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INTRODUCTION OF THREAT ANALYSIS FOR HAZARDOUS INDUSTRIAL INSTALLATIONS INTO THE LAND-USE PLANNING PROCESS

Dissertation

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Summary

The aim of this research has been to develop a method for introducing risk assessment into the land-use planning process. Due to adaptations of the results of risk assessment, which are needed to make the risk assessment usable by land-use planners, the overall process has been termed threat analysis. The key features of the threat analysis consist of three main steps. The first is determination of the threat intensity level of an accident, the second is analysis of the environmental vulnerability of the surroundings of an accident, and the third, integrating the previous two, is determination of a threat index in the accident impact zone. All three are presented in GIS based maps, since this is a common expression in land-use planning. Another aspect of the research is the implementation of the method into the land-use planning process. The methodology is illustrated by five examples in the context of renewal of a land-use plan for the Municipality of Koper in Slovenia. The results of the research show that threat analysis is a successful approach for the integration of risk assessment into the land-use planning process.

Keywords: risk, land-use planning, threat analysis

Povzetek

Namen te raziskave je zasnovati metodo za uspešno povezovanje ocenjevanja industrijskega tveganja in prostorskega načrtovanja. Za uspešno integracijo so nujne metodološke spremembe na področju ocenjevanja tveganja na način, da bodo ti uporabni za potrebe prostorskega načrtovanja. Omenjene spremembe in prilagoditve metod v okviru te raziskave imenujemo analiza ogroženosti. Analizo ogroženosti sestavljajo trije glavni koraki: določanje intezitete izrednega dogodka, določanje stopnje ranljivosti okolja za učinke obravnavanega izrednega dogodka v okolici vira ogroženosti ter povezava slednjih dveh v indeks ogroženosti. Rezultati vseh treh komponent so prikazani v sistemu GIS, ki je splošno uveljavljeno orodje na področju prostorskega načrtovanja. Drug vidik raziskave je osredotočen na postopkovne spremembe v prostorskem načrtovanju, ki bi omogočili uspešno integracijo predlagane metode s prostorskim načrtovanjem. Uporaba metode je prikazana na petih primerih v okviru novelacije prostorskega načrta za Mestno občino Koper. Rezultati raziskave kažejo, da je analiza ogroženosti učinkovit način za integracijo ocenjevanja tveganja v postopke prostorskega načrtovanja.

Ključne besede: tveganje, prostorsko načrtovanje, analiza ogroženosti

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1 EXTENDED INTRODUCTION

1.1 Problem description and relevance

The focus of this doctoral work is the investigation and resolution of issues in spatial/land-use planning related to the siting of hazardous industrial installations.

The problem of successful integration of risk assessment and spatial/land-use planning encompasses multiple issues such as the pressure of the investors, absence of communication between stakeholders, absence of communication between planners and risk assessors, long administrative procedures in land-use planning field and the lack of a methodology that would effectively integrate risk assessment and spatial/land-use planning. The latter is being sought within the framework of this doctoral research.

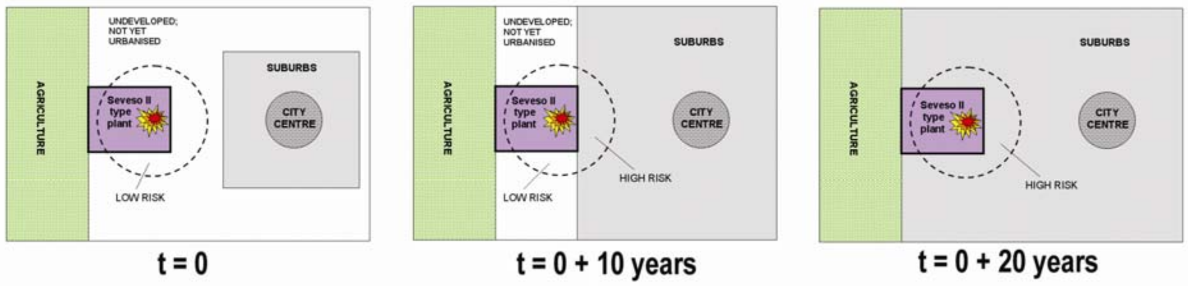
Currently available methods for risk assessment with spatial representation of results serve predominantly for emergency planning, rarely are the results applied for land-use planning purposes (Shape-Risk, 2005). The latter is due to the form of the result of risk assessment which is not directly applicable in land-use planning, mainly because of its probabilistic character. The problem on ineffective risk assessment/land-use planning integration is evident from numerous situations worldwide, especially in the areas where industrial accidents have occurred, e.g. Industrie Chimiche Meda Societa Azionaria – Seveso, Italy, 1976; Union Carbide – Bhopal, India, 1984; AZF de Toulouse – Toulouse, France, 2001; Buncefeld, United Kingdom, 2005, etc.

The key two issues, in terms of the lack of integrative risk assessment and land-use planning are:

- First, the absence of detailed and specific information about the new hazardous industrial installations at the stage of preparing and adopting a land-use plan. Namely, at this stage only generic data is available about hazardous installations which will be situated in an industrial zone. Such generic data are inadequate for preparing specific and quantitative risk assessment which could be the basis for designing a preventive policy with effective risk reduction measures/strategies at the stage of land-use planning. On the other hand detailed risk assessment for existing hazardous installations is possible; however its results have not been applied effectively in a land-use plan.

- Second, changes which appear due to the implementation of a land-use plan. This is illustrated in Figure 1. The message is that neither conformity assessment (confirmation against the selected risk criteria at the stage of land-use plan adoption), nor any kind of environmental impact assessment guarantees that risk will remain low (acceptable) throughout the land-use plan implementation, i.e. no matter what changes occur in urbanisation or other uses of the environment in the surrounding of hazardous installation.

a) CURRENT LAND-USE PLANNING



b) CONFORMITY ASSESSMENT

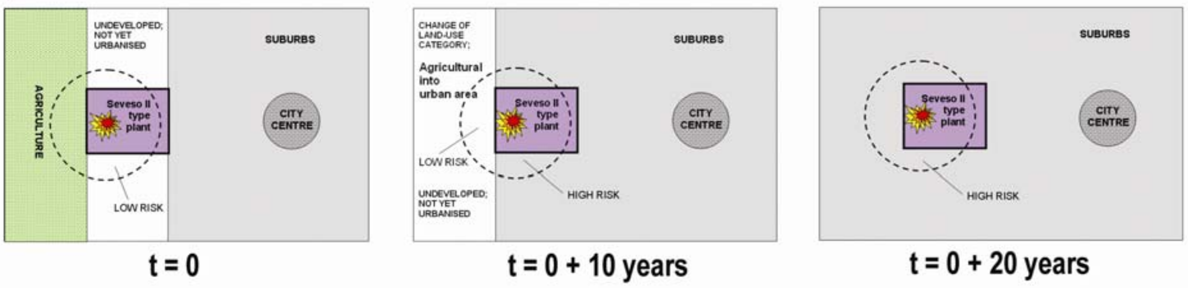


Figure 1: Illustration of risk related land-use planning issues

Part a) of the Figure 1 illustrates current situations: ten or twenty years after the plan approval, and due to urbanisation development in the surroundings of the industrial zone where a hazardous industrial installation, i.e. Seveso II plant[1] is situated, the situation is no longer satisfactory or acceptable (high risk) as it was at the time of plan adoption (at t=0). Possible land-use planning safety (risk) improvement measures are: relocation or shut down of the Seveso II plant; relocation of the population from the residential objects in proximity to the plant if the risk situation is extreme; implementation of additional preventive measures at the

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[1] Seveso II plant/establishment is a common term for hazardous industrial installations from the Seveso II Directive

plant (e.g., safety improvement by installing additional safety devices) as well as more effective protective measures in the surroundings (e.g., additional technical barriers against direct exposure of the population or improvement of the external emergency plan by assuring an effective evacuation). Part b) of the Figure 1 illustrates how the conformity assessment is to be understood. Such an assessment at t=0, i.e. at the time of adopting a plan, may show that the situation in terms of risk is acceptable (low risk). However, if the conformity assessment is done again after ten or twenty years, the result may no longer be satisfactory or acceptable. This would mean that only the "frozen" land-use state, as shown at t=0, assures conformity and low risk. If such a "freezing" of the current state of a land-use plan would indeed be applied it would fundamentally change the existing philosophy and practice of land-use planning. It would basically countermand what the plan (the society) was initially saying should happen as land-use development in the future, so a question about the very purpose of the land-use planning would arise.

In general, the solutions for risk reduction are usually sought in the following approaches:

- decreasing the probability (frequency) of incidents with possible severe consequences
- minimising the consequences if the incident occurs

These two approaches cover the control of both components of risk, i.e. probability and consequences.

Specifically, the most effective preventive approach for reducing the consequences of industrial accidents is provision of appropriate distances between hazardous installations and residential areas (Christou and Papadakis, 1998; Christou et al, 1999; Christou and Mattarelli, 2000; Papazoglou et al. 2000)

Also the new EU (and Slovene) legislation requires such issues to be solved through appropriate spatial/land-use planning (Seveso II Directive, 1996 and 2003; Uredba, 2008) however the legislation does not provide explicit guidelines on how risk assessment and spatial planning should be integrated. Member states are therefore searching for their own best and specific approaches (Papazoglou et al. 2000; Rasmusen et al. 2000; Spadoni et al. 2000; Smeder et al. 1996; Hauptmanns, 2005; Basta and Struckl, 2005, Kontić et al., 2006).

In the context of spatial plan development the appropriate distance can be assured in one of the following phases:

a) in the phase of spatial plan development, where the proposed/chosen location is reserved for new/proposed hazardous installation and is properly distanced from vulnerable areas which are subject of protection (urban areas – hospitals, schools; natural areas, etc.)
b) in the phase of spatial plan revision/change where by changing the land-use plan – predominantly urban use – further proximity of hazardous and vulnerable areas is disabled; in this phase additional social and economic disagreements and conflicts occur associated with desires for closing-down or relocation of existing installations.

Land use planning in Slovenia, like elsewhere, focuses on zoning policy, i.e., dedication of a particular piece of territory to a certain purpose/use. Plan implementation is lead through the licensing process. Licensing relates to the implementation of a plan and is not, strictly speaking, a component of the planning activities (see Figure 2). Licensing basically consists of two stages: i) confirming whether the location of a proposed development project is in accordance with the zoning plan, and ii) confirming whether environmental acceptability standards will be met during operation of the proposed activity (emission and imission standards, nature protection goals and targets, etc.). The latter is to be demonstrated in the framework of an Environmental Impact Assessment (EIA). It is important to note that, at present, no specific quantitative safety standards are available for both stages, neither in Slovenia nor elsewhere. However, the approaches are under development.

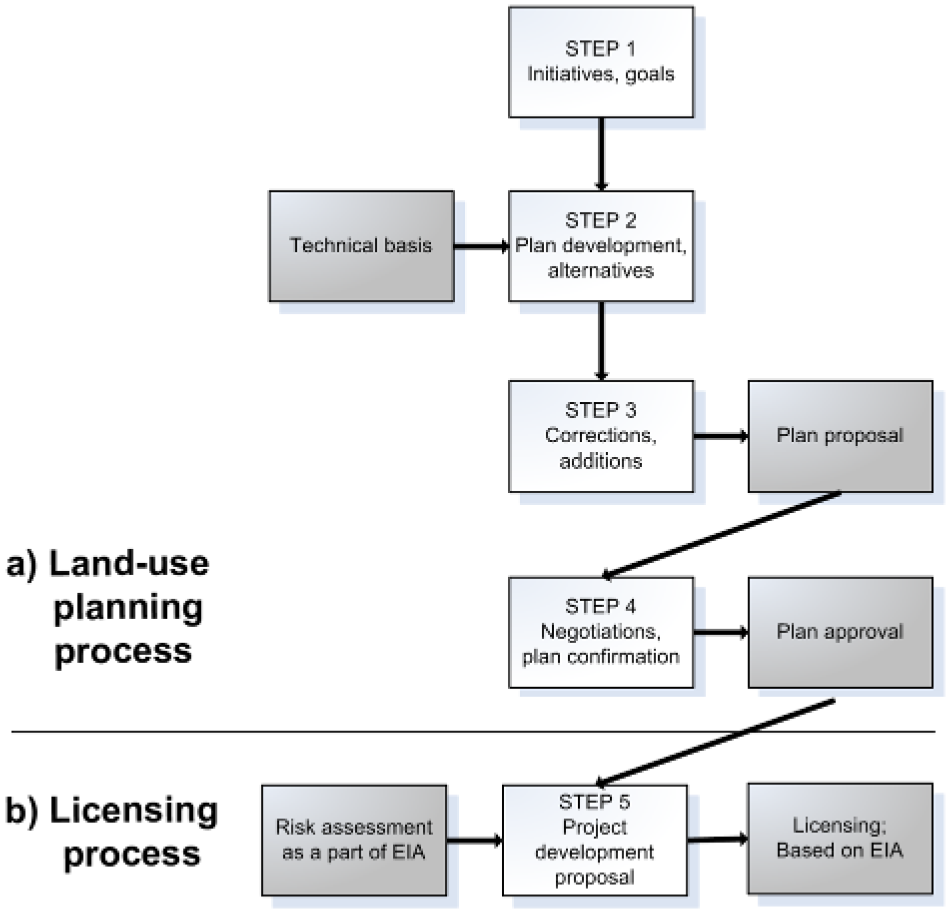

Figure 2: Schematic presentation of a spatial planning process in Slovenia; a) land-use planning process; b) licensing process. The scheme illustrates that at present risk assessment is applied within the licensing process and not in the planning stage.

One of the recent approaches for solving risk and land-use planning integration problems is focused on decision making based on data/experience from previous accidents – Table 1 (Hauptmanns, 2005). It is obvious that risk assessment results are unused in a land-use planning process.

Table 1: Dangerous phenomena and expected distances (Hauptmanns, 2005)

Accident consequence – dangerous phenomena	**Distance**
Toxic release (cloud)	Up to 30 km
Missile ejection	Up to 1200 m (Mexico City)
Explosion	Injuries up to 2 km (Toulouse), broken glass windows to 4,8 km, death to 7 km
Fireball	Radius to 300 m – skinburns to 300 - 400 m (Freyzin, Mexico City)
Vapour cloud explosion	Death up to 2-3 km
Boiling Liquid Expanding Vapour Explosion (BLEVE)	Severe injuries to 500m, broken glass windows to 3 km (Freyzin)

Table 2 provides a collection of information on consequences of selected major industrial accidents. In spite of the fact that this information is uncertain and that societies differ in opinion about its trustworthiness (e.g. number of immediate casualties in Bhopal accident, number of deaths due to the Chernobyl accident, environmental damage in Baia Mare accident, economic damage of Toulouse accident, etc.) it certainly gives an orientation about the relevance of this issue.

Table 2: Consequences of selected major industrial accidents

Accident	**Consequences**
Seveso, 1974 (Christou and Papadakis, 1998)	The "Seveso" accident happened in 1976 at a chemical plant in Seveso, Italy, manufacturing pesticides and herbicides. A dense vapour cloud containing tetrachlorodibenzoparadioxin (TCDD) was released from a reactor, used for the production of trichlorophenol. Commonly known as dioxin, this was a poisonous and carcinogenic by-product of an uncontrolled exothermic reaction. Although no immediate fatalities were reported, kilogramme quantities of the substance lethal to man even in small doses were widely dispersed which resulted in an immediate contamination of some ten square miles of land and vegetation. More than 600 people had to be evacuated from their homes and as many as 2000 were treated for dioxin poisoning.
Mexico city, 1984 (Pietersen, 1988)	Major fire and a series of catastrophic explosions occurred at the PEMEX LPG Terminal. As a consequence, 500 individuals were killed and the terminal destroyed.
Bhopal, 1984 (Christou and Papadakis, 1998)	A release of 40 tonnes of methyl isocyanate (MIC) gas. Consequences were immediate deaths of more than 3,000 people, and approximately 20,000 in total. Two decades later, more than 100,000 people have permanent injuries, light or severe. The groundwater around the plant area remains contaminated, and the question of cleaning up the area is still unresolved.
Chernobyl, 1986 (World nuclear…, 2008)	Severe release of radioactivity into the environment following a massive power excursion which destroyed the reactor. Thirty people died in the explosion, but most deaths from the accident were attributed to fallout. It is difficult to accurately tell the number of deaths caused by the events at Chernobyl.
Toulouse, 2001 (Salvi et al., 2005)	Runaway reaction – explosion in ammonium nitrate storage at AZF (Azote de France) fertilizer factory. Consequences were 30 fatalities and an estimated 10,000 injuries. The plant was located in the suburbs of Toulouse and the extent of damages was very large both on and off-site with a material damage estimated by insurers of 1,5 billion Euro.

1.2 Purpose of the research

The goal of this research is to develop operational, transparent and scientifically based methodology for the integration of risk assessment and spatial/land-use planning.

1.3 Hypothesis development

Generally it is assumed that risk assessment and spatial/land-use planning can be successfully integrated by modifications of both the existing risk assessment and the spatial/land-use planning methods.

The modification/improvement of a risk assessment methodology should include its transformation to yield results in a form useful for spatial/land-use planners. Comparative analysis of risk assessment methods plays an important part in this context in order to determine the applicability of existing risk assessment methods for land-use planning; also it serves as a guide for developing an integrative method as a goal of this research..

The main reasons why planning process for hazardous industrial installations should be modified are:

- Implementation of the concept of proper safe distances is possible only if a hazardous installation is known and specified, i.e. if the impact/risk area can be determined. This is achievable only for existing installations and those for which licensing process is taking place. At the level of preparing a new zoning (land-use) plan, precise information on new hazardous occupants of the zones are not available, so the concept of proper distances based on accurate risk assessment is not possible at this stage.
- Licensing means that a development project is in its final planning stage. No investor would start the licensing process during preparation of a new land use plan, i.e., without assurance that the proposed location for the project is in accordance with the approved land-use plan – acceptable in terms of administrative procedure and social/economic development;
- In order to make land-use planning successful, the participation of all stakeholders must be established in a plan developing process, not only in a plan implementation process. This is difficult to achieve in the case of lack of information or ineffective presentation of information.

Modifications of spatial planning methodology are required to successfully implement risk assessment into the plan development process. These include improvement of the spatial/land-use planning procedure, which would allow discussion and optimisation of industrial risk from the early beginning of a plan development process.

The method for risk assessment and spatial/land-use planning integration should encompass the following procedural components:

a) Determination of safety in association with threat caused by hazardous installation/activity
b) Determination of environmental vulnerability in the study area
c) Determination of proper land uses in risk areas (safety regime)

d) Optimisation and decision-making about the acceptance of possible accident consequences – spatial/land-use plan approval
e) Threat reduction measures imposed by land-use planning

1.4 Process of the research

The research was carried out in the following sequence:

1. Problem identification and definition
2. Hypothesis for solving the problem – direction of the research
3. Scope of the research
    - development of a method for integrating risk assessment and land-use planning
    - testing the method in the process of land-use plan renewal for the Municipality of Koper
    - consolidation of the method, critical response to the work and recommendations for future investigation
4. Reflection on the hypothesis; discussion
5. Practical implications of the work

1.5 Organisation of the text

The dissertation is organised as follows:

1. In the first chapter problem definition and relevance are described.
2. In the second chapter the theoretical background to risk assessment and planning for natural hazards as an analogy for industrial risk land-use planning are presented.
3. In the third chapter the threat analysis method, as the main "product" of this dissertation is described.
4. In the fourth chapter results of threat analysis applied to a test case of LPG storage facility in the context of a spatial plan revision in the Municipality of Koper are presented.
5. In the fifth chapter discussion and critical reflection to the work is provided.

1.6 Glossary

The following selected terms are defined for the purpose of this dissertation:

Hazard – a chemical or physical condition that has the potential for causing damage to people, property or the environment. Most hazards are potential with only a theoretical risk of harm. A hazard is usually used to describe a potentially harmful situation, although not usually the event itself – once the event has started it is classified as an emergency or an incident (Seveso II Directive, 1996, 2003; Defra, 2007; Merriam-Webster online dictionary, 2007).

Risk – a combination of the likelihood of occurrence of a defined hazard and the magnitude of the unwanted consequences of the occurrence; a combination of severity of the incident and the vulnerability of targets; a combination of hazard and exposure to the potential effects (AICHE, 1989; Seveso II Directive, 1996, 2003; Defra, 2007; Wikipedia, 2007).

Threat – specific evaluation of potential harm/loss being inflicted on the actual targets (Merriam-Webster online dictionary, 2007; Wikipedia, 2007). The key difference between hazard and threat is that threat relates to known subjects/elements of the environment which may experience consequences. The key difference between threat and risk is that threat does not specify likelihood of the consequences in question. The benefit of introducing threat into land-use planning is twofold:

- The land-use plan, as a product, does not involve the notion of likelihood of using land, so risk does appear to be an efficient basis for determining actual and neighbouring land uses.
- Actual consequence consideration in the land-use plan enables specification of conditions for neighbouring land uses, as well as organisational and architectural conditions and solutions for urbanisation.

Land-use planning – refers to the process of generating land use plans. The phase of plan implementation (i.e. confirming conformity in the process of approval of development proposals, licensing) is excluded from the understanding of this term; see also Figure 2.

Environmental threat-vulnerability – a state or characteristic of the environmental component which is the receptor of a negative change (effect) due to an accident involving hazardous materials (Kværner J., et al., 2006; Tixier J. et al., 2005, 2006; Marušič, 1993, 1997).

Spatial attractiveness – in the context of land-use planning the term attractiveness relates primarily to the economic efficiency (benefit) of a site where a development proposal is going to be realised, e.g. morphology of the terrain, availability of infrastructure (roads, electricity, etc.), water, workforce, etc.

Incident – a manifestation of an initiation or a sequence of events which deviates from a normal operation and leads to unwanted consequences, loss of containment – a release – of materials or energy (AICHE, 1989)

Accident – an incident with defined consequences (AICHE, 1989)

Accident scenario – a description of an unplanned event or sequence of events that result in an undesirable consequence (LOPA, 2001).

2 THEORETICAL BACKGROUND

The idea of risk-informed land-use planning is very old. Through the course of history human populations have been at risk of various hazardous events, typically in the form of war, plague, flood, volcanoes or earthquake. Those human populations who are still here to tell us about it are those which planned (Staines, 2002).

The main aim of planning for disasters is to acquire the basis for guiding the development scenarios away from risk sources (Paleo and Trusdell, 2002; Mušič, 1993)

2.1 Risk assessment and land-use planning

Industrial risk assessment in its broad definition is a structured procedure that evaluates qualitatively and/or quantitatively the level of risk imposed by the hazard sources identified within the industrial establishment. Its scope is recognised to be to assess the safety of the establishment and to determine the risk imposed on the surrounding population and environment, with aim of improving safety and minimising risks. It is noteworthy that although the various risk assessment methods, qualitative or quantitative, may differ in the results provided, they all have the same scope. The emphasis in a risk assessment should not necessarily be placed on the absolute accuracy of its predictions, but rather on its success or failure in demonstrating or improving the safety of the establishment.

The basic purpose of environmental risk assessment is to identify possible consequences – the impact on the environment (including humans, nature, resources and material values) in the case of an incident for the purpose of environmental protection and management. To achieve this purpose it is necessary to develop a so-called incident scenario (for each incident) as a basis for the analysis.

An incident scenario is a description of an unplanned event or sequence of events that result in an undesirable consequence (LOPA, 2001: 43). Each scenario consists of an initiating event and the consequence of that particular event. In addition, scenarios may include enabling events or conditions and/or the failure of safeguards or barriers. The comprehensive risk assessment process that involves all necessary steps is schematically presented in Figures 3 and 4 (Kontić and Gerbec, 2004; Kontić D and B, 2008; Gerbec and Kontić, 2008).

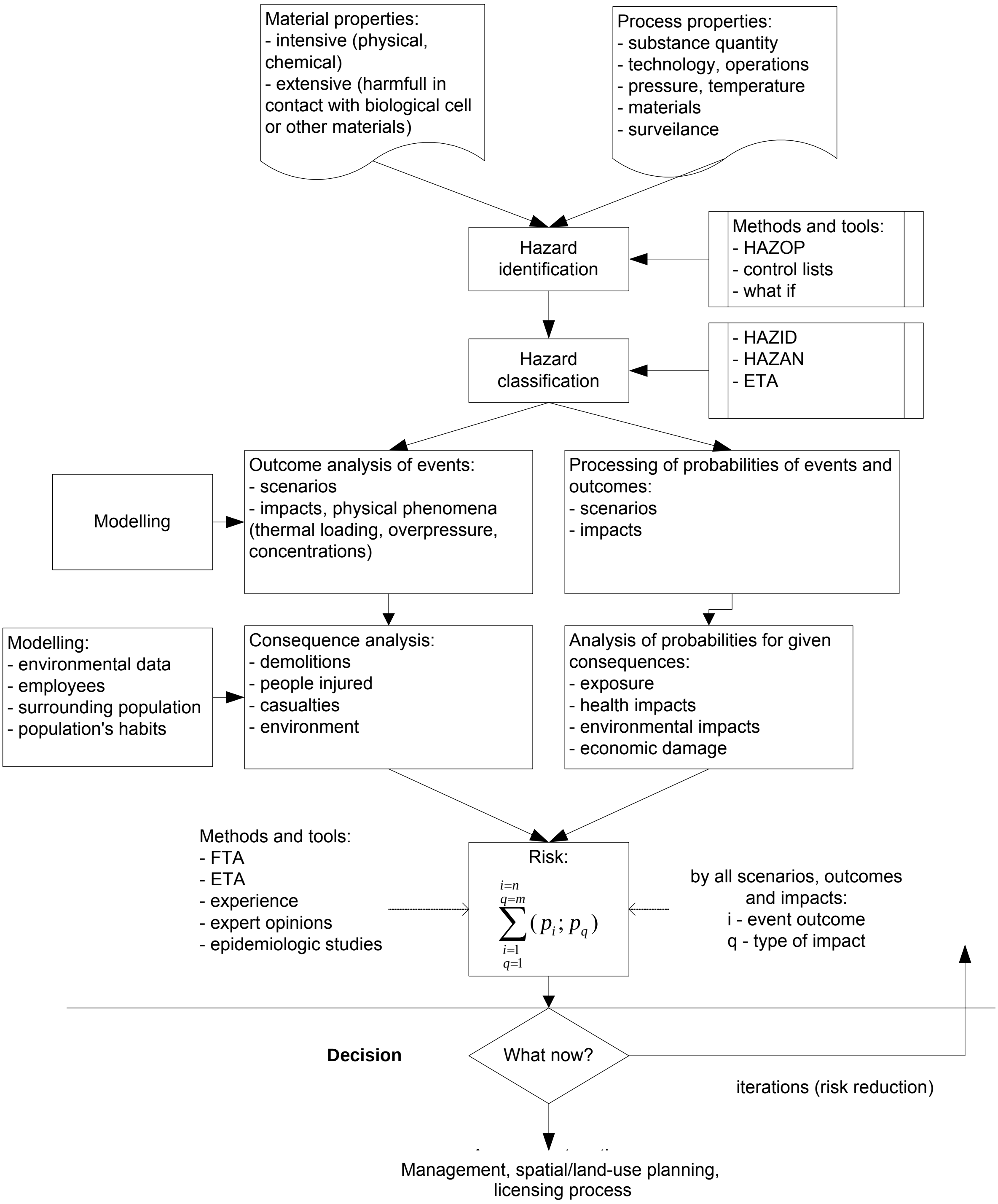

Figure 3: Schematic presentation of a risk assessment process

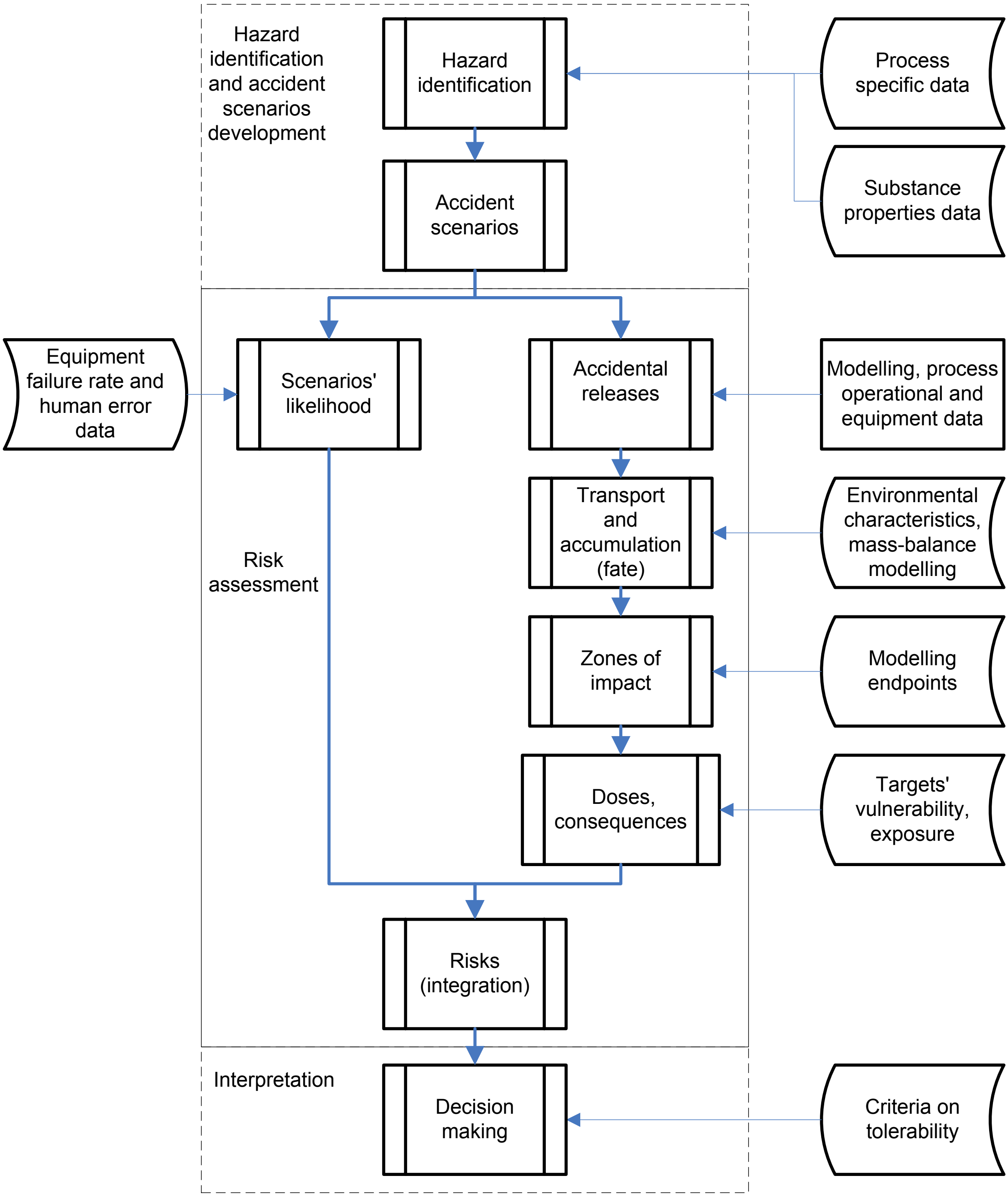

Figure 4: A flow diagram of risk assessment for the purpose of evaluating the environmental consequences

The process of risk assessment is complex, however it can be standardised in the following basic operations:

- Identification of process equipment susceptible to failure
- Determination of incident scenarios and possible dangerous/harmful consequences
- Determination/calculation of probabilities and frequencies of incident scenarios
- Determination/calculation of impacts of incidents

Based on this, risk is defined as a function of the following two main components – intensity, i.e. magnitude of an incident (severity), and its potential to cause concrete consequences, taking into account the vulnerability of potential targets.

Risk assessment methods have been developed for a wide range of applications. The existing risk assessment methods for land-use planning may be considered as a specific subdivision of those risk assessment methods used in the context of the safety of industrial establishments; some examples show a more integrated character that links risk assessment with land-use planning purposes (ARAMIS, 2004).

The results of risk assessment methods in principle may be represented by one of the following four types (also in various combinations):

Qualitative	**Quantitative**	**Deterministic**	**Probabilistic**
Non - Numerical Assessment	Numerical Assessment	Safety*[2] defined as a discrete value	Safety* defined as a distribution function

2.1.1 Role of risk scenario in land-use planning

Scenario development is a tool for achieving a basic understanding of the events and safeguards (barriers). The purpose of scenario analysis is to provide important information regarding the selection of the reference accident scenarios to be used as a basis for risk informed spatial/land-use planning (Kontić B. and Kontić D., 2007). The most common tool used in scenario analysis is a Bow-Tie (AICHE, 1989; ARAMIS, 2004b, Christou et al.,

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[2] the common term safety is used to reflect the hazard/risk related issues, respectively.

2006). It consists of fault tree and event tree analysis. The structure of a Bow-Tie is shown in Figure 5.

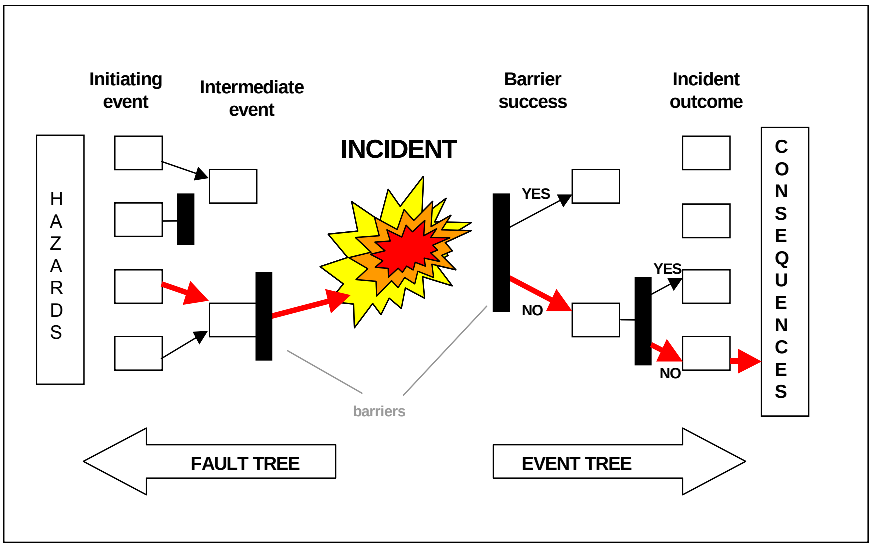

Figure 5: Schematic representation of the Bow-Tie approach.

Fault tree analysis permits the incident to be estimated from a logic model of the failure mechanisms of a system. The model is based on the combinations of failures of more basic system components, safety systems and human reliability (AICHE, 1989: 193).

An event tree is a graphical logic model that identifies and quantifies possible outcomes following an incident. The event tree provides systematic coverage of the time sequence of event development, either through a series of protective system actions or operator interventions (AICHE, 1989: 212).

Each scenario consists of an initiating event and the consequence of that particular event. In such a configuration the scenario consists of sequential consideration of the performance of each barrier that prevents propagation of the initial event towards its consequences. The key element of any accident scenario is therefore the failure of a barrier. If a barrier fails, it means that the initial event propagates towards exposure to a particular hazard. Barriers may be technical (safety device), human (organisational), or a combination of the two.

For land-use planning purposes any risk assessment scenario results should consist of at least the following four kinds of information: type of impacts which are expected in the case of an accident (physical phenomena like thermal radiation, overpressure, toxic concentrations), intensity of impacts (quantitative description of the phenomena in terms of potential damage in the surroundings of the hazardous facility), size of impact area (distances and geographical directions in which consequences are expected), and likelihood of the scenario and its consequences.

All these types of information call for detailed information about the technology, capacities, substance characteristics, process parameters, state of process equipment, characteristics of location, etc., which in the spatial/land-use planning stage are not available (Hauptmanns, 2005).

2.1.2 Severity – intensity, magnitude of incident

Severity represents the magnitude and spatial distribution of the consequences associated with selected physical effects of incident outcomes (overpressure, thermal radiation, toxic concentrations in air and water) (ARAMIS, 2004a; Casal et al., 2004; Planas et al., 2006). Risk severity allows the assessment of the risk level originated by a given installation over the affected zone (Planas et al., 2006). It represents one of the two components of risk assessment that are to be used in spatial/land-use planning.

The result of incident severity analysis consists of the intensity or magnitude of an incident; additional information is provided in terms of the probability of occurrence. It is desirable that the results are expressed as the size of the impact area.

2.1.3 Environmental vulnerability

Environmental vulnerability is defined as the state (quality) of a certain environmental component/phenomenon reflecting the potential, which can be a subject of manifestation of negative effects if a certain exposure occurs. Environmental vulnerability is, therefore, the characteristic of the environment expressed as a level (grade) of possible negative effects due to realisation of a certain activity (Marušič, 1999; Mlakar and Marušič, 2000), or hazard. This expression and interpretation is made based on appropriate simulations of realisation of the action.

The concept of vulnerability implies a measure of risk combined with the level of social and economic ability to cope with the resulting event (Smith, 1998). Vulnerability, in this context, can also be defined as the degree to which a system, or part of a system, may react adversely to occurrence of a hazardous event (Smith, 1998).

Vulnerability is also defined as "… those characteristics of a person or a group affecting his/their capacity to anticipate, cope with, resist or recover from the impact of a natural (or other) disaster" (Staines, 2002: 62).

The vulnerability level of an environmental element is defined as the ratio of expected loss to the maximum possible loss, on a scale of 0 – 100% (Coburn and Spence, 1992: 256). It takes into account a set of threshold levels concerning the diverse accident effects.

Vulnerability analysis is the key step in preventive environmental protection in the context of spatial planning, as well as being the tool for policy, program and plan assessments. In spatial planning the main goal is to solve the problem – finding an appropriate/suitable location for the development project (use of land). Vulnerability analysis as a tool is also useful for simulating possible negative effects of proposed spatial developments, through which their acceptance for realisation can be assessed. The fundamental basis of vulnerability analysis is the determination of locations where, for environmental protection reasons, the proposed development is not favoured, The elements of vulnerability analysis are also used for comparative assessment of development alternatives.

Vulnerability analysis is used in two forms of application, which relate to two approaches to solving environmental protection issues. These are:

- Spatial/location improvement – generation of location alternatives, which means compliance with environmental protection goals by locating the development/activity in a non-vulnerable environment for that particular activity;
- If a vulnerable area cannot be avoided when locating a new development/activity, vulnerability analyses notify the need for technological improvements of a proposed project. This relates to implementing a technology that complies with environmental protection goals in the particular area (e.g. Best Available Technologies – BAT).

2.1.4 Probability

Besides severity of an incident and vulnerability of potential receivers of unwanted consequences, probability plays an important role in risk based decision-making (Slovic et al, 1984; Wynne, B. 1992; Pidgeon and Beattie, 1999; Laheij, 2000; Burger, 2001; Slovic, 2001). In this regard, the most frequently addressed issue is the associated uncertainty and public perception of risk. This is associated with the rate of success of industrial establishment (or other activities) in a certain environment, which is in most cases based on the particular society's belief regarding the possible harmful effects toward themselves, the environment and resources.

The probability should have a role when considering minimising the risk to an acceptable level. Commonly, this is achieved by isolating a source of risk and potential targets (vulnerable environmental components). If we are to understand isolation not only geographically, but also chronologically, lowering the probability of an accident is a method of achieving the goal of isolating vulnerable environmental components from the source of risk. By this means, a new set of questions is raised regarding how to systematically include the aspect of time dilution (probability) in the spatial/land-use planning process.

Nevertheless, the praxis of "time dilution" is used in spatial/land-use planning for natural hazards. Few examples include land-use planning for flood areas and earthquakes, which are based on probability concept – the return period of high waterflows, probability of occurrence (Waananen, 1979; Berke and Beatley, 1992; Smith, 1998; Tamura, 2000).

Another role of probability in risk informed spatial/land-use planning would be the inclusion of probability of meteorological conditions (wind direction and velocity, temperature) for a designated scenario (of toxic release in the air, for example). It is evident that the expected consequences considering meteorological conditions would differ from those not considering meteorological conditions.

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2.2 Spatial/Land-use planning

2.2.1 General

Land-use planning is defined as "a systematic assessment of land and water potential, alternative patterns of land use and other physical, social and economic conditions, for the purpose of selecting and adopting land use options which are most beneficial to land users without degrading the resources or the environment, together with the selection and implementation of measures most likely to encourage such land uses…" (FAO, 1976).

A plan is an intellectual anticipation of a desirable situation in the future, or in more simple words: a plan describes how a situation will exist. Planning is therefore the procedure for elaborating a plan. Actually this term covers a range of activities, from procedures of a purely technical type to administrative or governmental arrangements.

Land-use planning has to be understood as an aspect of spatial planning, a term that refers to the space as a multidimensional concept that describes and reflects the synthesis of the physical environment and its use by humans, whereas traditional land-use planning deals only with the efficient use of land (land as a synonym for the surface of the earth).

The EC provides a definition of "spatial planning" in its 1997 Compendium of Spatial Planning Systems and Policies (European Commission, 1997):

"Spatial planning refers to the methods used by the public sector to influence the future distribution of activities in a space. It is undertaken with the aim of creating more rational territorial organisation of land uses and linkages between them to balance demands for development with the need to protect the environment and to achieve social and economic objectives. Spatial planning embraces measures to co-ordinate the spatial impacts of other sectoral policies to achieve more even distribution of economic development between regions than would otherwise be created by market forces and to regulate the conversion of land and property uses".

Spatial planning is thus a process of decision making, weighing between social, ecologic and economic demands. It is a steering instrument and also a regulatory procedure that:

- supports the economic development of the society
- safeguards environmental sustainability, including the safety of people
- achieves a reduction of regional disparity, and
- supports the development and stability of resources.

Spatial planning has also the character of a common generic term for the national physical/land use/territorial planning systems. The latter describe government action to regulate development and land uses in pursuit of agreed objectives. This form of planning is one policy sector within government, alongside policy sectors such as transport, agriculture, environmental protection and regional policy, although it may incorporate mechanisms to coordinate other sector policies.

The main objectives of land-use planning are:

- Achieving as equal as possible living conditions for the population
- Improvement of living conditions by creating a balanced structure of economy and the social system
- Protection of the population and the environment against harm caused by natural or man-made incidents
- Protection of natural resources
- Supply of the public with housing, infrastructure, recreation possibilities and facilities for social and educational needs
- Secure the agricultural resources in order to ensure the supply of the public with aliments and related raw products
- Develop the land use in balance with the ecological and economic capacities
- Give precedence to public over private interest.

Planning usually contributes only to small changes in the 'status quo' of the spatial structure. In 'normal' conditions, planning is rather remedial, correcting deficiencies; is performed in a step by step manner; is dealing with problem after problem; is explorative, and does not know all the results in advance. It addresses the spatial organisation of various human activities sharing the limited space of settlements and co-directs policies and decisions, where it brings together many functional, structural, environmental protection and, recently, safety determinants (Mušič, 1993).

The general plans are in essence models of a possible reality (Steinitz, 1976, 1990). Their service in connection with hazard mitigation is primarily in guiding future states of the environment against the identified scenarios of accidents (natural or technological in origin).

Many land-use planning methods are based on environmental impact assessment, whose basis is analysis based on interaction between environmental qualities and the activity which is to be introduced. This interaction undergoes the evaluation process and the output result is an environmental vulnerability model in which suitable locations for proposed activity are presented. However, such environmental vulnerability analysis is conducted exclusively for normal operation (taking in consideration continuous point source pollution and nuisance), and excludes the incident scenarios. Risk is, therefore, not implemented in planning process when new industrial sites are developed.

Environmental impact assessment has its basis in a systematic, interdisciplinary approach that ensures the integrated use of natural and social sciences and the environmental design arts in planning and decision making which would result in impact on the environment. The basic reason for enforcing environmental impact assessment (EIA) in decision making processes was that public/society could have a more thorough understanding of – and possible influence on – the results. The latter would consequently mean less aversion towards proposed new projects/establishments.

Land use planning in Slovenia is based on zoning process derived from spatial and economic analysis (structural analysis, urban analysis, acceptability analysis, feasibility analysis, etc.). At the end of the process, zones are identified in which activities are, through the later licensing process (an important part here is played by environmental impact assessment for a given activity – considering primarily normal operation), permitted to operate. As is clearly stated, in the process of zoning no industrial risk assessment is taken into consideration; on the other hand, natural hazards are included into the zoning process.

2.2.2 Tools relevant in land-use planning

In the framework of the land-use planning process several tools exist for determining and establishing the desired/planned state in the space. Some of these tools encompass:

- Development of spatial development strategies
- Zoning ordinance (spatial development conditions, building codes)
- Strategic Environmental Impact Assessment
- Designation of protection zones

Development of spatial development strategies

Spatial development strategies guide spatial development in order to achieve harmony among different stakeholders.

Commonly they define:

- goals of spatial development in a given entity
- general zoning in space with emphasised priorities and guidelines for achieving the aforementioned goals
- general zoning of a spatial/landscape system such as residential development, development of infrastructure, landscape planning, natural resources, special nature protected areas, threatened areas due to natural or man-made accidents.

Zoning ordinance (spatial development conditions, building codes)

The primary purpose of zoning is to segregate uses that are thought to be incompatible. In practice, zoning is used as the basis within a permitting system to prevent new development from harming existing spatial entities, their status and/or qualities. Zoning is commonly controlled by local governments (municipalities), though the nature of the zoning regime may be determined by state or national planning authorities.

Zoning includes regulation regarding the acceptable activities on particular lots (such as open space, residential, agricultural, commercial or industrial), the densities at which those activities can be performed (from low-density housing such as single family homes to high-density such as high-rise apartment buildings), the height of buildings, the amount of space structures may occupy, the location of a building on the lot (setbacks), the proportions of the types of space on a lot (for example, how much landscaped space and how much paved space), and how much parking must be provided.

A building code (or building control) is a set of rules that specify the minimum acceptable level of safety for constructed objects such as buildings and non-building structures. The main purpose of the building codes is to protect public health, safety and general welfare as they relate to the construction and occupancy of buildings and structures. The building code becomes law of a particular jurisdiction when formally enacted by the appropriate authority. Building codes are generally intended to be applied by architects and engineers, safety inspectors, environmental scientists, real estate developers, contractors and subcontractors, manufacturers of building products and materials, insurance companies, facility managers, tenants and others.

Strategic Environmental (Impact) Assessment

Strategic Environmental (Impact) Assessment (SEA) is a system of incorporating environmental considerations into policies, plans and programmes.

The SEA aims at introducing systematic assessment of the environmental effects of strategic land use related plans and programs. It typically applies to regional and local development.

To be effective, SEA should be fully integrated into the plan-making process. It should be started as soon as a new or revised plan is first considered, and should make inputs at each stage at which decisions are taken. It should also be used in developing the arrangements for monitoring the implementation of the plan, in order to identify problems and inform the next revision or replacement.

Development of protection zones

The philosophy behind the establishment of protection zones is a clearly identified regime of use of space (land) in the designated area. It should be noted that protection zones are often a subject of other legislation sectors rather than spatial planning (not directly related to land-use planning legislation), however they are often enforced through land-use planning processes (for example noise standards, special nature protected areas, etc.).

As spatial planning is aimed primarily at the optimisation of land-uses in a particular area, the approaches of standardisation are less favoured in spatial/land-use planning field of expertise (Marušič and Mlakar, 2004). Examples of establishing noise standards and special nature protection areas are presented in the following.

Noise standards

Noise emission is particularly interesting because it is a dissipation of energy. In this regard the analogy with pressure blast waves and thermal radiation dissipation in case of an accident is immediately seen.

Noise standards are set, based on the vulnerability of a designated area to the effects of noise, however the relation of these areas to land-use planning and management is not set. Noise assessment is usually performed on a case by case basis (for a particular development or in the context of environmental impact assessment), independently of land-use planning (Mlakar, 2006). However, a land-use plan could serve as an effective tool for implementing noise standards. A similar point is expected from the development of the treat analysis methodology proposed in this dissertation.

Strategic noise mapping is an important development in terms of protection zones as well as the emission implementation in spatial/land-use planning. However, such standardisation in the form of strategic noise maps, as suggested by the EU Directive on environmental noise 2002/49/EC, raises questions regarding its applicability in optimisation-oriented land-use planning. The disadvantages of this analogy are the pre-set “appropriate” distances from noise emission sources (roads, railways). The distances are set to a pre- specified level, and do not reflect the actual noise level.

The primary concept of spatial/land-use planning in relation to noise standard applications is that noise threshold levels are set for particular areas and that new developments should not contribute to the increase of noise impact (burden).

The aim of this method, in terms of providing answers for risk-informed land-use planning approach as developed in this research, is primarily in setting thresholds regarding the physical effects which should not be exceeded – this is the question oriented towards competent authorities i.e. the decision makers.

Another aspect in this regard would be the strategic noise mapping if upgraded to the possibility of including the actual reference levels. In the latter case the maps would be produced according to the actual situation in the environment and not solely on assumptions.

Special nature protection areas – Natura 2000

The most significant aspect for this analogy is the provision of management guidelines simultaneously with the designation of a particular area as the Natura 2000 site. The criteria for the designation (classification) are also provided. The establishment of such guidelines/regime is a necessary element in the risk informed land-use planning.

In terms of land-use planning the information regarding the special natural areas is involved in the process through the inclusion of the technical basis or in the phase of establishing or overviewing the planning incentives, background and technical basis.

The praxis in terms of land-use planning is that only the protection part is being addressed, which is not appropriate. Land-use planning, being a process of optimisation and negotiation about the most appropriate use of a certain piece of land, also requires the development needs (spatial attractiveness for certain activities) to be included in the process. The principle of establishing zones of spatial standardisation does not follow this concept.

2.2.3 Spatial/land-use planning for various types of hazard

For the purpose of finding a framework for appropriate spatial/land-use planning methodology for hazardous industrial installations, the research has been specifically focused on investigating the background for spatial/land-use planning for natural hazards such as earthquakes, volcanoes, landslides, floods and tsunamis and for nuclear establishments.

Approximately 25% of the world’s population live in areas at risk from natural hazards. The most vulnerable of these are indigent people, having little choice but to settle in unsafe locations – an economy driven phenomenon (Smith, 1998). In addition to location, building codes are rarely followed due to economic reasons; hence the potential disaster brings more severe consequences.

The main purpose of land-use planning for natural hazards is to guide new residential, commercial and industrial development away from identified hazard zones. However, land use planning has an additional role to play in lessening potential loss in areas already occupied (Smith, 1998: 114).

The main practical limitations on land use planning are imposed by (Smith, 1998):

- lack of knowledge about the location, recurrence interval and hazard potential of events which might affect parts of urban areas;
- the presence of extensive existing development;
- the frequency of most events and the difficulty of maintaining community awareness and the ongoing avoidance of hazard-prone land;
- the high costs of hazard mapping, including detailed inventories of existing land use, structures, occupancy levels, etc.;
- the high cost of many mitigation measures, especially structural responses;
- political resistance to land use controls on philosophical grounds;
- 'rent-seeking' processes which pass on the costs to others.

Successful land-use planning depends on the availability of information identifying particular hazardous locations/zones. Accurate delimitation of the hazard zone is crucial because the entire policy is based on the detailed recognition and community acceptance of different degrees of risk which, in turn, justify the implementation of selective development controls. Ideally, variations in risk should be identifiable down to the level of individual properties.

For many hazards, such as cyclones and earthquakes, such precision is unattainable (Smith, 1998). The greatest accuracy is achieved with hazards like floods, landslides and volcanoes. In the following section the prevention and mitigation measures for the latter categories of hazards are detailed. For Slovenia floods are of most relevance.

In recent disasters (tsunamis, volcanoes, tornados) the question of risk-informed land-use planning was again raised, however the extent of such events is too large and the uncertainty too great for measures to be sought within the framework of land-use planning (e.g. relocation of the residential areas in the southern coastal area of the United States of America.). However the rationale behind such measures is of course under concern, in view of the sum of ever-repeating damage /loss.

Earthquakes

The most direct goal of earthquake protection land use planning is to avoid development of hazardous areas (Berke and Beatley, 1992: 9; Smith, 1998: 152). This is achieved by cluster zoning, through which development is restricted to less hazardous areas, and high-hazard areas are left as open spaces (parks, etc.) (Berke and Beatley, 1992; Coburn and Spence, 1992).

Methodologically, earthquake hazard protection land-use planning consists of:

a) seismic microzoning (map) of the geological earthquake hazards and
b) seismic vulnerability mapping of the buildings and facilities in the area (city)

ad a) Some types of ground are safer than others in earthquakes. In addition to the numerous ground failures caused by earthquake vibrations, such as landslides, slope failures, liquefaction and rockfalls, it is well established that different types of ground vibrate with different severity in earthquakes, causing higher damage levels to environmental/manmade values (e.g. softer soils are known to amplify earthquake intensities). Identification of different ground conditions in terms of their earthquake hazard is an important tool for urban land-use planning (Coburn and Spence, 1992: 151; Smith, 1998: 152) aimed at avoidance of building in areas of higher earthquake hazard, hence reducing risk.

ad b) It encompasses physical attributes of the building stock in a more comprehensive way than required by other planning activities (Coburn and Spence, 1992). In addition to the characteristics and parameters such as function, plot development, density and gabarites normally associated with urban planning, earthquake protection requires information on construction materials and methods, structural form, height and size, engineering design quality, age and other indicators of seismic vulnerability.

The limitations of the land-use planning approach for earthquake consequence mitigation are the following – (i) land-use planning is essentially opportunistic; there must exist a need for new development (e.g. an expanding city), a choice between alternative areas in which development is possible, and the difference between earthquake hazard levels in those areas, (ii) development has to be controllable, however controlling risk through land-use practices is problematic in existing developed areas (cities), because they are likely to retain their historical layout (Coburn and Spence, 1992).

Volcanoes

Land-use planning has an important role to play in reducing volcanic disasters, both in terms of restricting development in hazardous areas and in the preparation of emergency evacuation plans (Zobin, 2001). Land-use zoning and the selection of safe sites depends on long-range predictions of the probability of volcanic activity and the identification of areas of potential risk. Past infrequent episodes require accurate geological-scale dating techniques. Volcanic-hazard maps can be prepared, which show the possible areal extent of volcanic phenomena in the future, as inferred from the geological evidence of past events. The major limitations of such mapping stem from lack of knowledge of the size of future eruptions which, for example, makes it difficult to assess the extent of a pyroclastic surge or the length of travel of a valley lahar (Petrazzuoli and Zuccaro, 2004). Environmental conditions at the time of eruption are also important.

Volcanoes introduce another aspect of physical effect into possible consequences – the overpressure released by explosion and toxic releases – therefore they may serve as an analogy for planning for industrial explosions and toxic releases as described and modelled by Saito (2001) and Carapezza et al. (2003).

Landslides

Techniques available to planners and decision makers to avoid landslide hazard and reduce potential damage can be divided into the following categories (Erley, 1981):

1. Discouraging development in landslide-prone areas
2. Regulating development in landslide-prone areas using land-use planning tools
3. Protecting existing development in landslide-prone areas with engineering solutions such as slide control, mudflow diversion, monitoring and warning system

4. Removing or converting existing development in landslide-prone areas
5. Stabilising slopes using vegetation

The techniques may be used in a variety of combinations to help solve both existing and potential landslide problems. A prerequisite for the successful use of any of these techniques is the availability of adequate and reliable earth-science information on the character of landslides, including debris flows, creep, lateral spreads, and rockfalls. On the other hand, lack of clear guidance on how to apply this information in a concrete land-use plan may discourage the approach and leave the techniques ineffective.

Floods

In Slovenia 40 % of the population is situated in flood-prone areas (MOP, 2002). Flood-prone area maps and other flood information facilitate effective land-use planning by providing an overview of the potential flood hazard and detailed information for planning. Various measures are available for reducing flood losses through protection, removal, or conversion of existing development, discouragement of development in high-risk areas, and regulation of land uses on flood plains.

The problems resulting from flood-plain occupancy and use have led to development of structural and non-structural measures for reducing flood damage.

A basic feature of flood-plain regulation is the establishment of a regulatory flood discharge, commonly the 100-year flood (Kidson et al, 2005). The 100-year flood generally has been accepted as the base flood for flood-hazard evaluation, flood insurance, and flood-plain planning.

In planning for flood-loss reduction, the main concern is defining appropriate land uses for flood-prone areas (Besio et al, 1998; Spalivero, 2002). The determination of appropriate land uses is a technical-social-political process involving personal and corporate aspirations and legal rights, as well as public goals and objectives. A well-conceived and implemented land-use plan can lead to significant reduction in flood losses at relatively small public cost, particularly in areas where little or no development of the flood plain has occurred.

Nuclear establishments

Even though nuclear objects are not included in the framework of Seveso II Directive, philosophically they cannot be excluded from the research. The main difference in terms of planning for such establishments is the hierarchy of planning. Nuclear objects are planned at the national level and therefore undergo a different planning process. The most important difference in this case is that locations are sought individually for a single establishment, unlike in the phase of preparation of a land-use plan. Also, multiple data regarding environmental impacts, safety, etc. are thoroughly analysed in the planning stage. Therefore, when seeking a location for such establishments, the impact from normal, as well as abnormal operation (incidents) can, to a large extent, be predicted.

2.2.4 Spatial/land-use planning for hazardous industrial establishments

There are three main approaches to risk-informed land-use planning (Cristou and Porter, 1999; Christou and Mattarelli, 2000; Cristou et al., 2006):

a) the approach of generic separation (safety) distances,
b) the consequence-based approach, which focuses on the assessment of consequences of a number of conceivable event scenarios and shows the consequence area for lethal effects and serious injuries resulting from the scenarios assessed,
c) a risk-based approach which focuses on the assessment of both consequences and probabilities of occurrence of the possible event scenarios; it defines an area within which there is a given probability of a specified level of harm resulting from the large number of possible accident scenarios

Besides these main categories, a hybrid approach is also in use which is a combination of the last two; however, integration with the land-use planning process has not yet been established with any of the approaches. However, the praxis worldwide is risk-based conformity assessment of a development proposal or an existing situation coupled with the land-use planning goals, rather than integration into the land-use planning process as it is usually stated.

2.2.4.1 Generic safety distances

The determination and use of generic separation distances is based on the type of activity rather than on a detailed analysis of the risks. These safety distances are usually derived from expert judgments and are mainly based on historical factors, experience from operating similar plants, rough consequence calculations or information regarding the environmental impact of the plant. The approach of generic separation distances has been established and used in Germany and Sweden (Christou et al, 1999; Christou and Mattarelli, 2000; Hauptmanns, 2005).

Tables of appropriate distances are often used because of the limited relevance/knowledge of the case. The distance depends mainly on the type of industrial activity or on the quantity and type of hazardous substances present. Design characteristics, safety measures and particular features of the establishment under question are not explicitly taken into account. “Look-up” tables of generic distances can be very useful for standardised installations, especially for screening purposes. However, their conservative nature should always be taken into consideration and wherever practicable a detailed analysis is preferred.

2.2.4.2 The “consequence-based” approach

The consequence-based approach focuses on assessment of the consequences of a number of reference scenarios obtained from a quantitative risk assessment (QRA) study. Damage threshold values for accident physical effects (overpressure, thermal radiation, toxic concentration) are determined with respect to undesired consequences (fatalities, irreversible effects, reversible effects, etc.) (Christou, and Mattarelli, 2000). The method has generally been used in France, Finland, Luxembourg, Spain, Belgium and Austria (Christou et al, 1999; Hauptmanns, 2005; Cozzani et al., 2006; Stangl, 2006; Besi et al., 1996, Salvi et al., 2005) for existing hazardous installations or in the licensing procedures for specific development proposals.

The “consequence based” approach is based on the assessment of consequences of credible (or conceivable) accidents, without explicitly quantifying the likelihood of these accidents.

A basic concept is the existence of one or more "worst case scenario(s)", which are defined using expert judgment, historical data and qualitative information obtained from hazard identification. The underlying philosophy is based on the idea that if measures exist that are sufficient to protect the population from the worst accident, there will be sufficient protection for any less serious incident. Therefore, this method evaluates only the extent of the accident's consequences, and not their likelihood, which is taken into account only implicitly. Extremely unlikely scenarios may not be considered as "credible" or "conceivable" and may be excluded from further analysis.

The pre-selected "reference scenarios" can be chosen in various ways, either by a numerical or non-numerical consideration of the likelihood of occurrence or by simple expert judgement. Then, the more conceivable/reasonable of these reference scenarios (based on consideration of specific limiting conditions such as barriers or initiating events) are identified and taken into account for land-use planning purposes. Other, more serious scenarios may not be considered for land use planning purposes, but possibly for emergency planning.

In this approach, the efficacy of measures (or barriers) is estimated qualitatively, also judging on the character of representing an "independent layer of protection" (LOPA, 2001). The qualification for these measures, defined by norms, standards, national legislation, testing, etc., is usually taken as sufficient proof in this respect.

Zones defining restrictions in terms of land-use planning are determined by the calculation of distances at which the magnitude of the hazard (e.g. toxic concentration) reaches the threshold value for undesired effects (e.g. irreversible health effect/harm or fatality). An example of such zones is presented in Figure 6.

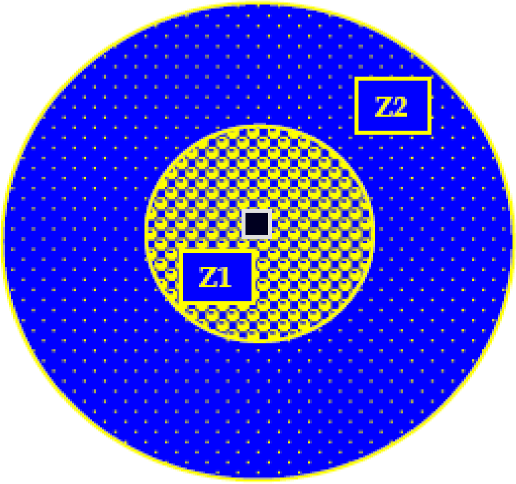

Figure 6: The land-use restriction zones according to the consequence-based approach. The zones correspond to pre-defined health effect thresholds Z1 and Z2.

This approach corresponds to the deterministic principle where safety, and thus undesirable consequences, are defined by a discrete value. The situation which is subject to planning restrictions is uniform (in terms of likelihood and severity) for the whole area within the calculated distance.

2.2.4.3 The risk-based / probabilistic approach

The risk-based approach (also known as the probabilistic approach) focuses on the assessment of both consequences and expected occurrence frequency or probability of possible accident scenarios. To estimate the likelihood of scenarios, various methods are in use, ranging from simple selection of scenarios and frequencies from the relevant databases to the application of sophisticated tools.

In general, the risk based approaches define the risk as a combination of the consequences derived from the range of possible accidents, and the likelihood of these accidents. The degree of quantification may vary.

Typically a risk-based approach consists of five phases:

- Identification of hazards (usually a deterministic step including the selection of realistic scenarios);
- Estimation of the probability of occurrence of the potential accidents;
- Estimation of the extent of consequences of the accidents and their probability;

- Integration into overall risk estimation that may include both individual and societal risk;
- Comparison of the calculated risk with acceptance criteria.

The results are represented as: (i) the individual risk, defined as the probability of the reference damage (e.g. fatality, or "receiving a dangerous dose or worse"), due to an accident in the installation, for an individual located at a specific point near the installation, and (ii) the societal risk, defined for groups of people, which is the probability of occurrence of any single accident resulting at reference damage (e.g. fatalities) greater than or equal to a specific figure. Individual risk is usually presented by the isorisk curves, while F-N curves provide a visualisation of the societal risk (Christou and Mattarelli, 2000; AICHE, 1989a; Kletz, 1992) (examples of criteria are presented in Figure 7).

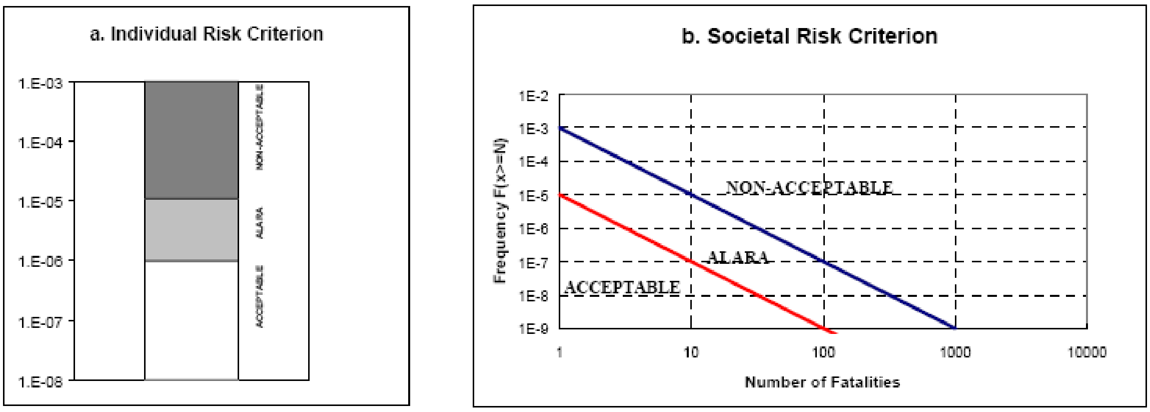

Figure 7: Examples of criteria for (a) individual and (b) societal risk

The general idea of establishing individual and societal risk criteria is given below. Usually there are three categories of risk; one that is acceptable (or "tolerable", or "desirable"), one that is non-acceptable, and a category where the risk can be considered as affordable, however strongly its reduction is desired (according to the national policy for the status of the "acceptability" criteria, such as the ALARA principle – As Low As Reasonably Achievable, or the ALARP principle – As Low As Reasonably Practicable).

Land-use planning criteria are based on specific acceptability criteria with respect to the calculated risk. In terms of land-use planning, the results are used as the basis for risk reduction measures in terms of lowering the probability of incidents, as well as being a guideline for determining the acceptability of proposed development in the vicinity of hazardous sites. This approach is used in the United Kingdom and in the Netherlands (Cozzani et al. 2006; HSE, 1989, 2006; Laheij, 2000; Basta et. al, 2007) and is usually performed in the licensing stage, not in the land-use planning stage.

2.2.4.4 Hybrid Methods

A hybrid approach combining the last two has been devised and used in Italy. It is based on a consequence-based approach, but takes frequencies into account (Cozzani et al. 2006). The method requires the identification of four damage zones. Threshold values for each of the three accidental cases (release, fire and explosion) are supported by legislation. The vulnerability of surrounding land-uses is also taken into consideration (Ministerial Decree, 2001; Carpignano et al., 2001, Colletta et al., 2002).

The frequency values calculated for each scenario are considered as mitigating factors for land-use planning restrictions and are not used to express the individual or societal risk.

Within the hybrid approach two sub-categories are distinguished:

- Deterministic approach with implicit judgment of risk
- Semi-Quantitative Method

2.3 Risk reduction measures/strategies

Ten strategies, in one combination or another, are available for reducing human and economic losses (Haddon, 2002). In their logical sequence, with the possibility of their application within the land-use planning framework, they are presented in Table 3.

Table 3: Risk reduction measures/strategies (adapted by D.Kontić after Haddon, 2002)

	Strategy description	**Application in land-use planning**
1	To prevent the marshalling of the form of energy in the first place: preventing the generation of thermal, kinetic, or electrical energy, or ionizing radiation.	Use zoning policy in combination with development conditions to prohibit such activities.
2	To reduce the amount of energy marshalled: reducing the amounts and concentrations of hazardous materials.	Use zoning policy in combination with development conditions to limit the activities.
3	To prevent the release of the energy: preventing the discharge of nuclear devices, armed crossbows, gunpowder, or electricity; the descent of skiers; the fall of elevators; the jumping of would-be suicides; the undermining of cliffs; or the escape of tigers.	Use inspection, audits, reporting, licensing to assure the “state-of-the-art”; best available technologies.
4	To modify the rate or spatial distribution of release of the energy from its source: slowing the burning rate of explosives, reducing the slope of ski trails for beginners, and choosing the reentry speed and trajectory of space capsules. The third strategy is the limiting case of such release reduction, but is identified separately because in the real world it commonly involves substantially different circumstances and tactics.	Use inspection, audits, reporting, licensing to assure the proper technology is used in order to achieve the goal of the strategy.
5	To separate, in space or time, the energy being released from the susceptible structure, whether living or inanimate. This strategy, in a sense also concerned with rate-of-release modification, has as its hallmark the elimination of intersections of energy and susceptible structure- a common and important approach.	Use zoning policy in combination with development conditions to achieve separation.
6	The very important sixth strategy uses not separation in time and space but separation by interposition of a material "barrier". Some "barriers," such as fire nets and other "impact barriers" and ionizing radiation shields attenuate or lessen but do not totally block the energy from reaching the structure to be protected. This strategy, although also a variety of rate-of- release modification, is separately identified because the tactics involved comprise a large, and usually clearly discrete category.	Building codes to increase the resilience of potential targets (buildings); development conditions to assure barriers.
7	To modify appropriately the contact surface, subsurface, or basic structure, as in eliminating, rounding, and softening corners, edges, and points with which people can, and therefore sooner or later do, come in contact.	Architectural design of buildings
8	The eighth strategy in reducing losses in people and property is to strengthen the structure, living or nonliving that might otherwise be damaged by the energy transfer.	Building codes to increase the resilience of potential targets (buildings); design of emergency exits, sheltering
9	The ninth strategy in loss reduction applies to the detection and evaluation of damage that has occurred or is occurring, and to counter its continuation and extension. The generation of a signal that response is required; the signal's transfer, receipt, and evaluation; the decision and follow-through	Early warning systems Emergency response, evacuation (urban design to allow for a more successful evacuation).
10	The tenth strategy encompasses all the measures between the emergency period following the damaging energy exchange and the final stabilization of the process after appropriate intermediate and long-term reparative and rehabilitative measures. These may involve return to the pre-event status or stabilization in structurally or functionally altered states.	Information strategies and praxis for proper use of buildings, infrastructure, health protection, etc. – safety regime, management plan. Remediation projects.

2.4 Risk perception and communication in land-use planning

Community attitudes have been shown to be important factors in planning and locating potential facilities. Strong opposition to proposed or existing facility location is clearly undesirable for both the users and providers. Public opposition is often aimed at the facilities that are socially desirable, but locally undesirable (e.g., landfills, incinerators, nuclear power plants) – NIMBY effect. Strong public opposition to public programs dealing with hazardous waste are often signalled by unfavourable attitudes toward those programs. Community sensitivity to hazardous materials is an important component of the conflicts that often surround existing and proposed hazardous facilities. Clearly the salience of the risk for the population, particularly in the form of distance, is an important issue in siting controversies, but it has also been argued that the perception of risk is an important factor in determining social behaviour associated with technology (Rogers, 1998; Slovic et al., 1985, 1986; Sorensen et al., 1987). It has been widely recognised that people accept technology and associated risks principally because of the benefits derived (Rogers, 1998). This can be observed as much for natural as for industrial hazards (Pareschi, 2002; Saleo and Trusdell, 2002).

Factors that are most likely to trigger public concern about risks are:

- Dread/Fear
- Catastrophic potential (worst if causing irreversible effects)
- Involuntary (e.g., pollution) or voluntary (e.g., smoking)
- Lack or self control (avoidable or inescapable by taking proper precautions)
- Inequity (imbalance between individual benefits and risk)
- Unequal distribution (some benefit while others suffer the consequences)
- Novelty (arising from an unfamiliar or novel source)
- Delayed effects
- Invisibility
- Uncertainty
- Lack of tangible benefit
- Man-made rather than natural sources
- Danger to children or pregnant women
- Damage to identifiable rather than anonymous victims
- Institutional control

Risks tend to be feared most when they appear to be uncontrollable, irreversible, or have unknowable future impacts.

Social structural processes and cultural influences affect the public's perception of risk (Covello, 1998; Shape-Risk, 2006). Acceptability is viewed in terms of the conditions under which technologies are accepted in communities. In a specific example, eight conditions of acceptability exist for hazardous facility (Rogers, 1998):

1. having such facilities in the area;
2. having additional facilities;
3. giving companies tax incentives;
4. requiring advisory boards;
5. requiring monitoring;
6. requiring emergency plans;
7. asking companies to provide scholarships, road or community facility improvements;
8. giving control to public to improve safety.

The facilities are accepted as a function of the benefits and inherent risks associated with the technology involved. The alternative explanation argues that facilities are accepted on the basis of the conditions of acceptability. Because the former states that facilities are accepted as a function of the technology, policies based on this explanation attempt to redistribute the risks and benefits associated with technologies to achieve fairness. The latter suggests that the acceptance of facilities that pose risk to the community is as much a function of the conditions of acceptability as it is the type of technology involved. From this perspective, policy should be sensitive to the process of siting, construction, operation and shutdown of the facility in the context of the comprehensive relationship between the technology and the community (i.e., in an ecological sense). Rather than focusing on the characteristics of the technology, this perspective focuses on the social institutional arrangements that make the technology acceptable (Rogers, 1998).

Siting and acceptable risk are also considered as a function of fairness in terms of public consent, distribution of liabilities, and trust in institutions, rather than of probability and magnitude. Social amplification of risk examines the communication process to conclude that hazards interact with social–cultural process to produce a public response that may amplify or attenuate perceived risk (Kasperson et al., 1988; Shape-Risk, 2006). Neither risk communication nor cultural theories of risk preferences provide a satisfactory understanding of acceptable risk.

The risk management literature examines acceptable risk as a function of management, which involves monetary gain, public participation in the siting process, and sometimes operational control as well as participation in reviewing operations at facilities (Shape-Risk, 2006). Risk management is another important element in the social acceptability of risk. Risk management includes reducing risk through improving the technology, aimed at reducing the probability of an undesirable event, restricting land use near potentially hazardous facilities, and creating emergency response capabilities aimed at reducing potential consequences. For mechanisms to be effective (particularly in reducing consequences), not only must the risk be communicated effectively, but mitigation mechanisms must be shown to effectively reduce the associated risks (Mileti and Fitzpatrick, 1991; Rogers, 1984).

In order for hazardous activities to gain public acceptance, the public must have confidence in the facility's management and also in the notion that risk acceptance is driven more by the degree of trust in the risk management system than in the degree of risk the technology presents. The argument here applies not just to systems of risk management but rather to social systems that can include risk management, but also include risk communication, knowledge, social power and experience. In terms of land-use planning, a discrepancy arises – while the management factors of the facility can be changed within a short time period, general land-use plans are made for long (longer) time periods. The emphasis regarding the need for continuous development monitoring around hazardous industrial installations is again evident.

In terms of information regarding risk, experts are in a privileged position, even if their values and decision processes are not always employed optimally. On the other hand, while non-experts may not possess as much relevant factual information, they may be in a position to augment expert risk analyses with additional useful information (also in terms of values regarding their environment), resulting in an overall superior analysis (Taylor, 1980; Golobič, 2002). There are many forms that this proposed enriching might take. For example, formal risk calculations often use the expected number of fatalities as the outcome variable of interest. The public, on the other hand, may care about other outcomes as well, such as non-fatal injuries, the distribution of risks and benefits, or 'societal risk'. A richer representation of the problem may therefore be arrived at by considering such issues in the decision process.

Role of probability

Probability plays an important role in risk based decision-making (Slovic et al, 1984; Wynne, 1992; Pidgeon and Beattie, 1999; Laheij, 2000; Burger, 2001; Slovic, 2001). In this regard, the most frequently addressed issues are uncertainty and public perception of risk – the psychological aspect. Imprecise distances acquired from incident severity analysis are an example of such uncertainty. Such results should be considered as approximations rather than absolute values that provide an exact basis for border drawing in an actual spatial/land-use plan (AICHE, 1989).

A psychological aspect is associated with the rate of success of an industrial establishment (or other activity) in a given environment, which is, in most cases, based on the particular society's belief regarding the possible harmful effects toward themselves, environment and resources.

The probability should have a role when considering minimising the risk to acceptable level. Commonly, this is achieved by isolation of the source of risk from potential targets (vulnerable environmental components). If we are to understand isolation not only geographically, but also chronologically, lowering the probability of an accident is a method of achieving the goal of isolating vulnerable environmental components from source of risk. Thus, a new set of questions is raised regarding how to systematically include the aspect of dilution in time (probability) in the spatial/land-use planning process. Nevertheless, the praxis of "dilution in time" is used in spatial/land-use planning for natural hazards. Land-use planning for flood areas and earthquakes, which are based on the probability concept – return period of high waterflows and probability of occurrence are examples of such an approach (Waananen et al., 1979; Berke and Beatley, 1992; Smith, 1998; Tamura, 2000).

Another role of probability in risk informed spatial/land-use planning would be the inclusion of probability of meteorological conditions (wind direction and velocity, temperature) for a particular scenario (of toxic release in the air, for example). It is evident that expected consequences considering meteorological conditions would differ from those not considering meteorological conditions.

3 PRACTICAL WORK – DEVELOPMENT OF THE METHODOLOGY OF THREAT ANALYSIS APPLICABLE IN LAND-USE PLANNING

3.1 General

The method introduces the threat index as a tool for distinguishing between different consequences expected on actual environmental components. The numerical (semi-quantitative) expression of a threat index represents different levels of threat. In its essence, the threat index builds on a consequence-based approach of risk assessment and combines it with the vulnerability of targets, i.e. receptors of consequences. As such, it requires the identification of accident scenarios with a consideration of the spatial distribution of physical effects.

If a land-use plan is established that takes into account risk characterisation as an important piece of information, we understand this as risk-informed land-use planning. For the purpose of avoiding confusion with the risk-based approach to land-use planning – which builds on consideration of both frequencies and consequences as opposed to a consequence-based approach that considers only consequences – we apply the term threat-informed land-use planning.

3.2 Philosophy

The method maintains as far as possible the current philosophy of spatial/land-use planning in Slovenia. It is therefore based on the following considerations:

a) the interaction of development and environmental protection goals and interests
b) maintaining the zoning policy/approach
c) the profiles of expertise composing the core of knowledge in the planning process

ad a) Interaction of development and environmental protection goals and interests

The approach of interacting development and environmental protection goals (i.e. the combination of spatial vulnerability with spatial attractiveness into spatial suitability) has been practised in Slovenia since the early 1990s (Marušič, 1993, 1999; Marušič et al., 1993; Marušič et al., 2004; Koblar et al., 1997). The concept is that it is possible to evaluate how attractive a certain piece of land is for a particular activity, and how vulnerable a particular environmental component on the very same piece of land is to the particular impact of the same activity. By superimposing these two values we can obtain an evaluation of which piece of land is better or worse for allocation of a particular activity. If this analysis makes use of GIS, it is easy to recognise geographically these better and worse sites.

The method suggests that, if the activity is hazardous, an additional consideration has to be made in the form of threat analysis, which combines environmental threat-vulnerability with risk severity analysis (threat intensity level) of an accident. This is presented schematically in Figure 8. The threat-vulnerability analysis identifies which environmental components are likely to be affected by a specific accident outcome. It is based on the past experience regarding the impacts of accident outcomes to the environment.

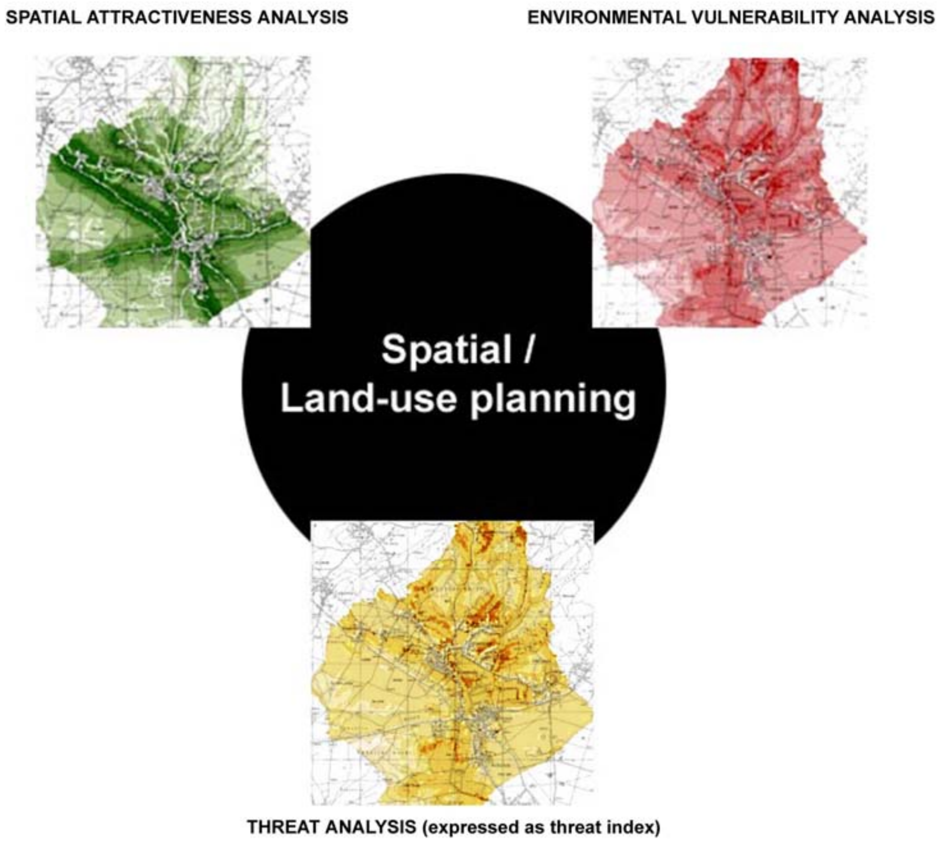

Figure 8: Introduction of threat analysis into the existing spatial suitability approach (spatial/land-use planning praxis)

The main advantage of the proposed approach is that it can provide preliminary guidelines for allocating new hazardous establishments, and act as a controlling instrument for development proposals around existing ones.

ad b) A zoning policy/approach should still guide spatial planning, while zones themselves should be kept as a basis for determination and approval of the spatial suitability for a particular development in the licensing process. Zones functioning as buffer zones would be identified in a plan with associated management guidelines.

ad c) The profiles of expertise compose the core of knowledge in the planning process (e.g., sectoral planning, infrastructural planning, landscape architecture, architecture, civil engineering). The proposed method assumes the inclusion of chemical, mechanical and civil protection engineers as important contributors to the core of knowledge in the spatial/land-use planning process, with the aim of acquiring the necessary dialogue among spatial/land-use experts on one side and experts from the risk assessment field on the other.

3.3 Analytical methods used in the research

The following analytical methods have been applied in the research:

Comparative analysis of risk assessment methods – to determine the applicability of existing risk assessment methodologies for the purpose of spatial/land-use planning. A summary of the comparison served as a basis for developing more supportive risk assessment methodology in terms of spatial/land-use planning.

Scenario analysis – the purpose was to determine the incident outcomes for a number of scenarios, which serve as a basis for identifying the impact area and the scope of risk to be implemented in spatial/land-use planning.

Sensitivity analysis – to serve as a tool for uncertainty reduction, validity assessment and building trust when identifying incident scenarios for spatial/land-use planning purposes.

Environmental threat-vulnerability analysis – to serve as a guide for allocating new industrial installations away from vulnerable environmental components (recipients of risk consequences) or to guide new residential, commercial and industrial development away from hazardous installations.

Environmental impact analysis – to confirm operability of the threat analysis methodology in the process of a land-use plan adoption

Threat analysis – to examine operability and usefulness in the process of land-use plan preparation and its integration with the renewal of the land-use plan for the Municipality of Koper

3.4 Practical background for methodology development

In the process of conceptualisation and early design of the methodology, a number of workshops and discussions were organised. Officials from the Municipality of Koper, representatives of Seveso II establishments located in the Municipality of Koper and risk assessors participated in these workshops. A summary of the discussions in terms of requirements for the methodology is presented in the following ten points combined into three methodological segments (see also Table 4):

Segment 1 - Conceptualisation

Maintaining the current philosophy and practice of spatial planning

The interest behind this requirement is that the legal and philosophical framework for spatial planning remains as it is. In that context, zones (i.e., areas of land having a particular purpose) should still be the final result of spatial planning, while zoning itself should be kept as a basis for determination and approval of the spatial suitability for a particular development in the licensing process. The same profiles of expertise should compose the core of knowledge in the planning process (e.g., sectoral planning, infrastructural planning, landscape architecture, architecture, civil engineering); an additional core of knowledge should be industrial accidental risk assessment.

Maintaining the approach of spatial suitability for development projects

The combination of spatial vulnerability with attractiveness analysis is the basis for determining spatial suitability. This approach has been commonly used in Slovenia; hence, it is well known, well understood and widely accepted among stakeholders. The interest is that introduction of risk assessment into the spatial planning process does not change this approach, but rather follows it as much as possible.

Holistic approach to environmental impacts

Standard risk assessment usually focuses on consequences to humans. Threat analysis takes into consideration the environment holistically and addresses, besides humans, also nature, natural resources and the built environment, since they are all categories encompassed by the land-use planning process.

Applying GIS tools

Application of GIS tools is obligatory and standardised in the spatial planning process. The form of presentation and the interpretation of risk assessment results for the purpose of spatial planning need to take this into account.

Consideration of the need for small impact zones

Each accident has its specific impact zone. In principal, these are determined based on specific accident scenarios, taking into account the relevant technical and organisational measures to prevent the accident and/or mitigate its consequences. For existing installations, impact zones may have been determined years ago when neighbouring urban development was not in such state as to pose an issue in terms of conflicting land use between (hazardous) industry and its surroundings. In the course of time, spatial development brought up situations in which impact zones prevent further urbanisation in the neighbourhood. Such situations are generally not well accepted either by potential land users or by administrators and the public. Therefore, requirements emerge for technological improvements at hazardous installations which would result in smaller impact zones or, eventually, for relocation of such industry. In either case more land is expected to be set free for other purposes, usually for residence and commerce. Small impact zones are imperative when siting new installations. In that sense the spatial planning process is recognised as a mechanism for enforcing technological optimisation for the purpose of reducing the size of impact zones as much as possible.

Segment 2 - Implementation design

Differentiation between existing and new installations

The method should differentiate between existing and new installations. For existing installations the technology, safety management systems, operational records, compliance status, standardisation, etc. are known. The determination of impact zones associated with particular accidents is thus relatively accurate. On the other hand, at the stage of preparation of a land-use plan for a new industrial zone, little is known about the particular establishment and specific industries which will occupy the zone in the future. In such cases determination of impact zones is uncertain, so the method should reflect this issue.

Interpretation and presentation of risk assessment results for spatial planning purposes

Risk assessment results are commonly presented in the form of probability for a certain accident consequence. Sometimes, the extent and spatial distribution of these consequences are also given. For spatial planning purposes, spatial interpretation and presentation of risk consequences comprise the only form which counts, so risk assessment end-points should be formulated accordingly.

Transparency of risk presentation by a GIS tool

In the process of combining spatial vulnerability and spatial attractiveness into spatial suitability, each cell of a GIS grid has a particular expression of vulnerability, attractiveness and suitability values. These are transparent, retrievable and justifiable. The same should apply for risk evaluation. Since the method applies a threat index as an expression of the final risk assessment results, this is assigned to each cell of the grid in the impact zone to meet this requirement. The threat index combines environmental risk vulnerability and the severity of an accident.

Segment 3 - Testing and Approval

Testing the method

The method should be tested by means of a case study. This should involve at least two different Seveso II establishments and renewal of an existing spatial plan for an administrative entity. The testing procedure should be clear and understandable for public participation purposes.

Generalisation of the method

The method should be aimed at general use. Approval is expected by the Ministry of the Environment and Spatial Planning.

Table 4: The requirements of spatial planners for the methodology and responses to these requirements

Segment	Description	Basic requirements	Responses to requirements and novelties
1: Conceptualisation	This segment introduces threat index. The threat index converts classical hazard and risk assessment results into a form which is applicable in the process of land-use planning.	Maintaining current philosophy and practice of land-use planning; threat index should be directly applicable	Legal and philosophical framework (current practice) for land-use planning remains as it is. In that context zoning policy/approach provides background for approval of spatial suitability for certain land-use. The same profiles of expertise are involved in the planning process (e.g., sectoral planning, infrastructural planning, landscape architecture, urban planning, architecture, civil engineering); an additional expertise is industrial accidental risk assessment.
		Applying/maintaining approach of spatial suitability for development projects	The combination of environmental vulnerability with spatial attractiveness analysis is the basis for determining spatial suitability. This approach is well known, well understood and widely accepted among stakeholders in Slovenia. The introduction of threat analysis into the land-use planning process does not change this approach, but follows it as much as possible. See Figure 8.
		Holistic approach to environmental impacts	Standard risk assessment usually focuses on consequences to humans. Threat analysis takes into consideration the environment holistically and, besides humans, also addresses nature, natural resources and the built environment, since they are all categories encompassed by the land-use planning process.
		Applying GIS tools	Application of GIS tools is common, widely used and standardised.
		Consideration of the need for small impact zones	Each accident has its specific impact zone. Reduction and optimisation of the extent of impact zones is provided by means of accidental scenario analysis and enforced by the relevant technical and organisational measures at the installation for the purpose of limiting releases or reducing the likelihood of occurrence, or both. Associated with siting new installations small impact zones are imperative in the first place. In that sense the land-use planning process is recognised as a mechanism for enforcing technological optimisation for the purpose of reducing impact zones as much as possible.
2: Implementation design	Implementation should encompass environmental modelling and should allow qualitative and quantitative determination of threat in designated area.	Differentiation between existing and new installations; existing installations should be able to adapt to identified threat while the new ones should maintain conformity by continuous monitoring of land developments of neighbouring land-use.	The method should differentiate between existing and new installations. For existing installations the technology, safety management systems (SMS), operational records, compliance status, standardisation etc. is known. Therefore, determination of impact zones for a particular accident is relatively accurate. On the other hand, at the stage of preparation of a land-use plan for a new industrial zone, this information is not available. In such cases determination of impact zones is uncertain, so the method should reflect this issue. At the moment the method is applied and tested for existing installations only. Regular auditing of SMS contributes to overall (safety) compliance assessment, which is a basis for prolongation of the operational permit of the establishment every five years. If violations of safety standards/expectations are recognised during the auditing, the inspector is obliged to decide whether to stop the operation of the establishment or particular facility
		Interpretation and presentation of threat analysis results for land-use planning purposes	Commonly risk assessment results are presented in the form of probability for a certain accident consequence. Sometimes the extent and spatial distribution of these consequences are given. For land-use planning purposes, spatial interpretation and presentation of risk consequences is the only form which is beneficial. In that context threat analysis end-points (expressed as threat index) are formulated accordingly.
		Transparency of the presentation of threat indices by means of GIS tools	In the process of combining environmental vulnerability with spatial attractiveness into spatial suitability, each cell of a GIS grid has a particular value. These values are transparent, retrievable and justifiable. The same applies to threat, where a threat index is assigned to each cell of the grid in the impact zone. The threat index combines environmental threat-vulnerability and the threat intensity level.
3: Testing and Approval	Testing should be done by means of a case study and revision of the land-use plan.	The method should be tested at the municipal level	The method should be tested by means of a case study. The testing procedure should be clear and understandable for public participation purposes. The municipality of Koper and an LPG storage facility were selected for a case study.

3.5 Key elements of threat analysis

Following the requirements for methodological segment 1, the introduction of the threat analysis into the land-use planning process is designed as an additional, i.e. third, component to the already existing spatial attractiveness analysis and environmental vulnerability analysis of the spatial suitability approach in the framework of the Slovenian land-use process (Figure 8).

Threat analysis consists of three sub-phases to be applied to different stages of land-use planning process. These are:

- preliminary threat analysis
- development of threat index
- resilience analysis – development of resilience index

3.5.1 Preliminary threat analysis

The main advantage of the approach is that it can provide preliminary guidelines for allocating new hazardous establishments, and act as a controlling instrument for development proposals around existing ones.

Results in the form of the preliminary threat analysis also represent the basis for decision-making about allocation of future industrial zones featuring hazardous industrial installations. It is important to note that such maps can provide the basis for siting future installations, for which detailed specifications in the stage of developing zoning ordinances are not available.

Preliminary threat analysis can serve as a tool for finding the most appropriate location for a proposed hazardous industrial installation for which the safety related information is available.

3.5.2 Development of threat index

Threat analysis resulting in a definition of a threat index aims at the identification of threat in the vicinity of existing hazardous industrial establishments (or planned with known location). The analysis consists of the following steps (the process is presented schematically in Figure 9).

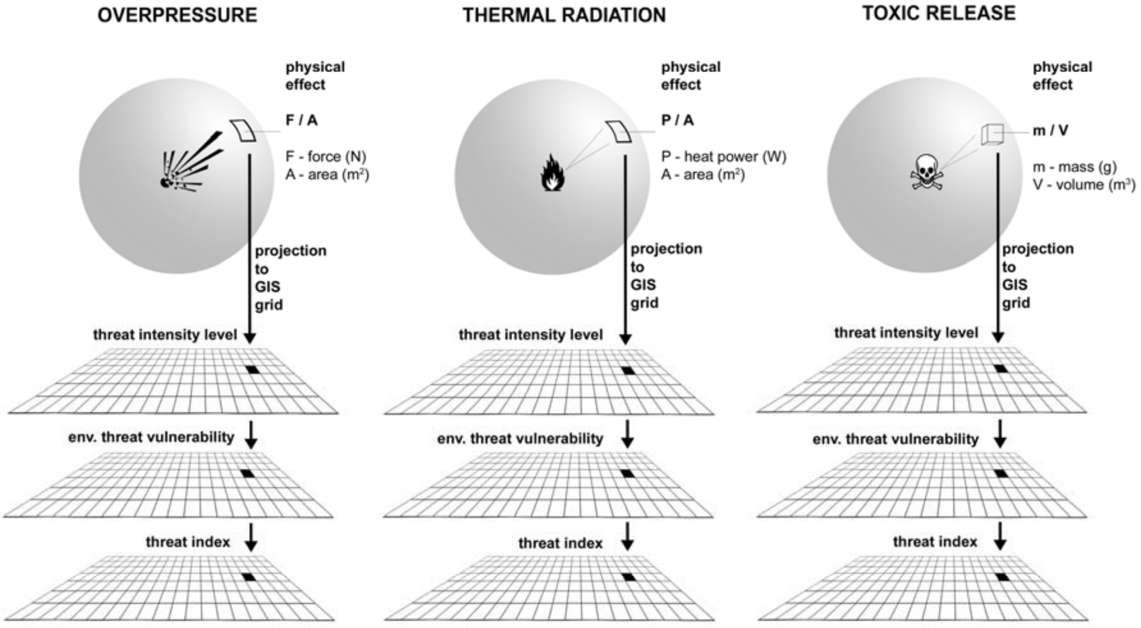

Figure 9: Schematic presentation of threat index identification

Figure 10 represents the methodological procedure for threat index determination.

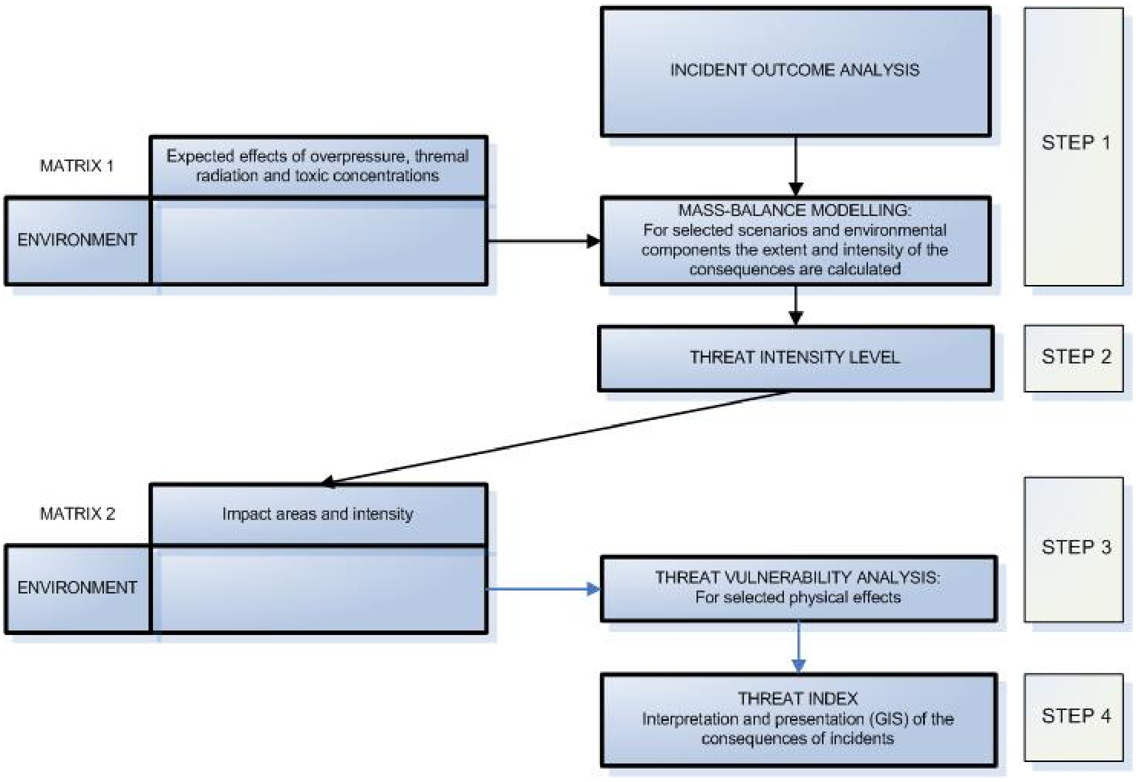

Figure 10: A scheme of threat index development methodology

Step 1

Quantitative assessment of the outcomes of an incident (e.g. fire, explosion, toxic cloud) and their physical effects (overpressure, thermal radiation, toxic concentrations in the air) is made. Mass-balance modelling is applied for selected scenarios.

General criteria for the selection of scenarios are based on the following principles (Christou et al, 2006):

- Reference scenarios to be used for risk assessment in land-use planning should be selected by the volume (scope) of their consequences and additionally by the frequency/likelihood of their occurrence.
- The time at which the scenario consequences come into effect is an important factor in making a decision whether the detailed accident scenarios are to be addressed within a framework of land-use planning or of emergency planning. The estimated delay of the effect for a realistic rescue/emergency response is of key importance. Scenarios involving a mechanical or chemical explosion as well as fires (effect of overpressure and thermal radiation) are considered as a priority for land-use planning, due to the lack of time to take proper emergency measures.

- According to the chosen level of volume and/or likelihood for the occurrence of a reference scenario the effectiveness of barriers should be taken into account for the selection. Passive (independent of the state of the process) and active barriers are distinguished. The latter can either interrupt a sequence of events (e.g. interlock systems, emergency shut down trips) or initiate one or more actions (e.g. opening of a relief valve or a process quench). Activated barriers always require a sequence of detection – diagnosis – action. The effects of passive barriers, active hardware or mixed barriers are considered in the definition and selection of scenarios where the evidence of good feedback and reliability is presented (in the safety report for upper-tier establishments).
- Land-use planning is both a prevention and mitigation measure, which may require that relevant safety measures have been implemented onsite. Along with emergency planning, land-use planning serves as a preventive tool for protecting targets (human, environment, etc.) in case of an incident, either by establishing safety (buffer) zones around the hazardous sites (zoning) or by implementing effective evacuation/ sheltering measures (urban design – evacuation roads). As a result, an incident may/would have fewer consequences because of the lack of vulnerable recipients.

The modelling of potential consequences is a complex task that must take into account many site-specific parameters, such as ambient weather conditions or components of the establishment concerned that may have an influence on the calculation.

Mass balance modelling is a tool which helps to identify the magnitude of an incident by providing results about spatial distribution of physical effects – overpressure, thermal radiation, toxic effects (air pollution and water pollution). The results may be in a form of curve representing the value of the physical effect on one axis and the distance from the source of the effect on the other.

Matrix 1 provides the basic identification of environmental components that are susceptible to being harmed due to the effect of an incident; in this step, thresholds for the effects are also determined. Results of mass balance are combined with the thresholds applied in matrix 1. The results of the combination are distances from the source of physical effect at which threshold values are expected. The distances are then inserted in matrix 2 which introduces the spatial distribution component into the analysis. The results of matrix 2 provide greater accuracy and concretisation of parameters than those of matrix 1.

Modelling is made by using standardised and widely accepted models (Defra, 2007; AICHE, 1989), e.g. TNT, Baker-Strehlow for explosions, Pasquill-Gifford model (Gaussian dispersion) for dispersion in the air. In addition to these, threat analysis also involves, based on the accident scenario, quantification of toxic concentrations in water for the purpose of evaluating the consequences for both water biota and humans (e.g. loss of drinking water source). Different dispersion models could be used for these quantifications, e.g. the Stream model[3]. This step is the initiating step of consequence estimation and represents the incident outcomes obtained by scenario analysis, associated with the impact on the surroundings that could develop from a certain incident of interest. These outcomes serve as a basis for determining the threat intensity level of an incident in the following step.

Step 2

Threat intensity level is a measure oriented to represent the magnitude and spatial distribution of the consequences associated with selected physical effects of incident outcomes (overpressure, thermal radiation, toxic concentrations in air and water). It takes into account a set of threshold levels concerning these consequences. At its core it is conceptually similar to risk severity (ARAMIS 2004c, Casal et al, 2004, Planas et al., 2006). The threat intensity is presented as a series of GIS based maps for selected physical effects, where each cell carries a value on a scale of 1-5 according to threshold level (1-low, 5-high), based on e.g. TEEL[4] or ERPG[5] values for the evaluation of threat intensity to humans, or concentration levels with dose assessment (e.g., LC_{50} or LD_{50}) for fish for the evaluation of threat intensity to river or lake biota. One should note that measures like the Probit model results are not applicable in the land-use planning process, since they describe human death probability (expectation of human death is not applied in land-use planning). Probit model results other than zero, if attempted to be applied in land-use planning, would most probably lead to strong societal disagreement and conflict, with the eventual result of not approving a plan, in spite of the accidental context of the issue. On the other hand TEEL and ERPG values provide a common basis for emergency planning.

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[3] Stream model as a module of *Risk*Assistant* for Windows, The computer programme developed by the Hampshire Research Institute, USA. Web page at: http://www.hampshire.org/, accessed on 3 May 2008

[4] Temporary Emergency Exposure Limit

[5] Emergency Response Planning Guideline

Step 3

Environmental threat-vulnerability analysis of potential receptors (humans, natural resources, built environment) located in the vicinity of hazardous industrial establishments is conducted. Environmental threat-vulnerability, as used in this method, is defined in the Introduction. Compared to environmental vulnerability, as defined in the ARAMIS project (ARAMIS 2004a), the environmental threat-vulnerability proposed in this dissertation answers not only the question as to which element is more precious to us, i.e. the question of weights assigned to the vulnerability of humans, material values and nature, but also whether the environmental element of interest will withstand the threat intensity level to which it is going to be exposed in the case of an accident.

Environmental threat-vulnerability analysis is conducted for the entire set of environmental components – generally these include: atmosphere, geosphere, hydrosphere, biosphere, human environment and resources (environmental components selected in matrixes 1 and 2). Data used in the vulnerability model is GIS data that describes the environmental components of interest.

The environmental threat-vulnerability is expressed as a ratio of the expected environmental damage/loss to the maximum possible damage/loss on a scale of 0 – 100%, translated to a scale of 1-5. The normalisation enables the comparison and further transformation of otherwise different and hardly comparable parameters. The five-grade scale is widely used in environmental impact assessments. Its descriptive (qualitative – semi-quantitative) and relative ordinary nature enables otherwise incomparable spatial characteristics and/or impacts to be compared and merged (Marušič et. al., 1999).

The scale is based on pre-set criteria for exposure and received amount of energy/mass, i.e. dose, taking into account the probability whether the actual environmental element will withstand[6] this dose (1-no effects, 2-negligible effects, 3-reversible effects, 4-irreversible effects, 5-destruction/loss). This probability assessment is derived as expert opinion, taking into account, for example, construction quality standards, building and architectural codes of practice, information on the sensitivity of specific population groups, resilience of structures/organisms to blast, thermal radiation, toxicity, etc. Presentation of the vulnerability is then provided for each grid cell.

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[6] We interprete this detail as the »resilience« index.

The thresholds may also consider passive and active protective measures designed by municipal policies or experience of particular sectors, such as the sector for civil protection and rescue. In the case that no specific thresholds are provided, the ones presented in Table 5 could be used.

Details and references regarding the thresholds are provided in the Appendix I.

Table 5: Thresholds to be applied in environmental threat-vulnerability analysis (SAVE II, 1992; Lees, 1996; IDEAS, 1988; U.S DOE, 2008; "The Green Book, 1992)

Environmental threat-vulnerability – reference values					
Damage/loss level	**Effects**	**Overpressure**	**Thermal radiation**	**Toxic release to air***	
1 - Low	No effects	< 2,1 kPa	< 4,5 kW/m^2	< TEEL 1	< ERPG 1
2 - Low to medium	Negligible effects	2,1 kPa – 6,9 kPa	4,5 kW/m^2 – 12,5 kW/m^2	TEEL 1	ERPG 1
3 - Medium	Reversible effects	6,9 kPa – 13,8 kPa	12,5 kW/m^2 - 25 kW/m^2	TEEL 2	ERPG 2
4 - Medium to high	Irreversible effects	13,8 kPa -20,7 kPa	25 kW/m^2 – 37,5 kW/m^2	TEEL 3	ERPG 3
5 - High	Death/loss	> 20,7 kPa	> 37,5 kW/m^2	> TEEL 3	> ERPG 3
* TEEL – Temporary Emergency Exposure Limits ERPG - The Emergency Response Planning Guideline					

The result of environmental threat-vulnerability analysis is a series of GIS based maps for selected environmental elements and certain physical effects of an incident. When combined with threat intensity maps, threat index maps are produced (see Figures 9 and 10).

Step 4

Threat index expresses the degree of threat to a specific environmental element in the case of an accident.

The index takes values ranging from 1 to 5 which are established by combining values on a 1 to 5 scale for both threat intensity and environmental threat-vulnerability. The combinations, presented in Table 6, are a simplified representation of the results obtained by a multiplication (product) of these values normalised again into a 1 – 5 scale. The function of multiplication was selected because of its non-linear increase in final result (especially with values 4 and 5). The function of multiplication also yields lower threat values in case when one component is of lower value (for example, when environmental threat-vulnerability level is high - 5, but is not reached due to low threat intensity level – 1, the final threat level remains low – 1).

The Table is similar to an ordinary risk matrix which combines the frequency/probability of an accident and the severity of its consequences.

Table 6: Combinations of threat intensity and environmental threat-vulnerability as a basis for determining threat index

		Threat intensity level				
		1	**2**	**3**	**4**	**5**
Environmental threat-vulnerability level	**1**	1	1	1	1	1
	2	1	1	1	2	2
	3	1	1	2	2	3
	4	1	2	2	3	4
	5	1	2	3	4	5

Note: each value is assigned to a specific GIS grid cell in the area under consideration. The product of this assignment is a threat index map.

A threat index map serves as a support in the process of revising the land-use plan around existing hazardous installations and as a guideline for developing a new plan or finding a suitable location for a proposed development project. If there are site alternatives for allocating hazardous industrial installation, threat index results could be used to evaluate which alternative would cause the least threat.

The threat index map also represents the basis for the discussion with those who live, work and/or place values in the affected area, and have therefore, according to physical planning legislation in Slovenia (Spatial Planning Act, 2007), the right to be included in the final determination of the use of land,.

3.5.3 Resilience analysis – development of resilience index

In order to perform optimisation in threat informed land-use planning, it is necessary to reflect the resilience (sustainability, probability of withstanding) of the environmental components to the physical effects of the incidents. Resilience is to be properly considered in the framework of environmental threat-vulnerability analysis and is conducted for majority of environmental components. The optimisation then is applied as schematically presented in Figure 11 and according to values obtained from Equation 1.

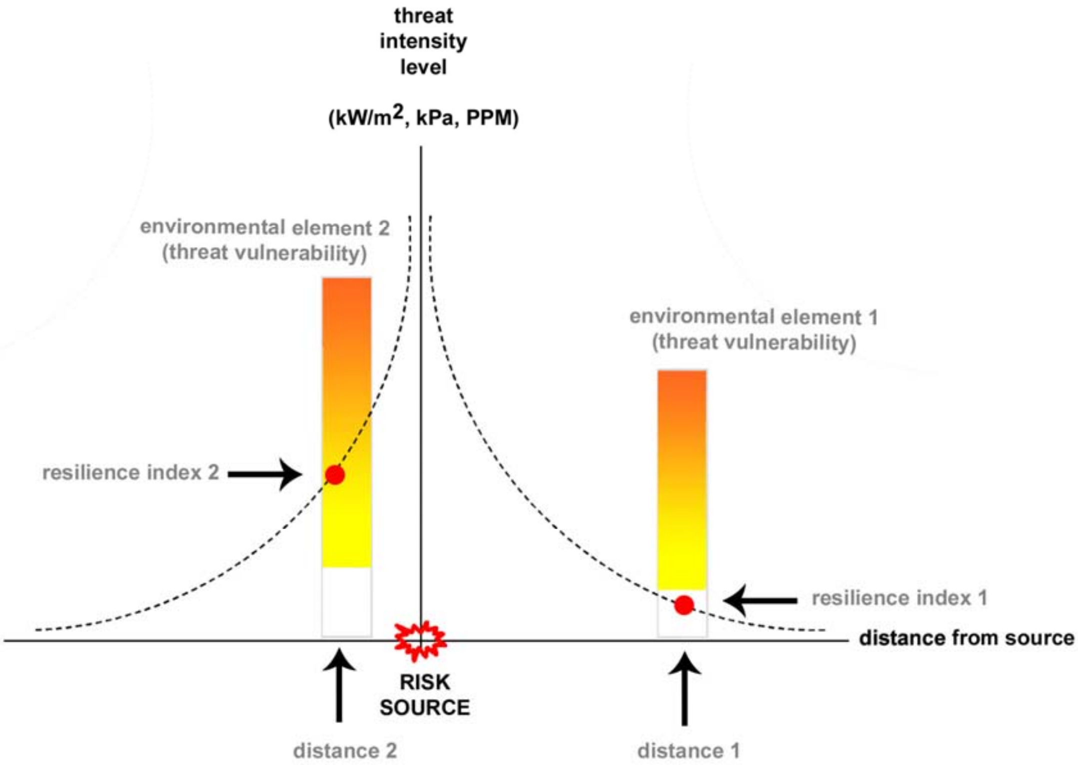


Figure 11: Illustration of threat analysis methodology for spatial development optimisation reflecting the resilience of environmental elements

The idea behind the introduction of resilience index is to identify the locations from the source of the incident (shown in Figure as "distances 1 and 2") at which the threat intensity level drops below the resilience of the environmental component to the effect in question. This is done by an intersection between the threat intensity level (dashed line) and the environmental threat-vulnerability (i.e. the effect level at which the consequences in question appear) of the environmental element in question, yielding resilience index. The intersection is represented by the red dots in the scheme (Figure 11).

This is obtained by the following equation:

$$\text{Resilience index} = \frac{\text{threat intensity level*}}{\text{environmental threat-vulnerability*}} \qquad (1)$$

* expressed with the actual threshold value at which the specific effect takes place at a given location (distance from the source of incident)

The results are interpreted using the following criteria:

- if the resilience index > 1 ; the element will not withstand the effect
- if the resilience index < 1 ; the element will withstand the effect

Resilience index is applicable for all physical outcomes/effects of incidents (overpressure, thermal radiation, toxic releases into air and water) as well as for environmental components (biosphere – flora, fauna; natural resources – agriculture, forestry, water sources, development potentials; human environment and health – direct and indirect; infrastructure, etc.).

3.6 Utility of the method for land-use planning

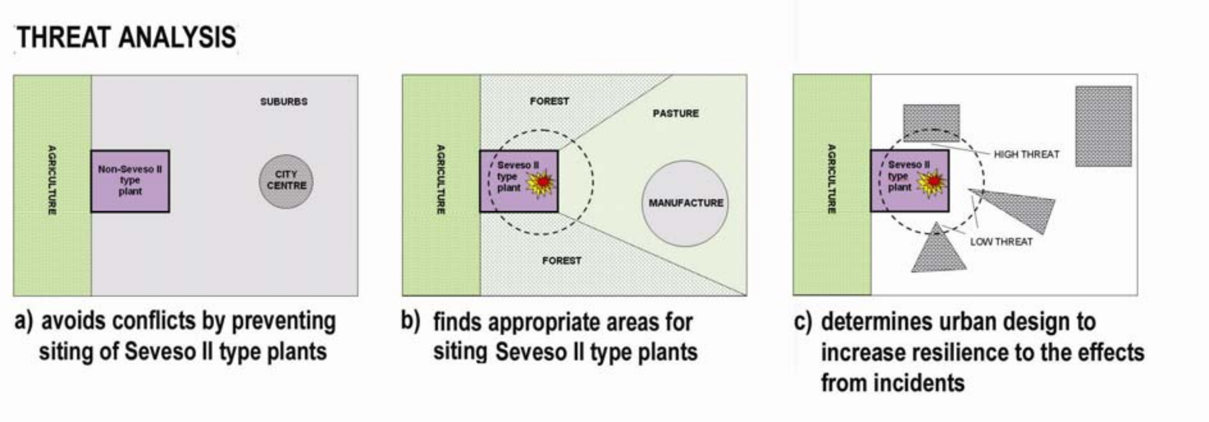
The threat analysis method is designed to provide readily applicable information about hazard/risk/threat to be used in the framework of land-use planning. This information is to be beneficial in terms of:

- ensuring that no Seveso II plants are allocated in industrial zones surrounded by urban or in other vulnerable areas (e.g. surface and groundwater for drinking purposes, natural protected areas, etc.) (Figure 12 a)

- limiting the development in the higher risk areas in order to minimise risk (Figure 12 b). The question posed in this regard is what regime would sustain the undeveloped land vis-à-vis ever-increasing pressure for development of open space.

- providing conditions for siting hazardous installations in the initial stages of preparing a land-use plan, so that risk conflicts are avoided during the whole timeframe of implementing the plan. This results in the minimisation of threat by separating human-made structures as far as possible from the source areas, and in the progressive inclusion of less vulnerable land uses or development towards the risk source (Figure 12 b). This conceptualisation is similar to the current praxis of appropriate distances (Christou et al., 2006).

- determination of the most appropriate urban design in the vicinity of the threat source by increasing the resilience of the objects to the effects/dangerous phenomena of incidents (by shape, orientation of buildings) (Figure 12 c). This relates to the previously discussed risk reduction strategy where the particular form of energy, and the geometry and other characteristics of the energy's path, and the point or area and characteristics of the structure on which it impinges, determine the final scope of the effect.



a) avoids conflicts by preventing siting of Seveso II type plants

b) finds appropriate areas for siting Seveso II type plants

c) determines urban design to increase resilience to the effects from incidents

Figure 12: Utility of the threat analysis method for land-use planning

4 RESULTS

The applicability of the threat index was tested in the framework of a renewal of spatial plan for the Municipality of Koper. Hazardous installations/establishments which served as case studies were the Port of Koper (chemical terminal, oil terminal, ammonia based refrigeration facilities); Instalacija Sermin (diesel and gasoline field of reservoirs); Istrabenz Plini (Liquefied Petroleum Gas - LPG - storage and handling facility); Kemiplas and Celanese Polisinteza (chemical process industry).

In the next section the case study of Istrabenz Plini (LPG storage and handling facility) is presented; the others are summarised in Appendix II.

4.1 Description of a case study

The purpose of the case study is to estimate the operability of the proposed method, as well as calibration, correction and adjustment to the process of implementation into the land-use planning process.

The interest behind the selection of the Municipality of Koper lies in the presence of Seveso II establishments, the size of the municipality, allowing for suitable scale and scope of land-use planning processes (a typical example in terms of the presence of problems associated with land-use planning for hazardous industrial establishments), and the diversity of potential targets for consequences of incidents.

Municipality of Koper is located in the south-western part of Slovenia, and covers the majority of the Slovenian coastal area. The main economic activities in the municipality are tourism, agriculture and port activity with logistics and industry.

The town of Koper has approximately 25 000 inhabitants. The average population density is 155 pers/km^2.

The characteristic landscape in the municipality is agricultural land (fields, vineyards, olive groves). An important spatial element in the municipality is the flatland around the town, formerly salty marsh, but dried out through history. The hinterland of the municipality is primarily hilly with mixed land-use of scattered urbanisation, agriculture and forest.

The LPG storage and handling facility selected for a case study is an upper tier Seveso II establishment, located in the industrial/commercial zone to the north-east of the town of Koper.

The operations in the establishment include:

- loading, unloading and storage of LPG; total storage capacity is 450 m^3 in three 150 m^3 vessels,
- filling LPG into 10 kg steel containers for households,
- distribution of LPG for industry by road tankers and 10 kg steel containers to households.

Three manufacturing organisations, employing approximately 120 persons, are located adjacent to the facility. The nearest residential area is 150 m north of the site.

Land-use in the vicinity of the site

Spatial plan – municipal level

In accordance with the long-term and mid-term spatial plans for the Municipality of Koper, the area is categorised as industrial zone Sermin. The intended use of land in the area is industrial, transport, and warehousing. In the vicinity of the area agricultural land use is present, however the area is intended to be developed as an industrial, transport, and warehousing zone.

Spatial plan – national level

In accordance with the national spatial plan the designated area is categorised as the area for expansion of the petrol derivatives warehouse, the LPG warehouse and the transport corridor (motorway) towards the Port of Koper.

Special nature protected areas in the vicinity of the site

- Towards the north, at a distance of 400 m, is a hill, Sermin (84 m altitude), which is classified as an archaeological monument.
- South-west, at a distance of approximately 400 m from the establishment, a salty shallow lake is situated (formerly sea) and is categorised as a special environmentally protected area – Natura 2000 site (European Commission, 1992).
- South-east, at a distance of 500 m, a protected tree line is located.

- North, at a distance of approximately 500 m, Ankaranska bonifika ("salty soil") is present, and extends from a cargo railway station towards Ankaran.

Demography

The population density in the vicinity of the site is presented in Figure 13 as GIS data in pers/ha. The background is a digitised map of the area with a scale of 1: 25000.

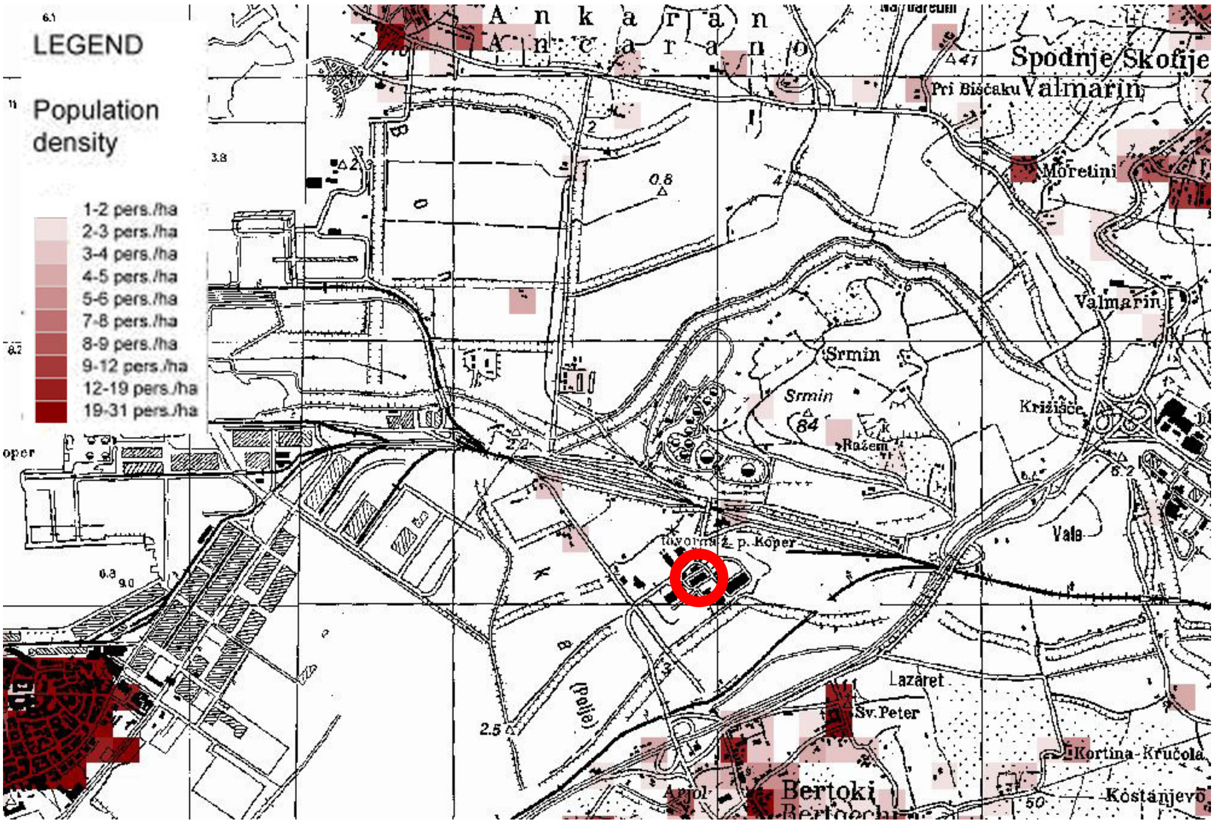


Figure 13: Population density in the vicinity of site Istrabenz Plini Koper, Sermin (red circle)

Infrastructure

Motorways

West of the location a local road, Bertoki to industrial zone Sermin to Ankaran, is the main connection to the industrial zone. South-West, at a distance of approximately 400 metres is situated the dual carriage way Ljubljana – Koper.

Railways

North at a distance of 200 m is a cargo railway station (the Ljubljana – Koper route).

4.2 Application of threat analysis methodology to the case study

4.2.1 Incident outcome analysis

The analysis is based on a safety report for Istrabenz Plini, location Sermin 8/A, Koper (Gerbec, 2006) and subsequent discussions with the establishment management personnel as well as the authorities at the Municipality of Koper.

Based on the former, the following scenarios are considered as relevant for land-use planning (a consequence-based approach used for the selection of scenarios):

a) A Boiling Liquid Expanding Vapour Explosion (BLEVE) of the 150 m^3 storage vessel after release from road tankers during loading/unloading.
b) A Vapour Cloud Explosion (VCE) after a spill of LPG during loading/unloading of road tankers due to a break (failure) of a flexible hose

Small leakages from standard 10 kg steel containers of LPG are not classified as relevant for land-use planning consideration.

The relevance of scenarios for land-use planning purposes is determined on the basis of the impact area consideration, meaning that a scenario is eliminated from the analysis if its consequences do not extend beyond the borders of the establishment. The only relevant scenario for land-use planning purposes associated with this establishment is scenario a) – the release of the entire quantity of LPG from any one of the 150 m^3 storage vessels (R1, R2, R3), which eventually leads to BLEVE. BLEVE is a sudden release of a large mass of pressurized superheated liquid or liquefied gas to the atmosphere (loss of containment) due to a catastrophic rupture of a pressure vessel (AICHE, 1989). BLEVE can occur as a result of any mechanism that results in the sudden failure of containment, allowing a superheated liquid to flash, typically increasing its volume over 200 times. This results in a pressure wave and, if the released liquid is flammable, a fireball occurs.

Scenario b) is treated both as an independent scenario and an initiating situation for the development of scenario a). In the latter, VCE causes damage to valves and connecting piping of the adjacent 150 m^3 storage vessel, as well as to a fixed fire extinguishing/cooling system at the loading/unloading and storage area, with additional major release of LPG leading to the final event of a BLEVE.

Basic modelling data is presented in Table 7.

Table 7: Overview of parameters for scenario of LPG spill during loading/unloading of road tankers

Parameter	Unit	Value
Substance quantity in road tanker	tonnes	19
Pressure	bar	6
Air temperature	^{o}C	20
Hole in the hose	mm	35
Diameter of the hose	mm	50
Height of hose rupture (from ground level)	m	1
Distance to source of ignition	m	50

The safety report (Gerbec, 2006) considers that a jet-fire at the end of the broken flexible hose could not cause BLEVE of the vessel, since impingement is excluded due to the parallel position of the road tanker at the loading/unloading facility and the vessels, the length of the hose being only 5 m, and the hydrostatic pressure which enables the spill after the hose failure. Also, such a jet-fire would initiate a pool fire of the part of the spilled LPG, while the rest would evaporate and eventually explode as VCE. It is important to note that this VCE would be less intensive in terms of damage to infrastructure and impact area than the one initiating BLEVE, since the amount of the evaporated gas exploded would be at least 50 times lower (this figure is a modelling result based on assumptions for LPG partition in terms of burning as a jet-fire and a pool fire, burning efficiency, evaporation rate, temperature, etc.). Consideration of two or even three BLEVE scenarios of the LPG vessels resulted in the conclusion that such a domino effect (one BLEVE at the time, three simultaneous BLEVE are physically impossible) would have an almost identical impact area to a single BLEVE. Also, additional damage in the surroundings due to the second and third BLEVE would be of lower importance than the first one.

Ignition

The source of ignition is assumed to be at a distance of 50 m (the distance to the facility boundary – outside of the facility ignition sources are not controlled).

In the case of a spill of the entire quantity of LPG from a road tanker, an ignition probability of 0,8 was considered. The most severe consequences are expected from a vapour cloud explosion (VCE); the safe distance is estimated at approximately 200 m (overpressure 2,1 kPa), while damage to buildings and infrastructure is expected within a radius of 80 m (overpressure 20,7 kPa). Damaging effects from thermal radiation caused by a pool fire are expected within distances of 70 m (thermal radiation of 12,5 kW/m^2).

In the case of a 900 kg spill, an ignition probability of 0,6 was considered. The most severe consequence again is a VCE; the safe distance is estimated at approximately 190 m (overpressure 2,1 kPa), while damage to buildings and infrastructure is expected within a radius of 75 m (overpressure 20,7 kPa). Damaging effects from thermal radiation caused by a pool fire are expected within distances of 30 metres (thermal radiation of 12,5 kW/m^2).

4.2.2 Threat analysis

The analysis is conducted for the BLEVE scenario discussed above. The incident outcomes considered are pressure wave (overpressure) and thermal radiation. The modelling of BLEVE consequences was performed using PHAST v. 6.1 software (Gerbec, 2006).

The BLEVE scenario assumes that the LPG is partly exploded, partly burned and partly evaporated and dispersed. The analysis was made for 72 tonnes of LPG (maximum vessel capacity – a conservative approach). The threat interaction matrix applied in threat analysis is presented in Table 8. Reference to the selected thresholds is provided in the Appendix I.

Threshold levels used in the analysis were obtained from past experiences in regard with risk assessment for hazardous industrial establishments, from the revision of threat assessment for the municipality of Koper, as well as from consultations and workshops with municipality officials.

Table 8: Threat interaction matrix for BLEVE

			PHYSICAL EFECT							
			OVERPRESSURE [kPa]				THERMAL RADIATION [kW/m^2]			
			Death / loss	Irreversible	Reversible	No effects	Death / loss	Irreversible	Reversible	No effects
ENVIRONMET	BIOSPHERE	Fauna	140	50	30	2,1	37,5	12,5	4,5	1,6
		Flora	34,5	13,8	6,9	2,1	25	4,5	1,6	<1,6
	NATURAL RESOURCES	Agriculture	34,5	-	-	-	25	4,5	1,6	<1,6
	HUMAN ENVIRONMENT	Human health - direct	140	50	30	2,1	37,5	12,5	4,5	1,6
		Human health - indirect	70	35	2,1	<2,1	37,5	12,5	4,5	1,6
		Infrastructure	20,7	13,8	6,9	2,1	37,5	-	-	-

4.2.2.1 Threat analysis for overpressure

The results on spatial distribution of effects obtained by modelling are presented on a chart in Figure 14. The results of the threat intensity level for overpressure for the BLEVE scenario are summarised in Table 9.

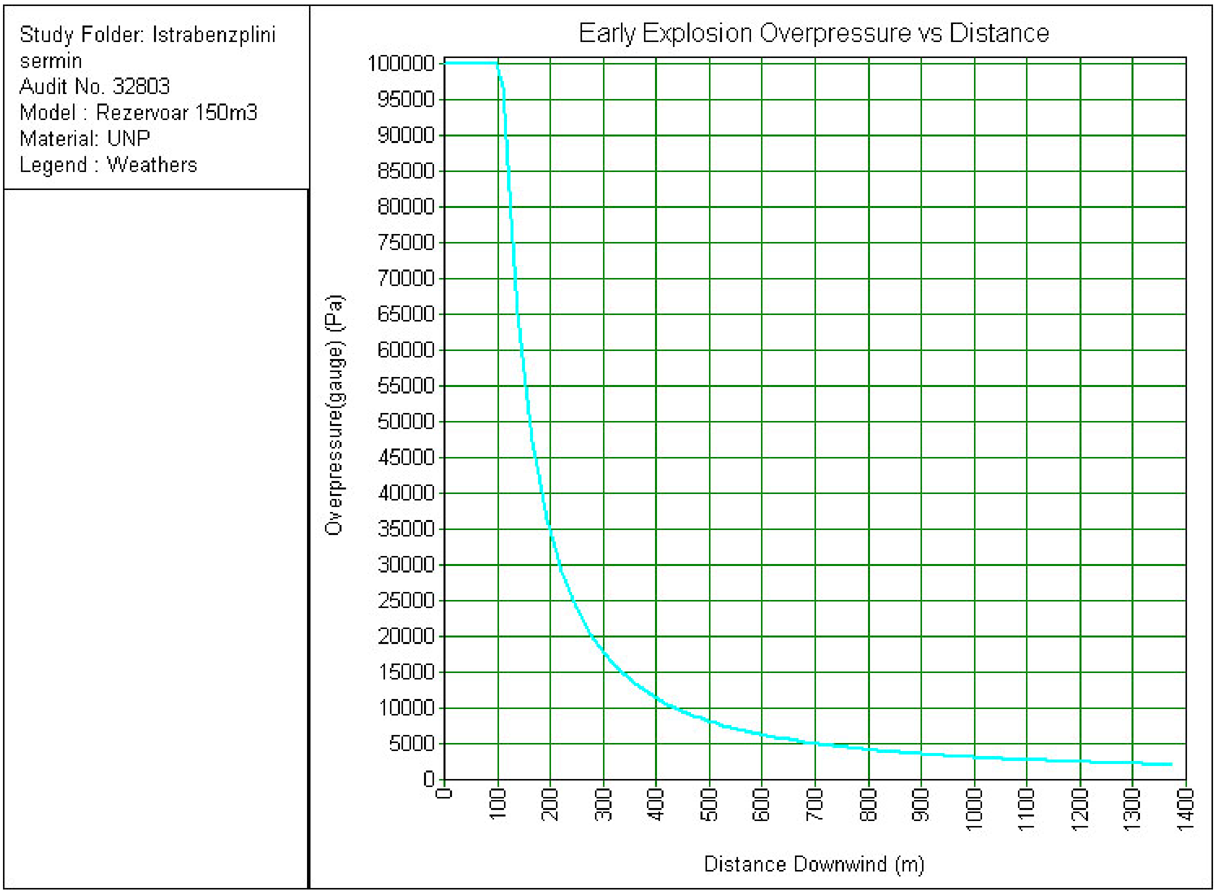


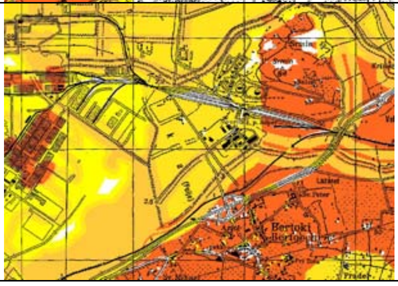
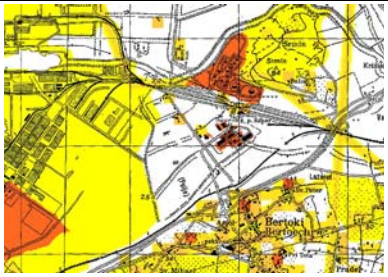
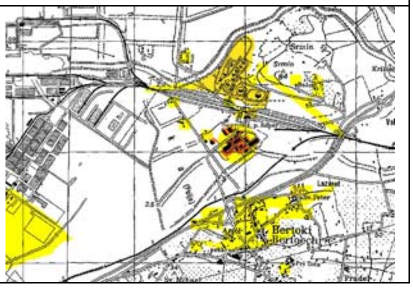
Figure 14: Spatial distribution of effects for overpressure for BLEVE scenario

Table 9: Threat intensity levels for overpressure for BLEVE scenario of 150m^3 LPG reservoir

			Threat intensity level – *OVERPRESSURE – distances*				
			5 – high	***4 – medium to high***	***3 – medium***	***2 – low to medium***	***1 – low***
			Death / loss	Irreversible	Reversible	Negligible	No effects
ENVIRONMET	**BIOSPHERE**	Fauna	100 m	170 m	220 m	1300 m	1300 m
		Flora	200 m	330 m	590 m	1300 m	1300 m
	NATURAL RESOURCES	Agriculture	200 m	-	-	-	-
	HUMAN ENVIRONMENT	Human health - direct	100 m	170 m	220 m	1300 m	1300 m
		Human health - indirect	130 m	200 m	590 m	1300 m	1300 m
		Infrastructure	< 180 m	280 m	340 m	960 m	> 960 m

The threat index is derived from the combination of threat intensity level and environmental threat-vulnerability as presented in Table 6 . The details on environmental threat-vulnerability analysis are presented in Appendix III. The results of threat analysis for overpressure for all environmental components are presented in Table 10. The results are intentionally not merged into a single map due to ethic reasons, which are greater in accidental cases.

Table 10: Threat index for overpressure for BLEVE scenario of 150m^3 LPG reservoir

	Threat intensity level	**Environmental threat-vulnerability**	**Threat index**
Biosphere			
Natural resources			
Human environment			
Infrastructure			

Results show the highest threat indices (categories 4 and 5) to be within the industrial/commercial area, posing a threat to the neighbouring facilities/buildings and environmental entities (special protected area Škocjanski zatok). Note that threat indices are presented up to the distances determined by the threat intensity levels; beyond these distances no threat indices are indicated, no matter how vulnerable environmental components may be.

Appendix IV provides specifications on threat categories.

4.2.2.2 Threat analysis for thermal radiation

The results on spatial distribution of effects obtained by modelling are presented in Figure 15. The results of the threat intensity level for thermal radiation for the BLEVE scenario are summarised in Table 11.

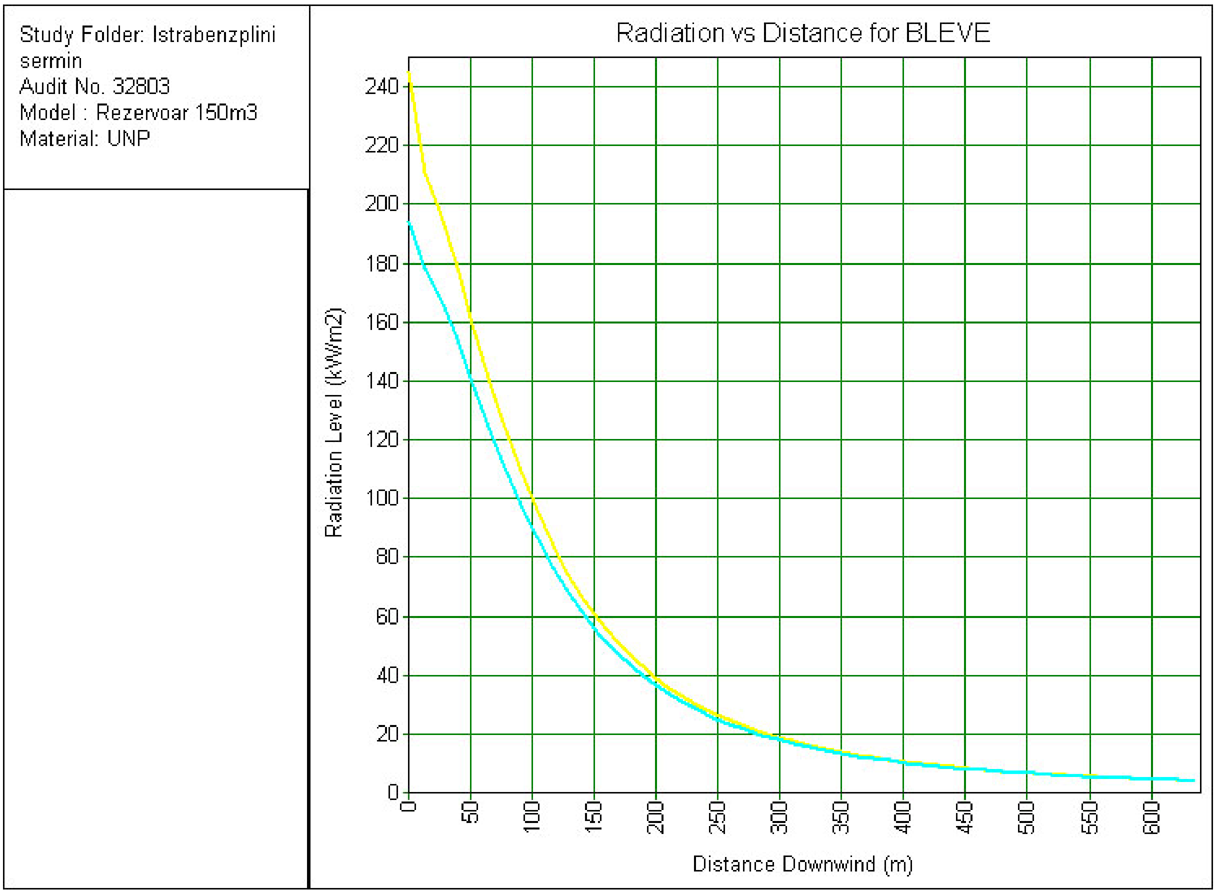


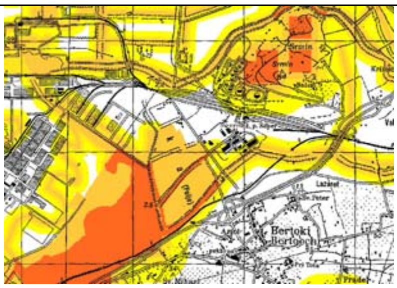
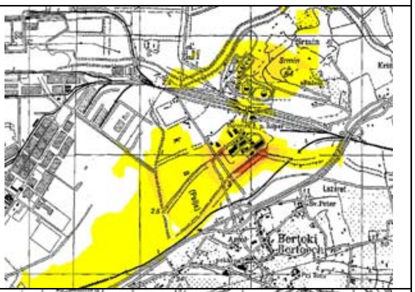
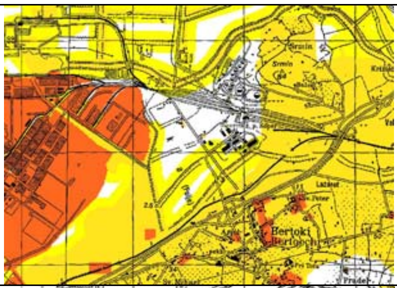
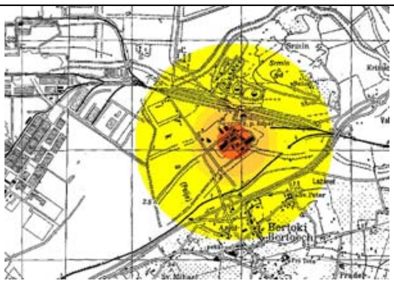
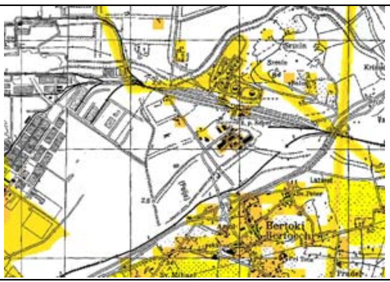
Figure 15: Spatial distribution of effects for thermal radiation for BLEVE scenario; curves represent modelling results for different weather conditions: yellow – summer, blue – winter

Table 11: Threat intensity levels for thermal radiation for BLEVE scenario of 150m^3 LPG reservoir

			Threat intensity level – *THERMAL RADIATION*				
			5 – high	***4 – medium to high***	***3 –medium***	***2 – low to medium***	***1 – low***
			Death/loss	Irreversible	Reversible	Negligible	No effects
ENVIRONMET	**BIOSPHERE**	Fauna	160 m	320 m	400 m	900 m	900 m
		Flora	230 m	320 m	400 m	900 m	900 m
	NATURAL RESOURCES	Agriculture	230 m	-	-	-	-
	HUMAN ENVIRONMENT	Human health - direct	160 m	320 m	400 m	900 m	900 m
		Human health - indirect	160 m	-	-	-	-
		Infrastructure	< 160 m	190 m	290 m	500 m	> 500 m

Threat index is derived from the combination of threat intensity level and environmental threat-vulnerability (as presented in Table 6). The details on environmental threat-vulnerability analysis are presented in Appendix III. The results of threat analysis for thermal radiation for all environmental components are presented in Table 12. The results are intentionally not merged into a single map due to reasons described above.

Table 12: Threat index for thermal radiation for a BLEVE scenario of 150m^3 LPG reservoir

	Threat intensity level	**Environmental threat-vulnerability**	**Threat index**
Biosphere			
Natural resources			
Human environment			
Infrastructure			

Results show the highest threat indices (categories 4 and 5) to be within the industrial/commercial area, posing a threat to the neighbouring facilities/buildings and environmental entities (special protected area Škocjanski zatok).

4.2.3 Sensitivity analysis

Models are often used to simulate reality in many different fields of application. The available knowledge of the model input is subjected to many sources of uncertainty including errors of measurement, inadequate sampling resolution, conceptual uncertainty etc. This imposes a limit on the confidence in the response or output of the model. Good modelling practice requires that the modelling process includes an evaluation of the confidence in the model, possibly assessing the uncertainties associated with the outcome (response) of the model itself with the application of sensitivity analysis (Crosetto et al., 2000; Campolongo and Saltelli, 1997).

Sensitivity analysis (SA) is a prerequisite for model building in any field where models are used. The general purpose of sensitivity analysis is to study how the variation in the model output can be apportioned to different sources of variations and how the given model depends on the information fed into it (Crosetto, et al. 2000). Sensitivity analysis helps investigating the way uncertainties of different orders propagate on the output variables, and on the inference which the model is called to support. Sensitivity analysis aims at establishing the relative importance of the input factors involved in the model (Cariboni, et al. 2007).

The sensitivity analysis for this research focus on the following variable parameters:

- the quantity of exploded LPG,
- the variations in threshold levels relating directly to index setting (classification) and thus decision-making
- variations within the threat-vulnerability modelling
- variations in the development of threat index (combinations of the of threat intensity and threat-vulnerability values into threat index)

4.2.3.1 Sensitivity analysis regarding the quantity of LPG

The purpose of varying the quantities was to observe variations in the final result (spatial distribution of effects). The aim was to analyse the uncertainties associated with the factor of ever-changing quantities in the vessel due to the nature of operations (loading/unloading).

The consideration of reduced quantity of LPG in the storage tank (36 tons – reasonable approach instead of 72 – conservative approach) was made as follows.

Overpressure

The results of the sensitivity analysis regarding the variations in the quantity of exploded PLG are presented in Table 13 and Figure 16.

Table 13: Threat intensity level for overpressure for BLEVE scenario of 150m^3 LPG reservoir

Threat intensity level	**Reference values for overpressure**	**Distance – impact radius (72 tonnes)**	**Distance – impact radius (36 tonnes)**
5 - high	> 20,7 kpa	< 275 m	< 180 m
4 – medium to high	13,8 kpa -20,7 kpa	275 m - 355 m	180 m - 280 m
3 -medium	6,9 kpa – 13,8 kpa	355 m - 500 m	280 m - 340 m
2 – low to medium	2,1 kpa – 6,9 kpa	500 m - 1370 m	340 m - 960 m
1- low	< 2,1 kpa	> 1370 m	> 960 m

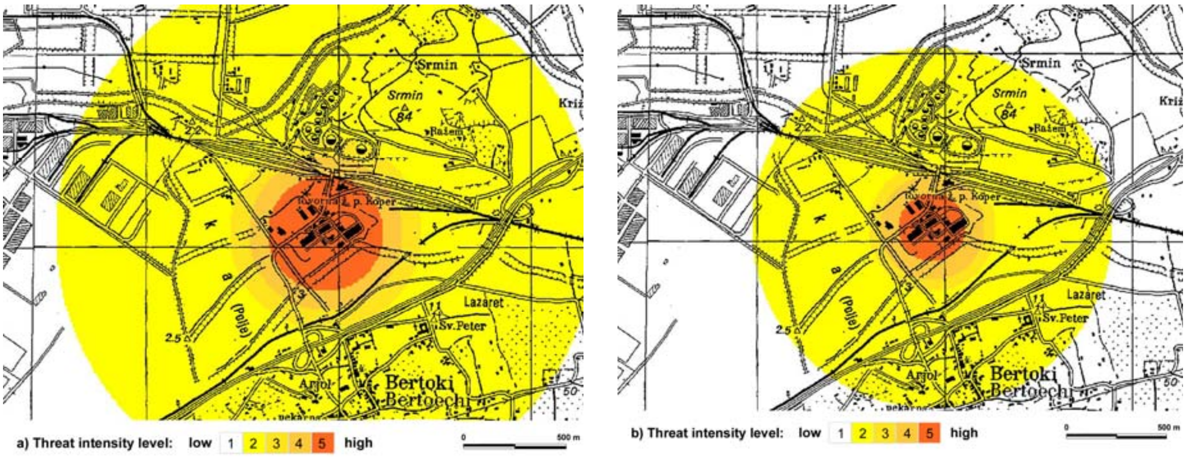


Figure 16: Threat intensity level for overpressure – conservative approach 72 t (a); reasonable approach 36 t (b)

Threat index maps for sensitivity analysis are presented in Figure 17.

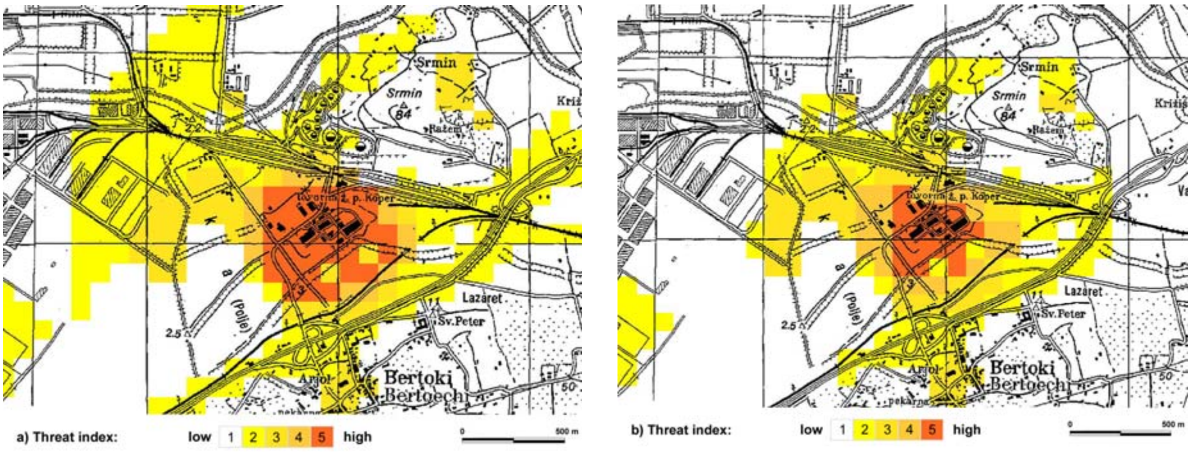


Figure 17: Threat index map for overpressure – conservative approach 72 t (a); reasonable approach 36 t (b)

Thermal radiation

The results of the sensitivity analysis regarding the variations in the quantity of exploded LPG are presented in Table 14 and Figure 18.

Table 14: Threat intensity level for thermal radiation for BLEVE scenario of 150m^3 LPG reservoir

Threat intensity level	Reference values for thermal radiation	Distance – impact radius (72 tonnes)	Distance – impact radius (36 tonnes)
5 - high	> 37,5 kW/m2	< 210 m	< 160 m
4 – medium to high	25 kW/m2 – 37,5 kW/ m2	210 m - 250 m	160 m - 190 m
3 -medium	12,5 kW/m2 - 25 kW/m2	250 m - 370 m	190 m - 290 m
2 – low to medium	4,5 kW/m2 – 12,5 kW/m2	370 m - 650 m	290 m - 500 m
1- low	< 4,5 kW/m2	> 650 m	> 500 m

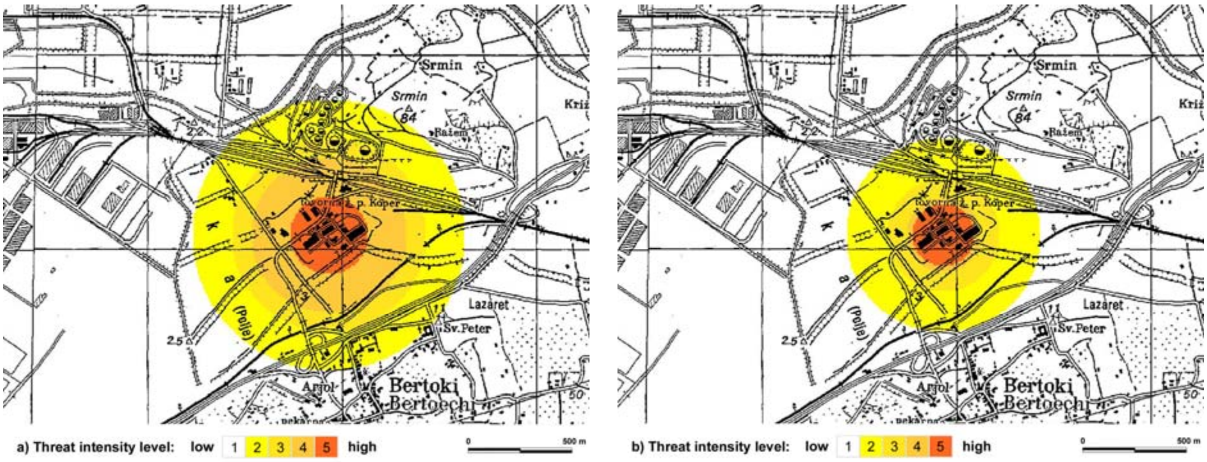


Figure 18: Threat intensity level for thermal radiation – conservative approach 72 t (a); reasonable approach 36 t (b)

Threat index maps for sensitivity analysis are presented in Figure 19. The results are similar to those for overpressure, only distances in the conservative approach are smaller.

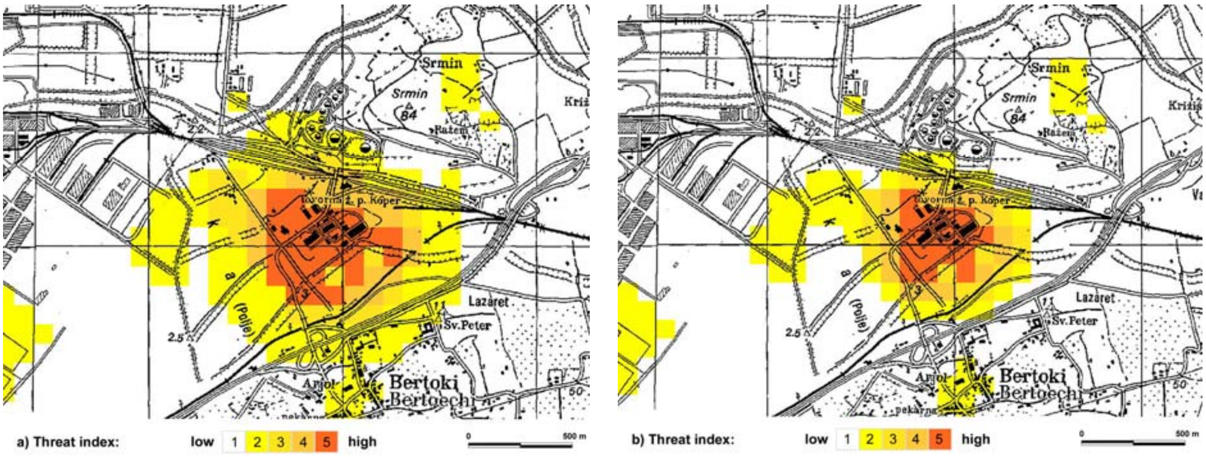


Figure 19: Threat index map for thermal radiation – conservative approach 72 t (a); reasonable approach 36 t (b)

The variations in the impact areas based on the sensitivity analysis are presented in Figures 20-22. Modelling results show that impact area ranges from 10 to 40 ha depending on the outcome[7]: thermal radiation 37,5 kW/m^2, 12,5 kW/m^2 and overpressure of 13,8 kPa.

Figure 20: Impact area for BLEVE scenario for thermal radiation (ThR) 12,5 KW/m^2

Figure 21: Impact area for BLEVE scenario for thermal radiation (ThR) 37,5 KW/m^2

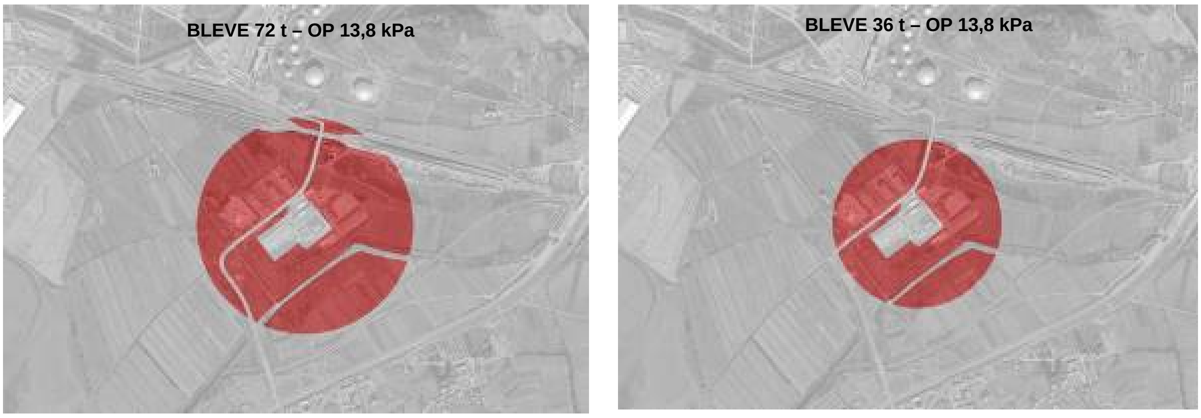


Figure 22: Impact area for BLEVE scenario for overpressure (OP) 13,8 kPa based on the sensitivity analysis of the quantity of LPG exploded

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[7] Thermal radiation of 37,5 kW/m^2 may cause damage to process equipment, 12,5 kW/m^2 enables ignition of wood and melting of plastics, overpressure of 13,8 kPa causes structural damages of buildings

What these variations in the scope of the impact area may mean in terms of the economy and alternative land development is presented in Tables 15 to 17.

The expected financial loss of opportunistic income due to establishing buffer zones in the impact area (no development) compared to land development scenario (housing, commercial zone) is presented. The land development categories considered are individual housing (U1), block apartments P/4 (U2) and commercial areas (U3). Table 17 specifically shows the implication of results for land-use planning if the existing agricultural purpose of land was changed (developed) due to elimination of a BLEVE scenario or explosion of only half of the vaporized LPG from the vessel, i.e. 36 tonnes instead of 72. Elimination of BLEVE requires either re-location of the facility or full expected performance of the barriers which prevent propagation of the initial event to BLEVE: installation of the mechanical arm, fire extinguishing system and safety relief valve may bring an economic gain of approximately 30 million Euros.

Table 15: Current property values in Koper region

Land-use	**Price (€ /m^2)**
Agriculture, pastures	8
Vineyards/Olive groves	30
Development plots	150
Individual housing (U1)	700
Blocks of flats P/4 (U2)	3500
Commercial (U3)	1000

Table 16: Implication of the BLEVE scenario – realistic approach (36 t) on land value loss due to no land development; selected categories of thermal radiation and overpressure

				Values of land according to different uses based on Table 15 (M €)				
	Physical effect – selected reference values	**Distance to selected reference values (m)**	**Area associated to reference values and distances (ha)**	**Agriculture/ fields, pastures**	**Vineyards/ Olive groves**	**U1***	**U2***	**U3***
BLEVE 36 t	ThR – 12,5 kW/m^2	290	22,4	1,8	6,7	62,8	314,0	89,7
	ThR – 37,5 kW/m^2	160	5,0	0,4	1,5	14,0	70,1	20,0
	OP – 13,8 kPa	280	20,7	1,7	6,2	57,9	290,0	82,8
BLEVE 72 t	ThR – 12,5 kW/m^2	376	40	3,2	11,9	105,0	526,8	150,5
	ThR – 37,5 kW/m^2	210	10	0,8	3,1	29,3	145,2	41,7
	OP – 13,8 kPa	355	35	2,8	10,5	49,1	472,6	135,0
BLEVE elimination		Impact area 10-40 ha enabled for development						

* U1, U2 and U3 categories take into consideration an urbanisation density factor of 0,4.

The results show that the impact radii for 72t/36t BLEVE scenario on reservoirs R1, R2 and R3 vary by approximately 30%.

Table 17: Possible land value gain after BLEVE scenario elimination

Land-use	**Area (ha)**	**Price (€ /m2)**	**Value (M €)**
Agriculture, pastures	10	8	0,8
Individual housing (U1*)	6	700	16,8
Commercial (U3*)	3	1000	12,0
SUM			**29,6**

* U1and U3 categories take into consideration urbanisation density factor of 0,4.

4.2.3.2 Sensitivity analysis regarding the selection of threshold levels

The purpose of varying the threshold levels was to observe variations in the final result (spatial distribution of effects) due to the uncertainties associated with classification into the threat categories.

The aim was to analyse the uncertainties in the scope of the impact area associated with the adoption of reference values (thresholds) evolving from the generalisation when estimating the effects on targets. The main reason being that the threshold levels have been set on the basis of experiments or past experiences (AICHE, 1989; IDEAS, 1988; Lees, 1996; Ngo, et al., 2007; SAVE II, 1992; The "Green Book", 1992; U.S DOE, 2008) and do not reflect the actual state/characteristics of the targets in the reality (i.e. the threshold levels are mostly an assumption about the possible effect the target will experience).

The selected intervals (20%, 50%) were selected based on the difference in values, based on the types of materials (characteristic of targets) and on different interpretations of values by administrative officials concerned with safety (ARAMIS, 2004).

Overpressure

In the modelling of the consequences for overpressure the following threshold values have been used:

- 20,7 kPa – Severe damage to steel construction; damage to storage vessels (reservoirs); severe damage to buildings and equipment.
- 13,8 kPa – Partial demolition of house walls and roof-tops.
- 6,9 kPa – Damage to housing (some inappropriate for dwelling)
- 2,1 kPa - "safe distance"; 5 % probability for severe injuries; 10 % probability for broken window glass.

Results of the sensitivity analysis are presented in Table 18 and Figure 23 and show moderate differences between the different threshold levels applied. The highest variation of results is observed in the threat index level 1. Minor variation is observed for the threat index levels 4 and 5 which are more relevant for decision-making in the context of land-use planning.

Table 18: Variations in threat intensity level for overpressure for BLEVE scenario of 150m^3 LPG reservoir

Threat intensity level	**Reference values for overpressure** (kPa)	**Distance – impact radius** **(72 tonnes)** (m)	**Area** (ha)
5 - high	> 20,7	< 275	18
4 – medium to high	13,8 – 20,7	275 – 355	7
3 -medium	6,9 – 13,8	355 – 500	43
2 – low to medium	2,1 – 6,9	500 – 1370	742
1- low	< 2,1	> 1370	
Threat intensity level + 20%	**Reference values for overpressure** (kPa)	**Distance – impact radius** **(72 tonnes)** (m)	**Area** (ha)
5 - high	> 25,0	< 230	13
4 – medium to high	15,9 – 25,0	230 – 310	25
3 -medium	8,5 – 15,9	310 – 420	42
2 – low to medium	2,8 – 8,5	420 – 850	516
1- low	< 2,8	> 850	
Threat intensity level - 20%	**Reference values for overpressure** (kPa)	**Distance – impact radius** **(72 tonnes)** (m)	**Area** (ha)
5 - high	> 16,0	< 310	23
4 – medium to high	10,5 – 16,0	310 – 400	6
3 -medium	5,5 – 10,5	400 – 650	23
2 – low to medium	1,6 – 5,5	650 – 1520	837
1- low	< 1,6	> 1520	
Threat intensity level + 50%	**Reference values for overpressure** (kPa)	**Distance – impact radius** **(72 tonnes)** (m)	**Area** (ha)
5 - high	> 31,8	< 210	12
4 – medium to high	20,7 – 31,8	210 – 275	4
3 -medium	10,5 – 20,7	275 – 420	78
2 – low to medium	3,1 – 10,5	420 – 950	434
1- low	< 3,1	> 950	
Threat intensity level - 50%	**Reference values for overpressure** (kPa)	**Distance – impact radius** **(72 tonnes)** (m)	**Area** (ha)
5 - high	> 10,4	< 360	14
4 – medium to high	6,9 –10,4	360 – 500	32
3 -medium	3,5 – 6,9	500 – 850	37
2 – low to medium	1,0 – 3,5	850 – 2200	962
1- low	< 1,0	> 2200	

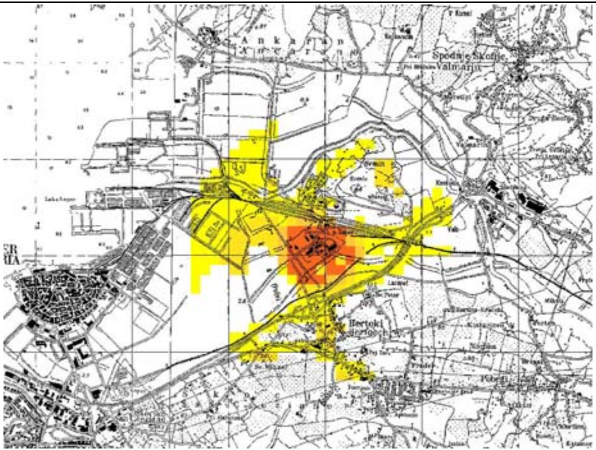
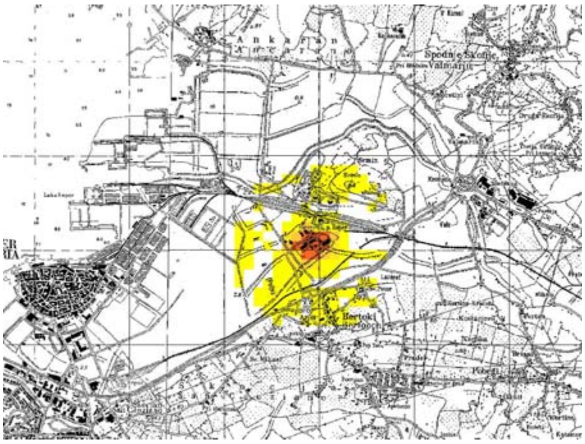
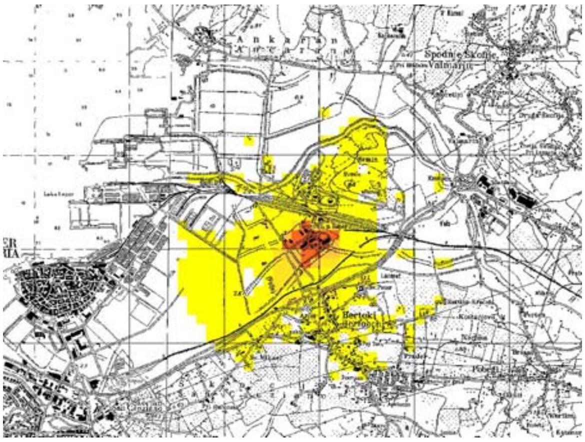
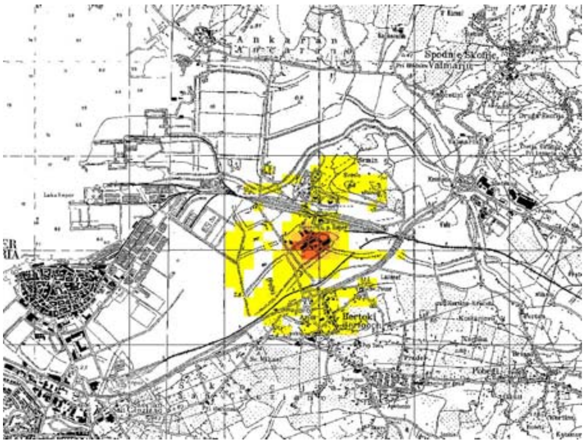
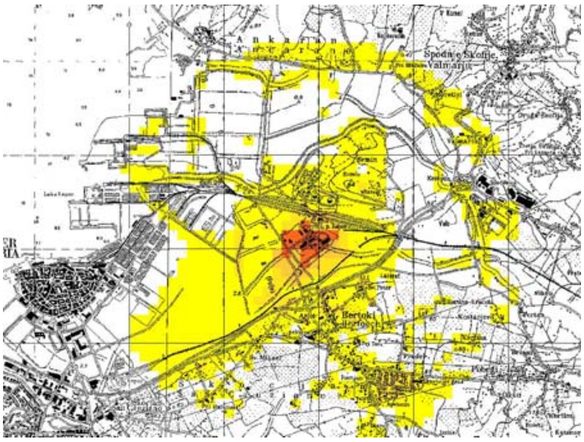
Threat index		
Threat index +/- 20 %		
Threat index +/- 50 %		

Figure 23: Variations in threat index for overpressure for BLEVE scenario of 150m^3 LPG reservoir based on the sensitivity analysis of the threshold levels

Thermal radiation

In the process of modelling the consequences of thermal radiation the following threshold values have been considered:

- 37,5 kW/m^2 – causes damage to process equipment,
- 25 kW/m^2 – minimal required energy for ignition of wood under longer exposure periods (without initial ignition – flame)
- 12,5 kW/m^2 – sufficient energy for ignition of wood with initial ignition, melting of plastics, etc.,
- 4,5 kW/m^2 – sufficient energy for causing pain to people if protection is not provided within 20 seconds.

Results of the sensitivity analysis are presented in Table 19 and Figure 24 and show moderate differences between different threshold levels applied. The highest variation of results is observed in the threat index level 1. Minor variation is observed for the threat index levels 4 and 5 as more relevant for decision-making in the context of land-use planning.

Table 19: Variations in threat intensity level for thermal radiation for BLEVE scenario of 150m3 LPG reservoir

Threat intensity level	**Reference values for thermal radiation** (kW/m^2)	**Distance – impact radius** **(72 tonnes)** (m)	**Area** (ha)
5 - high	> 37,5	< 210	14
4 – medium to high	25 – 37,5	210 – 250	1
3 -medium	12,5 – 25	250 – 370	16
2 – low to medium	4,5 – 12,5	370 – 650	374
1- low	< 4,5	> 650	
Threat intensity level + 20%	**Reference values for thermal radiation** (kW/m^2)	**Distance – impact radius** **(72 tonnes)** (m)	**Area** (ha**)**
5 - high	> 45	< 180	8
4 – medium to high	30 – 45	180 – 220	4
3 -medium	15,0 – 30	220 – 310	3
2 – low to medium	5,5 – 15,0	310 – 500	330
1- low	< 5,5	> 500	
Threat intensity level - 20%	**Reference values for thermal radiation** (kW/m^2)	**D Distance – impact radius** **(72 tonnes)** (m)	**Area** (ha)
5 - high	> 30	< 220	12
4 – medium to high	20 – 30	220 – 280	3
3 -medium	10 – 20	280 – 400	8
2 – low to medium	3,6 – 10	400 – 720	371
1- low	< 3,6	> 720	
Threat intensity level + 50%	**Reference values for thermal radiation** (kW/m^2)	**Distance – impact radius** **(72 tonnes)** (m)	**Area** (ha)
5 - high	> 55	< 150	6
4 – medium to high	37,5 – 55	150 – 210	3
3 -medium	18,8 – 37,5	210 – 280	2
2 – low to medium	6,8 – 18,8	280 – 450	280
1- low	< 6,8	> 450	
Threat intensity level - 50%	**Reference values for thermal radiation** (kW/m^2)	**Distance – impact radius** **(72 tonnes)** (m)	**Area** (ha)
5 - high	> 18,8	< 280	14
4 – medium to high	12,5 – 18,8	280 – 370	7
3 -medium	6,8 – 12.5	370 – 450	17
2 – low to medium	2,3 – 6,8	450 – 1000	472
1- low	< 2,3	> 1000	

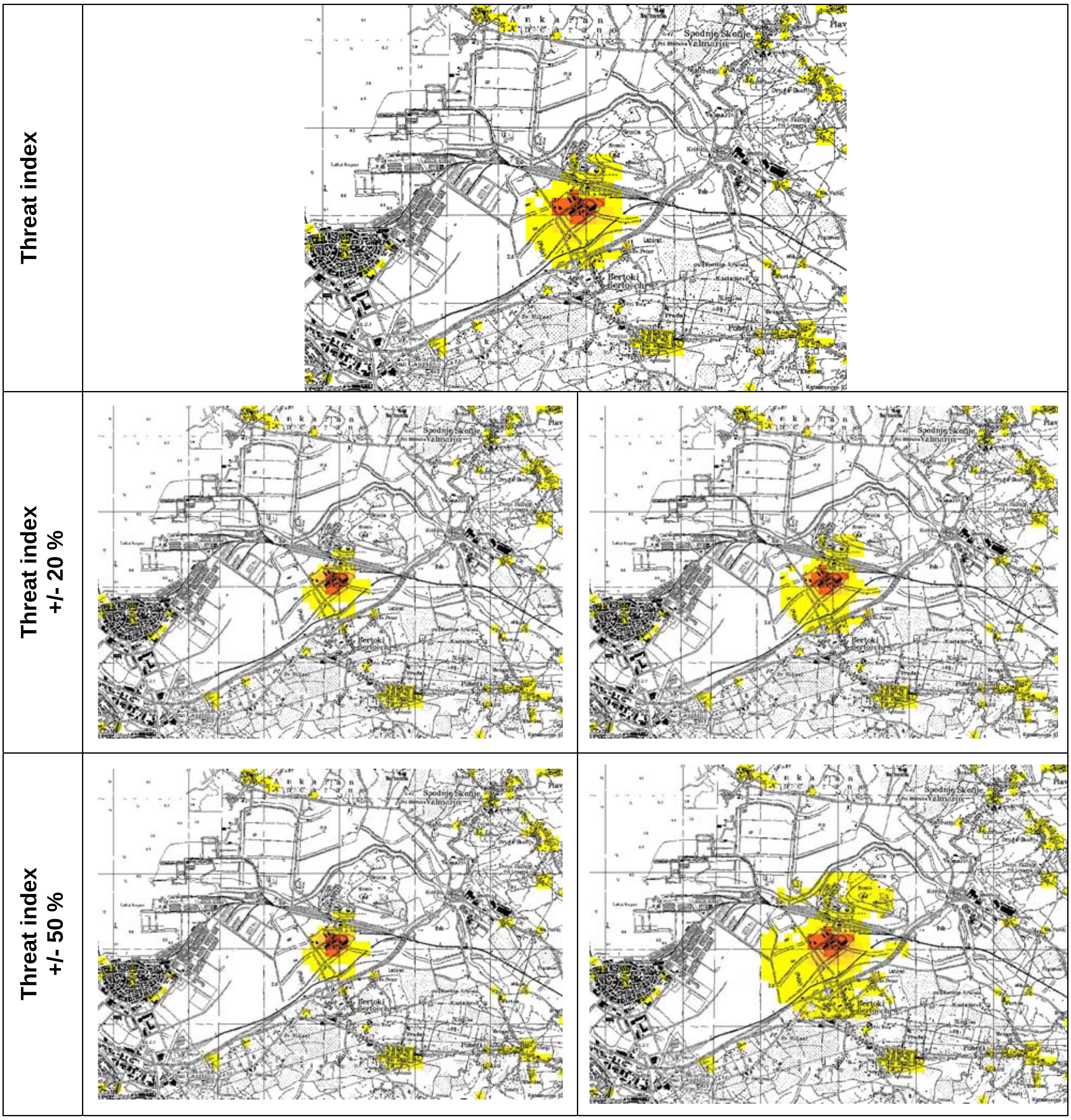


Figure 24: Variations in threat index for thermal radiation for BLEVE scenario of 150m^3 LPG reservoir based on the sensitivity analysis of the threshold levels

4.2.3.3 Sensitivity analysis regarding the variations within the environmental threat-vulnerability modelling

Since the values in threat vulnerability analysis are quantitative/qualitative in nature the potential subjectivity of the analyst can be introduced in the final result. The purpose of varying the threat-vulnerability values is to identify the impact of these variations on the final result.

Considered approaches to assigning values are:

- pessimistic approach (assigning higher values)
- optimistic approach (assigning lower values)
- yes/no approach (binary scale approach – differentiates whether environmental entity is present or not)

Environmental threat-vulnerability of biosphere and human environment and the effect of overpressure were analysed. The results are presented in Tables 20 and 21.

Table 20: Variations in environmental threat-vulnerability of biosphere for overpressure

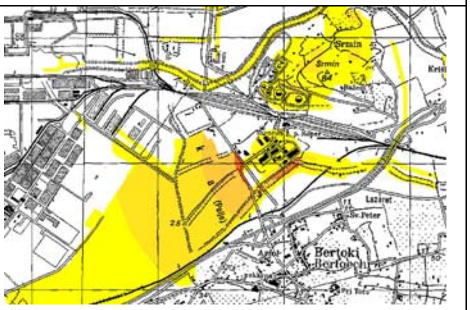
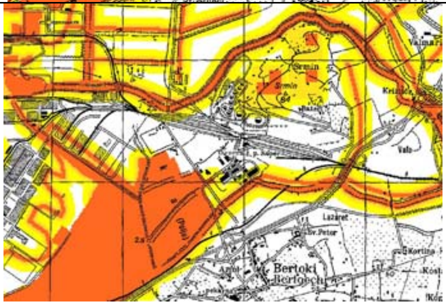
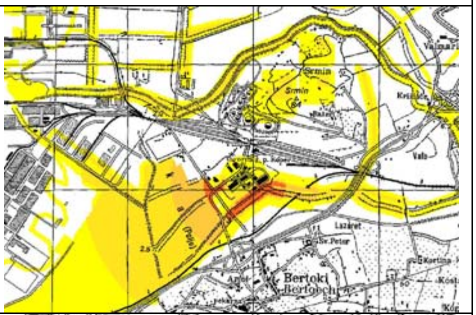
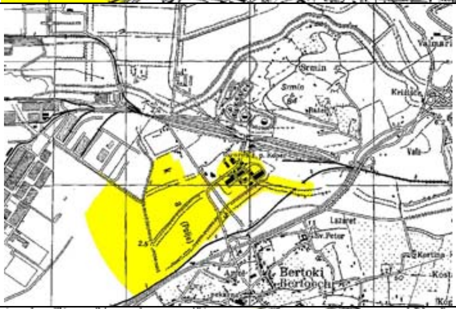
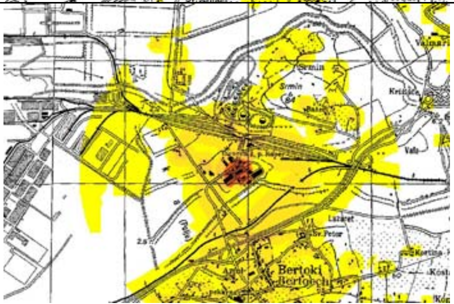
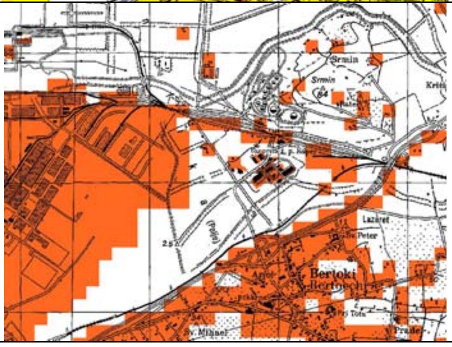
	Environmental threat-vulnerability	**Threat index**
Initiating status (see chapter 4.2.2)		
Pessimistic approach		
Optimistic approach		
Yes/no – binary scale approach		

Table 21: Variations in environmental threat-vulnerability of human environment for overpressure

	Environmental threat-vulnerability	**Threat index**
Initiating status (see chapter 4.2.2)		
Pessimistic approach		
Optimistic approach		
Yes/no – binary scale approach		

The sensitivity analysis in terms of variations of environmental threat-vulnerability values shows significant level of variation in final result. This implies potential high level of uncertainty if values assigned are of subjective (qualitative) nature (instead of threshold based – quantitative/semi-quantitative, as is the case in the "initiating status"). The greatest confidence in this regard is present in binary scale approach, however the questions arise in terms of data accuracy.

4.2.3.4 Sensitivity analysis regarding the variations in the development of threat index

The combination of threat intensity level and environmental threat vulnerability yields threat index. This can be achieved by various means. For the purpose of building confidence in threat index development, various ways of combining the two were analysed.

These include the combinations by using:

- multiplication and consequent normalisation into 1-5 scale
- the maximum value function – the approach commonly used in environmental vulnerability analysis
- the mean value function – the concept commonly practised in environmental suitability approach
- arbitrary approach – assigning combination values by the use of matrix

The sensitivity analysis in terms of variations in the development of threat index shows significant level of variation in final result. The greatest confidence in this regard is present in multiplication and arbitrary approach – the latter also allows implementation of synergetic effects which might be identified in the process of integration.

Table 22: Variations in threat index development; impact of overpressure on biosphere

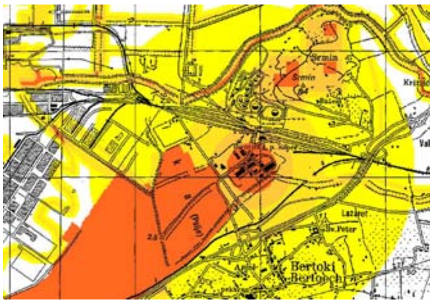
<table>
<tr><th>Threat intensity level</th><th>Environmental threat-vulnerability</th></tr>
<tr><td> </td><td> </td></tr>
<tr><th>Combination function</th><th>Result – threat index</th></tr>
<tr><td>Multiplication</td><td> </td></tr>
<tr><td>Maximum value function</td><td> </td></tr>
<tr><td>Mean value function</td><td> </td></tr>
<tr><td>Arbitrary – matrix
<table>
<tr><td></td><td colspan="6">Threat intensity level</td></tr>
<tr><td rowspan="6">Environmental threat vulnerability</td><td></td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>1</td><td>1</td><td>1</td><td>2</td><td>3</td><td>3</td></tr>
<tr><td>2</td><td>1</td><td>2</td><td>3</td><td>3</td><td>4</td></tr>
<tr><td>3</td><td>1</td><td>2</td><td>3</td><td>4</td><td>4</td></tr>
<tr><td>4</td><td>1</td><td>2</td><td>3</td><td>5</td><td>5</td></tr>
<tr><td>5</td><td>2</td><td>3</td><td>4</td><td>5</td><td>5</td></tr>
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Table 23: Variations in threat index development; impact of overpressure on human environment

<table>
<tr><th>Threat intensity level</th><th>Environmental threat-vulnerability</th></tr>
<tr><td></td><td></td></tr>
<tr><th>Combination function</th><th>Result – threat index</th></tr>
<tr><td>Multiplication</td><td></td></tr>
<tr><td>Maximum value function</td><td></td></tr>
<tr><td>Mean value function</td><td></td></tr>
<tr><td>Arbitrary – matrix
<table>
<tr><td></td><td colspan="6">Threat intensity level</td></tr>
<tr><td rowspan="6">Environmental threat vulnerability</td><td></td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>1</td><td>1</td><td>1</td><td>2</td><td>3</td><td>3</td></tr>
<tr><td>2</td><td>1</td><td>2</td><td>3</td><td>3</td><td>4</td></tr>
<tr><td>3</td><td>1</td><td>2</td><td>3</td><td>4</td><td>4</td></tr>
<tr><td>4</td><td>1</td><td>2</td><td>3</td><td>5</td><td>5</td></tr>
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4.2.4 Threat reduction measures at Istrabenz Plini

Based on the results of threat analysis, the proposed threat reduction measures are:

a) The replacement of the flexible hose with a mechanical arm. This would eliminate the possibility of an initiating event, i.e. a spill as a result of a hose failure during loading/unloading of road tankers. The decoupling mechanism of the mechanical arm allows the release of only 0,1 litre of LPG (FMC, 2007). This measure eliminates both the VCE and the BLEVE scenario.

b) Burial of the 150 m^3 LPG vessel, i.e. underground storage. Such a technological change would eliminate the BLEVE scenario, but it is more expensive than the installation of a mechanical arm. In addition, the VCE scenario still remains as possible.

c) Guiding future land-development away from the risk source. This approach is less favoured by establishment managers, since certain areas potentially suitable for development would be left unused, functioning as safety buffer zones. Management of such buffer zones is usually the responsibility of the authorities, while the costs are covered by the establishment.

In the context of both economic and risk considerations the only reasonable option is option a). Option b) is significantly more expensive in terms of investment expenditure than option a), while option c) is basically a prolongation of the existing situation that is no longer desirable (tolerable) by either the Municipality of Koper or other users/owners of land in the buffer zones. Therefore, managers of the Istrabenz Plini selected option a).

4.3 Integration of threat analysis and land-use planning

Threat analysis for hazardous industrial installations enables transparent and understandable interpretation of threat for land-use planning purposes. The presentation of threat index in a GIS format is focused towards compatibility with other results of various spatial/environmental analyses conducted in the framework of land-use plan preparation.

Threat analysis can be used as a scientifically supported basis for siting new hazardous industrial installations, as well as for controlling development around them, as was shown in the case studies given. In the latter case, threat analysis serves as a basis for taking appropriate measures for prohibiting or controlling development in areas of high threat (level 4 and 5), or conditionally allowing development in areas with medium threat (level 2-3). Moreover, the results can serve as guidelines for determining priorities for management within the impact area.

Three approaches for managing threat in terms of land-use planning are considered:

a) standardisation – prohibition and/or control of development in areas of high threat (level 4 and 5), or conditionally allowing development in areas with medium threat (level 2-3)

b) technological optimisation – implementing technical measures on the installation to prevent or minimise the occurrence of incidents and associated consequences. Technological solutions in this case are indirect land-use planning measure, since it is a consequence of the pressure from various stakeholders (investors) aiming at the development of the vicinity of the establishment; another aspect is the remediation of the state evolving from the already present development in the vicinity of the establishment.

   Spatial planning is achieving consensus among different stakeholders; it initiates the technological optimisation (or closing-down of the establishment) which is directly translated into land-use plan change.

c) spatial development optimisation – based on the detailed threat index determination and the introduction of resilience index – a selection of uses of land and structures that would be able to withstand the threat intensity level they are going to be exposed to in the case of an accident on a given/proposed location. The approach is analogous to resilience management (the term used in earthquake management).

In the following concrete suggestions for implementing the threat analysis results into the new municipal land-use plan for the Municipality of Koper are given.

4.3.1 Standardisation – buffer zone

The existing situation, i.e. with no implementation of the threat reduction measures a) and b), requires at least a safety buffer zone around the LPG facility, i.e. threat reduction measure c), as presented in Figure 25. Such a zone has not yet been established.

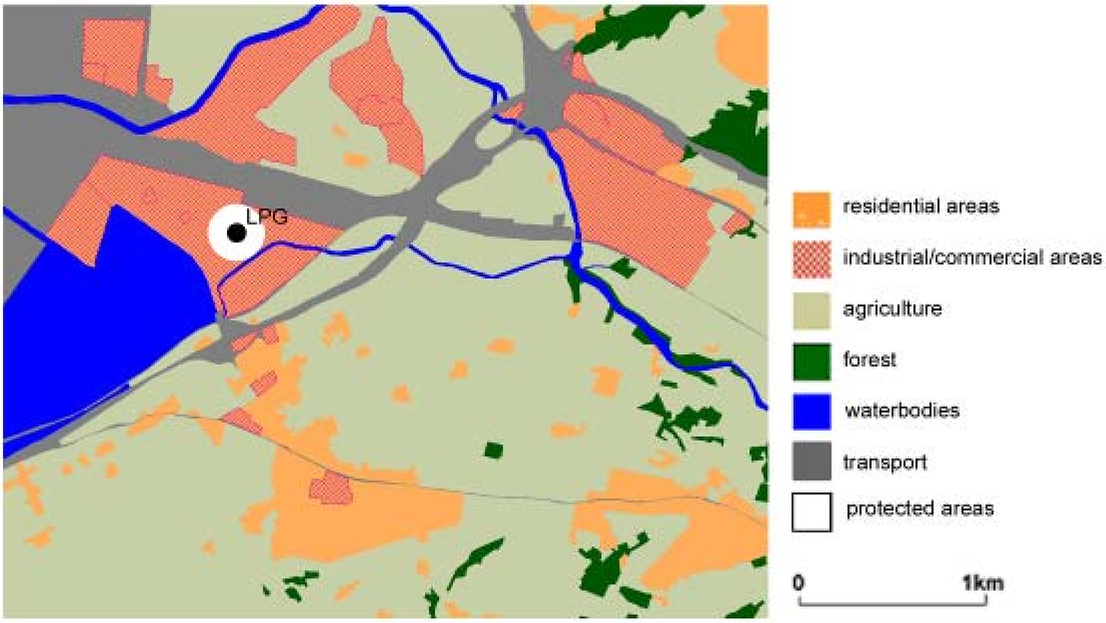


Figure 25: LPG storage and handling facility – existing situation with the required safety buffer zone

If the buffer zone were to be established, it would remain under constant development monitoring, where no development would be encouraged. Location, construction and operational permits would be a question of case-by-case considerations by the authorities.

4.3.2 Technological optimisation

On the other hand, if either of the other two threat reduction measures was applied – measures a) and b) – the consequent reduction of the impact area could make future use of the surroundings more liberal and oriented towards stronger economic development. Possible land-use planning changes in that context are presented in Figures 26 and 27 and in Tables 15 to 17.

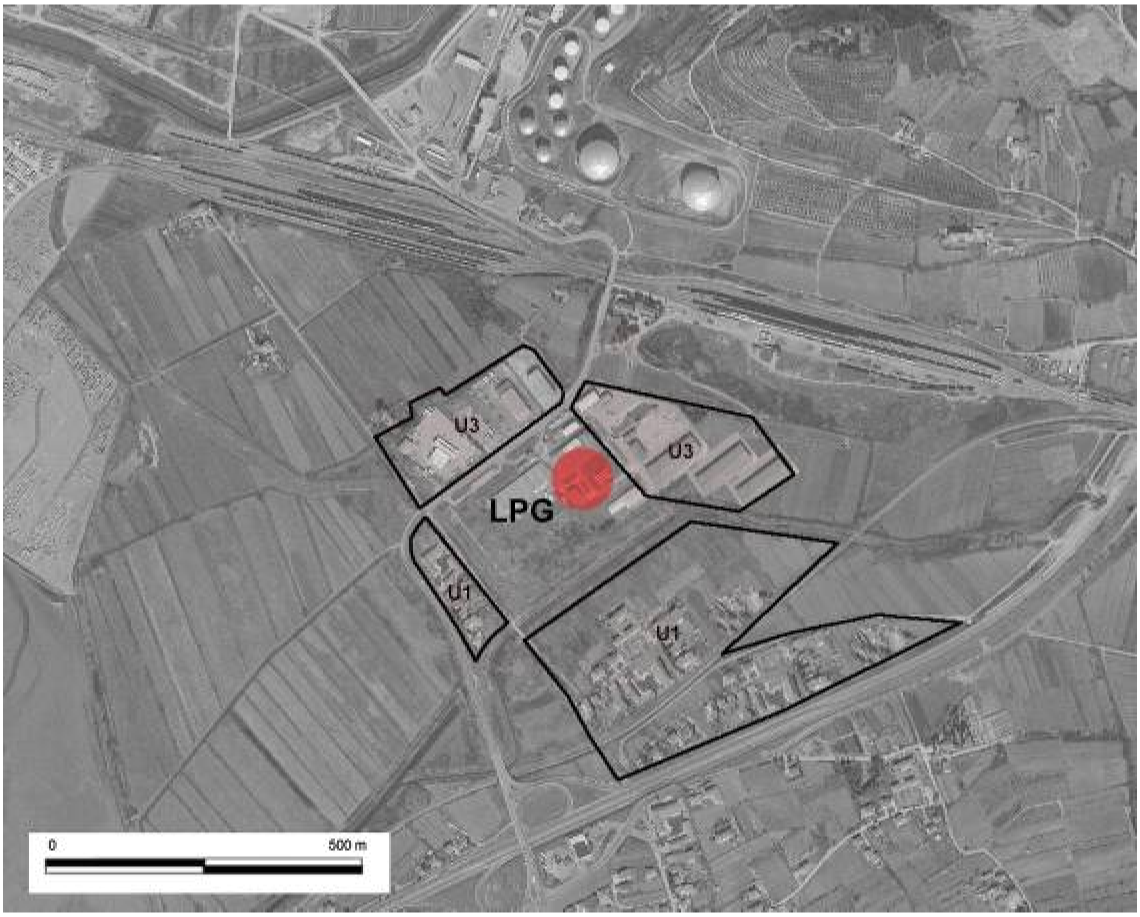


Figure 26: Illustration of possible land development scenario after elimination of the BLEVE scenario. U1 and U3 are explained in Table 15.

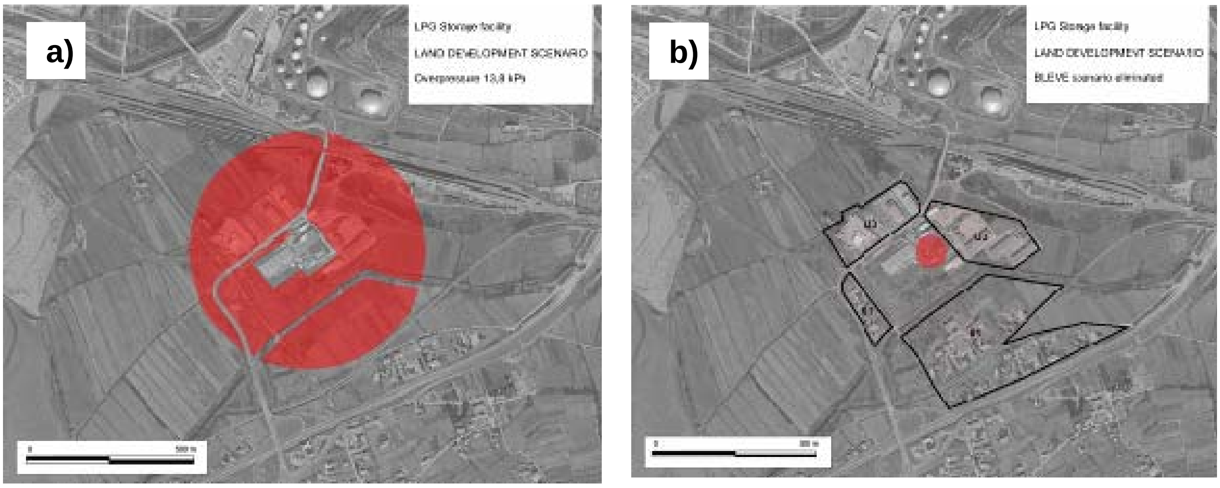


Figure 27: a) existing situation; no development is available in the impact area b) possible development scenario after implementation of a threat reduction measure a) or b).

4.3.3 Spatial development optimisation – resilience analysis/index

In order to perform optimisation in threat informed land-use planning, resilience analysis is performed. An example of the approach is presented for the proposed development of the commercial-service zone in the vicinity of the LPG site (Istrabenz Plini, Sermin). The proposed development is divided into 6 areas; a situation is presented in Figure 28.

Area I is situated on the eastern part of the zone and covers approximately 9,6 hectares. The complex consists of the three units – commercial object, business centre and business hotel.

- commercial object; the maximum dimensions are 385 x 101 m, the maximum height is 22,7 m. On the western side of the object is a yard with commercial access. A subsurface parking garage is located underneath the object offering 1180 parking places.
- business centre – located at the eastern side of the commercial object. The maximum dimensions are 40 x 23 m, the maximum height is 31,5 m.
- business hotel – located north of the commercial object. The maximum dimensions are 55 x 30 m at ground level and 40 x 23 m at other levels, with the maximum height of 46,5 m.

The complex is accessible from all four directions – from west (delivery) and all other directions (clients). 1473 parking places are located in the surroundings of the complex. An extensive landscaping design is established in the vicinity of the complex.

Area II is situated on the south-eastern part of the zone and covers approximately 1,2 hectares. The complex consists of two units – the technological park of Slovene Istria and object A.

- technological park of Slovene Istria - The maximum dimensions are 80 x 65 m, and the maximum height 16 m. Surrounding the object a landscape design with local flora is planned. The patios and outdoor surfaces will be paved, elevation differences will be overcome by ramps (access for disabled).
- object A – consists of 5 semi-detached units. The maximum dimensions are 70 x 16 m, the maximum height of the object is10 m.

130 parking places are planned in the surrounding of the area. The landscape design in the area consists of tree lines and lawns.

Area III is situated on the southern part of the zone and covers approximately 1 hectare. The complex consists of the two units – object B and object C.

- object B – consists of 6 semi-detached units. The maximum dimensions are 70 x 20 m, the maximum height is 13,2 m.
- object C – consists of 7 semi-detached units. The maximum dimensions are 70 x 20 m, the maximum height is 10 m.

The object is accessible from the east. In the area approximately 94 parking places are situated.

Area IV is situated on the south-western part of the zone and covers approximately 1,6 hectares. The complex consists of 10 semi-detached objects grouped as an object D. The horizontal dimensions of the object are 150 x 10 m, height 14 m. The object is accessible from the north. In the area approximately 120 parking places are situated.

Area V is situated on the north-western part of the zone. The complex consists of the two larger units – object E and object F:

- object E – consists of 7 semi-detached units. The maximum dimensions are 100 x 15 m. the maximum height is 13 m.
- object F – consists of 8 semi-detached units. The maximum dimensions are 120 x 35 m. The maximum height is 13 m.

Area VI is the existing complex of LPG storage and handling facility under study.

Table 24 presents the threshold values for resilience of particular objects as a function of type (volume) of consequence.

Table 24: Threshold values for overpressure and thermal radiation for resilience of particular objects

		Threshold values for overpressure		**Threshold values for thermal radiation**
		Destruction – collapse of buildings (kPa)	**Reversible damage – breakage of the window glazing** (kPa)	**Destruction – ignition of buildings** (kW/m^2)
Area I				
	commercial object	21,7	2,1	37,5
	business centre	21,7	2,1	37,5
	business hotel	21,7	2,1	37,5
Area II				
	technological park	21,7	2,1	37,5
	object A	30,7	3,0	53,0
Area III				
	object B	30,7	3,0	53,0
	object C	30,7	3,0	53,0
Area IV				
	object D	21,7	2,1	37,5
Area V				
	object E	21,7	2,1	37,5
	object F	43,4	4,2	75,0

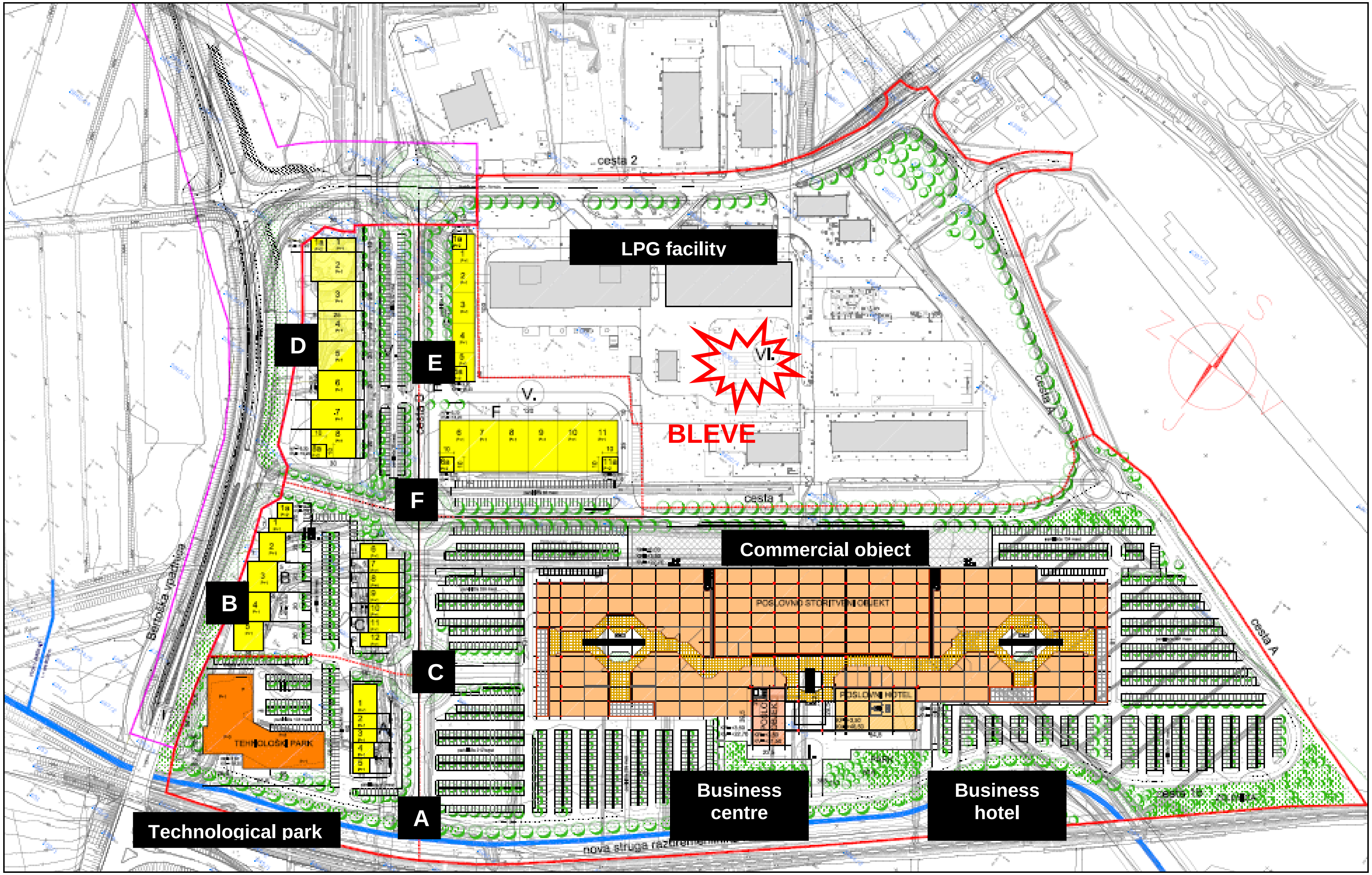


Figure 28: The plan of the Sermin commercial / service zone

Resilience analysis (resilience index) indicates the extent of damage in the vicinity of Istrabenz Plini if the BLEVE were not eliminated. The resilience analysis is focused on the building collapse – serious damage – and, comparatively, for breakage of window glazing due to overpressure and building ignition due to thermal radiation (i.e. analogous to environmental threat-vulnerability value 5).

Overpressure

The expected collapse/destruction of the infrastructure due to the effects of overpressure after BLEVE is presented in Figure 29. The areas of expected collapse/destruction of infrastructure are presented by the resilience index value 1 and above (yellow – red colour). The results show that collapse/destruction of the infrastructure can be expected throughout the LPG facility as well as to the existing manufacturing/commercial infrastructure in the zone. The proposed commercial zone (a plan shown in Figure 28) is expected to be less affected, with the exception of buildings D, E, F and area I.

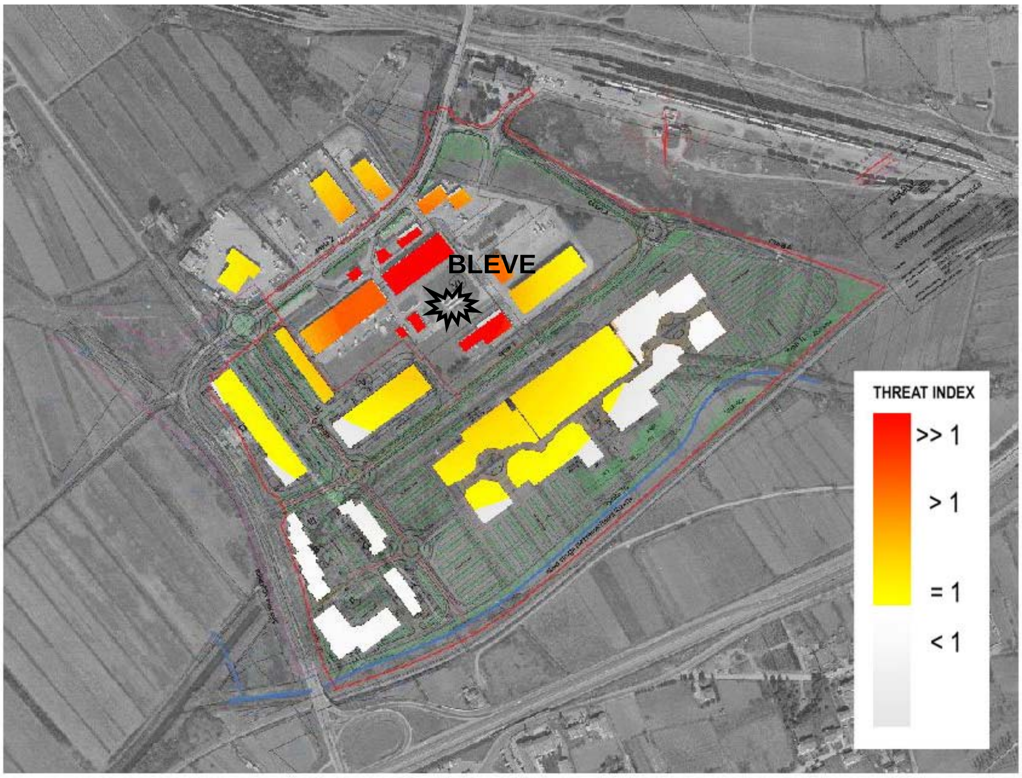


Figure 29: Resilience index for overpressure – building collapse/damage

Figure 30 presents the results for resilience to the breakage of glazing due to overpressure from the BLEVE scenario. The results indicate that the breakage of glazing can be expected in the residential and industrial/commercial areas far beyond the boundary of the LPG establishment (at a distance of approximately 1400 m).

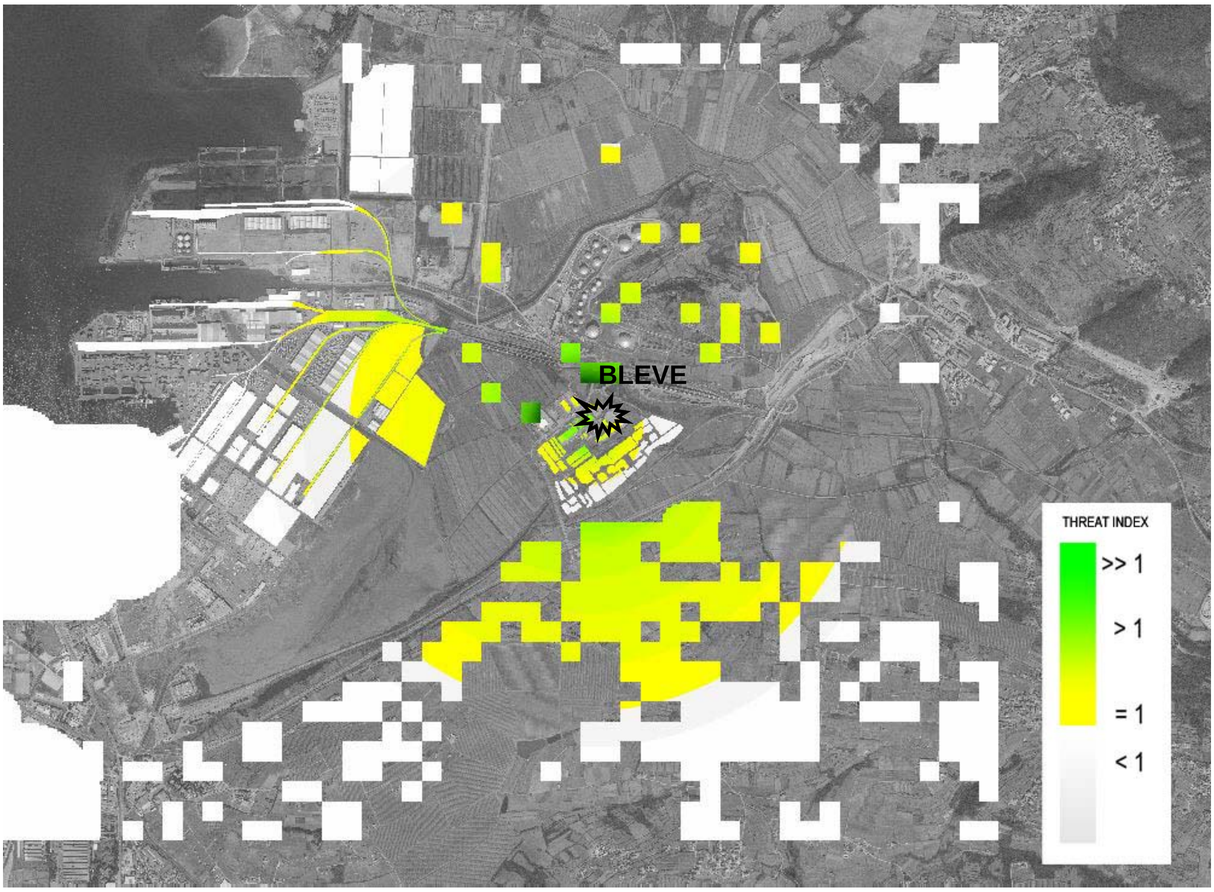


Figure 30: Resilience index for overpressure – breakage of window glazing

Thermal radiation

The expected destruction of the infrastructure due to the effects of thermal radiation is presented in Figure 31. The areas of expected destruction of buildings are presented by the resilience index value 1 and above (yellow – red colour). The results show that the destruction the whole of the LPG facility can be expected to be destroyed, as well as the majority of the existing manufacturing/commercial buildings in the zone. In the proposed commercial zone (plan shown in Figure 28) only buildings E, F and the commercial object are expected to be affected.

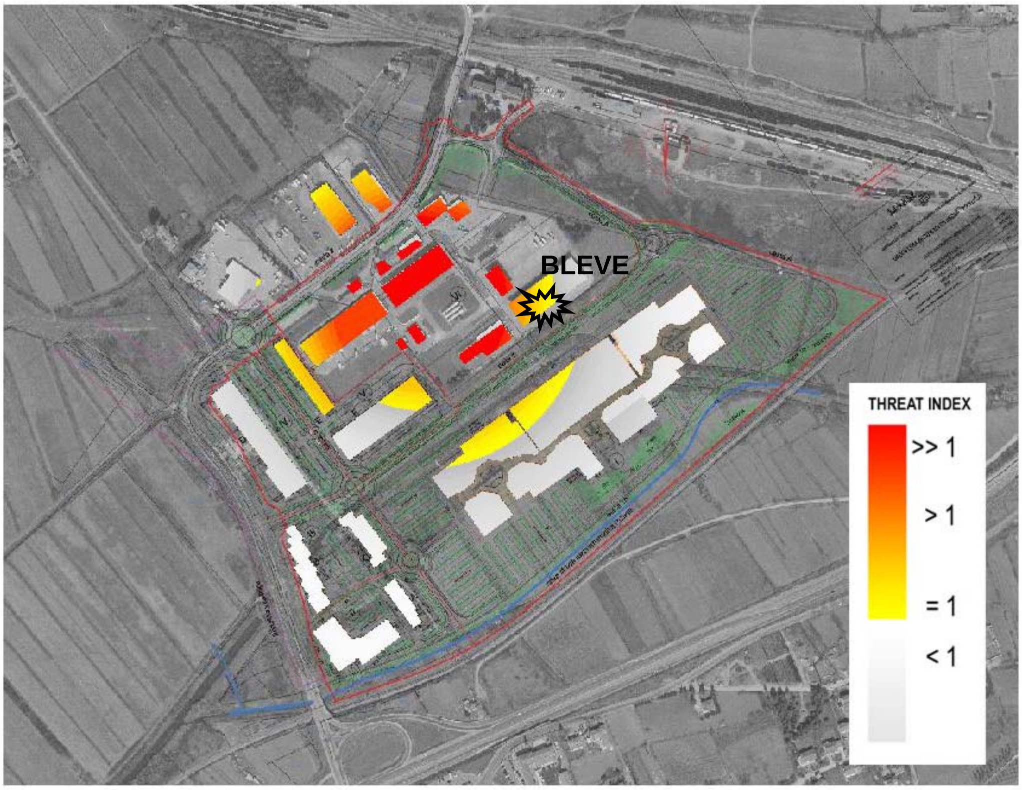


Figure 31: Resilience index for thermal radiation – building damage

The results for thermal radiation take into account the thermal flux and exclude the duration of the exposure (i.e. actual ignition is expected only in the areas with a direct contact with the fireball). This is considered to be a drawback of the approach, however if required this could have been taken into consideration with a more sophisticated modelling of the resilience to thermal radiation.

Comparison of the geographical extent of the resilience index results again calls for attention to be paid to the importance of selection of the threshold levels to be applied as the basis for risk informed land-use planning and, consequently, decision-making.

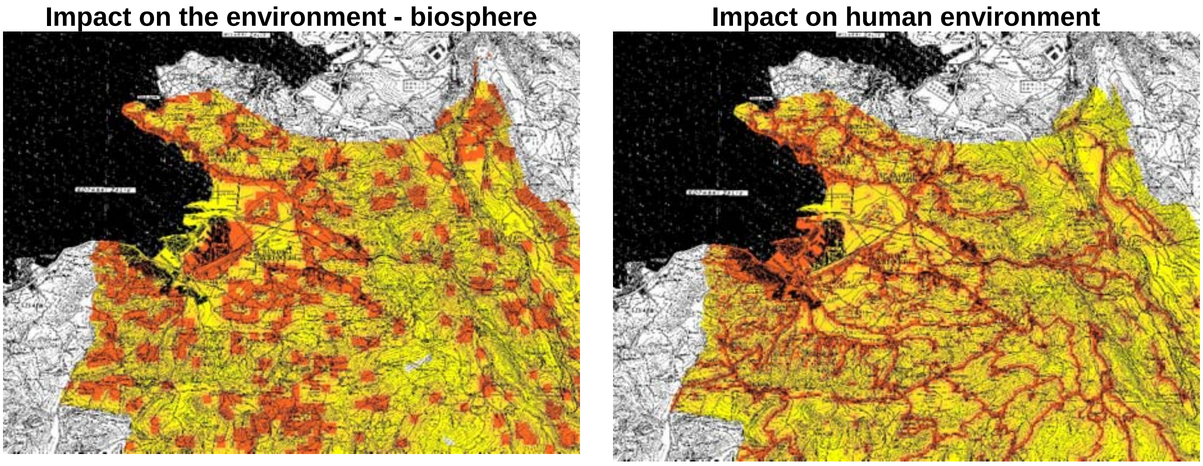
Another important feature that resilience index brings to the risk informed land-use planning is the ability to guide/determine the urban design of development in the vicinity of the risk source – the shape and orientation of building in order to withstand the highest possible value of the effect (illustrated in Figure 12 c). The evidence for the latter may be observed in Figures 30 and 31**,** where buildings closer to the source appear less prone to damage as a result of their orientation.

4.3.4 Preliminary threat analysis – new location for Istrabenz Plini facility

To demonstrate the ability of the threat analysis method to find the most suitable location for hazardous industrial establishment, a simulation of its relocation was carried out.

The simulation predicts the scenario of development of a large commercial zone in the zone where the facility is presently located. The location with current technology is to be relocated to a new location within in the surrounding of town of Koper.

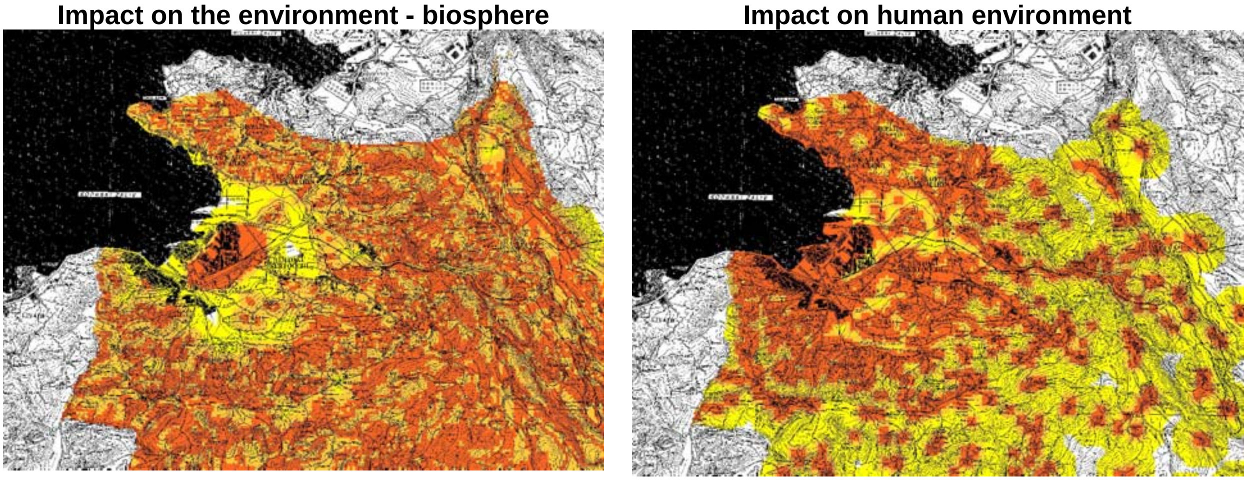
The analysis is based on the risk assessment/threat index results presented in chapter 4.2.2. The results are presented in Figures 32 and 33.



Impact on the environment - biosphere

Impact on human environment

Figure 32: Preliminary threat analysis results for relocation of Istrabenz Facility – overpressure


Impact on the environment - biosphere

Impact on human environment

Figure 33: Preliminary threat analysis results for relocation of Istrabenz Facility – thermal radiation

The map in Figure 34 shows alternatives for new location for Istrabenz facility.

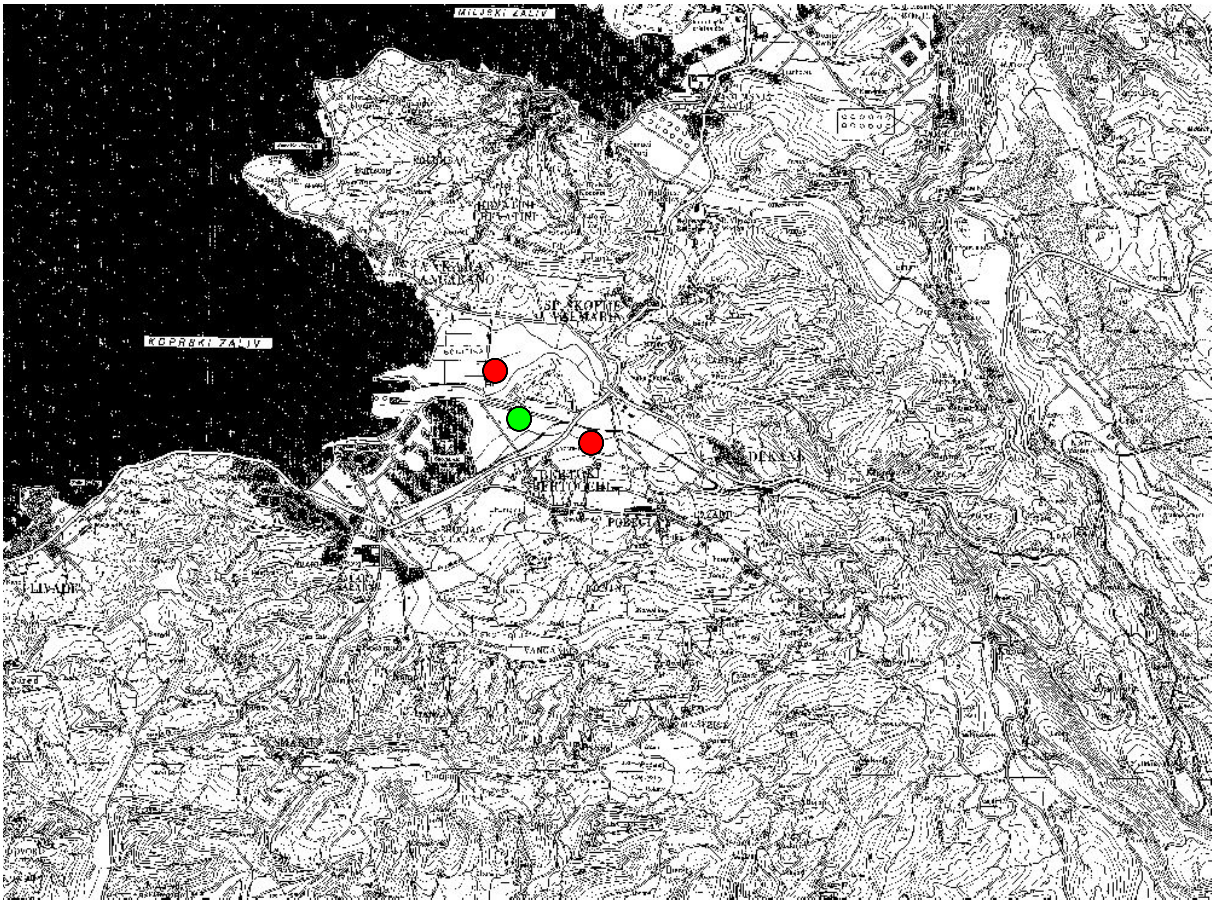


Figure 34: Proposed new alternative locations for relocation of Istrabenz Facility (red); current location (green)

5 DISCUSSION

5.1 About indices/normalisation

Threat index has been selected as the factor by which to describe the land-use planning related risk issues, because of its ability to present information in a more comprehensive manner by the process of abstraction. Usually this refers to a transformation of information into a normalised value system, which provides a clearer representation of information that is relevant for decision making. An index in this case is a measure, quantitative or qualitative, oriented to integrate a set of environmental factors that have an influence on the threat of a system, into a numerical value or into a descriptive adjective referring to the level of its acceptability/un-acceptability (Marušič, 1994; Planas et al., 2006).

The use of indices/normalisation enables the comparison and further transformation of otherwise different and hardly comparable analytical parameters (Spiegel, 1961). Their descriptive (qualitative – semi-quantitative) and relative ordinariness enables the comparison and merging of otherwise non-comparable spatial characteristics and/or impacts (Marušič et. al., 1999; Mlakar, 2006).

Environmental impacts are, by their nature, different and therefore not additive because of the different scopes of interventions and different scales, so the use of normalisation (i.e. transformation of different values into a common denominator) is imperative. By this means, generalisation is subjected to uncertainties, which often results in the introduction of bias into results. The use of the indexing system in threat analysis appears reasonable, however its disadvantage becomes evident with the effort to combine the indices for different incident outcomes (physical effects) such as overpressure, thermal radiation and toxicity. Even though the indices are normalised to a uniform scale, their meaning is different. This calls for independent consideration of each effect in the decision-making stage.

It should be noted that threat index is not strictly speaking an index by definition – however the term was adopted to describe the meaning/significance of the value. In essence it is a categorisation of the synthesis of quantitative values for threat intensity level and the numerically expressed environmental threat-vulnerability level. It reflects the true character of the index since in the process of combining threat intensity levels and threat-vulnerability a normalisation/classification into a scale 1-5 for operability is made (Table 6). The resilience index, on the other hand, is a true index.

5.2 Methodological specificities and comparison with existing praxis

5.2.1 Relation to common risk assessment results

For the purpose of aiding the selection of the most appropriate hazard/risk assessment methods to be used as the initial step of threat analysis, the comparison of three most commonly used risk assessment methods in terms of their potential for integration into spatial/land-use planning and scenario analysis was carried out.

The compared methods include:

- Rapid Risk Assessment methodology (RRA) developed by the IAEA, UNEP, UNIDO and WHO (IAEA, 1996);
- Quantitative Risk Assessment Methodology – QRA (AICHE, 1989) and
- Accidental Risk Assessment Methodology in the Context of Seveso II Directive (ARAMIS) (ARAMIS, 2004b; ARAMIS, 2004c).

Regarding the RRA methodology the following conclusions can be made:

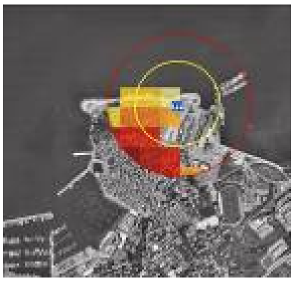
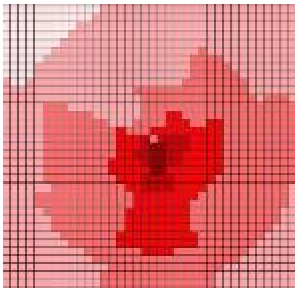
- RRA considers only human casualties; other consequences are not the subject of analysis
- It overestimates the consequences
- For certain scenarios the method is not applicable either because of exceeding or not reaching the upper or the lower limit of hazardous substance present at site, respectively.
- Risk assessment based on the RRA does not present solid ground for risk reduction planning; however the impact zones can be used as a basis for emergency planning.
- Evaluation of potential for domino effects is not possible
- The method is very useful for quick risk assessment and the development of priorities among different risk sources. It gives directions for allocation of resources for further detailed quantitative risk assessment.

The RRA method is powerful as a screening tool. As an independent risk assessment method may be misleading due to potential for overestimation of results. Method is not applicable in the context of spatial/land-use planning.

QRA method provides detailed view into the risks at a given site, including ability to pinpoint at possible causes or initial events that can lead to major accidents. Ultimate results of the analyses in all three cases were detailed lists of recommendations (in technical and organizational terms) for future risk reduction. Possible impact areas and people at risk were identified. QRA is powerful method for risk assessment. It enables systematic hazard and consequence analysis. Results are transparent, specific and can be used as a basis for developing safety improvements. It also provides the necessary information/data for emergency planning. Quantitative Risk Analysis provides trustful results for risk reduction policy development, inspection/auditing, emergency planning, in terms of land-use planning it is less informative because of the lack of qualitative representation of environmental vulnerability.

ARAMIS risk assessment methodology is trustworthy and straightforward. Its components can be used as standing-alone or in combination with other methods (e.g., MIMAH can be used in combination with HAZOP), depending on the installation under investigation and experience of a risk assessor. Vulnerability mapping was proven useful as a basis for administration in regulation process (licensing) or development and decision making regarding land use planning in the vicinity of existing or proposed installation with known location (as a decision-making support tool). Vulnerability analysis method is very robust; it is based on pre-set values of environmental components (ARAMIS, 2004a).

Table 25: Summary of results of risk methodology comparison

METHOD	Advantages	Disadvantages	Form of result	Spatial/land-use planning application
Rapid Risk Assessment **(RRA)**	The RRA method is quick and easy to conduct. It is powerful as a screening tool.	Too coarse, may be misleading due to its potential for overestimating results.	Estimation of casualties (individual and collective risk). Probability of death.	Not applicable
Quantitative Risk Assessment **(QRA)**	QRA is powerful method for risk assessment. It enables systematic hazard and consequence analysis. It provides trustworthy results for risk reduction policy development, inspection/auditing, emergency and land-use planning.	Complex and time consuming; extensive data requirement	Probability of incident outcome. Impact area is presented with radius within which certain consequences can be expected (overpressure, thermal radiation, toxic release).	
Accidental Risk Assessment Methodology in the Context of Seveso II Directive **(ARAMIS)**	ARAMIS risk assessment methodology is trustworthy and straightforward. It provides results useful in a licensing process and spatial/land-use planning. Intended for multiple users.	Requires familiarity with various risk assessment tools Robust vulnerability analysis	Probability of incident outcome. Impact area is presented in a form of Severity index and Vulnerability index – transformed into grid around hazardous installation.	

The conclusion of the comparative study is that QRA and ARAMIS methods have the potential and can be supportive in land-use planning and in the licensing process. RRA requires very coarse input data for the analysis, which is welcome in the early stages of planning, however, the end results do not provide sufficient information for spatial planning purposes. The problem with QRA and ARAMIS in terms of land-use planning is that they require detailed information about the installation which is not available in early planning stages. Also they are not applicable when finding the most suitable location for proposed hazardous industrial establishment

5.2.2 Comparison with other methods and tools in terms of description of vulnerability due to the risk factors

Probit functions

Measures like Probit model results are not applicable in the land-use planning process, since they describe human death probability (expectation of human death from industrial accidents is not applied in land-use planning, due primarily to ethical and equity reasons). Probit model results other than zero, if attempted to be applied in land-use planning, would most probably lead to strong societal disagreements and conflicts, with the eventual result of not approving a plan, in spite of the accidental context of the issue.

SAATY

The purpose of the SAATY method is to assess priorities (Saaty, 1984; ARAMIS 2004a). The aim is to identify the contribution of each target to the level of vulnerability on the basis of a multi-criterion decision approach (Tixier et al., 2005). The result of SAATY analysis is a classification and allocation of numerical values of subjective judgments, or the aggregation of judgements to determine criteria having the highest priorities. The multi-criterion hierarchical method allows decision-making. Each element or criterion of a hierarchical structure takes place at a given level of the structure. Its upper level corresponds to the global objective (or dominant element). Some binary comparisons are made between all the elements of a given level according to the element of the upper level, in order to rank the elements among them. The various levels of a hierarchy are then interconnected.

SAATY methodology raises issues from the fact that the values obtained are qualitative and normalised to a global parameter used in the analysis. The latter, along with the subjective nature of the method, allows the results to introduce bias into the analysis. Another aspect is the difficulty of adopting the results of the analysis for to different value concepts – for example, different situations or cultures have different points of view towards the environment as was the case in the development of the ARAMIS methodology (ARAMIS, 2004c). In the final version of the ARAMIS vulnerability tool, the results of the SAATY method, applied as weighting factors in the calculation of vulnerability index (V), could be changed according to the user's set of values, preferences, etc.

The threat index approach differs from SAATY in the way that categories applied in threat intensity level, threat-vulnerability level and resilience index, build on the explicit quantitative empirical data, while the threat index matrix is somewhat similar to the SAATY approach.

5.2.3 Thresholds

The difficult decision, in terms of planning for hazardous elements decision, rests primarily on the acceptable level of risk, which is related to many factors. It has to be defined according to the prevailing system of values, etc. A survey of threshold levels over diverse countries showed that uniform criteria concerning the values of thermal radiation, overpressure, etc. do not exist, even though several similar threshold values were found (ARAMIS, 2004).

Thresholds appear to be an important factor when determining the scope of the impact area, as seen from figures presented within the sensitivity analysis. The selection of consequences, in relation to specific thresholds to be applied in the analysis, is of significant importance. Environmental values differ in different societies, therefore the design for incorporation of thresholds into the proposed method originates from the possibility of expressing the specific values, i.e. the values from various stakeholders in the area for which the planning is conducted. Normativism, as one of the possible approaches to acquiring threshold levels in regard with land-use planning, has been intentionally avoided in this research. However the method allows for normative values to be used as well.

It should be pointed out that the threshold levels adopted for the purpose of method application are not an attempt to propose a new set of harmonised threshold levels.

The approach of threat analysis will require analysts to learn how to share their decision-making power with the public, and will require that those familiar with environmental modelling learn to incorporate social values into their models.

5.2.4 Implication of probabilities

Likelihood of hazardous events plays an important role in decision-making. However, the implication of probabilities into land-use planning is a difficult task, because of a diametrical difference between the nature of risk and a land-use plan.

A land-use plan is a definite, static, and compulsory agreement between stakeholders about land uses in a particular area. Specific land uses in an actual land-use plan have sharp and static borders; there are no “grey” zones between neighbouring land uses, which would imply uncertain nature of risk.

Once a land-use plan is approved it only remains to be executed. In this perspective it appears that the best foundation for assuring proper incorporation of variable risk assessment results is the probability density function analysis of the outcomes of the scenario in question. Otherwise, uncertain and diverse results in terms of size of impact area should be considered only as an orientation; they do not represent exact basis for border drawing in an actual spatial/land-use plan.

The risk management literature examines acceptable risk as a function of management, which involves monetary gain, public participation in the siting process, and sometimes operational control as well as participation in reviewing operations at facilities (Shape-Risk, 2005). Risk management is an important element in the social acceptability of risk. Risk management includes reducing risk through improvements in the technology aimed at reducing the probability of an undesirable event, restricting land use near potentially hazardous facilities and creating emergency response capabilities aimed at the reduction of potential consequences (Hale et al., 2005).

In terms of land-use planning a discrepancy occurs, in that the safety management factors of the facility can be changed within a short time period, while general land-use plans are made for long (longer) time periods (10 or 20 years – a typical life of a land-use plan). Safety management system (SMS) is the subject of regular safety auditing and inspection. If violation of safety policy and standards is recognised, which can be associated with conformity with the land-use plan, the responsible inspector is obliged to require improvements for the purpose of harmonisation of the SMS and overall safety of the installation with the land-use plan. The emphasis regarding the need for continuous development monitoring around hazardous industrial installations is again evident.

The question posed in this context is perception of probability as temporal distancing of accident consequences. The public addresses this problem inconsistently: in natural hazards they may accept a probabilistic approach or even be ignorant about natural hazards – return to disaster areas, redevelopment of such areas. Towards industrial hazards the public reacts with great aversion, regardless of probability of accident and characteristics of consequences. It appears that administration politics supports such a public attitude toward natural hazards. Thus, in Slovenia, no systematic, specific obligatory infrastructure insurance exists in risk areas, as is the praxis elsewhere in Europe (Raschky, 2005). When a natural disaster occurs, government aid is always expected, and is in most cases granted; the government finances safety barriers (infrastructure – levees), government and local administration inconsistently enforce housing/developing legislation in natural hazard areas, therefore situations of development of hazard (flood) areas are common.

5.2.5 Integration of GIS and risk/threat assessment tools

Risk assessment and management includes both spatially distributed as well as dynamic problems. While geographic information systems (GIS) provide powerful tools for spatial analysis, their capabilities for complex and dynamic analysis are limited. Traditional simulation models, on the other hand, are powerful tools for complex and dynamic situations, but they often lack the intuitive visualization and spatial-analysis functions that GIS offers. Obviously, the integration of GIS and simulation models, together with the necessary databases and expert systems, within a common and interactive graphical user interface should make for more powerful, easy-to-use and easy-to-understand risk information systems (Fedra, 1998).

In the context of further work the need is oriented towards the development of a common software tool which would combine the spatial distribution modelling of the effects of incident scenarios with the tool for environmental threat-vulnerability modelling. This could be achieved through the upgrade of GIS software. Such integration was accomplished within the XENVIS project (Fedra, 1998), ARIPAR-GIS (Basta and Struckl, 2005), however these systems address the integration through the probabilistic approach of risk-informed land-use planning (and are as such often used in emergency planning rather than land-use planning) (Shape-Risk, 2005). They include tools for spatial risk assessment based on externally generated risk contours, and links to models describing accidental and continuous atmospheric releases, spills into surface water systems, and transportation risk analysis. All the models used are fully georeferenced and integrated with the underlying GIS layer, and include an embedded rule-based expert system to help with model input specification and the interpretation of model results. Model results take the form of interactive graphics and animated topical maps for an intuitive understanding. However, the unfortunate fact concerning all the recent improvements in this field is that they remain unused by spatial planners, predominantly because of the probabilistic representation of results which is not applicable in land-use planning. Results need to be integrated and obstacles removed. In any case, closer collaboration between spatial planners and risk assessors needs to be achieved.

5.2.6 Interdisciplinary work

Despite the progress in post-disaster relief operations, in methodology for disaster preparedness and emergency planning (and management), the preventive (hazard) planning and its linkages with 'regular' planning is still in its very early stage of affirmation. The reason for this is the very complex and interdisciplinary nature of planning and the sectoral approach to environmental management and specifically planning. It must be emphasised therefore, that the collaboration of scientists in the integration of risk assessment and spatial/land-use planning is imperative. If spatial planning is the area of landscape architects, urban planners and architects, risk assessment is the area of expertise for engineers, and health officials. Successful collaboration is achievable only by an interdisciplinary approach, in the sense that the experts indeed work together and avoid data and partial analysis results exchange. This has been confirmed during the work on this thesis, especially when dealing with case studies.

Coordination between different interests and respective actions, and particularly between different sectors of the government is a critical part of planning because most planning involves multiple interacting organisations.

5.3 Implementation of the method - possible developments of the land-use planning process in Slovenia

It has been shown in the application of the method, as well as in the overview of existing methods, that important improvements in methods, approaches and techniques of land-use planning for natural hazards are needed to facilitate successful integration. The same applies in the technological hazard realm.

Landscape is a dynamic system. As such, it imposes many different challenges on planners and decision makers. These challenges have been constantly strengthened by the concern with increasing natural and industrial hazard vulnerability (threat) of the above mentioned entities. Therefore, it is the general planning methodology and practice appropriate for hazard prone areas that must be improved, rather than specific styles of planning. The uncertain likelihood of occurrence of accidental events, and the low priority given to preventive measures (because of their high costs and pressure of other more immediate social needs), demand that planning for impacts of natural and man-made hazards must be incorporated into "normal" planning activities, and it must also look for maximal rationalisation (Mušič, 1993).

The existing land-use planning process in Slovenia is schematically presented in Figure 35a. It consists of four main steps. It is evident that neither industrial hazard, threat nor risk analysis are involved in this process. Within the technical basis as an input in step 2 the information about natural hazards is to be provided. However, industrial risk assessment is required in the implementation stage – step 5; after the plan making process – as part of the Environmental Impact Assessment (EIA) process during the licensing procedure (Spatial Planning Act of the Republic of Slovenia, 2007; Environmental Protection Act of the Republic of Slovenia, 2004). The Environmental Impact Assessment of proposed development projects is an important base for the decision-making process in urban development, land-use planning, and other human activities related to altering the natural and built environments. Typically, environmental impact assessment comes "post factum", i.e. once the design of a project has been completed. Such an approach is not in accordance with the Seveso II Directive which requires consideration of risk assessment results in the land-use planning process as a means of minimising the consequences of accidents. A suggested improvement of the planning process so as to meet this requirement is presented in Figure 35b, requiring primary inputs to happen at early analytical stages of the plan-making process.

The proposed modification extends the technical basis by general terms for siting hazardous installations, and provides preliminary determination of appropriate distances between a hazardous installation and vulnerable surrounding land-uses.

In the second step of the procedure (2a) general criteria and terms for allocation of hazardous installations are determined based on past experience for similar installations. In the new (proposed) sub-step (2b), a detailed allocation (within the industrial zone and in the surroundings) is determined, including safe distances, orientation, safety zones, etc. based on more detailed information about the proposed project. Additional detailed information about the hazardous industrial installation, including analysis of the resilience of the proposed installation/development, would also be included in this and the subsequent steps 3, 4 and 5. These steps would also provide the guidelines for architectural design, traffic infrastructure, locating new vulnerable objects (hospitals, schools, etc.), as well as other infrastructure (hydrant infrastructure, means of information in case of emergency, emergency infrastructure – fire escapes, routes of evacuation), which would contribute to more efficient evacuation in case of an accident.

In addition, the proposed alteration of the process requires continuous monitoring of the plan implementation (loop from step 5 to sub-steps 2a, 2b, 3, 4). Such feed-back loops enable prevention of conflicting spatial development around hazardous installations at all stages of the planning process by maintaining proper distances as long as needed. The fact that planning is seen as a process, is also one of the earliest and most essential factors to be recognised in the context of hazard and spatial/land-use planning integration. A continuous planning activity is more important than plans (Mušič, 1993).

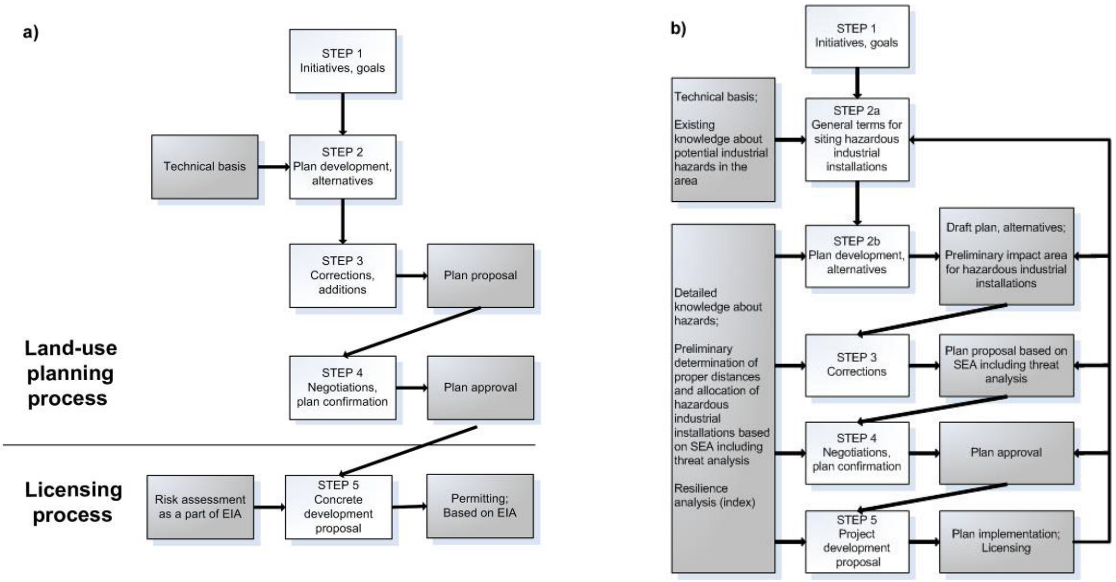


Figure 35: Schematic presentation of threat analysis and land-use planning integration; a) existing spatial/land-use planning process, b) proposal for modification of the spatial/land-use planning process

The above methodological considerations can be defined as efforts in developing a comprehensive interdisciplinary approach in land-use planning as a synergetic commitment of different professional perceptions and contributions, and all the agents involved in the land-use planning process.

The common practice of land-use planning and environmental management leaves little space for fear of disasters, and thereby for the necessary preparedness, as a special activity or concern. Therefore, risk assessment, expressed through threat analysis (threat index), and the resulting measures for protection against the consequences of incidents are integrated into overall environmental planning and management activities.

The new spatial plan for the Municipality of Koper, considering threat index, may be developed by the following three alternative approaches already established in spatial planning procedures – with certain modifications:

a) Determination of an industrial area in combination with requirements/conditions that must be satisfied by an industrial establishment seeking a license in that particular area.

b) Determination of an industrial area resulting from environmental threat-vulnerability analysis based on past experiences for certain industrial types.

Vulnerability analysis would yield areas with lower expected consequences and would also suggest buffer zones between industrial area and vulnerable surroundings. However, hazard-threat-risk related conditions would have to be employed in order to include only the activities of selected types in the designated industrial area.

c) The third approach is integration of threat analysis (index) and spatial planning in the form of strategic threat analysis which would enable continuous feed-back loops of information within the planning process. It would also require the investor to submit the information in the initial stages of the planning process – in the step of developing objectives, initiatives and policies of the detailed plan. This approach also reduces uncertainty in comparison with the previous two approaches, since it is based on more concrete information, and it enables qualitative or at least semi-quantitative risk assessment in the phase when spatial/land-use plan is being developed. In this manner risk assessment and spatial/land-use planning are integrated in an approach for solving acute problems of land-use related to hazardous installations.

Similar integration (in the context the seismic risk management) was proposed by Mušič (1993) – see Figure 36. It is based on the integration of the three mentioned and already well established forms of environmental management (land-use planning, risk management and environmental impact assessment). The intention behind the proposal is integration of well established methods within the plan-making process, as well as in the continuous planning process in which detailed plans, programmes or allocation decisions are being prepared and/or evaluated. The central element of the proposed scheme is the exchange of information, interdisciplinary consultation and public participation. The scheme also suggests an inter-organisational integration, which also requires a “common language” of the disciplines engaged.

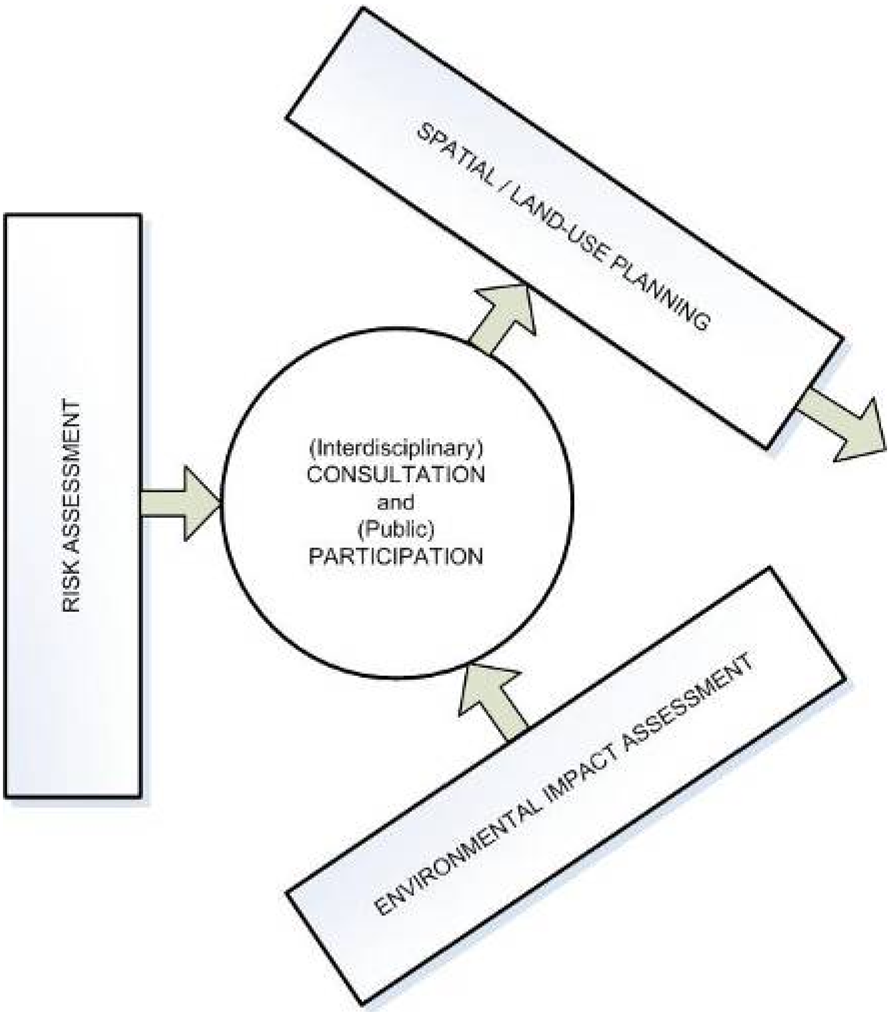


Figure 36: Integration of the physical planning process, the environmental impact assessment system and seismic risk assessment (adapted after Mušič, 1993)

Summarising “the state of the art” within the natural (and industrial – note by D.Kontić) hazard planning approaches, an integration of different current methodologies, involved in environmental management, merging of planning methods, environmental impact assessment, and risk-vulnerability analysis (aiming at preventive planning), may facilitate the “inter-organisational coordination”, and serve the promotion of interdisciplinary professional work, needed in light of ever-increasing risk (Mušič, 1993).

As mentioned previously, a new spatial/land-use planning procedure, in order to successfully integrate threat analysis, requires continuous monitoring of plan implementation. Different governmental agencies and sectors may incline to different styles of planning, since they all have their own form and approach to preparing plans. They may be oriented towards immediate and short-term results, while some might have a specific long-range view. The need for constant "development monitoring", by which the aforementioned differences of planning processes and results are brought to the same denominator must be emphasised again. As such, development monitoring would help to diminish the possible incoherence among local and hierarchically higher levels of planning (e.g. national). The results of such monitoring of plan or development proposals should be re-evaluated in terms of threat analysis.

To successfully complete and materialise planning proposals, the following set of "sub categories" ought to be observed (Mušič, 1993):

- Legal and institutional arrangements; regulations of urban development and building, as well as authoritative administrative organisation in this field. Policies and practices should be present on all government levels: national, regional and local (municipal) for implementation of large scale projects.

- Economic incentives and obligations are probably the most directly effective implementation mechanism; they may attract, or discourage development.

- Technology of design; the technological aspect can also be a very direct and specific element for implementing planning goals or formulating policies for environmental management. However, plans, designs, and all other "technical" documents must be conceived in such a way that they correspond to the implementation procedures. Safety requirements must be visible in these documents and their implementation must be separately specified to support selected characteristics of the acceptable level of risk/threat etc.

- Public education and promotion; Public education, promotion and risk communication must be systematic and must reach all layers of the population. It is one of the aspects of an integrated approach to land-use planning and development, defining many interdependencies between the "normal" and the "risk/threat-informed" development attitudes.

- Work with the community; work with the community must cover the whole planning and development process, starting with the formulation of goals and objectives, through expression of acceptance of averse proposals, ending with implementation. The goals,

> acceptance (consensus) and the implementation mechanisms are closely related to the prevailing system or values in a given community. Work with the community is not easy for the planner, and is even more difficult for the developer, because of the essentially political character of most of the environmental changes. Lack of transparency of planning proposals and of many technical solutions contributes to the phenomena of NIMBY ("not in my back yard") and LULUs ("locally unwanted land uses"), which are blocking many projects.

The praxis of the implementation of the threat index will show how effectively Slovenia succeeded in avoiding situations and conflicting developments as presented in Figure 1 a) and b). In this context it is important to note that the threat analysis approach is applicable not only for avoiding conflicts among industrial zones and outer land uses but also land-uses in the industrial zones themselves as shown in the Port of Koper example (Appendix II). One of the examples of such applications is the allocation of process and other plants (e.g., storage facilities) in a way that prevents domino effects. The other could be design and organisation of the whole industrial zone which emphasises vulnerability and importance of the common infrastructure in the zone, e.g. fire fighting installations or cooling water systems. Application of the threat analysis early enough in the design process is certainly in line with preventive strategy of risk assessment and a good safety management system.

5.4 Lessons learnt from the case study

Testing the methodology revealed several important topics which require further attention and discussion.

5.4.1 The role of accident scenarios for the determination of impact area

One should be aware of the implications of the accident scenarios at two levels. The first is selection of a scenario which has an impact on land-use planning. It is obvious that for this purpose some kind of preliminary threat or risk analysis should be made first, providing a geographical indication of the scope of the consequences before detailed threat analysis is performed. In land-use planning, impacts of the scenario are relevant in terms of both human interests for land use and environmental protection. How much land a certain scenario "covers" (i.e. how big is the impact zone) and what environmental qualities may be degraded or lost in the case of an accident is ultimately a question of acceptability. Whether or not accident scenarios clearly and adequately associate these issues is a question to be identified during the land-use planning process.

The second level is accuracy or rather trustworthiness of the scenario. If the uncertainty of the selected scenario is too big and subsequent alteration of the impact area too significant, the land-use planning process may reject the approach as too vague or too sensitive. Namely, specific land uses in an actual land-use plan have sharp and static borders; there are no “grey” zones between neighbouring land uses, which would imply uncertainties of the scenario (e.g., alteration of the impact zone due to different modelling assumptions causing variations of the amount of exploded gas). If scenario uncertainties are so big that they affect the land-use planning process, additional efforts should be made either to identify their sources, classify them into categories (e.g. epistemic or statistical) and find the means for their reduction, or to investigate what additional safety measures could be applied (improvement of the SMS at the plant) for the elimination of the scenario or diverting it into one with lower uncertainty, or to one non-relevant for land-use planning.

To illustrate this, Tables 16 and 17 are merged into Table 26; the difference in impact areas for selected reference values is approximately a factor 1,6 – 2,1, when applying a conservative or realistic approach (different assumptions) to scenario analysis.

Table 26: Implication of the scenario uncertainty to the scope of impact area

Physical effect – selected reference values	**Distance to selected reference values (m)**		**Impact area (ha)**		**Difference in impact area; ratio between conservative/realistic approach**
	BLEVE 36 t	BLEVE 72 t	BLEVE 36 t	BLEVE 72 t	
ThR – 12,5 kW/m^2	290	370	22,4	37,6	1,7
ThR – 37,5 kW/m^2	160	210	5,0	10,4	2,1
OP – 13,8 kPa	280	355	20,7	33,8	1,6

5.4.2 Economic implications of threat analysis in the framework of land-use planning

The expected financial loss or gain due to establishing buffer zones in the impact area (no development) or allowing land development (housing, commercial zone) may be considerable (Tables 15 to 17). Presentation of such results in a transparent way may support the land-use planning process as a vehicle for enforcing threat/risk reduction measures at certain installations. Actually, this has been the case in the Municipality of Koper. In the stage of reviewing the land-use plan, the Municipality, i.e. the local authority, required the managers of the LPG establishment to reduce the impact area by applying either measure a) or b), see subsection 4.2.4. The managers of the LPG facility decided to install a mechanical arm at the loading/unloading facility.

5.4.3 Application of the method for new hazardous installations

The method is designed to contribute to land-use management around existing hazardous installations, as well as to inform the search for suitable locations for new ones (proposed) and to be used when preparing a new land-use plan. However, there are a number of issues related to the latter. The main problem here is lack of information about new installations (technology, capacity and safety measures) in the early land-use planning phases. The solution for the land-use planning process in Slovenia is being sought in an additional methodological step in land-use plan development, as well as revision (amendment) of existing steps (see Figure 35). The main idea here is that, through strategic environmental assessment (e.g. assessment of a municipal plan), the general terms and conditions for allocation of hazardous installations are provided, based on past experience or generic distances, while in the following steps a precise siting process is applied along with the determination of appropriate distances, orientation, eventual buffer zones and use of land in the vicinity of the establishment – based on more specific information provided by the investors. In this phase guidelines for urban (traffic routes, allocation of vulnerable buildings – hospitals, schools, etc.) and architectural design would also be provided, with the goal of assuring the efficiency of an emergency response. Application of the suggested guidelines, terms, and conditions would be realised in combined and harmonised processes of land-use planning, strategic environmental assessment and finally project level environmental impact assessment.

For new industrial installations this would require adaptation of threat index calculation methodology, which was presented in Figure 10. Adapted methodology is presented in Figure 37.

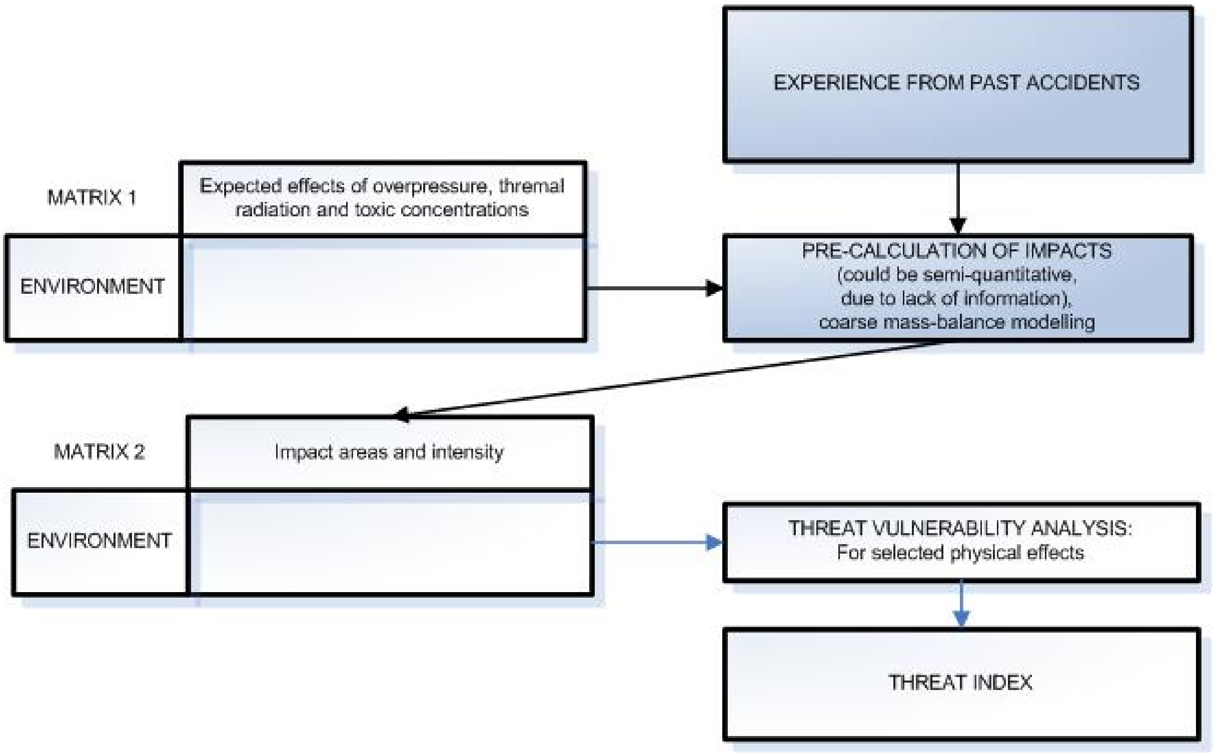


Figure 37: A scheme of a modified risk/threat index development methodology for new industrial installations

5.4.4 Relation between risk assessment and threat analysis

It is obvious that risk assessment results could be efficiently used in threat analysis and vice-versa. The outcome in both cases is upgrading of the methods and improved land-use plans. No matter where the analysis starts, e.g. from consequence analysis in the framework of risk assessment through environmental vulnerability to threat index, or from environmental threat-vulnerability through accident scenario consequence analysis to threat index, the land-use planning process will gain a solid scientific basis for achieving long-term stable agreement among the stakeholders involved regarding uses of land around a hazardous installation.

Threat-vulnerability analysis of land-uses, environment and structures is used as a professional concept for achieving optimisation in the framework of the risk-threat-hazard informed land-use planning.

5.5 Uncertainties

Risk and uncertainties are by definition inter-related terms (Petersen, 2002; Mlakar, 2006). The primary source of uncertainty concerning (risk-informed) land-use planning is the lack of data about the risk/threat source as well as about the receptors (humans, environment) on a designated level of analysis. Others include uncertainties associated with the understanding of the legislative framework, methodologies used, estimation of impacts to the environment, systems of values, etc. (Covello, 1998; Mlakar, 2006). To overcome these issues certain estimates must be made. When data is not available or of a quality which cannot be verified, generalised expert judgment and/or scenarios can be used (Mlakar, 2006). The issues of thereby related uncertainties are additionally problematical when following the EU Guidelines which require that risk-informed land-use planning is to be based on the selection of reference scenarios (Christou et al., 2006). As mentioned previously, in the land-use planning (predominantly for new hazardous industrial installations, zones) the details about the installations are not known, therefore the related uncertainties are so much greater.

Identifying uncertainties within risk management activities is important for building confidence in the proposed measures. The purpose of confidence building in the context of a risk assessment is to provide readily understandable qualitative and quantitative evidence that all aspects of the risk assessment are based on sound scientific and technical principles. In practice, confidence building is achieved by a range of activities throughout the risk assessment process including the following: comparison of assessment results with certain criteria, indicators and guidelines; use of sensitivity analysis; striving for transparency in all aspects of the assessment; demonstrating good science and good engineering practice; applying a quality assurance programme; using peer review, etc (Covello, 1999). In this framework, the risk analyst makes every effort to reduce uncertainty of the assessment results and to ensure consistency of the assessment process. Uncertainty analysis is recognized as a key factor in the decision process where risk assessment plays a role. Each proposed planning measure dealing with uncertainties and with contingencies is in serious danger of not being accepted if it is competing with more immediate priorities (Mušič, 1993).

The risk assessment for selected potential damage of environmental components and facilities (e.g., infrastructure) in the case of an unusual event often requires the interaction of a large number of disciplines. The physical systems involved can be very complex. Typically, the risk analyst has to simplify the physical system into a conceptual model that can be represented mathematically. An important step in this process involves defining a scenario of an incident, and this is often a significant source of uncertainty (scenario uncertainty). Simplification of the physical system to a mathematical model is another source of uncertainty, commonly called model uncertainty. Some other sources of uncertainty, like imprecise knowledge of the processes and conditions expected in the future, where expert judgement substitutes for scientific evidence, can be classified as subjective uncertainty (Cooke, 1991; Honano et al., 1990; Carmines and Zeller, 1979).

In the context of land-use planning, scenario and subjective uncertainty are of primary importance. Scenario uncertainty may be the reason for errors in consideration of type of consequences, while wrong expert judgements may bring erroneous interpretation of results. Both have potential for triggering conflicts and questionable decision-making, with long-term societal implications.

Risk impact area determination is also uncertain, which undoubtedly affects the perception and related decision-making. Distances presented in metre accuracy are an example of such uncertainty. Such results should be considered as an approximation and do not represent absolute values or background for possible border drawing in actual spatial/land-use plan. Generally the accepted level of uncertainty lies within an order of magnitude, while independent/individual components vary between 10% and factors of 2, 3 or more (AICHE, 1989; Kontić and Gerbec, 2004, 2008).

5.6 Terminology

Elaboration regarding the terminology is needed. In addition to the glossary provided in Section 1, special consideration should be given to the terms “planning” and “plan making process”.

Land use planning in risk assessment circles is often understood as the process of planning the execution of a plan and not the process of making a plan as the definition of a word suggests (Mušič, 1993; Marušič, 1999; Mlakar, 2006). This often results in misinterpretation of the issues dealt with in the framework of this research. Overviewing the current risk-informed land-use planning methods, all of them are focused on remediation/management of the sites around the existing installations (the general difference in approaches was described in the introductory section) in the stage of licensing/permit issuance – which is not planning. Also the methods are not applicable for finding the most appropriate location for new industrial installation – this occurs in the zoning stage of the plan making process (i.e. a pro-gnostic activity – as planning is).

As described in Christou et al. (2006), "planning" is a procedure for elaborating a plan. Actually this term covers a range of activities, from procedures of a purely technical type to administrative or governmental arrangements, however the existing risk-informed land use planning methods discussed in (Christou and Porter, 1999) do not focus on the activities of preparation of a plan but on the activities of execution of an already developed plan, i.e. permitting and licensing.

The main difference between approaches in different countries and threat analysis is that, based on distinguishing a land-use plan generation phase from a land-use implementation phase, the method aims at including threat analysis in the plan generation phase. However, it is applicable also in the plan implementation phase (checking conformity of the site of a hazardous installation or neighbouring development proposals with the plan, licensing). The novelty of the proposed method in Figure 35b is that it also contributes to the generation of a land-use plan, not only to its execution.

Additionally, behind the proposed method is the recognition that risk assessment experts and spatial planners do not "speak the same language". One of the problems is a form of commonly used risk assessment results, which are not directly applicable for land-use planning (e.g., frequencies, probabilities, risk curves, sometimes radius of impact zones). Land-use planning is a process which is led by spatial planners who (in our experience) have little or no experience of risk assessment. On the other hand, risk assessors usually do not work in the area of land-use planning. Therefore, efforts should be made for their better mutual understanding and stronger collaboration. Our attempt in this direction is a proposed upgrading and transformation of risk assessment into threat analysis so as to be understandable and useful for spatial planners. We have not seen similar operational attempts in other countries. Other countries usually concentrate on the licensing, i.e., regulatory needs rather than on planning and optimisation.

5.7 Future work

Future work to be performed in the context of this research should include:

- Testing the method for larger hazardous industrial installations posing major risks in terms of toxic release into the air – such installations do not exist in Slovenia; the Port of Koper and Kemiplas, as examples presented in this dissertation, are excluded from this category.
- Testing the method for new hazardous industrial installations – the enlargement of industrial zones in Koper may seem insufficient in regard to lack of information
- Development of a consolidated mechanism for threat index and resilience index as an upgrade of environmental vulnerability analysis, in terms of making it a more explicit process with quantitative results
- Presentation of the method to a larger circle of spatial/land-use planners (perform demonstrations, discussions, workshops; collaborate in the generation new proposals/changes of land-use plans, etc.)
- Development of a common GIS tool which would combine the spatial distribution modelling of the effects of incident scenarios with the tool for environmental threat-vulnerability modelling
- Emphasising the importance of urban/architectural/construction design based on the resilience index results in order to further help the optimisation of development in the risk impact areas – an idea presented in Figure 12 c and confirmed by the results presented in Figures 28 and 31**.**

6 CONCLUSION

The results of this research prove/demonstrate that risk assessment and spatial/land-use planning can be successfully integrated by modifying existing risk assessment and spatial planning methods. This was successfully accomplished by the introduction of threat analysis which includes the modification/improvement of the commonly used risk assessment methodologies to yield results in the form of threat index. Modifications of the spatial planning process are also a key factor for successful implementation of risk assessment into the plan development process. The latter thus allows discussion and optimisation of industrial risk at the beginning of a plan development process. The integration was successful due to the fact that the analysis is simultaneously scientifically accurate and flexible to the point that it can be used for existing as well as new establishments. The second important factor is that the method allows the preliminary identification of potential problems/issues when technological and/or spatial modifications are feasible. The third important factor of the method is that it is transparent, requiring the participation of all stakeholders in the plan developing, not only the plan implementation process.

This research succeeded in integrating two areas of concern regarding the risk-informed land-use planning. First, the interaction of different technical backgrounds, professional methods and approaches used in the preparation of plans (design and introduction of threat analysis), and second, the implementation of the technical basis concerning risk (hazard) into plans (changes to land-use planning process in order to accept threat analysis as an integrative component).

It has been presented in this research that the application of the specific planning criteria reduces or eliminates the negative effects of incidents to the environment. It is not only the question of reinforcing the existing buildings or of the improvements in construction methods, i.e. the strengthening of the ability of resilience (a tendency of an element under stress, to return to its previous condition), but also in the optimisation of the location of targets combined with their ability to withstand the possible exposure to mass/energy/toxicity at a given distance.

The criteria used in threat analysis are complex for they are based on rules for combining variables, on thresholds that exclude or include areas or values, and weights that increase or decrease the contribution of a variable in the final results. These results are inevitably open to different interpretations, depending on the perspective of the user. Threat analysis is therefore vulnerable to a degree similar to that of the other analyses in the planning process. The results still need to be translated into policies reflecting and addressing scientific and social expectations and needs.

The work on this dissertation was conducted simultaneously with the new proposal/change of the municipal land-use plan for the Municipality of Koper. Because of the administrative nature of planning and thereby related delays the results of this work have been only partially implemented in the land-use and contingency planning policies and goals of the Municipality. The most evident result in this relation is the elimination of the BLEVE scenario at the Istrabenz Plini Sermin, by the installation of mechanical arm at the loading/unloading station, and by consequent ability for the development of the surroundings of the facility; the closing down of Istrabenz Plini Dolinska facility; the plan for reconstruction/relocation of the fruit terminal at the Port of Koper.

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APPENDICES

APPENDIX I

Threshold levels

1 INTRODUCTION

The threat index has been defined taking into account the threshold levels for designated physical effects. A survey of these levels over diverse countries showed that there does not exist a uniform criterion concerning the values of thermal radiation, overpressure, etc. An overview of various consequences (damage, injuries) for specific physical effect levels is provided in the following section in order to provide references for selection of threshold levels to be applied in the process of threat index determination.

Emissive properties concern values for specific accident scenarios like thermal radiation or overpressure and depend on physical properties of the substances involved. Similar values apply for the release of toxic substances. The values are provided in the literature and databases. For heat transmission the values are derived from test cases because the emissive load is influenced by fire conditions. For overpressure the calculations are based on the thermodynamic and reactivity properties of the substances. Laboratory tests are a commonly used approach for toxicity.

The "threshold values" of consequence assessment of major accidents are of particular importance for the threat-informed land-use planning process in general. Decisions regarding acceptability depend on these values. They may relate to the following factors:

- human vulnerability, e.g. fatal consequences
- major obstacles for emergency response or
- severity in terms of loss of material or equipment.

Two main concepts to define threshold values may broadly be distinguished:

- the dose/probit concept and
- the concept of fixed thresholds

The dose/probit concept considers the impact on the recipient over time and relates this impact to the probability of a certain damage (physiological or material). The concept of fixed thresholds sets limits on damage due to an expected impact without any damage percentage. The border between these two concepts is not precisely defined, depending on the type of impact (e.g. the thresholds for airborne substances always relate to the time of possible intake). Since land-use planning praxis does not apply any measures/indicators which interpret death probability the methodology is based on the concept of fixed thresholds.

A set of threshold values in regard to land-use planning comprises the following types:

- Thermal radiation (static and dynamic)
- Overpressure
- Accidental release toxic substances

2 THERMAL RADIATION

2.1 The effects of heat radiation on people

Heat radiation has a twofold effect on people: psychological and pathological. The attention in this research will be given to the latter – the development of burns/injuries/fatality due to heat transfer to the skin. In calculating the extent of the damage due to a calamity, the various ways in which people can be injured are considered. In the case of injuries due to a fire the causes for the injuries fall in two categories:

- Injuries due to direct flame contact with fire.
- Injuries due to heat radiation.

Fatality is expected within the dimension of the fire due to direct flame contact. Considering a realistic average exposure of 10 seconds at a heat radiation level of 17 kW/m^2, a lethality of 1% among the people exposed is expected (The Green Book, 1992). Personal injury, in the case of the absence of protection provided by clothing can be incurred for a long term exposure for a radiation intensity of about 1 kW/m^2. It must be emphasised, in this regard, that long term exposures to lower levels of evident physical effects (discomfort) are rarely observed in cases of incidents – with the exception of professionals present at the incident site.

According to the "Green Book" (1992), the radiation level at the surface of the flame is in the range of 100 kW/m^2 (LPG pool fire). In the case of a fire-ball, this radiation level can reach approximately 200 kW/m^2. The area in which at least 1 % of fatal injuries due to radiation can take place is approximately 20% of the radius for a pool-fire and about 10% of the diameter for a fireball.

In the case of instantaneous thermal effect (flash fire), the threshold values are related to the concentration of flammable product in the cloud. Thus, the flammable concentration corresponding to 0.5 lower flammability limit (LFL) was set assuming lethal effect inside the flammability contour.

Clothing can provide a protective effect if it does not ignite due to either auto-ignition or spark. If the clothing catches fire, the lethality probability can be considered as 1.

2.2 Material damages due to thermal radiation

The concept of material damage applies to damage to built environments, including installations. Materials which are considered suitable for buildings play an important role. In this regard considered are:

- wood
- synthetic materials
- glass
- steel

The first two materials are combustible and can lead to secondary fires.

Glass is considered for its potential breakage under the influence of temperature changes. As glass is used in facades in large quantities the breakage of the glass can lead to significant consequent damages.

Steel is also not a combustible material. However, when the temperature rises, the strength and stiffness of steel decrease rapidly. It is consequently foreseeable that a structural steel element can fail as a consequence of heat radiation. Primarily in installations this in turn can lead to appreciable damage. Due to the above reason attention is given to steel which is not protected against heat.

Non combustible and heat resistant materials, such as reinforced concrete and coated steel, are considered as prone for failure as a consequence of thermal radiation only if located inside the flame or in very close proximity.

The specific purpose of this investigation is to provide indications regarding the critical radiation intensities leading to damage of the above mentioned different materials and the damage levels. In the evaluation of the effect of the radiation a constant radiation is assumed. With the intensity and an exposure of such duration on the surface of the materials under consideration a stationary heat balance is established. Since this study is oriented towards a global appreciation of the damage mechanism it is based on strongly schematic heat flux models.

Surfaces of materials can catch fire as a consequence of heat radiation. The presence or absence of primary heat sources located on the surface of the material is of foremost importance in this respect. The following conditions are often differentiated:

- Presence of fire in direct contact with the surface of the material;
- Presence of fire without direct contact with the surface of the material;
- No presence of fire.

An overview of values obtained experimentally for the critical radiation intensity, as defined above, for different materials, is given in Table 1.

In a typical fire situation, primary heat sources cannot be excluded (for instance sparks or flying brands). Generally, in an evaluation of a possible "fire-spreading", it is not direct contact with the flame that must be taken into account. For this reason, in fire safety evaluations, the values shown in the centre column of table are often the ones which are considered.

Table 1: Some critical radiation intensities for different materials

	Critical radiation intensity [kW/m^2]		
Material	**With ignition flame; in contact with the surface**	**With ignition flame; without contact with the surface**	**Without ignition flame**
Wood	5	15	35
Hemp, jute. flax			40
Roofing material soaked in asphalt-bitumen	3		
Roofing material protected by aluminium panes	75		
Textile			35
Soft board		6	25
Hard board	5	10	30
Cork		3	23

Other damage mechanisms include:

- The breakage or failure of structural elements without its surfaces actually burning – such damage is usually associated with glass, steel and composite materials.
- Such a degree of deformation of the surface of materials - even without initiation of fire - that the elements are no longer useful and must be repaired or replaced.

With the help of a heat balance it is possible to establish a relationship between the radiation intensity acting on a given surface (in W/m^2). In the following section, values and reference intensity levels for selected materials (wood, synthetic materials, steel, glass) are given.

Wood

As already previously indicated, it is customary for the evaluation of the damage level of failure/destruction to consider a critical radiation intensity of 15 kW/m^2. It would be of interest, making use of the assumptions of the previous paragraph, to find out to which surface temperature the radiation intensity would correspond.

For the evaluation of the damage at a damage level of serious discolouration/deformation, the corresponding thermal radiation intensity is approximately 2 kW/m^2.

Synthetic materials

Synthetic materials, which are often used on the outer faces of buildings are:

- reinforced polyester in façade panels
- PVC in window frames
- Perspex and synthetic window

The behaviour in fire conditions of synthetic materials displays a strong variation and is dependent on both the nature of the material as well as its composition. Regarding the thermal threshold levels it can be considered that combustion or deformation of synthetic materials can be compared to those of wood. Therefore, for the critical radiation intensity for damage level 1, the value of 15 kW/m^2 can be adopted. The critical radiation level for the deterioration/deformation is again a value of approximately 2 kW/m^2.

Glass

Considering the effects of thermal radiation on glass, only the consequence of breakage is relevant. On the basis of theory and tests the difference in temperature which leads to breaking of the glass is approximately 100 K. Based on the calculation acquired from “The Green Book” (1992), the thermal radiation intensity for glass breakage is approximately 4 kW/m^2.

Steel

Failure or collapse of structural steel elements under the influence of thermal radiation takes place in elements with the load bearing functions. The failure temperature depends on the load and, for a conventionally dimensioned steel element, lies between 673 and 873 K. Lower damage levels such as deformation for which maintenance is necessary are usually present at 473 K.

Damage described above occurs after approximately 20 minutes are approximately:

- 100 kW/m^2 for failure
- 25 kW/m^2 for deformation.

Particularly for materials with good heat conducting properties such as glass and steel, a relatively important heat transfer to the environment will take place.

2.3 Summary

Reference values for thermal radiation are presented in Table 2.

Table 2: Reference values for thermal radiation

Thermal radiation (kW m^{-2})	**Consequences / effects**
100	Destruction of steel components
37,5	Damage to process equipment
25	Minimal required energy for ignition of wood under longer exposure periods (without initial ignition – flame); deformation of steel components
15	Ignition/destruction of wood and synthetic materials
12,5	Minimal required energy for ignition of wood with initial ignition, melting of plastics, etc.
4,5	Causes pain to people if protection is not provided within 20 seconds, Third degree burn injuries are not common; destruction of glass panels
2,0	Damage/deformation of wood and synthetic materials
1,6	Causes discomfort under longer exposure time

3 OVERPRESSURE

An explosion is defined as a large scale, rapid release of energy. In the cases of explosions, energy can be released from the catastrophic failure of a compressed gas, nuclear reactions or rapid oxidation of fuel elements (carbon and hydrogen) (Ngo T. et al, 2007).

An explosion causes a number of effects. The explosive material or mixture converts into reaction products with very high temperature and exerted pressure. A shock/blast wave develops in the surroundings as a result of the released energy, travelling with supersonic velocity through the surrounding air (The Green Book, 1992, Dharaneepathy et al, 1995). At the same time pressure is exerted on the soil, generating a ground shock, which moves through the ground. This pressure can be so high that a crater may form. If the explosion occurs within a confined space, debris (fragments) will take the effect of missiles. Due to their impact and due to blast, other breakage and consequent debris may appear.

The blast and missiles are the two most frequent elements associated with damage/injuries d to infrastructure and the environment, including humans.

An important task in blast resistant design is to make realistic predictions of blast pressures and associated effects at given locations in the framework of threat resilient land-use planning/infrastructure design.

Consequences of blast in terms of overpressure are calculated while the effects of missiles are obtained with experience and statistical data – which are insufficient for an accurate determination of the damage.

7-15 kPa	Not habitable without very major repair works. Partial roof failures. 25% of all walls have failed, serious damages to the remaining carrying elements. Damages to window frames and doors.
3 kPa	Habitable after relatively easy repairs. Minor structural damage.
1-1,5 kPa	Damages to roofs, ceilings, minor crack formation in plastering. more than 1 % damage to glass-panels.

For typical American-style houses the following applies:

70 kPa	Total collapse.
30 kPa	Serious damage. Collapse of some walls.
15 kPa	Moderate to minor damage. Deformed walls and doors; failure of joints. Doors and window frames have failed. Wall covering bas fallen down.
7-10kPa	Minor damage. Comparable to damage due to a storm; wooden walls fail; breakage of windows.

An overview is given in Table 3, from data available in literature (SAVE II, 1992; Lees, 1996; IDEAS, 1988; “The Green Book, 1992). Showing overpressure levels and corresponding damages, established from tests or actual accidental explosions (The Green Book, 1992).

This data enables a relationship to be established between the quantity of explosives and the distance to the centre of the explosion at which a given degree of damage bas taken place. The parameters of a shock wave – peak overpressure and positive phase duration or impulse – are determined at a certain distance by this quantity of explosives. It is then possible to establish a relation between these parameters and a given degree of damage. The results in this manner are of more general application. A combination of empirical data with analytical modelling enables the effect of blast on structures to be obtained.

Table 3: Reference values for overpressure – consequences for infrastructure (SAVE II, 1992; Lees, 1996; IDEAS, 1988; "The Green Book, 1992)

Overpressure (kPa)	**Description of Damage**
0,3	Very loud bang; equivalent to noise level 143 dB; damage to glass due to wave generated
2,1	"safe distance"; 5 % probability for severe injuries; 10 % probability for broken window glass.
4,8	Limited infrastructural damage
6,9	Damage to housing (some inappropriate for dwelling)
7	The roof of a storage tank collapsed
7-14	Connections between steel or aluminium undulated plates have failed
8-10	Minor damage to steel frames
13,8	Partial demolition of house walls and roof-tops
15,9	Lower limit for severe damage to infrastructure
15-20	Walls made of concrete blocks have collapsed
20-30	Industrial steel self framing structure collapsed
20-30	Cracking in empty oil-storage tanks
20-30	Slight deformations of pipe bridge
30	Cladding of light industry building ripped off
34,5 – 48,3	Wooden beam breakage; almost entirely demolished houses
35	Plating of cars and trucks pressed inwards
35	Breakage of wooden telephone poles
35-40	Displacement of a pipe bridge
35-80	Damage to fractioning column
48,2 – 55,1	Deformation or demolition of brick walls (thickness 23-30 cm)
50	Brickstone walls , 20-30 cm, have collapsed
50	Loaded train carriages turned over
50-100	Displacement of a cylindrical storage tank, failure of connecting pipes
50-55	Collapse of a pipe bridge
68,9	Entirely demolished buildings; heavyweight machinery displaced and severely damaged
100	The supporting structure of a round storage tank has collapsed

3.1 Effects on humans

The effects on humans submitted to an explosion are presented. The consequences to man of the following effects occurring in an explosion are investigated: blast; whole-body displacement and debris and collapse of buildings.

The explosion effects are divided into the following categories: direct and indirect effects.

a) Direct or primary effects - The pressure change caused by the blast can cause injury to sensitive human organs.

b) Indirect effects - The indirect effects are always sub-divided into secondary and tertiary effects:

- Secondary effects; Consequences due to fragments, debris and missiles are considered with this term. These fragments can originate directly from the source of the explosion, but they can also come from objects located in the surroundings of the source of the explosion which are ejected as a result of the blast wave.

- Tertiary effects; As consequence of the blast and associated explosion wind, people may experience whole-body displacement and collide with stationary objects or structures (total body impact). An injury which can occur as a result of this impact belongs to the category of tertiary effects.

One of the reasons for the distinction between direct and indirect effects is that, for direct effects it is assured that a human being will be subjected to the pressure increase. By indirect effects on the other hand, there is only a possibility that a person might be hit by fragments or debris, or that a person who undergoes a whole-body displacement may collide with an obstacle.

An effect also considered is the possible injury to people inside a building when the building either partially or completely collapses as a result of an explosion.

The human body is capable of adapting to large changes in pressure. The condition is, however, that this pressure change must take place gradually, so that it can be compensated by a pressure change in the organs which contain air. If this change is sudden, a pressure difference arises which can lead to the damage of these organs – primarily lungs. In the available literature most attention is given to lung damage, since this can provoke death. A less vital organ, however most sensitive to pressure changes, is the ear (The Green Book, 1992).

3.1.1 Lung Damage

When a pressure difference arises between the inside and the outside of the lungs, the outer pressure is generally higher than the inner pressure in the case of an explosion. Due to this, the thorax is pressed inwards, which can lead to lung damage. Since this "pressing inwards" process requires some time, the duration of the load, besides the value of the overpressure, is significant.

Experiments on animals have shown that for a long term load only the magnitude of the overpressure is important, while for a short term load only the total impulse is important.

3.1.2 Damage to hearing

The ear is a sensitive organ that reacts to very small pressure variations.

Rupture of the ear drum is decisive for damage to hearing. On the basis on data from other sources, the reference gives the probability of a rupture of an eardrum at a particular peak overpressure.

It can be observed that the 50% probability for the rupture of an ear drum lies around the 100 kPa mark.

3.1.3 Effects of whole-body displacement

The air particles behind the shock or pressure wave have a specific velocity in the same direction as the blast. As a consequence of this so-called explosion wind a person can be picked up and displaced over a particular distance. The effect of the whole-body displacement will occur if the person is standing upright.

During such a displacement, tumbling and sliding over the surface as well as the collision with a rigid object can lead to injury. The extent of such injuries depends on the velocity of the impact, characteristics of the object or obstacle and on the part of the human body involved in the impact.

In the case of a collision, the skull is the most vulnerable part of the body. Due to this, criteria are given in literature whereby the probability of survival is to be determined when the skull strikes a rigid obstacle. In Table 4 critical impact velocities are shown which correspond to a particular probability of fracture of the base of the skull and for the determination of the probability of survival in the case when the entire body collides with a rigid obstacle.

Table 4: Probability of a scull-base fracture and death in case of impact of the whole-body

Criterion	**Impact velocity (m/s) - scull fracture**	**Collision velocity (m/s) - whole body displacement**
Safe	3,0	3,0
Threshold	4,0	6,5
50%	5,5	16,5
Almost 100 %	7,0	42,0

3.2 Missiles – The effects of fragments of debris

An explosion can give rise to fragments which are accelerated and which can be dangerous to people who are hit by them. These fragments can originate directly from the explosion source, but can also originate from objects in the surroundings of the explosion, when such objects are subjected to the blast wave.

In discussing the effects of fragments on a human body it is mostly customary to divide them into two categories: cutting and non-cutting fragments. Cutting fragments penetrate through the skin; this category is usually classified as fragments. The non-cutting fragments produce injuries due to contact pressure; this category is usually referred to as debris. .

The effects of fragments and debris, the so-called secondary effects. must be determined on the basis of their mass, velocity and shape.

3.2.1 Fragments

At a greater distance from an explosion, damage to buildings is mostly restricted to broken window panes due to the low overpressure. However, the mass and velocity of glass fragments may be sufficiently high to be able to injure people who are behind the window panes during the explosion. Consequently, injuries due to glass fragments can be incurred even at great distances from the centre of the explosion.

The initial velocity and the mass of glass fragments coming from a failing window pane depend on the dimensions of the pane length, width and thickness, and the load on the pane. If the load is a number of times higher than the failure load of the pane, more dangerous fragments will occur than in the case when this load is slightly greater than the failure load.

3.2.2 Debris

Debris causes high compressive stresses and deformations in the body when it collides with it. High stresses can lead to fracture of the bones. Large deformations can also lead to damage of various organs, with consequent internal bleeding etc. Since a human body is a very complex structure it is virtually impossible to predict which quantities are decisive for the injuries which will occur. Furthermore, the occurrence of an injury may be strongly dependent on the part of the body which has been hit. Consequently, only very general criteria can be found in literature regarding possibilities of injury due to the impact of debris on human bodies.

For a piece of debris a 4,5 kg mass is used as a reference for serious injury in case of a collision with a human head (taking into consideration a velocity above 5 m/s).

3.2.3 Collapse of buildings

Buildings can collapse due to blast by pressure loads which are far lower than the ones required to produce direct damage to human beings. If people are present inside a collapsing building, they may suffer serious injuries or even be killed.

The number of deaths caused by collapse is dependent on age of the people in question (young children and old people, in houses, have a lower probability of survival). It also appears that, in almost all age categories, women are more susceptible to a serious or fatal injury.

It can be concluded, that 20% to 50%, of the people present will die after a building collapse.

In the modelling of environmental threat vulnerability the presence of buildings in the impact area (collapse) was considered as a possible pathway for fatalities among people.

3.3 Summary

A summary on thresholds for the effects of overpressure is given in Table 5.

Table 5: Reference values for overpressure – consequences for humans

Reference values for overpressure (kPa)	Consequences
2,1	No consequences – safe distance
35	Ear-drum damage
70	Lung damage
300	Fatality

The consequences of the direct effects of the blast have mostly been presented; however, these consequences will only be effective for high peak overpressures. With regard to the secondary effects the impact of fragments, debris and missiles can be evaluated if such fragments are considered dangerous, based on their velocity and mass. The consequences of the tertiary effects are determined on the basis of the assumption that a person will be displaced and will collide with a rigid object at maximum displacement velocity. This assumption represents an estimate of this effect.

For blast effects, the value of 50 kPa was taken for irreversible effects. For reversible effects, taking a conservative criterion, a value of 30 kPa was assumed (values for Italy and Spain, respectively, 30 and 50 kPa). The threshold value for lethality applied in Italy and France is 140 kPa (ARAMIS, 2004).

In the case of missiles (fragments and debris) the criteria to establish the threshold values was to consider the maximum level of effects for distances within which the missiles are expected.

4 TOXICITY

For toxic effects, several reasons make the definition of the threshold levels more difficult than in the previous cases:

- most of the countries only agree on one threshold value, corresponding to the start of irreversible effects, taken as the IDLH;
- many exposure guidelines exist, the selection of one of them being very difficult because the scientific and statistical background is in all cases rather poor;
- each guideline covers only a limited number of substances;
- the effects of toxic substances on humans are in most cases related to the dose and not to a given concentration;

The threshold levels for toxic effects in the proposed method are derived considering Temporary Emergency Exposure Limits (TEEL) and The Emergency Response Planning Guideline (ERPG). The thresholds are based on the TEEL and ERPG levels because of their wide use (primarily for emergency planning purposes) and thus the availability of toxicity data for majority them.

Additional established toxicity levels could also be applied, e.g. AEGLs , LC, etc.

Since different substances have different effects on organisms in certain concentrations, differentiation between toxic substances and their effects based on their actual concentrations and/or dose received by the targets is necessary.

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APPENDIX II

Results – case studies

1 INTRODUCTION

The results for hazardous industrial installations in the municipality of Koper are presented in this section. The installations include:

1. Istrabenz Plini – Dolinska location, LPG storage and handling facility
2. Port of Koper, port and logistics
3. Instalacija, storage and handling of petroleum products
4. Kemiplas, chemical industry
5. Celanese Polisinteza, chemical industry

2 SUMMARY OF RESULTS – ISTRABENZ PLINI, DOLINSKA LOCATION

2.1 Location description

The surrounding of the location is a mixture of urban-industrial land use. Towards the north and east several industrial and manufacturing establishments are present. Towards the South the location is bordered by a local road; towards the west agricultural land use is present.

In accordance with the long term and mid-term spatial plans for the Municipality of Koper, the area is categorised as industrial/commercial zone. Residential land use is present in the vicinity of the area.

Further towards the south stands St. Margarite hill (92 m alt.), which has visual dominance in the area.

Demography

The population density in the vicinity of the site is presented in Figure 1 in GIS data in pers./ha. The background is a digitised map of the area with the scale 1: 5000.

The nearest residential areas are located 100m towards the south from the establishment.

Adjacent to the establishment manufacturing, industrial and commercial objects are present where, during the day, besides the employees, a large number of people can be present (clients, visitors, etc.).

Infrastructure

Motorways

Adjacent to the southern border is a local road, frequented mostly by the users of the industrial/commercial zone. Also present in the area is a parking garage for the commercial centre (at a distance of 50 m). In the East at a distance of approximately 500 metres a motorway Pula – Koper is situated (an important transport corridor).

Railways

North at a distance of 2 km is a railway station.

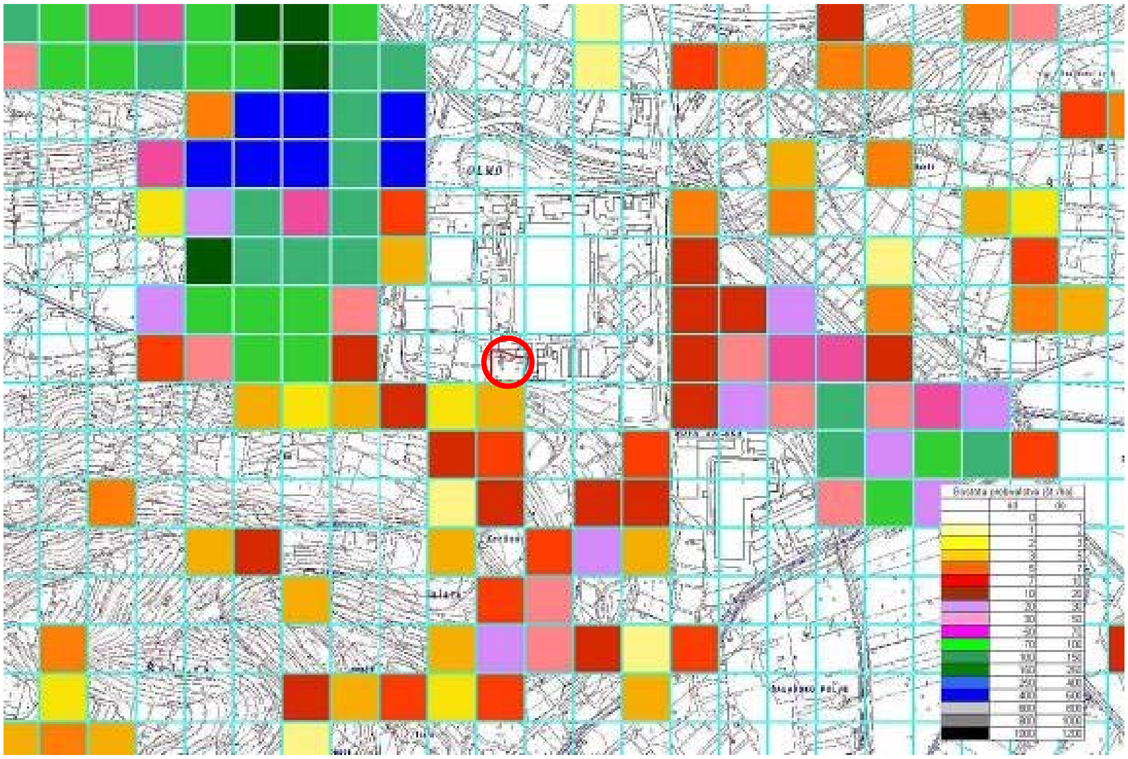

Figure 1: Population density in the vicinity of Istrabenz Plini, Dolinska location

2.2 Incident outcome analysis

The following objects and equipment are present at the location:

- 2 surface LPG storage vessels with a capacity of 60 m^3 each
- Road tanker LPG loading/unloading station
- LPG pumping station
- Evaporation station for LPG
- 5m^3 propane storage vessel
- Evaporation station for propane
- 6 m^3 argon storage vessel
- 16 steel containers of oxygen O_2
- acetylene (C_2H_2) (5+5 steel containers),
- 2 piles of 20 steel containers of CO_2 and N_2
- Argon loading/unloading station
- Surface and sub-surface pipelines
- Fire extinguishing/cooling system

The majority of operations include manipulation of LPG (transport, vaporisation), transport of technical gases (oxygen, nitrogen, CO_2 and argon). No full time employees are present at the location. Occasionally, at the gas vaporising station, one employee is present.

Annual capacities of materials in the establishment are:

- 1800 tons of LPG (delivered by 19 t road containers)
- 9000 kg of LPG in steel containers
- 9400 kg propane in steel containers
- 1500 kg oxygen in steel containers containing 8,8 kg of compressed gas each
- 20000 kg CO_2 in steel containers containing 30 kg liquid CO_2 each
- 660 kg argon in steel containers
- 100 tons liquid argon in 11 ton road tankers
- 14 tons of Stargas mixture in steel containers
- 1200 kg nitrogen in steel containers containing 7,1 kg of compressed gas each
- 1600 kg acetylene in steel containers containing 7 kg of acetone dissolved gas

- 3000 kg ammonia in steel containers

The majority of operations include delivery of LPG with unloading/loading operations. On this basis the following scenario was selected for further analysis: a spill of LPG during loading/unloading operations (frequent), the ignition and subsequent VCE (Vapour Cloud Explosion) with consequent damage to one of the 60 m^3 LPG storage vessels, which propagates to BLEVE of the storage vessel.

2.3 Threat analysis

The basis for the analysis is a threat interaction matrix which combines the consequences/physical effects of BLEVE scenario and the targets i.e. recipients (Table 1).

Table 1: Threat interaction matrix for BLEVE

Physical effects / Targets	Overpressure	Thermal radiation	Toxic release into air	Toxic release into water
Biosphere	●	●		
Natural resources	●	●		
Human environment	●	●		

2.3.1 Threat analysis for overpressure

Threat intensity level

The results of the threat intensity level for overpressure for the BLEVE scenario are summarised in Table 2 and presented in Figure 2.

Table 2: Threat intensity level for overpressure for BLEVE scenario of 60m^3 LPG reservoir

Threat intensity level	Reference values for overpressure	Distance – impact radius
5 – high	> 20,7 kpa	< 200 m
4 – medium to high	13,8 kpa – 20,7 kpa	200 m – 260 m
3 – medium	6,9 kpa – 13,8 kpa	260 m – 370 m
2 – low to medium	2,1 kpa – 6,9 kpa	370 m – 1000 m
1 – low	< 2,1 kpa	> 1000 m

Figure 2: Threat index map for overpressure for the BLEVE scenario

2.3.2 Threat analysis for thermal radiation

The results of the threat intensity level for thermal radiation for the BLEVE scenario are summarised in Table 3 and presented in Figure 3.

Table 3: Threat intensity level for thermal radiation for BLEVE scenario of 60m^3 LPG reservoir

Threat intensity level	**Reference values for thermal radiation**	**Distance – impact radius**
5 - high	> 37,5 kW/m^2	< 150 m
4 – medium to high	25 kW/m^2 - 37,5 kW/m^2	150 m - 180 m
3 -medium	12.5 kW/m^2 - 25 kW/m^2	180 m - 270 m
2 – low to medium	4.5 kW/m^2 - 12,5 kW/m^2	270 m - 470 m
1- low	< 4,5 kW/m^2	> 470 m

Figure 3: Threat index map for thermal radiation for BLEVE scenario

Both figures show the highest levels of threat (categories 4 and 5) to be within the industrial and service area, posing a threat to several neighbouring facilities.

2.4 Technical and organisational threat reduction measures in the context of land-use planning

The analysis of the altered BLEVE scenario shows that, in the scope of spatial planning, the only successful measure is elimination of the BLEVE scenario. This can be achieved by the installation of mechanical arm with valves with locking mechanism or by relocation of the establishment. The managers' decision was for a relocation of the establishment, therefore the area can be acknowledged for a different use in the new land-use plan of the Municipality of Koper.

3 SUMMARY OF RESULTS – PORT OF KOPER

3.1 Location description

The premises of the Port of Koper are situated on a swampy terrain which is partially land-filled.

The location of the establishment is characterised by flat swampy terrain. In the vicinity is the hill Sermin. Land use in the area is mainly residential and commercial.

Figure 4: Panorama of the Port of Koper

Demography

Residential areas are present at the southern border of the establishment's premises with an average population density between 150 and 200 pers./ha.

Land-use in the vicinity of the site

In accordance with the municipal plan of the Municipality of Koper from 2001, the port area is categorised as an area for transport and communications.

At present no physical buffer is established between the terminals and the town centre.

Special nature protected areas in the vicinity of the site

- Towards the north-east at a distance of 400 m, Sermin (84 m altitude) is classified as an archaeological monument
- To the east, at a distance of approximately 100 m from the establishment, a salty shallow lake is situated (formerly sea) and is categorised as a special environmentally protected area – Natura 2000 site (European Commission, 1992; Ur.l. RS št. 20/98)
- South-east, at a distance of 500 m, is the protected tree line
- North-east, at a distance of approximately 200 m, Ankaranska bonifika ("salty soil") is present
- North, at a distance of approximately 1 km, is a park near the hospital in Ankaran

Objects of cultural heritage

Adjacent to the establishment stands the ancient city centre of Koper. No objects of cultural heritage are present in the vicinity.

Infrastructure

Motorways

Adjacent to the southern border of the establishment is a local road/city street. East, at a distance of approximately 400 metres, a motorway, Ljubljana – Koper is situated.

Railways

South-west at a distance of 200 m is a railway station (the Ljubljana – Koper route). Cargo railway is a part of the establishment's infrastructure.

3.2 Incident outcome analysis

The port manages approximately 14 million tons of cargo/year. Hazardous substances at the port are:

- fuels – jet fuel A-1; diesel, gasoline
- o-xylene

- phosphoric acid
- ammonia – refrigeration warehouses

The Quantitative Risk Assessment (QRA) identified the following incident scenarios (Luka Koper, 2006):

a) release from the liquid cargo terminal (terminal for chemicals)

  - release of chemicals during unloading from a ship
  - release from a storage vessel
  - release from a road tanker / railway loading/unloading station
  - release from pipelines and connections

b) release from the liquid cargo terminal (terminal for gas-oils)
  - release from a storage vessel
  - release from a road tanker / railway loading/unloading station

c) release of ammonia from the refrigeration system at the fruit terminal

  - release of ammonia from the refrigeration unit due to valve malfunction
  - release of ammonia due to damage to storage tank or piping
  - release of ammonia during loading operations

d) release at the tanker terminal

From the listed scenarios, a), b) and d) are relevant to the sea pollution and use, while scenario c) is relevant to land-use planning. The tanker terminal d) is managed by the Instalacija establishment; therefore this scenario is described in detail in the relevant chapter.

a) release from the liquid cargo terminal (terminal for chemicals)

A release from a storage vessel; the storage vessels on the terminal are placed in a pool (within a bund). Smaller or larger releases from the reservoirs can occur due to inappropriate maintenance, valve leakage, overfilling, human error during loading/unloading operations or during maintenance operations.

The most severe incident would be a release of Jet fuel, o-xylene or ethanol initiated by overfilling the reservoir, erroneous attachment of equipment during the loading/unloading operation, damage to the equipment as a consequence of inappropriate manipulation or due to sabotage in combination with failure of safety measures. The cause of ignition in the area can be human error (use of flame, use of sparking tools).

A release from a road tanker / railway loading/unloading station; among the possible scenarios on the loading/unloading station, the scenario of release from road/railway tankers, was chosen for further analysis. The initiating events in this case are: overfilling, movement of the road tanker / railway composition with consequent breakage of piping equipment, traffic (commotion) accident and inappropriate maintenance of the equipment.

The most severe incident at the loading/unloading station would occur in the case of breakage of piping equipment due to the movement of the railway composition. Four tankers are involved in the operation simultaneously. The flow of material during operation is 60 m^3/h. The release time is assumed to be 1 minute, after which the operators would manage to close the valves to prevent leakage. The quantity of released material is assumed to be 4 m^3, which is captured in an underneath pool with dimensions 6x45m and begins to evaporate. Assuming immediate ignition the thermal radiation of the pool fire can affect up to 3 additional tankers.

A release from pipelines and connections: release can occur due to leakage of valves, increased pressure in the system (as a result of temperature increase), hydraulic impact, outside impacts (traffic accident), corrosion, etc.

The most severe expected impacts are associated with the breakage of the pipeline due to a traffic incident or sabotage during the loading/unloading of Jet fuel. The flow during the operation amounts to 120 m^3/h. The release is estimated to last for 1 minute in which the released quantity would be 2 m^3. In the case of release in the area of pumping equipment and loading/unloading stations the released materials would be caught in a safety pool. Outside these areas the release means pollution of the ground and the aquatic environment.

A release of chemicals during unloading from a ship; an incident at the dock can occur due to leakage of operation equipment during loading/unloading (inappropriate maintenance of equipment), erroneous use of process equipment, severe weather conditions (wind) .

The most severe incident at the loading/unloading station would occur in the case of breakage of piping equipment due to movement of the ship. The release is estimated to last for 1 minute in which the released material would be spilled onto the water surface or the safety pool (within a bund). The ignition can result in a fire or vapour cloud explosion.

b) the release from the liquid cargo terminal (terminal for gas-oils)

A release from a storage vessel; the storage vessels on the terminal are placed in a pool (within a bund). Smaller or larger releases from the reservoirs can occur due to inappropriate maintenance, valve leakage, overfilling, human error during loading/unloading operations or during maintenance operations. The most severe incident is a release of gas-oil of diesel fuel initiated by the overfilling of the reservoir, erroneous attachment of equipment during the loading/unloading operation, damage to the equipment as a consequence of inappropriate manipulation or due to sabotage in combination with failure of safety measures. The cause for ignition in the area can be human error (use of flame, use of sparking tools). Expected consequences are fire and/or vapour cloud explosion.

A release from a road tanker / railway loading/unloading station; among the possible scenarios on the loading/unloading station, the scenario of release from road/railway tankers was chosen for further analysis. The initiating events in this case are: overfilling, movement of the road tanker / railway composition with consequent breakage of piping equipment, traffic (commotion) accident (derailment), inappropriate maintenance of the equipment.

The most severe incident at the loading/unloading station would occur in the case of breakage of piping equipment due to movement of the railway composition. Four tankers are involved in the operation simultaneously. The flow of the material during operation is 170 m^3/h. The release time is assumed to be 1 minute, after which the operators would manage to close the valves to prevent leakage. The quantity of released material is assumed to be 12 m^3, which is captured in an underneath pool (bund) with dimensions 6x68 m and begins to evaporate. Assuming immediate ignition the thermal radiation of the pool fire can affect up to 3 additional tankers (the possibility of a BLEVE scenario if the lid is closed). Domino effects are possible in the case of failure of safety measures.

c) the release of ammonia from the refrigeration system at the fruit terminal

The scenario anticipates release of ammonia during loading of ammonia into the refrigeration system. Loading operations take place every 2 years. Ammonia is supplied by a road tanker carrying maximum 2 tonnes of ammonia. Using a flexible hose, ammonia is transferred from the tanker into the refrigeration system. The quantity of ammonia in the system is approximately 6 tonnes.

The initiating events considered are:

- breach of the flexible hose used during the operation
- movement of road tanker and consequent detachment of the hose
- traffic incident

The most severe consequences in regard with this scenario would result from a traffic accident during loading/unloading of the ammonia into the refrigeration system. The operation is scheduled to take place every 2 years. Ammonia is delivered pressurised in a road tanker with a capacity of 2 tons. The duration of the loading operation is 3 hours. The volume of the tank is 1,3 m^3 with pressure 3-4 bar (300 - 400 kPa). The ammonia is transferred into a separator through a flexible hose 18 mm in diameter. The pressure in the separator is 1-2 bar. The refrigeration system contains a maximum of 6 tons of ammonia.

Ammonia forms an explosive mixture with air at concentrations between 15,8 - 25,7%, however, additional energy is required for an explosion (initial ignition). In the case of ammonia release to the atmosphere at 20°C, 18% of the released quantity is immediately vaporised; the remaining quantity is spilled on the ground or is released as a cloud of aerosols. At 40°C, 25% of released ammonia is evaporated and at 0°C, 10%.

On the release of 1-10t of ammonia the evaporation rate is up to 0,01 kg/m^2s. Weather conditions (wind) can accelerate the evaporation by a factor of 1,5.

After release, the ammonia is transported within the atmosphere as a heavy cold cloud, visible due to the presence of aerosols. The spread of the cloud is spherical. Due to dilution with air the density of the cloud decreases, while the temperature increases. In the third phase of the dilution dispersion into the atmosphere occurs. Obstructions significantly affect the spreading of the cloud.

d) the release at the tanker terminal

An incident – a release from the equipment at the tanker terminal during the unloading operations – can occur due to damage (breakage) of the mechanical arm used in the operation as a consequence of movement of the ship, bad weather conditions, or acts of sabotage.

The most severe incident would result from movement of the ship, causing breakage of the loading/unloading mechanical arm. Due to the locking mechanism on the equipment the maximum released quantity is $8m^3$. Another incident might be release due to damage to the mechanical arm if the operator does not see the spill immediately.

If the vapour of the spilled material reaches an ignition a possibility of VCE and consequent pool fire exists.

The released material could reach the aquatic environment (sea) at which point it would remain on the surface. In the case of release of D-2 diesel fuel, which is less soluble in water, the released material would be removed, while the spread would be prevented by the installed floating barriers around the ship. In the case of the release of unleaded motor fuel (95), which is soluble in water, negative impacts to the aquatic ecosystem can be expected.

In the technological pipeline from the tanker terminal to the Instalacija company, an incident of breakage of the pipeline (40 cm in diameter) is considered. The length of the pipeline is 2437 m, the flow of the materials is 1600 m^3/h. The duration of the release is estimated to be 1 minute, in which time approximately 26 m^3 of fuel would be released. In the case of ignition jet-fire is expected and/or a pool fire. In the absence of ignition, the formation of a pool is expected with consequent impact to the ground and aquatic ecosystem.

3.3 Threat analysis

The basis for the analysis is a threat interaction matrix which combines the consequences/physical effects of selected scenarios and the targets i.e. recipients (Table 4). The consequences for incidents in the Port of Koper include overpressure, thermal radiation and release into air and water.

Table 4: Threat interaction matrix for the port of Koper

Physical effects / Targets	Overpressure	Thermal radiation	Toxic release into air	Toxic release into water
Biosphere	●	●	●	●
Natural resources	●	●	●	●
Human environment	●	●	●	●

3.3.1 Threat analysis for overpressure

The liquid cargo terminal

The results of threat analysis for overpressure for scenario of a VCE at the reservoir area R100 and R200 (storage for ethanol and o-xylene) are summarised in Table 5 and presented as a threat index map (Figure 5). Higher levels of threat are evident within the port's premises (objects and infrastructure).

Table 5: Threat intensity level for overpressure for VCE at R100 and R200 at the liquid cargo terminal

Threat intensity level	Reference values for overpressure	Distance – impact radius
5 - high	> 20,7 kpa	< 12 m
4 – medium to high	13,8 kpa -20,7 kpa	32 m
3 -medium	6,9 kpa - 13,8 kpa	57 m
2 – low to medium	2,1 kpa - 6,9 kpa	100 m
1- low	< 2,1 kpa	> 100 m

The release of ammonia from the refrigeration system at the fruit terminal

The results of threat analysis for overpressure for the scenario of VCE of ammonia cloud are summarised in Table 6 and presented as a threat index map (Figure 5). A higher level of threat is evident in the vicinity of the release.

Table 6: Threat intensity level for overpressure for ammonia fumes explosion at the fruit terminal

Threat intensity level	Reference values for overpressure	Distance – impact radius
5 - high	> 20,7 kpa	< 10 m
4 – medium to high	13,8 kpa -20,7 kpa	18 m
3 -medium	6,9 kpa – 13,8 kpa	32 m
2 – low to medium	2,1 kpa – 6,9 kpa	95 m
1- low	< 2,1 kpa	> 95 m

Release at the tanker terminal

The results of threat analysis for overpressure for the scenario of VCE of unleaded gasoline are summarised in Table 7 and presented as a threat index map (Figure 5). Higher level of threat is evident in the vicinity of the release.

Table 7: Threat intensity level for overpressure for gasoline (95) fumes explosion at the tanker terminal

Threat intensity level	Reference values for overpressure	Distance – impact radius
5 – high	> 20,7 kpa	< 10 m
4 – medium to high	13,8 kpa -20,7 kpa	19 m
3 – medium	6,9 kpa – 13,8 kpa	37 m
2 – low to medium	2,1 kpa – 6,9 kpa	130 m
1 – low	< 2,1 kpa	> 130 m

Figure 5: Threat index map for overpressure for the Port of Koper

3.3.2 Threat analysis for thermal radiation

The liquid cargo terminal

The results of threat analysis from thermal radiation for a scenario of 10 minute release of diesel fuel and its ignition at the terminal for gas-oils are summarised in Table 8 and presented as a threat index map (Figure 6). Higher level of threat is evident within the port's premises (objects and infrastructure).

Table 8: Threat intensity level for thermal radiation at the liquid cargo terminal

Threat intensity level	**Reference values for thermal radiation**	**Distance – impact radius**
5 – high	> 37,5 kW/m^2	< 20 m
4 – medium to high	25 kW/m^2 - 37,5 kW/ m^2	20 m
3 – medium	12,5 kW/m^2 - 25 kW/m^2	50 m
2 – low to medium	4,5 kW/m^2 - 12,5 kW/m^2	100 m
1 – low	< 4,5 kW/m^2	> 100 m

Release at the tanker terminal

The results of threat analysis for thermal radiation for the scenario of breakage of loading mechanical arm and the ignition of spilled material are summarised in Table 9 and presented as a threat index map (Figure 6). The analysis takes into the consideration the size of a pool fire within the floating barriers.

Table 9: Threat intensity level for thermal radiation at the tanker terminal

Threat intensity level	**Reference values for thermal radiation**	**Distance – impact radius**
5 – high	> 37,5 kW/m^2	< 1 m
4 – medium to high	25 kW/m^2 - 37,5 kW/ m^2	1 m
3 – medium	12,5 kW/m^2 - 25 kW/m^2	3 m
2 – low to medium	4,5 kW/m^2 - 12,5 kW/m^2	12m
1 – low	< 4,5 kW/m^2	> 12 m

The scenario for the breakage of the technological pipeline 40 cm in diameter estimates the release and immediate ignition of D-2 or unleaded gasoline. Formation of a jet-fire 73 m long is expected. The impact of thermal radiation is summarised in Table 10 and presented in Figure 6.

Table 10: Threat intensity level for thermal radiation – jet-fire after technological pipeline breach

Threat intensity level	**Reference values for thermal radiation**	**Distance – impact radius – jet fire 73 m**
5 – high	> 37,5 kW/m^2	< 2 m
4 – medium to high	25 kW/m^2 – 37,5 kW/ m^2	4 m
3 – medium	12,5 kW/m^2 – 25 kW/m^2	10 m
2 – low to medium	4,5 kW/m^2 – 12,5 kW/m^2	26m
1 – low	< 4,5 kW/m^2	>26 m

The threat index map for thermal radiation shows a higher level of threat in the vicinity of the fire. In the case of pool fire on the sea surface, a higher level of threat for the aquatic environment is evident.

Figure 6: Threat index map for thermal radiation for the Port of Koper

3.3.3 Threat analysis for toxic release into air

The scenario estimates the release of ammonia during loading of ammonia into the refrigeration system. In the case of release the formation of a toxic cloud is expected. The results for this outcome are summarised in Table 11 and presented in the form of a threat index in Figure 7. The expected consequences are breathing difficulties, possible damage to health of the inhabitants in the nearby town of Koper, as well as passengers at the terminal adjacent to the refrigeration facility.

Table 11: Threat intensity level for ammonia release into the air

Threat intensity level	Reference values for ammonia release	Distance
5 – high	>5000 ppm	< 200 m
4 – medium to high	700 ppm	400 m
3 – medium	500 ppm	500 m
2 – low to medium	150 ppm	700 m
1 – low	< 150 ppm	> 700m

Figure 7: Threat index map for toxic release (ammonia) into the air from the fruit terminal

3.3.4 Threat analysis for toxic release into water

Threat analysis for toxic release into water was conducted based on the expected release into the water and expected transport of substances through the aquatic environment.

The threat at the release points is presented in Figure 8. The higher level of threat is expected in the narrower release area, from which it is estimated that the vulnerability of the aquatic environment within the dock areas of the port is similar, thus the threat reflects the same principle.

Figure 8: Threat index map for toxic release into the water from the liquid cargo (chemicals) terminal

3.4 Threat reduction measures

The only relevant scenario for land-use planning purposes is scenario b) release of ammonia during loading operations.

From the application of the threat analysis to the Port of Koper and its surrounding areas, some conclusions may be drawn about the mitigating actions that should be considered.
These are:

- technological measures for risk reduction (frequencies of possible accidents and/or expected consequences) by means of removal of the pressurized ammonia storage at its current location (i.e. relocation) and replacement with a Freon based refrigeration system; or a
- relocation of vulnerable targets away from hazardous areas in terms of revision of the new passenger terminal design.

4 RESULTS – INSTALACIJA, STORAGE AND HANDLING OF PETROLEUM PRODUCTS

4.1 Location description

The main activity of the company is warehousing and manipulation of petroleum derivatives (gasoline, diesel fuel, gas-oil).

The location of the establishment is at the north-west part of Sermin hill. The area with accompanying infrastructure covers approximately 3,5 hectares. The natural form of Sermin hill was significantly altered due to establishment's infrastructure development.

The tanker terminal is located on the premises of the Port of Koper (western part of dock II) and is a part of Instalacija infrastructure.

The number of personnel at the establishment is 58.

Figure 9: Panorama of Instalacija, storage and handling of petroleum products

Demography

Residential use in the vicinity of the establishment includes detached single-family houses, which are located toward the north-east at a distance of approximately 100m. The average population density in the area is 5 pers./ha. 10 residents are in close proximity to the establishment.

Land-use in the vicinity of site

At the north-western boundary of the establishment is river Rižana. Further in the same direction is agricultural land-use. South from the location also agricultural land-use is present with several industrial and manufacturing establishments.

Spatial plan – municipal level

In accordance with the long term and mid-term spatial plans for the Municipality of Koper, the area is categorised as industrial zone Sermin. The intended use of land in the area is industrial, transport, and warehousing. In the vicinity of the area, there is agricultural land use, however the area is intended to be developed as an industrial, transport, and warehousing zone for petroleum derivatives and LPG.

Spatial plan – national level

In accordance with the national spatial plan the designated area is categorised as the area for expansion of petrol derivatives warehousing, LPG warehouse and transport corridor (motorway) towards the Port of Koper.

Special nature protected areas in the vicinity of the site:

- In close proximity in the east, a hill Sermin (84 m altitude) is found, which is classified as an archaeological monument.
- South-west at a distance of approximately 500 m from the establishment, a salty shallow lake is situated (formerly sea) and is categorised as a special environmentally protected area – Natura 2000 site (European commission, 1992; Ur.l. RS št. 20/98).
- South-east, at a distance of 500 m, the protected tree line is located.

- North at a distance of approximately 200 m Ankaranska bonifika (“salty soil”) is present, and spans from a cargo railway station towards Ankaran.

Infrastructure

Motorways

West of the location a local road Bertoki - industrial zone Sermin - Ankaran, is situated and represents the main connection to the adjacent industrial zone. South-West at a distance of approximately 500 metres a motorway Ljubljana – Koper is situated.

Railways

Cargo railway is a part of the establishment’s infrastructure.

4.2 Incident outcome analysis

Hazardous materials and their quantities on the premises are:

- Diesel fuel D-2 (135.000 m^3)
- Unleaded gasoline 95 (143.000 m^3)
- Oil (70.375 m^3)

The main infrastructure features that represents the hazard for major accident are the following (Instalacija 2005, 2006):

a) Storage area with surface storage vessels for petroleum derivatives
b) Road tanker loading/unloading station
c) Railway tanker loading/unloading station
d) Technological pipelines and pumping stations
e) Vapour recovery unit
f) Tanker terminal

a) Storage area with surface storage vessels for petroleum derivatives

The initial events or causes of release at the surface storage area are overfilling, leakage on connections, corrosion, acts of sabotage.

In the area of installation two types of storage vessels for petroleum derivatives are found:

- reservoirs (P+Al membranes) in soil constructed bunds,
- reservoirs (P+Al membranes) in steel constructed bunds.

The most severe incident in the storage area would be the release of unleaded gasoline from one of the R-17 or R-19 reservoirs, initiated by overfilling of the reservoir in addition to failure of all safety measures. Additional initiating events for release are damaged valve or mechanical damage to the pipeline. The incident is estimated to occur during the loading/unloading operations or during maintenance in the case of erroneous procedures.

In the case of release the material is captured within a bund (soil or metal). In the case of immediate ignition, a pool fire is expected. In the case of extended evaporation after the release, cloud formation is expected, which can be transported to a distant ignition source. This can result in VCE under the appropriate conditions (concentration of petroleum vapour in the air).

In the case of fire in the storage area, the automated alarm system is activated; after 4 minutes automatic fire extinguishing/cooling system is activated, if the operator does not abort the process.

The most severe incident in the storage area would be the release of unleaded gasoline from one of the R-14 or R-16 reservoirs, initiated by overfilling of the reservoir and damage of the valve in addition to failure of all safety measures.

In the case where the vapour cloud reaches an ignition source a VCE or fire at or on the reservoir itself is expected. As a consequence a pool fire in a bund is expected. Due to the blast wave of the explosion damage to the infrastructure or the equipment of the neighbouring reservoirs can occur. In the case of damage to the automatic fire extinguishing system, an intervention with mobile equipment can be organised in 3-5 minutes.

Before the operator can stop the spill approximately 120 000 kgs of fuel can be released into the bund and will start to evaporate. In the case of ignition a pool fire is formed with an outer diameter of 67 metres and 3,5 metre width.

b) Road tanker loading/unloading station

Among the possible scenarios on the loading/unloading station, the scenario of release from a road tanker was chosen for further analysis. The initiating events in this case are: overfilling, movement of the road tanker with consequent breakage of piping equipment, inappropriate attachment of the equipment or technical error on the equipment.

Also considered within the scenario was the ignition of the spilled fuel with the propagation of the events towards BLEVE scenario, due to the overheating of the tankers in the vicinity of fire.

The analysis considers the impacts of BLEVE scenario, which would be the result of overheating of a tanker if it was left too long within the impact area of thermal radiation caused by an adjacent fire. This scenario is, according to the operation guidelines of the establishment, unlikely to happen, while the operators would have removed the undamaged road tanker out of the impact area.

In the analysis of the scenario the release considered was occurring at the flow of 150m^3/h and duration 1 minute, at which the quantity of the release amounts to 2,5m^3 or 1800 kg. The released material forms a pool in a bund with 4,5x16m in size. In the case of immediate ignition the thermal effect can impact the detailed tanker as well as 2 tankers on adjacent loading/unloading stations (the possibility of BLEVE).

In the case of delayed ignition, the formation of vapour cloud is expected and consequent VCE (gasoline). With the release of D-.2 diesel fuel or oil, the phenomenon of VCE is eliminated due to physical characteristics of the material.

c) Railway tanker loading/unloading station

Among the possible scenarios on loading/unloading station, the scenario of release from road tanker, was chosen for further analysis. The initiating events in this case are movement of the railway tanker with consequent breakage of piping equipment as a result of a collision with incoming train due to brake malfunction and/or railway operator error. Other possible initiating events include inappropriate attachment of the equipment or technical error on the equipment.

The most severe incident at the loading/unloading station would occur in the case of breakage of piping equipment due to movement of the railway composition during the loading/unloading of unleaded gasoline.

Four tankers are involved in the operation simultaneously.

In the case of delayed ignition, the formation of vapour cloud is expected and consequent VCE (gasoline). With the release of D-2 diesel fuel or oil, the phenomenon of VCE is eliminated due to the physical characteristics of the material.

d) Technological pipelines and pumping stations – vehicle collision; leakage on valves; hydraulic impact

The causes for a release in the segment of technological pipelines and pumping station are a collision of a vehicle into the piping infrastructure, leakage of the connecting flanges or valves, hydraulic impact.

The scenario relevant for land-use planning is the release of fuel in the case of breakage of the 35 cm pipeline during unloading from the storage reservoirs for the requirement of road/railways loading/unloading stations. The flow rate in the main pipeline is 930 m^3/h and 480 m^3/h in secondary pipelines. The duration of the release considered is 1 minute, which represents the reaction time of the operator for operation shut-down. The released quantity of fuel is 12000 kg or 6000 kg, respectively. The most severe incident includes the release of unleaded gasoline, where in the case of immediate ignition the formation of jet-fire 20 metres long is expected. In the case of a delayed ignition the formation of pool fire or Technological pipelines and pumping stations VCE is expected.

The largest expected consequences due to the breakage of the pipeline would occur on the pipeline connecting the tanker terminal in the Port of Koper with the Instalacija establishment.

The initiating event considered is the traffic incident – a vehicle collision with the pipeline.

The most severe incident would occur during the transfer of unleaded gasoline, which would in the case of delayed ignition result in a VCE. If such incident involved diesel fuel or oil, the rise of temperature above the ignition level (55^0C) is not expected, therefore the occurrence of fire is not expected.

In the case of a spill the pollution of soil and aquatic environment of sea and river Rižana is likely to happen, due to the fact that ground under this pipeline is not impermeable.

The estimation used in modelling is the total breach of the 40 cm in diameter pipeline The length of the pipeline is 2437 m, the flow of the materials is 1600 m^3/h. The duration of the release is estimated to be 1 minute, in which time approximately 26 m^3 of fuel would be released. In the case of ignition the phenomena of jet-fire with a distance of 73 metres is expected and/or the formation of a pool fire. In the case of absence of the ignition, the formation of pool is expected with consequent impact to the ground and aquatic ecosystem is expected.

e) Vapour recovery unit

In the vapour recovery unit saturated petroleum fumes are stored. The volume of the object is 2000 m^3. In the case of a release the fumes would dilute to an explosive mixture with air and be involved in an explosion in the presence of ignition. The object is designed in such manner that the only cause for the release would be a vehicle collision. Due to overpressure created in the explosion damage to the adjacent personnel or equipment is expected.

Leakages on the object may occur due to small leakages at the flange connections or valves of membrane breach.

In the case of fire, the alarm system in this area is activated manually – consequently a fire brigade arrives at the scene and commences the extinguishing procedure.

f) Tanker terminal

The most severe incident on the tanker terminal involves the breach on the connecting mechanical arm for loading/unloading. This is the result of movement of the ship or bad weather condition causing the detachment of the equipment. Due to installed safety locking mechanism on the mechanical arm the maximum released quantity is estimated at 8 m^3.

Another incident might be the release due to damage to a mechanical arm if the operator does not witness the spill immediately.

In the case where the vapour of the spilled material reaches an ignition a possibility of VCE and consequent pool fire exists. During loading/unloading operation the personnel are present at the site, which would commence the fire extinguishing operations.

In the case of VCE the largest impact area is expected due to flying debris/projectiles at a distance radius of 47 m.

The released material could reach the aquatic environment (sea) at which point it would remain on the surface. In the case of release of D-2 diesel fuel, which is less soluble in water, the released material would be removed, while the spread would be prevented by the floating barriers around the ship. In the case of the release of unleaded motor fuel (95), which is soluble in water, negative impacts to the aquatic ecosystem can be expected.

4.3 Threat analysis

The basis for the analysis in threat interaction matrix which combines the consequences/physical effects of the scenarios and the targets i.e. recipients (Table 12). The consequences for incidents in the Instalacija include overpressure, thermal radiation and the release into water.

Table 12: Threat interaction matrix for Instalacija, storage and handling of petroleum products

Physical effects / Targets	Overpressure	Thermal radiation	Toxic release into the air	Toxic release into the water
Biosphere	●	●		●
Natural resources	●	●		●
Human environment	●	●		●

4.3.1 Threat analysis for overpressure

Storage area with surface storage vessels for petroleum derivatives

The results of threat analysis for overpressure for VCE scenario are summarised in Table 13 and presented on a threat index map (Figure 10). The threat index map shows higher levels of threat within the surface storage area (reservoirs). Higher threat level is evident also in the vicinity of Rižana river. Outside the premises of Instalacija, higher levels of threat are not expected, due to the incidents at the surface storage area, therefore these scenarios are irrelevant in context of land-use planning.

Table 13: Threat intensity level for overpressure in the surface storage area

Threat intensity level	Reference values for overpressure	Distance R17, R19	Distance R14-R16
5 – high	> 20,7 kPa	20m	20m
4 – medium to high	13,8 kPa -20,7 kPa	40m	50m
3 – medium	6,9 kPa – 13,8 kPa	80m	100m
2 – low to medium	2,1 kPa – 6,9 kPa	150m	300m
1 – low	< 2,1 kPa	>150m	>300m

Road tanker loading/unloading station

The results of threat analysis for the overpressure for VCE scenario are summarised in Table 14 and presented on a threat index map (Figure 10). The threat index map shows higher levels of threat to be within the area of infrastructure and objects.

Table 14: Threat intensity level for overpressure for the BLEVE scenario at the road-tanker loading/unloading station

Threat intensity level	Reference values for overpressure	Distance BLEVE
5 – high	> 20,7 kPa	15m
4 – medium to high	13,8 kPa -20,7 kPa	47m
3 – medium	6,9 kPa – 13,8 kPa	70m
2 – low to medium	2,1 kPa – 6,9 kPa	120m
1 – low	< 2,1 kPa	>120m

Railway tanker loading/unloading station

The results of threat analysis for the overpressure for VCE scenario are summarised in Table 15 and presented on a threat index map (Figure 10). In the case of explosion the impact of projectiles and debris is expected at a distance of 130 m.

The threat index map shows higher levels of threat to be in the vicinity of the release point, primarily in the area of establishment's infrastructure.

Table 15: Threat intensity level for overpressure at the railway loading/unloading station

Threat intensity level	Reference values for overpressure	Distance
5 – high	> 20,7 kPa	20m
4 – medium to high	13,8 kPa -20,7 kPa	50m
3 – medium	6,9 kPa – 13,8 kPa	80m
2 – low to medium	2,1 kPa – 6,9 kPa	150m
1 – low	< 2,1 kPa	>150m

Vapour recovery unit

The results of threat analysis for the overpressure for VCE scenario are summarised in Table 16 and presented on a threat index map (Figure 10). In the case of the explosion the impact of projectiles and debris is expected at a distance of 65 m. The threat index map shows higher levels of threat to be in the vicinity of the release point.

Table 16: Threat intensity level for overpressure at the fumes-collector

Threat intensity level	Reference values for overpressure	Distance
5 – high	> 20,7 kPa	5m
4 – medium to high	13,8 kPa -20,7 kPa	15m
3 – medium	6,9 kPa – 13,8 kPa	30m
2 – low to medium	2,1 kPa – 6,9 kPa	80m
1 – low	< 2,1 kPa	>80m

Tanker terminal

The results of threat analysis for the overpressure for VCE of unleaded gasoline scenario are summarised in Table 7 and presented on a threat index map in Figure 10. The threat index map shows higher levels of threat to be in the vicinity of the release point.

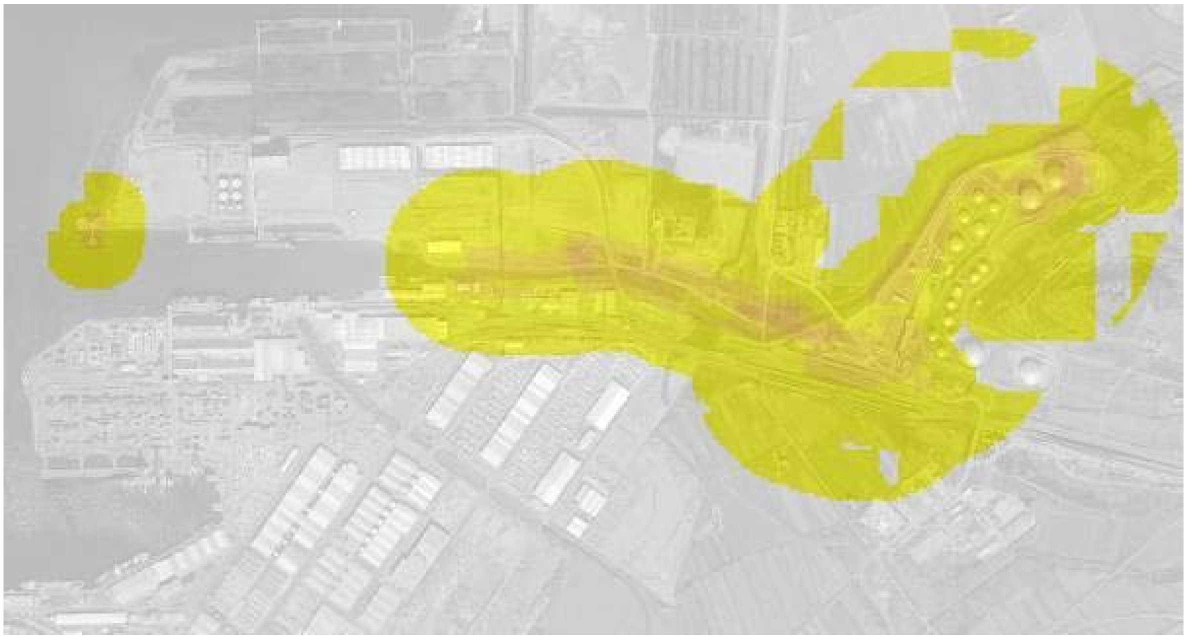

Figure 10: Threat index map for overpressure – Instalacija, storage and handling of petroleum products

4.3.2 Threat analysis for thermal radiation

Surface storage vessels

The results of threat analysis for the thermal radiation for the jet-fire scenario are summarised in Table 17 and presented on a threat index map (Figure 11).

Table 17: Threat intensity level for thermal radiation in the surface storage area

Threat intensity level	Reference values for thermal radiation	Distance R1-R13	Distance R14-R16	Distance R17, R19
5 – high	> 37,5 kW/m^2	<50m	20m	<25m
4 – medium to high	25 kW/m^2 – 37,5 kW/ m^2	50	24m	25m
3 – medium	12,5 kW/m^2 - 25 kW/m^2	71m	34m	38m
2 – low to medium	4,5 kW/m^2 – 12,5 kW/m^2	165 m	88m	96m
1 – low	< 4,5 kW/m^2	>165m	>88m	>96m

Road tanker loading/unloading station

The results of threat analysis for the thermal radiation for the jet-fire scenario at the road tanker loading/unloading station due to a breach of loading/unloading arm are summarised in Table 18 and presented on a threat index map (Figure 11).

The estimated size of the jet, based on the calculation of pressure and flow is approximately 25 m. The threat index map shows higher levels of threat to be within the area of infrastructure and objects.

Table 18: Threat intensity level for thermal radiation at the road-tanker loading/unloading station

Threat intensity level	**Reference values for thermal radiation**	**Distance - jet-fire**
5 – high	> 37,5 kW/m^2	25m
4 – medium to high	25 kW/m^2 – 37,5 kW/ m^2	25m
3 – medium	12,5 kW/m^2 - 25 kW/m^2	29m
2 – low to medium	4,5 kW/m^2 – 12,5 kW/m^2	34m
1 – low	< 4,5 kW/m^2	>34m

Railway loading/unloading station

The results of threat analysis for the thermal radiation for the jet-fire scenario at the railway tanker loading/unloading station due to a breach of loading/unloading arm are summarised in Table 19 and presented on a threat index map (Figure 11).

The estimated size of the jet, based on the calculation of pressure and flow is approximately 25 m. The threat index map shows higher levels of threat to be within the area of infrastructure and objects.

Table 19: Threat intensity level for thermal radiation at the railway loading/unloading station

Threat intensity level	**Reference values for thermal radiation**	**Distance**
5 – high	> 37,5 kW/m^2	25m
4 – medium to high	25 kW/m^2 – 37,5 kW/ m^2	25m
3 – medium	12,5 kW/m^2 - 25 kW/m^2	29m
2 – low to medium	4,5 kW/m^2 – 12,5 kW/m^2	34m
1 – low	< 4,5 kW/m^2	>34m

Technological pipelines

The analysis is based on a breach of 0,4 m pipeline from tanker terminal to the premises of the establishment. In the case of immediate ignition 73 m jet-fire is expected. The scope of thermal radiation impacts is presented in Table 20 and shown in the threat index map (Figure 11).

Table 20: Threat intensity level for thermal radiation – jet-fire after technological pipeline breach at Instalacija

Threat intensity level	Reference values for thermal radiation	Distance – impact radius – jet fire 73 m
5 – high	> 37,5 kW/m^2	< 2 m
4 – medium to high	25 kW/m^2 – 37,5 kW/ m^2	4 m
3 – medium	12,5 kW/m^2 - 25 kW/m^2	10 m
2 – low to medium	4,5 kW/m^2 – 12,5 kW/m^2	26m
1 – low	< 4,5 kW/m^2	>26 m

Figure 11: Threat index map for thermal radiation - Instalacija, storage and handling of petroleum products

4.3.3 Threat analysis for toxic release into water

The analysis is based on a scenario of a breach of the pipeline or the loading/unloading arm at the tanker terminal in The Port of Koper. The consequence of a breach of a pipeline is a jet of fuel, which in the absence of ignition results in a spill of 26 m^3 onto the ground or into the water, with consequent pollution of soil and/or aquatic environment. The consequences of detachment/breach of a mechanical arm include the spill of 8 m^3 of fuel onto the dock or into the sea.

Threat analysis is conducted based on the potential pollution of aquatic environment in the case of a spill (sea, Rižana river). The results in a form of threat index are presented in Figure 12.

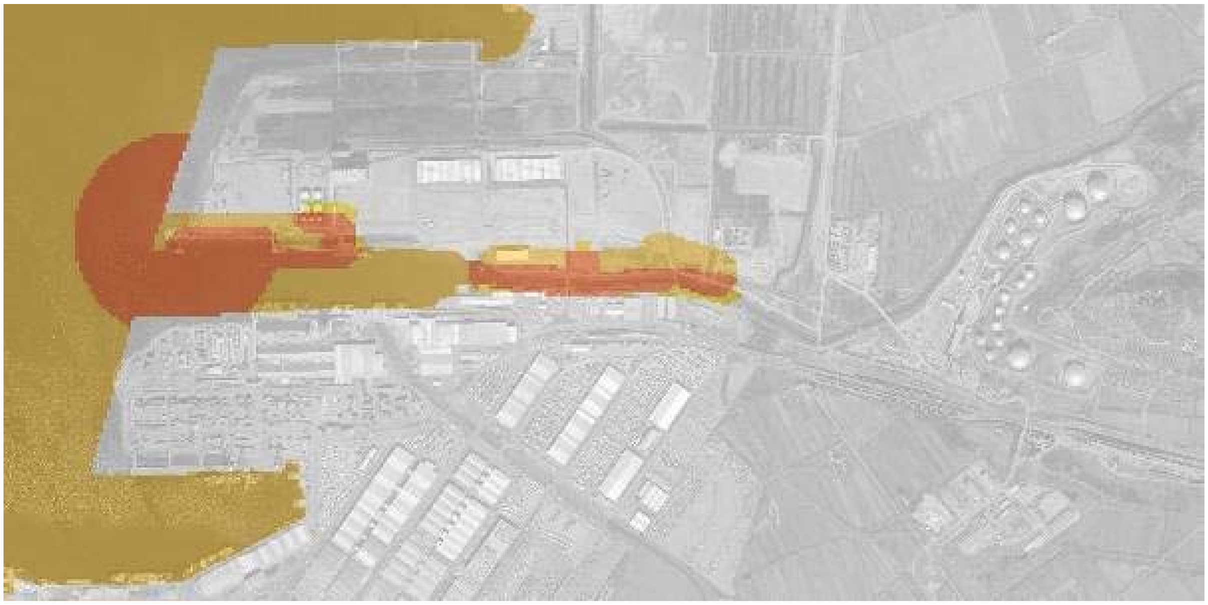

Figure 12: Threat index map for toxic release into the water - Instalacija, storage and handling of petroleum products

4.4 Possible technical and organisational measures for reduction of impact zone

The impact areas of incidents at Instalacija establishment do not exceed the boundaries of the establishment. However, the problem that remains is potential pollution of the aquatic environment of the Rižana river and the sea. Based on the latter, the future land-use planning should search for possibilities of relocating the pipeline away from the vulnerable area (Rižana river).

5 RESULTS – KEMIPLAS, CHEMICAL INDUSTRY

5.1 Location description

Kemiplas, chemical industry is located in the suburbs of the town of Koper in the area categorised as industrial/production and service area.

The establishment is currently employing 94 personnel.

Demography

Direct vicinity of the establishment is uninhabited. The nearest residential building is at a distance of approximately 200 m.

Land-use in the vicinity of site

In accordance with the long- and mid-term municipal plans of the Municipality of Koper, the area under study is categorised as the area for production activities.

The surroundings of the establishment are characterised by flat land with a mixture of urban and industrial environment. Towards the north and the east the establishment is surrounded by industrial and manufacturing infrastructure, southern boundary is characterised by the Rižana river, on the west smaller agricultural areas are present along with the node of the Ljubljana-Koper motorway.

Special nature protected areas in the vicinity of the site are:

Towards the north-east at a distance of 1 km a hill Sermin (84 m altitude) is found, which is classified as an archaeological monument.

Objects of cultural heritage

Sermin is categorised as the area of planned protection of cultural – archaeological heritage.

Infrastructure

Motorways

Adjacent to the northern boundary of the establishment a regional road Ljubljana – Koper is present (segment Bivje – Pobegi). West at a distance of approximately 500 metres a motorway Ljubljana – Koper is present (highway).

Railways

The railway route Ljubljana – Koper is located approximately 200 m south from the establishment.

5.2 Incident outcome analysis

Incidents in the industrial processes in the establishment can occur due to technical errors or due to human errors during the operation/management and/or maintenance.

Technical errors mainly occur due to mechanical stress and ageing of the equipment.

The following process installations were studied:

- Process of the production of phthalic anhydride acid (APA)
- Process of the production of maleic anhydride (AMA)
- Support systems: reservoir areas with pumping stations, warehouses, cooling system
- Fire-extinguishing system, energy systems, boiler room, chemical preparation of water
- Transport department with road-tankers,

Hazardous materials which are produced or manipulated with in the establishment include:

Products:

- phthalic anhydride (APA)
- maleic anhydride (AMA)

Raw material:

- o-xylene

Support materials:

- catalyst for APA production – salt mixture
- diphyl DT
- extra light heating oil (EL–HO
- diesel fuel
- LPG (liquefied petroleum gas)
- middle weight oil
- cleaning concentrate
- potassium hydroxide 5%
- hydrochloric acid (HCl) 31%
- Aquasan algaecide
- Aquasan chlorine granulate 65
- Ammonium water 25%
- salt mixture (includes potassium nitrite)

Potential incidents considered in the analysis were:

a) the release and fire during the warehousing of APA
b) the release and fire during the loading/unloading of APA
c) spill of catalyst for the production of APA during the replacement operations
d) the release of the cleaning concentrate during storage
e) the release of the cleaning concentrate during loading/unloading operations
f) the release and fire during the loading/unloading of o-xylene into a reactor
g) the explosion of air/o-xylene mixture inside the reactor
h) the release and fire during the unloading of o-xylene from the road-tanker into a reservoir
i) the release of o-xylene during storage with subsequent ignition
j) the release of salt mixture (includes potassium nitrite) from a closed system in the reactor

k) the breach of salt melt into the catalyst piping of the reactor
l) the release of Diphyl DT from the system
m) the release of extra light heating oil (EL–HO) due to leaks on pumping equipment and pipelines
n) the release of extra light heating oil (EL–HO) from the reservoir during storage
o) the release of diesel fuel from the reservoir during storage
p) the release of LPG from a steel container or the installation
q) the release of Keminol DOP during loading/unloading operations
r) the release of Hydrochloric acid (HCl) from the reservoir or piping infrastructure
s) the release of Hydrochloric acid (HCl) or Potassium hydroxide from the reservoir during storage
t) spill of the chemicals used in processes: Aquasan algaecide, Aquasan chlorine granulate 65, Ammonium water 25%
u) the release of medium weight oil due to leaks on pumping equipment and pipelines

Of the listed incidents, only incident i) the release of o-xylene during storage with subsequent ignition has the potential for causing impacts outside the premises of the establishment and is the only one of relevance for land-use planning.

The release of o-xylene during storage with subsequent ignition

In the event of release from the reservoir, o-xylene would form a pool within a concrete-made bund in which the reservoir is situated. In the case of ignition and subsequent pool-fire the threat would be posed to the o-xylene reservoir and adjacent R3 (EL-HO – extra light heating oil) and R4 (heavy fuel oil) reservoirs. In such case the reservoir walls should be immediately subjected to cooling operations.

Vapour cloud explosion would have additional impact due to released thermal radiation and overpressure from a blast wave.

The quantity of the released o-xylene depends on the extent of the damage of the reservoir and from the fact how fast the leak would be noticed and stopped. The scenario estimated the collapse of the floating roof of the reservoir and the release of o-xylene through the pipe for roof runoff into the bund. An event of a release of o-xylene into the bund has already occurred at the installation.

The estimated release time is 8 hours, assuming the event occurring at night, at which time the operators would not notice the release or take the appropriate measures until the morning.

In the event of release in absence of the ignition, only the bund of the R1 reservoir would be subjected to the impact. In the case of ignition the impact area would cover the premises of Kemiplas and possibly the areas outside the boundary of the establishment.

In the latter case the bund would contain, beside the released o-xylene, also the fire extinguishing water (foam) used during the fire-fighting operation. The scenario also presumes the runoff of o-xylene and fire extinguishing water into adjacent Rižana river water-body.

5.3 Threat analysis

The basis for the analysis is a threat interaction matrix which combines the effects of overpressure, thermal radiation and toxic release into the air and water with the potential targets – receivers of the threat (Table 21).

Table 21: Threat interaction matrix for the release and ignition of o-xylene from the storage vessel

Physical effects / **Targets**	**Overpressure**	**Thermal radiation**	**Toxic release into the air**	**Toxic release into the water**
Biosphere	●	●	●	●
Natural resources	●	●	●	●
Human environment	●	●	●	●

5.3.1 Threat analysis for overpressure

The radii for the size of the anticipated impact area for overpressure due to an explosion are summarised in Table 22 and presented in Figure 13.

Table 22: Threat intensity level for overpressure – the ignition of o-xylene fumes in the R1 and R2 reservoir area

Threat intensity level	Reference values for overpressure	Distance
5 – high	> 20,7 kPa	9 m
4 – medium to high	13,8 kPa -20,7 kPa	12 m
3 – medium	6,9 kPa – 13,8 kPa	20 m
2 – low to medium	2,1 kPa – 6,9 kPa	50 m
1 – low	< 2,1 kPa	>50 m

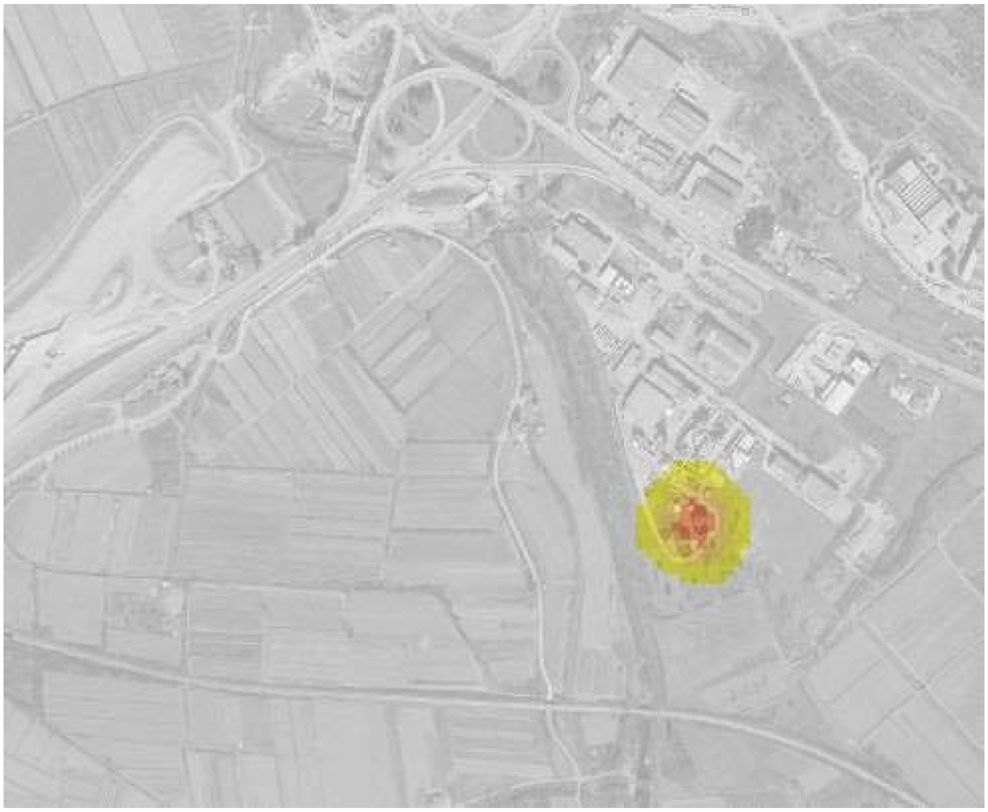

Figure 13: Threat index map for overpressure – the ignition of o-xylene fumes at the R1 and R2 reservoir area

5.3.2 Threat analysis for thermal radiation

The radii for the anticipated impact area for thermal radiation due to a fire at the R1 o-xylene reservoir are summarised in Table 23 and presented on a threat index map in Figure 14.

Table 23: Threat intensity level for thermal radiation – the ignition of o-xylene fumes in the R1 and R2 reservoir area

Threat intensity level	Reference values for thermal radiation	Distance
5 – high	> 37,5 kW/m^2	n/a
4 – medium to high	25 kW/m^2 – 37,5 kW/ m^2	20m
3 – medium	12,5 kW/m^2 - 25 kW/m^2	36m
2 – low to medium	4,5 kW/m^2 – 12,5 kW/m^2	50m
1 – low	< 4,5 kW/m^2	>50m

Figure 14: Threat index map for thermal radiation – the ignition of o-xylene fumes at the R1 and R2 reservoir area

In the case of fire the impact outside the establishment would be caused mainly by the release or spreading of the smoke and soot. The scope of impact would be a function of distance and weather conditions, primarily wind velocity and direction.

The vaporisation of o-xylene into the air due to release from the R1 reservoir is estimated. The results are presented below (Table 24) and in a threat index map (Figure 15).

Table 24: Threat intensity level for the release of o-xylene fumes from R1 or R2 reservoir into the air

Threat intensity level	**Reference values for o-xylene release into the air**	**Distance**
5 – high	>900 ppm	Within the premises
4 – medium to high	900 ppm	Within the premises
3 – medium	200 ppm	Within the premises
2 – low to medium	150 ppm	Within the premises
1 – low	< 150 ppm	Within the premises

Figure 15: Threat index map for toxic release of o-xylene fumes at the R1 and R2 reservoir area into the air

The expected released concentrations in the air are up to 100 ppm within the establishment and below 10 ppm at a distance of 200 m.

Threat is posed to the personnel at Kemiplas and to the personnel of the intervention teams. The scenario is irrelevant from the land-use planning aspect.

5.3.4 Threat analysis for toxic release into water

The release of fire extinguishing water, mixed with burning compounds and o-xylene, through the meteor runoff infrastructure into the Rižana river is estimated. Although o-xylene is poorly soluble in water it is estimated that the pollution of the water would be significant. Therefore higher levels of threat are evident in the threat index map (Figure 16).

Figure 16: Threat index map for toxic release into the water - o-xylene mixed fire-extinguishing water

6 RESULTS – CELANESE POLISINTEZA

6.1 Location description

Celanese Polisinteza is located in the suburbs of the town of Koper in the area designated as an industrial/production and service area.

Land-use in the vicinity of the site

In accordance with the long- and mid-term municipal plans of the Municipality of Koper, the area under study is categorised as an area for production activities.

The surroundings of the establishment are characterised by flat land with a mixture of urban and industrial environment. Towards the north and the east the establishment is surrounded by industrial and manufacturing infrastructure, the southern boundary is characterised by the Rižana river, and, on the west, smaller agricultural areas are present along with the node of the Ljubljana-Koper motorway.

Demography

The direct vicinity of the establishment is uninhabited. The nearest residential building lies at a distance of approximately 200 m.

Special nature protected areas in the vicinity of the site are:

Towards the north-east at a distance of 1 km is a hill, Sermin (84 m altitude), which is classified as an archaeological monument.

Objects of cultural heritage

Sermin is categorised as the area of planned protection of cultural –archaeological heritage.

Infrastructure

Motorways

Adjacent to the northern boundary of the establishment a regional road Ljubljana – Koper is present (segment Bivje – Pobegi). West at a distance of approximately 500 metres a motorway Ljubljana – Koper is present (highway).

Railways

The railway route Ljubljana – Koper is located approximately 200 m south from the establishment.

6.2 Incident outcome analysis

The main activity of the Celanese Polisinteza establishment is the production of polyvinyl acetate and polyacrylate dispersions. Annual production capacity is 6000 t; the production takes place 220-240 days a year (seasonal production). The work is organised in three shifts.

Delivery of vinyl acetate is organised three times in a week in quantities of 30-50 t and daily in a quantity of 200 t by road-tankers. The delivery of other substances is organised in railway containers.

The production runs in two reactors with 10 t capacity each (one contains a reflex condenser, the other just a condenser)

The analysis considers the following incidents:

- Spill of the materials (vinyl acetate, butyl-acrylate, methyl-methacrylate) during loading/unloading operations and storage
- Fire and explosions during the manipulation of the hazardous materials
- Fire and explosions in the production or during adding of substances or uncontrolled polymerisation

Based on the capacities of the production and the quantities of the substances present in storage or used in the production, the calculated impact area remains within the boundaries of the establishment.

6.3 Threat analysis

The basis for the analysis is a threat interaction matrix which combines the effects of overpressure, thermal radiation and toxic release into air and water with the potential targets – receivers of the threat (Table 25).

Table 25: Threat interaction matrix for Celanese Polisinteza

Physical effects / Targets	Overpressure	Thermal radiation	Toxic release into the air	Toxic release into the water
Biosphere	●	●	●	●
Natural resources	●	●	●	●
Human environment	●	●	●	●

6.3.1 Threat analysis for overpressure

The expected effect of overpressure is associated with an explosion during the manipulation of substances and during the process of polymerisation. The impact areas of both incidents remain within the establishment and are therefore irrelevant from the land-use planning aspect.

6.3.2 Threat analysis for thermal radiation

The expected effect of thermal radiation is associated with an occurrence of fire during the manipulation of substances and during the process of polymerisation. The impact areas of both incidents remain within the establishment and are therefore irrelevant from the land-use planning aspect.

6.3.3 Threat analysis for toxic release into air

The results of threat analysis for the toxic release of vinyl acetate and butyl-acrylate into the air are summarised in Table 26 and shown in Figure 17.

Table 26: Threat intensity level for the release of vinylacetate and buthylacrilate into the air

Threat intensity level	**Reference values for the release of vinyl acetate into the air**	**Reference values for the release of butyl-acrylate into the air**	**Distance**
5 – high	>500 ppm	>250 ppm	< 100 m
4 – medium to high	500 ppm	250 ppm	100 m
3 – medium	75 ppm	25 ppm	160 m
2 – low to medium	5 ppm	3,5 ppm	200 m
1 – low	< 5 ppm	<3,5 ppm	> 200 m

Figure 17: Threat index map for the release of vinyl acetate and butyl-acrylate into the air

6.3.4 Threat analysis for toxic release into water

In the event of fire it is assumed that fire extinguishing water mixed with burning compounds and o-xylene will pass through the meteor runoff infrastructure into the Rižana river. Therefore higher levels of threat are evident in threat index map (Figure 16). The possible safety measure is to close the outflow of runoff reservoir and store the contaminated water for subsequent treatment.

7 POSSIBLE CHANGES TO THE MUNICIPAL PLAN

7.1 Istrabenz Plini – Dolinska location

The company plans the abandonment of the activity at this location. In this case the impact area for the incidents is eliminated, therefore the threat due to Istrabenz installation ceases to exist.

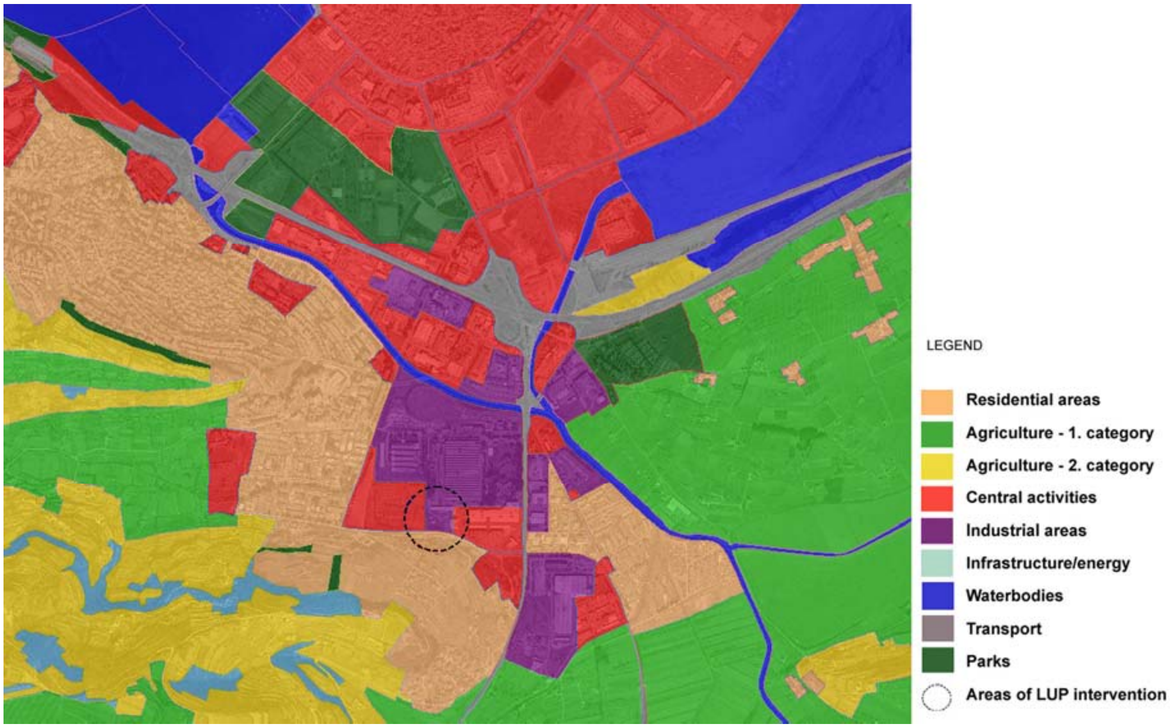

Figure 18: The area of LUP measures to be applied for decrease of threat in the vicinity of Istrabenz Plini, Dolinska location

7.2 Port of Koper

In accordance with the results of the threat analysis, the measure taken within spatial planning for reduction of the threat posed to the ancient town centre is elimination of the ammonia release scenario by traffic reorganisation in the vicinity of the refrigeration unit, relocation of the ammonia-based refrigeration warehouse elsewhere within the Port’s premises or replacement of the refrigeration technology with a less hazardous one. In the latter case the ammonia is to be replaced by the use of freons. The impact area is consequently reduced to within a 100 m radius of even eliminated.

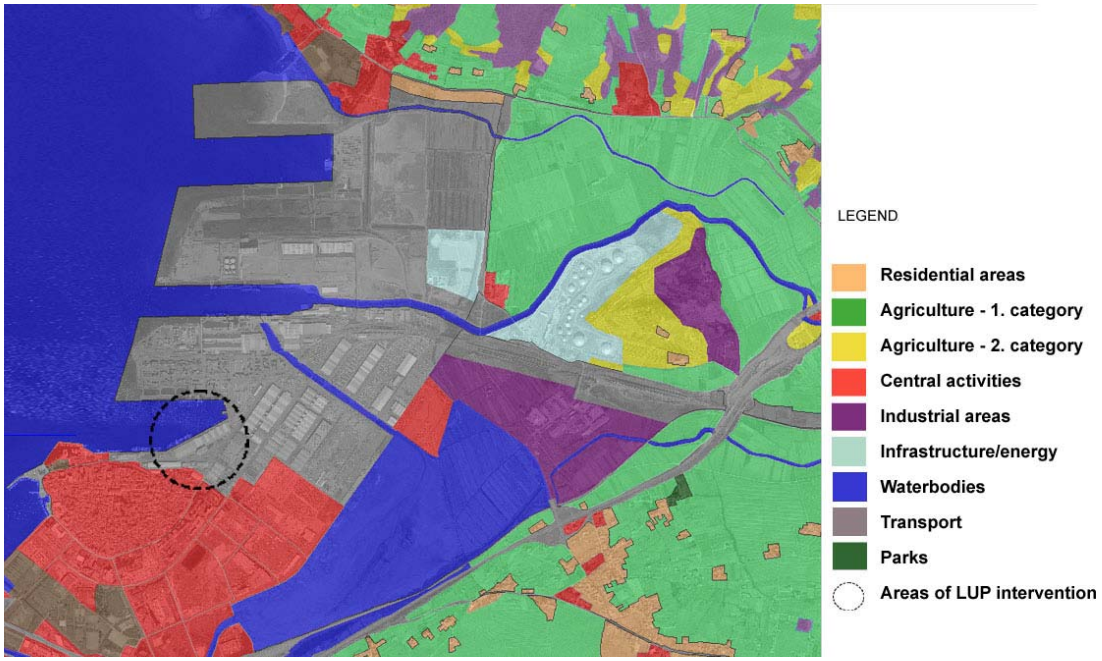

Figure 19: The area of LUP measures to be applied for decrease of threat from ammonia release scenario at the Port of Koper

In the case of relocation of the refrigeration facility within the Port's premises, threat analysis can also be used for micro-location planning, as shown in Figure 20.

Figure 20: Optional relocation of the refrigeration facility within the Port of Koper

7.3 Instalacija: storage and handling of petroleum products

The installation does not present a conflict in terms of land-use planning. The problem, however, remains in the potential for pollution of the Rižana river and the sea in the case of release.

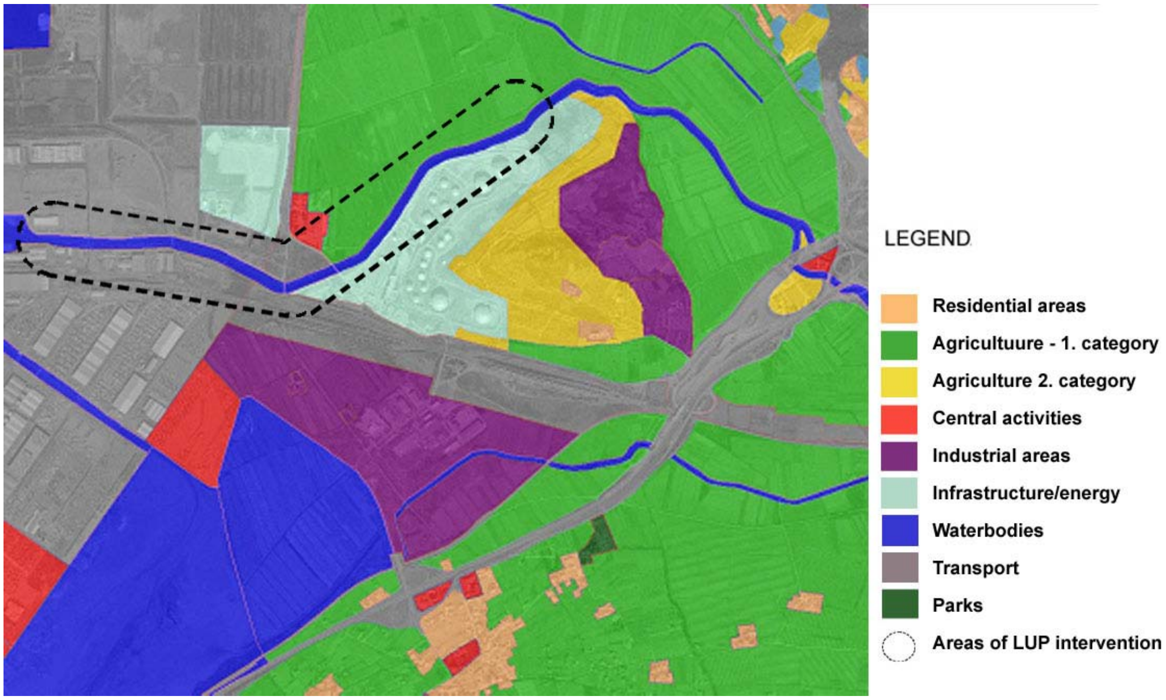

Figure 21: The area of LUP measures to be applied for decrease of threat in the vicinity of Instalacija, storage and handling of petroleum products

7.4 Kemiplas

Measures for the collection of the entire quantity of fire-extinguishing water.

7.5 Celanese Polisinteza

Measures for the collection of the entire quantity of fire-extinguishing water.

Note:
Incidents in Kemiplas and Celanese Polisinteza pose great threats for the owner and management, while explosions of the reactors would probably lead to abandonment of the production in these establishments. This stems from the fact, that the managers probably will not be willing to invest in new process equipment – the current process equipment is severely aged and obsolete.

8 REFERENCES

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Luka Koper. 2006. Safety report.

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European Commission. 1992. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora

APPENDIX III

Preliminary threat vulnerability analysis for the territory of Municipality of Koper

1 INTRODUCTION

The analysis has been conducted based on the methodology described in Chapter 3. The values use in the analysis are quantitative/qualitative in origin and are obtained from past experience, testing results, modelling, etc. (please see Appendix I and Kobler A et al., 2007), as well as on the experience from risk assessment for hazardous industrial establishments and on the revision of threat assessment for the municipality of Koper (Kontić B. and D., 2006). The data used was the GIS database of the Municipality of Koper.

The aim of this analysis is to determine the areas of greater susceptibility to harm by the outcome of an incident. The analysis is conducted independently for each incident outcome (overpressure, thermal radiation, toxic release) for each group of targets (environment – biosphere, natural resources, human environment). The combinations of threat vulnerability maps (all targets) are presented with purpose to identify the areas with the lowest levels of threat in order to guide future siting of new hazardous industrial establishments.

Threat vulnerability categories are based on the following classification:

5	High – destruction/fatality
4	High to medium – permanent, irreversible effect (damage/injuries)
3	Medium – temporary, reversible effect (damage/injuries)
2	Low to medium – negligible effect (damage/injuries)
1	Low – no effect

2 THREAT VULNERABILITY ANALYSIS FOR OVERPRESSURE

Overpressure is a consequence of the blast wave from an explosion.

2.1 The impact of overpressure on the environment (biosphere)

The expected impact of overpressure on the environment is demolition/loss of habitats and direct impact of blast effect on the fauna (modelling parameters and assigned values are presented in Table 1). On the threat vulnerability map (Figure 1), the areas of higher vulnerability are forest and water habitats and natural protected areas (Škocjanski zatok).

Table 1: Modelling parameters for the impact of overpressure on the environment (biosphere)

Parameter	**Category**	**Value**
Forest - buffer		
	0-100 m	4
	100-200 m	3
	200-300 m	2
	> 300 m	1
Protection forest		
	Yes	5
	No	1
Water - buffer		
	0-100 m	4
	100-200 m	3
	200-500 m	2
	> 500 m	1
Natura 2000 areas - buffer		
	0-300 m	5
	300-500 m	3
	> 500 m	1
Special protected areas		
	Yes	5
	No	1

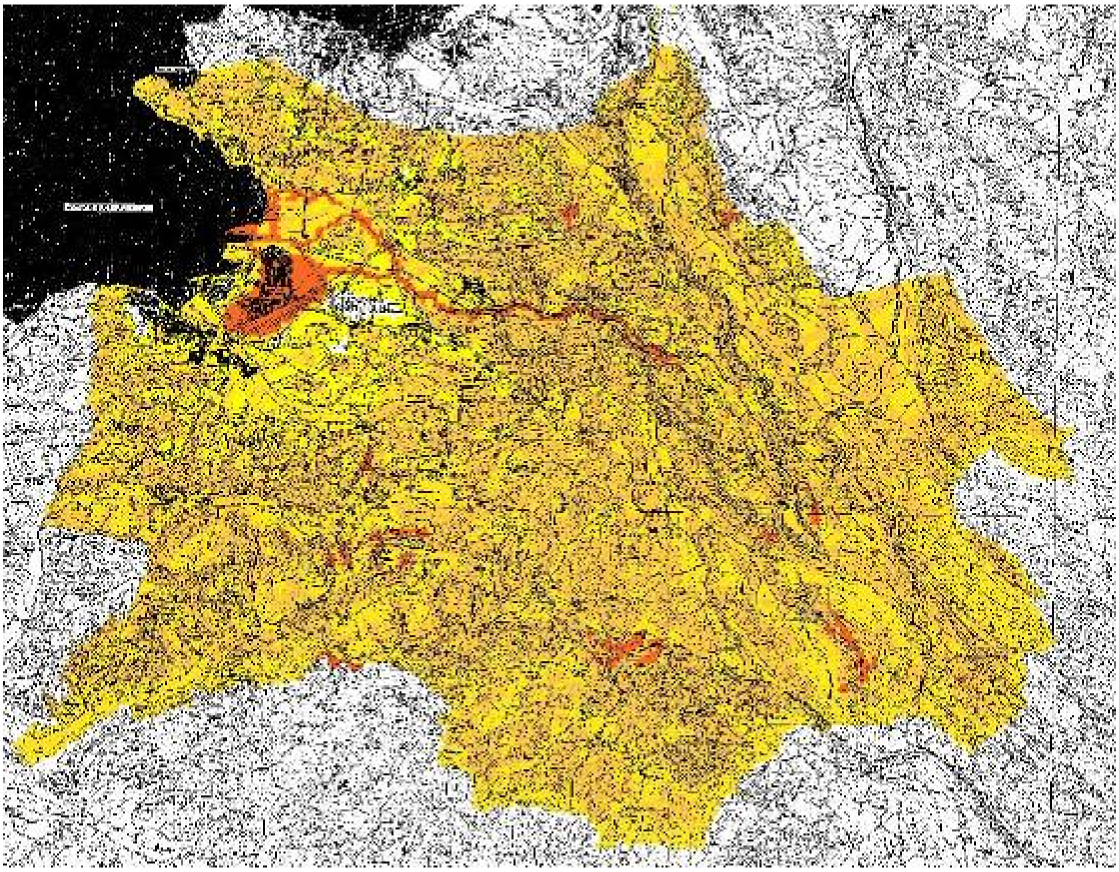

Figure 1: Environmental threat vulnerability map for the environment (biosphere) for overpressure

2.2 The impact of overpressure on natural resources

High vulnerability of natural resources is expected given the reduced potential for settlement development due to possible restrictions in response to expected consequences of overpressure (Figure 2). Smaller impacts in this context are associated with loss of wood production (damage to trees) and loss of recreational areas and tourist attractions as an important economic activity in the area.

Modelling parameters and assigned values are presented in Table 2.

Table 2: Modelling parameters for the impact of overpressure on the natural resources

Parameter	**Category**	**Value**
Forest - buffer		
	0-100 m	4
	100-200 m	3
	200-300 m	2
	> 300 m	1
Agriculture		
	Yes	3
	No	1
Water (recreational use) - buffer		
	0-100 m	3
	100-200 m	2
	> 200	1
Settlements (future development) - buffer		
	0-300 m	5
	300-500 m	4
	500-1000 m	2
	> 1000 m	1
Coastal area (tourism) - buffer		
	0-1000 m	4
	> 1000 m	1

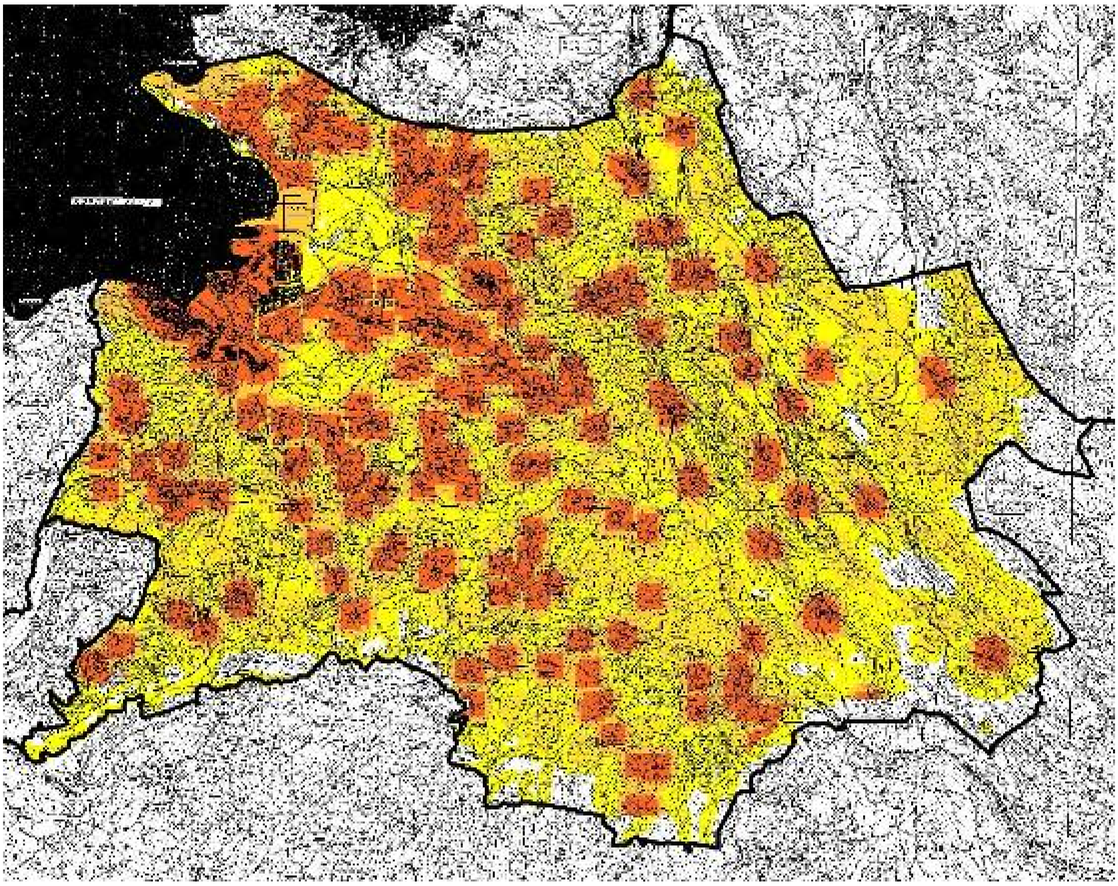

Figure 2: Environmental threat vulnerability map for natural resources for overpressure

2.3 The impact of overpressure on the human environment

In the case of an incident with the expected consequences of overpressure, higher impact is expected on built environmental components (buildings, infrastructure) and a direct impact on humans (fatalities, injuries associated with building demolition). Modelling parameters considered in the analysis and assigned values are presented in Table 3. Figure 3 shows areas of higher population density as high threat vulnerability areas.

Table 3: Modelling parameters for the impact of overpressure on the human environment

Parameter	**Category**	**Value**
Population density		
	0-1 pers./ha	1
	1-10 pers./ha	3
	10-30 pers./ha	4
	30-50 pers./ha	5
	50-100 pers./ha	5
	100-200 pers./ha	5
	200-300 pers./ha	5
	300-500 pers./ha	5
Commercial areas		
	Yes	5
	No	1
Industrial areas		
	Yes	4
	No	1
Coastal area (tourism) - buffer		
	0-1000 m	3
	> 1000 m	1
Roads - buffer		
	0-100 m	4
	100-200 m	2
	> 200 m	1
Railways - buffer		
	0-100 m	3
	100-200 m	2
	> 200 m	1

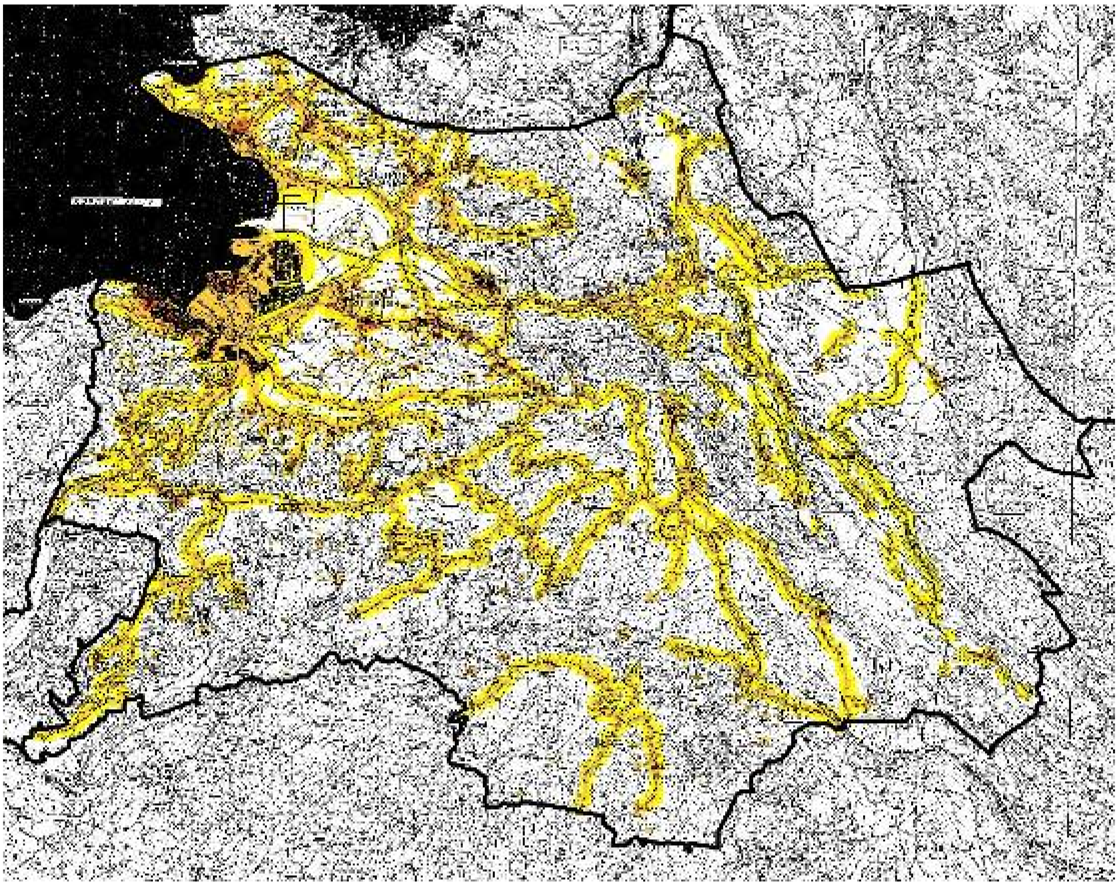

Figure 3: Environmental threat vulnerability map of human environment for overpressure

The result of combined threat vulnerability analysis for overpressure shows higher levels of threat on areas of infrastructure and higher population density – assuming that the highest level of damage is present on resident and commercial buildings (Figure 4).

Models are merged into a single map as an informative representation of less threatened areas, overlooking the ethical issues arising from the combinations.

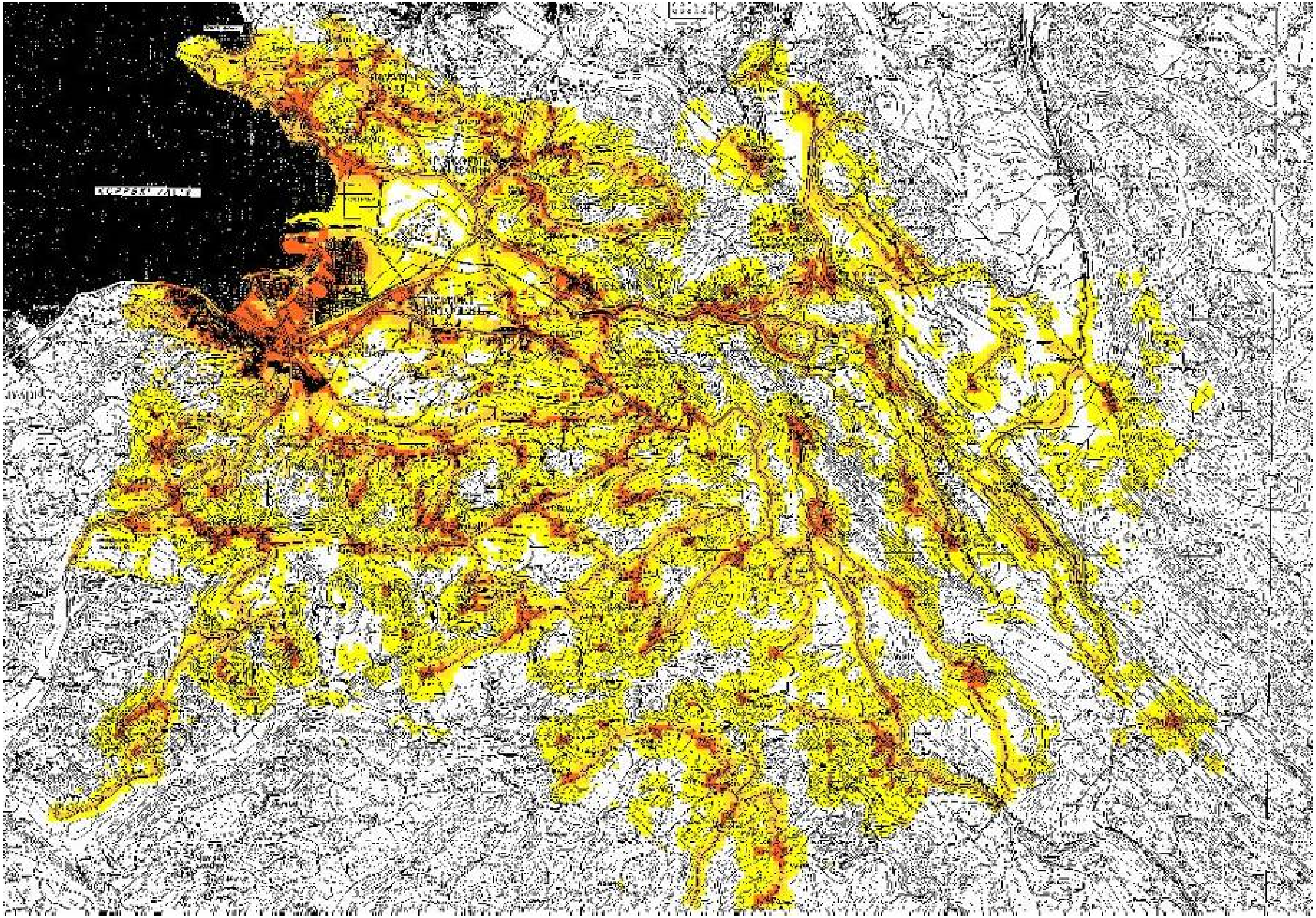

Figure 4: Combined environmental threat vulnerability map for overpressure (all targets)

3 THREAT VULNERABILITY ANALYSIS FOR THERMAL RADIATION

Thermal radiation is a consequence of incidents such as fires and explosions.

3.1 The impact of thermal radiation on the environment (biosphere)

The highest impacts are expected on forest and semi-aquatic habitats due to ignition, with a direct impact on fauna.

Modelling parameters in the analysis and assigned values are presented in Table 4.

Table 4: Modelling parameters for the impact of thermal radiation on the environment (biosphere)

Parameter	**Category**	**Value**
Forest - buffer		
	0-100 m	5
	100-200 m	4
	200-300 m	2
	> 300 m	1
Protection forest		
	Yes	5
	No	1
Water - buffer		
	0-100 m	5
	100-200 m	4
	200-500 m	3
	500-1000 m	2
	> 1000 m	1
Natura 2000 areas - buffer		
	0-300 m	5
	300-500 m	4
	> 500 m	1
Special protected areas		
	Yes	5
	No	1

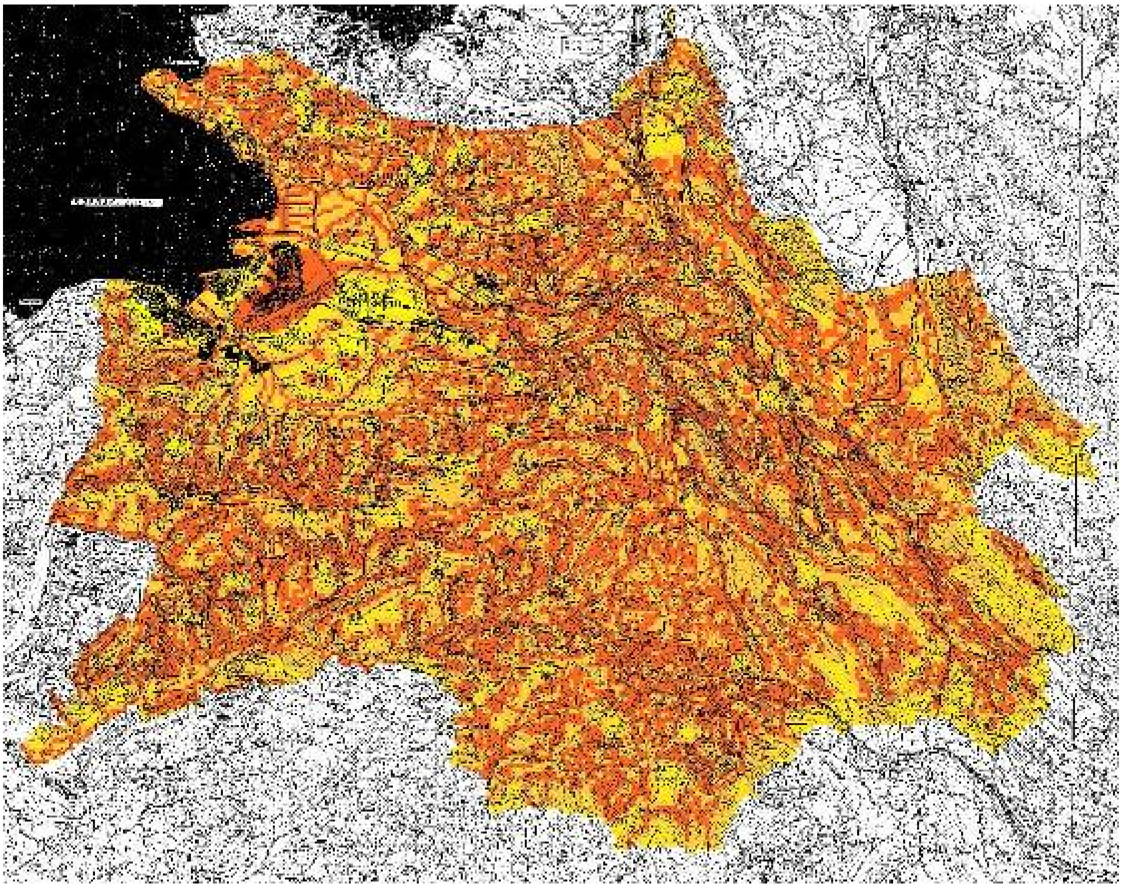

Figure 5: Environmental threat vulnerability map for the environment (biosphere) for thermal radiation

3.2 The impact of thermal radiation on natural resources

Higher threat vulnerability areas are the result of reduced potential for settlement development (Figure 6). Smaller impacts in this context are associated with loss of wood production (damage to trees) and loss of recreational areas and tourist attractiveness.

Modelling parameters in the analysis and assigned values are presented in Table 5.

Table 5: Modelling parameters for the impact of thermal radiation on the natural resources

Parameter	Category	Value
Forest - buffer		
	0-200 m	5
	200-500 m	3
	> 500 m	1
Agriculture		
	Yes	3
	No	1
Water (recreational use) - buffer		
	0-100 m	4
	100-200 m	2
	> 200	1
Settlements (future development) - buffer		
	0-100 m	5
	100-200 m	4
	200-300 m	3
	300-500 m	2
	> 500 m	1
Coastal area (tourism) - buffer		
	0-1000 m	4
	> 1000 m	1

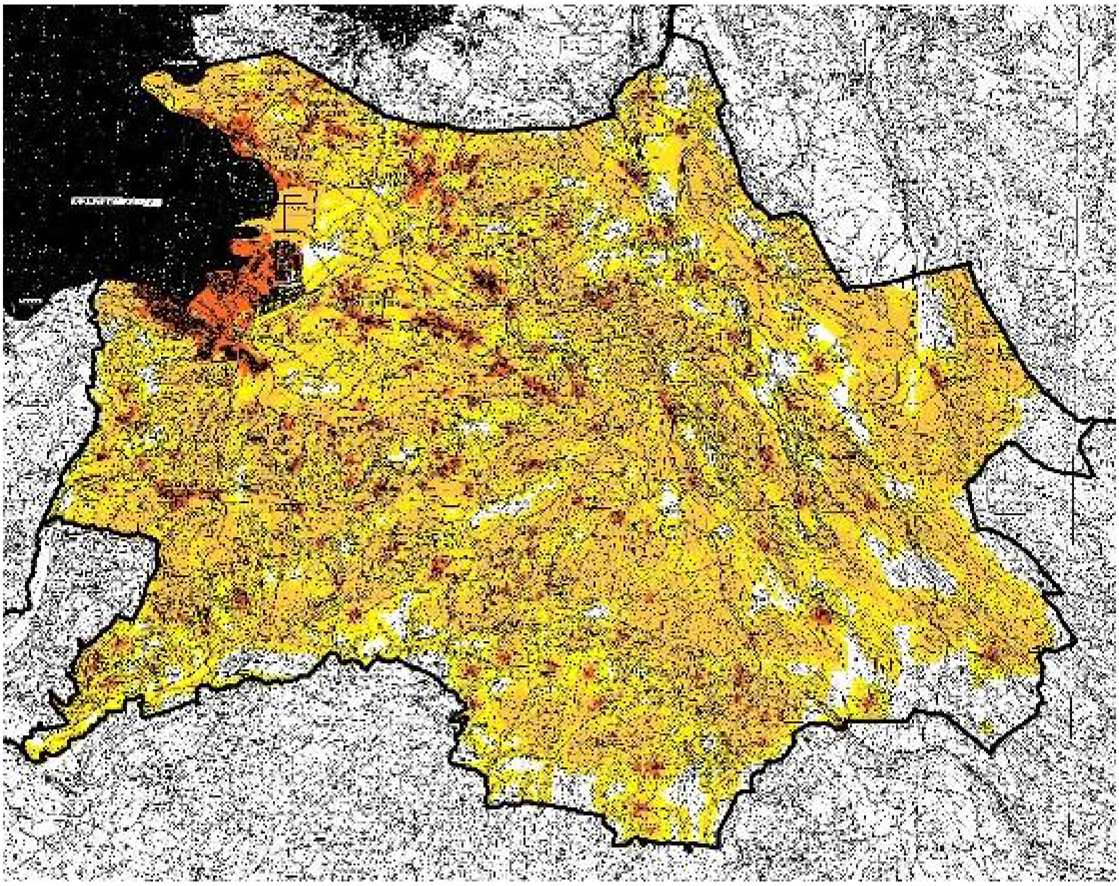

Figure 6: Environmental threat vulnerability map for natural resources for thermal radiation

3.3 The impact of thermal radiation on human environment

Higher consequences of thermal radiation are expected on built environment (buildings, infrastructure) and people (fatalities and injuries). The threat vulnerability map (Figure 7) shows higher values in areas of infrastructure and higher population density.

Modelling parameters in the analysis and assigned values are presented in Table 6.

Table 6: Modelling parameters for the impact of thermal radiation on the human environment

Parameter	**Category**	**Value**
Population density		
	0-1 pers./ha	1
	1-10 pers./ha	3
	10-30 pers./ha	4
	30-50 pers./ha	5
	50-100 pers./ha	5
	100-200 pers./ha	5
	200-300 pers./ha	5
	300-500 pers./ha	5
Commercial areas		
	Yes	4
	No	1
Industrial areas		
	Yes	4
	No	1
Coastal area (tourism) - buffer		
	0-1000 m	3
	> 1000 m	1
Roads - buffer		
	0-100 m	3
	100-200 m	2
	> 200 m	1
Railways - buffer		
	0-100 m	3
	> 100 m	1

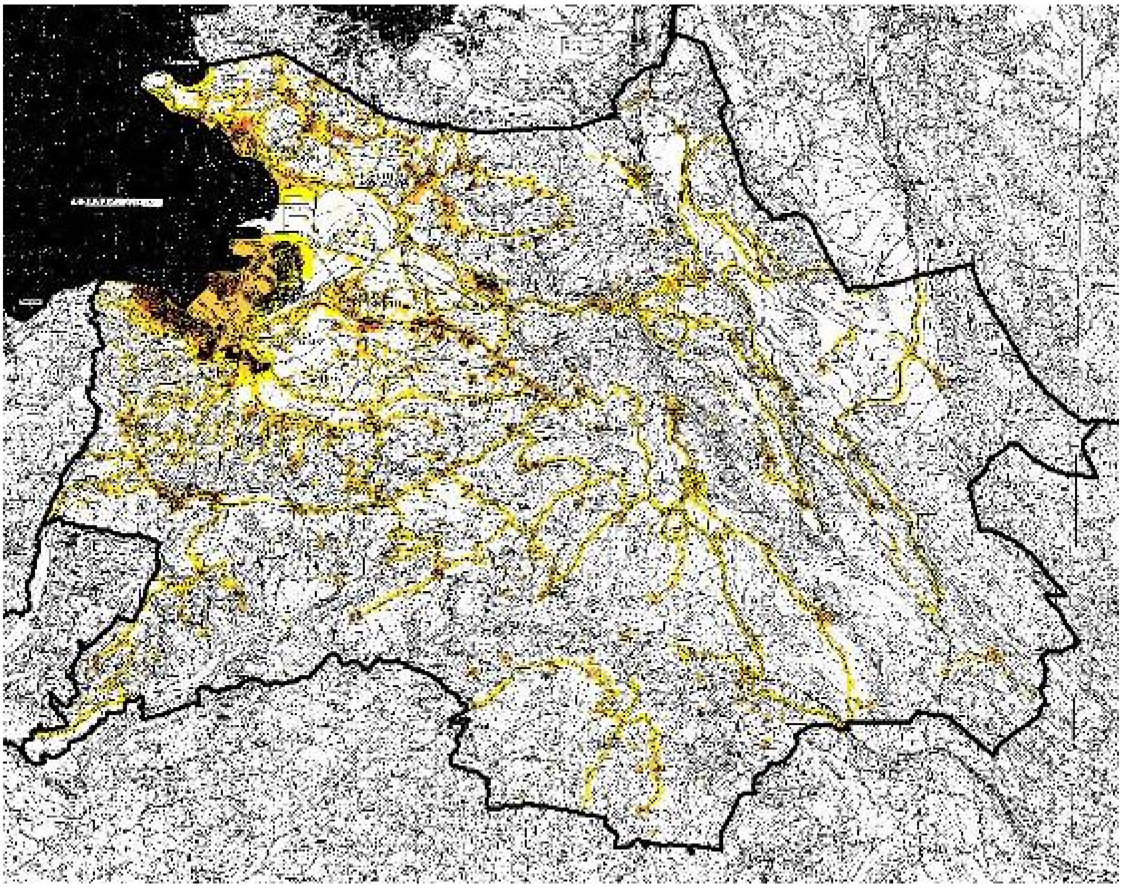

Figure 7: Environmental threat vulnerability map for human environment for thermal radiation

Thermal radiation causes the greatest impact on built infrastructure and environment (forest, natural protected areas). This is expressed as a loss of residences, habitats or reduced potential for primary production (forestry) and other economic branches (tourism).

The result of combined threat vulnerability analysis for overpressure shows higher levels on the areas of infrastructure and areas of higher population density – assuming that the highest level of damage is present on resident and commercial buildings (Figure 8). A lower level of vulnerability due to thermal radiation is observed on a significant part of the Municipality of Koper. These values represent agricultural and forestry areas which could face degradation in the case of ignition.

Models are merged into a single map as an informative representation of less threatened areas, overlooking the ethical issues arising from the combinations.

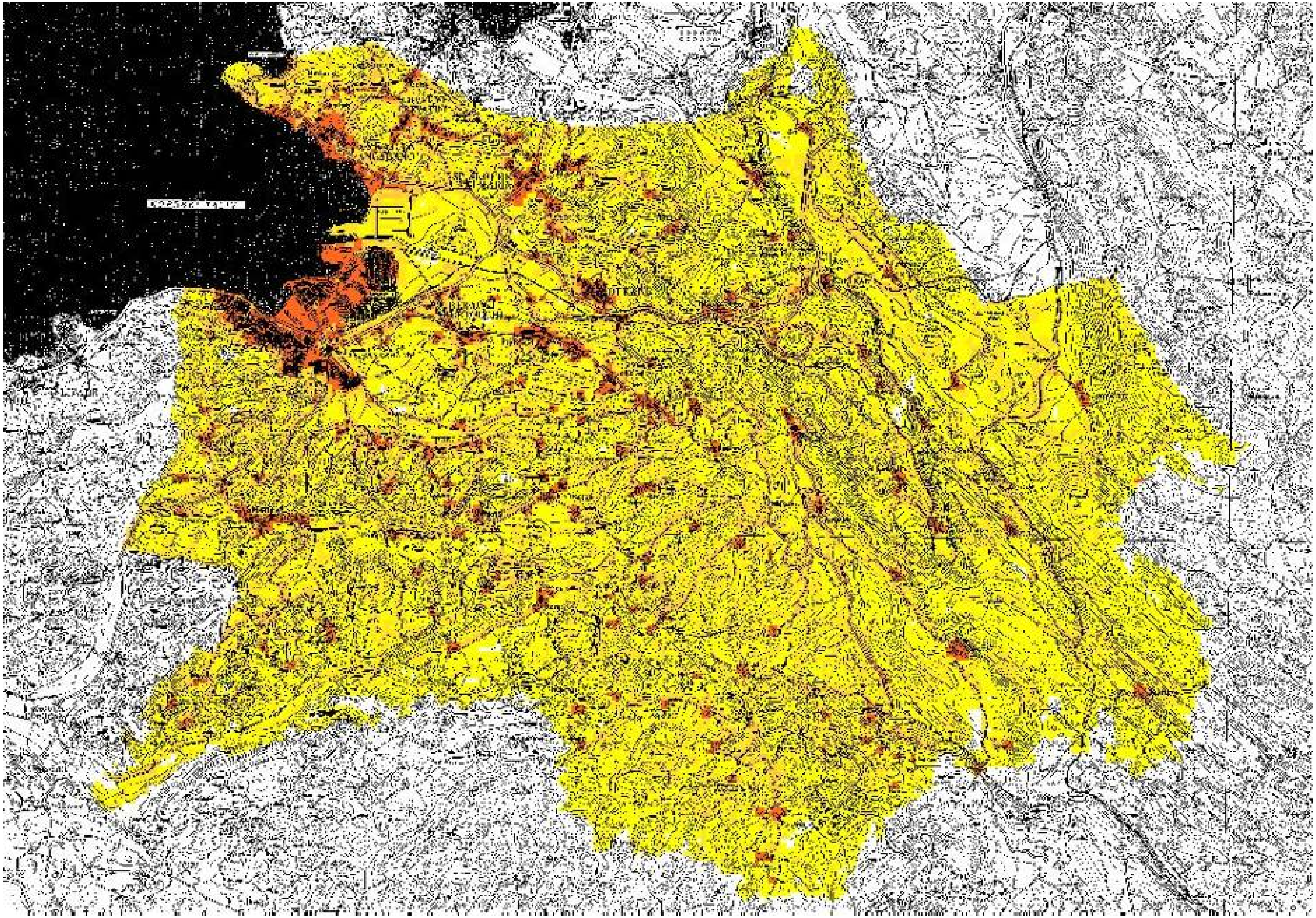

Figure 8: Combined environmental threat vulnerability map for overpressure (all targets)

4 THREAT VULNERABILITY ANALYSIS FOR TOXIC RELEASE INTO AIR

Incidental release into air arises from failure of reactors, reservoirs, pressurised vessels, pipelines, spills and evaporation, etc.

The reference values commonly used for quantifying the release into air are TEEL* values (Temporary Emergency Exposure Limits), and ERPG (Emergency Response Planning Guide) (U.S.DOE, 2007) are in use as general guidelines for emergency planning purposes.

In Table 7 threshold values are listed, representing five levels of risk vulnerability. Presented values are generalised and serve solely as an orientation – for a detailed example of toxic release, the appropriate values for certain substances must be acquired.

Table 7: Threshold levels for toxic release into air

Threat vulnerability level	Threshold values	Threshold values	Description
1	< TEEL 1	< ERPG 1	No effect
2	TEEL 1	ERPG 1	Negligible effect
3	TEEL 2	ERPG 2	Temporary, reversible effects
4	TEEL 3	ERPG 3	Permanent, irreversible effects
5	> TEEL 3	> ERPG 3	Fatality

The values presented above are for effects on humans (derived from laboratory testing). When detailed analysis is performed threshold values should be obtained for all relevant environmental components.

4.1 The impact of toxic release into air on the environment (biosphere)

Degradation of forest habitats and of natural protected areas as well as direct effect on fauna can be expected in the case of toxic release into air. The threat vulnerability map (Figure 9) shows forest areas (higher level of natural preservation) recognised as areas of higher vulnerability.

Modelling parameters in the analysis and assigned values are presented in Table 8.

Table 8: Modelling parameters for the impact of toxic release into air on the environment (biosphere)

Parameter	**Category**	**Value**
Forest - buffer		
	0-100 m	5
	100-200 m	4
	200-300 m	2
	> 300 m	1
Protection forest		
	Yes	5
	No	1
Water - buffer		
	0-100 m	4
	100-200 m	3
	200-500 m	2
	> 500 m	1
Natura 2000 areas - buffer		
	0-300 m	5
	300-500 m	4
	> 500 m	1
Special protected areas		
	Yes	5
	No	1

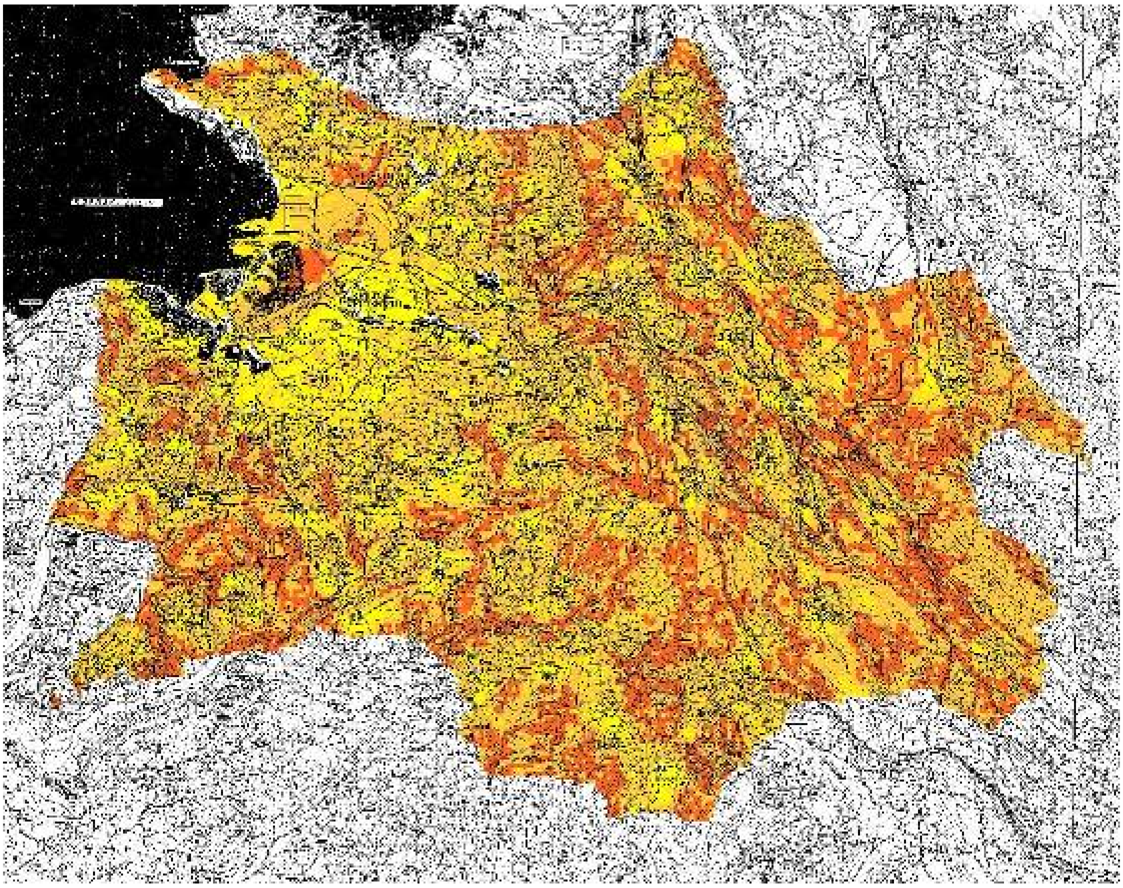

Figure 9: Environmental threat vulnerability map for the environment (biosphere) for toxic release into air

4.2 The impact of toxic release into air on natural resources

The expected impacts are on the reduced potential for agriculture and tourism (tourism in the hinterland). The threat vulnerability map (Figure 10) shows agricultural and aquatic areas as areas of higher vulnerability.

Modelling parameters in the analysis and assigned values are presented in Table 9.

Table 9: Modelling parameters for the impact of toxic release into air on the natural resources

Parameter	**Category**	**Value**
Forest - buffer		
	0-100 m	3
	100-200 m	2
	> 200 m	1
Agriculture		
	1st category	5
	2nd category	3
	No	1
Water - buffer		
	0-100 m	3
	100-200 m	2
	> 200	1
Water protection zone - buffer		
	0-100 m	4
	100-200 m	3
	200-500	2
	> 500	1
Settlements (future development) - buffer		
	0-100 m	3
	100-300 m	2
	> 300 m	1
Coastal area (tourism) - buffer		
	0-1000 m	4
	> 1000 m	1

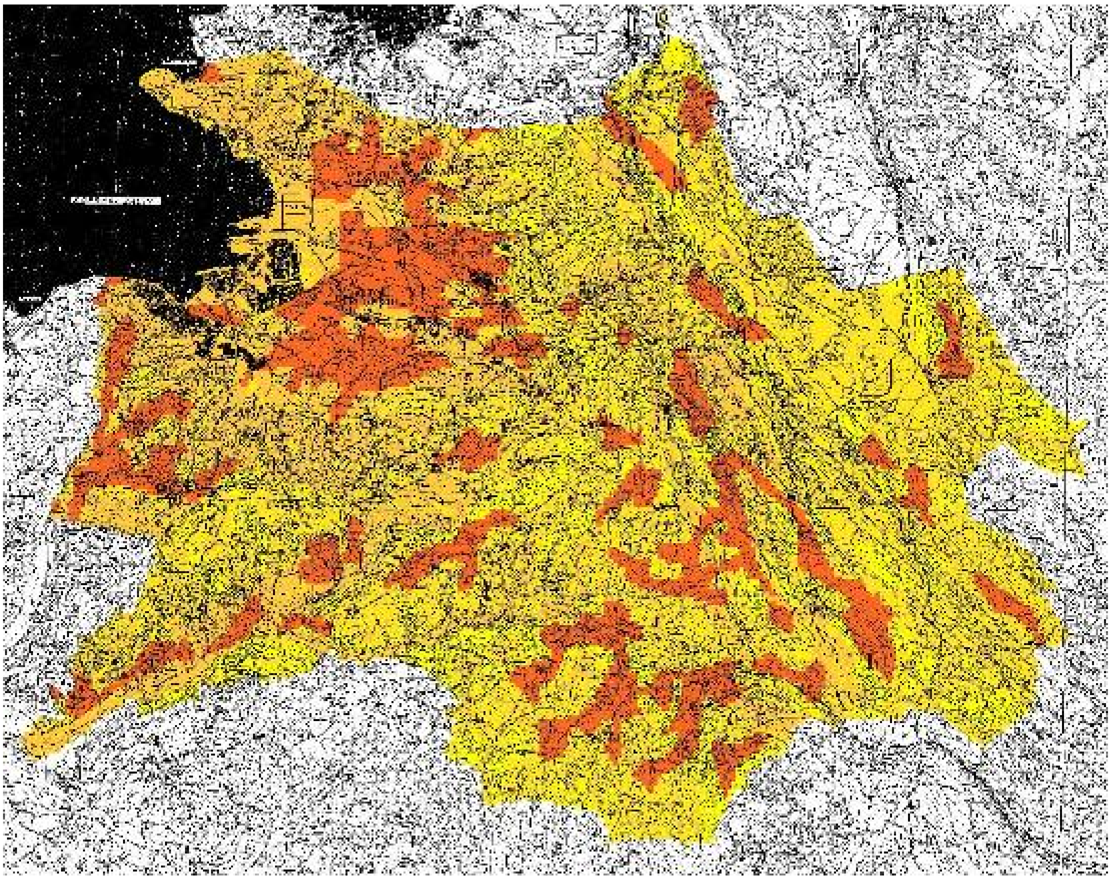

Figure 10: Environmental threat vulnerability map for natural resources for toxic release into air

4.3 The impact of toxic release into air on human environment

The expected impacts include health problems (breathing difficulties, sore eyes, poisoning). The threat vulnerability map (Figure 11) shows higher vulnerability on densely populated areas.

Modelling parameters in the analysis and assigned values are presented in Table 10.

Table 10: Modelling parameters for the impact of toxic release into air on the human environment

Parameter	**Category**	**Value**
Population density		
	0-1 pers./ha	1
	1-10 pers./ha	3
	10-30 pers./ha	4
	30-50 pers./ha	5
	50-100 pers./ha	5
	100-200 pers./ha	5
	200-300 pers./ha	5
	300-500 pers./ha	5
Residential areas - buffer		
	0-100 m	5
	100-200 m	4
	200-300 m	3
	300-500 m	2
	> 500 m	1
Commercial areas		
	Yes	5
	No	1
Industrial areas		
	Yes	5
	No	1
Coastal area (tourism) - buffer		
	0-1000 m	4
	> 1000 m	1

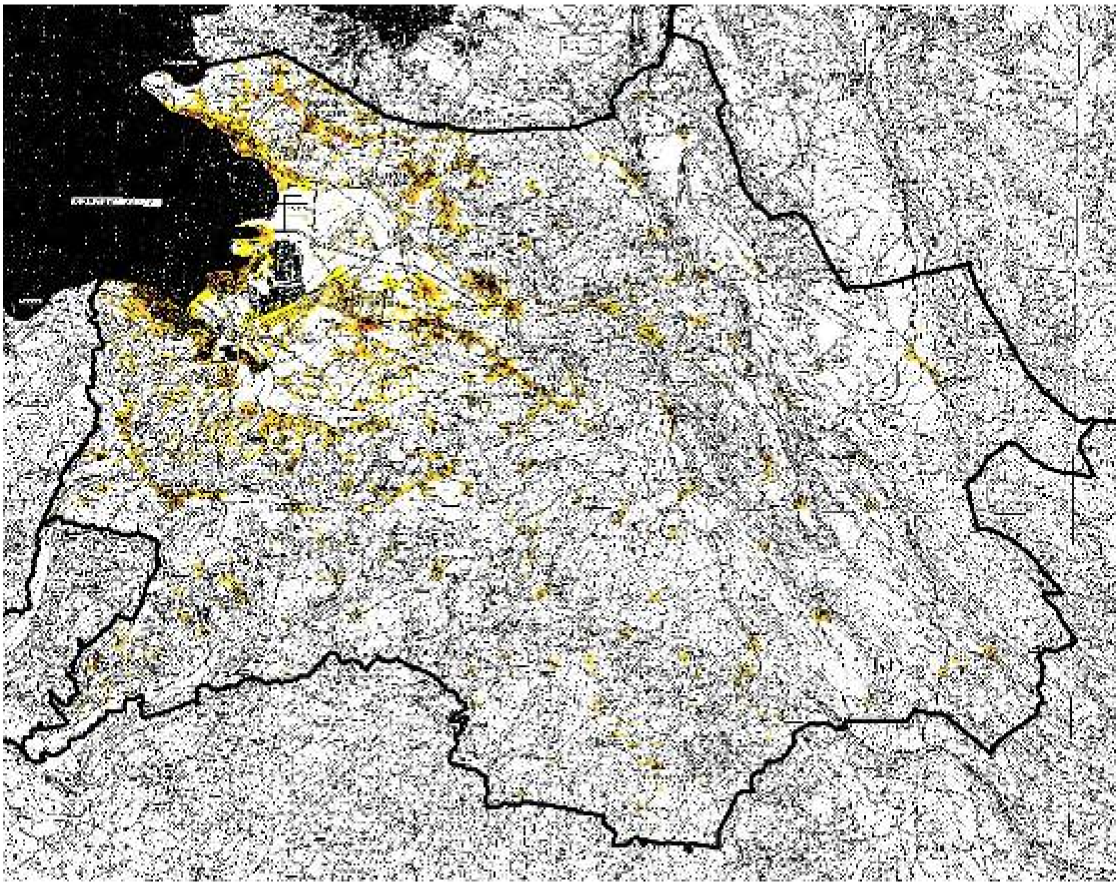

Figure 11: Environmental threat vulnerability map for the human environment for toxic release into air

The results of combined risk vulnerability analysis show relatively low level of vulnerability with the exception of densely populated areas (Figure 12). Relatively higher vulnerability levels are based on the assumption that the consequences of toxic release into air have an effect on the potential for agriculture (contaminated soil).

Models are merged into a single map as an informative representation of less threatened areas, overlooking the ethical issues arising from the combinations.

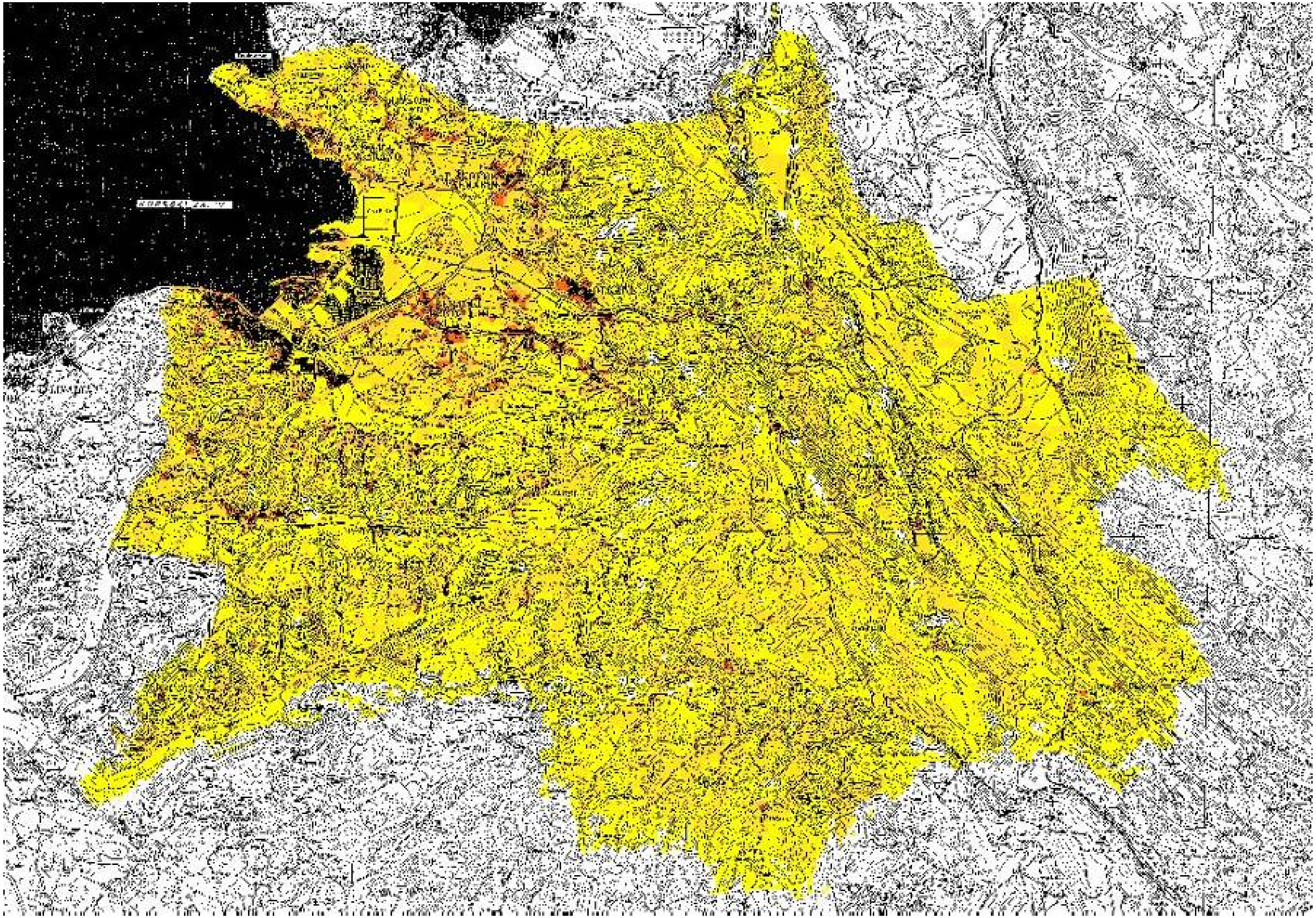

Figure 12: Combined environmental threat vulnerability map for toxic release into air (all targets)

5 THREAT VULNERABILITY ANALYSIS FOR TOXIC RELEASE INTO WATER

The analysis was conducted based on the assumptions regarding the transport of toxic substances through the aquatic environment.

5.1 The impact of toxic release into water on the environment (biosphere)

Degradation/loss of aquatic and associated habitats is expected, with degradation of special natural areas as well as direct impact on »surface« fauna (drinking water). Areas of higher threat vulnerability are aquatic habitats with associated buffer (Figure 13).

Modelling parameters in the analysis and assigned values are presented in Table 11.

Table 11: Modelling parameters for the impact of toxic release into the water on the environment (biosphere)

Parameter	Category	Value
Waterbodies - buffer		
	0-100 m	5
	100-200 m	4
	200-500 m	3
	500-1000 m	2
	> 1000 m	1
Water protection zone - buffer		
	0-300 m	5
	300-500 m	4
	500-700 m	3
	700-1000 m	2
	> 1000 m	1
Water sources protection zone - buffer		
	Yes	5
	No	1
Flood areas		
	Yes	4
	No	1

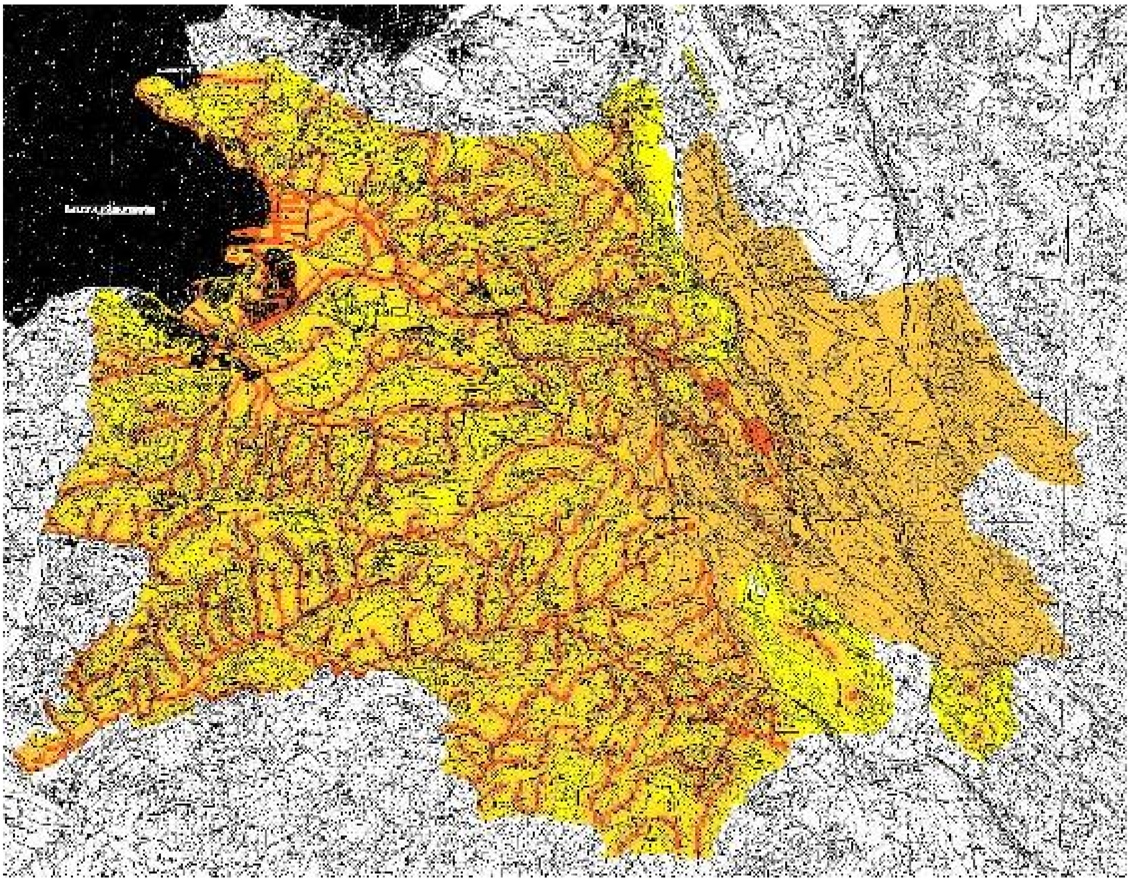

Figure 13: Environmental threat vulnerability map for the environment (biosphere) for toxic release into water

5.2 The impact of toxic release into water on natural resources

The impacts include degradation of water resources and reduced potential for tourism. Threat vulnerability map shows higher values in the areas of water resources (aquifers) as well as on coastal areas – tourism (Figure 14).

Modelling parameters in the analysis and assigned values are presented in Table 12.

Table 12: Modelling parameters for the impact toxic release into the water on the natural resources

Parameter	**Category**	**Value**
Forest - buffer		
	0-100 m	3
	100-200 m	2
	> 200 m	1
Agriculture		
	Yes	4
	No	1
Water (recreational use) - buffer		
	0-100 m	3
	100-200 m	2
	> 200	1
Water sources protection zone - buffer		
	Yes	5
	No	1
Coastal area (tourism) - buffer		
	0-1000 m	4
	> 1000 m	1

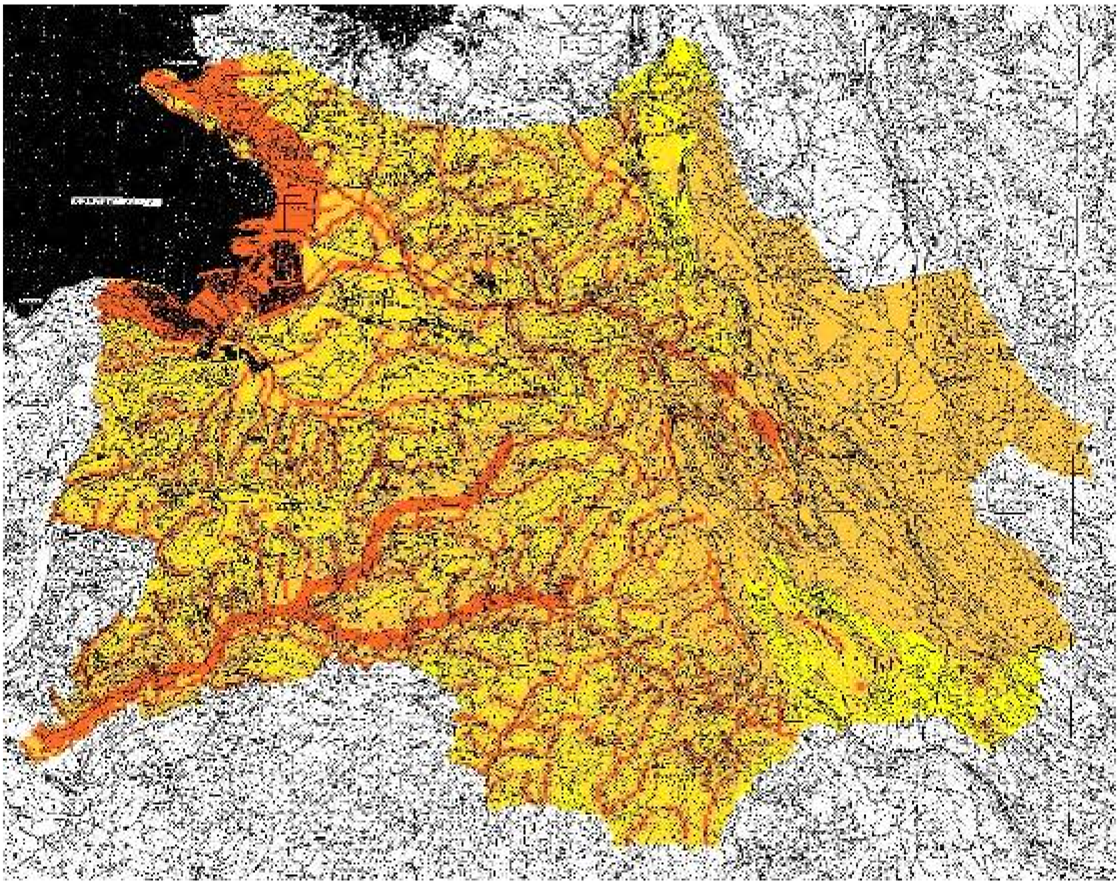

Figure 14: Environmental threat vulnerability map for natural resources for toxic release into water

5.3 The impact of toxic release into water on human environment

Direct impact is expected on health; indirect impacts include consequences and measures associated with assurance of alternative drinking water sources.

Modelling parameters in the analysis and assigned values are presented in Table 13.

Table 13: Modelling parameters for the impact of toxic release into the water on the human environment

Parameter	**Category**	**Value**
Population density (vicinity of waterbodies)		
	0-1 pers./ha	1
	1-10 pers./ha	3
	10-30 pers./ha	4
	30-50 pers./ha	5
	50-100 pers./ha	5
	100-200 pers./ha	5
	200-300 pers./ha	5
	300-500 pers./ha	5
Waterbodies - buffer		
	0-100 m	5
	100-200 m	4
	200-300 m	3
	300-500 m	2
Coastal area (tourism) - buffer		
	0-1000 m	3
	> 1000 m	1
	> 500 m	1

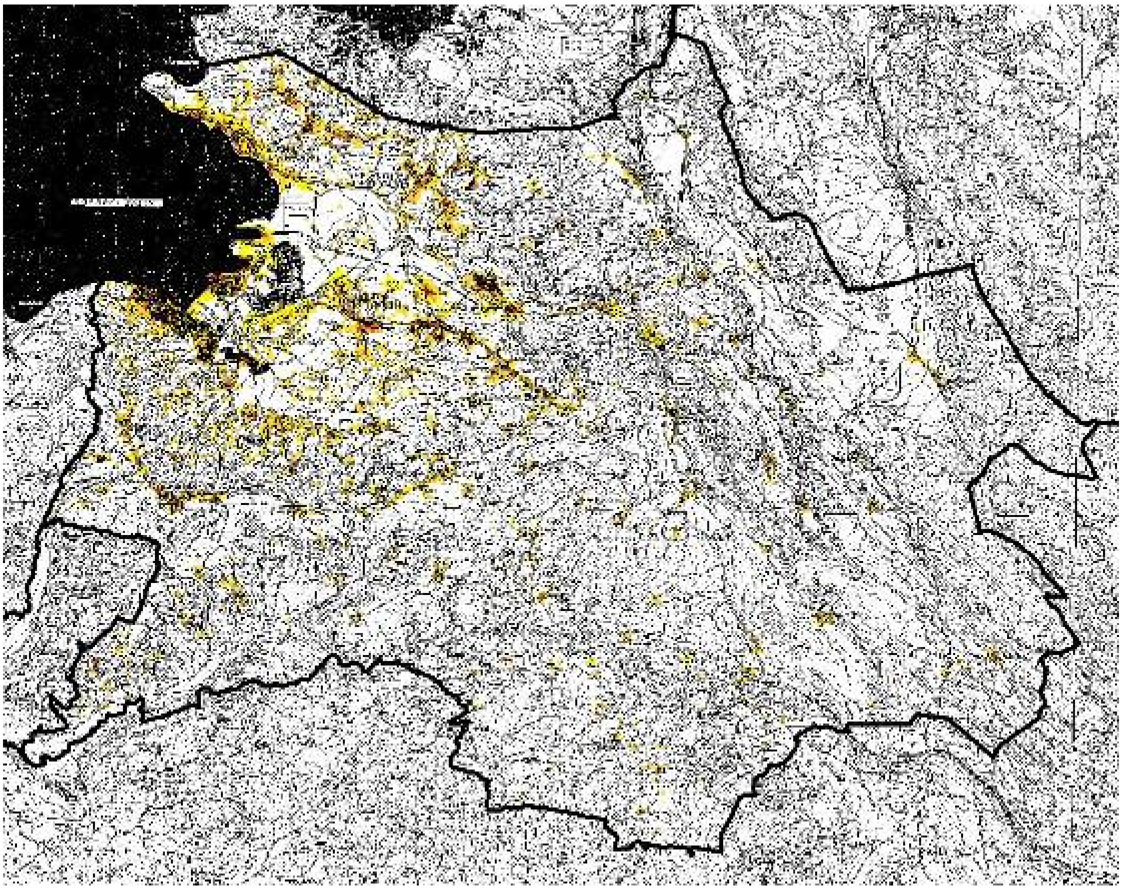

Figure 15: Environmental threat vulnerability map for the human environment for toxic release into water

Results of combined threat vulnerability analysis shows higher levels in the areas of water bodies and their catchments as well as on the areas of water resources (Figure 16).

The higher threat vulnerability level in the coastal area is based on the assumption of reduced potential for coastal tourism as a consequence of toxic release into water.

Models are merged into a single map as an informative representation of less threatened areas, overlooking the ethical issues arising from the combinations.

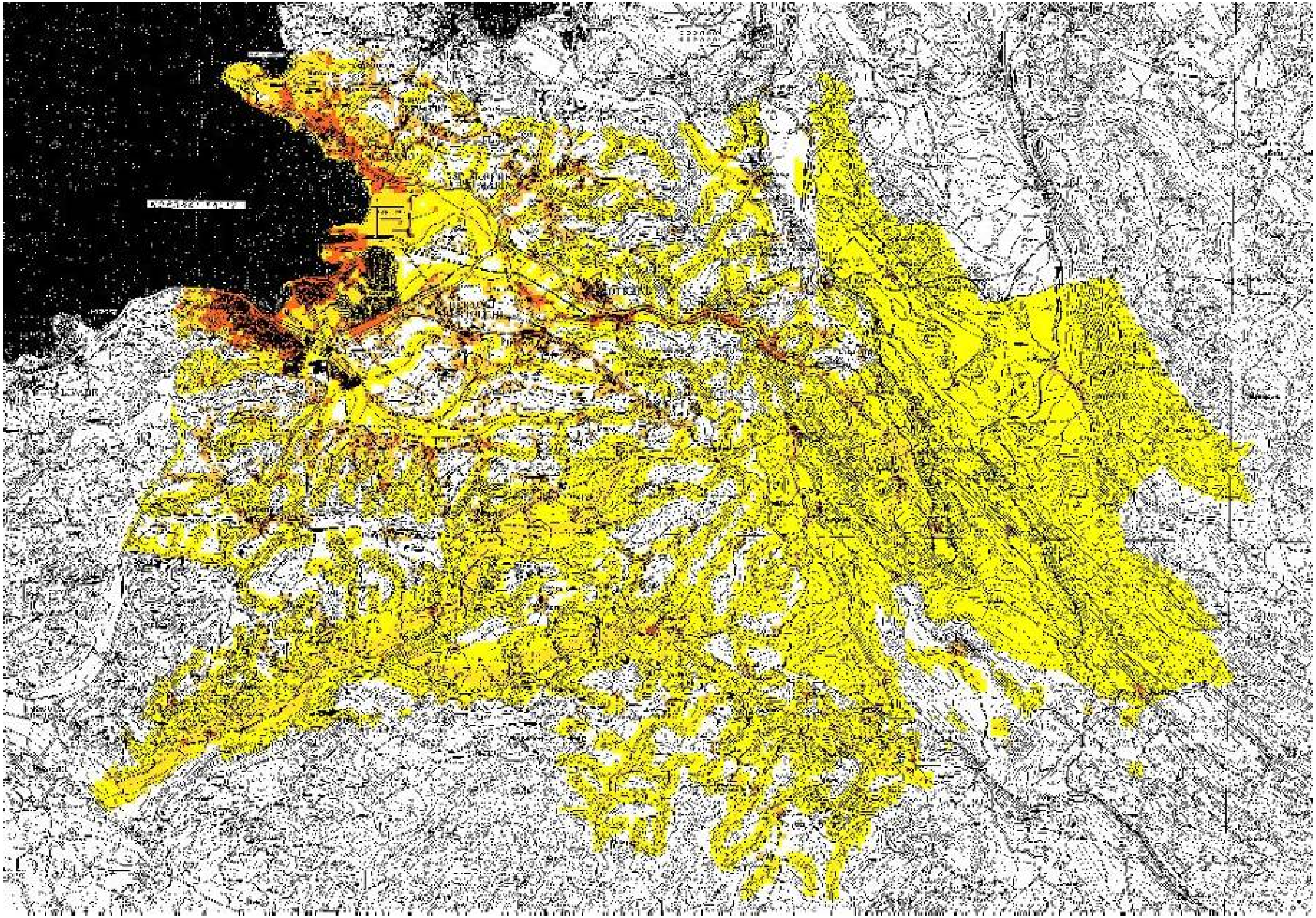

Figure 16: Combined environmental threat vulnerability map for toxic release into air (all targets)

6 REFERENCES

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APPENDIX IV

Threat index categorisation

Threat index categorisation

Threat		Description
index	**level**	
1	Low	Types and quantities of hazardous substances low or on the level of medium sized companies; common activity; appropriate safety management; technical and organisational measures for incident reduction and protection are sufficient in terms of ALARA[1] and BAT[2]; impact area for consequences to health is within establishment's premises, in the vicinity the consequences relate to minor material damage (breaking glass windows, facade damage due to falling ash) and psychological effect (fear) due to explosions and fires. Concentrations in environmental components (air, water, soil) are low/negligible; vulnerability of environmental components might be high, but is not reached due to low severity of possible incidents
2	Low to medium	Types and quantities of hazardous substances low or on the level of middle sized companies; intensive activity; safety management partially exists; technical and organisational measures for incident reduction and protection must be confirmed in terms of ALARA and BAT, even though they are formally sufficient; general organisation of the site is acceptable; impact area for consequences to health is within establishment's premises, in the vicinity the consequences relate to minor material damage (breaking glass windows, facade damage due to falling ash) and psychological effect (fear) due to explosions and fires, low level of localised pollution is possible (e.g. water, soil) due to hazardous leaks, uncontrolled runoff of fire-water, the concentrations of toxic substances are not threatening at normal exposure; vulnerability of environmental components might be high, but is not reached by low severity of possible incidents.
3	Medium	Types and quantities of hazardous substances intermediate or on the level of middle sized companies; intensive activity; concern of staff for safety is not systematic, safety management partially exists; technical and organisational measures for incident reduction and protection formally exist, their state and maintenance is poor – need for improvements in terms of ALARA and BAT; general organisation of the site is barely acceptable; impact area for consequences to health is within establishment's premises, in the vicinity the consequence relate to minor material damage (breaking glass windows, facade, wall damage) and psychological effect (protests due to material damage) due to explosions and fires, pollution is possible (e.g. water, soil) due to hazardous leaks, uncontrolled runoff of fire-water, the concentrations of toxic substances are threatening to health; vulnerability of environmental components might be high – reached by intermediate severity of possible incidents
4	Medium to high	Types and quantities of hazardous substances intermediate/high or on the level of middle/large sized companies; intensive activity; concern of staff for safety is not systematic, safety culture is not part of company's policy, safety management does not exist; technical and organisational measures for incident reduction and protection formally exist, their state and maintenance is poor – improvements in terms of ALARA and BAT; general organisation of the site is not acceptable; impact area for consequences to health exceeds establishment's premises, need for protective measures (evacuation), possible protests and demands for relocation of establishment; vulnerability of environmental components might be high – reached by intermediate/high severity of possible incidents
5	High	Types and quantities of hazardous substances high or on the level of large sized companies; intensive activity; concern of staff for safety is not systematic, safety culture is not part of company's policy, safety management does not exist, quality assurance and environmental policy do not exist; technical and organisational measures for incident reduction and protection are unacceptable – are out of date and unreliable – introduction of new in terms of ALARA and BAT; general organisation of the site is not acceptable; necessary action for safety of staff and environment; impact area for adverse consequences to health exceeds establishment's premises, need for protective measures (evacuation) and environmental remediation, possible protests and demands for termination/relocation of establishment; vulnerability of environmental components might be high – reached by intermediate/high severity of possible incidents

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[1] ALARA – As Low As Reasonably Achievable

[2] BAT – Best Available Techniques