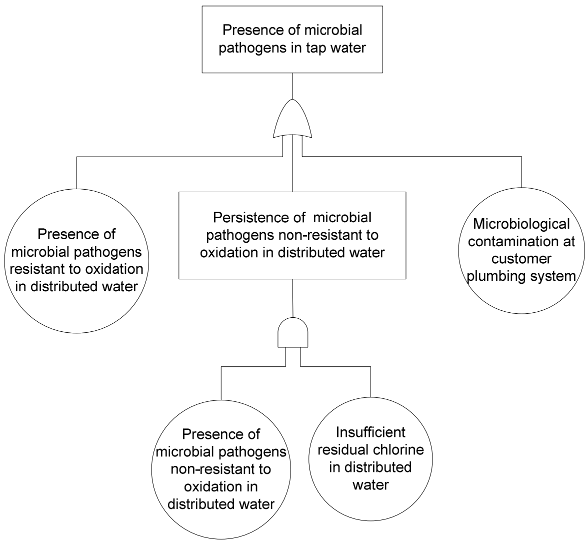

Figure 4 – Simplified fault tree for the hazard 'Presence of microbial pathogens in tap water'

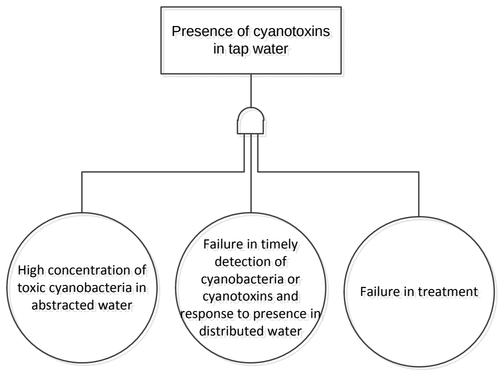

Figure 5 – Simplified fault tree for the hazard 'Presence of cyanotoxins in tap water'

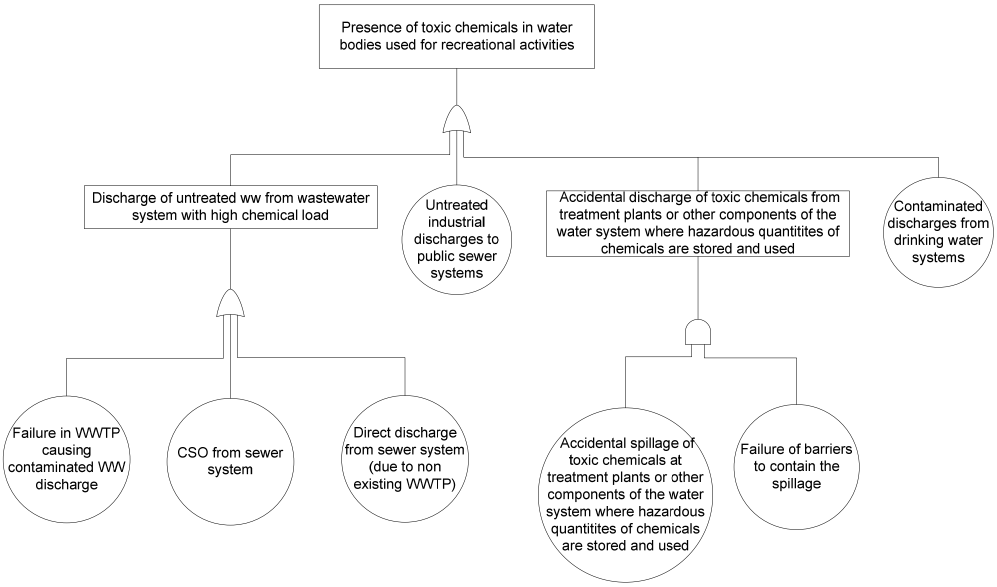

Figure 6 – Simplified fault tree for the hazard 'Presence of toxic chemicals in water bodies used for recreational activities'

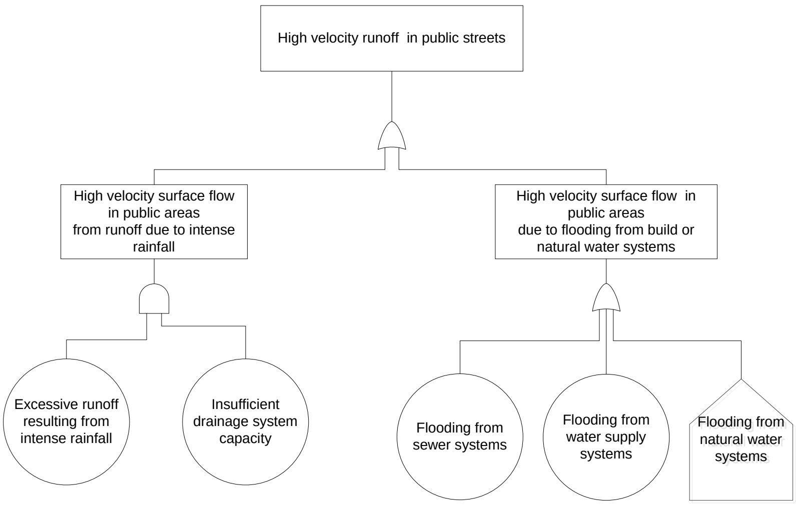

Figure 7 – Simplified fault tree for the hazard 'High velocity runoff in public streets'

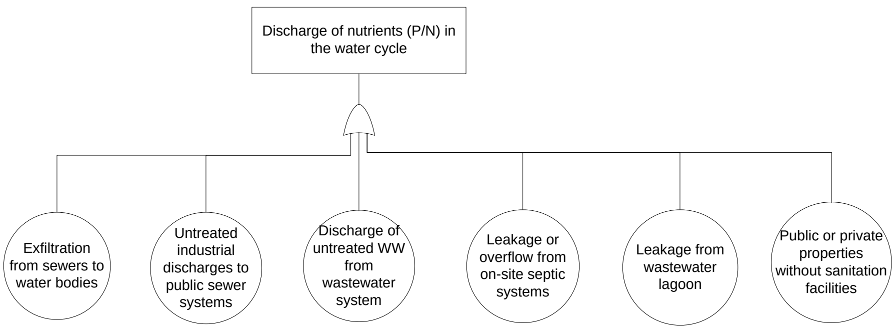

Figure 8 – Simplified fault tree for the hazard 'Discharge of nutrients (P/N) in the water cycle'

3 Applications to support risk identification

3.1 Applications

Within PREPARED three main applications were developed to support risk identification: the risk identification database (RIDB), the register of historical events and the checklist to filter risk sources. In the following sections a brief description of these applications is provided.

3.2 Risk identification database (RIDB)

The PREPARED risk identification database (RIDB) is intended to be a source of information to facilitate the task of identifying potential events relevant for risk analysis. The RIDB is an essential element to support the application of the framework at the different levels. At the integrated level, the RIDB is a tool for supporting step 3 (see Figure 2). Preliminary risk identification in the water cycle; at system level, the RIDB is a tool for supporting step 5.4. Risk identification (Almeida *et al.*, 2010).

The RIDB cannot substitute the comprehensive identification of risks for each application; however, the examples given allow the users to commence the process and draw their attention to some possibilities that should be investigated, when local conditions indicate that it is somehow likely to happen. Furthermore, events considered in the database are not necessarily realistic for each application and others might exist that are not included.

The events are only considered for systems in operation; accidents that might occur in other phases of the life cycle of systems and components are not included (e.g. during construction).

Almeida *et al*. (2011) provides an overview of the RIDB, by providing background information, identifying information requirements for the RIDB and proposing a database structure as well as the structure for a register for historical accidents.

3.3 Proposed register of historical accidents

Sources of information for the risk identification step include data on past events in similar systems. Therefore, one alternative for identifying the events is a register of historical accidents related to the water cycle systems as defined in the project.

Similar databases exist for other areas. For instance, the comprehensive energy-related severe accident database (ENSAD) proves to be a good example of such a structure of data, in this case limited to the class of events with higher consequence (Burgherr and Hirschberg, 2008).

Database structure to compile list of events or accidents includes the detailed description and the fields used in RIDB. Additional information includes local information.

To avoid populating the register with larger number of events having low levels of consequences associated, only consequence classes of 3, 4 and 5 are to be considered, independent of the consequence dimension (See Almeida *et al*., 2010).

The results are the contents of the database, a dynamic application that will be completed with new information available. During the PREPARED project the register is filled with the contributions from the different partners and with examples from the literature (e.g . Walkerton, Canada; Bergen, Norway).

3.4 Proposed check list to filter risk sources associated to selected hazards

The RIDB is completed by an inspirational check list to guide the water utility in identifying "what can go wrong" in the system managed by proposing examples of hazards and risk sources for different systems and sub-systems.

Annex 3 includes print screens of the checklist developed in Microsoft Access. Examples of use of the check list in order to obtain a list of risk sources related to different hazards are also shown (Figure A 28 and Figure A 29).

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Annex 1 ▸ Guidelines for building fault trees and event trees

Introduction

An important and not straightforward step in the risk assessment process is to identify events and their possible paths. Each risk event has its causes, and identifying and understanding the causes will help in estimating the risk. The risk source, causes, hazardous event and consequences are parts of each event path. When event paths are well understood and information is available, the probability of an event can be calculated from the combined probabilities of the event processes. Generally, complex relationships can be broken down into a chain of relations and individual processes, which finally leads to the investigated set of events associated with each hazard.

Fault trees provide a means to schematise the ways a hazardous event can occur. Event trees provide a way of identifying consequences that can potentially arise once a hazardous event occurs. Both methods allow identifying interactions, causes and risk factors. These trees can be used for qualitative or quantitative analysis.

The combination of simplified fault and event trees, in the form of bow tie diagrams, can be helpful in identifying the existence or absence of barriers to block the development of the events. These trees are built using symbols that are also called events. Thus, events from risk point of view are composed in a tree by paths that are a combination of individual event symbols having standard names and meanings, e.g. basic event, as it is described later in this annex.

Fault trees use a deductive approach as they are constructed by defining TOP events and then use backward logic to define causes. An event tree is a graphical representation of the logic model that identifies and quantifies the possible outcomes following an initiating event. Event tree analysis provides an inductive approach to reliability assessment as they are constructed using forward logic. Event tree analysis and fault tree analysis are, however, closely linked. The logical processes employed to evaluate event tree sequences and quantify the consequences are the same as those used in fault tree analyses.

In this annex a short description of the techniques "fault tree analysis" and “event tree analysis” is given. The information provided on how to build a tree, data needed to perform a quantitative analysis and on how to use the trees is mainly based on Rausand and Høyland (2004).

Fault tree analysis

Fault tree analysis (FTA) is a top-down approach to failure analysis, starting with a potential undesirable occurrence (hazardous event) called a TOP event, and then determining the ways it can happen. The analysis proceeds by determining how the TOP event can be caused by individual or combined lower level failures. The causes of the TOP event are “connected” through logic gates.

FTA can be used in qualitative or quantitative risk analysis, depending on the objectives of the analysis. The difference is that the qualitative fault tree can be looser in structure and does not require use of the same rigorous logic as the formal fault tree.

The tree-based method is mainly used to find cut sets[1] leading to the hazardous events. However, a fault tree is a static picture of the combinations of failures and events which can cause the TOP event to occur.

The application of this method requires the definition of the primary events used in FTA and the use of the appropriate logic symbols as described in this annex.

Building and analysing a fault tree

The analysis of a system by the fault tree technique is normally carried out in four steps:
1) Definition of the problem and of the boundary conditions.
2) Construction of the fault tree.
3) Identification of minimal cut sets.
4) Evaluation of the FT: qualitative or quantitative analysis of the fault tree.

Definition of the problem and of the boundary conditions

The activity consists of:
- Definition of the hazardous event (the TOP event) to be analysed.
- Definition of the boundary conditions for the analysis.

It is very important that the TOP event is given a clear and unambiguous definition. If not, the analysis will often be of limited value. The description of the TOP event should answer the questions: what, where and when. The fault trees included in annex 2 do not include the “when” since it is case dependent.

Construction of the fault tree

The fault tree construction always starts with the TOP event. Thereafter, carefully identification of all fault events which are the immediate, necessary and sufficient causes that result in the TOP event should be carried out. These causes are connected to the TOP event via logic gates. It is important that the first level of causes under the TOP event is developed in a structured way. This first level is often referred to as the TOP structure of the fault tree. Then construction of the tree proceeds, level by level, until all fault events have been developed to the required level of resolution. The analysis is deductive and is carried out by repeatedly asking "What are the reasons for ..... ?"

[1] A cut set is a combination of fault events which can result in a critical failure.

To identify the top event the user can get inspired by the past events, using some typical general methods like:

- Explore historical records (own and others);
- Look at risk sources;
- Develop “what–if” scenarios,
- Use “checklists”.

Identification of minimal cut sets

A fault tree provides valuable information about possible combinations of fault events which can result in a critical failure (TOP event) of the system. Such a combination of fault events is called a **cut set**. A cut set in a fault tree is a set of basic events whose (simultaneous) occurrence ensures that the TOP event occurs. A cut set is said to be minimal if the set cannot be reduced without losing its status as a cut set. The cut sets can be used to define the relevant risk events in the risk identification.

Evaluation of the fault tree

The evaluation can include both a qualitative and quantitative evaluation, depending on determination or not of the probabilities associated with the tree and individual events.

The nature of the basic events and the number of basic events in the combined sets give important information about the top event occurrence. Cut sets are usually sorted by cut set order (the number of events in a cut set) to provide information on the combinations of basic events that can result in the top event.

The quantitative evaluation produces not only the probability of the top event but also the dominant cut sets that contribute to the top event probability, as well as quantitative importance of each basic event contributing to the top event. Cut sets in this case are sorted by probability, and low probability cut sets are truncated from the analysis.

Different quantitative importance is determined for different applications. Sensitivity studies and uncertainty evaluations provide further key information.

The **qualitative evaluation** of a fault tree may be carried out on the basis of the minimal cut sets. The importance of a cut set depends obviously on the number of basic events in the cut set. The number of different basic events in a minimal cut set is called the order of the cut set. A cut set of order one is usually more critical than a cut set of order two, or higher. When we have a cut set with only one basic event, the TOP event will occur as soon as this basic event occurs. When a cut set has two basic events, both of these have to occur at the same time to cause the TOP event to occur.

The **quantitative evaluation** of a fault tree consists of the determination of top event probabilities and basic event importance. Uncertainties in any quantified result can also be determined. In a quantitative analysis, the reliability of a fault tree is in the interval of the reliability obtained from the reliability diagram considering the fault sets and the reliability obtained from the reliability diagram considering the minimum sets.

The cut sets can then be sorted by probability. In addition to the identification of dominant cut sets, importance of the events in a fault tree are some of the most useful information that can be obtained from a fault tree quantification. Quantified importance allows actions and resources to be prioritized according to the importance of the events causing the top event. The importance of the basic events, the intermediate events, and the minimal cut sets can be determined. Different importance measures can be calculated for different applications. One measure is the contribution of each event to the top event probability. Another is the decrease in the top event probability if the event were prevented from occurring. A third measure is the increase in the top event probability if the event were assured to occur. These importance measures are used in prioritization, prevention activities, upgrade activities, and in maintenance and repair activities.

When a quantitative analysis of a fault tree is carried out the analyst must collect the required and reliable data. Data provides the information to compute the probability of each basic event and, consequently, the probability for the TOP event to occur in a given period of time through the calculations made by the software in use.

Symbols and logic gates

The basic symbols used in the construction of fault trees are grouped as events, gates, and transfer symbols.

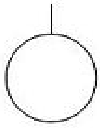
Event symbols are used for basic events, intermediate events and TOP events. Basic events are not further developed on the fault tree. Intermediate and TOP events are found at higher levels and at output of a gate, respectively.

The **basic events** of a fault tree are those events which, for one reason or another, have not been further developed. These are the events for which probabilities will have to be provided if the fault tree is to be used for computing the probability of the TOP event. There are four types of basic events. These are presented in Table A 1.

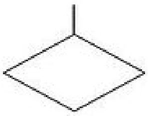
Table A 2 presents the symbols for representing **intermediate events** and **TOP events**. An intermediate event symbol can be used immediately above a basic event to provide more room to type the event description.

Gate symbols describe the relationship between input and output events. The symbols are derived from Boolean logic symbols and are presented in Table A 3

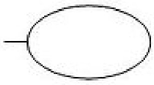
Table A 1 – Symbols for basic events



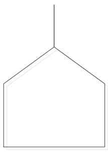
Initiating event - The circle describes a basic initiating fault event that requires no further development. In other words, the circle signifies that the appropriate limit of resolution has been reached.



Undeveloped events - The diamond describes a specific fault event that is not further developed, either because the event is of insufficient consequence or because information relevant to the event is unavailable.

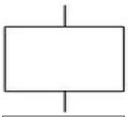


Conditioning event - The ellipse is used to record any conditions or restrictions that apply to any logic gate. It is used primarily with the *INHIBIT* and *PRIORITY AND*-gates

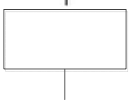


External event – The house is used to represent an event that is normally expected to occur. This event is not, by itself, a fault.

Table A 2 – Symbols for intermediate events and TOP events



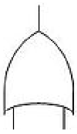
Intermediate event



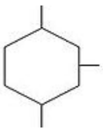
TOP event

Table A 3 – Gate symbols

AND gate - the output occurs only if all inputs occur (inputs are independent)



OR-gate - the output occurs if any input occurs



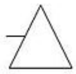
Inhibit gate - the output occurs if the input occurs under an enabling condition specified by a conditioning event

Priority AND gate - the output occurs if the inputs occur in a specific sequence specified by a conditioning event

Exclusive OR gate - the output occurs if exactly one input occurs

Transfer symbols are used to connect the inputs and outputs of related fault trees. The triangles are introduced as transfer symbols and are used as a matter of convenience to avoid extensive duplication in a fault tree or to allow a large tree to be represented on a number or smaller trees for clarity. A "transfer in" gate will link to its corresponding "transfer out." This "transfer out," usually on another sheet of paper, will contain a further portion of the tree (Table A 4).

Table A 4 – Transfer symbols

	**Transfer - IN**
	**Transfer - OUT**

The use of the FTA

The TOP event contributors have different level of importance in terms of effect on the probability of the TOP event to happen. The FTA allows computing the importance of each event:

- Each basic event in the fault tree can be prioritized for its importance to the top event;
- Different importance measures are obtained for different applications;
- Basic events generally are ordered by orders of magnitude in their importance;
- In addition to each basic event, every intermediate event in the fault tree can be prioritized for its importance.

The results of FTA can be used to reduce the probability of the TOP event to happen. After having performed the FTA, the user can play with different scenarios to check ways to test the TOP event probability with the goal to reduce it. The system can be first tested to evaluate the effects on system availability simulating directly the effects of changes on the fault tree built for the system, or actions can be directly performed on the system based on FTA results.

Using the tree, scenarios can be checked in the following:

- Inspect tree — find or operate on major contributors to the total probability of failure
- Add redundancy;
- Reinforce maintenance;
- Examine or alter system architecture;
- Evaluate cut set importance and rank;
- Evaluate item importance and rank;
- Identify items amenable to improvement.

Acting in practice, the user can reduce the TOP event probability in the following ways:

- Reinforce maintenance;
- Derate components (increase robustness/reduce probability of happening for contributing factors);

- Relocate existing components;
- Add redundancy;
- Suppress common causes;
- Reduce stresses (Service stresses or environmental stresses).

Software for Fault Tree Analysis

A number of software applications exist for FTA and new applications are continually being developed. Some applications provide the capability to draw and quantify fault tree models, while others provide an integrated set of Probabilistic Risk Assessment PRA tools that include the capability to draw and solve FTs.

Event tree analysis

This is a complementary technique to FTA where definition of the progression after the hazardous event. Event trees are used to investigate the possible outcomes in order to find ways of reducing losses. A hazardous event may lead to many different consequences. The potential consequences may be illustrated by a consequence spectrum (Figure A 1).

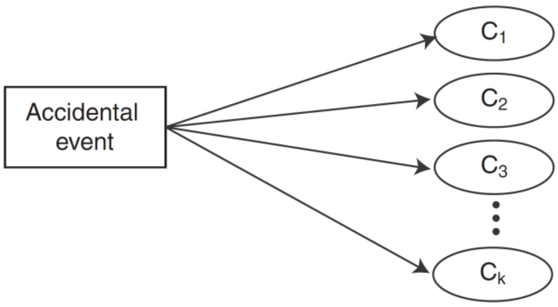


Figure A 1 – Consequence spectrum of an event

Most well designed systems have one or more barriers that are implemented to stop or reduce the consequences of potential events. The probability that an event will lead to unwanted consequences will therefore depend on whether these barriers are functioning or not.

An event tree analysis (ETA) is an inductive procedure that shows all possible outcomes resulting from an (initiating) event, taking into account whether installed safety barriers are functioning or not, and additional events and factors. By studying all relevant events that have been identified in risk identification, the ETA can be used to identify all potential scenarios and sequences in a complex system. Design and procedural weaknesses can be identified, and probabilities of the various outcomes from an event can be determined as shown in Figure A 2.

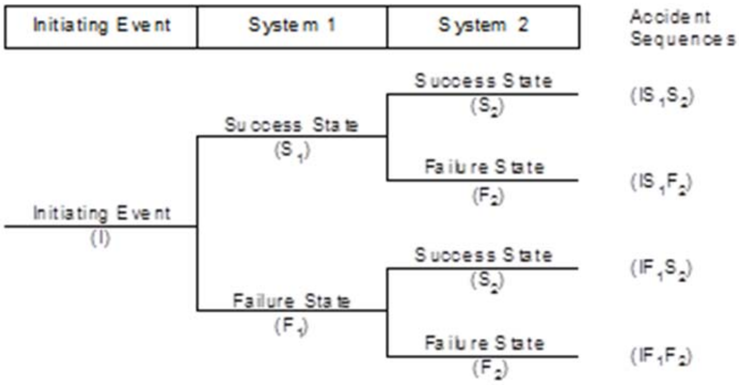


Figure A 2 – Example of ET from IEC 60300-3-9 (Rausand and Høyland, 2004)

Event tree construction

The main steps for building an event tree are:

1. Identification (and definition) of relevant (initiating) hazardous event that may give rise to unwanted consequences;

   When defining an event, we should answer the following questions: What type of event is it? Where does the event take place? When does the event occur?

   For each accidental event we should identify: the potential event progression(s); system dependencies; conditional system responses.

2. Identification of the barriers that are designed to deal with the event;

   The barriers that are relevant for a specific accidental event should be listed in the sequence they will be activated.

3. Construction of the event tree;

4. Description of the (potential) resulting sequences;

   Each barrier should be described by a (negative) statement, e.g., "Barrier X does not function" (This means that barrier X is not able to perform its required function(s) when the specified accidental event occurs in the specified context).

   Additional events and factors should also be described by (worst case) statements (Figure A 3).

5. Calculation of the probabilities/frequencies for the identified consequences (outcomes);

6. Compilation and presentation of the results from the analysis.

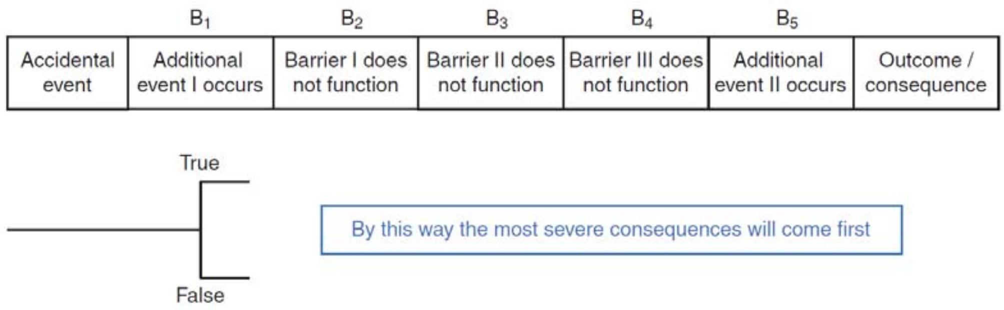


Figure A 3 – Event sequence creation

In practice, many event trees are ended before the "final" consequences are reached. Including these "final" consequences may give very large event trees that are impractical for visualization. This is solved by establishing a consequence distribution for each end event and the probability of each consequence is determined for each end event. In effect, this is an extension of the event tree, but it gives a more elegant and simpler presentation and also eases the summary of the end results (Figure A 4)

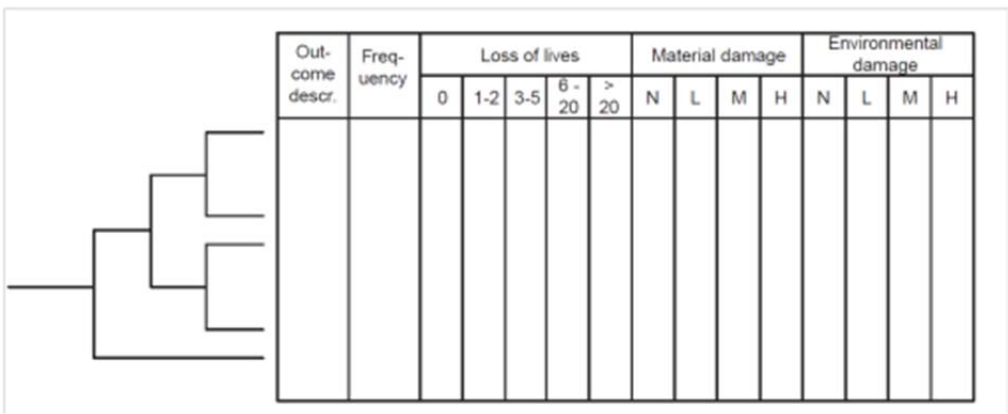


Figure A 4 – ET summary of results (Rausand and Høyland, 2004)

Annex 2 ▸ Fault trees for WCSP hazards

General

In this annex a list of generic fault trees corresponding to the identified hazards in Table 3 are presented. The fault trees are divided according to the WCSP aims and exposure modes, namely:

- Hazards to public health from tap water;
- Hazards to public health from recreational and other non-consumer exposure modes;
- Hazards to public safety;
- Hazards to environment.

As climate changes may aggravate existing problems, in each FT, basic events that may be influenced by climate changes are highlighted in red.

Hazards to public health from tap water

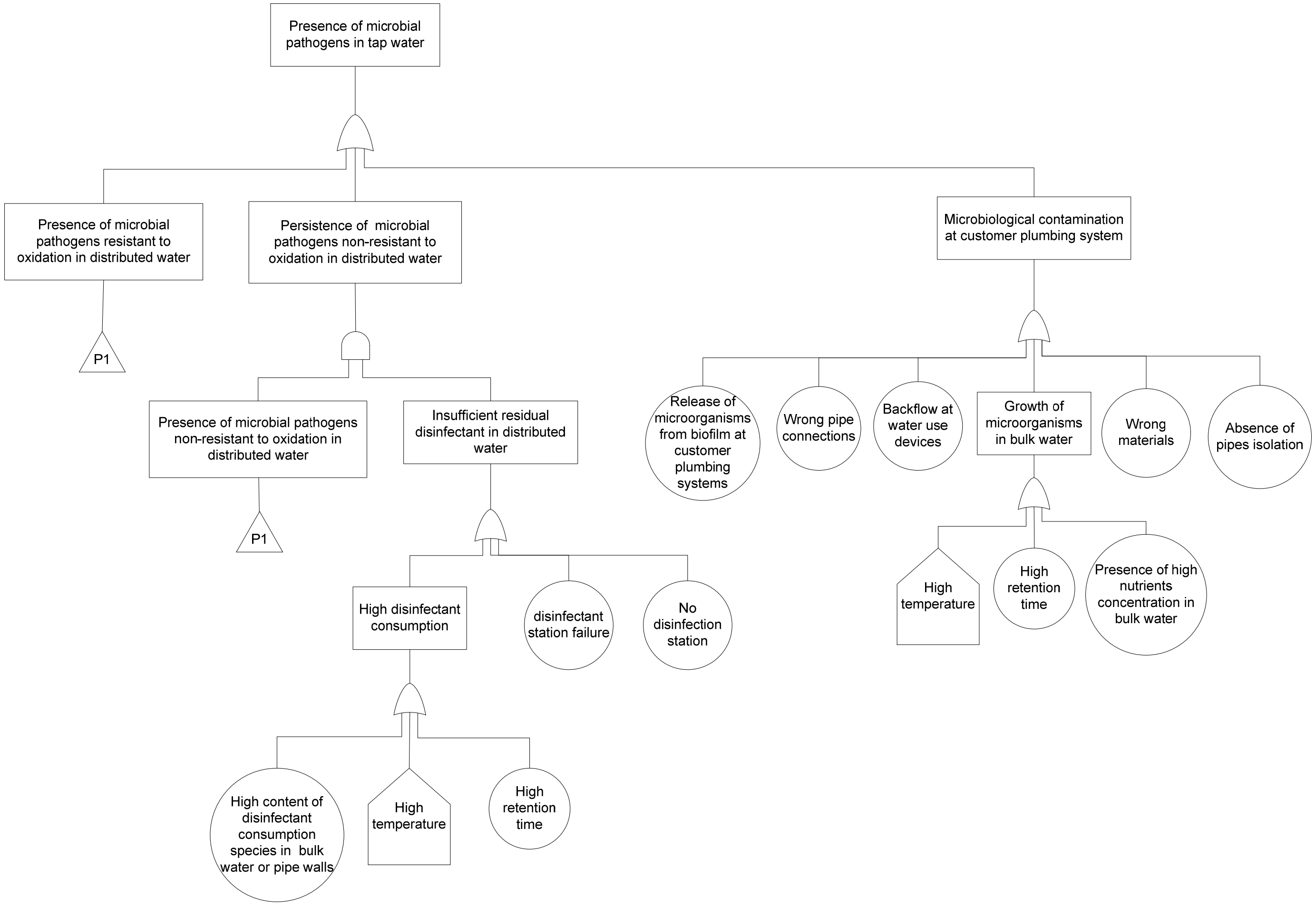


Figure A 5 – Fault tree for the hazard 'Presence of microbial pathogens in tap water'

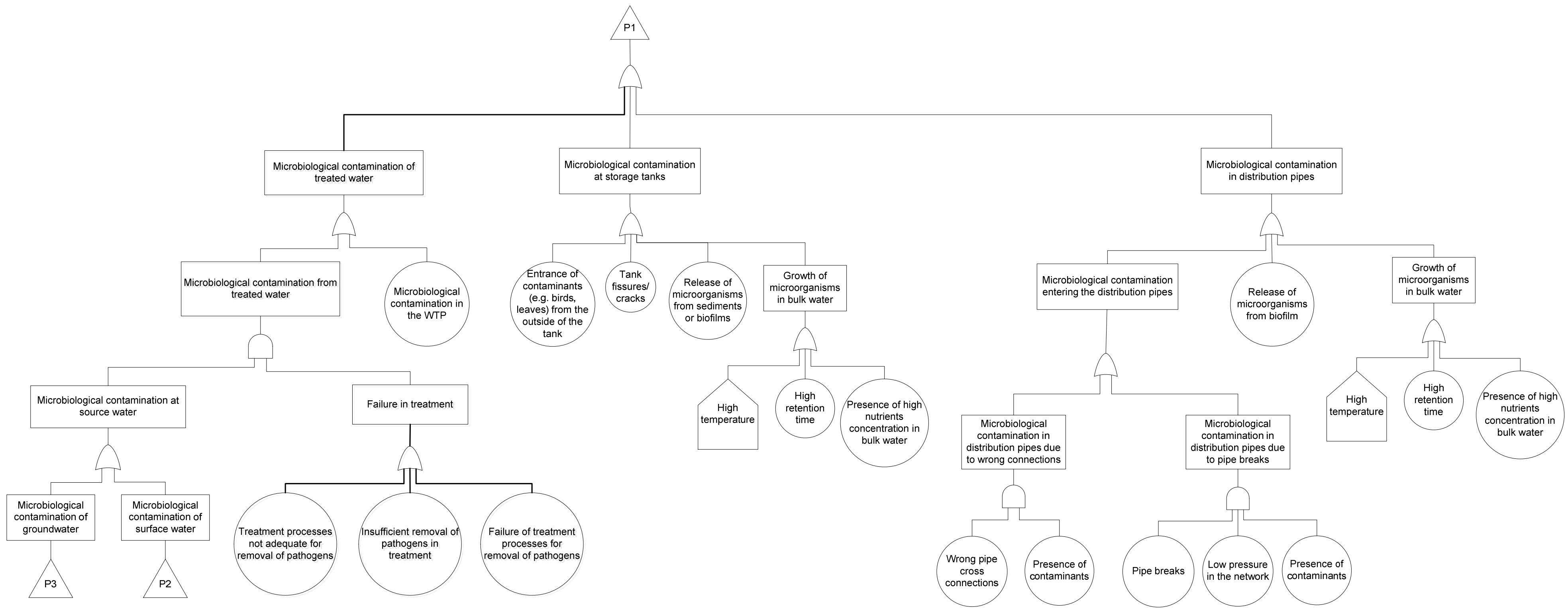
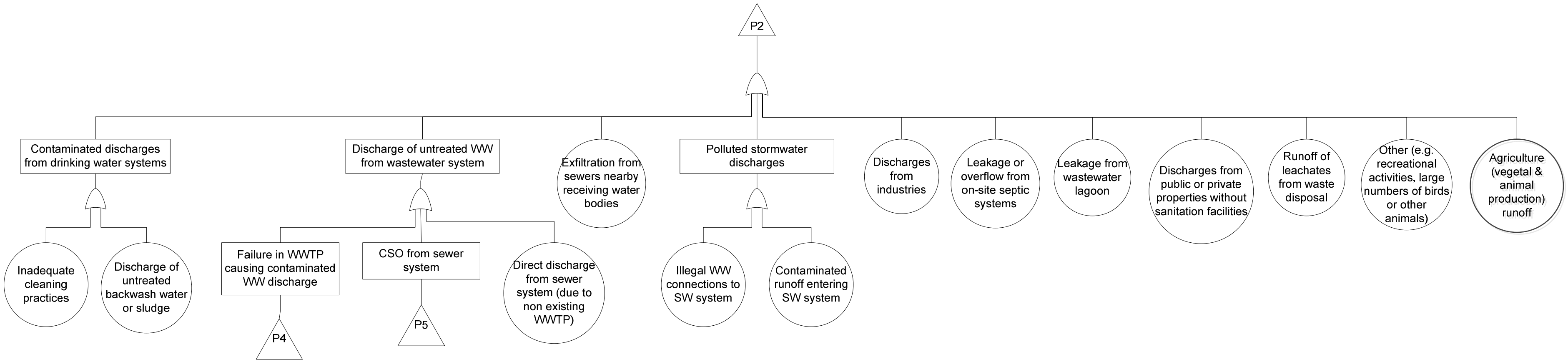


Figure A 5 (cont.) – Fault tree for the hazard 'Presence of microbial pathogens in tap water'



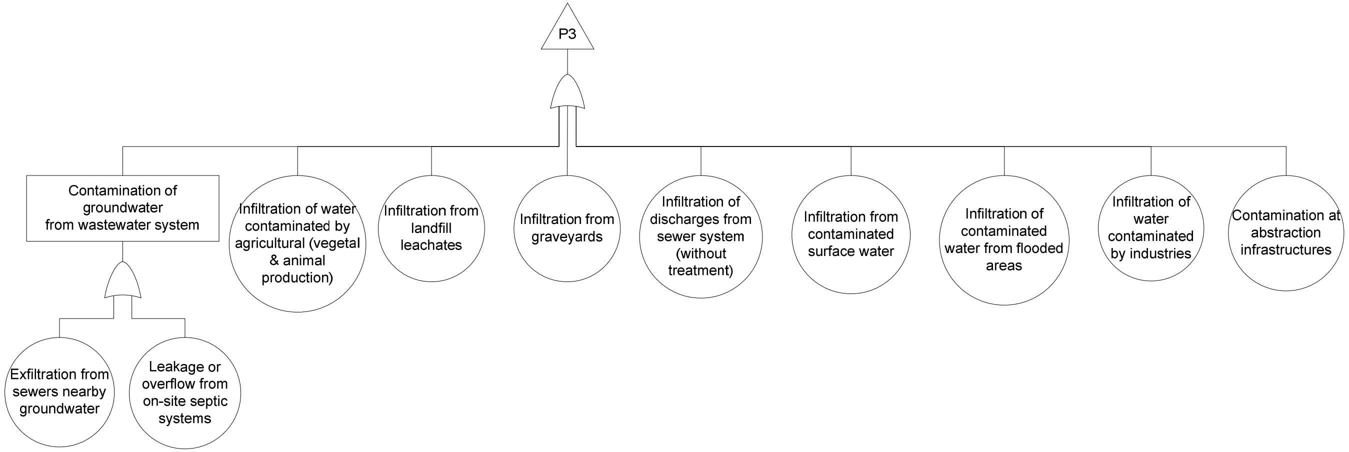


Figure A 5 (cont.) – Fault tree for the hazard 'Presence of microbial pathogens in tap water'

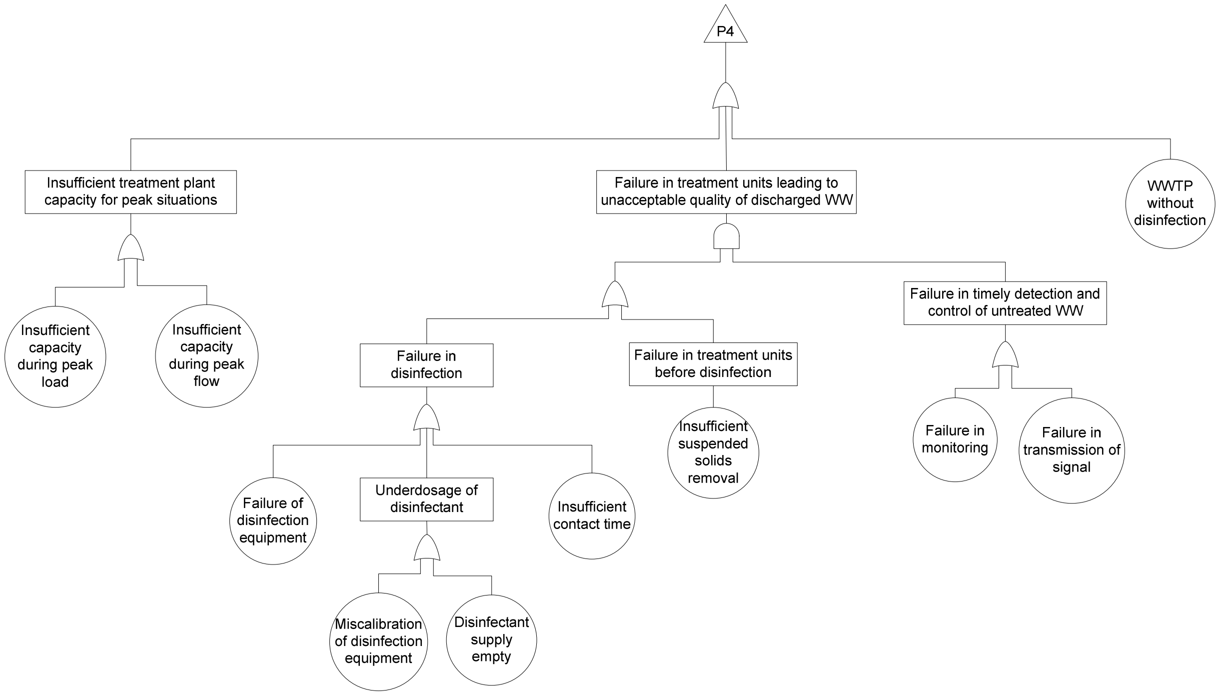


Figure A 5 (cont.) – Fault tree for the hazard 'Presence of microbial pathogens in tap water'

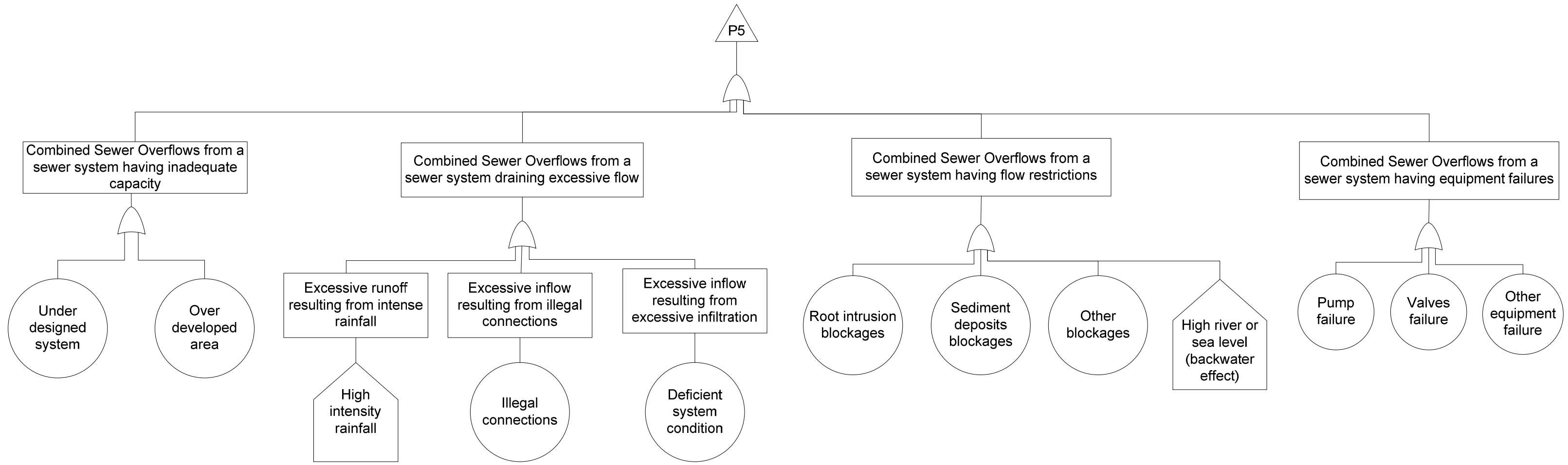


Figure A 5 (cont.) – Fault tree for the hazard 'Presence of microbial pathogens in tap water'

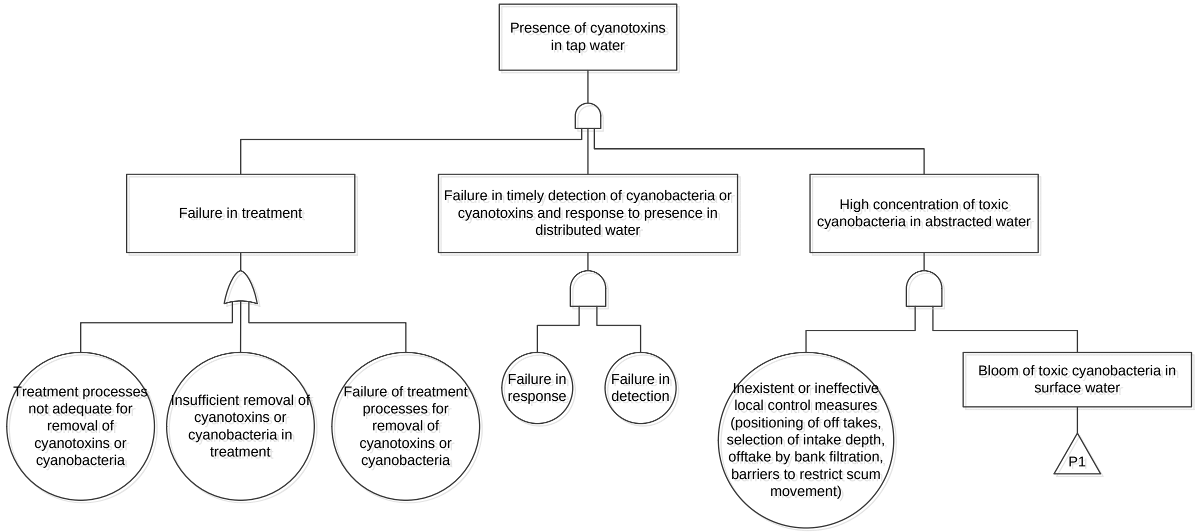


Figure A 6 – Fault tree for the hazard 'Presence of cyanotoxins in tap water'

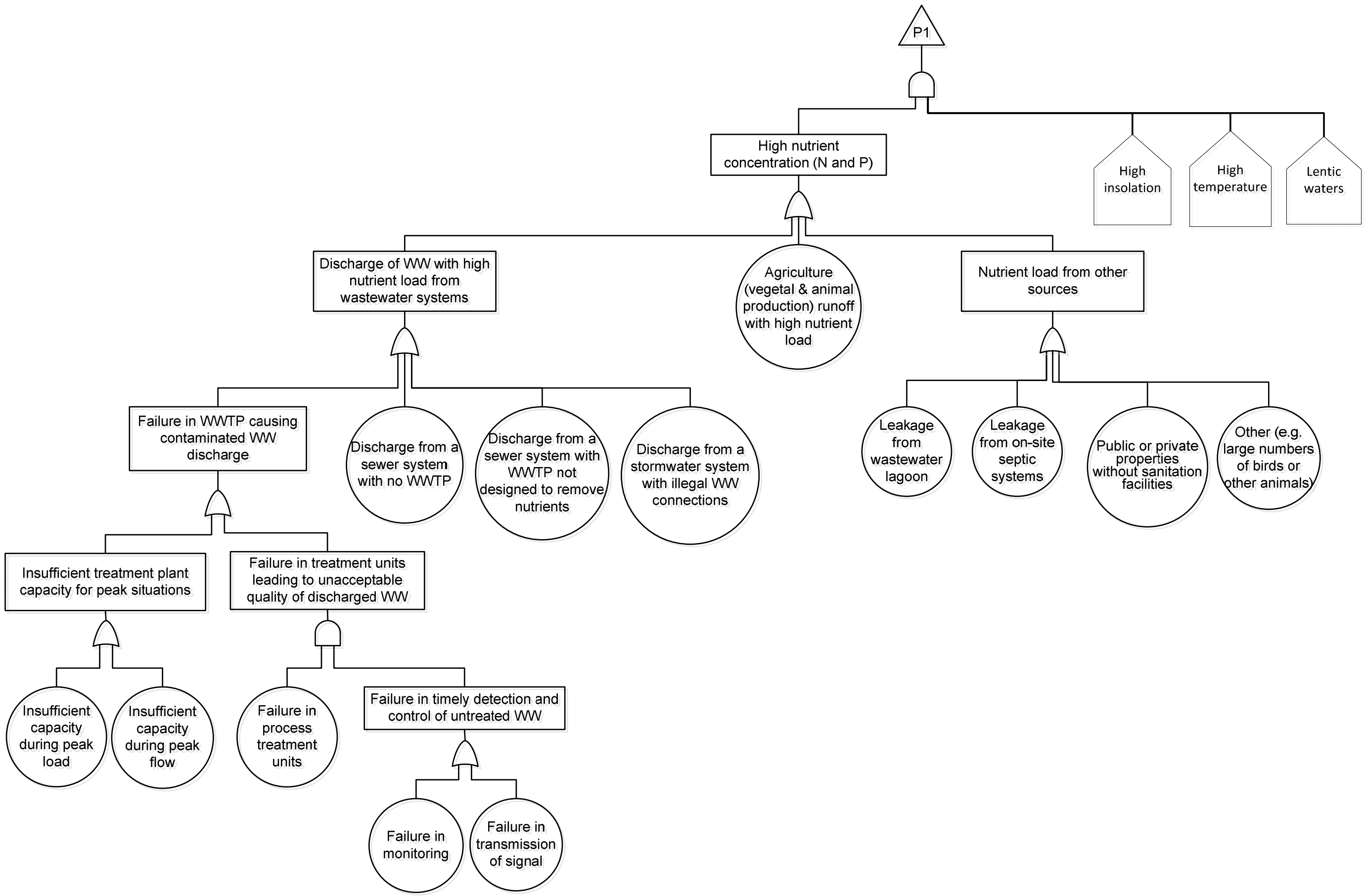


Figure A 6 (cont.) – Fault tree for the hazard 'Presence of cyanotoxins in tap water'

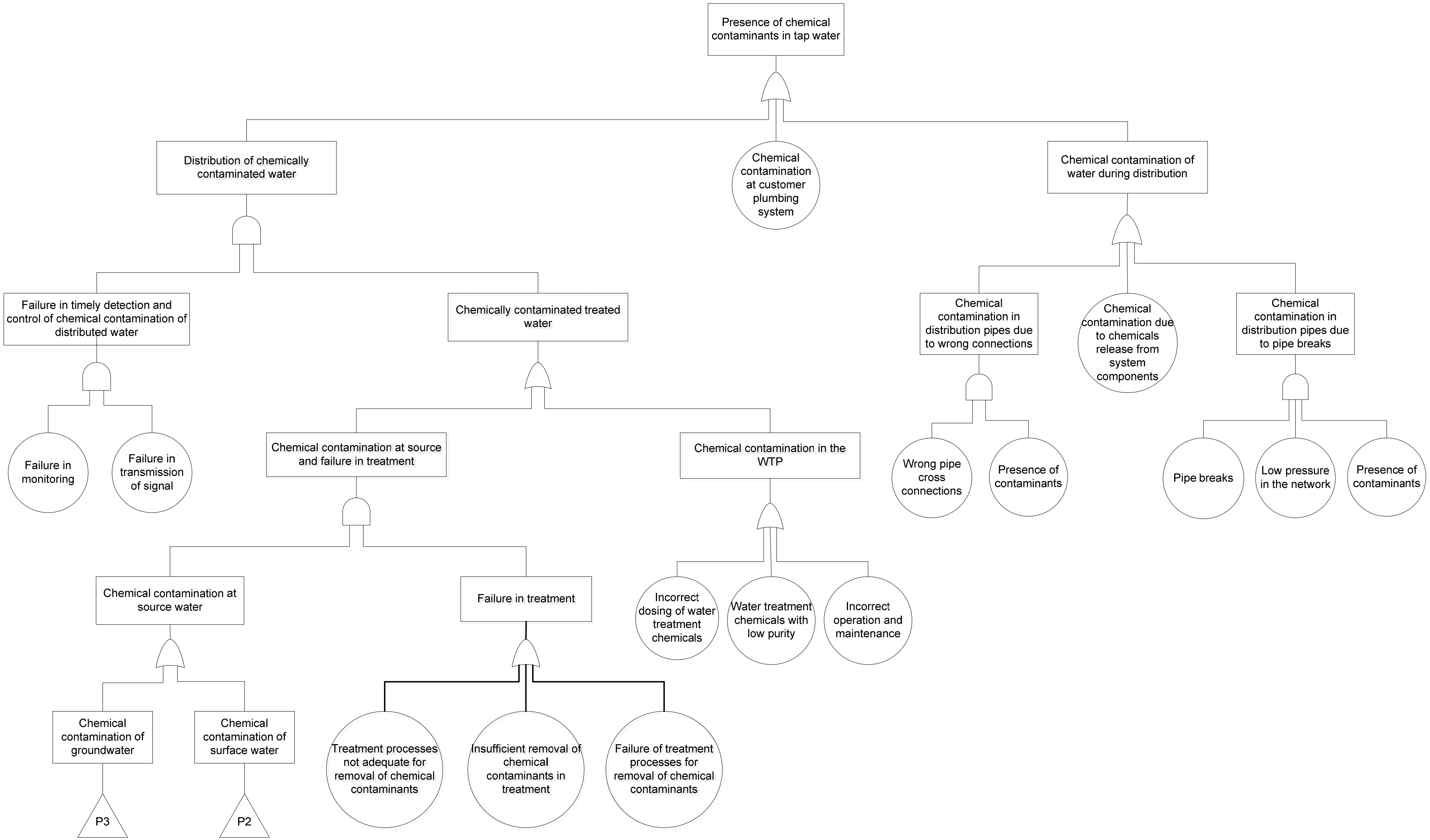
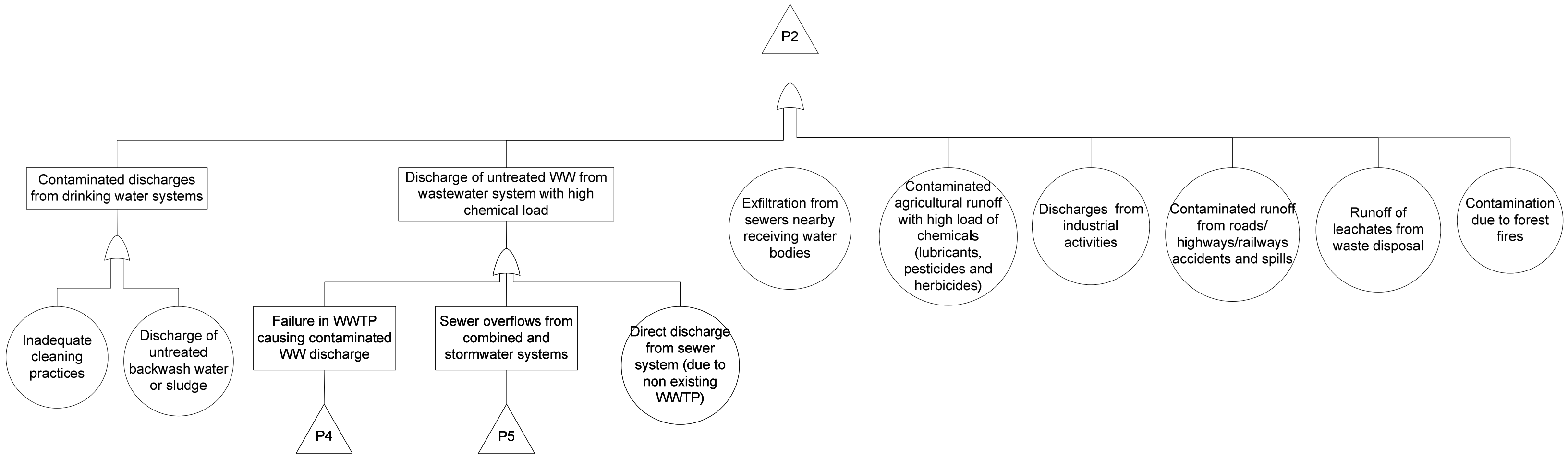


Figure A 7 – Fault tree for the hazard 'Presence of chemical contaminants in tap water'



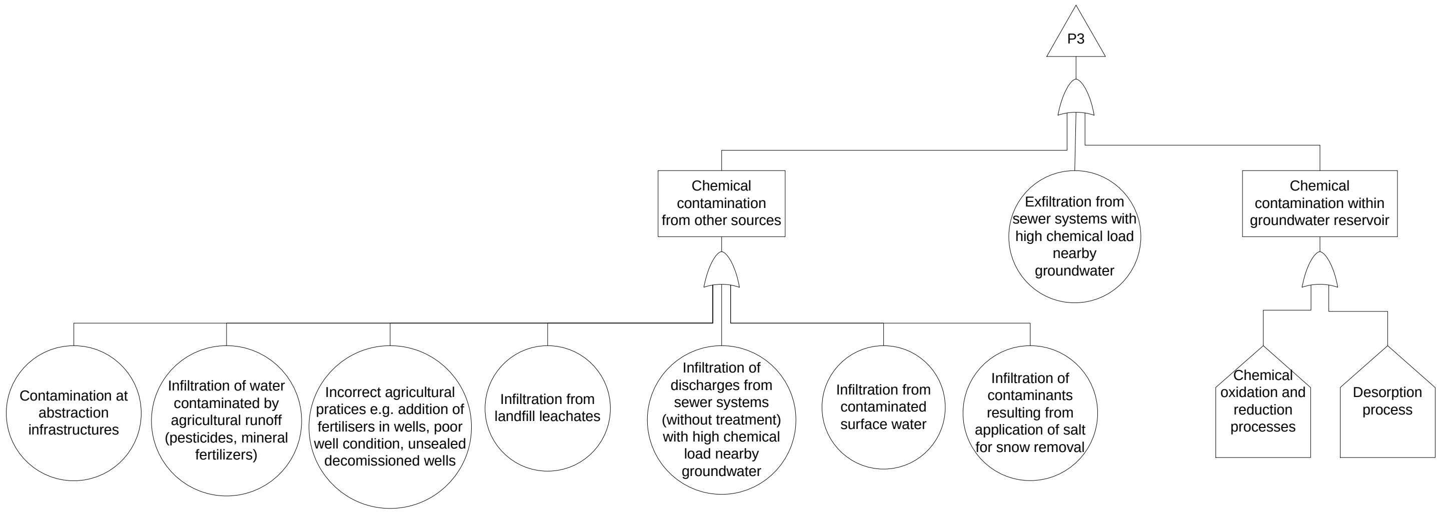


Figure A 7 (cont.) – Fault tree for the hazard 'Presence of chemical contaminants in tap water'

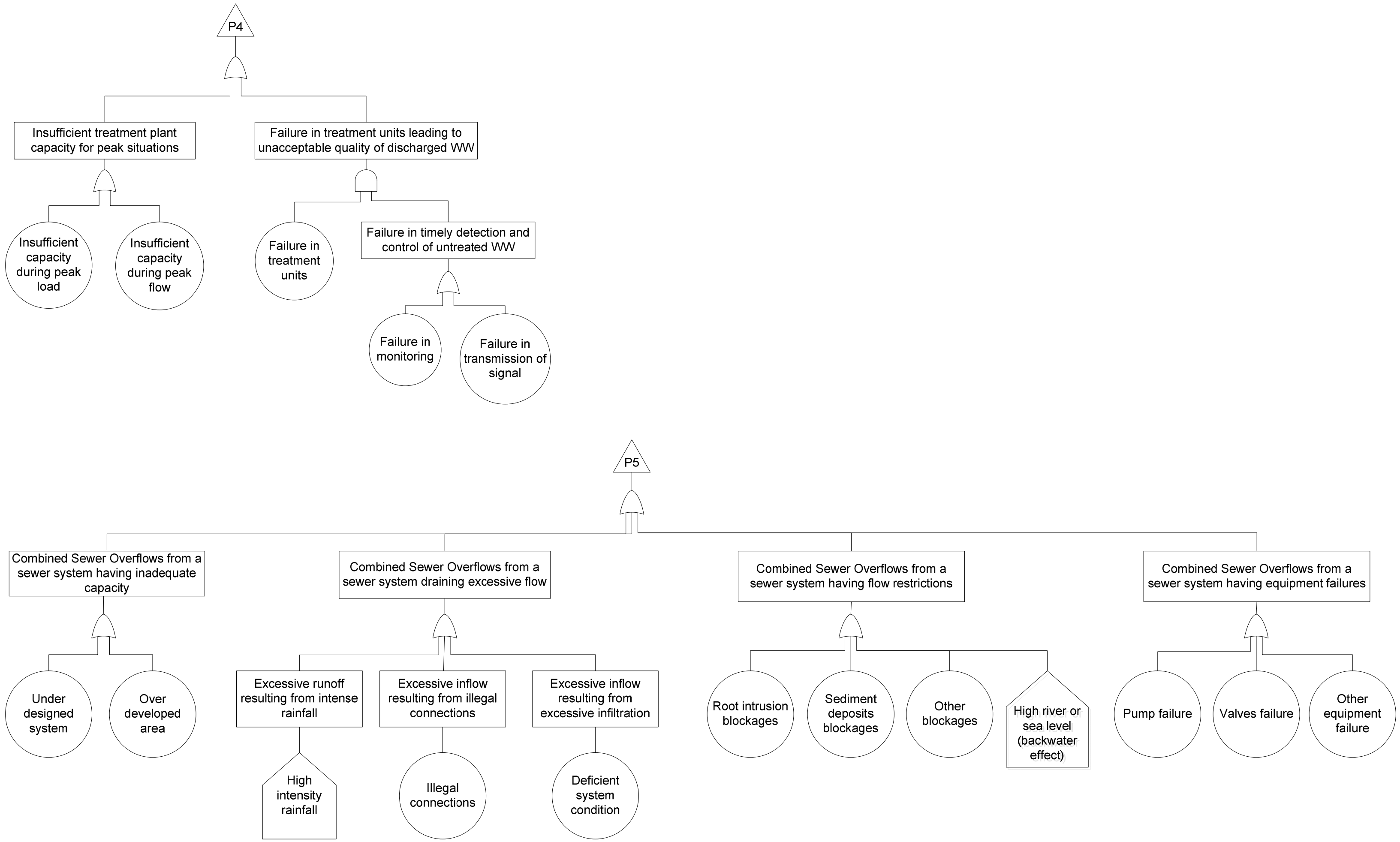


Figure A 7 (cont.) – Fault tree for the hazard 'Presence of chemical contaminants in tap water'

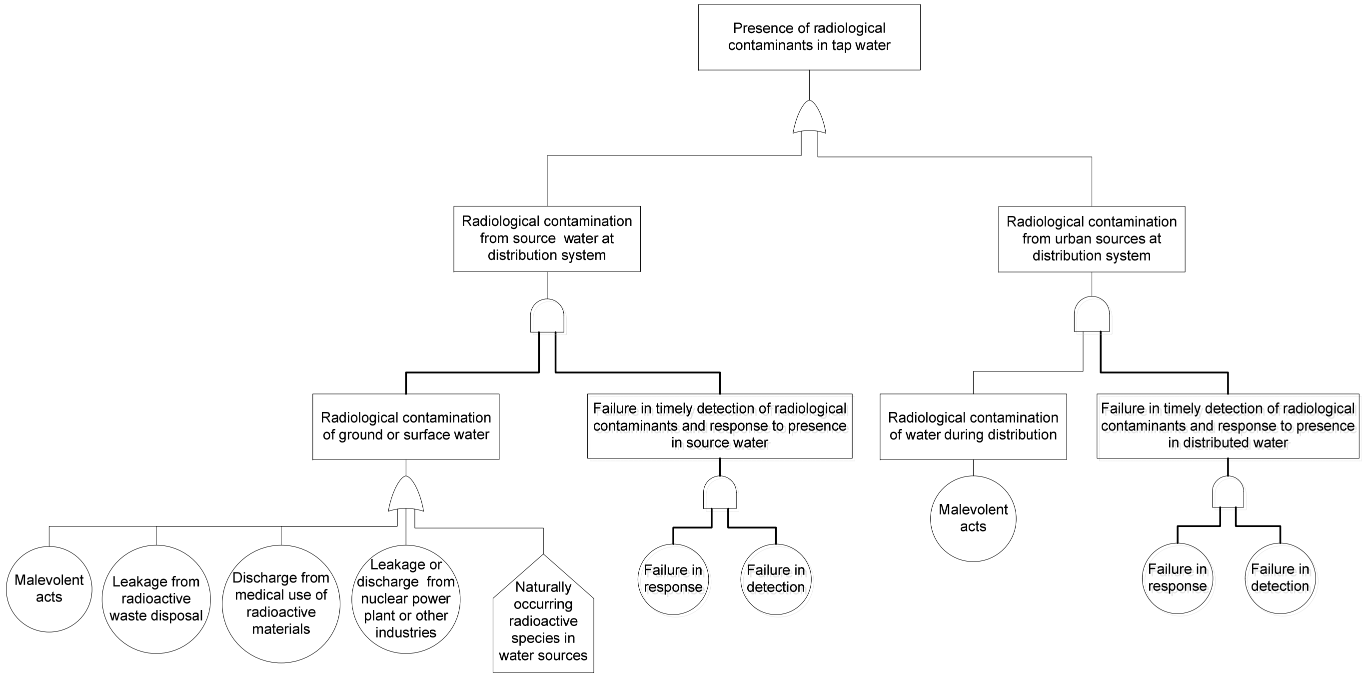


Figure A 8 – Fault tree for the hazard 'Presence of radiological contaminants in tap water'

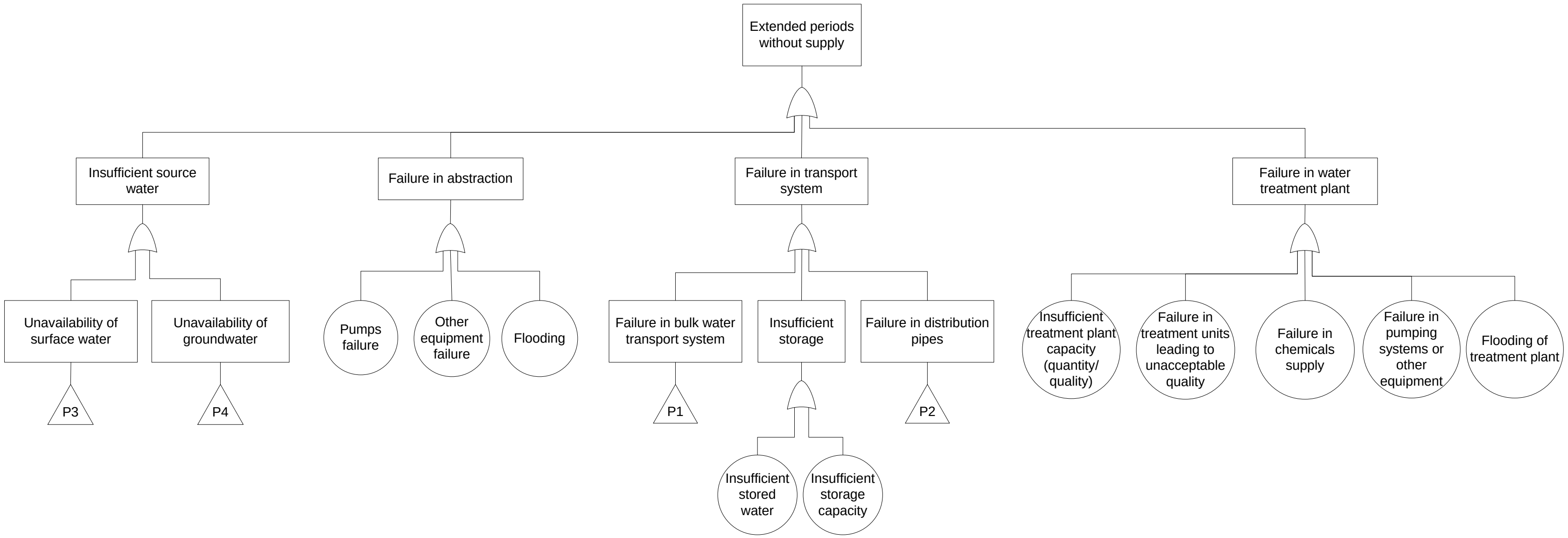


Figure A 9 – Fault tree for the hazard 'Extended periods without supply'

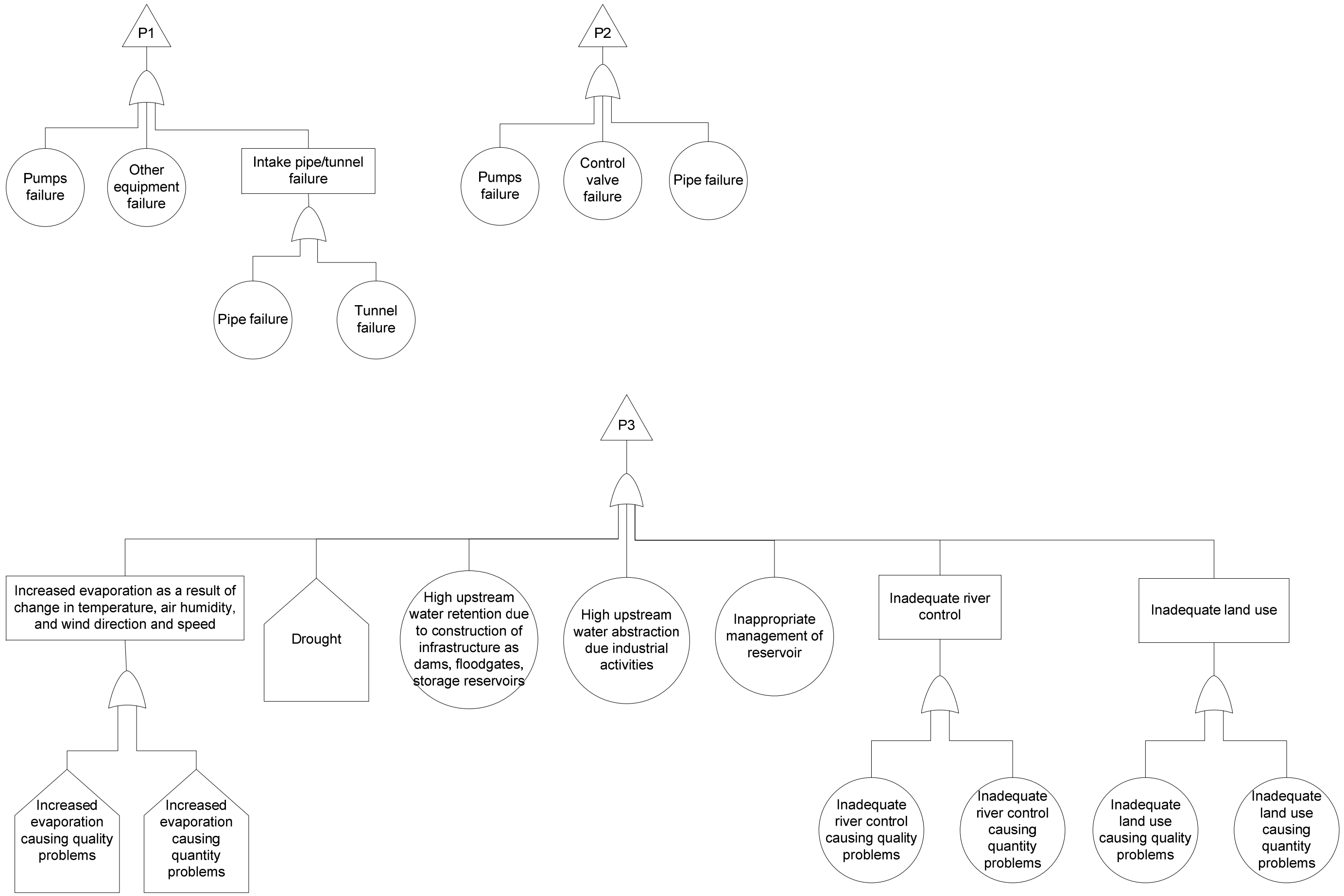


Figure A 9 (cont.) – Fault tree for the hazard 'Extended periods without supply'

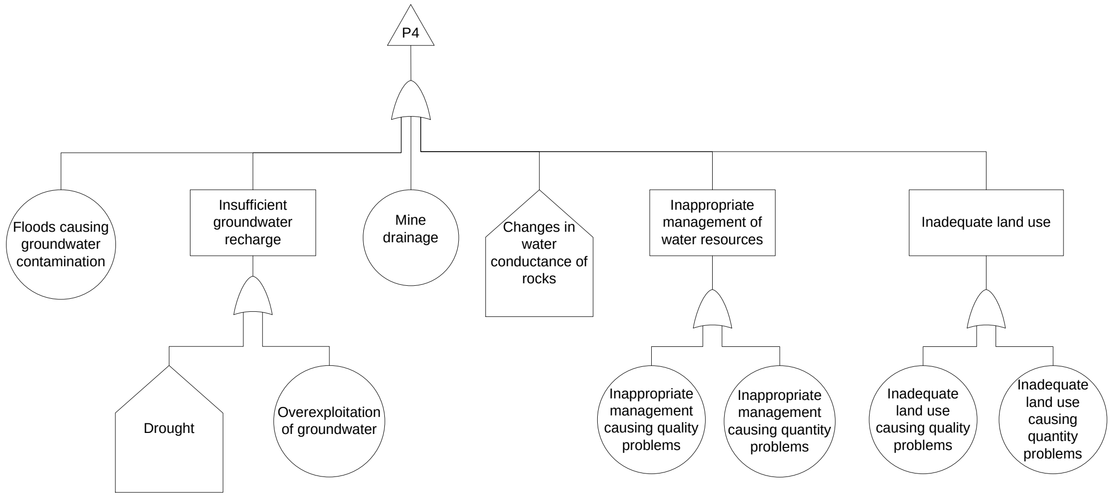


Figure A 9 (cont.) – Fault tree for the hazard 'Extended periods without supply'

Hazards to public health from recreational and other non-consumer exposure modes

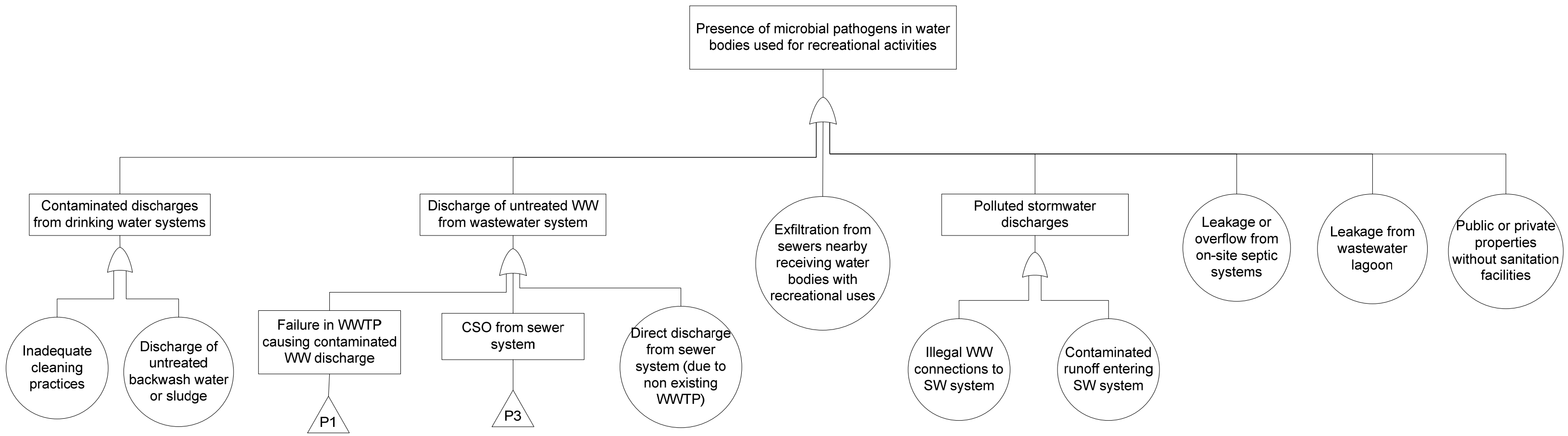
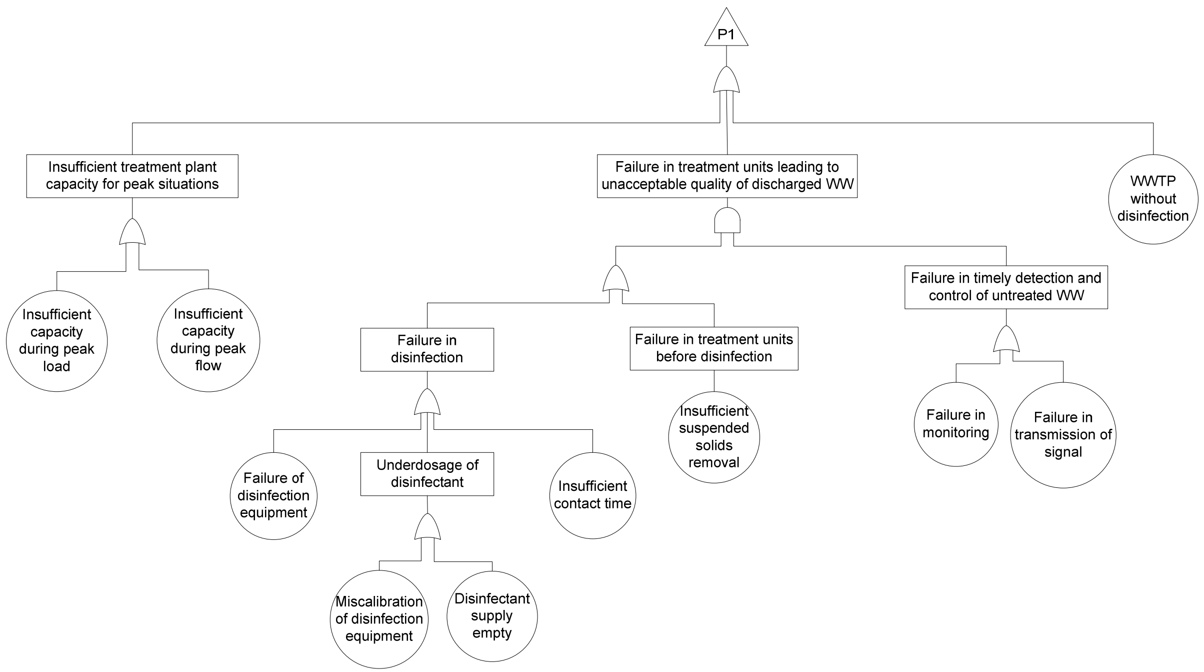


Figure A 10 – Fault tree for the hazard 'Presence of microbial pathogens in water bodies used for recreational activities'



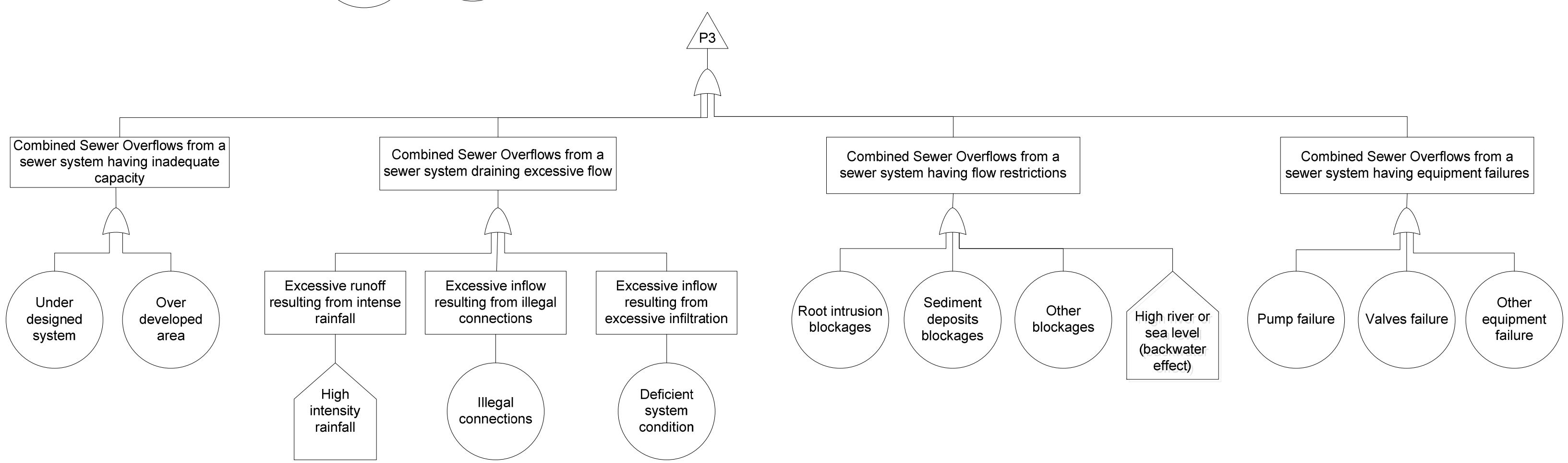


Figure A 10 (cont.) – Fault tree for the hazard 'Presence of microbial pathogens in water bodies used for recreational activities'

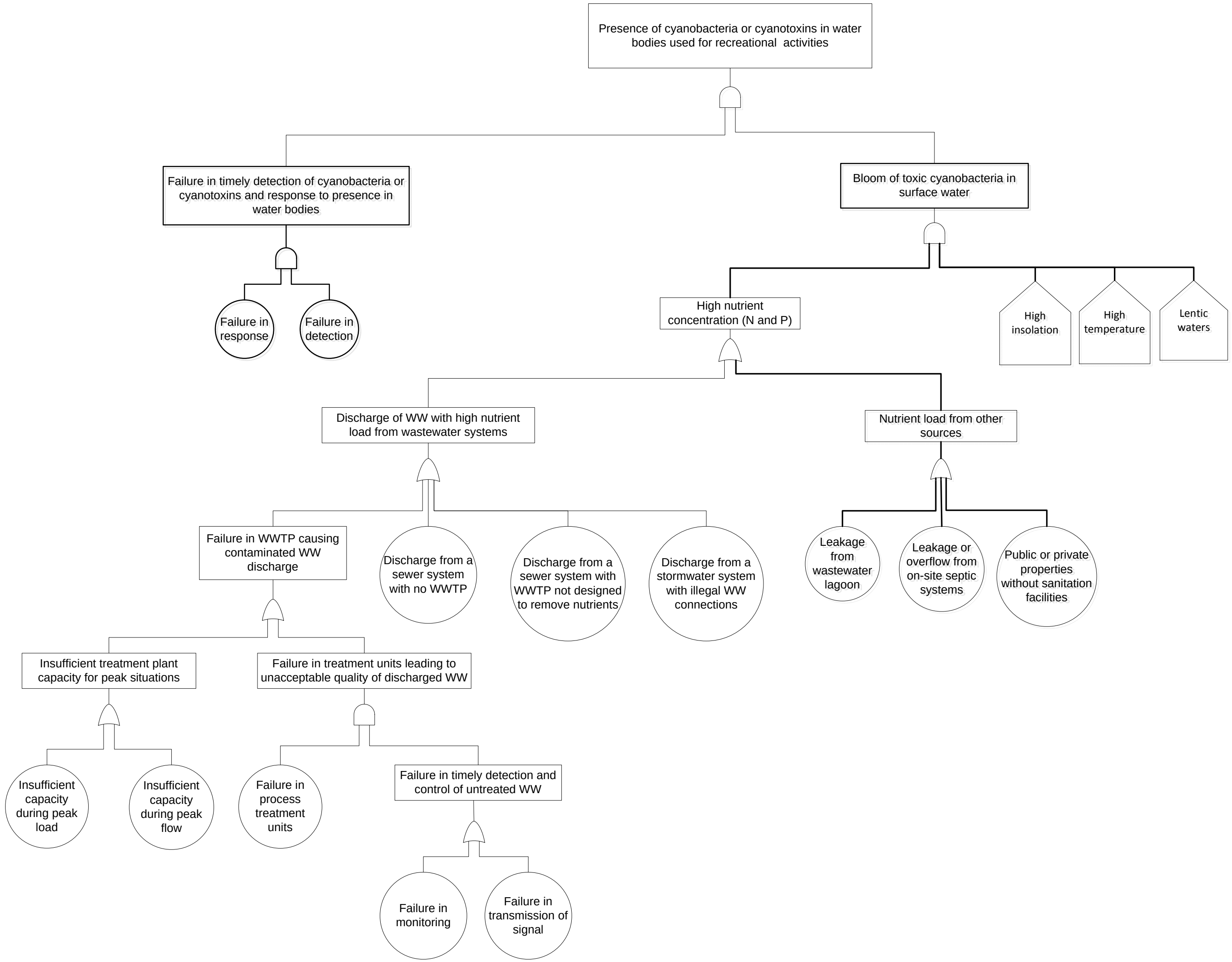


Figure A 11 – Fault tree for the hazard 'Presence of cyanobacteria or cyanotoxins in water bodies used for recreational activities'

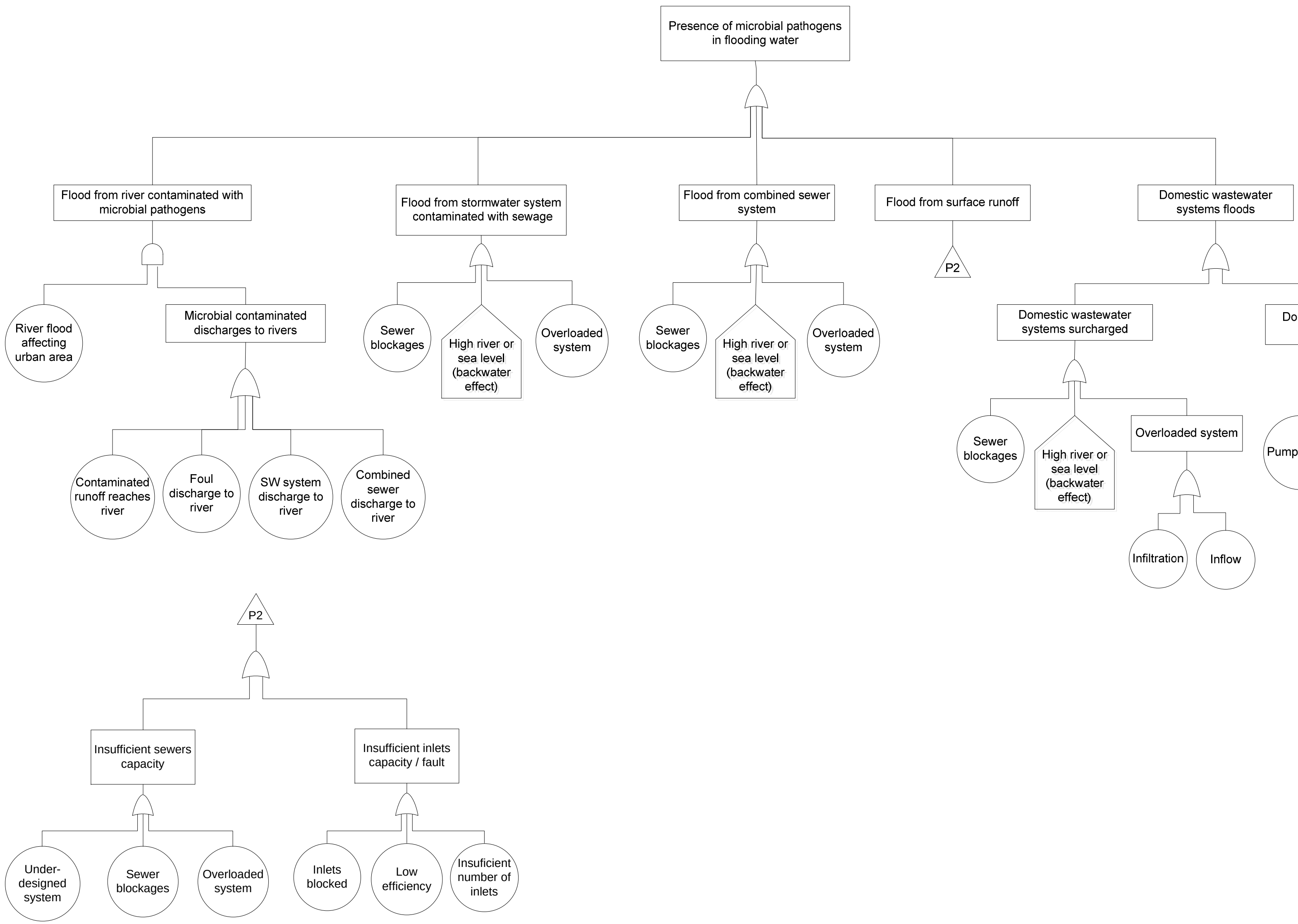


Figure A 12 – Fault tree for the hazard 'Presence of microbial pathogens in flooding water'

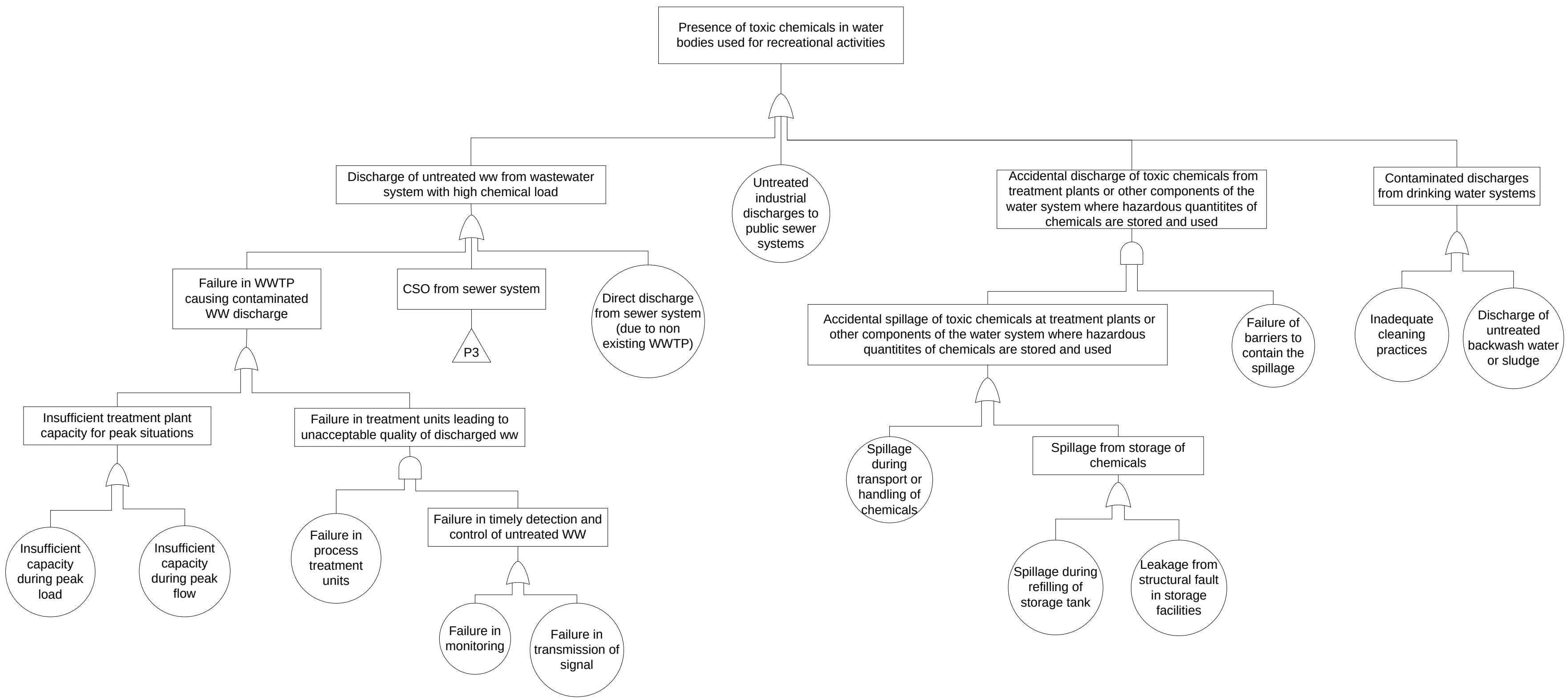


Figure A 13 – Fault tree for the hazard 'Presence of toxic chemicals in water bodies used for recreational activities'

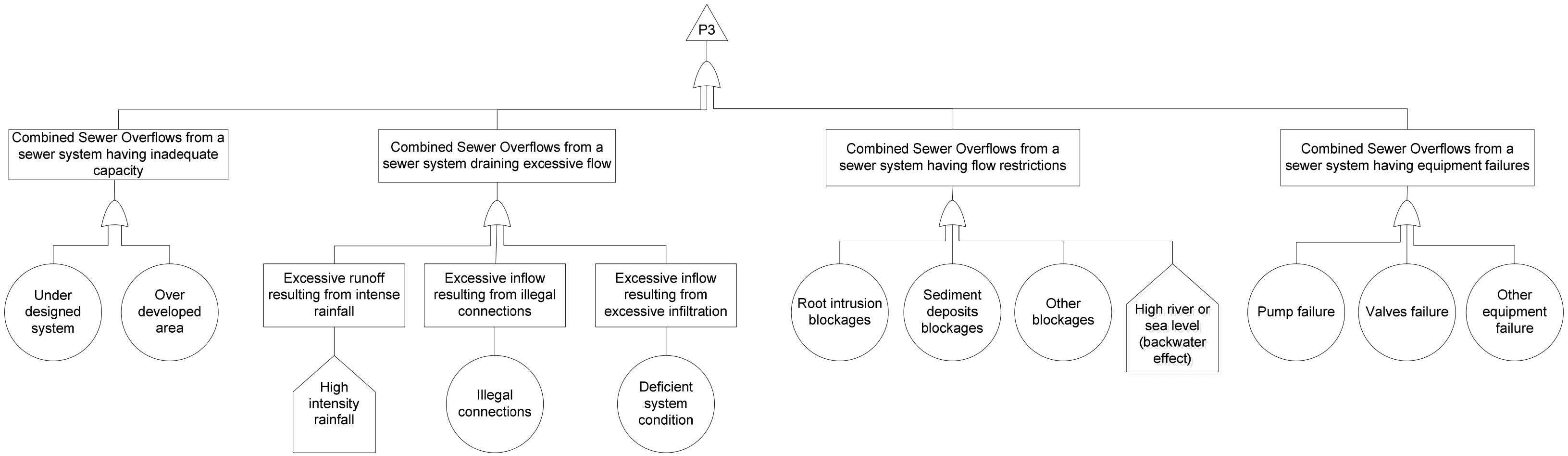


Figure A 13 (cont.) – Fault tree for the hazard 'Presence of toxic chemicals in water bodies used for recreational activities'

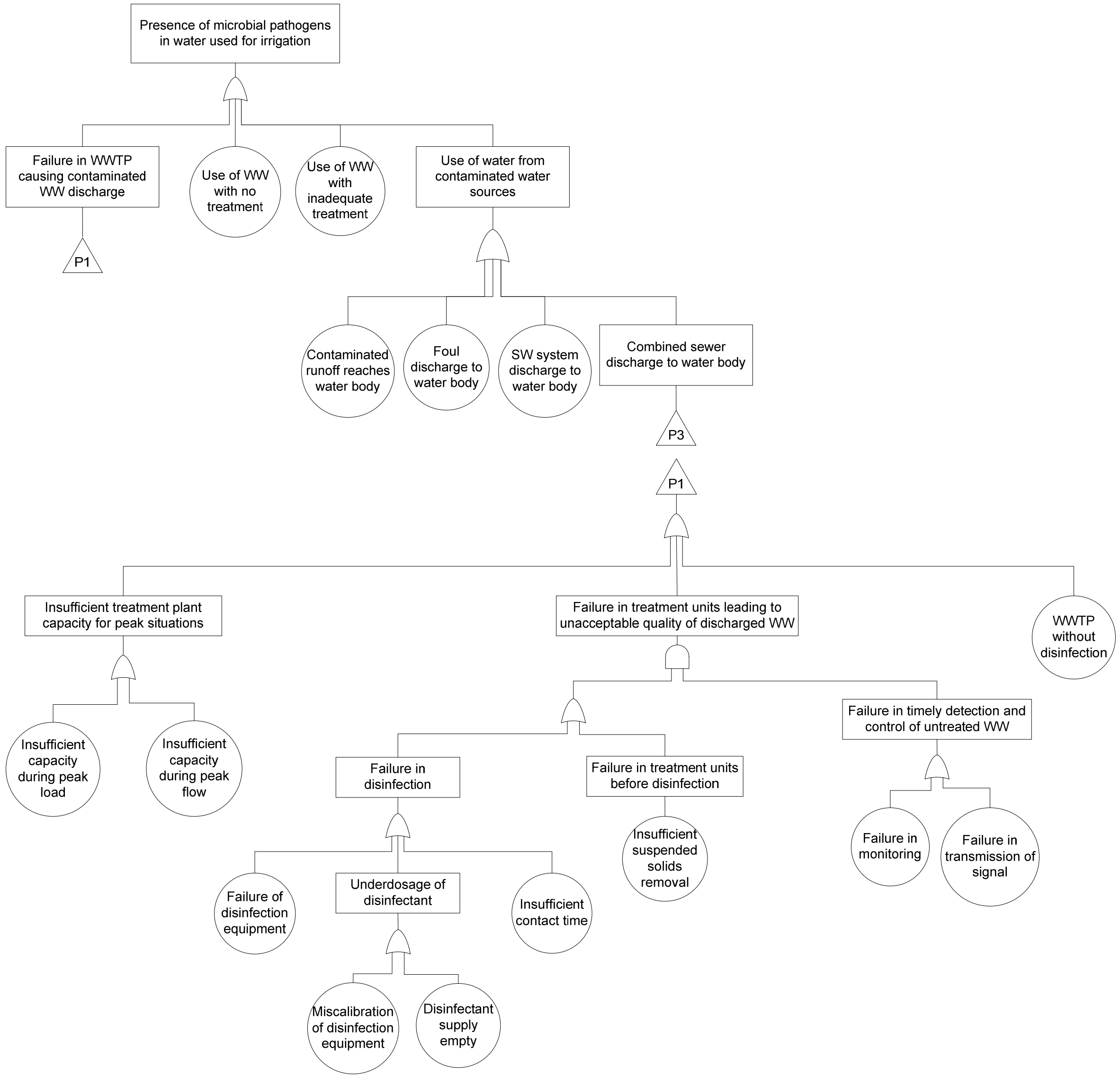


Figure A 14 – Fault tree for the hazard 'Presence of microbial pathogens in water used for irrigation

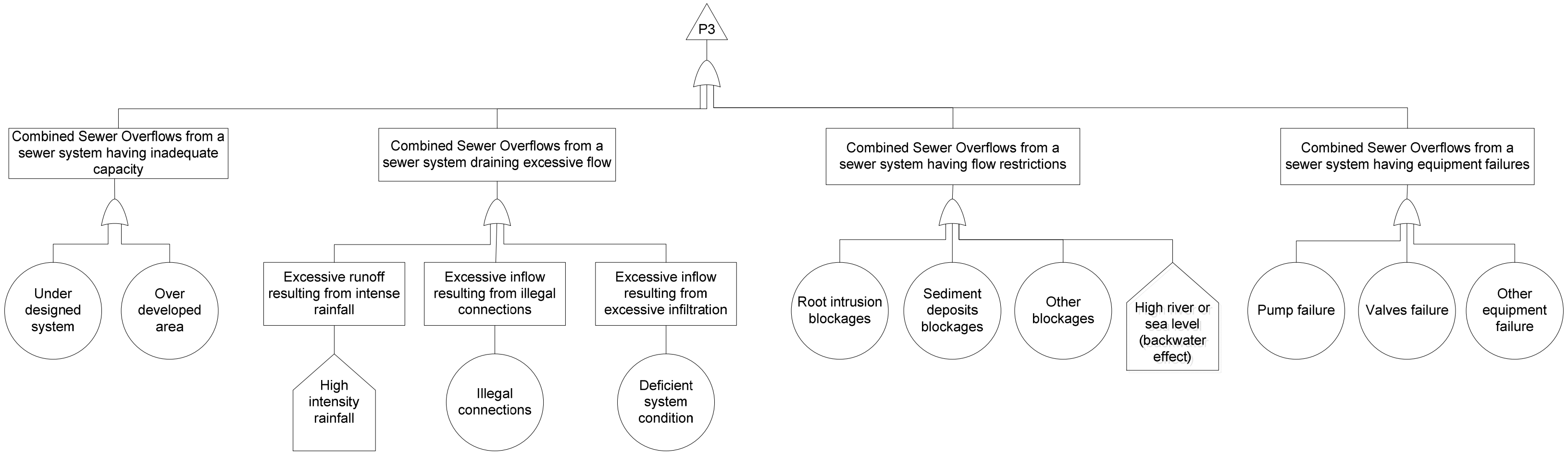


Figure A 14(cont.) – Fault tree for the hazard 'Presence of microbial pathogens in water used for irrigation

Hazards to public safety

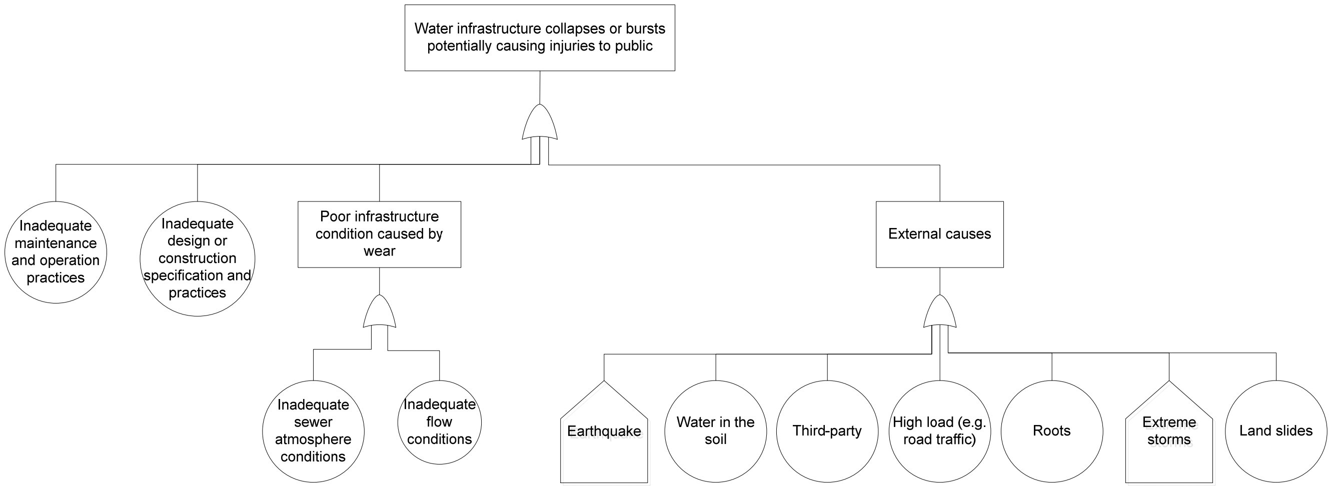


Figure A 15 – Fault tree for the hazard 'Water infrastructure collapses or bursts potentially causing injuries to public'

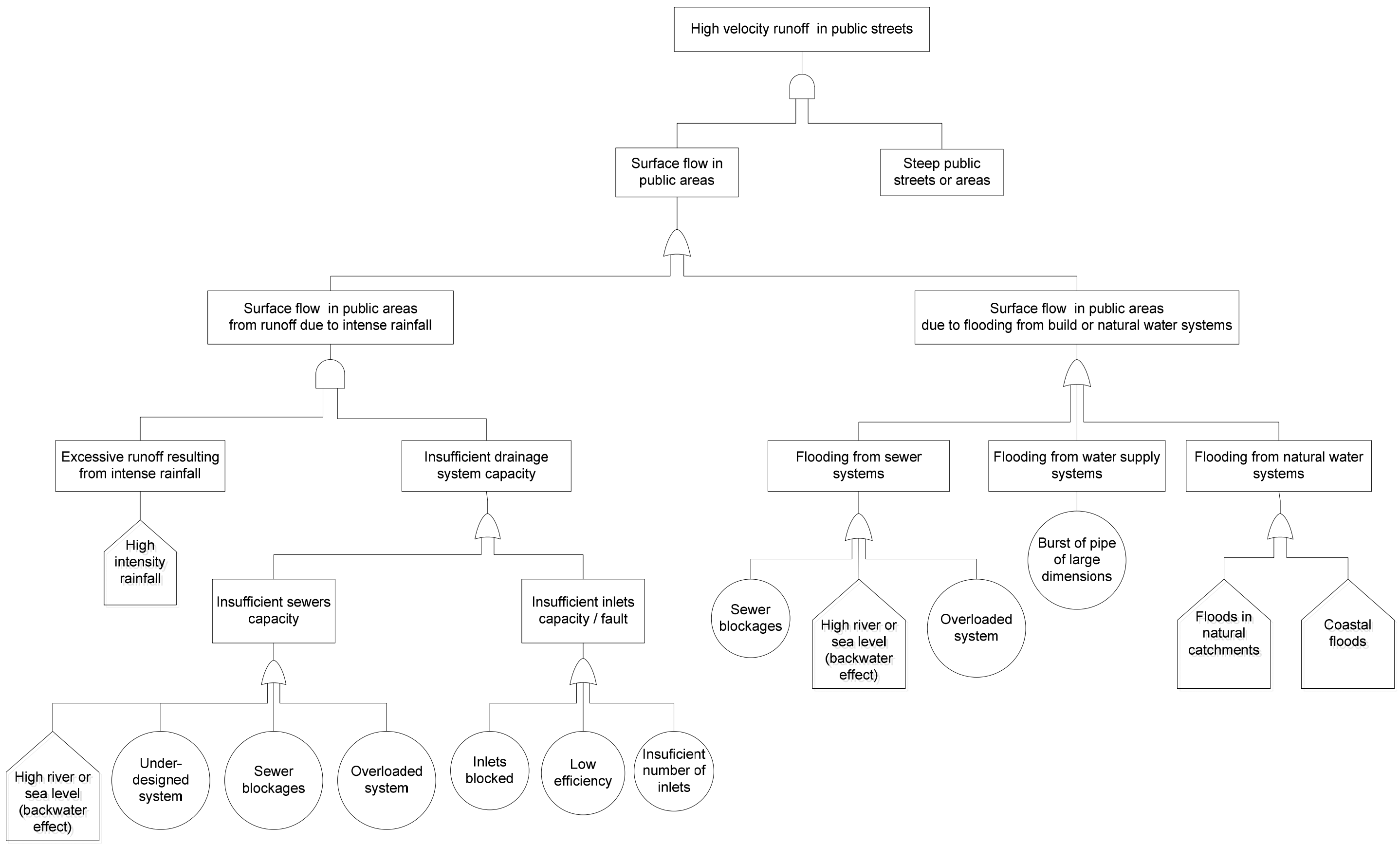


Figure A 16 – Fault tree for the hazard 'High velocity runoff in public streets'

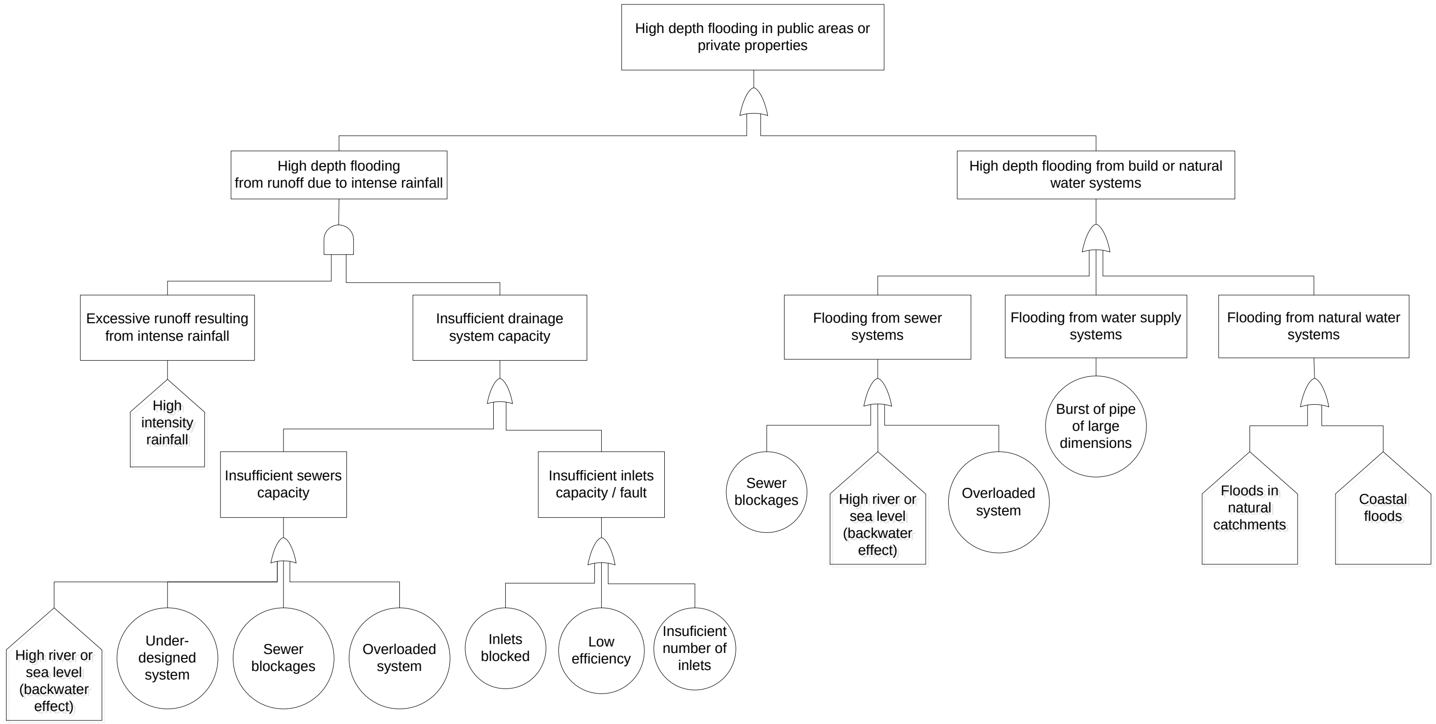


Figure A 17 – Fault tree for the hazard 'High depth flooding in public areas or private properties'

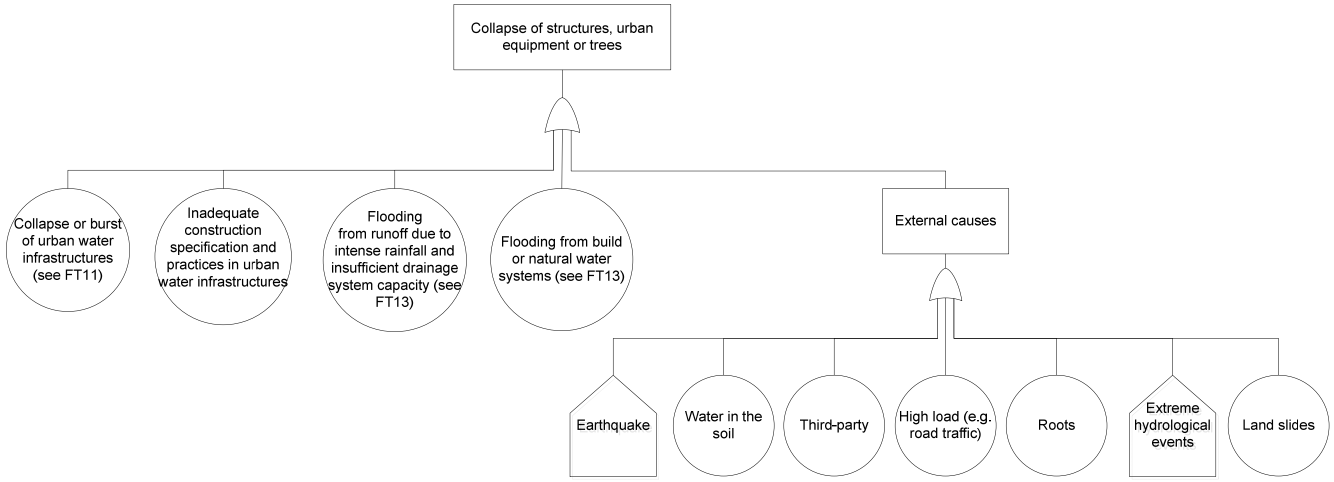


Figure A 18 – Fault tree for the hazard 'Collapse of structures, urban equipment or trees due to effect of water'

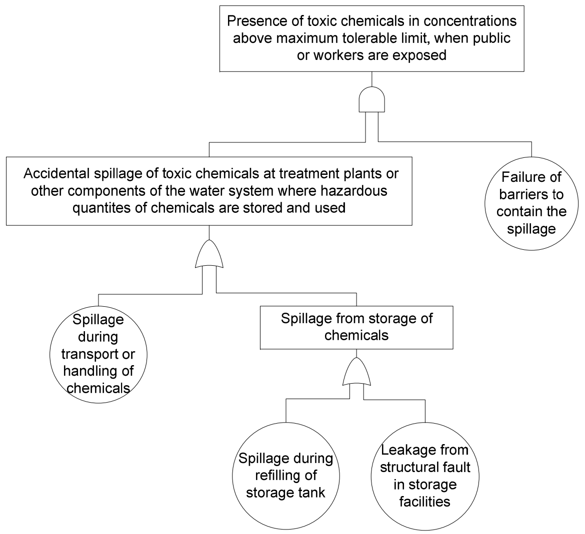


Figure A 19 – Fault tree for the hazard 'Presence of toxic gases in the atmosphere of locations where public or workers might have access to'

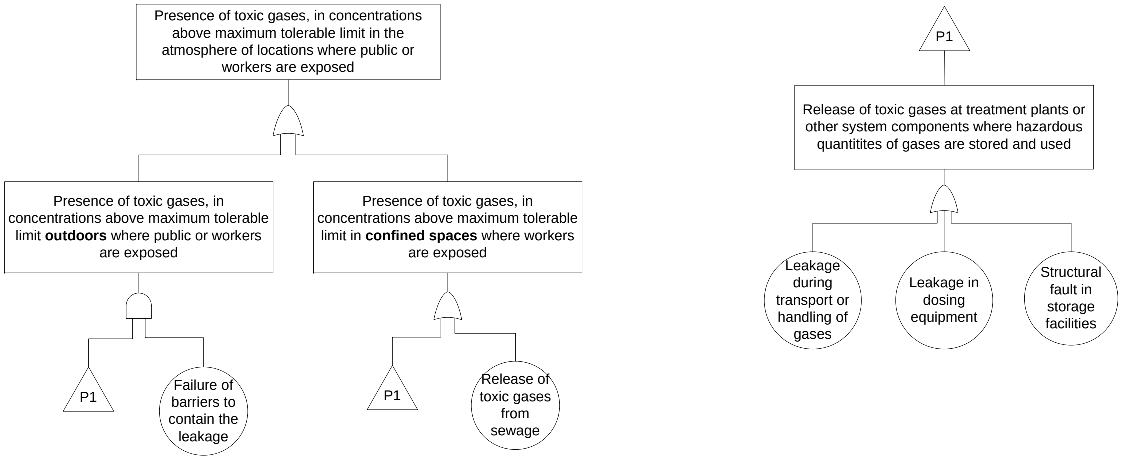


Figure A 20 – Fault tree for the hazard 'Presence of toxic chemicals in locations where public or workers might have access to'

Hazards to environment

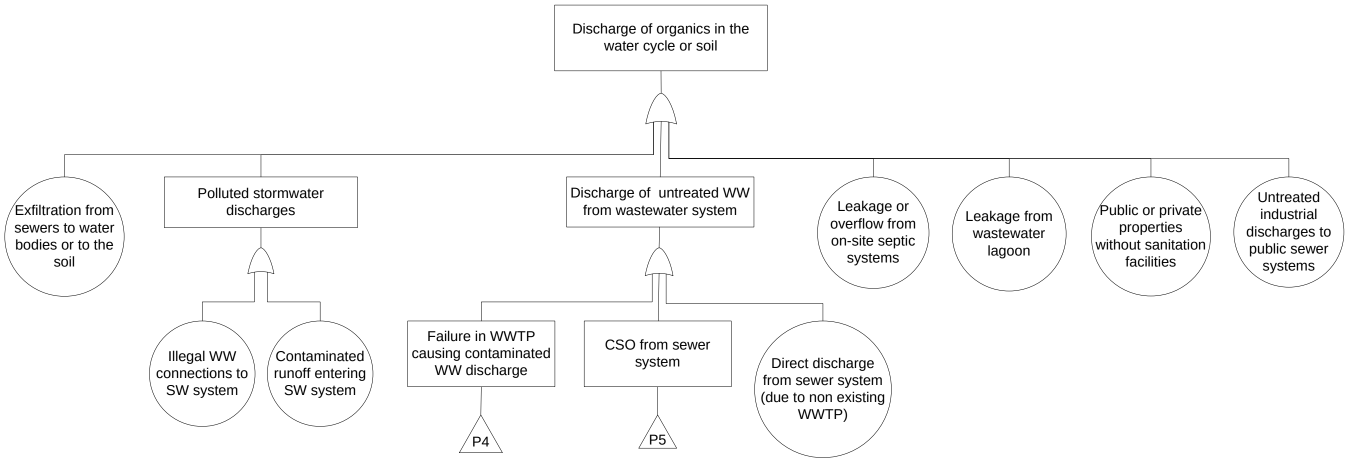


Figure A 21 – Fault tree for the hazard 'Discharge of organics in the water cycle or soil'

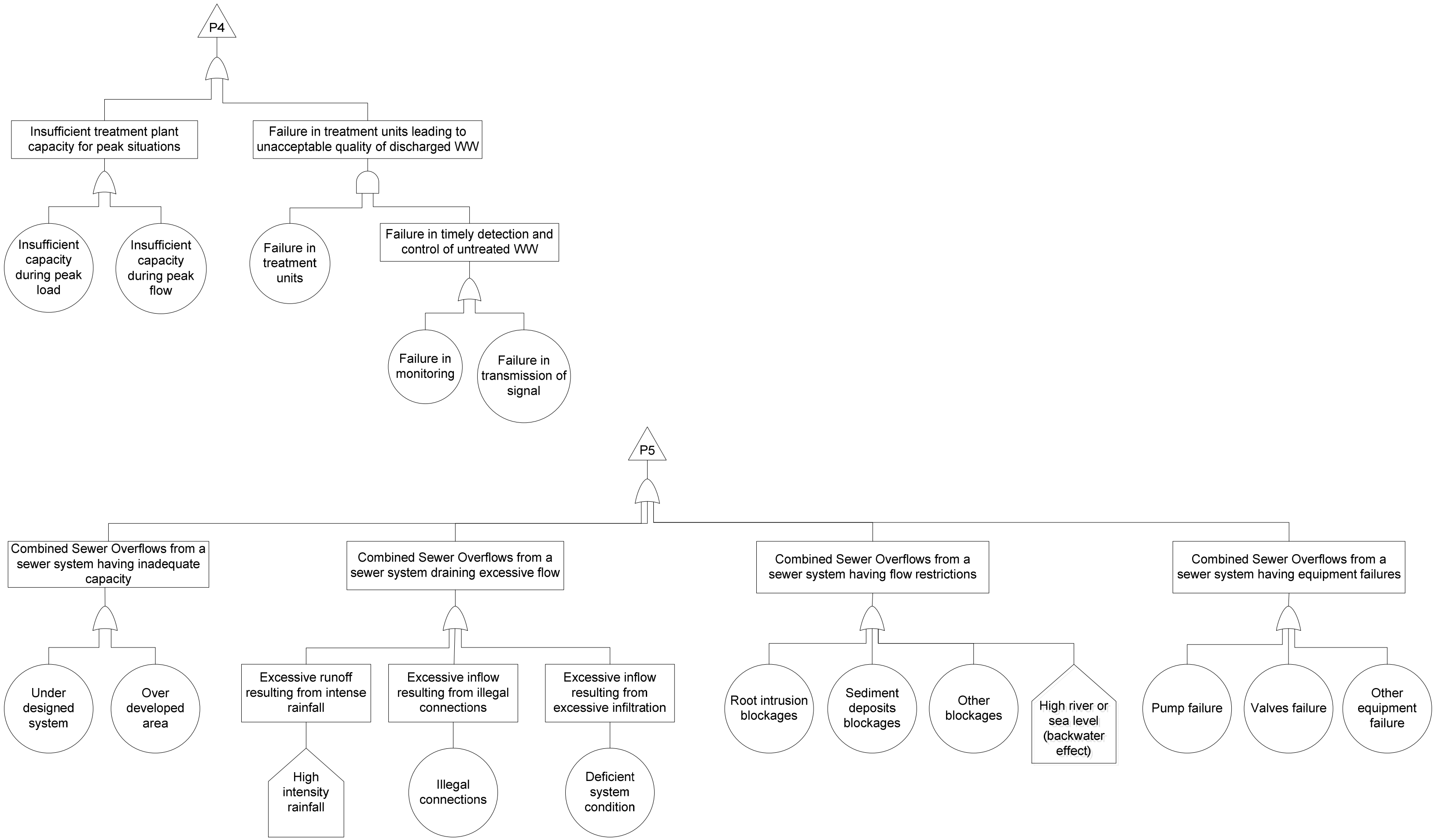


Figure A 21 (cont.) – Fault tree for the hazard 'Discharge of organics in the water cycle or soil'

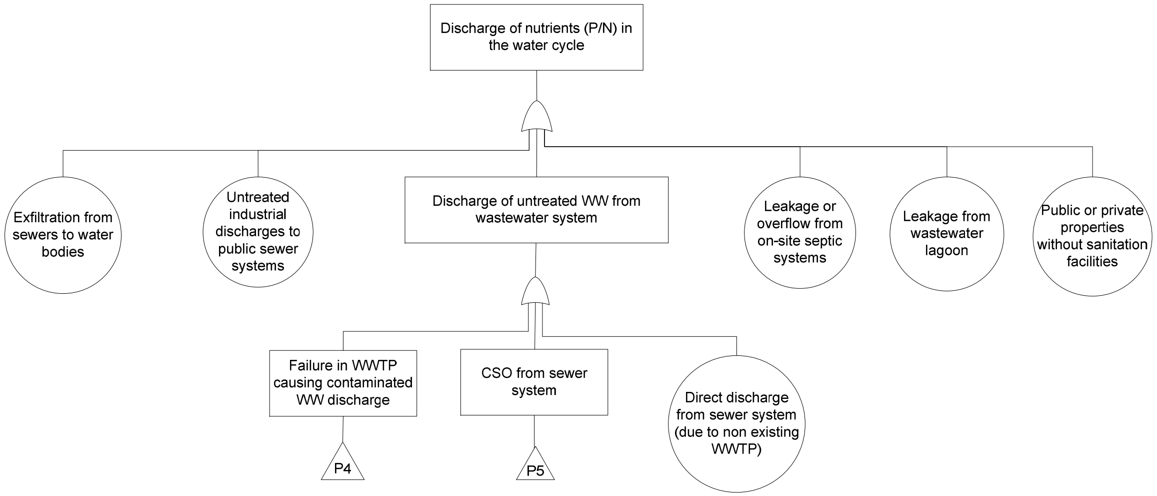


Figure A 22 – Fault tree for the hazard 'Discharge of nutrients in the water cycle'

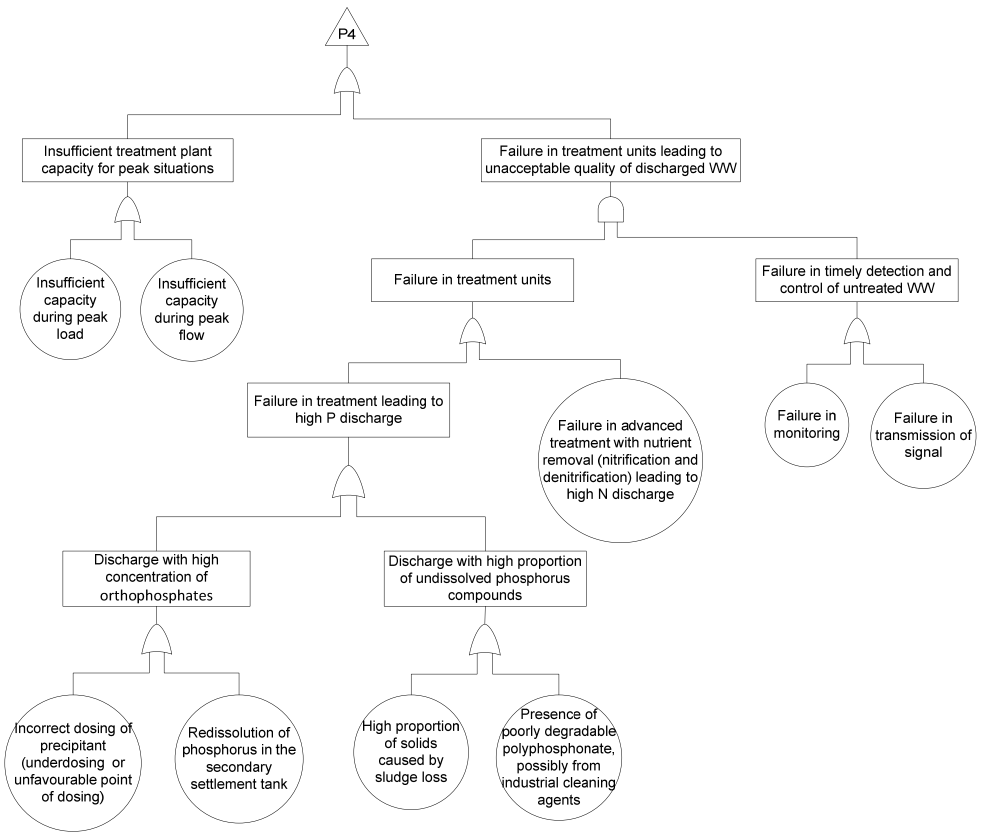


Figure A 22 (cont.) – Fault tree for the hazard 'Discharge of nutrients in the water cycle'

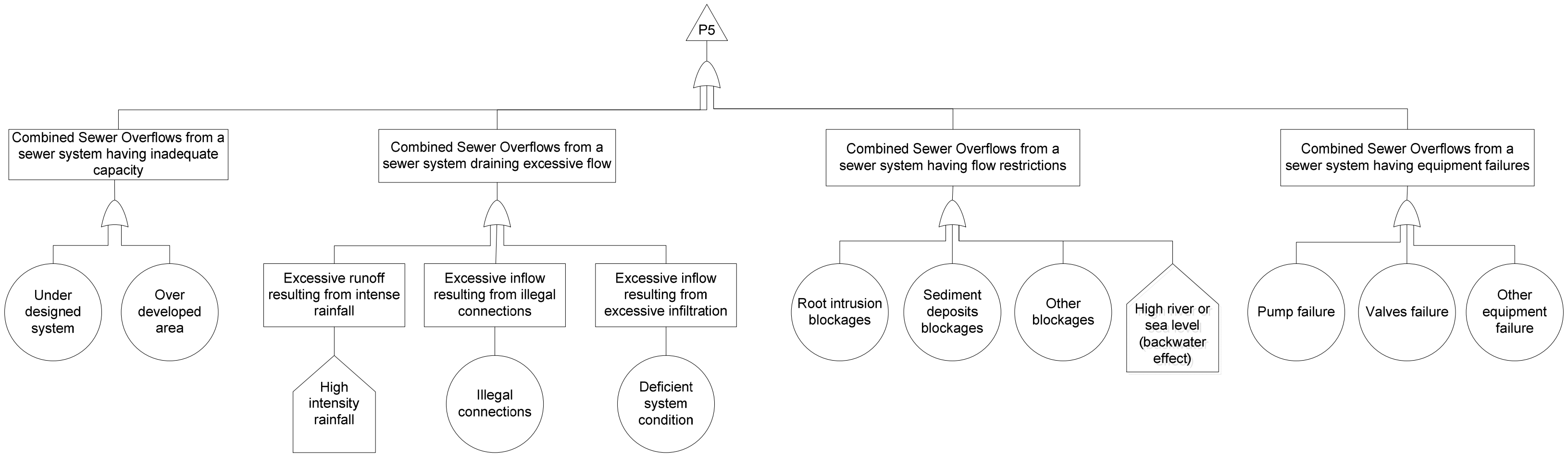


Figure A 22 (cont.) – Fault tree for the hazard 'Discharge of nutrients in the water cycle'

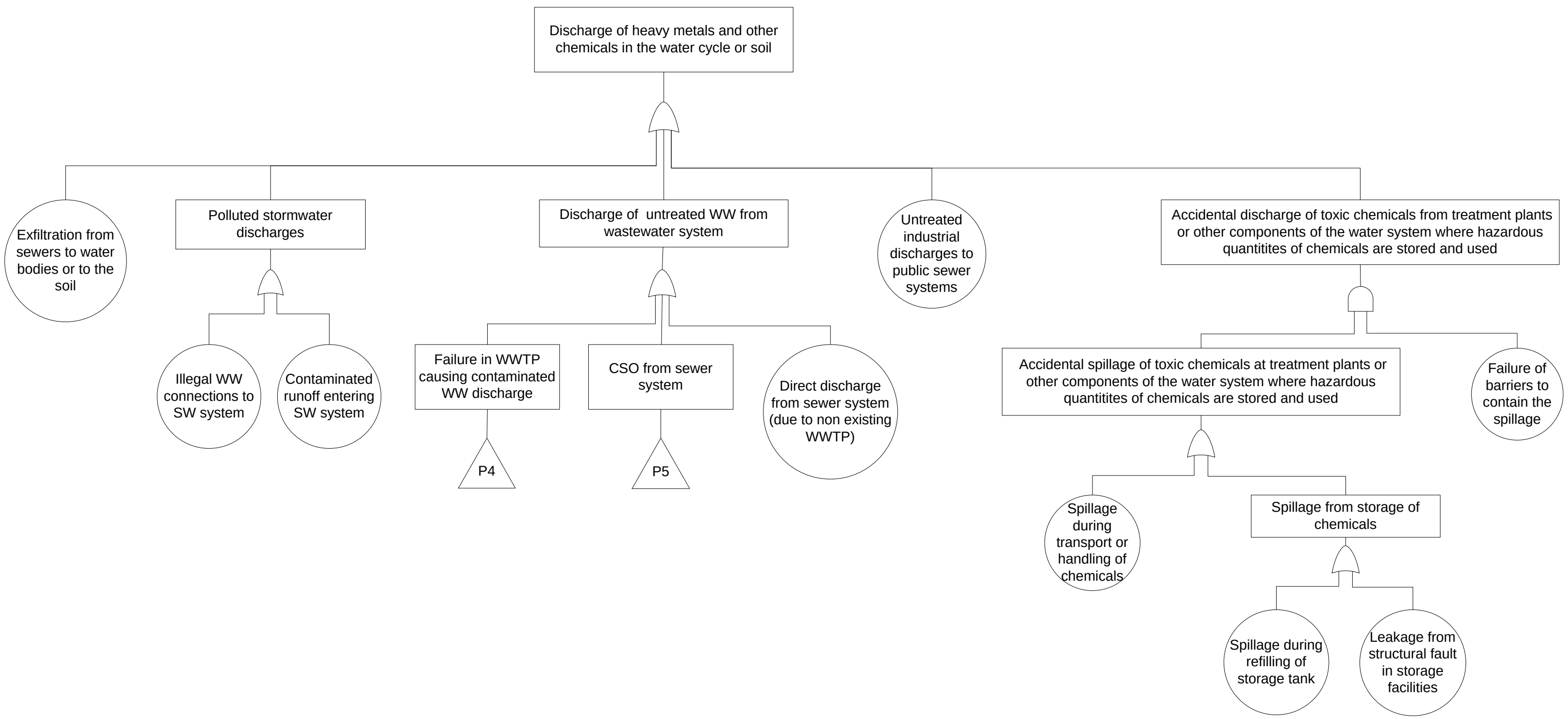


Figure A 23 – Fault tree for the hazard 'Discharge of heavy metals and other chemicals in the water cycle or soil'

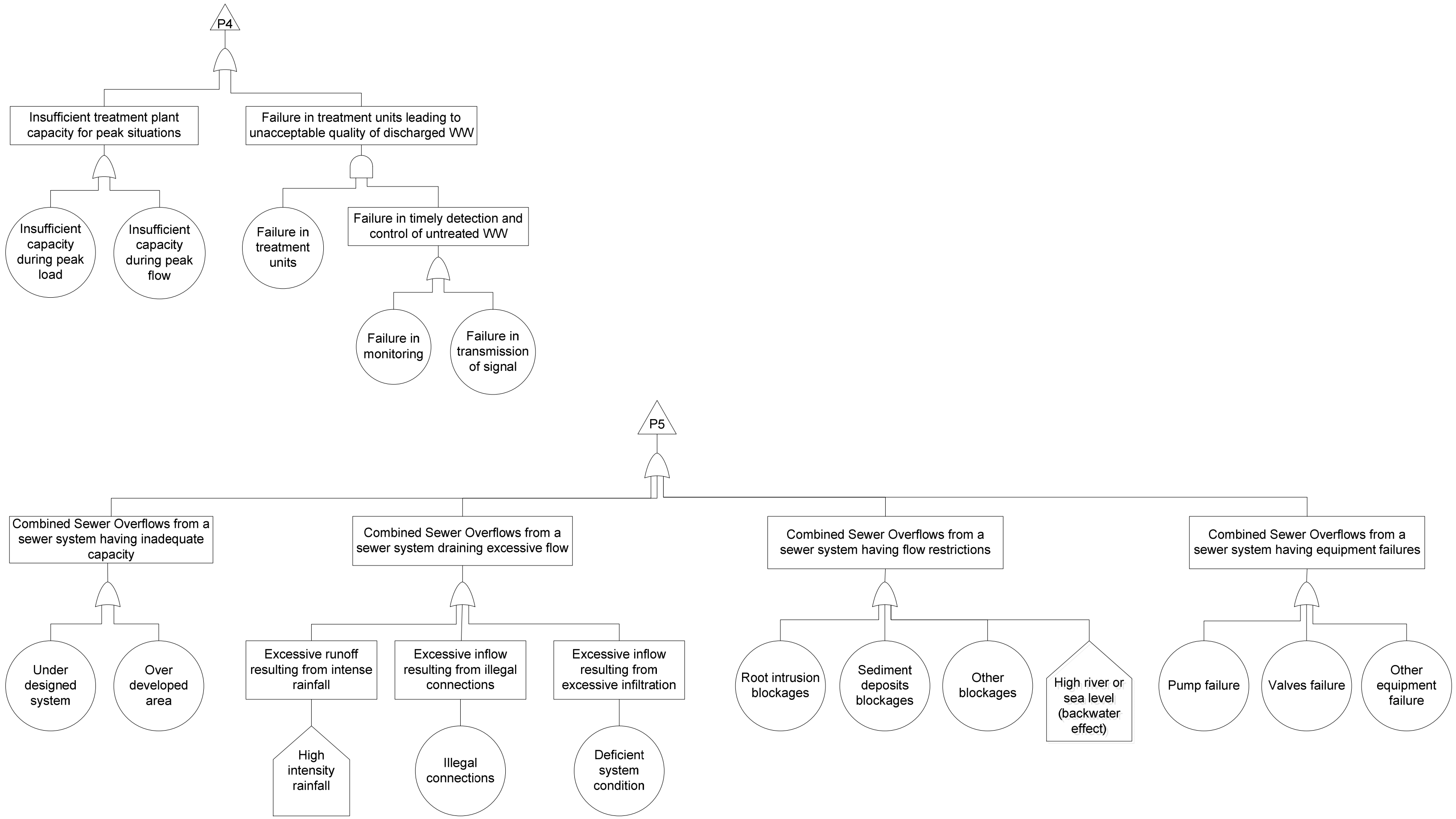


Figure A 23 (cont.) – Fault tree for the hazard 'Discharge of heavy metals and other chemicals in the water cycle or soil'

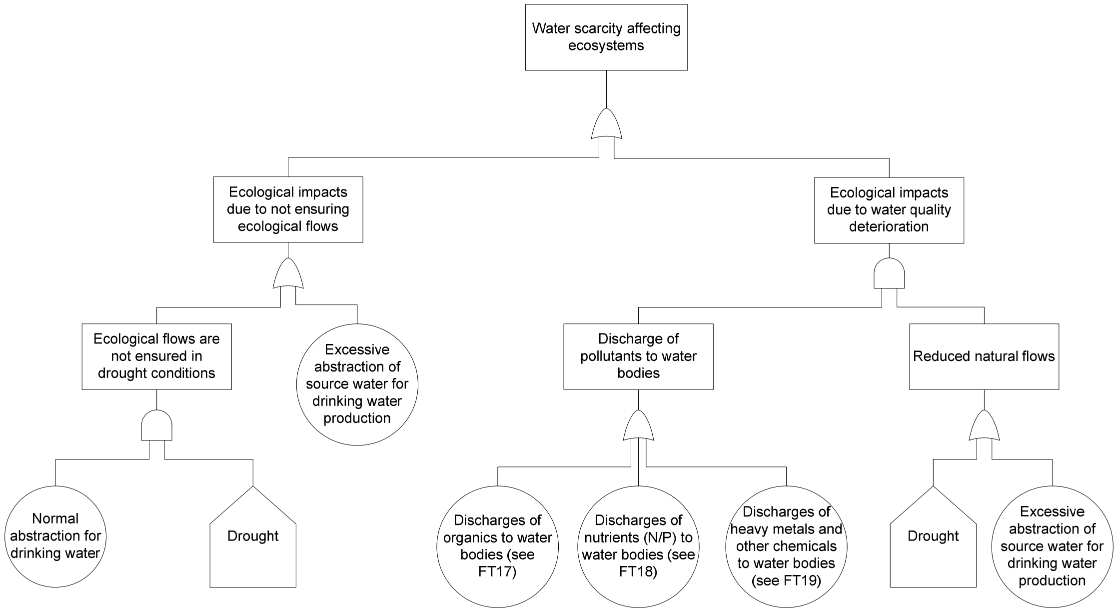


Figure A 24 – Fault tree for the hazard 'Water scarcity affecting ecosystems'

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Annex 3 ▸ Checklist to filter risk sources

To use the “check list” the following procedure is recommended (Figure A 25):

1. “Open DB” (Figure A 26)
2. Select primary aim of the WCSP (Health, Safety and/or Environment) OR Select (sub)system (Figure A 27)
3. “Refresh Hazards” (list all hazards from selected group) OR
4. “List all Risk Sources” (list all Risk Sources)
5. Click on one of the hazards and a list of risk sources will show up under “list all risk sources”
6. Click on one of the risk sources and a list will show up in the last window
7. “Exit” (quit the program)

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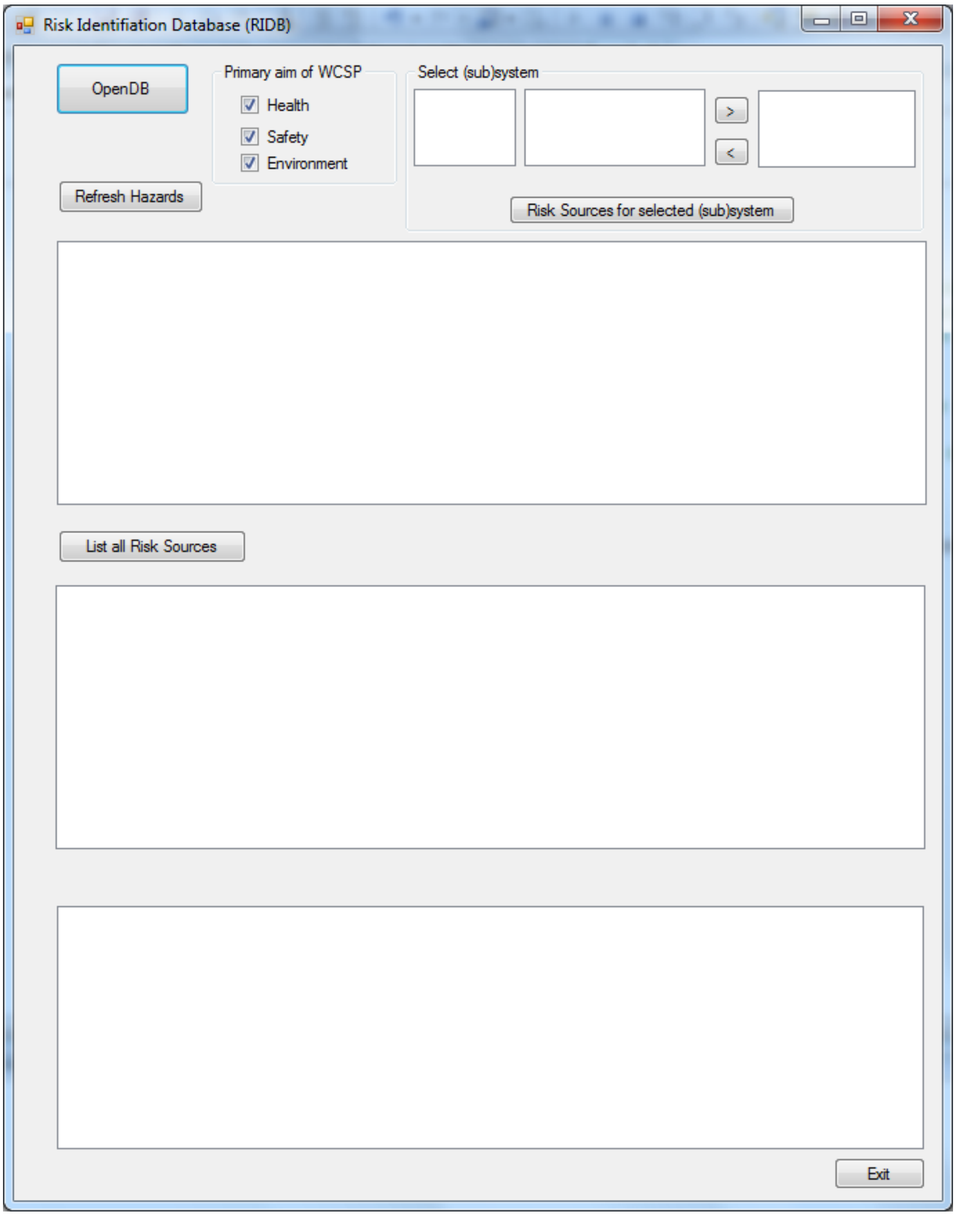

Figure A 25 – Screen print of the risk identification database – check list

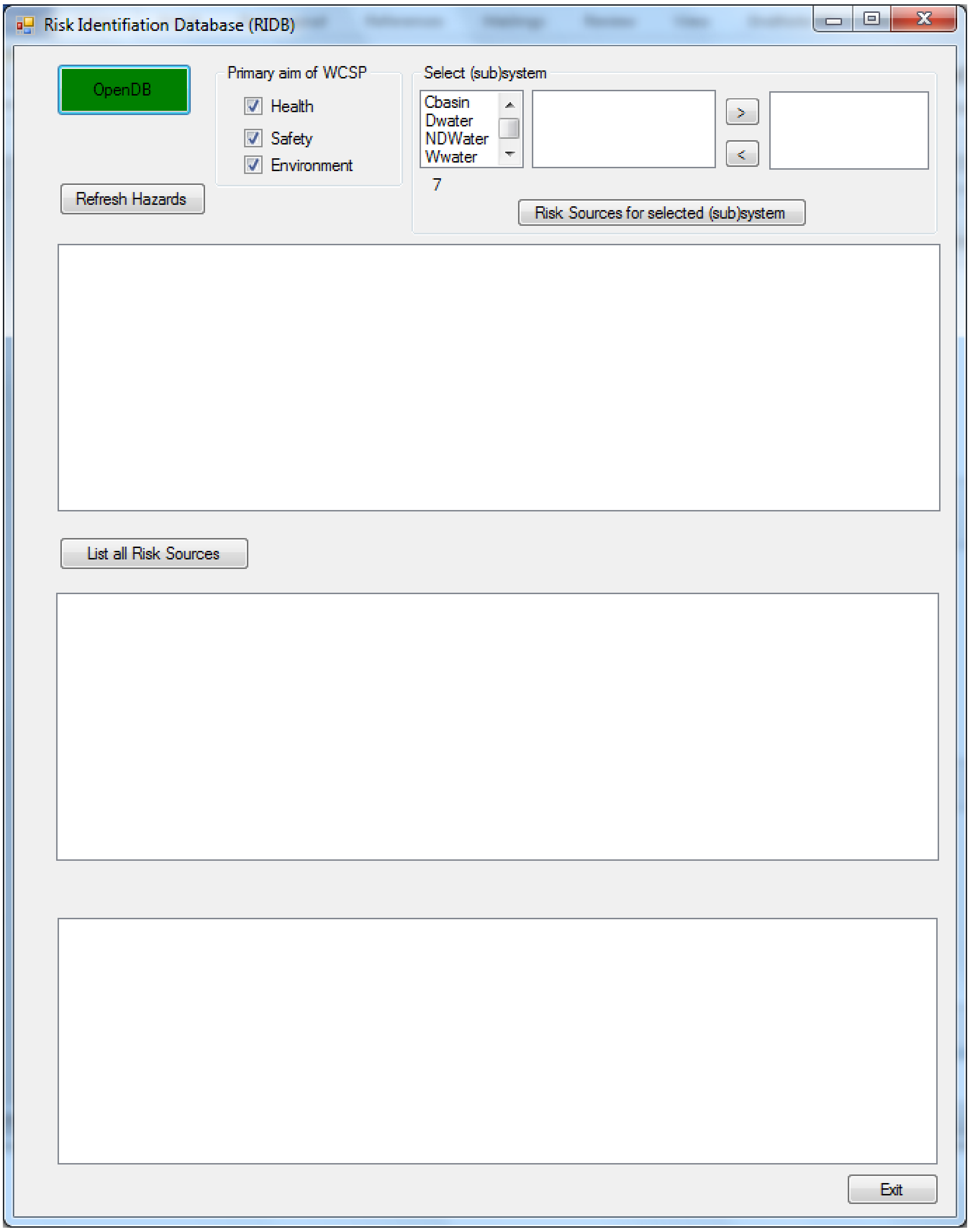

Figure A 26 – Starting the program

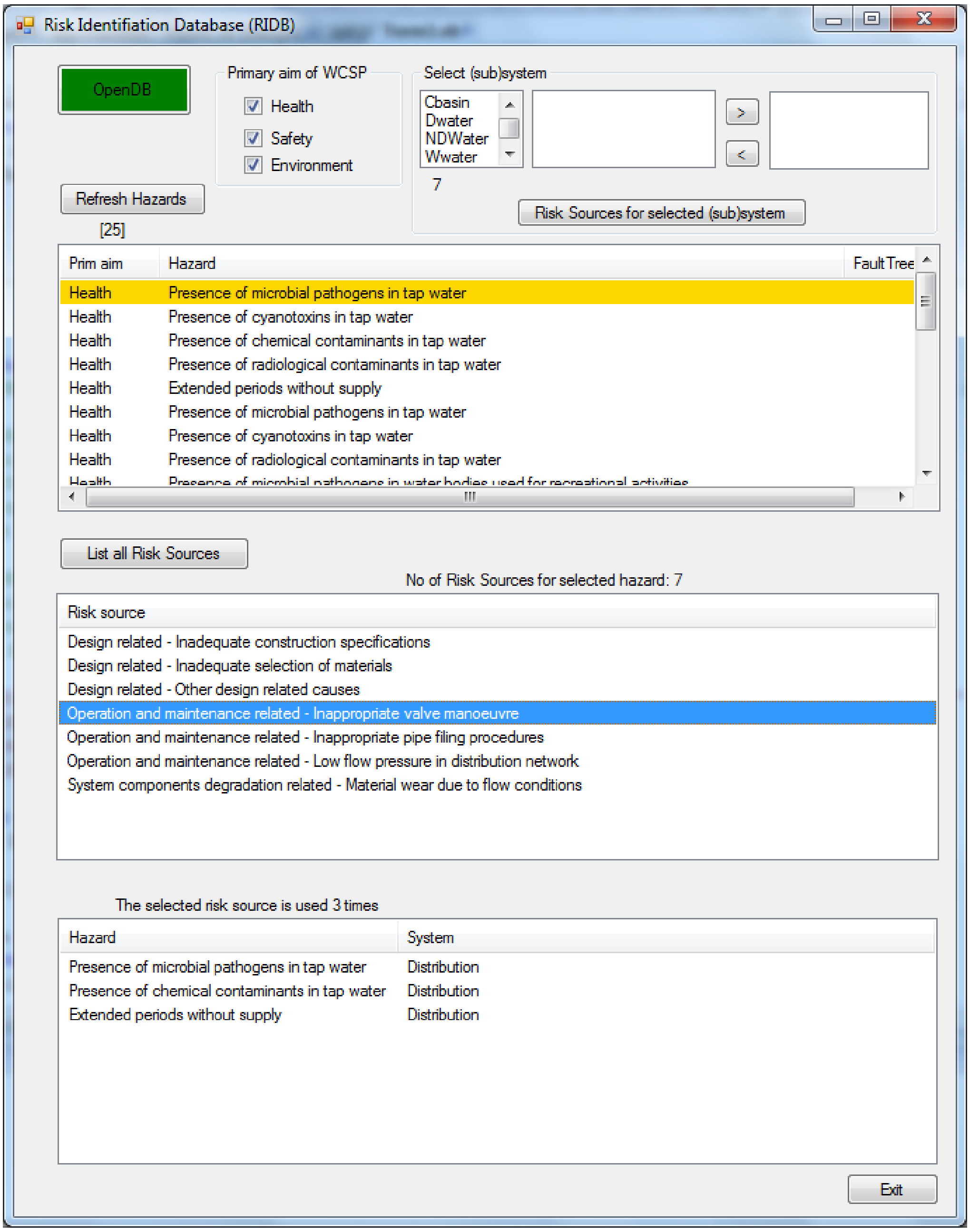

Figure A 27 – Identification of hazards and risk sources

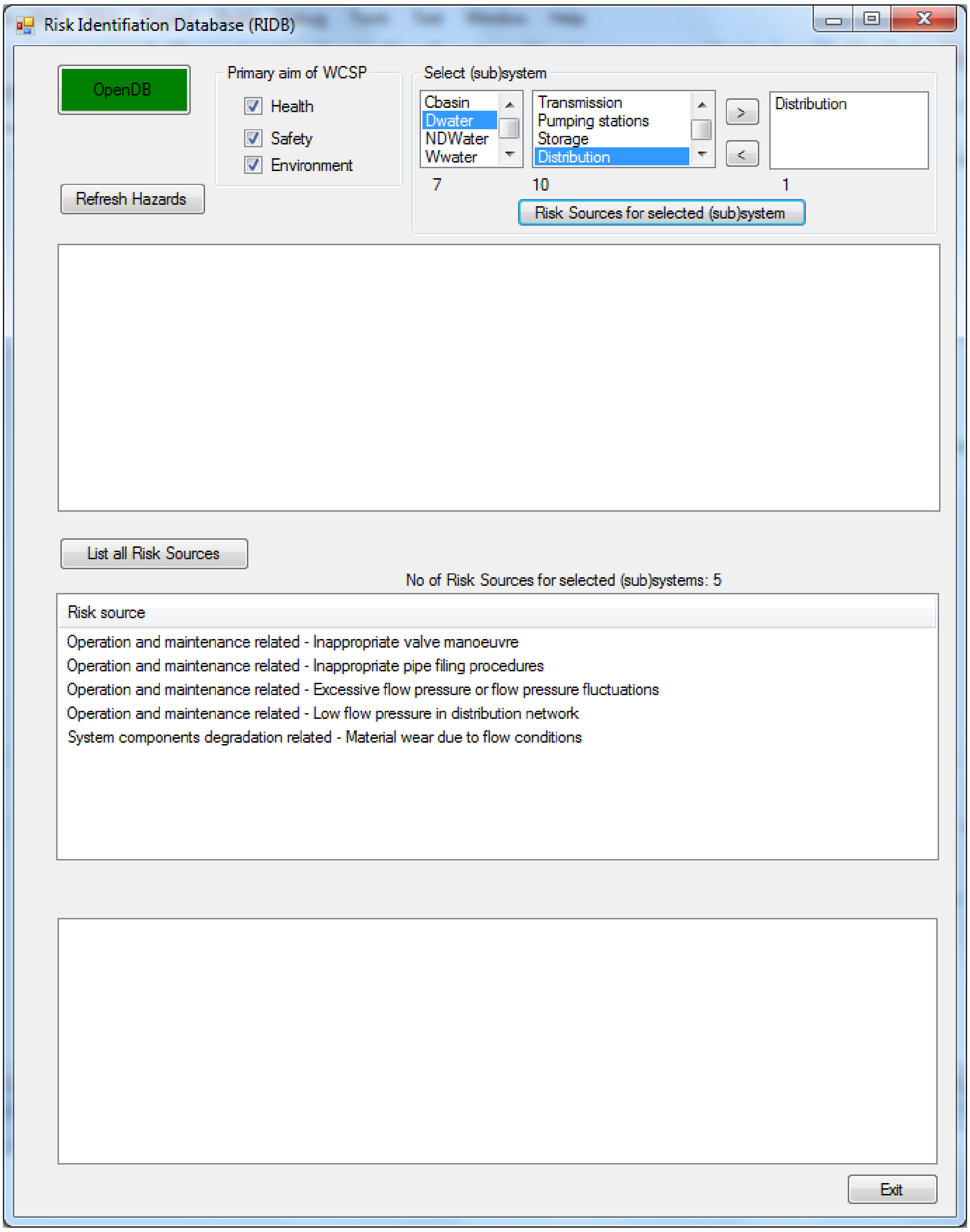

Figure A 28 – Identification of the risk sources only

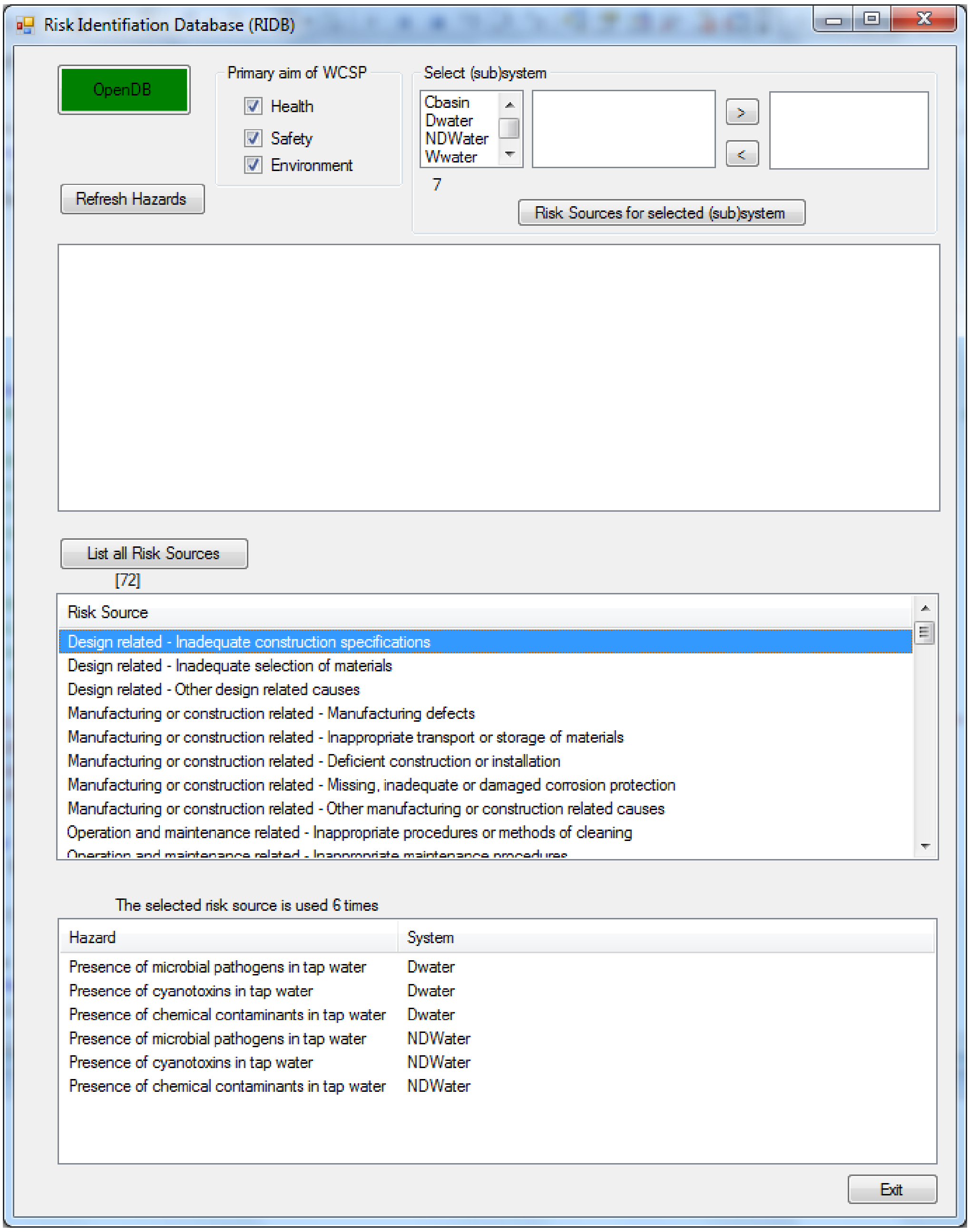

Figure A 29 – Selection of the risk sources only and related hazard