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Risk management and land use planning for environmental and asset protection purposes

By

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Declaration

I hereby declare that, the contents and organization of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

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Abstract

The PhD thesis presents a semi-quantitative methodology, developed to increase the efficacy of Land Use Planning related to the Management of risks, in particular as far as it concerns multiple risks impinging on the same territory (Multi-risks).

At the moment, each risk is managed through a dedicated sectorial plan, having its proper procedures and scale, and the only "meeting point" for these plans – at least in Italy - are the Municipal city plans. The Municipalities have to implement the contents related to the various risks and directly intervene on the territory, but the lack of linkage and coordination between the plans and the authorities in charge often makes the emergency management and LUP less effective towards the achievement of a real safety of territories. In addition, the actual legislative framework does not face the possible consequences of risk interactions.

In this context, the objective of the thesis was to develop a simple risk pre-screening tool, expressly designed for local planners, able to point out the areas more exposed to risks and risks interactions, in order to better address the distribution of the municipal resources for further studies and interventions. The local planners that, especially in Italy, have a central role for the risk management of the territory, became the central point for the proposed framework, assuming the role of evaluators, and then decision-makers.

The methodology was developed taking into account the existing experimental frameworks developed for Multi-risks and NaTech events. Both qualitative and quantitative methodologies were settled in the last years, however the scales and the complex approaches proposed collide with the objectives of this PhD thesis. In fact, few methodologies were elaborated for little scales, and frequently the application of quantitative multi-risk methodologies at a local scale encountered difficulties related to data availability; in addition, all the methodologies require the involvement of experts of several disciplines. These aspects, in particular considering the scarce financial resources of Municipalities, risk to limit the awareness of the importance of a multi-risk approach for LUP planners.

Therefore, a semi-quantitative approach, based on an index scale from 0 to 3 onwards was developed for a direct use from Municipal technicians; the proposed scale is applied to measure both the impact of the risks and risk interaction. The methodology is composed by 4 steps: 1) characterization of the risks; 2) assignation of the ratings to the risks; 3)

assessment of binary risk interactions; 4) assessment of the compatibility and planning phase. Each step is accompanied by GIS mapping.
Steps 1 and 2) *Risk characterization and rating*. The users (local planners) are required to describe the main territorial risks according to 3 macro-categories: Historical Events, Protection Measures and Strengthening Effects. The macro-categories help in majorly focus on the different aspects of the risks, in particular those that could enhance its final impact, or that could have been neglected in the existing plans. Each macro-category is evaluated and rated on the basis of a dedicated guide, developed on the basis of literature data.
Step 3) *Risk interaction*. The impact of one risk on another one (binary interaction) is assessed in the areas where risks overlay, thanks to a weighted average sum of the values of their macro-categories. An excel table for the application of the formula was developed. The calculation of the interaction vales can be also executed directly through GIS.
Step 4) *Compatibility*. Territorial and environmental vulnerabilities are classified in compliance with E.R.I.R. national and regional regulations. Then, the compatibility is assessed on the basis of an “alarm threshold”; when highly vulnerable territorial or environmental elements fall down in areas where the risks macro-categories or risks interaction are above 2,5, a potential incompatibility is detected. The Municipalities will have to focus here further studies, and then possible interventions: a collection of the possible actions, extracted from existing Guidelines and Manuals was drafted to guide this process.
An optional step for the compatibility assessment was added to provide the Municipalities with an indicative mapping of the spatial consequences of the interactions involving industrial plants. This is the only step of the methodology that could presents difficulties for not expert users, because it entails the use of two modelling software (ALOHA and HSSM), that simulates the consequences of the releases.

The methodology was tested on two Italian case-studies, two Municipalities affected by multiple types of risks which could interact. Both the territories were connoted by low levels of risk, however the application of the methodology highlighted possible unforeseen problems deriving from the interactions, that currently are not described in any existing sectorial or local plan. Once that the areas more exposed are identified, ad-hoc investigations and actions can be settled to address the problem, on the basis of a guide-line.

The proposed approach demonstrated to be able in identifying and bring multi-risks aspects to the attention of the decision makers; in this way, they have a simple guide to risk that can be integrated with the existing planning instruments to improve the quality of decisions related to risks. Furthermore, local administrators recover a more active role, increasing their awareness about the contents and information of the sectorial plans, but also exploiting their major direct knowledge of the territory. This approach tried to fill two different existing gaps: on one side, the absence of an official and recognized legislation on Multi-risks; on the other side, the difficulties for non-risk experts to effectively use the Multi-risk and NaTech experimental methodologies developed so far now.

The framework developed for this PhD thesis can be easily adapted to LUP procedures of other countries, through a re-construction of the tables that guide the risk-rating; the simple index scale can be easily managed by different types of users. Being the methodology a risk pre-screening, it can be useful in every context in which it is necessary to acquire more information about multi-risks and their consequences, to better define future actions and drive the application of quantitative methodologies. Some further steps could strengthen and promote the use of the methodology:

1) Development of the guidelines for rating for other territorial risks, defining the levels for the three macro-categories in cooperation with experts of each specific discipline (landslide, volcanic risk, sea risk etc.)
2) Strengthening of the approach in relation to the local extreme events caused by climate change, with a wider local data collection and definition of the phenomena.
3) Enhancement of the representation of the spatial consequences. At the moment the simulations related to the interactions were essentially focused on industrial assets; however, a major involvement of experts of other disciplines could allow to set tools and instruments to analyze and study the consequences of all the types of interaction, creating an all-inclusive and more powerful tool.
4) Strengthening of the approach in relation to the vulnerability analysis, in order to evaluate the different aspects of susceptibility presented by the vulnerable elements, and trying to settle possible solutions to enhance the resilience.
5) Developing a participative process to improve the application of the methodology among the Municipalities, to reinforce the cooperation between the users and external authorities. In this context, also the adoption of a Multi-criteria Decision Analysis (MCDA) could be useful, to better guide and support the choice of the possible planning actions, as proposed by (Nivolianitou & Papazoglou, 2014) for LUP around Seveso plants.
6) Integrating the methodologies with procedures related not only to structural interventions, but also to emergency management, i.e. taking into account the guidance for flood disaster management with the use of AHP by (Nivolianitou & Synodinou, 2015).

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Chapter 1

Introduction

1.1 Foreword

The present research has its starting point in the candidate's previous experiences in the field of E.R.I.R. drafting, an instrument for the safe planning around Seveso plants[1]. The problem of Land Use Planning related to hazardous industrial plants was explicitly addressed by the EU Seveso directives, and implemented in Italy with the Ministerial Decree DM 09/05/2001, executive decree of the Legislative Decree 334/1999.

The Municipalities with a Seveso plant within their territory are committed to draft the E.R.I.R. plan (*Elaborato Tecnico per il Rischio di Incidente Rilevante* – Technical Plan for major risk accidents) for a safe integration of their urban functions with the existing plants.

The application of E.R.I.R. evidenced some shortcomings related to the environmental aspects, and to the analysis of the interaction of the industrial risks with natural risks, as later discussed in Paragraph 1.2.2, t.

However, the Municipalities not only implement in their City plans the indications about industrial risks; they have to cope with seismic risk, flood, volcanic risk etc.; furthermore, they are the first authority in charge for emergency interventions.

Therefore, the starting questions for this thesis were: have the Municipalities sufficient tools to grant a safe management of the territory? Is it possible to improve them, introducing multi-risks aspects?

[1] Seveso plant = plant detaining a quantity of hazardous substances equal or overcoming the thresholds defined by the Annex I of the EU Directive 2012/18/UE (Seveso III).

The following paragraphs aim at providing a general framework of the legislative situation in Italy, in relation to industrial risk and natural risks, highlighting the main problems related to the current management; in the end, the main objectives of the research are presented.

1.2 E.R.I.R.

In Italy, the national criteria for Land Use Planning (L.U.P.) related to major accidents dated back to 2001, with the Ministerial Decree DM 09/05/2001. A new Seveso Directive 2012/18/EU, and a new Legislative Decree (no. 105/2015) were issued, but the new Guidelines for L.U.P., mentioned in the article 22, have not been issued yet. According to DM 09/05/2001, Regions, Provinces, and most of all Municipalities, are the authorities in charge for the definition of minimum criteria to grant the safety around Seveso plants. Regions and Provinces have the function of guidance and supervision, while the direct fulfilment of the prevention and protection measures for the safeguard and safe planning of the areas around Seveso plants is a direct competence of the Municipalities, which have to draft the E.R.I.R. plan. The scopes of this planning instrument are: the identification of the environmental and territorial vulnerabilities, the assessment of the compatibility of Seveso installations, and finally the introduction of binding areas around them.

1.2.1 Procedure

A short summary of E.R.I.R. steps is here provided; in particular, the procedure adopted in Piedmont Region is presented. The Guidelines attached to Piedmont Regional Decree 17/377 (Regione Piemonte, 2010) gave the Municipalities more detailed indications with respect to the national law; they can be considered one of the most accurate regional regulation in the field of safe planning around Seveso plant.
According to (Regione Piemonte, 2010), the drawing up of E.R.I.R. consists of three different phases:

a) The data collection related to Seveso plants and other industries, and to territorial and environmental receptors;
b) The evaluation of the territorial and environmental compatibility;
c) The planning phase.

a) The data collection: identification and characterization both of the environmental/territorial vulnerabilities and of the industrial network. It entails a constant interaction between the various municipality offices, and the analysis of Regional and Provincial Strategic Plans, thematic plans and maps with reference to water, hydrogeological instability, architectonic and landscape protection sites, and Emergency plans and Safety Reports of the plants.

Seveso plants are characterized through their Safety Reports and Notifications, which point out the relevant accidental scenarios. In addition, (Regione Piemonte, 2010) required to investigate non-Seveso installations that could represent a risk: the Municipalities should include in E.R.I.R. plan the so-called Sub-threshold Seveso plants, which hold an amount of hazardous substances equal or higher than 20% of the thresholds established for each category of substances by the Legislative Decree 334/1999, Annex I - Parts I and II. Both the Sub-threshold plants and the other activities are under no obligation to declare the substances stored, therefore the quantity of hazardous substances, the storage type, the manufacturing process, the prevention and protection measures adopted, and the transport modalities of the hazardous goods are determined through a questionnaire. The collection of these data can create some problems, as the companies are not so accustomed to Seveso regulations and frequently have difficulty with the compilation of the questionnaire.

As far as it concerns the territorial and environmental receptors, the Municipalities have to classify as vulnerable territorial elements all the areas, buildings and infrastructures connoted by a significant presence of people. Six decreasing levels of vulnerability are defined by the D.M. 09/05/2001, depending on the population density or on the number of people, the attendance, and the mobility capacity, as detailed in Table 14.

In relation to the environmental vulnerabilities, (Regione Piemonte, 2010) provided a more detailed list with respect to that of the D.M. 09/05/2001; it includes protected natural areas, areas suffering from hydrogeological instability, historical-environmental-landscape areas of high value, zones with high vulnerability aquifers, etc. These environmental receptors should be grouped into two categories: "Extreme environmental vulnerability" elements and "Relevant environmental vulnerability" elements.

b) The territorial and environmental compatibility: in this phase, the data from the industries are crossed with those relative to the territorial and environmental vulnerabilities, and the interaction between industrial activities and urban functions, the road conditions and the environmental characteristics of the examined area are evaluated case by case.

For the territorial compatibility, both the D.M. 09/05/2001 and (Regione Piemonte, 2010) require to overlay the damage areas of each Seveso plant onto the territorial vulnerable categories identified during the previous data collection stage. A matrix defined by the D.M. 09/05/2001 reports the territorial categories compatible with each level of damage (Elevated Lethality, Start of Lethality, Irreversible Damage and Reversible Damage), on the basis of the probability of occurrence of the analyzed scenario.

For non-Seveso activities, which do not have risk analysis, (Regione Piemonte, 2010) introduced an indicative methodology for the compatibility, based on the type of stored substances. A specific buffer zone of potential damage is associated to the main hazardous substance detained (i.e. toxic substances = 1500 m., flammable substances = 500 m.), then a judgment of "very critical/critical/not critical" is assigned to each plant, depending on the territorial and environmental vulnerable elements falling into the potential damage buffer.

Both the D.M. 09/05/2001 and Piedmont regional guidelines provide about the environmental compatibility more generic procedures; the first only distinguishes two possible environmental consequences, significant damage and severe damage, based on the time requested for a complete recovery of the previous situation. A plant causing a potential severe damage is not compatible.

Piedmont region considered the D.M. 09/05/2001 approach of difficult application; therefore, it proposed for the environmental compatibility a judgment of criticality, based on the type of substance stored, the foreseen accidental events (energetic, toxic or with environmental effects), and the vulnerable environmental elements. Seveso plants and Seveso sub-thresholds plants located in Extreme environmental vulnerable area are considered “Very critical”; all the other plants, except those whose protective and management measures make unlikely a potential environmental scenario, are considered “critical”. In the Relevant vulnerable areas, if the vulnerable elements are underground aquifers with Very high/High vulnerability; groundwater recharge areas; areas with water table depth < 3 m., Seveso plants and Seveso sub-thresholds plants detaining substances hazardous for the environment shall be considered “Very critical”; in the other cases, Seveso plants are only “critical”.

As far as it concerns the environmental compatibility, the Turin Province guidelines for E.R.I.R. drafting provide a more precise approach, which will be explained further on.

c) Planning: Piedmont Guidelines defined precise criteria for the planning stage, imposing the definition of two concentric areas of respect, named “Exclusion area” and “Observation area”, around the Seveso activities and the “critical” or “very critical” activities.

The two areas are drawn up starting from the border of the plant: the exclusion area is a binding area, which can be of 100, 200 or 300 m, depending on the level of criticality assigned to the plant. The observation area must extend to at least 500 m from the plant boundary, and correspond to the area identified in the Emergency Plan for the management of emergencies related to the accidental events.

In the exclusion area, modifications that involve an increase in the anthropic load, introducing urban functions belonging to categories A and B are not admitted. In the observation area, management measures relative to the control of the traffic conditions in case of an accident can be applied, but no land-planning bonds are imposed.

In the end, (Regione Piemonte, 2010) allows the Municipalities to decide specific additional protection measures in the exclusion areas, in order to mitigate the impact on the environment and on the already existing buildings. For instance, the Municipality can impose to the plant owners the building of perimeter walls, the waterproofing of the yards and the building of settling tanks, and so on.

1.2.2 Shortcomings

Even though Piedmont Region established very detailed Guidelines for E.R.I.R. drafting, the practical application, developed in cooperation with several Municipalities, still evidenced some shortcomings, in part related to the lack of technical skills of the Municipalities in comparison to the level of knowledge required by the E.R.I.R., but most of all concerning the environmental aspects.
On one side, the assessment of the environmental compatibility remains less clear than that for the territorial compatibility and do not generate specific binding provisions. On the other side, the entire E.R.I.R. procedure neglects the possible influence of the natural elements and events on the Seveso plants (shown in **Figure 1**), even if the particular physiognomy of the Italian territory could massively favour this interaction. In fact, the major part of the nation is characterized by a high seismic risk, many areas have been interested by huge floods, and Italy is connoted by extended coastal zones. The land available for urban development was very limited and caused the creation of a jumble of residential and industrial zones, a massive urban expansion that complicates the relationship with natural events, increasing their dangerousness.

The inclusion of possible NaTech[2] interactions in E.R.I.R. is also impeded by reasons related to the probability of occurrence. These events are connoted by high impact and very low probability, but unfortunately, Italian Seveso regulations allow the plant owners to not develop scenarios for events whose probability of occurrence is below 10^{-6}. D.M. 09/05/2001 established compatibility criteria also for these extremely rare events, but since E.R.I.R. plans are entirely based on the contents of the risk assessment of the Safety reports and Notifications provided by the plants, in the end NaTech events are mostly neglected.

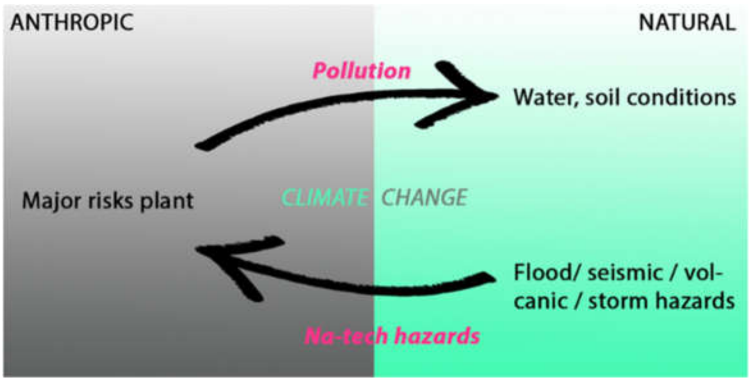

Figure 1: Mutual influence of anthropic and natural elements

[2] NaTech = natural disasters triggering technological disasters

Therefore, in Italy neither Land Use policies nor Seveso regulations deal with the possible interaction between industrial and natural hazards: as highlighted also by (Galderisi et al, 2008), these risks are generally handled separately.

1.3 Sectorial risk plans and emergency plan

As anticipated, the direct land use management in Italy is delegated to Municipalities, that implement, in their City Plan and in the Emergency Plan, the provisions of the superordinate sectorial risk plans. The City Plan norms urban and land functions, adapting the needs of urban development to the natural specificities of the territory (geomorphological, hydrological, etc.). The Emergency Plan provides a survey on the state of conservation of the territory based on existing risk analysis and on superordinate plans indications; it then set up the operational activities, the materials, capacities and means needed to deal with possible emergencies. The following paragraphs provide an insight of the sectorial plans related to earthquake and flood, of the Emergency Plan, and of the criticalities observed at a local level.

1.3.1 Flood and Earthquake

1) SEISMIC RISK: The Italian Seismic legislation is composed by two national laws, the *Ordinanza* OPCM 3519 (Presidente del Consiglio dei Ministri, 2006) and the Ministerial Decree D.M. 14th January 2008, which introduced the *NTC Norme Tecniche per le Costruzioni* – Technical standards for buildings (Ministero delle Infrastrutture, 2008). The *Ordinanza* OPCM 3519 proposed a classification in four zones, based on the values of Peak Ground Acceleration (PGA), with a 10% excess probability in 50 years, calculated for rigid soils[3] (see **Table 1**).

Table 1: OPCM 3519 4 seismic zone classification

SEISMIC ZONE	*PGA* [4]
1	PGA > 0.25
2	0.15 < PGA < 0.25
3	0.05 < PGA < 0.15
4	PGA ≤ 0.05

The NTC were adopted later, in compliance with the CEN Structural Eurocodes, and imposed to architects and engineers to assess the specific seismic risk related to each new

[3] The 4 seismic zones calculation and mapping is provided by the *INGV - Istituto Nazionale di Geofisica e Vulcanologia.*
[4] Peak ground acceleration on rigid soil with a 10% excess probability in 50 years

construction, by evaluating the specific response spectres of the construction itself in relation to the kind of soil, the life-time of the building, etc.
After the adoption of NTC, the 4 seismic zones defined by the *Ordinanza* OPCM 3519 remained only as an administrative indication for the Regions aimed at identify the territories with a potential higher risk, while the in-depth assessment of the seismic risk was delegated to the single building scale, through the application of the *NTC Norme Tecniche per le Costruzioni*.

Therefore, currently no effective information on seismic risk is available at an intermediate scale: Municipalities know their general seismic class, but no in-depth analysis is provided on the actual distribution of the seismic risk on the territory. The classification into 4 seismic zones is based on the parameter of a rigid soil, that is a too general and not conservative condition if applied at a local scale, where the quality of soil deeply influences the seismic behaviour. On the other side, the analysis required by NTC (response spectres to take into account the characteristics of the soil) is punctual and cannot define areas connoted by homologous features.

In addition, NTC can ensure to a new construction/building a good level of protection against earthquakes, but most part of the buildings and constructions in Italy are older than NTC, and were built in absence of any analysis on the soil conditions. Even if NTC established some criteria for the seismic adaptation and improvement of existing buildings, they can be imposed only if an intervention on the building itself is programmed and consequently requested to the Municipality.

In 2009, the Civil Protection issued the Guidelines "*Indirizzi e criteri per la microzonazione sismica*", aimed at introducing new practices to assess the reactions of the different types of soil under a seismic solicitation. In fact, it was observed that the same ground acceleration could produce completely different effects, depending on the local characteristics of soil, so that a correct estimation of the seismic behaviour (micro-zoning) of the soil was interpreted as key element to identify the real priorities both for emergency and planning interventions.
A multi-level approach for micro-zoning was defined:

- The First level is a preparatory study for the successive steps, based on pre-existing data, and has the scope to identify inside the territory of a Municipality the soils which present homogeneous characteristics, and which could be affected by instability or amplification effects.
- The Second level, the proper Micro-zoning study, provides a semi-quantitative assessment of the amplification related to each type of soil identified.
- The third level is related to specific areas which need more in-depth analysis.

After the L'Aquila earthquake of 6th April 2009, the Italian government approved a National Risk Plan for seismic risk (Legge no. 77/2009, art. 11), that required the micro-zoning studies at least for the most dangerous areas, mainly located in the Appennine zone (1877

Municipalities). An annual fund was assigned to contribute to the draft of microzoning but, until 2015, only 779 Municipalities had prepared the studies, introducing an instrument able to fill the gap of the intermediate scale.
According to (Protezione Civile, 2009), the Regions are the authorities in charge to organize and plan the development of the micro-zoning studies on their territory: they usually use the generic seismic classes to identify the areas where a micro-zoning study is overriding. Therefore, generally, the priority for 2nd and 3rd micro-zoning level studies is reserved to Municipalities classified in Classes 1 and 2; these levels require further technical and financial efforts, and can be partially financed with the funds made available by the *Piano nazionale per la prevenzione del rischio sismico*. The 1st micro-zoning level could be required to Municipalities located in Classes 3 and 4, as one of the accompanying studies for the draft of the City Plan.
An extensive adoption of the micro-zoning studies, at least of those belonging to the 1st level, would be able to represent that local in-deth analysis that is currently missing for the Italian Municipalities.

2) FLOOD AND LANDSLIDE RISK: The National law 183/89, integrated by law 253/90, conferred the soil conservation to new authorities created on purposes: River basin authorities (*Autorità di bacino*). In 1998, the decree D.P.C.M. 29th September 1998 imposed to the Basin authorities the draft of plans expressly dedicated to the assessment of the hydrogeological risks at river basin scale, named P.A.I. - *Piano per l'Assetto idrogeologico*, Hydrogeological-setting plan.
P.A.I. adopted a simplified approach for the risk estimation, based on qualitative methods; the analyses were conducted in areas in which floods and landslides events were historically proved. Floods hazards were organized on 3 categories with different probabilities, while for landslide hazards the information provided by other National Research institutes were collected and reported. Four levels of risk were identified, depending on the potential damages to different types of target (see **Table 2** below).

Table 2: D.P.C.M. 29th of September 1998, Flood hazards, and Risk categories

FLOOD HAZARDS categories		***RISK LEVELS (Floods and landslides)***	
A	HIGH PROBABILITY FLOODS, return time ≤ 20-50 years	R1 low	Negligible social, economic and environmental damages
. B	MEDIUM PROBABILITY FLOODS, return time ≤ 100-200 years	R2 medium	Minor damages to buildings, infrastructures and people, which don't affect people and building safety, and economic activities development
C	LOW PROBABILITY FLOODS, return time ≤ 300-500 years	R3 high	Possible damages to people safety, structural damages to buildings and infrastructures, which affect socio-economic activities. Relevant damages to the environment
		R4 very high	Death and severe injuries to people, severe damages to buildings, infrastructure and environment, loss of socioeconomic activities.

P.A.I. plans studied and imposed specific buffer zones to the main rivers basins; these binding areas were expanded by Regions and Provinces, that included in the risk analysis also minor water courses. Finally, the local City Plans were committed to integrate all these indications, establishing specific requirements for the compatibility of the urban functions. As already highlighted for seismic risk, the most problematic situations were related to existing buildings in condition of incompatibility, for which no specific binding tools were provided.

Recently, the described framework was changed by the Legislative Decree 49/2010: in compliance with 2007/60/CE Directive, it required to create new plans and maps for the Management of Flood Risks, involving for the first time in their draft the Civil Protection, and therefore dealing with aspects of Emergency Planning. The Basin authorities have produced the new Maps for the Flood Risk, which recover P.A.I. information with the aim to homogenise their representation at a national level. An example of these new plans is the P.G.R.A - *Piano di Gestione del rischio alluvioni,* Plan for the flood risk management, recently issued by the Po basin authority (A.D.B.Po, 2015); the flood buffer zones identified by the existing P.A.I. and other plans were led back to 3 new flood scenarios (High, medium and low probability). The return times corresponding to these flood scenarios are reported in **Table 3** and **Table 4** below, extracted from (A.D.B.Po, 2014).

Table 3: Po basin authority, summary of the flood risk elements

FLOOD RISK ELEMENT		*Authority in charge for surveys*
Code	*Description*	
RP	Main hydrographic network	Basin authorities
RSCM	Secondary hydrographic network of hills and mountains	Regions
RSP	Secondary hydrographic network of flat lands (RSP)	Regions and Consortia for water management
ACL	Lake coastal areas	Regions and Consortia for lakes regulation
ACM	Sea coastal areas	Regions

Table 4: Po basin authority, flood scenarios

Flood directive		*Dangerousness*	*Return times of each flood element (yrs)*				
Flood Scenario	*Return time (yrs)*		*RP*	*RSCM (P.A.I. legend)*	*RSP*	*ACL*	*ACM*
High likelihood (H)	20-50 frequent	P3 high	10-20	Ee, Ca, RME 20-50	> 50	15	10
Medium likelihood (M)	100-200 infrequent	P2 medium	100-200	Eb, Cp 100-200	50-200	100	100
Low likelihood or extreme event scenario (L)	> 500 rare or max. registered impact	P1 low	500	Em, Cn 300-500	-	Max.registered impact	> 100

1.3.2. Emergency

The National law no. 225/1992, later modified by the National law 100/2012, introduced for all the Italian Municipalities the obligation to draft an Emergency plan for their territory, aimed at preventing the risks and coordinating the emergency operations. According to a survey realized in September 2016 by the Civil protection, it resulted that 80% of the Italian municipalities is now provided with an Emergency plan. However, the contents could deeply vary from a Region to another, and from Municipality to Municipality; in addition, in some cases the Emergency plans showed a serious inefficacy in preventing and managing the risks (i.e. during Genova's multiple floods).

As for industrial risk, each Region is responsible for the implementation of studies and programmes aimed at managing possible risks and prevent consequent damages, and therefore for the draft of specific Guidelines for the Municipal Emergency Plans.
Usually, a Municipal emergency plan should identify the major risks and vulnerabilities present on the territory, then evaluate the most dangerous risk scenarios, in order to define tools and actions for the emergency management. Each regional Guideline defined its proper method for the risk identification, however, the contents of the sectorial plans are often assumed as basis for the risk scenarios. Since 2007, a national Guideline (Presidenza del Consiglio dei Ministri, 2007) is available in relation to the assessment of fire risk, to be evaluated with a speedy method, and of hydrogeological risk (based on the P.A.I. provisions). For the seismic risk, some online instruments for the drafting of the scenarios are available on the website of the Civil Protection http://www.protezionecivile.gov.it/jcms/it/rischio_sismico.wp .

Nevertheless, many Emergency Plans have already been prepared on the basis of different indications, provided by each Region: i.e. Piedmont stated with the Regional Law n. 44/2000 that all the Municipalities should prepare and adopt a *Municipal* or *Inter-Municipal Civil Protection Plan*, publishing dedicated Guidelines in 2004 (Regione Piemonte, 2004). According to these Piedmont guidelines, plans should include:

- general information about the territory and its characteristics (Territorial analysis);
- an accurate risk scenario analysis for each possible risk as precondition of each following provisional or operational action (Risk scenarios, considering different types of hazards and vulnerabilities);
- a verification of the present structures, capacities and resources (Organization and resources), on the basis of which an adequate configuration for emergencies can be configured (Emergency procedures, Capacity building, communication and training).

Turning back to the Emergency plan contents, their final objective should be in agreement with the UN/ISDR (2009) definition for disaster risk management (also known as emergency management): "the systematic approach of using administrative decisions, organization, operation skills and capacities to implement policies, strategies and coping capacities of the society to lessen the impacts of natural hazards and related environmental and technological disasters. This comprises all forms of activities, including structural and non-structural measures to avoid (prevention) or to limit (mitigation and preparedness) adverse effects of hazards".

However, the Italian Emergency Plans do not include recommendations for the implementation of structural mitigations able to contain and/or prevent disasters, but only work as a basis for rescuing operations only, while the planning actions are left to other tools. Furthermore, it has to be added that, once again, the issue of the interaction between the risks is not faced in the Emergency plan.

1.3.3. Shortcomings

The analysis of the different territorial risks in a separate way, with different procedures, timings, methodologies, do not allow to the Municipalities to have a clear and updated concept of the actual dangers that threaten their territory. In particular, the implementation of the seismic, industrial and hydrogeological provisions at a local scale is characterized by the following critical issues:

- A correct application of the indications of the sectorial plans could be sometimes affected or delayed by lack of financial and technical resources; external o partial interests could compromise contents and provisions of the City plans;
- Information and analysis contained in larger scale plans could become obsolete in the period between the release of the sectorial Plan and its integration in the City plans. Therefore, the state of the territory reported in the sectorial plans in some cases does not reflect any more the actual situation.
- Sectorial plans provide prescriptions and recommendations on how to reduce and contain related risks, but their effectiveness is rarely direct, because only Municipalities can impose bindings on the territory through the City Plans, and these are mainly related to regulate new constructions. Supra-local legislation does not provide Municipalities proper means to be able to intervene on ascertained high-risk situations, or cases of incompatibilities between risks and existing urban functions.

As far as it concerns the local scale tools, the City Plan and the Emergency Plan, it can be observed that even if they share the same basic indications, they are not mutually linked in the matter of long-term risk management: one is specifically related to the territory and the other to the emergency, without establishing common preventive structural measures that could contribute to reduce risk and prevent emergency. Both the plans implement measures related to the risks present in the territory, however they do not consider the possible risk increase related to the risk interactions.

1.4 The proposed solution

Considering the above-mentioned difficulties, the present research was focused on the development of a new methodology, able to jointly take into account, and analyse for preventive and planning purposes:

- The main risks on the Municipal territory
- The main environmental and territorial vulnerabilities
- The interaction between the risks and their impact.

The objective was to define a quick and easy to use methodology that the Municipalities could directly use without need of intermediations, in order to spare money and time. The proposed methodology was not intended as a replacement of the existing plans, but as an all-inclusive "Rapid guide to the risk", aimed at immediately highlighting the most threatened areas, in order to allow the Municipalities to proceed with further analysis and interventions on specific points of the territory. All this information should be inserted from the beginning in a GIS tool, that returns an immediate and easy to read overlapping of the different thematic layers (vulnerabilities and risks), able to show in a simple way the main zones of possible risks interaction.

In order to develop the methodology, firstly a literature review related to the Multi-risk approaches and NaTech methods was carried on, as better explained in next chapter. It should be noticed that even if, recently, many research projects at national and European level were developed to identify and produce methodologies able to take into account and manage the different types of risk, until now no one of these approaches was ratified by a law. Also, not many reference methodologies at local scale are yet available, and the approaches and data used at a larger scale for the vulnerability analysis and risk analysis result not adequate and too general to be effective at a minor scale. In example, in Italy are usually adopted the statistical data released by ISTAT for the estimation the vulnerability related to the population, but they cannot show the distribution of population and its density inside the territory of a Municipality.

The scheme reported below show the steps of the methodology proposed, later explained in Chapter 3.

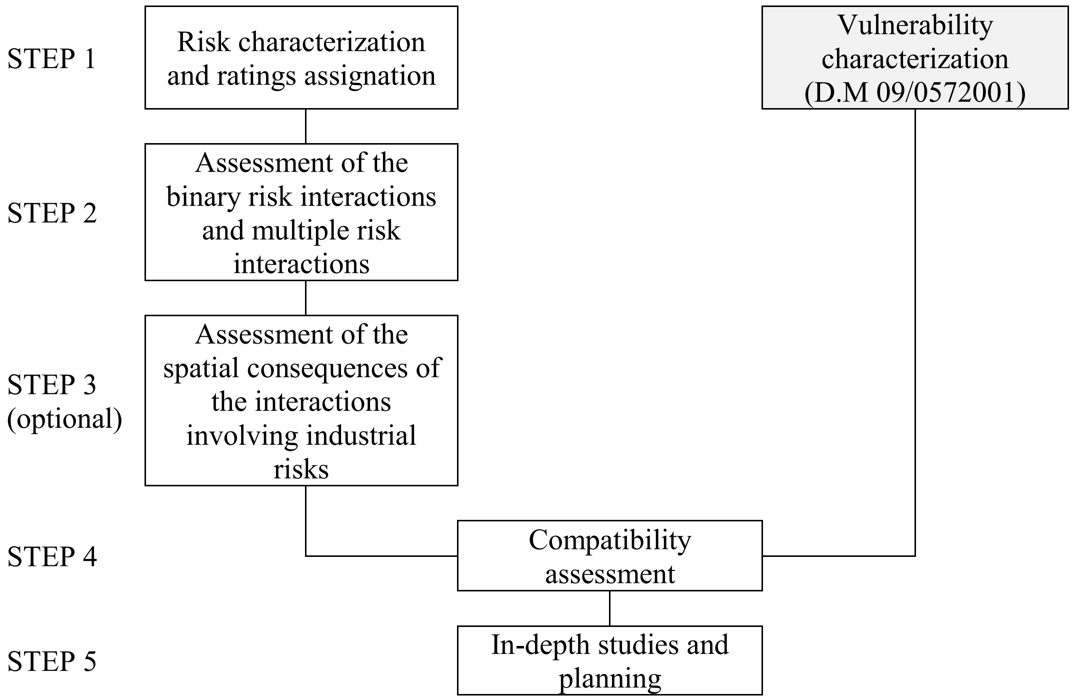

Figure 2: Scheme of the proposed methodology

Chapter 2

Literature review

2.1 Overview

The present chapter aims at providing an overview of the main practices related both to Multi-risk and NaTech assessment, trying to better define the basis of the research approach. As far as it concerns Multi-Risk, several risks can affect the population, the environment, the material assets and infrastructures of any inhabited area of our planet; they are generated by very different sources, both natural and anthropogenic, and acquire a major impact in case of interaction, and in relation to the peculiar characteristics of the hit areas. Presumably because of the climatic variations in progress, it was observed in the last years a growing tendency in the magnitude and frequency of the natural accidental events, that is aggravated by the great diffusion of human settlements in hazard prone areas.
Therefore, a growing attention was dedicated by the scientific community and also by the political institutions and decision-makers to the theme of Multi-risk assessment: many multi-risk approaches were proposed worldwide and at European level to properly deal with this challenge, with the aim of creating tools and procedures for an improved land use planning and management of territory.

A peculiar type of Multi-risk events is constituted by Na-Tech risk, intended as the risk produced by the combination of Natural hazards and Technological risks; according to (ARMONIA Project, 2006) in NaTech events, a vulnerable exposed object (an industrial plant or a network infrastructure) becomes a hazard itself. Also in this field, many studies were developed in the last decade, aimed at defining the actual incidence of NaTech accidents and the most vulnerable assets, but also focused on the development of methodologies able to insert the natural events in the current practices for industrial risk assessment.
According to (Cruz et al., 2004), Na-Tech incidents are characterized by the following peculiarities:
• the cause of the event is external to the industrial site, thus the prevention and mitigation of such events may not be managed only at a site level;
• the extension of the natural event triggering the technological accident is wide, thus several equipment items may be simultaneously affected and loss of utilities may take place, leading to common cause failures;

• emergency response may be hampered or delayed by the natural event.

According to (Cozzani, 2010), the possibility of damage to process equipment due to the impact of natural events is well known in industrial practice, and it is addressed through a design approach that foresees protection from lightning and accounts the stresses caused by wind, snow, and seismic events; however, the safety studies developed by the plants rarely include Na-Tech scenarios.

Both for Multi-risk and NaTech assessment, many authors underlined the importance to predispose dedicated land-use practices; (Schmidt-Thome and Klein, 2011) consider land-use planning as a "useful tool to protect settlements from hazard impacts", while (Cruz et al., 2004) considers that common land use practices could represent an extremely effective method for reducing the risk of Na-Tech. The restriction of development in high risk areas, the relocation of exposed elements, or changes in land use could be effective for Na-Tech risk prevention.

However, at the moment the European legislation still have not implemented L.U.P. or risk assessment regulations explicitly related to the Multi-risk events.

2.2 European legislative approach for Na-Tech and multi-risk

In 2011, the European Commission issued the "Risk assessment and mapping guidelines for Disaster Management", aimed at providing the European governments with a common framework for processes and methods of the national risk assessments, and for mapping during prevention, preparedness and planning stages. The guidelines explicitly specified that national risk assessments should attempt to take into account multi-risk scenarios, therefore also Na-tech events, in compliance with the following procedure:

(1) Identification of possible multi hazard scenarios, starting from a given top event and evaluating the possible triggering of other hazards or events leading to hazards;
(2) Exposure and Vulnerability analysis for each individual hazard and risk within the different branches of the scenarios;
(3) Risk assessment for each hazard and adverse event and for the multi-risk scenarios.

However, the Guidelines recognized that multi-risk approaches raise several difficulties: i.e. the available data for different single risks may refer to different time windows, different typologies of impacts are used, etc., therefore comparisons and rankings can be difficult if not impossible. In particular, an important issue of multi-risk approach consists of the necessary co-ordination and interfacing between different specialized authorities and agencies: each one deals with specific hazards or risks without developing a complete overview of the knock-on, domino and cascading effects.

The difficulty in facing the multidisciplinarity required by Multi-risk approaches is somehow reflected also by the corpus of regulations issued by the European Commission; in fact, in spite of the increased awareness of the European institutions about the risks related to multi-hazard interaction, each risk remain addressed by single dedicated Directives.

2.2.1 Seveso directives

Since this research started from E.R.I.R. planning, which is a direct emanation of the European Seveso directives, this paragraph is particularly focused on the contents of these “industrial” regulations, and their approach to Na-Tech risk and related planning practices.

As far as it concerns Seveso II directive, an in-depth analysis was provided in 2004 by the JRC in the publication “State of the Art in the Na-tech Risk Management”: the authors stated that the Directive did not have any specific requirements for Na-tech risk management, but addressed it indirectly. In particular, articles 8 and 12 were considered of particular importance for the Na-tech risk reduction: Article 8 calls for the analysis of potential domino effects, while Article 12 focuses on L.U.P. According to this article, the prevention of chemical accidents and mitigation of their potential consequences should be taken into account through the establishment of land use policies, which aim is to establish appropriate distances between establishments, residential areas and areas of particular “natural sensitivity”. In any case, the authors recognized that the Directive did not introduce dedicated methodologies or actions that can be widely adopted to address Na-tech risk. The levels of preparedness on this field encountered among the European Countries were quite different (Cruz et al., 2004).

The recent revision of the Seveso Directive could have constituted an occasion to introduce practices related to Na-Tech hazards, however the Directive 2012/18/EU, issued after 14 years from Seveso II Directive, mainly focused on the adoption of the new system of dangerous goods classification (according to the REACH and CLP regulations).
As far as it concerns Na-tech risk, no substantial evolution was introduced, both for the methodology for risk assessment and for the land use planning practices related to major accidents. Once again, 2012/18/EU Directive has some articles (7, 10 and 13) dedicated to L.U.P., but their content is analogous to the previous Directive: the authorities have to deal with domino effects and Land Use Planning around Seveso plants; the operators shall provide the Authorities with information about the immediate environment of the establishment. No further information on the interaction between natural and industrial hazards are required.

Therefore, as previously mentioned, the current European and national legislation seemed to have had a slower assimilation of the Na-tech issue: natural and technological hazards are generally still handled separately, even if an increasing number of studies demonstrated that earthquakes, floods and lightning are responsible of a relevant amount of accidents in chemical and process installations. I.e. in 2011, the analysis of the Accident case histories extracted from the main European industrial-accident databases ARIA (2006), FACTS (2006), MARS (2008), MHIDAS (2001) and TAD (2004), as well as from the US National Response Centre’s (NRC) database (2008) showed that 79 records for Natech accidents were triggered by earthquakes, 272 were caused by floods and 721 were triggered by lightning (Krausmann et al, 2011).

2.3 Review of methodologies for multi-risk assessment

In the last ten years, several researches and projects were dedicated to the identification of methodologies aimed at dealing with multi-risk, a concept that requires assuming both a multi-hazard and a multi-vulnerability perspective.
While many projects particularly focused on multi-hazard identification, even if with different approaches, as later specified, the concept of multi-vulnerability was less investigated. In fact, it presents many obstacles: the level of vulnerability is related to the hazard analyzed, and depends on several elements: the exposure, the intrinsic characteristics of the element, the coping capacity etc.
In the end, many uncertainties characterize the path of the projects developed in multi-risk field, both when a quantitative approach is chosen or a qualitative one is preferred: in fact, the great differences between the risks analyzed in terms of time-variability, of methodologies for risk assessment, and required data, often constitute a hard challenge for the authors.

(Garcia-Aristizabal and Marzocchi, 2011) noticed that the concept of "multi-hazard" can assume different connotations, and this initial different interpretation lead to the development of very different methodologies. The majority of the projects tends to interpret multi-hazard as different sources of hazard that threaten the same exposed elements (with or without temporal coincidence); therefore, multi-risk assessment is seen as the assessment of different independent hazards that threat a common area or common exposed elements.
More rarely, the projects consider that one hazardous event can trigger other hazardous events (cascade effects), and concentrate their efforts in trying to define the effects of these triggering, domino, or cascade effects.
(Garcia-Aristizabal and Marzocchi, 2011) signalled that the first interpretation of multi-hazard assessment is the most common found in literature; generally, these methodologies begin with the identification of different hazard sources in a given region of interest, and evaluate the single hazards independently, on the basis of their specific assessment methodologies. The objective is to identify the spatial distribution of the effects of the different hazards and for different intensities of the hazard, and to estimate the occurrence probability or return period for different hazard intensities. The results, according to the scale of the specific problem, are generally presented as single hazard maps, layers (in a GIS environment), aggregated maps (overlapping all the maps), and hazard curves (for each hazard), where it is plotted the probability (or return period) against the intensity measure of the hazard.
The main efforts within this multi-hazard perspective are addressed to the homogenization of the hazard assessment, in order to make different risks comparable. This 'harmonization'

process is generally conducted on the basis of the evaluation of hazards in probabilistic terms; or, more frequently, in a qualitative way, through indexes based on the frequency and / or intensity of the hazards (projects TEMRAP, ESPON, ARMONIA).
Sometimes, the willing of homogenization mainly aims at defining a unique "multi-hazard score", but the efficacy of this type of methodology has been criticized. I.e. (Menoni et al., 2006) considered that the concept of a unified unit of measure can result appealing for scientists, but it is not equally useful for planners. Emergency managers and urban and regional planners mostly need to understand and face the specific problems provoked by hazards in a given context, trying to verify the expected damage and consequences triggered by natural hazards, also comparing the expenses needed to prevent this or that risk.

As far as it concerns the second methodological multi-risk approach, that considers interactions and/or triggering effects, it is in general a more demanding process because of the complexity in managing the necessary input data, and in constructing the potential hazard 'chains'. According to (Garcia-Aristizabal and Marzocchi, 2011), this kind of multi-hazard assessment implies different interpretations:

1. The occurrence of a certain hazardous event 'triggers' other hazards (triggering or cascade effects), therefore the probability of occurrence of the triggered event changes;
2. The simultaneous occurrence of two or more hazardous events entails changes to the vulnerability of the exposed elements (i.e. the probability to have a given damage), which at the end may be also reflected in the final risk assessment (interactions).

A review of some of the main important Multi-risk projects at European level is provided below; the different possible approaches are exemplified.
Although many different projects were examined, the major attention was reserved to those mainly focused on local or at least a regional scale, or to projects that provided useful suggestions for the definition of practices and tools which could be useful to elaborate a tool for the Italian municipalities.

2.3.1 FP6 Project NARAS - 2004

NARAS project (Natural Risk Assessment) focused on a local scale, and adopted a "multi-hazard → triggering effects" perspective, by proposing a multi-risk assessment based on the definition of risk chains scenarios.
The methodology proposed begins with the characterization of the investigated area and the definition of a time interval of reference. The width of this area is defined case by case, since the features of the zone (type and number of vulnerable territorial and environmental elements) and the extension of the consequences due to the events may induce to expand or reduce the investigated area. Then the following steps are proposed: 1) Identification of hazards/risk sources; 2) Characterization of adverse events and their propagation path; 3) Exposure and Vulnerability analysis; 4) Definition of the phenomenon intensity distribution (e.g. ground acceleration, pressure waves, distribution of chemical substance concentration

for various areas, thermal flow, etc.); 5) Identification of vulnerable elements (population at risk, strategic infrastructures, historical structures, buildings).
In order to make the analyzed risks comparable, it was identified a common reference damage for all the single risks (i.e. a given number of casualties); the different risks were ranked on the basis of their probability to originate the reference damage. Then each risk concurred in the creation of a set of scenarios correlating adverse events from different sources. For each "risk scenario", adverse events, phenomena and damage were correlated in a series parallel sequence of happenings through an "event-tree". Each branch of the event tree was quantified through a probabilistic analysis of the "history" of the events, the vulnerability and the exposed values of the specified targets. In the end, a final risk was estimated.

2.3.2 ESPON project - 2006

ESPON - The Spatial Effects and Management of Natural and Technological Hazards in Europe has a wider scale in comparison with other projects, but it has been analyzed because is based on a pure qualitative approach, a choice that helped the authors in keeping under control the uncertainties related to the big scale of the analysis (European level).
The scope was to spatially represent the patterns related to the distribution of the natural and industrial hazards in Europe, also taking into account some risks related to climate change; in case the risks overtook some intensity thresholds, the possible interactions were considered.
The hazards included in the analysis were chosen based on a spatial principle (recurrence of the hazard on the same area): Natural hazards - avalanches, droughts, earthquakes, extreme temperature, floods, forest fires, landslides, storm surges, tsunamis, volcanic eruptions, winter and tropical storms; Technological hazards - traffic accidents, major accident hazards nuclear power plants, oil processing.
On the basis of their intensity, the hazards were classified in five classes (from very low to very high) and then weighted with Delphi method to establish the relevance of each hazard in comparison to another and obtain an integrated hazard map. This procedure allowed verifying that the most relevant European hazards were floods, forest fires, earthquakes and major technological accidents.
The integrated risk map was obtained by superimposing the hazard map to the vulnerability one, drafted on the basis of the indexes assigned to 4 components of the vulnerability: regional GDP capita, population density, fragmented natural areas, and national GDP capita intended as an indicator for the coping capacity.
As far as it concerns the risk interactions, ESPON proceeded with the draft of a Hazard interaction map, trying to point out the areas where high impact hazards could interact. A dedicated matrix analysed the possible interactions, through the attribution of the following values: 1 = existing influence of a hazard on the other hazard, 0 = no physical influence on the other hazard.

In case of existing vice-versa interactions (e. g. earthquakes – volcanic eruptions), these were counted twice. The interactions above mentioned were evaluated only for areas where the hazard intensities reached a range between the classes IV and V, that means High or Very high. 59 hazard combinations were studied across Europe: 8 possible combinations were not encountered in any European region (i.e. the combination of volcanic eruption and large river floods), while the most common hazard combination resulted major river floods – landslides: the hazard intensity of these two hazards was high in 146 European areas. Other common hazard combinations were: winter storms – storm surges (103 areas); hazards from chemical production plants – hazards from nuclear power plants (89 areas); droughts – forest fires (74 areas); storm surges – landslides (52 areas); storm surges – hazards from nuclear power plants (41 areas); earthquakes – landslides (33 areas); and tsunamis - landslides (33 NUTS3 areas). The interaction matrix showed on one hand the dominance of geological hazards (earthquakes and volcanic eruptions) in influencing other hazards, on the other hand, that technological hazards are the most sensitive hazards to external events.
In the end, interaction hazard maps were drafted. They identified the areas where interactions of intense hazards could happen, and the number of possible combinations that can interested the analysed zone. However, the maps cannot represent the cumulative effects of the identified interactions. Indeed, ESPON authors recognized that the coincidence of different hazards in space and time could produce an additional hazard potential, but the difficulties in evaluating the physical processes as well as the unforeseeable social and political implications led them to avoid any changes in the weighting of hazards for the interaction hazard map.

2.3.3 IPSC project - 2006

IPSC project – *Drafting of thematic maps for the vulnerability and risk* had a regional focus and was developed in Piedmont region, with the aim of drafting maps for the vulnerability and risk expressly dedicated to civil protection actions. A quantitative risk approach based on scenarios was applied; however, the interaction between different elements was not taken into account, and the methodology majorly focused on how to evaluate the vulnerabilities.
The hazards considered in the analysis were: earthquakes, hydrogeologic elements (Floods and landslides), forest fires and hazardous industrial plants, that are the main risks which interest Piedmont region. Starting from 8 possible defined scenarios (1 seismic, 2 hydrogeological, 1 forest fire and 3 industrial), the dangerousness was characterized through the definition of impact areas, to which a frequency of occurrence was associated. In these areas, the exposure (density or number) of the following elements was evaluated: population, critical infrastructures, buildings, environmental and architectural heritage.
However, in order to assess the risk, not only the exposure but also other factors composing the vulnerability were evaluated, like i.e. the susceptibility and the coping capacity. In the end, the risk related to each hazard was calculated on the basis of vulnerability functions expressly developed for the project.

2.3.4 A mathematical generic multi risk approach

The quantification of low probability high consequences events: a generic multi risk approach – an approached proposed by (Mignan et al., 2014). This methodology constitutes a particular approach inside the overview here provided, and it is briefly presented to give an idea of the variety of approaches that can be encountered in the analyzed field. The authors proposed a pure mathematical methodology, aiming at defining a novel, generic, multi-risk framework based on the sequential Monte Carlo Method (MCM), to allow for a straightforward and flexible implementation of hazard interactions, which may occur in a complex system. The goal was specifically to capture and quantify extreme low-probability–high consequences events using inductive generalization. The authors did not define any specific hazard or risk interaction, but only a framework to implement any type of interaction, within which real interaction processes have to be abstracted to more basic concepts and engineering methods by-passed. The MCM was employed to generate N time series, each one representing a risk scenario; then the analysis allowed to identify the more or less probable risk paths.

2.3.5 MATRIX project - 2011

MATRIX project - *New methodologies for multi-hazard and multi-risk assessment methods for Europe* was an extensive European financed project, aimed at defining a framework for multi-risk assessment, in order to assess the expected losses deriving from significant interactions among the hazards.
A three-levels approach was introduced for the draft of multi-risk assessment (**Figure 3**):

1) The First Level consists of a flow chart aimed at understanding if it is required a multi-type assessment approach, considering cascade effects and dynamic vulnerability.
2) The Second level consists of a semi-quantitative method, based on a matrix approach deriving from system theory, where the mutual influence between the hazard is described on the basis of the following scale: 0 No interaction; 1 – Weak interaction, 2 – Medium interaction, 3 – Strong interaction. Thanks to the values assigned, it is possible to estimate an interaction index; over a certain threshold of interaction index, it is recommended to pass to Level 3.
3) The Third Level consists of the quantitative multi-risk assessment, where Bayesian networks are employed instead of event trees to both estimate the probability of a triggering/cascade effect and to model the time-dependent vulnerability of a system exposed to multi-hazard. The authors considered that the flexible structure and the unique modelling techniques offered by Bayesian networks make it possible to analyze cascade effects through a probabilistic framework.

A further detail is here provided in relation to the Second Level. According to the explanation by (Nadim and Liu, 2013): "A matrix is developed by means of the choice of a couple of hazards, considered as the basic components of the system (Table *a*). It will be followed by a clockwise scheme of interaction (Table *b*), with the description of the mutual influence between different hazards (Table *c*). More specifically, each element of the row, which crosses one of the hazards in the mean diagonal, shows the influence of this hazard on the system, thus indicating the cause of the phenomena; whereas each element of the column, which crosses the same hazard analysed, shows the influence of the system on this hazard, thus focusing on the effect of the 24 phenomena. After the descriptions contained in the matrix, they are assigned numerical codes varying between 0 (No interaction) and 3 (Strong interaction) with intervals of 1, as a function of their degree of the interaction intensity (Tables *d*, *e*). Once all the hazards in the matrix are filled, it is possible to verify the degree of the impact of each hazard on the others and the effect from other hazards. In order to avoid the excessive weighting of a single hazard, the sum of the codes for the row and the column is considered (**Figure 4**)".

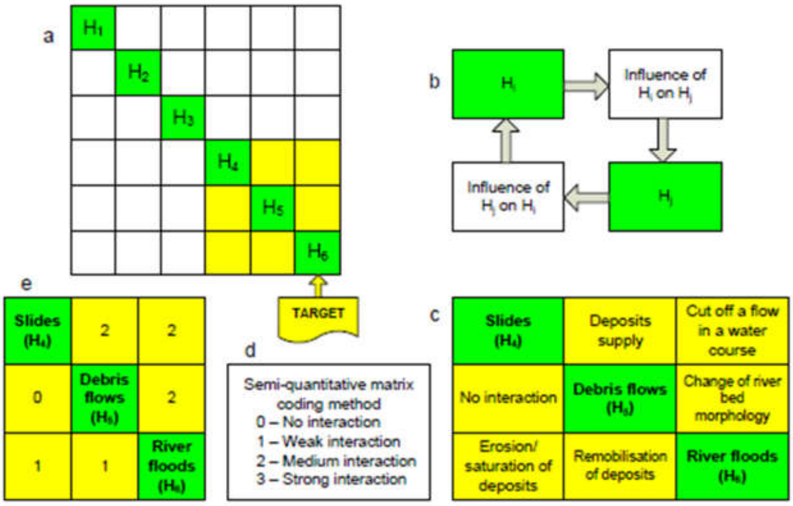

Figure 3: MATRIX, identification of the interactions between hazards

Number	Hazard	Causes (Rows)	Effects (Columns)	Causes + Effects
1	Slides	4	1	5
2	Debris flows	2	3	5
3	River floods	2	4	6
Total		8	8	16

Figure 4: MATRIX, sum of the interaction values

For MATRIX approach, the maximum possible value for the total sum of causes and effects that appear in table *a* is 25; this number contributes to the calculation of a hazard interaction index, which value is the basis to verify if it is necessary or not to step into the third level of analysis.

2.3.6 ARMONIA project - 2007

ARMONIA project - *Applied multi-risk mapping of natural hazards for impact assessment* was a European financed project, dedicate to Multi-risks assessment in relation to natural hazards. With respect to the other projects, it demonstrated an approach more focused on the planners' needs, defining multi-risk maps aimed at addressing spatial planning procedures in areas prone to natural disaster, and introducing a dedicated Decision Support System. The objectives of the DSS were: to provide a basis for planning in areas subjected to multiple risks related to natural hazards; to include exposure and vulnerability assessments; to help planners understand the implications of uncertainties and probabilities in decisions concerning land-uses and location of strategic facilities.

The scale adopted for the project was deliberately regional and local, because according to (Menoni et al., 2006), the analysis of available methods and legends suggested that hazard methodologies could produce better results at local and regional scales. However, while regional approaches are mainly simplified methodologies with simplified data, local approaches, mainly multi-risk, should be rigorous methodologies, sometimes simplified in the synthesis output, with rigorous data. ARMONIA kept this distinction, producing different methodologies for the two scales, based on semi-quantitative or quantitative procedures which entailed the definition of vulnerability curves and matrixes.

The proposed approach is here reported: Step 1: identification of individual hazards for ARMONIA main spatial scales (strategic regional, local general, local site); Step 2: assessment of vulnerability functions for any individual category of natural event, having as input the event location, intensity or severity parameters hazard category and as output an average expected damage; Step 3: assessment of fragility curves when possible, for any individual category of hazard, obtaining the probability of damage (e.g. for seismic hazard the % of cracks in walls, the % of not statically safe buildings, the % of collapsing buildings) for a given categories of exposed elements defined by spatial planners; Step 4: analysis of risk for any individual category of hazard; Step 5: harmonization of different individual values of damage (risk), likely in terms of fragility curves (probabilities of different damages for the same stock), for the same return period.

For the regional scale, the above-mentioned methodology was simplified with the introduction of a scale to measure the intensity of the hazards, the utilization of matrices for the vulnerability instead of the functions, and the development of a matrix aimed at relating the degree of risk with the use of territory in order to provide dedicated planning actions.

2.3.7 PRIM - 2007

The methodology here presented was developed and applied for the PRIM - *Regional Integrated Program for Risk mitigation of Lombardy region*. The aim of the research was the realization of integrated multi-hazard and multi-risk maps, through an indicator-based approach, aimed at identifying hot-spots (areas at major risk) where addressing the public intervention. (Regione Lombardia, 2007) clarified that the methodology proposed was complementary to the traditional methodologies of risk analysis, and had to be interpreted as first qualitative-quantitative estimation of integrated risk. On the basis of a characterization of the hazards and vulnerabilities based on ISTAT datasets for the latter, and on databases and sectorial risk plan for the first, nine major risks affecting the Lombardy Region were analyzed. A dedicated set of indicators was developed, in order to express the physical risk RF, composed by the level of hazard and by the level of vulnerabilities. The relevance of the indicators was weighted with the method of the budgetary allocation and Fuzzy sets. The total risk was then obtained by mediating the physical risk with factors expressing the coping capacity.

Once obtained the 9 total risks, their respective importance was assessed through AHP (Analytic Hierarchy Process) method. In this way, it was possible to develop maps of integrate risk, able to point out the dominant risks for each zone, and a number of risk hotspot areas: three maps were developed, characterized by: at least 1 threat with a very high risk value, 10 times the regional mean, or more; at least 3 threats with medium risk value, 1.5 times the regional mean, or more; at least 2 threats with high risk value, 3 times the regional mean, or more. The proposed approach can be applied with different degree of detail depending on the quality of the available data. This allows the application of the method even in case of non-homogeneous data, which is often the case for regional scale analyses. Moreover, it allows the integration of different risk types or metrics.

It has to be evidenced that however, the effects of possible interactions are not taken into account.

2.3.8 Shortcomings

A large part of the approaches presented in the previous paragraph was based on quantitative techniques for risk analysis; the methodologies that adopted a qualitative index-approach were usually related to wider scales (i.e. ESPON).

However, even if a mathematically rigorous approach to multi-risk assessment apparently seems the most reliable one, many authors evidenced shortcomings and difficulties that could severely affect its efficacy. In particular, even when the methodologies define well-structured theoretical frameworks for the multi-risk assessment, their application to real cases usually require great simplifications, mainly related to the difficulties in obtaining the detailed information needed.

Some of the main criticalities of the quantitative risk assessment methodologies were punctually highlighted by (Garcia-Aristizabal and Marzocchi, 2011):

1) Not many methodologies take into account the possibility of hazard interaction or cascade effects: the importance of the risk combinations is recognized, however very few projects try to quantify some basic scenarios.
2) The fragility curves derived by intensity (of the hazardous event) vs. typology of exposed elements are not available for many risks analyzed. This topic can be

considered as one of the most significant matters to be addressed for future developments of multi-risk analysis, especially in high-resolution analysis (at local scale).

3) Multi-risk approach implies that one or more hazard affects different categories of exposed elements; this produces difficulties on the definition of a common metric for loss assessment, and the weighting of the different categories of exposed elements.
4) The choice of a specific kind of loss metric may present different problems and limitations. In fact, the effect of different hazards may have different temporal characteristics (e.g. the recovery of construction is not the same of that of agricultural land or trees). Also, different return periods, for different hazards, may pose difficulties to integrate the cost over a given period of time.

2.4 NaTech impact and methodologies

NaTech events constitute a peculiar type of multi-risk, where industrial plants or other facilities represent a second hazard that is activated by an external natural hazard. As remarked by (Chiaia et. al, 2016) this interaction produces an increment of the frequency and intensity of the accidental scenarios, that could reach areas not calculated and not foreseen inside the plants' safety reports.

Many authors pointed out that even if natural events are actually addressed in industrial safety, because national and international design standards require to address the issue of additional loads induced by natural events (earthquakes, wind, waves, lightning, etc), the procedures to include the external events in design are usually derived from those developed for structural integrity of residential buildings. This goes to the detriment of a real protection against NaTech events. In fact, i.e. for seismic stress, the main purpose of regulations like the Italian Technical Standards for Buildings (NTC), is to avoid the collapse of the building; it means that the building could endure damages until it is able to protect human life avoiding the complete breakdown. In an industrial field, a simple damage of the structures and facilities could assume a different meaning, because it can bring to loss of containment of hazardous materials.
(Cozzani, 2010) stated that the need of specific requirements to enhance NaTech resilience is rarely recognized at design level.

(Cozzani et al., 2010) and (Krausmann, Renni et al., 2011) developed a wide data collection on NaTech accidents on 5 European and 1 American accident databases, and other literature sources: it demonstrated that about 2–5% of industrial accidents fall inside NaTech category, but they can be triggered by several different natural events. The research aimed at identifying the main damage dynamics and consequences and, in the end, it pointed out that floods and lightning constitute the most frequent natural hazards triggering technological accidents, while seismic events have the greatest disruptive potential.

The following lines describe in detail, for each type of natural event, the most vulnerable equipment types, their modes of failure due to natural-event impact and the final accident scenarios.

1) FLOOD: The problem related to floodwaters is mainly due to the additional loads imposed on industrial structures and facilities, both due to the compressive force caused by the water itself and by its high-velocity flowing.

   Structural damage (displacement, impact with floating objects, yielding of support structures, failure of flanges and connections, collapse) and failure of electrical equipment are the two main damage modes identified. Storage tanks resulted the most vulnerable equipment, with 74% of the equipment involved in flood-triggered accidents, followed by transport pipelines and pipework with 17%, while cylindrical vessels (condensers, separators and boilers) and compressors and pumps were involved in 5% and 4% of accidents. In particular, atmospheric tanks are 3 times more vulnerable than pressurized tanks, because of their lower structural resistance, which favours the collapse of the tank shell or induces tank floating or overturning. These two conditions, together with the displacement of equipment due to water drag, are responsible of the more severe and continuous releases observed. Tank collapse resulted in several cases in catastrophic loss of containment with instantaneous release of the complete inventory. However, the main cause for loss of containment observed during floods is the failure of connections and valves, pipework detachment, and failure of pipelines, which led to minor leaks of hazardous substances.

   The primary consequences of a LOC are fires, explosions, toxic dispersion, but there are also additional flood-related consequences, as water contamination and formation of hazardous substances due to violent reactions of chemicals with water. In particular, the most frequent final scenario is related to water contamination: in many cases, it was observed that the released substances stratified on and were spread by the floodwaters, thereby contaminating them and also spreading over wider areas. Consequently, also surface and ground water contamination are possible. Frequently, no dedicated measures are adopted in industrial sites to manage the consequences of releases triggered by floods, even if flood events can cause the failure of the present disposals, like i.e. confinement barriers as catch basins, whose content may be washed out by floodwater.

2) EARTHQUAKE. The damages provoked by earthquake to industrial structures are mainly produced by direct shaking and soil-liquefaction effects. In 73% of the cases, the structural damage ended with a release of hazardous materials.

   The most vulnerable portions of the tank are the connections between shell and roof, shell and foundation plate, shell and supply pipes. The latter are the elements majorly damaged by the sloshing, that means the oscillation of the liquid inside the tank. Effects of the sloshing on the bottom elements of the shells are the break of connections of service valves and pipes, and the so-called elephant foot-buckling, which consists of a local bending near the base. Elephant foot-buckling could provoke the lift and overturning of the tank, if it is not anchored. The severity of the consequences of sloshing appears higher if the tank has a height-to-radius ratio of 0.8, and is at least 50% full: it.

As far as it concerns the roofs, the presence of rigid connections can amplify the vibration effects, leading to the bending of the top part of the shell, and other problems to the roofs. Finally, tanks that are simply placed on the ground without anchoring systems can widely suffer the effects of the soil liquefaction.

The most frequent final scenarios triggered by earthquakes were fires and the release of hazardous materials without ignition (based on the analysis of 48 case histories). In addition, explosions, the dispersion of toxic substances and water contamination were observed.

3) LIGHTNING: Lightning strikes on equipment of storage and processing activities are the most common cause of accidents triggered by natural hazards. Even if lightning protection measures are by far more diffused than those for other natural hazards (i.e. grounding of tanks, installation of lightning rods), their efficiency in preventing lightning-triggered fires is unclear, because it was observed that tank shunts could generate sparks when struck by lightning. This could lead to the ignition of the flammable vapors on tank roofs.

Lightning can also disrupt electrical control and safety systems and thereby cause dangerous process upsets.

Once again, the storage tanks resulted the items most frequently damaged by lightning impact (60% of equipment involved in accidents): the atmospheric tanks, and in particular those with floating roofs, were the most vulnerable to lightning strikes. Pipework was directly involved in over 11% of lightning-triggered accidents.

The majority of lightning-triggered accidents resulted in the release of hazardous materials which did not ignite or explode, but fires occurred in over a third of the analysed case histories, while a lower number resulted in explosions.

The results of the accident analysis showed that:

- atmospheric storage tanks, and in particular floating-roof tanks, are the most vulnerable elements in relation to all the natural hazards analysed;
- 27% of registered events interesting chemical and petrochemical industry (petrochemical storage, chemical industry, plastics manufacturing),
- gasoline, oil and diesel are the hazardous substances more frequently involved in NaTech accidents. These substances, extremely flammable and dangerous for the environment, are detained in high capacity storage tanks (up to 50,000 m^3 in a single unit), and can therefore lead to accident scenarios with significant severity, when loss of containment occurs. Clearly, the ignition probability is high after the release of a flammable substance during an earthquake or a lightning strike, but the release in case of flood could also produce water contamination and consequences of the reaction of the substances with water.

(Krausmann, Renni et al., 2011) evidenced how managing the above descripted NaTech risks could be difficult without targeted measures or procedures for the prevention or the mitigation; the latter should be particularly important for the existing plants located in natural-hazard-prone, where land-use-planning restrictions can hardly be imposed retroactively.

An additional complication in most NaTech accidents is the downing of lifelines by the natural event. Emergency-response plans do not usually consider the loss of utilities during a natural disaster, which renders the mitigation of the accident difficult if not impossible.

Even if the presented data collection considered only one climate-related event (the lightning), also other phenomena are able to cause problems to the industrial facilities. Heavy rains, storm surges and extreme temperatures, for which it was observed an increasing tendency in relation to climate change, can once again produce consequences particularly on the tanks. I.e. heavy rain can cause sinking of tank roofs, while the sites can be affected by insufficient water drainage or increased groundwater levels. As for the flood events, in case of loss of containment the presence of the water deriving from rainfalls provides a medium for the dispersion of the released substances.

The extreme temperatures can also provoke damages: high temperatures could conduct to ignition of substances stored outside, and lead to pressure increases in storage facilities, while low temperatures may produce the freezing and bursting of pipes, and the ice formation can also damage the equipment and break pipes.

As far as it concerns the Italian situation, unfortunately many Seveso plants result included in hazardous-prone areas: the particular physiognomy of the Italian territory exposes the plants to several natural hazards, from floods to landslides and coastal risks. (Chiaia et. al, 2016) observed that a high number of so-called E.R.I.R. industrial plants is settled in correspondence of sites with medium or high seismic hazard, as shown by **Table 5** , that shows Region by Region the amount of Seveso plants located in seismic areas. Frequently the installation of these plants date back to periods with a minor legislative control, both as far as it concerns the constraints deriving from natural risk presence, and the rules related to the management of hazardous substances. The absence of dedicated planning practices and clear procedures for the zoning led to plants located nearby residential areas, or close to highly vulnerable environmental zones, and/or in areas interested by hydrogeological frailties, seismic effects etc.

Table 5: Major risk plants located in seismic zones (Smanio, 2013)

Region	*Total plants*		*Plants in seismic zone*		*Plants in seismic zone 1*		*Plants in seismic zone 2*		*Plants in seismic zone 3*		*% plants in seismic zone*	
Abruzzo	16	10	6	3	-	-	6	3	-	-	37.5	30
Basilicata	4	5	2	1	-	1	2	-	-	-	50	20
Calabria	10	7	5	6	3	4	2	2-	-	-	50	87.5
Campania	52	18	32	18	-	-	15	5	17	13	61.5	100
Emilia Romagna[5]	36	93	18	3	-	-	18	3	-	-	50	3.2
Friuli V. Giulia	14	20	11	3	4	2	7	1	-	-	78.6	15
Lazio	33	36	24	12	-	-	24	12	-	-	72.7	33.3
Liguria	10	24	1	2	-	-	1	2	-	-	10	8.3
Lombardy	133	155	1	1	-	-	1	1	-	-	0.75	0.65
Marche	9	7	7	7	-	-	7	7	-	-	77.8	100
Molise	3	5	-	1	-	-	-	1	-	-	-	20
Piedmont	50	53	1	1	-	-	1	1	-	-	2	1.9
Puglia	23	20	-	-	-	-	-	-	-	-	-	-
Sardinia	14	28	-	-	-	-	-	-	-	-	-	-
Sicilia	37	34	37	25	1	-	36	25	-	-	100	73.5
Toscana	32	30	29	13	-	-	29	13	-	-	90.6	43.3
Trentino	11	6	-	-	-	--	-	-	-	-	-	-
Umbria	12	5	8	3	-	-	8	3	-	-	66.7	60
Valle d'Aosta	5	1	-	-	-	-	-	-	-	-	-	-
Veneto	52	60	2	-	-	-	2	-	-	-	3.8	-
Italy	556	617	196	109	8	7	169	83	19	19	32.5	17.7

The previous description clearly evidences the urgent need for the adoption of a NaTech assessment methodology to integrate Safety reports risk assessment; until now, several methodologies were proposed, mainly quantitative, but still a dedicated regulation is missing. Below, some of the most known procedures are reported; it can be noticed that all the approaches usually require a deep experience as risk analysts, even when they foresee the adoption of simplified procedures. They were usually developed to address one natural risk at time, and are generally restricted to some plant typologies and to the area of the plant itself, with the exception of the Integrated Quantitative Risk Assessment (Q.R.A.).

2.4.1 Integrated Quantitative Risk Assessment

The methodology of the integrated Quantitative Risk Assessment was developed by (Antonioni et al., 2007), (Salzano et al., 2009) (Cozzani et al., 2010), (Krausmann et al., 2011), during 10 years; it aimed at inserting domino risk and nature-related risk in the

[5] The seismic class classification of many municipalities of Emilia Romagna and Lombardy was changed after the earthquake of 2012; therefore, probably the Seveso plants included in the seismic zones are more than those reported.

conventional Q.R.A., in particular considering the impact provoked by flood, earthquakes and lightning.
The identification of the possible failures of equipment triggered by a natural event, and its potential consequences, can suggest the plant managers the correct measures to be adopted to increase the resilience of the facility. I.e. at a design level, an enhanced solidity of the equipment or the addiction of safety barriers, together with appropriate emergency measures and procedures, and implementation of early-warning systems.
Therefore, the conventional procedure for quantitative risk assessment (Q.R.A.) was modified and extended to include the assessment of Na-Tech events. Some steps of the proposed procedure follow the traditional ones, but dedicated tools for the inclusion of external events had to be introduced, in particular as far as it concerns the identification of the more frequent damage modes and the release scenarios associated to them.
The following framework for a NaTech inclusive QRA was identified and proposed for three types of natural hazards: earthquake, flood and lightning.
Step 1: characterization of the external event through a parameter representing its impact strength:

- for earthquake → P.G.A.- Peak Ground Acceleration;
- for flood → maximum water depth expected at the site, or maximum water speed;
- for lightning → ground flash density Ng, measured in number of flashes per year and m^2

Step 2: identification of the relevant target equipment items, which can cause a severe scenario due to an escalation triggered by the natural event. Following the results of the data collection analysis by (Cozzani et al., 2010) and (Krausmann, Renni et al., 2011), the proposed procedure particularly focused on the atmospheric tanks. Reference scenarios were associated to each critical equipment item, as explained in the following steps.
Step 3: identification of a limited number of possible damage modes that can be associated to the reference target equipment identified in step 2. The definition of damage states (DS) is used to calculate the consequent intensity of loss of containment: three classes of releases were considered for storage and process equipment, as well as for piping.

- R1 → instantaneous release of the complete inventory (in less than 2 min) following severe structural damage;
- R2 → continuous release of the complete inventory (in more than 10 min);
- R3 → continuous release from a hole having an equivalent diameter of 10 mm.

Later, the development of specific event trees, based on the properties of the released substance, identifies the NaTech reference scenarios that could be associated to the damage mode. The following **Table 6** shows, for each type of natural hazard, the possible damage states and the releases associated; it is a recap of the tables reported in (Salzano et al., 2009), (Cozzani et al., 2010), (Renni et al, 2010).

Table 6: Damage modes and release states

Impact	Type of damage	Definition	Release mode
		Earthquake	
	Elephant Foot Buckling	Large axial compressive stresses due to beamlike bending of the tank wall	R1
	Base uplifting	Overturning moment may be cause a partial uplift of base plate; this vertical displacement can cause the failure of tank wall and/or the failure of piping connection	R1
	Sloshing	Roof or Top damage due to liquid movement	R3
	Sliding	For un-anchored tank only: the horizontal relative displacement between tank and base can cause the failure of I/O piping	R2
	Collapse (Liquefaction)	Rapid release of content due to total collapse of structure for the ground liquefaction due to earthquake	R1
		Flood	
Slow submersion	Failure of flanges and connections		R3
Moderate speed	Failure of flanges and connections		R3
High speed wave	Impact of/with adjacent vessels or with trailed objects		R1
	Shell fracture		R2
	Failure of flanges and connections		R3
		Lightning	
	Electrical device malfunctions		-
	Explosion		n.s.
	Pipework detachment		R3
	Pool fire		R2 or R1
	Roof fire		R1

Step 4: Estimation of the damage probability. A probability of occurrence for the damage state identified is calculated for each equipment.

The damage probabilities should be assessed through specific vulnerability or fragility models; but in literature, vulnerability functions were available only for seismic events. New simplified vulnerability functions were proposed both for flood and for lightning, based on the analysis of the accident collection and literature data.

Step 5: Consequence analysis for the reference scenarios. It can be carried out through conventional models, i.e. post-event trees.

In this phase, it is necessary to consider simultaneous occurrence of reference, due to the damage of more than one unit. The further steps of the analysis are related to the definition of the characteristics of the combined events: Step 6: credible combinations of events; Step 7, the frequency calculation; Step 8, the consequence assessment of each credible combination of reference releases (or overall final scenario).

Finally, the last step of the procedure consists of risk re-composition (step 9) aimed at assessing the additional contribution to individual and societal risk.

The methodology above descripted was partially developed also in the field of the European project Integ-Risk (Krausmann et al., 2011), where a further detail was introduced to describe the equipment vulnerability. Hazard indices for natural and technological events, and an equipment vulnerability ranking were introduced. Using this natural-hazard and technological-hazard classifications, vulnerability analyses for industrial equipment under natural-event loading was performed.

2.4.2 AHP applied to NaTech risk

The methodology for the assessment of NaTech seismic risk through AHP techniques was developed by a team of the Politecnico di Milano, as an alternative to the execution of a Q.R.A. procedure, with the aim of reducing the required resources in terms of time and expertise (Callioni, 2010), (Busini et al., 2011), (Marzo et al., 2015).

The objective was to define a Global Key Hazard Indicator (KHIG), which could help the decision makers in distinguish between high-risk situations, for which it is necessary to undertake a Q.R.A. and to provide risk mitigation measures, and low-risk situations, therefore avoiding wasting of resources using unnecessary expensive methods of Risk Analysis. The assessment of the KHIG was based on two different indexes: the Key Hazard Indicator (KHI), and the Vulnerability Indicator (KVI), whose values were calculated by applying the hierarchies of AHP methodology, a multi-weighted criteria method that allows choosing between alternatives thanks to binary comparisons.

I.e. for the assessment of KHI, the main elements that can influence the vulnerability of the plant with respect to earthquakes were identified and inserted in a system of AHP hierarchies, which represent different possible events. Three different hierarchies were structured, to define three KHI, representing the main potential seismic consequences on a plant: fires, toxic dispersion and explosion. The overall KHI was obtained from the sum of the previous mentioned three indexes.

The comparisons are structured as shown in **Figure 5**. The alternatives, placed at the bottom of the hierarchy, can represent different plants, or items of a single plant; the possible impact on them is expressed as a normalized index of the mass which can be released following a seismic event.

The process of the assessment follows the branches structured at different levels, which have to be compared; the elements are placed on the same level of the hierarchy if they respond to the same question. The comparisons are expressed as qualitative judgments that can be traduced in quantitative through the semantic scale of Saaty, which may allow an array of binary comparisons between elements belonging to the same level. Simple algebraic manipulations of these binary comparisons determine the weights for the various branches of the hierarchy.

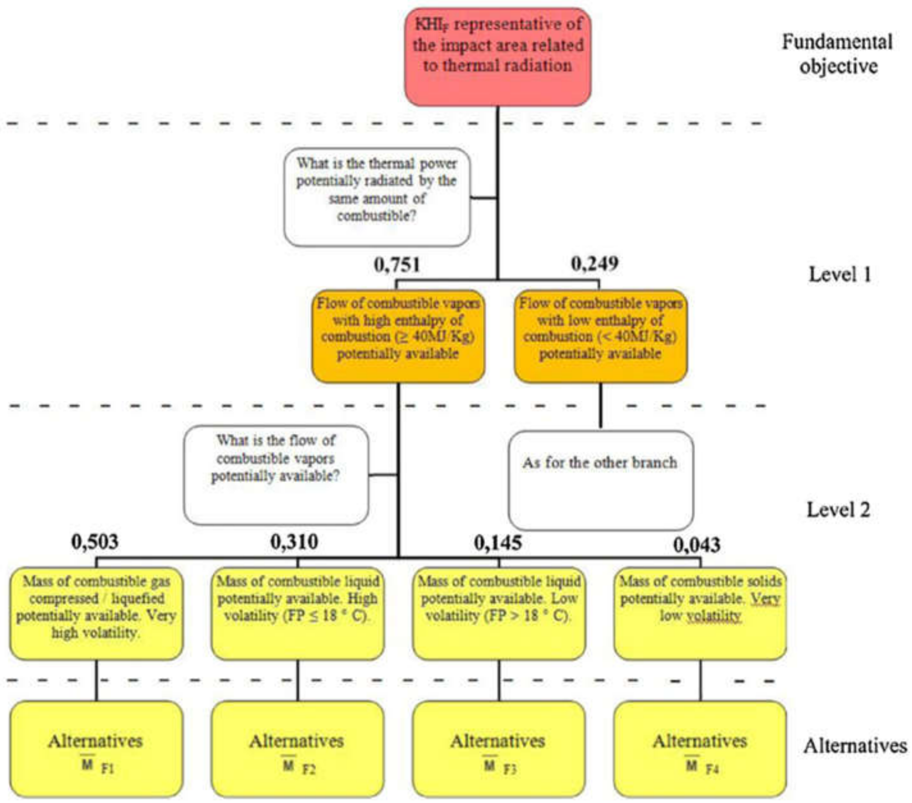

Figure 5: KHI index assessment

The index KVI expresses the level of vulnerability associated to a given territory around an industrial plant; also in this case, AHP method is applied, and the alternatives inserted in the hierarchies are all the vulnerable elements. The KVI computation requires the evaluation of both the number of people and the number of vulnerable centers present inside 1k m and/or 7km radius from the plant, which are the areas associated to fire/ explosion or toxic dispersion. Once KVI value is computed, the overall risk indicator KHIG can be estimated.

2.4.3 NaTech risk index

(Galderisi et al., 2008) developed a risk assessment method able to act as a supporting tool for land use planning strategies aimed at reducing NaTech risk in urban areas. The method provided planners with a NaTech risk index, useful to rank the territorial units and to single out the priority intervention areas. A multi attribute decision-making method, combined with fuzzy techniques, was proposed.

The first step consisted of the characterization of the natural and technological hazards affecting the urban area; the identification of NaTech prone areas was carried out through the overlaying of the natural and technological hazard-prone maps.

Each NaTech prone area was then divided into spatial units (SUs) based on census units, combined with the main land uses (residential, industrial, agricultural, etc.) The SUs constituted the elemental units with respect to which hazard, exposure and vulnerability features were assessed. The authors defined criteria, parameters and procedures for measuring the three factors above-mentioned:

- the parameters related to natural hazards were defined on qualitative hazard levels (high, medium, low), provided by the hazard analyses and maps.
- the parameters for the industrial hazard were defined on the basis of the scenarios provided by the Safety Reports, selecting the ones which could had been triggered by the natural hazards. However, the authors recognized that these event scenarios could not be totally adequate to represent the effects of Na-tech events, since in Safety Report natural hazards are not generally taken into account as triggering factors. Thus, the ‘‘unordinary’’ chains of failures and damage due to natural hazards should be outlined and investigated through specific analyses carried out by expert risk analysts.
- the parameters for exposure and vulnerability were defined on: type, quantity and relevance of elements that may be threatened by each hazardous event. The grid of vulnerability indicators developed within the ARMONIA Project (2006) with respect to several natural hazards was adopted.

Once numerical values were assigned to the defined parameters, converting the linguistic values into numerical ones through fuzzy techniques, all of them were systematized and processed through a MADM – Multi-Attribute Decision Making system.

The different SUs of the NaTech prone area were assumed as the ‘‘alternatives’’ of the MADM, while hazard, exposure and vulnerability indicators were interpreted as the ‘‘attributes’’. An aggregate NaTech risk index can be defined through the final rating of the attributes.

Different techniques can be applied for rating the attributes; nevertheless, attributes’ values are usually standardized for obtaining comparable values and then aggregate through adequate formulas. Then, the priority intervention areas can be singled out through the ranking order of the alternatives with respect to the NaTech risk index.

2.4.4 RAPID-N

The RAPID-N methodology was developed by the Joint research Centre, with the aim of providing a quick tool for NaTech risk assessment and mapping methodology at a regional level (Girgin & Krausmann, 2013). RAPID-N is basically an online software constructed on some risk assessment procedures, that does not entail a complete quantitative risk assessment (QRA). RAPID-N methodology is based on the calculation of on-site hazard parameters for natural hazard scenarios and on the use of fragility curves to determine damage probabilities at plant units (e.g. storage tanks) for different damage states. Damage states are linked to risk states, which define possible hazardous consequence scenarios resulting from the natural hazard triggered damage. Finally, the probability and severity of the potential consequences are calculated by using conventional industrial accident consequence models. The structure of RAPID-N is based on modules, which constitute interconnected subsystems focusing on different aspects of NaTech risk assessment: RAPID-N consists of 4 main modules:

- The Scientific module, that includes the property definition and estimation framework that is a key component of damage assessment and consequence analysis calculations. It also provides support for bibliographic citation, unit conversion, and GIS analysis.
- The Natural hazards module, which provides source and site specific (on-site) natural hazard data.
- The Industrial plants and units module, which covers information on industrial plants, their units, and hazardous substances found therein.
- The NaTech risk assessment module, which constitutes the core module of RAPID-N. It covers the elements needed for performing NaTech risk assessment, such as fragility curves, damage states, and risk states.

2.4.5 NaTech seismic risk assessment for oil plants

ENI spa designated (Chiaia et al., 2016) for the development of a methodology for the assessment of the seismic vulnerability of oil tanks, LNG vessels and process items (like, e.g., cracking columns, reactors, desalters and chimneys) to be adopted in the Italian oil and gas refineries and deposits. The proposed approach is based on a 3-stages protocol.
The first activity (Stage 1) is represented by the selection of the items to be analyzed on the basis of their risk exposure; they can be identified through classical indexes methods, considering the nature and quantity of the hold-up (related, e.g., to inflammability and environment danger), the specific process, the plant layout and the possible activation of domino effects.
In the second stage, a simplified structural analysis is carried out for the selected items. Normally, the API650 code is used in the case of tanks, whereas the Italian and European building codes are adopted for process items and chimneys. The seismic loads are obtained through linear dynamic analyses on simplified structural models, assuming conservative values whenever a direct knowledge of some mechanical quantity is not available. Then, the state of stress and some critical displacement are computed at significant points (e.g., piping connections, anchorages) and an estimate of vulnerability is obtained. Combining this value with the seismic hazard and with the quantified potential for loss that might occur because of an accident, a first quantification of the seismic risk is obtained for each item.
The third and last stage includes the direct knowledge of materials (also through experimental tests) and detailed structural calculations (FEM models and nonlinear analyses). It is developed only for items whose seismic risk is above a threshold value.

2.5 Discussion and proposals

As already evidenced in this chapter, the land-use regulations demonstrated a general slowness in integrating practices that account for different risks; indeed, it should be said that so far now the importance to adopt mitigation and protection planning practices to address Multi-risk events was not completely recognized, partially because of the very low probability that connotes these events. The question of the probability of occurrence of the events represents a crucial node: societies and decision makers tend to focus their attention and resources on events that happen frequently, even if the risk associated with a rare, extreme event might be much greater. The intensity of attention paid to natural hazards mostly depends on the experiences of recent disastrous events rather than on the occurrence of disastrous events in a distant past or on scientific hazard assessments. The result is a tendency to underestimate the hazard and thus the risk presented by extreme events. (Menoni et al., 2006) stated that planners are generally reluctant to consider risk estimates expressed in probability terms, when deciding for example a residential development; especially in the case of potentially rare but very harmful events, planners often end up taking the risk, as they do not fully understand the implications of probabilities.
Another problematic aspect related to probability is related to uncertainty: dealing with the exact prediction of the temporal occurrence of a hazardous event always produces uncertainties, which could increasingly grow for multiple hazards acting in the same moment, or triggering hazard-related chains. In addition, in many cases, the uncertainty in the risk assessment can be significantly increased by the lack of historical and technical data and analysis, both for hazard and most of all for vulnerability.
Some quantitative methodologies analysed the Multi-risk probability with a rigorous approach based on event trees (Marzocchi et a., 2009, Cozzani et al., 2010), but (Nadim & Liu 2013) in their report for MATRIX project warn that "in many situations the decision-maker in charge of risk management can identify the optimum alternative among those options available without doing a detailed, rigorous multi-risk analysis. One may also encounter situations where the gain in the accuracy of the risk estimate through a rigorous multi-risk analysis approach, where the interactions among the different hazards are explicitly accounted for, is insignificant compared to the uncertainty in the risk estimate".
In the end, (Menoni et al., 2006) concluded that "on one hand planners understand too little about risks, in the sense that they ignore many technical components that are central to well informed decisions; on the other hand, though, perhaps specialists in various fields studying risks have failed to produce results in a form that could be useful to planners".

With reference to the Italian situation, the national framework for land-use planning could represent a further obstacle for the integration of Multi-risk procedure in the common planning tools. As mentioned in Chapter 1, the risks are usually addressed through dedicated sectorial plans in charge of superior authorities, as Basin Authorities, External Agencies, Civil Protection, Regions, Provinces; the Municipal City Plans, that directly manage the use of territory, implement the results of hazards and risk assessment studies. This planning structure produces two different effects: on one side, the high level of sophistication and precision of sectorial plans is rarely translated into likewise sophisticated local land-use planning tools. On the other side, even if the scale of the sectorial plans sometimes does not allow to reach high levels of detail for the local analyses, the knowledge patrimony that the local authorities have on their territory remains completely unused. (Delmonaco et al., 2006) observed that hazard methodologies generally produce better results at a local level, which become crucial in avoiding larger disasters that may involve regions far away from the area directly hit by an extreme event or accident. Indeed, the local managers have a deeper knowledge of their territory and its mechanisms, and dealing with a limited area allows them to carry out analysis with a higher level of precision.

Therefore, as far as it concerns Italy, in order to have an effective integration of multi-risk concepts in common practices, this should start with the City plans; but the analysis at local level is exposed to several technical, organizational and financial difficulties, which could complicate the process.

In fact, at the moment the Italian local administrations seem to be not so prepared to correctly manage a process of integration of multi-risk rigorous methodologies in their planning instruments.

First, the approaches previously presented entail very heterogeneous competencies: beside the data collection on natural and technological hazards, all the methodologies require to have specific skills in risk assessment techniques, AHP methods and Multi-attribute decision making systems, G.I.S. planning. All these fields, that so far now have been separated both scientifically and operatively, have to be kept together and managed in an overall risk perspective.

However, traditionally the local planners responsible of the City plans come from the architectural or, rarely, civil and building engineering sectors; the issues strictly related to environment, and marginally to industrial settlements, are not even directly managed by the Land Use department, and in any case, competencies related to risks are rarely available. The only case in which risk is directly faced is in relation to the Emergency Plan, which however recovers once again many indications from the sectorial plans.

This organization could make difficult for the local administration even the draft of E.R.I.R. planning, therefore it is quite clear that the management of the multidisciplinary knowledge and techniques required by the multi-risk and NaTech approach here presented, also for those proposed as “simplified methodologies”, would require in any case a mediation role by experts of the sectors. However, currently the local administrations in Italy are subject to spending review problems, which difficulty allow them to invest in projects different from the everyday administration, particularly when in the end no national laws require to address Multi-risk problems.

Another difficulty for an effective Multi-risk assessment is the lack of a structured and detailed assessment of the local vulnerabilities. In 2003, Civil Protection made an attempt to

identify the elements more exposed to seismic risk, requiring to the Municipalities the draft of Vulnerability data-sheets, at least for the strategic buildings and infrastructures. Three different data-sheets were structured, with different levels of detail, to better know and therefore reduce the earthquake effects, particularly in the Highest risk zones. However, so far now, and after two postponements, only the first level sheets, more generic and related to statistical purposes, have been compiled by all the Italian municipalities.
As far as it concerns the other risks, no vulnerability mapping was predisposed at a national level, with the exception of some studies executed at local or regional level.

The result of the mentioned situation is an overall diminution in the safety of the territory and in the protection of the people. Despite of the current planning systems, in Italy the consequences of natural hazards continue to cause victims and malfunctions, in particular as far as it concerns risks activated by extreme climatic conditions like intense rainfalls and storms.
I.e. in the last decade, Geneva was interested by repeated severe flood events with a frequency of occurrence dramatically higher than the foreseen return times. Even if an Emergency plan was drafted, it demonstrated to be inadequate: both by the Municipality and the citizens long knew the major point of criticality, consisting of an underground portion of the Bastogne creek, but it was not analysed in the plan. The creek overflew exactly in that point, causing 12 deaths, and great economic damages.
The recent tragedy of Rigopiano hotel, invested by a snow avalanche provoked by repeated earthquake shakes, is an emblematic case of multi-risk event connoted by a very low probability. After the tragedy, a hydrogeological hazard map of 1990, that evidenced the presence of dejection conoids in the area that generated the avalanche, was found; but this map had not been included in any planning and risk management instrument in force. Therefore, the City plan authorized the construction of the hotel in an area exposed to an extremely high risk of avalanches.

Some general data that underline the particularly delicate Italian conditions can be found in the ISPRA Annual Environmental report (ISPRA, 2016), which shows some of the main risks affecting Italy and their effects. 66% of the landslides registered in Europe takes place in Italy, that mean 600.000 landslides per year, which in 2015 caused 12 victims and 271 damage episodes, mainly involving the railways and road networks. At the moment in Italy, 500 thousand people live in areas with very high landslide risk, 744 thousand people in zones with high landslide risk, and 1,5 million people in areas connoted by medium landslide risk. As far as it concerns earthquakes, Italy is the second most exposed country in Europe after Greece. According to (ISPRA, 2016), 10.297 Italian municipalities are located in First class seismic zones, equal to 5,4% of the total number of Italian local administrations; the 28% of the Unesco Italian sites is also located in seismic zones. 2016 was characterized by an intense seismic activity that hit and is still interesting the areas of the centre of Italy, already labelled as First class seismic risk areas (areas in which the ground acceleration registered is > 0,25, with the probability to overcome the registered values of more than 10% in 50 years). From

August 2016 to January 2017, 4 major earthquakes hit the Apennine portions of Marche, Abruzzo, Umbria and Lazio Regions, causing more than 300 victims and an incalculable damage to the artistic and cultural heritage.
In spite of the presented data, the consumption of land continues to increase; 21.000 square meters of territory result already urbanized, and this exacerbates the effects of natural hazards and combined events. Finally, another alarming data reported by (ISPRA, 2016) is related to climate change: the increasing of the medium temperature registered in the last 30 years in Italy resulted higher than that globally registered; in particular, 2015 resulted the hottest year, with an increased temperature of +1,58 °C.

The integration of Multi-risk and Na-Tech approaches in the European and national regulations would represent the best solution to extensively improve the land-use planning practices and grant a higher safety for the territories. However, a rapid change of the Italian regulations in that sense appears to be far. Currently, the Municipalities are still demanded to firstly intervene on the territory both for planning and emergency without any basics about Multi-risk.
Considering the actual situation, the Municipalities should be put in the position to assume a more active role towards these commitments, at least being able to recognize and point out the main criticalities of their territory. However, if the objective is to make them more aware and ready to face the events related to Multi-risk and NaTech events, the proposal of complex approaches in this field, even if accurate and detailed, could not be the proper solution. In fact, the lack of the necessary technical and financial resources risks to keep any knowledge and improvement about Multi-risk confined inside Universities and research centers, because the Municipalities prefer to address their financial budget to the contingent priorities.

As already proposed by other projects, which introduce multi-level strategies, maybe the implementation of an easy-to-use screening instrument, based on a simplified methodology like an index approach, would allow the Municipalities to directly understand and evaluate the risks and possible risk interactions that affect their territory. In accordance with the superior authorities, they could then define possible further actions, also including the adoption of more specific risk-assessment procedures.

The following chapters present the methodology proposed for this screening path. Since the research started from E.R.I.R. shortcomings and from the lack of specific indications related to the relationship Industry – Natural events, the entire development of the methodology maintained a strong connection with the E.R.I.R. planning procedures, and particularly focused on the industrial risk and its implications.

Chapter 3

Proposed methodology

3.1 Methodological foreword

The methodology proposed aims at representing a screening tool for the Municipalities, able to return a clear image of the points of major criticalities on the territory, also including areas where interactions between hazards could take place, producing unexpected consequences. The methodology had the objective to be as much as possible user-friendly and easy for a direct use by the Municipalities technicians, therefore this was the principle that guided the development of each step.

As already stated in the Chapter 1, the general framework adopted for the methodology partially reflects that of the E.R.I.R. drafting. However, new procedures for each step were developed and introduced, in order to face multiple hazards and the specific need to return an estimation of their interaction. One of the main difference with respect to E.R.I.R. consists of the choice of not taking into account neither the probability of each hazard, nor the probability of the interactions, therefore not to proceed with a proper quantitative risk assessment based on probability. This choice was due to different reasons, partly related to the nature of the events analysed, partly due to considerations related to the purposes and final users of this methodology, which are summarised below for clarity purposes:

1. Some difficulties towards the estimation of probability for NaTech and Multi-risk events are embedded in the current risk assessment methodologies themselves. I.e. for the industrial accidents, the Safety reports of the companies usually do not develop the analysis of the consequences - and therefore the scenarios, for events with a frequency of occurrence inferior to 10^{-6} events/year. Consequently, the land use planning developed with the E.R.I.R., which is based on the probability of the scenarios, in the end does not take into account the consequences of high impact but low probabilities events, as those deriving from the interactions of multiple risks.
2. The proposed methodology had to consider not only industrial hazard, but also other technical and natural hazards characterized by different recurring times and methodologies for the probability assessment. As remarked in Chapter 2, this step is one of the main issues of the Multi-risk and NaTech methodologies. Fundamentally, two different types of approach tried to deal with it: the adoption of a detailed Quantitative Multi-risk analysis, or simplified methods based on indexes, aimed at "homogenizing"

the risks. Even if an integrated Q.R.A. demonstrate to return better results, it also entails problems related to the time and costs, and still huge uncertainties can remain for the estimations of probabilities.

3. The climate change is reducing the reliability of the probabilities assessed for risks influenced by climate, as i.e. flood and landslides. In fact, as demonstrated by the IPCC report on Climate Change 2014, Europe is undergoing an observed climate modification in relation to temperature variations and precipitations, with different consequences for Northern and Southern Europe (Kovats and Valentini, 2014). In particular, Italy (Southern Europe) underwent an increase of 1°C in the medium yearly maximum temperature, and a diminution of the rainy events in the last ten years; the frequency of extreme precipitation events passed from 2% to 4%. As specified by IPCC, “Climate change will increase the likelihood of systemic failures across European countries caused by extreme climate events affecting multiple sectors”; therefore, at the moment, i.e. the probabilities calculated for hazards prone to the influence of climate events could be in some cases considered optimistic, because they do not account for the increase frequency of extreme rainy events. This initial uncertainty could produce mistakes in the estimation of the probabilities of occurrence of the final events, even if these data are assumed as reliable and certain.
4. As pointed out in Chapter 2, L.U.P. decision-makers have a singular relation with the concept of probability: high probability – low impact events have a great influence on the choices of policy-makers, but the consequences of events with minor probability are frequently addressed on the basis of different logics, i.e. public opinion trends, recent striking events etc. In the end, high impact - low probabilities events tend to be neglected; therefore, the elimination of the probability analysis, at least in a first screening of the territory, could help the decision-makers to consider more objectively the risks that threaten the area that they administer.
5. The skills of the Municipal technicians have to be taken into account: they deal with land use planning and direct administration of the territory issues; however, rarely they are experts in Risk analysis. Even if, as previously stated, many authors recognized the validity of a quantitative risk approach applied to multi-risk scenarios, the difficulties related to the lack of data, required skills, time consuming, etc. could be insurmountable for not-expert users; maybe a simpler approach, based on the main strengths of the final users, could facilitate and spread the habits to include risk interaction in the planning practices. In any case, even if a proper probability was not calculated, still the historical and recent recurrence of the events was taken into account in the proposed methodology as an “influencing factor”, considered for the phase of Hazard characterization.

3.2 An index semi quantitative approach

On the basis of the above-mentioned considerations, a semi quantitative index-approach was proposed, similarly to those adopted for European projects like i.e. ESPON and ARMONIA, which are briefly exposed below:

- In ESPON (Schmidt-Thomé, 2006), the hazards were homogenized on the basis of an intensity scale divided into five classes, from very low to very high (1 to 5); however, due to the huge number of hazards analyzed (13), the parameters adopted for each hazard to express the intensity have very different contents and precision, and in most cases, they could not be useful for a local-scale approach. I.e., for the industrial hazard, the intensity scale was founded on the number of plants insisting on the areas, which is a parameter too general for a Municipality.
- ARMONIA (Menoni et al., 2006) proposed a two-level approach: a simplified one for the regional scale, and a more detailed framework for the local one. In particular, for the first one, the natural hazards were rated as “Low, Medium, High” on the basis of intensity parameters, that were more detailed than for ESPON, as it is possible to observe in the following table. However, it should be said that some of these parameters are rarely available in the sectorial plans, like i.e. the flood depth.

A 4 levels scale, influenced by these two experimentations, is here proposed by the Candidate, with the scope to evaluate both the impact of each hazard and of their interaction. The scale expressed in absolute value is:

$0 < I \leq 0{,}99$: Negligible
$1 < I \leq 1{,}99$: from Low to Moderate
$2 < I \leq 2{,}99$: from Moderate to High
$I \geq 3$ onwards: from High to very high.

The scale is employed with a double perspective. On one side, it is used during the phase of hazard characterization to evaluate the hazards, through the assignation of ratings to three macro-categories which describe different components of the same risk. On the other side, it measures the possible impact of the interactions between hazards.

A proper re-composition to obtain a unique index was not executed; in fact, from the point of view of the intended final users (municipal technicians), a unified unit of measure may not be so practical, as remarked also by (Menoni et al., 2006). On the contrary, a unique index, aimed at classifying the different impact of the various risks on the entire municipal territory, could present a problem of scale and significance: in fact, it could not point out the areas where the same risk assumes higher values, neither the areas more exposed to possible risk interactions. In the end, the identification of a unique risk index could not properly guide the decisions to be taken at a local scale.

As detailed in the following paragraphs, the introduction of the macro-categories to describe each hazard aimed at improving the current hazard characterization, trying to bring the final users to examine and point out every aspect of the hazard analysed, in every portion of the

Municipal territory. This partition was maintained also for the compatibility assessment stage, where the ratings assumed by the macro-categories are taken into account, together with the values calculated for the interaction. Focusing on these aspects allow the Municipalities to better identify the nature of the problems analysed and to better address them during the last phase of the methodology, dedicated to the choice of further studies and interventions.

The macro-categories are effectively summed up only the during the assessment of the binary interaction value, where the components of each hazard are interpreted as elements contributing in various degrees to the final impact of the interaction. However, in this case, the scope is to provide the Municipalities with an esteem of the possible consequences of the interaction, giving them a basis to verify if carry out further studies.

The proposed methodology is organized on the basis of the following steps:

- STEP 1, Hazard characterization, described in the following Paragraph 3.3.
- STEP 2, Assessment of the binary hazard interactions and multiple hazard interactions, described in Paragraph 3.4.
- STEP 3 (optional), Assessment of the spatial consequences of the interactions involving industrial hazards, described in Paragraph 3.5. Two free modelling software were employed to verify possible atmospheric releases and pollution caused by the possible impact of natural events on Seveso plants, to help the Municipalities in improving the compatibility assessment.
- STEP 4, Compatibility assessment, described in Chapter 3.6. Vulnerable territorial and environmental elements are identified according to national and regional guidelines for E.R.I.R., the compatibility is assessed on the basis of a threshold of 2,5, corresponding to a Medium-High impact, evaluated for the macro-categories, and the interactions.
- STEP 5, Planning, described in Chapter 3.7. On the basis of the potential incompatibilities encountered, the Municipalities can proceed with further studies and quantitative analysis, and then settle possible interventions. Possible measures and recommendations provided by existing manuals and guidelines were collected and listed to guide the process.

3.3 Hazard characterization

The hazard characterization is composed by 3 phases, which should be carried out by the Municipalities technicians: 1) Collection of the data, analysis and maps contained in the existing sectorial plans, thematic studies, Emergency plans etc; 2) Organization of the collected information on the basis of three macro-categories (Strengthening effects, Historical events, Protection Measure); 3) Attribution of a rating to each macro-category of each hazard, in compliance with the 4-level scale.

3.3.1. Data collection

An in-depth study of the sectorial plans, hydrogeological studies, surveys etc. should be the unavoidable basis of the proposed hazard characterization. In fact, in spite of the structural difficulties presented in Chapter 1, a good knowledge of the existing plans is very important for the local technicians and managers to reach a safer use of their territory. For each hazard analysed, the spatial distribution of the events, the criticalities, the intensity and any other important element signalled in the existing plans has to be collected and kept to be used in the following phase, to evaluate the effective dangerousness of the hazards insisting on the Municipal territory.

For the hazards choice, very different approaches were found in the existing methodologies. Sometimes, a heterogeneous range of risks is taken into account, i.e. PRIM Lombardia included road accidents, workplace accidents, urban safety, climate, industry, hydrogeological elements, earthquake, and forest fires. Piedmont regional guidelines for Emergency Plans requested to elaborate risk scenarios for asteroids, health emergencies, degradation of hydric resources, dykes' failure, technological networks, in addition to the most common events related to earthquake, flood, landslides and avalanches.
On the other side, other projects like ESPON analyses a huge series of hazards too, but majorly related to "local" territorial causes, like avalanches, drought potential, earthquakes, extreme temperatures, floods, forest fires, landslides, storm surges, tsunamis, volcanic eruptions, winter and tropical storms, air traffic hazards, major accident hazards, nuclear power plants, oil production, processing, storage and transportation.

The introduction of numerous hazards and scenarios in the analysis could complicate the data collection, and provoke many uncertainties that in the end reduce the accuracy of the final evaluation. Also, since the hazards analysed have different influence, in these cases a mutual weighting of the risks becomes indispensable, and this entails the application of dedicated tools which could increase the level of difficulty for not-expert users, and protract the time required for the analysis.
A filter is frequently introduced to limit the number of hazards analysed: i.e. (Di Mauro et al., 2006) considered only the main sources of dangerousness for Piedmont region, that means industrial risk, forest fires, earthquake and hydrogeological risk (flood and landslides).

For the methodology here proposed, it was decided to follow the criteria of the "Spatial relevance" adopted for ESPON project: only hazards that regularly or irregularly interest the same area should be taken into account, disregarding those that could take place everywhere, like i.e. asteroids (Schmidt-Thomé, 2006). Therefore, the analysis carried out by each Municipality shall be settled on the specific hazards that characterize the territory, depending if it is located in coastal, volcanic or seismic areas. At the moment, the methodology was developed and for three main "spatial" hazards that are quite uniformly diffused on the entire

Italian territory: seismic, flood and industrial. The latter is particularly subjected to external influences.

A fourth hazard was then introduced in the analysis, even if not properly spatial relevant: extreme local climatic events. In fact, climate change has increased the number of violent rains, windstorms and other events that could heavily affect a territory and influence the other risks; therefore, this possible hazard and its interactions were considered through a simplified approach, explained in **Table 7** (See Paragraph 3.3.3).

3.3.2 Hazard macro-categories

The impact of each hazard has to be analysed and described through the identification of three different macro-categories, which represent different aspects of the same hazard that can influence its final effect, and that in some cases could also have been neglected by the overarching sectorial plans. The characterization through the macro-categories on one side enhance and better exploit the local knowledge of the territory of the Municipality technicians; on the other side, it helps in focusing the attention on the possible elements that could provoke unexpected consequences in case of interaction.

The identified macro-categories to describe the hazard are:

1) *Strengthening effects (S.E.)*: the scope of this parameter is the identification of the "intrinsic inherent characteristics" of the analysed hazard that could produce an increase in the final impact. I.e., for the industrial hazard: two Seveso plants, both classified as Upper tier installations, could have a very different dangerousness depending on the quantity and type of substances detained, and the type of assets they own. For earthquakes, the strengthening effects are strictly related to the characteristics of the soil, which could produce amplification effects, liquefactions etc. enhancing the effects of the shakes.
2) *Historical and recent events (H.E.)*: this parameter aims at representing the recurrence of the events on the territory, therefore is the one more related to the surveys and analysis of the existing sectorial plans. However, not only return times and probabilities of the plans should be taken into account, but also the most recent events have to be checked, to verify if their occurring times are compliant or not with those estimated.
3) *Protection measures (P.M.)*: some of the hazards which affect the territory could be contained with dedicated protection measures, especially as far as it concerns industrial risks, flood, landslides etc. Some measures adopted can be effective also towards combined risk effects. These measures reduce the impact of the hazard.

3.3.3 Hazard rating assignation

Once that each hazard is accurately described through its three Macro-categories, a rating shall be attributed to each of them to evaluate their influence on the final impact of the hazard. **Table 7**, reported in the following pages, constitutes a Guide for the attribution of the rating: the indications on which the scores are based derive both from existing literature and sectorial plans, and experts' judgement. The table works as a basic guiding manual for the Municipal technicians but, clearly, it cannot widely represent all the possible situations and problems related to the hazards. For floods, this is particularly evident: this kind of event is generated by a network of linear elements (main rivers and secondary creeks, canals etc.), which are connoted by several hydraulic devices, different dynamics, and complex interactions, whose extension can difficultly be limited to the parameters reported in the table below. An in-depth analysis of the characteristics of the rivers and their criticalities is therefore advocated.

As far as it concerns local extreme climate events, they are evaluated with a simplified approach, due to the difficulties of analysis for data collection and interpretation of the trends on a local sale. Therefore, indicative ratings based on the global tendencies were expressed, as specified in **Table 7.** Final users are obviously free to adopt more precise ratings if the data available can support them.

Table 7: Guideline for ratings assignation

Macro-category	Hazard	1 < I ≤ 1,99 Low to Moderate	2 < I ≤ 2,99 Moderate to High	I ≥ 3 High to very high
[SE] Elements which could have strengthening effects	*Seismic*	Rigid soils, without local amplification effects	Soils with local amplification effects classes Z3 - Z5[6]	Soils with local amplification effects classes Z1 - Z2
	Flood	Interaction between elements of the water network with low or reduced criticalities; hydraulic devices in good state; no or very few critical points like: crossing and bridges with insufficient flow section; eroding or sliding banks/levees; sudden section variations with possibility to provoke obstructions, portions flowing in culverts etc.	Interaction between elements of the water network, and hydraulic control devices show moderate criticalities; critical points (see precedent column) have been identified; the part of the river /creek / etc. analysed contains key element for the safeguarding of the general safety of the system	Problematic interaction points with the elements of the networks, presence of recognized high critical points, also reported in Flood plans by A.D.B.Po, Urban Plans etc (i.e. throttling points, areas interested by erosion etc). Hydraulic devices in bad conditions, with recognized criticalities
	Industry	Only few and little items are exposed to Na-tech risks for their position / intrinsic characteristics / detained substances; limited extension of the damage areas. The substances detained are slightly above the thresholds	There are items which could provoke NA-TECH risk; the quantity of substances detained is significantly higher than the thresholds; the potential scenarios overcome the plant boundaries and are related to flammable and environmental substances	There are huge quantities of hazardous substances and many items with NA-TECH risk. Domino effects are possible. The scenarios are related to toxic substances and / or have a great extension.
	*Climate**	When no data on specific local trends are available, adoption of a unique value for the Strengthening effects, aimed at evidencing the increasing tropicalization, which could produce a major intensity and therefore major consequences for climate related events like i.e. raining, lightning, extreme temperatures etc		

[6] See **Table 25** for the definitions of the soil classes.

Macro-category	Hazard	1 < I ≤ 1,99 Low to Moderate	2 < I ≤ 2,99 Moderate to High	I ≥ 3 High to very high
[HE] Historical events	*Seismic*	Class 3 zone, or: no unforeseen events with P.G.A. > Class 3 zone occurred	Class 2 zone, or: seismic events with P.G.A. ≥ to that of the higher class occurred	Class 1 zone, or seismic events with P.G.A. 2 times higher than that assigns, with unexpected amplification effects, reduced return times
	Flood	Main flood events have been rare, return time given by P.A.I. / P.G.R.A. is confirmed. P.A.I. zone C, or Em, Cn (if recent events do not evidence different distributions / timing of the floods)	Flood history shows the presence of areas interested by floods of moderate impact and/or in areas not included in P.A.I. / P.G.R.A., with a short return time (≥ 50 years) P.A.I. Zone B, or Eb, Cp (if recent events do not evidence different distributions / timing of the floods)	Flood history shows the presence of areas interested by events with return time > than that of P.A.I. /P.G.R.A zone A, which provoked damages to people and things. P.A.I. Zone A, or Ee, Ca (if recent events do not evidence different distributions / timing of the floods)
	Industry	No relevant or NaTech accidents occurred.	Accident history shows low impact events related to NaTech scenarios and / or with repercussion on the territorial and environmental receptors	High impact NaTech events occurred, and / or with severe repercussion on the territorial and environmental receptors
	*Climate**	Continental climate (Plane zones)	Climate characterized by elevate temperature and/or with relevant temperature gaps: arid continental climate / cold continental climate / Mediterranean climate / mountain climate	Climate characterized by extreme temperature conditions / raining / intense storms: Tropical climate / equatorial climate / Desert climate / Subpolar climate

Macro-category	Hazard	1 < I ≤ 1,99 Low to Moderate	2 < I ≤ 2,99 Moderate to High	I ≥ 3 High to very high
[PM] Protection Measures	*Seismic*	-	-	-
	Flood [7]	Water regulation artefacts / systems are not present, or are present in an insufficient number/way, or showed criticalities and an inadequate safety level	Water network / river / creek is properly controlled, the artefacts do not show relevant criticalities	The management of the water network / river / creek is well coordinated, evidencing no falls both for the management and the artefacts
	Industry	No dedicated measures for NaTech have been adopted; the protective measures towards the environment show shortcomings which can cause pollution	The protection measures guarantee a good safety level also for the environment, and could be partially effective also towards NaTech accidents	Adoption of all the preventive measures indicated in the checklist of Turin province and NaTech table by Cruz et al., in any case adequate for avoiding NaTech risk and domino effects
	*Climate**	-	-	-

As far as it concerns the Protection measures adopted to face the Industrial hazard, not only all the safety measures implemented by the plants should be checked, but also an in-depth analysis on two different checklists has to be carried out.

The first checklist is contained in the Turin Province guideline for E.RI.R. drafting, and consists of a series of measures mainly focused on the environmental protection, reported in **Table 8.** These measures could at least constitute a "passive protection" against Na-Tech events, because they try to improve the operational procedures and the arrangements of the plant for emergency and safety, to increase the general level of protection against environmental pollution.

[7] As far as it concerns the protection measures adopted against floods, the more recent tendencies demonstrated that an excessive artificialization of the natural flows of rivers and creeks could enhance instead of protect the vulnerable areas from the consequences of a flood events. The best choice would be the creation or reactivation of the river's natural areas for the flood expansion; however, this is not always compatible with the current uses of the territory. Therefore, the efficacy of the existing protection measures has to be carefully evaluated to verify if they actually work as a protection, or if on the contrary they could act as elements producing strengthening effects.

Table 8: Protection measures for the environment (Provincia di Torino, 2010)

	POINT 1a
1.	Identification of the supply and lines with a label containing the name of the substances and safety information
2.	Formalisation of a schedule to check and maintain the entirety of tanks and basins
3.	Formalisation of a schedule to check and maintain the entirety of pipes and lines, included the drainage lines and interception valve
4.	Constant updating of the documents, capable to demonstrate the physical and chemical compatibility of the substances chosen
5.	Provision of a system for the collection of the small releases (adsorbing materials and pads nearby wells, sewer covers etc.)
	POINT 1b
6.	Separation of the areas potentially involved by releases from the other areas, using containment basins and dedicated collection lines
7.	Arrangement of two different drainage lines for the rainfall water and the water employed in the process or interested by potential releases.
8.	Reduction of the areas interested by potential releases and provision of protection devices, such as waterproof paving, dedicated collection lines, etc.
9.	Elimination or reduction of the junctions with flanges, and adoption of completely soldered lines
10.	Provision of devices for the registration and alarm related to unexpected loss of level of the tanks and basins
11.	Substitution or renovation of the underground tanks, according to the decree 20/10/1998 n. 260
	POINT 2
1.	Definitive lock of the unused wells located inside the plant, and external protection of those still in operation
2.	Arrangement of the devices and measures foreseen by of the Regional regulation 20/2006 n 1/R on rainfall water collection.
3.	Provision of emergency devices (Adsorbing material, pads..) nearby wells and sewer covers in order to obstacle the access of the pollution agents to the municipal sewer
4.	Arrangement of devices for an automatic lock of the drainage lines whether is detected the presence of pollution agents.
5.	Arrangement of emergency management procedures
	POINT 3
1.	Assessment of the hydrogeological conditions nearby the plant and the points of possible release
2.	Assessment of the times employed by the pollution agents to arrive to the sensitive elements
3.	Arrangement of emergency safety measures (Hydraulic barrier)
4.	Employment of off-ground tanks instead of those underground
5.	Paving of the area for the new plant with layers of waterproof materials
6.	Employment of off-ground lines instead of those underground

The second checklist is extracted from (Cruz et al., 2004), and indicates a series of safety and mitigation actions, both organizational and structural, aimed at address natural disaster-triggered accidents. The list, reported in **Table 9**, is clearly quite generic, but it can provide a first feedback on the plant preparedness against NaTech events.

Table 9: NaTech protection measures (Cruz et al., 2004)

Safety and mitigation measures	Earthquakes	Flooding / landslide	Wind / storm /hurricane	Structural measure
Use of structural design codes or retrofitting	√	√	√	Y
Containment dikes or walls	√		√	Y
Use of structural design codes or retrofitting of walls and dikes	√		√	Y
Anchoring mechanisms of tanks and equipment (e.g. anchor bolts, bracing)	√	√	√	Y
Bracing of pipes and connections	√	√	√	Y
Flexible connections for pipes	X			N
Restraining straps or chains for barrels or pressure vessels	√	√	√	N
Strapping and anchoring of emergency equipment	√	√	√	N
Emergency shut off/safety valves	√	√	√	N
Emergency water systems, and foam spraying systems	√	√	√	N
Adequate siting of emergency water and foam spraying systems to avoid damage from falling debris	√		√	N
Redundancy in pipeline systems, particularly emergency water	√		√	N
Warning systems	√	√	√	N
Emergency power generators designed to maintain critical equipment housing hazardous chemicals in safe condition for extended periods of time	√	√	√	N
Routine inspection and maintenance for corrosion and deterioration	√	√	√	N
Inventory control (e.g. minimizing the amount of hazardous materials used)	√	√	√	N
Strategic placement of substances inside plant in order to avoid chemical incompatibility	√	√	√	N
Placement of storage tanks with hazmats above the maximum height reachable by water		√		Y
Construction of drainage system		√		Y
Interruption of production process		√	√	N
De-inventory of main processing units		√	√	N
Giving transport priority to most dangerous chemicals (those that react violently with water)		√	√	N
Verification of storage tank seals		√		N
Hermetic sealing of silos and underground storage tanks		√	√	N
Wrapping of substances in watertight packing and labelling		√	√	N
Raising of electrical equipment such as motors, pumps and control panels to avoid water damage and system failure		√	√	Y
Maintaining NaTech emergency response plan	√	√	√	N
Construction of retaining walls and levees or dykes		√		Y
Drills and Training	√	√	√	N
Plan to allow workers to check on family	√	√	√	N
Training plan for external responders on management of hazardous chemicals onsite	√	√	√	N

3.3.4 GIS mapping

The characterization and assignation of the ratings, similarly to the other steps of the methodology, is reported in a geo-referenced GIS map, that shows the spatial implications of the hazards analysed. It would also allow the integration of the proposed tool with existing regulation instruments. The GIS map is an instrument that is almost universally employed by multi-risk projects, because it helps in clarifying the problems and illustrating thematic maps for an easy understanding; it can be used as base for further planning interventions.
GIS give the possibility to represent geographic datasets as *layers*. A *layer* is composed by *polygons, polylines or points*, which are the basic elements of the subject drawn; each one is identified by homogenous and univocal characteristics. These descriptive identifying features, both numerical or textual, are reported in the *Attribute table* associated to each layer; each line of the table corresponds to a basic element, while the columns report the features. The features can be used to produce thematic maps: i.e. the attribute table of a layer representing Buildings can be composed by the columns Function, Address etc: it is possible to draw a thematic map by functions of the buildings.

For the proposed methodology, each hazard dataset corresponds to a layer; therefore 4 layers were drafted: SEISMIC, FLOOD, INDUSTRIAL and CLIMATE. The macro-categories S.E., H.E. and M.P. were represented introducing three columns in the *Attribute tables* of each hazard layer: for each basic element identified, the correspondent ratings assigned were inserted in the columns. Since each hazard varies on the territory, depending on specific local characteristics, each Hazard-layer is composed by several basic elements (polygons).
Figure 6 in the following page shows an example of polygon for the Seismic hazard layer, accompanied by its descriptive features (ground type, S.E., P.M., H.E.). When the identifier features S.E., P.M. and H.E. vary, a new polygon has to be represented.
The layer Climate-related events is the only one represented by a unique polygon, because of the simplified approach adopted: since H.E., S.E., P.M. maintain the same values on the entire territory, a unique polygon having the exact extension of the Municipal territory was drafted.

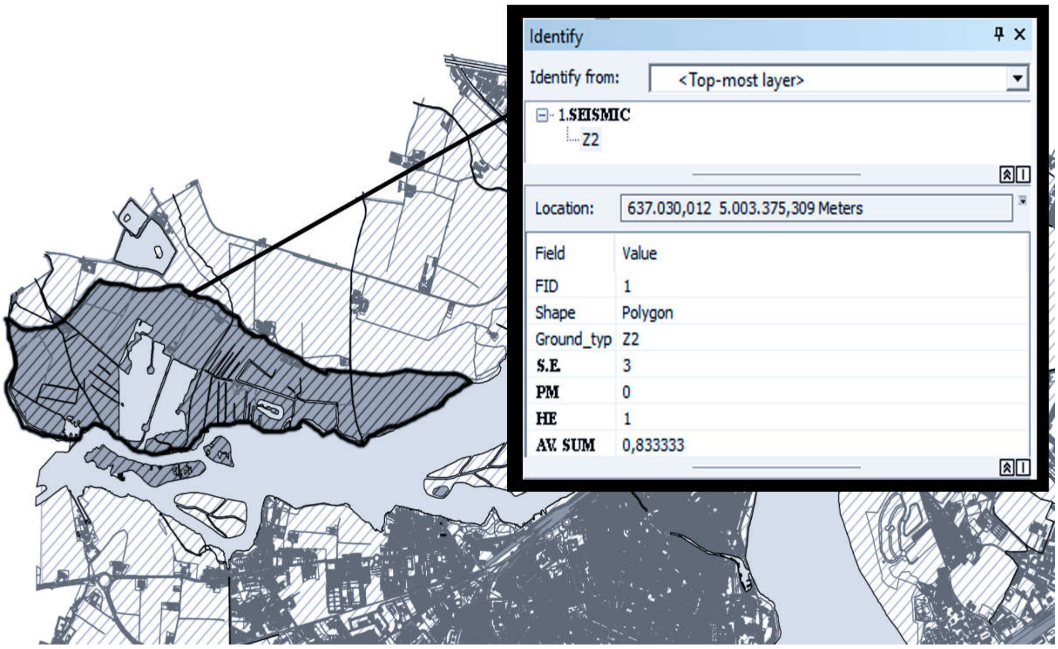

Figure 6: Polygon for the Seismic hazard layer, soil Z2.

Although the variations of the ratings for H.E., S.E. and P.M. were quite clear during the assignation phase, their spatial representation was not just as simple. In fact, the identification of the perimeters of the homogenous basic elements (polygons) was complicated by the difference between the hazard sources analysed (punctual for industry, linear for flood, areal for earthquake) and the presence of proved impact areas. Some assumptions and simplifications were introduced for the representation of polygons, in order to facilitate both the drawing and the further steps of the analysis:

1) SEISMIC HAZARD: the category H.E. maintains the same value on the entire territory, following the current regulation related to the seismic classes, and the same is for M.P. that is always = 0. The difference between basic elements is exclusively determined by the typology of soil, which can cause potential Strengthening effects (S.E.). Therefore, the polygons shall be identified and drawn on the basis of the soil classification reported in the micro-seismic preliminary or detailed studies (see **Figure 6**).
2) INDUSTRIAL HAZARD: A simplified approach was adopted in this case; the plant itself is assumed as source of the hazard, therefore each polygon coincides with one plant, even if usually internal or external damage areas are associated to the plants.
   The choice to exclude the damage areas generated by the scenarios assessed in the Safety reports is related to different reasons. The first is their extreme variability from one plant to another, and inside the same plant: they are strictly related to the substances employed, therefore can be subjected to quick modifications. In many cases, they do not, or slightly, overcome the plant boundaries, a condition that could bring to consider the plant as “safe” during i.e. the development of land use actions. However, as already

remarked, the damage areas for events with a probability lower than 10^{-6} are not produced; but these low probability-high impact events are exactly the type of scenario that could be activated by NaTech events. Therefore, the current damage areas cannot be considered completely representatives of the danger represented by the plant.

Also, damage areas are not available for non-Seveso plants (the so-called Sub-threshold plants and hazardous plants[8]); these activities are under no obligation to denounce the substances they use, but they could detain items and substances that could provoke serious consequences.

However, the damage areas are important for the Land Use Planning phase, in order to assess the compatibility with the vulnerable elements; for this reason, a buffer zone representing a potential damage area was drafted around the plants. The extension chosen for the buffer zone is 500 m.: this is the area usually considered by the Prefecture for the draft of the external Emergency Plan of the companies, and assumed in the E.R.I.R. as area subjected to specific planning actions. As explained in the following paragraphs, the values of H.E., S.E., P.M. and of the interaction are projected in this buffer zone to assess the impact on the vulnerabilities; however, an optional step based on the use of two modelling software allows to define with major precisions the possible damage areas consequent to a natural event impacting on the industry (Paragraph 3.5).

3) FLOOD HAZARD: the definition of the polygons for flood hazards entailed more complexities that the others. Rivers and creeks not always represent a source of hazard; if yes, the spatial representation should consider that the hazard for the territory does not properly reside in the linear course of the river itself, but in the possibility of its expansion on areas not normally interested by the water flow. Surveys, historical events and simulations contained in the Sectorial flood plans[9] usually identify these areas,

[8] See footnote no. 1 in this same chapter.

[9] The maps of the P.G.R.A. - Piani per la Gestione del Rischio di Alluvioni (Plans for the Management of the Flood risk) report the maximum extension of the flooding related to events with high, medium and low return times. Different criteria and documents were adopted for the definition of the perimeters for the main water network, the secondary network, the lakes banks and coastal areas.

Main water network: data based on previous analysis made for P.A.I. – Piani per l'Assetto Idrogeologico, feasibility studies and detailed studies drafted by regional, provincial and dedicated authorities. Maps for the flood level corresponding to medium probability events obtained through with hydraulic modelling, using: 1) interpolation of the extreme flooding points of the transversal sections, on technical maps and ortho-photos; 2) depth map elaborated with GIS obtained by the coupling of DEM-Digital Elevation Model and DTM-Digital Terrain Model; 3) maps of the flooded areas and levels of the most recent flooding events. The definition of the areas subjected to low return time events derives from the envelope of scenarios both due to extreme events, and to residual dangerousness due i.e. to dykes' ruptures.

Secondary water network (mountain and hills): the scenarios for high, medium and low return time were considered, taking into account the P.A.I. studies on the instability areas and regional, provincial and municipal studies. The definition of the areas potential subjected to flooding was made on the basis of simplified methodologies, based on geomorphological analysis and inventory and historical which have different probabilities to be invaded by water; the assigned H.E. category mainly depend on these return times estimated. Therefore, the spatial representation of the flood hazard layer cannot disregard these flood expansion areas: even if they cannot be considered completely reliable, because i.e. the climate change effects on the extension of these areas were not taken into account, they actually are the only way to verify possible interactions with other potential hazards like i.e. the industrial one.

However, the perimeters of uniform polygons are difficult to be identified as far as it concerns the spatial distributions of the macro-categories S.E. and M.P.: as showed in **Table 7**, they depend on the artefacts present on the analyzed watercourse, and on the interaction with other elements of the water network. But how to determine and draw the "influence" of these elements on the different areas potentially interested by flood? It was decided to attribute the same values of S.E. and M.P. to portions of watercourses with homogeneous characteristics; where discontinuity points like i.e. modifications in the sections, quotes, criticalities etc. could determine a variation, another polygon has to be draft.

Figure 7 in the following page synthetizes the criteria above exposed for the determination of the polygons: it reports an exemplificative river, with damage areas A and C identified by former P.A.I. plan. A critical narrowing point determines a discontinuity in the attribution of the values to the flood hazard, because it could cause a strengthening effect with unforeseen consequences (i.e. obstructions etc.). Therefore, a different value of S.E. is assigned after this point. The values of H.E. change in function of the return time calculated by the former P.A.I. for the different damage areas.

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data. The processes of sediment transport, riverbed mobility, and debris flow were also taken into account.
Secondary water network (plain): definition of the areas made only for the scenarios with high and medium return time, on the basis of inventory and historical data, particularly related to the last 20-30 years. Some limited zones were drafted on the basis of hydrogeological models, or on indications by the Management authorities in relation to flooding episodes, consequent to rainy events with return times over 50 years (on average). The maps do not consider possible dykes' ruptures, malfunctions of the water lifting plants or other hydraulic artefacts, for which it would be necessary a detailed local analysis.
*Lake*s: the three flooding scenarios were considered; the maps were based on the statistical regularization of the lake levels historically registered in the main measurement points, and on the DTM.
In this first phase of adoption in Italy of the European flood directive, the possible effects provoked by climate change on the potential flooded areas were not analyzed, because no reliable scenarios on the variation of the flood levels are available.

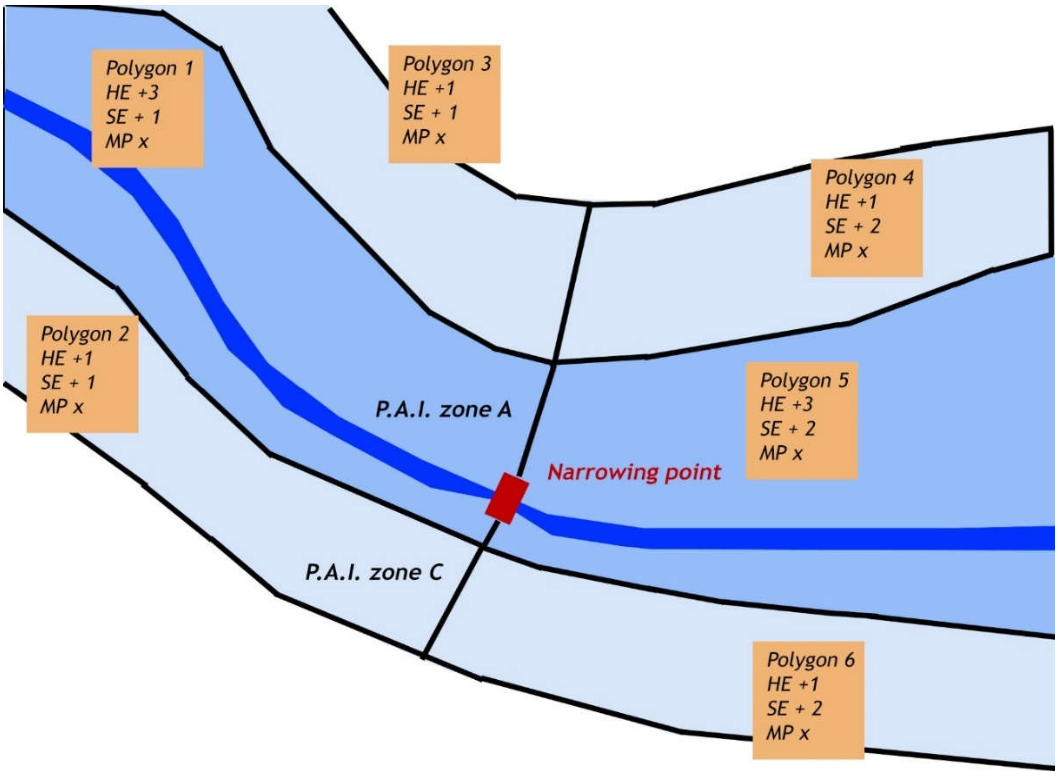


Figure 7: Identification of the polygons for Flood hazard

It should be remarked that when recent events, or surveys, modified the damage areas and return times reported by the sectorial plans, both the attribution of the values and the identification of the polygons shall keep into account these variations.
In case no damage areas are assessed and no spatial surveys are available, as could happen i.e. for secondary networks, on the basis of the recent events and local knowledge, the Municipality could eventually decide to assign a buffer zone as damage area.

3.4 Assessment of the interactions

This paragraph is dedicated to the assessment of the interactions between the hazards, which is the core of the proposed methodology; indeed, where overlaying of different hazards occurs, it is necessary to understand the detrimental effects that the occurring of one hazard could provoke on the others.

The quantitative risk assessment methods, like that proposed by (Marzocchi et al., 2009), defines the multiple risk scenarios through event-trees. Since the probability was not taken into account for the proposed methodology, a dedicated approach for the interaction had to be constructed. Two inspiring sources were found in the projects ESPON and MATRIX (see Par. 2.3.2 and 2.3.5); as for ESPON project, each hazard received a rating in the first phase, (based on the macro-categories). These three parameters were considered as key elements for the assessment of the interaction: in fact, as intrinsic characteristics of the hazard, they can provide good information on the possible role played by each hazard in the interaction. Therefore, in order to assess the possible impact of one hazard on another (binary interaction), a sum of the 3 macro-categories of the two hazards was proposed; two possible formulas were tested: a simple sum (Equation 1) and an average sum of the parameters (Equation 2).

Equation 1

$$\boldsymbol{Interaction} = [(\boldsymbol{H.E._{haz1}} + \boldsymbol{H.E._{haz2}}) + (\boldsymbol{S.E._{haz1}} + \boldsymbol{S.E._{haz2}}) + (\boldsymbol{P.M._{haz1}} + \boldsymbol{P.M._{haz2}})]$$

Equation 2

$$\boldsymbol{Interaction} = [(\boldsymbol{H.E._{haz1}} + \boldsymbol{H.E._{haz2}}) + (\boldsymbol{S.E._{haz1}} + \boldsymbol{S.E._{haz2}}) + (\boldsymbol{P.M._{haz1}} + \boldsymbol{P.M._{haz2}})]\ \boldsymbol{/\ 6}$$

The results obtained for the interaction should have fallen inside the index scale explained in Paragraph 3.2, returning a direct value for the possible interaction impact:

- $0 \leq I \leq 0{,}99$: negligible
- $1 \leq I \leq 1{,}99$: from Low to Moderate
- $2 \leq I \leq 2{,}99$: from Moderate to High
- $I > 3$ onwards: from High to very high.

However, the equations tested on a case study did not return reliable results: for Mantua case study (detailed in chapter 4), where the initial values of the macro-categories were quite low, the first equation returned extremely high values of interaction, trespassing by far the highest value of the index scale. The second equation returned only negligible interaction values, lower than the initial hazard values.

3.4.1 Weighting of the macro-categories

In order to solve the problem mentioned in the previous Paragraph, that means, obtaining credible Interaction results, in line with the index scale range, it was decided to intervene on the 3 parameters of the equations, the macro-categories H.E., S.E. and P.M. In fact, the implausible results obtained could be ascribable to an effective different influence of the Macro-categories on the final interaction value. In addition, the 3 parameters are founded on available data and proofs very different, and this was another aspect to be kept into account to evaluate the results.

Therefore, the candidate assigned simple experimental weights to each macro-category to measure both the ability to describe and influence the possible effects on the interaction, and the solidity in terms of data available. Scores from 0 to 2 were attributed; this range was chosen because it answered the necessity of maintaining the final interaction value in line with the general scale adopted for the proposed methodology:

- 2 points were assigned to H.E. - Historical events, because the past and recent events could give an immediate clear idea to describe the impact of potential future events.

Even if high impact, low extreme events could be not perfectly described in this category, thus it remains the most “reliable” category, proved by many surveys and observations;

- 1 point was assigned to the category Strengthening effects; this category is the most innovative one, whose aim is to explicit possible elements intrinsic to the analyzed hazard, that could enhance the final impact. Because of the possible uncertainties that could arise i.e. for the definition and consequent rating of the criticality associated to each element, the scores assigned in the previous phase were maintained as they were, in order not to excessively influence the final score of the interaction.
- 0,5 point was assigned to the category Protection measures; this low weight takes into account the possibility that protection measures could unexpectedly fail, or have unforeseen malfunctions, in particular when combined events are considered. As reminded by (Menoni et al, 2006, even when protection measures are put in place, the resulting overconfidence can be an important drawback for their potential to actually protect exposed communities towards whatever hazard. Indeed, the overconfidence leads to risky behaviors, increasing the overall community’s exposure and vulnerability to events that, though rare, are not impossible and which are beyond the “acceptable level of risk” explicitly or implicitly set by any built defense system.

The weighting of the macro-categories was tested and validated through an experts’ judgement, which involved a little panel of risk analysts and LUP experts from various EU countries. The experts’ judgement confirmed the importance of the macro-categories HE and SE; more details are provided in Annex 1.

The weights assigned were employed into the average sum of the macro-categories proposed in **Equation 2**: the final formula proposed to assess the interaction of two hazards is reported in **Equation 3** below:

Equation 3

$$Interaction = [(H.E._{haz1} + H.E._{haz2}) * 2 + (S.E._{haz1} + S.E._{haz2}) * 1 + (P.M._{haz1} + P.M._{haz2}) * 0{,}5] / 6$$

Through the application of Equation 3, the Municipality technicians can verify the possible impact of one hazard on another one (binary interaction), starting from observable characteristics and data of the hazards themselves. As later explained, this is a first step to orientate further in-depth studies and actions; even if indicative, it can in any case provide a great help to identify possible problematic areas starting from shared and common knowledge on the risks.

3.4.2 Interaction table

Equation 3 can be applied to calculate the binary interaction values in every area of the territory where hazards are superimposed, with a particular attention for the areas where many territorial or environmental vulnerabilities are present. A dedicated Interaction table, elaborated with Excel, allows the Municipalities to verify and calculate the binary interaction values in a determined point of the territory.

The points of hazard overlaying can be easily identified with the GIS map: i.e., **Figure 8** shows the distribution of the hazards for Mantua territory. Where the color is darker, four hazards are overlaid, where it is clearer, only two hazards are superimposed (in this case, seismic hazard and climate, that do not have mutual influence).

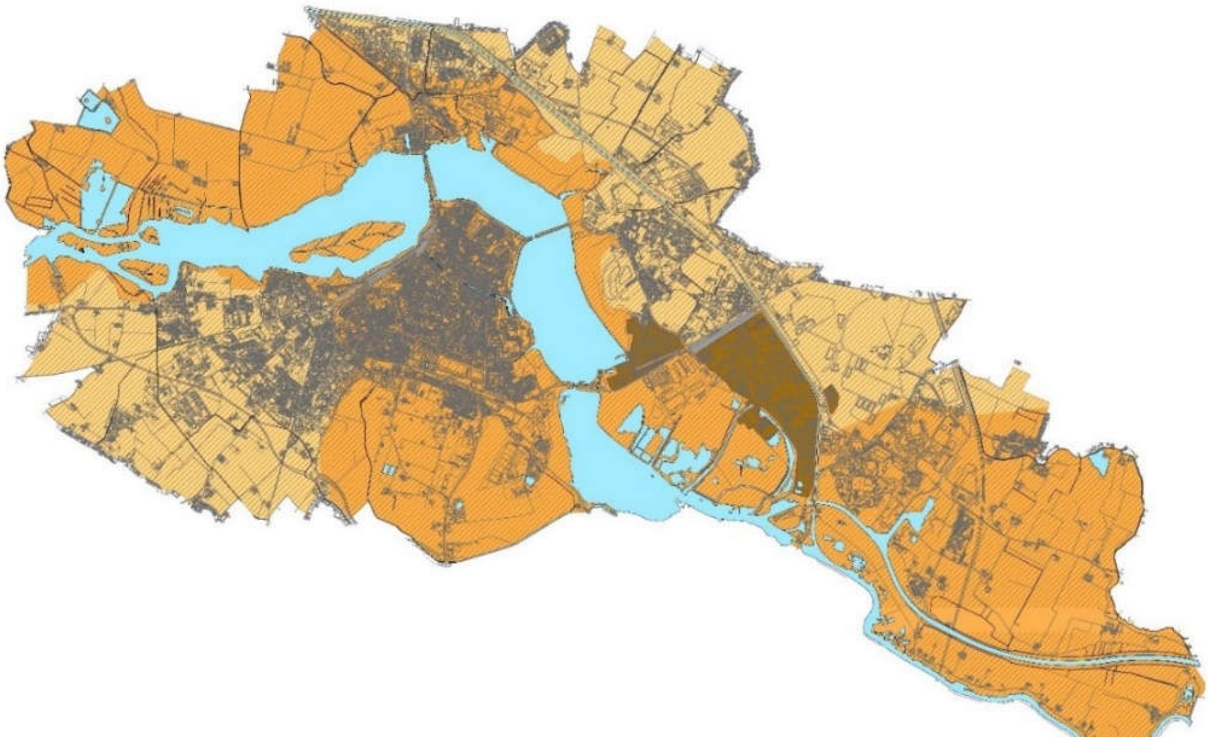


Figure 8: Hazard layers overlaying in Mantua

Mantua case study, further explained in Chapter 4, is also employed to illustrate the Interaction table.

Table 10 in the following page shows an example for the areas where four hazards overlay: the table reports the hazards and their ratings. The influence is evaluated following the lines; when a possible correlation is detected, **Equation 3** is applied.

Table 10: Example of Interaction table

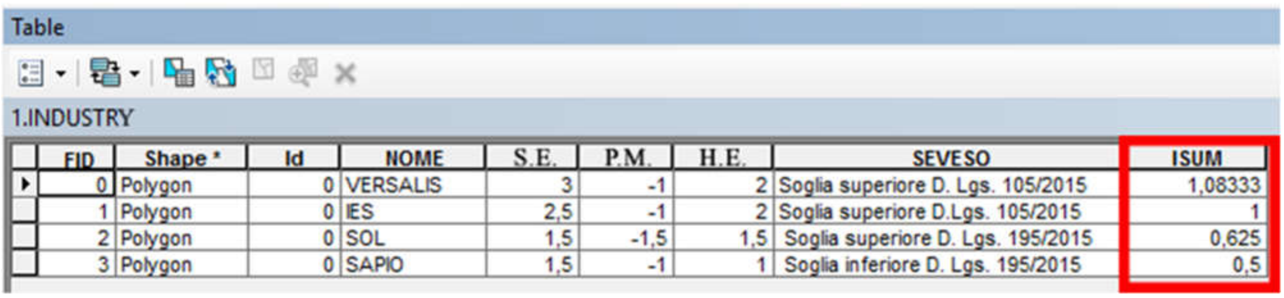
HAZARDS & Macrocategories			Seismic			Flood			Industrial			Climate		
			SE	**HE**	**PM**	**SE**	**HE**	**PM**	**SE**	**HE**	**PM**	**SE**	**HE**	**PM**
			2	1	0	1,5	1	-3	3	2	-1	2	1	0
Seismic	**SE**	2												
	HE	1	No interaction			1,00			1,75			No interaction		
	PM	0												
Flood	**SE**	1,5												
	HE	1	No interaction			No interaction			1,42			No interaction		
	PM	-3												
Industrial	**SE**	3												
	HE	2	No interaction			No interaction			-			No interaction		
	PM	-1												
Climate	**SE**	2												
	HE	1	No interaction			1,00			1,75			No interaction		
	PM	0												

The results of the binary interaction tables constitute the basis for the final step of the methodology, the compatibility assessment. A further focus on the consequences of the interactions was introduced for the Na-tech events, which combine industrial and natural hazards.

3.4.3 GIS & interaction tables

The Interaction values obtained through the draft of the Interaction tables can be directly calculated in ArcGIS®. In the following lines, the steps to reach this objective are explained:

1) *Addition of a Field calculator column to each attribute table:* as mentioned in Chapter 3, each hazard layer has an attribute table, where the values of the three macro-categories S.E., M.P. and H.E. are reported, aside to other columns of description. In order to proceed with the calculation of the binary interactions, a column is added to the attribute table (see **Figure 9**), with the feature "Field calculator", that allows introducing formulas into GIS. The columns were named ISUM for industrial hazard layer, FSUM for Flood hazard layer, SSUM for Seismic hazard layer and CSUM for Climate related events layer.



Table

1.INDUSTRY

FID	Shape *	Id	NOME	S.E.	P.M.	H.E.	SEVESO	ISUM
0	Polygon	0	VERSALIS	3	-1	2	Soglia superiore D. Lgs. 105/2015	1,08333
1	Polygon	0	IES	2,5	-1	2	Soglia superiore D.Lgs. 105/2015	1
2	Polygon	0	SOL	1,5	-1,5	1,5	Soglia superiore D. Lgs. 195/2015	0,625
3	Polygon	0	SAPIO	1,5	-1	1	Soglia inferiore D. Lgs. 195/2015	0,5

Figure 9: Attribute table with "Calculator field" column

Equation 4 shows the formula inserted in the column ISUM: it is the weighted average sum of **Equation 3**, without the parameters of the second hazard. In this way, the values of the Macro-categories are automatically weighted and summed up by the GIS.

Equation 4

$$(H.E._{haz1} * 2 + S.E._{haz1} * 1 + P.M._{haz1} * 0{,}5) \,/\, 6$$

Figure 10 shows how the "Field calculator" works: all the parameters of the Attribute table columns are reported in the box on the left. They can be extrapolated and employed into **Equation 4**, inserted in the lower box.

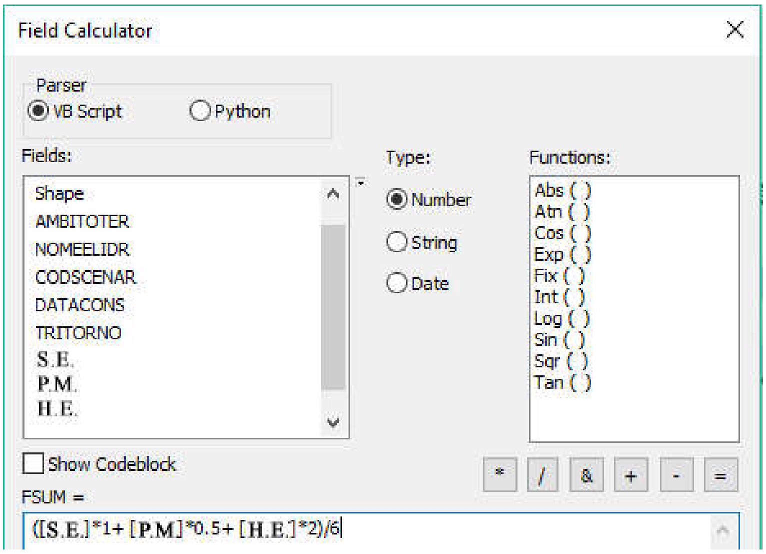


Figure 10: Equation 4 reported in the field calculator (column ISUM)

2) *Intersection of the layers:* the GIS tool called "Intersect" is applied to obtain the exact boundaries of the areas where the interaction can take place; the tool creates a new layer containing only the exact portions of overlaying. All the values contained in the 4 original attribute tables of the hazards are put together in the unique attribute table of the new Intersect layer, reported in **Figure 11** This table is the basis for the calculation through GIS of the binary interaction.

Table

c1_Intersect11

		FLOOD										SEISMIC HAZARD					
FID *	Shape *	FID	AMBI	NOME	COD	DATACONS	TRITO	S.E.	P.M.	H.E.	FSUM	ID 1	Grou	S.E.	P.M.	H.E.	SSUM
0	Polygon	0	RP	Mincio	H	20131126	20	1,5	-3	3	1	0	Z4	2	0	1	0,666667
1	Polygon	0	RP	Mincio	H	20131126	20	1,5	-3	3	1	0	Z4	2	0	1	0,666667
2	Polygon	9	RP	Po	L	20131126	500	1,5	-3	1	0,333333	0	Z4	2	0	1	0,666667
3	Polygon	9	RP	Po	L	20131126	500	1,5	-3	1	0,333333	0	Z4	2	0	1	0,666667
4	Polygon	9	RP	Po	L	20131126	500	1,5	-3	1	0,333333	0	Z4	2	0	1	0,666667

	CLIMATE						INDUSTRY						
FID *	FID	Id	S.E.	P.M.	H.E.	CSUM	FID 1	Id	S.E.	P.M.	H.E.	NOME	SEVESO
0	0	0	2	0	1	0,666667	0	0	3	-1	2	VERSA	Soglia superiore D. Lgs. 105/2015
1	0	0	2	0	1	0,666667	1	0	2,5	-1	2	IES	Soglia superiore D.Lgs. 105/2015
2	0	0	2	0	1	0,666667	0	0	3	-1	2	VERSA	Soglia superiore D. Lgs. 105/2015
3	0	0	2	0	1	0,666667	1	0	2,5	-1	2	IES	Soglia superiore D.Lgs. 105/2015
4	0	0	2	0	1	0,666667	2	0	1,5	-1,5	1,5	SOL	Soglia superiore D. Lgs. 195/2015

Figure 11: Attribute table of the Intersect layer

The "Intersect table" reported in **Figure 11** was re-elaborated in order to make it clearer for the following steps: all the columns not representing a Macro-category or a Sum were removed, and a column with the Name of the polygons was added (**Figure 12**).

Table

4 HAZARDS INTERACTION

			F				S				C				I			
FID	Shape *	NAME	S.E.	P.M.	H.E.	FSUM	S.E.	P.M.	H.E.	SSUM	S.E.	P.M.	H.E.	CSUM	S.E.	P.M.	H.E.	ISUM
0	Polygon	Versalis incinerator + free areas (south portion)	1,5	-3	3	1	2	0	1	0,666667	2	0	1	0,666667	3	-1	2	1,08333
1	Polygon	les west limit (portions of tanks included)	1,5	-3	3	1	2	0	1	0,666667	2	0	1	0,666667	2,5	-1	2	1
2	Polygon	VERSALIS	1,5	-3	1	0,333333	2	0	1	0,666667	2	0	1	0,666667	3	-1	2	1,08333
3	Polygon	IES	1,5	-3	1	0,333333	2	0	1	0,666667	2	0	1	0,666667	2,5	-1	2	1
4	Polygon	SOL	1,5	-3	1	0,333333	2	0	1	0,666667	2	0	1	0,666667	1,5	-1,5	1,5	0,625

Figure 12: Reworking of the Attribute table of the Intersect layer

3) *Addiction of the Field calculator columns for Interaction:* the last step to obtain through GIS the same values calculated with the Excel Interaction table consists in adding three columns to the Intersect table, where it is applied the "Field calculator" to sum by twos the values of the Sums of each hazard.

In the example below, the interactions between Industry and the other hazards were assessed:
F → I (FSUM + ISUM),
S → I (SSUM + ISUM),
C → I (CSUM + ISUM)
but it is also possible to add two other columns for S → F (SSUM + FSUM) and C → F (CSUM + FSUM).
The columns of the interactions are highlighted in red in **Figure 13** below; the central row corresponds to the Interaction Table reported in **Table 10.**

Table

4 HAZARDS INTERACTION

FID	Shape *	NAME	S.E.	P.M.	H.E.	FSUM	S.E.	P.M.	H.E.	SSUM	S.E.	P.M.	H.E.	CSUM	S.E.	P.M.	H.E.	ISUM	F I	S I	C I
0	Polygon	Versalis incinerator + free areas (south portion)	1,5	-3	3	1	2	0	1	0,666667	2	0	1	0,666667	3	-1	2	1,08333	2,08333	1,75	1,75
1	Polygon	les west limit (portions of tanks included)	1,5	-3	3	1	2	0	1	0,666667	2	0	1	0,666667	2,5	-1	2	1	2	1,66667	1,66667
2	Polygon	VERSALIS	1,5	-3	1	0,333333	2	0	1	0,666667	2	0	1	0,666667	3	-1	2	1,08333	1,41666	1,75	1,75
3	Polygon	IES	1,5	-3	1	0,333333	2	0	1	0,666667	2	0	1	0,666667	2,5	-1	2	1	1,33333	1,66667	1,66667
4	Polygon	SOL	1,5	-3	1	0,333333	2	0	1	0,666667	2	0	1	0,666667	1,5	-1,5	1,5	0,625	0,958333	1,29167	1,29167

Figure 13: Attribute table of the Intersect layer, showing the Interaction values

Finally, **Figure 14** reports an example of the Field calculator applied to the Interaction column, where the Interaction F → I is calculated. As anticipated, the Interaction result is obtained simply summing the two columns FSUM and ISUM.

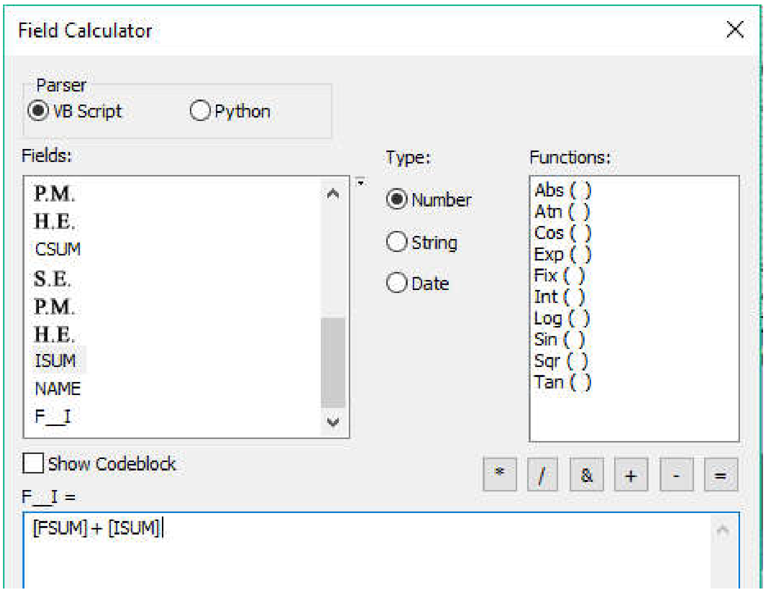


Figure 14: Calculator field with the formula for interaction

3.4.4 Damage areas deriving from the interactions

The GIS Intersect tool allows to precisely identify the areas of hazards overlaying and to assign them the values of the interaction; however, the effects of the interaction could overcome these boundaries.

For interactions related to earthquake / climate hazards impacting on flood, it was decided to maintain the areas as assessed by the sectorial plans and/or through direct surveys.
On the contrary, for interactions involving industries, it is not possible to assume the plant boundaries as limit of the interaction effects. As previously anticipated, the effects of the interaction calculated through GIS or Interaction table should be projected into the buffer zone around the plant of 500 m. In some specific cases, i.e. when all the hazards involved have values from “High to very high”, or for precautionary reasons related i.e. to the presence of high vulnerable elements in the surroundings of the industrial plant, the Municipality can decide to expand the limit of the buffer zone. In these cases, a suggestion for its distance from the plant is provided by (Regione Lombardia, 2007) that uses buffer areas of 1000 m.

In case of adjacent or very close industries, it is possible to observe a superimposition of the buffer areas, signalling a possible domino effect. Dedicated Interaction tables can be drafted for the areas where the industrial buffer zones overlay; Mantua case study provides a clear example of the above-mentioned situation. As highlighted by the following **Figure 15**, the buffer zone of Versalis plant is crossed by the buffer zones of Ies, Sol and Versalis. The interaction caused by other industries (I → I) in the crossing areas assumes the following values:

A. (Ies → Versalis) = [(2+2)*2+(3+2,5)*1+(-1-1)*0,5] / 6=2,08
B. (Sol → Versalis) = [(2+1,5)*2+(3+1,5)*1+(-1-1,5)*0,5] / 6=1,70
C. (Sapio → Versalis) = [(2+1)*2+(3+1,5)*1+(-1-1)*0,5] / 6=1,54

Figure 15: Intersecting areas of Versalis, IES, Sol and Sapio buffer zones

However, the uncertainties for the I → I interaction increase. In fact, the Interaction in this case is calculated considering the buffer zones, which however are precautionary conventional areas that do not represent the actual damage areas. They do not take into account the position of the items, the type of substances detained, the meteorological conditions and other aspects, but slightly variations in these factors could also completely exclude the possibility of a domino effects. Therefore, the interaction values obtained for the industrial intersecting areas, as the sample areas A, B, C, always need to be verified, acquiring a deepen knowledge of the hazardous items and substances present inside the areas of superimposition. In case the dangerousness is confirmed, the interaction value can be considered reliable and further considerations can be done on the safety of the interested areas.

3.4.5 Multiple interactions

As already explained, the proposed Table of interaction allows evaluating only the effects of interaction between hazards correlated, that means one hazard impacting on another one, provoking unexpected consequences. However, there could be rare cases of multiple interactions or simultaneous occurring; even if these events are usually connoted by a very low probability, it could be helpful to at least obtain a first measure of the possible impact.
In this case, the best solution to actually return the potential impact of a multiple interaction was identified in a simple sum of the values obtained from the interaction table; indeed, it was observed that it can well represent the increase of dangerousness due to the interactions of multiple hazards, or their simultaneous appearance.

In order to understand all the possible multiple influences, the values assumed by the binary interactions are reported in a dedicated scheme, which allows relating the hazards, also highlighting their possible combinations.

The following **Figure 16** is an example of the proposed diagram, once again based on the example of Versalis and its Interaction table. The 4 analyzed hazards are represented by the spots (I = Industry, F = flood, S = seismic hazard, C = climate events); the arrows show the direction of the influence, and aside them the value of the binary interaction between two hazards, as calculated in the Interaction table, is reported. In order to analyze the possible multiple events, it is sufficient to consider all the possible interactions between the chosen hazards.

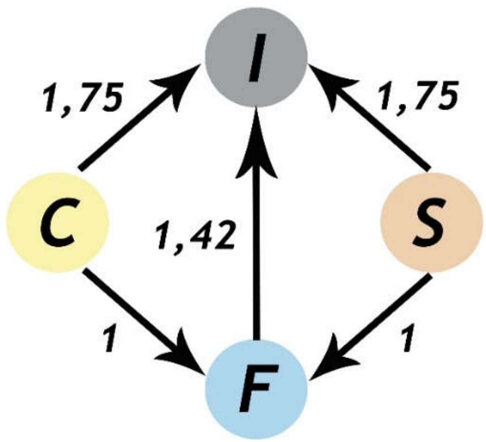


Figure 16: Diagram for multiple interactions

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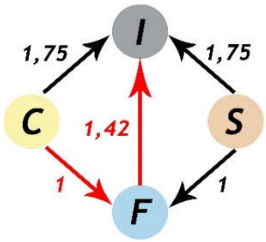
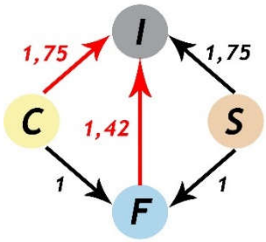
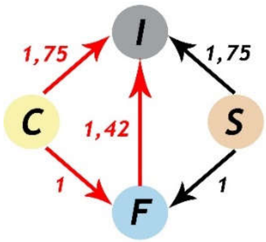
Example: FCI – Flood Climate Industry



1) Interactions climate/flood and flood/industry: C → F → I
Value = 1 + 1,42 = 2,42 "From moderate to high" influence



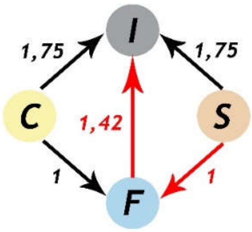
2) Simultaneous occurring of C → I and F → I interactions:
Value = 1,42 + 1,75 = 3, 17 "High" influence



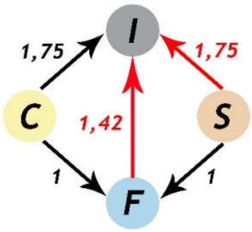
3) Interactions C → F → I and C → I
Value = 1 + 1,42 +1,75 = 4,17 "Very high" influence

With reference to Mantua specific conditions, the most likely situation is the first one, because strong localized rainy events could provoke growth of the water level and stress the functioning of the entire system, leading to a flood event. The second case could be represented i.e. by the simultaneous occurring of a lightning hitting the industry, and a flood, i.e. provoked by Po river. Finally, the last case represents the contemporary occurring of all the interactions; even if it has a very high possible impact, it is for sure the rarest condition.

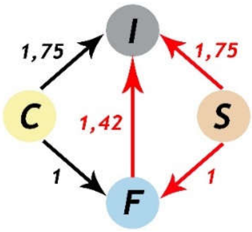
Example: FSI – Flood Earthquake Industry



1) Interactions earthquake/flood and flood/industry: S → F → I
Value = 1 + 1,42 = 2,42 "From moderate to high" influence



2) Simultaneous occurring of S → I and F → I interactions:
Value = 1,42 + 1,75 = 3, 17 "High" influence



3) Interactions S → F → I and S → I
Value = 1 + 1,42 +1,75 = 4,17 "Very high" influence

Concerning the first case, the interaction here is multiple: an earthquake could damage the flood protection devices and system, which cease their protecting functions towards industries and other urban functions. In addition, Flood and Earthquake could simultaneously occur, affecting the Industry, or all the interactions can take place, causing a Very high impact.

The multiple interaction of the 4 hazards analyzed would reach a value equal to 1+1+1,42 + 1,75 + 1,75 = 6,92. It is possible to observe that the values of multiple interaction have a great increase even if the starting values are quite low; however, these extreme values reflect events barely impossible.

3.5 Spatial consequences of the industrial interactions

Before the compatibility phase, a further optional step was developed for the assessment of the spatial extension of the interactions produced by natural events on industry. As anticipated, the whole methodology deserves a particular attention to the industrial interactions, as it explicitly descends from E.R.I.R. framework; therefore, it was considered particularly important to provide the Municipalities with clearer spatial data on the industrial consequences, to better addressing the compatibility phase and the future L.U.P. provisions.

This spatial analysis entails the use of modelling tools for the hazardous zones, therefore its level of difficulty for not-expert users increases; however, in order to maintain a usability as simplest as possible, modelling tools freely available and with a user-friendly interface were chosen. For the evaluation of toxic releases, flashfires, pool fires etc ALOHA® software was adopted, developed by EPA - United States Environmental Protection Agency.
The choice of the software for the environmental consequences was more difficult. The analysis of the environmental pollution was particularly important, because is an aspect frequently neglected: environmental scenarios are frequently excluded by Safety reports on the basis of probability analysis, but they could be easily triggered by NaTech events. However, no simple modelling tools are available yet, because of the difficulties in assessing the transfer of pollutant agents into soil and underground water. The property of the substance, and the local properties of the soil (like the porosity or hydraulic conductivity) determine very different behaviours and, in particular, in the vadose zone of the soil, characterized by the juxtaposition of liquid, solid and gaseous phases, the movement of the pollutant is influenced by the specific characteristics of the transport media and by the pedology. Transfer equations for the three different states are required to assess the behaviour of the pollutant.
The software *RBCA – Environmental modelling and risk-assessment software*, or the Italian *Giuditta*, designed for the recovery procedures of industrial zones, estimate the capability of areas characterized by high environmental pollution to reach sensitive objectives; however, these tools assume that the users already know the quantity of pollutant present in the aquifers or soils. On the contrary, for the purposes of the present study, it would have been necessary to estimate the quantity of pollutant that effectively can contaminate the water table.

Therefore, another EPA software, HSSM®, was adopted, even if it suffers the limitation that can assess the penetration into soil and diffusion on the aquifer only for LNAPL - Light Non-Aqueous Phase Liquids. If a pollutant denser than water is suspected to provoke possible environmental scenarios, the Municipality should carry on (or commission to the Employer of the plant) an in-depth investigation on the plant. Both the items presenting risk of pollution, and the specific quality of the soil and aquifer should be investigated, in order to dispose preventive and protective environmental measures; the questionnaire reported in **Table 23** can be used for the first step of the analysis.

3.5.1 ALOHA®

ALOHA® (Areal Locations of Hazardous Atmospheres) is a software aimed at modelling chemical releases (toxic gas dispersions, fires, and/or explosions), especially for emergency planning and training purposes; it has been explicitly designed to produce good results quickly enough to be of use to first responders, therefore "its computations represent a compromise between accuracy and speed". The following lines describe the main steps of the program:

1) Choice of the chemical: ALOHA assessment starts with the choice of the hazardous substance which can possibly provoke an accident; the software chemical library contains information about the physical properties of approximately 1,000 common hazardous chemicals, however only 5 solutions are included. It is also possible to expand the library adding other substances, but several parameters have to be specified in order to allow the program to simulate the chemical releases. The online database cameochemicals.noaa.gov can provide useful information for the parameters of the added hazardous substances.
2) Information on the weather conditions: the software has two dedicated boxes for the weather conditions, where the following information should be inserted: the wind speed in m/s; the wind direction; measurement height and ground roughness; the conditions of cloud cover and humidity. ALOHA automatically assigns a stability class, depending on the settled conditions. The weather information can be found at a local level by weather stations on the Municipal territory, whose data are frequently freely available.
3) Choice of the source of release: ALOHA® presents 4 different sources of release: direct / tank / puddle and gas pipeline, for which the gas release is estimated. The first source, to be used when little information is available, requires to directly insert the amount of gas released (also an esteem could be ok), while the other source options better define the originating conditions of the release. Both the puddle and the tank can produce different types of scenarios, depending if the chemical immediately burns or not. The user can choose between these options, and can then specify the type of soil on which the release take place, the dimension of the hole for the tank and other information.
4) Display threat zone: on the basis of the data inserted by the user in the previous phases, ALOHA® software calculates the extension of the toxic release, poolfire, flashfire or VCE that can be produced by the release of the substance analysed. The areas obtained can be exported in a file extension compatible with ArcGIS or in *.kml* extension. The latter can be opened through GoogleEarth®, returning an immediate idea of the areas in the surroundings that can be interested by the accident.

3.5.2 HSSM®

Fluids less dense than water migrate downward through the vadose zone; once they have reached the water table, they tend to form lenses (floating) on the top of the aquifer. HSSM® (Hydrocarbon Spill Screening Model) simulates the flow of the light non aqueous-phase liquid (LNAPL) and transport of a chemical constituent of the LNAPL from the surface to the water table. It also calculates the radial spreading of the LNAPL at the water table, and the dissolution and aquifer transport of the chemical constituent. The LNAPL is assumed to be released at or below the ground surface in sufficient quantity to form a fluid phase, that remains distinct from the water.
HSSM is not suitable for liquids denser-than-water (DNAPLs). According to HSSM manual (Weaver et al., 1994), only the first module of HSSM, named KOPT (Kinematic Oily

Pollutant Transport), could be used for a DNAPL, as the qualitative behaviour of that module is not affected by fluid density; however, the substance analysed shall not be easily soluble. HSSM is composed by three modules, that can be run at the user's choice: 1) KOPT simulates the flow of the LNAPL from the surface to the water table; 2) If the volume of hydrocarbon released is sufficient to reach the water table, OILENS simulates the radial spreading of the LNAPL on the aquifer surface; TSGPLUME simulates the transport of the chemical constituent through the aquifer.
In order to run the models, the user is required to fill three input boxes: Hydrologic parameters, Hydrocarbon phase parameters and Simulation parameters. The data for soil and water connoting the analysed area, the data about the LNAPL, and the parameters for the simulation (i.e. beginning time, release time etc.) have to be inserted; if the user decides not to run some of the modules (i.e. OILENS or TSGPLUME), less fields have to be compiled.

3.5.3 Limitations

As previously mentioned, the easy usability of ALOHA and HSSM software implicates some limitations, that should be taken into account when the results are shown.

As far as it concerns the first software, the most important limit is related to the duration of the simulation: ALOHA calculates the evaporation rate or burn rate for no more than an hour, because the variations of the atmospheric conditions after this period would affect the predictions. Also, the software cannot draw release areas of reduced dimensions, in particular nearby the source of release, because of the so-called "Concentration patchiness": in fact, in these areas the wind eddies produce a cloud unpredictably about, characterized by highly variable gas concentrations from one point to another. Finally, other limitations are related to: 1) poolfire accidents, whose extension cannot be simulated for the water; 2) depth of the puddle source, that is automatically settled by the program as 0,5 cm and 3) release from the tank, which do not consider the pressure produced by the mass of liquid present above the rupture point. A further description of all the limitations can be found in (EPA, 2007).

With reference to HSSM, it requires to search and collect a major quantity of data with respect to ALOHA, which in some cases could be highly specialized. This can partially affect its usability; also, its outcomes are not exportable to any drawing software. However, the main HSSM limit is related to the field of application: the simulation could be conducted only for LNAPL, that means petroleum derived substances; but many pollutants have not these characteristics and their effects on the underground aquifers cannot be simulated with HSSM.

3.5.4 Damage states for the simulation

HSSM and ALOHA can return the effects of industrial accidental events, but their use for the present methodology was subordinated to the settlement of credible initial conditions,

able to represent the possible effects of the interactions. Therefore, the interaction indexes obtained through the Interaction tables or GIS had to be associated to a possible damage, depending on the different initial strength of the natural event impacting on the plant.
In order to satisfy this request, a helpful and easy classification was found in (Salzano et al., 2009), (Cozzani et al., 2010), (Renni et al, 2010): as reminded in paragraph 2.4.1., these authors established simplified damage states (DS to calculate the intensity of loss of containment from tanks. The possible release scenarios, called R1, R2, and R3 (reported in **Table 6)** were coupled to the interaction levels, as shown in **Table 11** below:

Table 11: Coupling of interaction levels and damage states

INTERACTION VALUE		*DAMAGE STATE*	
$1 \leq I \leq 1{,}99$	Low to Moderate	R3	continuous release from a hole having an equivalent diameter of 10 mm
$2 \leq I \leq 2{,}99$	Moderate to High	R2	continuous release of the complete inventory (in more than 10 min)
I > 3 onwards	High to very high	R1	instantaneous release of the complete inventory (in less than 2 min) following severe structural damage

However, some adjustments of these initial conditions were required in order to answer the basic information required to use ALOHA and HSSM software. In particular, for ALOHA, a determined area for the hole of release was requested, which was not available for R2 and R1 damage states. In addition, HSSM required inserting both depth and extension of the puddle of release.
(HSE, 2012) was employed for the definition of possible areas for the hole of release of R2 and R3, with particular reference to the dimensions of release reported for the tanks (Table 12):

Table 12: Diameters for tank ruptures (HSE, 2012)

Hole diameters for tank volumes (m^3)			
Category	>12000	12000-4000	4000-450
Major	1000 mm	750 mm	500 mm
Minor	300 mm	225 mm	150 mm

As far as it concerns the puddle dimensions and depth requested by HSSM, the Bernoulli principle was initially applied to calculate the spills from the tanks. However, a validation carried out with EFFECTS® software demonstrated that the puddle extensions calculated were excessive. Therefore, the extension of the puddle was extracted from ALOHA simulations; in fact, when tank is settled as release source, ALOHA automatically provides he measure of the puddle diameter. Unfortunately, ALOHA does not calculate the pond depth but assumes that, after 1 hour of release, the depth is equal to 0,5 cm. For HSSM, this depth can be considered credible only to simulate R3 damage states.

The following **Table 13** resumes all the initial parameters settled on ALOHA and HSSM to simulate the effects of the NaTech interactions.

Table 13: Parameters for the estimation of the interaction consequences

Interaction level	*Damage state*	*ALOHA*	*HSSM*
1 ≤ I ≤ 1,99	R3	*Source*: tank *Release hole:* 1 cm, or minimum hole area able to produce effects (2-3 cm)	*Source:* puddle Diameter calculated with ALOHA for 1 cm release. *Depth*: 0,5 cm (conventional ALOHA depth)
2 ≤ I ≤ 2,99	R2	*Source:* tank *Release hole:* (HSE, 2012) minor damages = 150 mm or 225 mm or 300 mm.	*Source:* puddle Diameter calculated with ALOHA for 150/225/300 mm. *Depth:* to be assessed
I > 3 onwards	R1	*Source:* puddle (more suitable to represent the catastrophic scenario correspondent to R1). *Diameter:* containment basin diameter Volume: total volume of substance contained in the tank	*Source:* puddle Diameter equal: containment basin diameter *Depth:* calculated through: volume of the substance / area of the containment basin

The parameters adopted allowed employing ALOHA and HSSM to obtain a first and immediate idea of the possible consequences of NaTech interactions: However these two programs were not created for NaTech assessment scopes, and this has to be taken into account:

- The damage states R1, R2, R3 represent simplified release scenarios, however, the consequences of NaTech events entail also complicated chains of events or unforeseen damages (i.e. failure of the electric supply etc.) that would require a more detailed approach to be precisely evaluated and modelled.
- The damage states R1, R2, R3 are specific for tanks. If simulations for other items are required, they shall be adapted to the different situations, also verifying if (HSE, 2012) or other literature data provide specific hole release measures for the chosen items. Barrels, tanker trucks, rail tanks, can be simulated in ALOHA as tanks, while the pipelines have a dedicated ALOHA source. For HSSM, the only important thing is to settle in ALOHA conditions of soil and containment as much as possible close to the reality, in order to obtain a reasonable simulation of the possible extension of the puddle.
- Neither ALOHA or HSSM were designed to represent a NaTech event. The specific conditions produced by a flood or seismic event were simulated in ALOHA through the settlement of atmospheric features and type of soil. For earthquake, a sunny day, with low wind speed (2 m/s, stability class = B) and humidity = 50% was assumed; the ground was chosen on the basis of the type of containment basin analyzed. For flood, a cloudy and rainy day was assumed, with wind speed = 5 m/s (stability class = D); the ground on which the release takes place was settled as “Water”.

With reference to HSSM, the dataset of parameters made available by the software only allows to insert the characteristic of soil and of substances in normal conditions; the program is not able to represent the peculiar condition of a release on the water, that can spread the pollutant towards superficial waters and to major distances. Therefore, the simulations made with HSSM shall necessary be referred to damages provoked by earthquake, or releases occurring with the soil in normal conditions.

- Since ALOHA assumes as starting point the release from a tank or puddle, NaTech interactions related to Extreme climate events like i.e. lightning, or rain accumulation, could not be simulated. In fact, they usually provoke types of accidents that are not ascribable to a release, like i.e. the immediate ignition of the vapors present on the tank roof, the roof overturning etc. For this reason, even if (Renni et al, 2010) elaborated three simplified damage states also for Lightning, this type of event could not be modelled.
- The standard depth of ALOHA pond (0,5 cm) can be assumed for HSSM, to simplify the simulations. However, this depth is credible only for R3 damage state, and cannot be valid for R2 damage state, which necessities more calculations.
- ALOHA and HSSM cannot include the possible passive or active monitoring and protection measures disposed by the industries (i.e. level control, tanks firefighting systems, emergency team intervention etc.). Since the action of an external event could provoke problems also for the protection systems, it is assumed for the simulations that the leaking conditions and creation of a pond could not be detected in time to stop the consequent scenario. However, the results obtained have to be interpreted in the light of the existing measures, and on the basis of the level of impact calculated (i.e., malfunctions and failures of the protection measures and emergency systems are more probable for medium-high levels of NaTech interactions).

3.6 Vulnerability analysis

The current approach to vulnerability defines it as a multi-dimensional concept, which should not only represent the predisposition of the exposed elements (people, buildings, infrastructures, activities, etc.) to be subjected to the risk, but also the capacity of a system to face and overcome a hazardous event (Coping capacity). Many multi-risk projects tried to define a framework for the vulnerability assessment, defining analytical o qualitative methodologies, and facing problems related to: the different vulnerability presented by the exposed elements towards the risk analyzed; the lack of detailed information and reliable parameters to take into account the copying capacity.

As it concerns the quantitative methods, there is a general agreement on the use of vulnerability functions (fragility curves) to express the physical vulnerability: the input is the single hazard analyzed (e.g. intensity, magnitude, category) and the output is the average loss of a given element at risk, possibly defined as probability of occurrence (fragility curve).

However, reliable vulnerability or fragility curves are not available for all the types of risks: the only exception is seismic risk, for which long years of studies and researches allowed to clearly reconstruct the relation between damage, hazard intensity (in this case Peak Ground Acceleration) and vulnerability. For flood and other hazards, only experimental proposals like that of ARMONIA project are available yet (Menoni et al., 2006). Also, the fragility curves do not express the vulnerability assessment for social and environmental factors, so that it can be difficult to integrate them within a multi-risk framework. In other cases, vulnerability is defined through semi-quantitative or qualitative methods, therefore the elements are described through indicators, which can be also weighted and summed up in order to establish an integrate vulnerability index. The choice of the indicators and of the scale of the analysis are strictly related to the scale of the project: i.e. a transnational project as ESPON (Schmidt-Thomè, 2006) defined 3 main indicators for the vulnerability, able to express the damage potential (regional GDP/capita, population density, fragmented natural areas) and the coping capacity (regional GDP/capita), while more exposed elements and vulnerability indicators are defined by projects whose focus is at a regional/local scale. I.e. the project ARMONIA identifies the many different types of exposed elements; for some of these elements, a vulnerability index was introduced (i.e. for the population, the presence of people younger than 5 years, and older than 65 years).

While the elements exposed to the danger are simpler to be identified (type, number or surface, etc.), the vulnerability and coping capacity entail more complexity. The Guidelines prepared by (Regione Piemonte, 2004) and the vulnerability maps by (Di Mauro et al., 2006) represent a first attempt at regional level to cope with these aspects. According to (Regione Piemonte, 2004), the damage depends on the target elements, but also on factors which can increase or reduce the effects of the event; the anthropic and territorial vulnerability of each target should be analysed, compiling detailed sheets which contain the indicators for the vulnerability. The values will be summed up through a weighted sum to obtain an aggregated vulnerability index.

In their research for the Institute for the Protection and Security of the Citizen, (Di Mauro et al., 2006) calculated the damage as a mathematic function, composed by 4 different factors (exposure level and impact area (potential damage), susceptibility and facing capacity (vulnerability). The damage was calculated for each type of risk on the basis of this equation. Another proposal at regional level came from (Regione Lombardia, 2007): in this case, the importance and vulnerability of each element were assessed through the methodology of the budgetary allocation.

In spite of the increasing attention dedicated to the theme of vulnerability, it is possible to observe that currently the regulations both in the field of risk planning and emergency management are mainly focused on the aspects related to the exposure. Probably, the difficulties in identifying the parameters to determine a specific vulnerability and to measure the coping capacity, and the scarce data available did not favour an official adoption and implementation of more precise techniques. The approaches above exposed entailed an in-depth analysis and a high involvement of resources (technical and financial) that on site could complicate their adoption, particularly if the authorities involved are the Municipalities. A clear example of this problem is represented by the compilation of the vulnerability data sheets requested in Italy for the seismic risk, already mentioned in Chapter 1. In 2003, the *Ordinanza OPCM 3274* (Presidente del Consiglio dei Ministri, 2003) required the assessment of the safety state for two types of buildings: a) strategic buildings and infrastructures whose functions during seismic evens are fundamental for civil protection operations; 2) Public buildings and infrastructures whose collapse could provoke severe consequences. Three types of safety data sheets were foreseen: a level 0, mainly containing statistical information related to the building, and then levels 1 and 2, containing more in-depth information on the structural characteristics of the building. Each Region should have issued a dedicated Regional law for this scope, and then the Municipalities should have proceeded with the compilation of the data sheets; for the Municipalities located in very risky area (Class 1 and 2 of the national seismic classification), a governmental contribution was foreseen for the operations. In spite of these special measures, the deadline for the compilation of the data sheets was postponed three times, because of the delays caused by the lack of financial and technical resources. The last term for the submission of the safety data sheets (level 0) was 2013, but it is still not clear if all the involved Municipalities have submitted their ones.

For the proposed methodology, the step related to the assessment of vulnerability followed the ERIR approach: even if it is exposure-oriented and does not include indicators related i.e. to the specific vulnerability of buildings and other aspects, it has the advantage of a quick and quite easy utilization, that can be more compliant with the general purposes of the research. This step should proceed in parallel with the hazard characterization, with the aim of identifying all the territorial and environmental vulnerable elements present on the territory of the Municipality.

Both the vulnerabilities related to the population and those related to the environment are identified, establishing a first classification of vulnerability on the basis of 6 classes for the population (territorial) vulnerability, and of 2 classes for the environmental vulnerability.

This approach, even if established to assess the vulnerability towards industrial risk, can be easily extended to other types of risks and to risk interactions: as far as it concerns the territorial vulnerability, the assessment of the people density and frequentation provides a valid representation of the exposure towards any type of risk, because a high concentration of people increases the risk with respect to any hazard analyzed (industrial, seismic etc.). Even if the type of building and the proper characteristics of the construction can influence the vulnerability level, this analysis could be demanded to successive steps, i.e. it could be developed if the frequentation and number of people point out a risky situation.

As far as it concerns the environmental risk, the E.R.I.R. approach suggested by (Regione Piemonte, 2010) and (Provincia di Torino, 2010) identified a series of elements whose vulnerability can be defined as Very High or Relevant; however, the concept of environmental vulnerability results always “variable” in function of the danger analyzed. In fact, an environmental element can be vulnerable or not to the specific risk presented by a plant (i.e. in case of presence of flammable substances, the vulnerable element “Wooden area” is clearly at risk), and the same “variability” is found towards the other risks analyzed in the proposed methodology.

Finally, a further step was added with respect to the ERIR vulnerability: shelters and areas for the emergency management indicated in the Municipal emergency plan, strategic infrastructures ad buildings were also analysed and considered to verify their compatibility.

3.6.1 Territorial vulnerability

The framework of D.M. 09/05/2001 was adopted; it defined the basic principles for a safe planning around Seveso plants, implementing in Italy the provisions of Legislative Decree 334/1999 and EC Directive 96/82/CE. Further extensions of this approach, defined by (Regione Piemonte, 2010), and by (Provincia di Torino, 2010), were also taken into account. According to D.M. 09/05/2001, art. 6.1, two different categories of vulnerable elements should be identified on the municipal territory:

- The territorial vulnerabilities, related to the human use of the territory (functions and infrastructures)
- The environmental vulnerabilities.

As showed by **Table 14**, the decree is very accurate as far as it concerns the territorial elements: 6 different categories of vulnerability are defined on the basis of the urban function, the building ratio index, and the presence of people.

Table 14: D.M. 09/05/2001, territorial vulnerable classification

Category DM 09/05/2001	*Vulnerable elements*
A	1. Residential areas, with building ratio index > 4,5 m^3/m^2 2. Buildings hosting people with limited mobility (more than 100 people or 25 hospital beds) – hospitals, hospices, nursery schools 3. Outdoor places interested by high presence of people, like markets or other commercial functions (more than 500 people)
B	1. Residential areas, with building ratio index from 1,5 m^3/m^2 to 4,5 m^3/m^2 2. Buildings hosting people with limited mobility (up to 100 people or 25 hospital beds) – hospitals, hospices, nursery schools 3. Outdoor places interested by high presence of people, like markets or other commercial functions (up to 500 people) 4. Indoor places interested by high presence of people, like shopping centres, business districts, hotels, universities, high schools, etc. (more than 500 people) 5. Places interested in limited periods by high presence of people, i.e. places for public entertainment and for cultural, sporty, religious activities (more than 100 people for outdoor places, more than 1000 people for indoor places) 6. Railway stations (more than 1000 passengers by day).
C	1. Residential areas, with building ratio index from 1 m^3/m^2 to 1,5 m^3/m^2 2. Indoor places interested by high presence of people, like shopping centres, business districts, hotels, universities, high schools, etc. (up to 500 people)

Category DM 09/05/2001		*Vulnerable elements*
	3.	Places interested in limited periods by high presence of people, i.e. places for public entertainment and for cultural, sporty, religious activities (up to 100 people for outdoor places, up to 1000 people for indoor places)
	4.	Railway stations (up to 1000 passengers by day).
D	1.	Residential areas, with building ratio index from 0,5 m^3/m^2 to 1.5 m^3/m^2
	2.	Places interested by high presence of people once a month, i.e. local fairs, flea markets, events, cemeteries etc.
E	1.	Residential areas, with building ratio index < 0,5 m^3/m^2
	2.	Industrial, artisan, agricultural and livestock activities
F	1.	Area inside the plant boundaries

(Regione Piemonte, 2010) grouped territorial vulnerable elements into three categories:

- Areas (to be classified on the basis of the activities established by the City Plan)
- Punctual elements (Buildings or places characterized by high presence of people or people with limited mobility)
- Linear elements (Energy infrastructures, railways, highways etc.)

According to (Regione Piemonte, 2010), the presence of these territorial elements should be verified in a 1 km area around the Seveso plants; nevertheless, both for E.R.I.R. drafting, and most of all for the proposed approach, it is preferable to examine the whole Municipal territory. This extended analysis allows to evaluate in each point of the territory the relationship between vulnerable elements and the identified risks, and could help the Municipality in a correct and safe planning of future actions.

3.6.2 Environmental vulnerability

As far as it concerns the environmental vulnerabilities, the DM 09/05/2001 provides less precise indications (see Chapter 1): it identifies 5 main environmental matrixes, whose vulnerability should be evaluated depending on the typology of accidental events considered. The matrixes are: Landscapes and environmental assets ex D.Lgs. 29/10/1999, no. 490; Protected natural areas (i.e. parks and other areas delimited by law); Superficial water resources (i.e. phreatic aquifer; primary and secondary hydrography); Deep water resources (i.e. dwells for potable use or irrigation, unprotected or protected deep aquifer; recharge areas for the underground water); Soil use (i.e. quality cultivated areas, woody areas)

Since (Regione Piemonte, 2010) and (Provincia di Torino, 2010) implemented these matrixes with a more detailed list of the vulnerable elements to be analysed, this approach was chosen for the research. In particular, 2 levels of vulnerability are identified: Extreme vulnerability elements, and Relevant vulnerability elements. **Table 15** in the following page reports the list of environmental vulnerable elements whose presence has to be checked.

Table 15: Environmental vulnerable elements (Regione Piemonte, 2010)

EXTREME VULNERABILITY	1. Protected natural areas (national, regional, provincial) 2. *Natura 2000 ex* Direttiva 92/43/CEE "*Habitat*" areas 3. Landscapes protected by D.Lgs.42/2004 s.m.i. art. 142, letters: *b*, (300 m. areas around the lakes), *d* (mountains higher than 1600 m), *m* (archaeological areas) 4. *A and B* zones from PAI plan, areas with very high or high hydrogeological instability 5. Landslides 6. Residential areas to be transferred or consolidated according to legge 9 luglio 1908 n. 445 e s.m.i.
RELEVANT VULNERABILITY	1. Historical monuments, protected landscape / environmental archaeological areas 2. Geological-geomorphological elements of interest 3. Landscapes protected by D.Lgs.42/2004 s.m.i. art. 142, letter g: (wood areas) 4. Area subjected to hydrogeological restrictions ex l.r. 45/1989. 5. Landscapes protected by D.Lgs.42/2004 s.m.i. art. 142, letter c, (150 m. areas around rivers and public creeks) 6. Environmental passageways 7. Land use capacity categories 1 and 2 8. Typical / specialized agriculture 9. C zones from PAI plan, areas with moderate hydrogeological instability 10. River buffer zones with medium flooding probability identified by Province studies 11. Underground water with very high or high vulnerability 12. Aquifer recharge areas 13. Underground water depth > 3 m. 14. Underground water depth from 3 m. to 10 m., sandy or loamy soils

3.7 Compatibility assessment

The compatibility assessment represents the final step of the proposed methodology: the hazards identified and described through the 3 macro-categories, together with their interactions, are superimposed to the vulnerable elements, in order to verify the overall compatibility. This assessment could be directly developed on the basis of the Interaction tables described in Paragraph 3.3, or when possible, taking into account the mapping of consequences obtained through the procedures explained in Paragraph 3.5.
The areas to be analysed are those with highest concentration of population, or where particular high environmental vulnerabilities are encountered or, on the contrary, where natural hazards can activate NaTech scenarios.

The compatibility assessment does not consider the Multiple hazards interactions, but takes into account only binary Interactions. The reason is that multiple interactions have a high disruptive potential, according to the calculations made, but their results could be misleading for a correct compatibility analysis. Indeed, their very high scores are affected by great uncertainties related to the several possible event chains, and also, they have extremely low probabilities. Even if the probability was not considered in the current methodology, it could be unusually alarmist to base the evaluation of compatibility on these results.

For the proposed methodology, the compatibility assessment is based on a threshold of 2.5 (medium riskiness tending to high), validated through experts' judgment. A potential

incompatibility is identified if in areas of superimposition with highly vulnerable elements, the macro-categories Strengthening Effects and Historical Events, or some values of interaction overcome the threshold. Following this check, the Municipality will have to carry out more in-depth studies in the area, aimed at confirming the incompatibility, and verifying possible preventive solutions, or protective measures.
As far as it concerns the threshold, some specifications have to be provided:

- For the single risk, the judge is based on the values assumed by the categories Strengthening effects and/or Historical Events, because of their importance: both S.E. and H.E. express aspects of the risks that could be neglected in the existing plans, thus representing an unforeseen threat for the exposed vulnerable elements. Therefore, for a precautionary purpose, it is fundamental to consider them in the compatibility assessment.
- As already reminded in Chapter 4, the value of interaction considered for the compatibility analysis derives from the binary interactions; even if multiple levels of interaction can be considered for further analysis, at a first stage it could be more convenient to analyse the situations that could provoke problems even with two only hazards interacting.

3.7.1 Territorial compatibility

The D.M. 09/05/2001 defines the territorial compatibility criteria for Seveso plants on the basis of their damage areas; they have to be overlaid on the vulnerable territorial areas, then the compatibility is assessed depending on the probability of occurrence of the event and of its type of effects (High Lethality, Early Lethality, Irreversible Damage and Reversible Damage). **Table 16** shows the compatibility criteria established by the DM 09/05/2001: i.e. for an unlikely event, BCDEF categories are considered compatible in the Reversible Damage zone; for a probable event, only DEF can be present in the Reversible Damage zone.

Table 16: DM 09/05/2011 Compatibility criteria

Probability of occurrence	Effects			
	High lethality	Early lethality	Irreversible Damage	Reversible Damage
$< 10^{-6}$	EF	DEF	CDEF	BCDEF
10^{-4} - 10^{-6}	F	EF	DEF	CDEF
10^{-3} - 10^{-4}	F	F	EF	DEF
$> 10^{-3}$	F	F	F	EF

Table 16 helps evidencing that territorial elements belonging to the categories A and B are the most vulnerable ones, never considered compatible with an industrial scenario, because of their high presence of people, or presence of people with reduced mobility. These characteristics also make them vulnerable to other natural risks.

Therefore, in order to evaluate the territorial compatibility for the proposed methodology, if A and B elements are included in an area characterized by values of the risk macro-categories or hazard interactions > 2.5, there could be a potential incompatibility that shall be further analysed.
The strategic and emergency buildings, areas, infrastructures or linear elements are not classified on the basis of the 6 classes, however if one of this element is located in areas with values > 2.5, further analyses shall be carried out.

The assessment of the territorial compatibility can be easily developed through the use of the GIS thematic map, superimposing the vulnerability maps with the hazard maps and Interaction polygons; however, in relation to the industrial hazard and interactions, some specifications are needed in relation to the spatial distribution.
As specified in Paragraphs 3.3 and 3.4, for the industries, the possible impact is simulated through the creation of a buffer zone of 500 m. around the plants, where the values of the Industrial three macro-categories and of the interactions are projected. However, it has to be considered that the values of other risks inside the 500 m. buffer zone could be subjected to modifications, because of the variation of their characteristics.
Figure 17 provides a simple explanation of this situation, and of the method chosen to deal with it:

- An industry (I) is located in an area interested by Seismic (S) and Flood (F) hazards; in the overlaying zone A, the macro-category S.E. has the following values: I = 3; S = 1, F = 1.5. S and F maintain the same values in the area A^1.
  The binary interaction value S → I (calculated only for S.E. macro-category) in the overlaying zone A is 2.
- Inside the 500 m. buffer zone, in the area identified as B, the value of S.E. for the seismic hazard changes (S.E. = 2,5), because of a different quality of the soil.

In this case, in the area indicated as A^1, the compatibility assessment will be based on the following values: projection of the interaction value S→ I =2 and of S.E. Industry = 3; S.E. seismic risk 1, S.E. hydrogeological risk 1,5.
For the assessment in the B zone, the projected values remain the same (Interaction value = 2, and S.E. Industry = 3), but the seismic S.E. to be taken into account will be = 2,5. S.E. for Flood hazard in zone B is no more considered, because is not present.

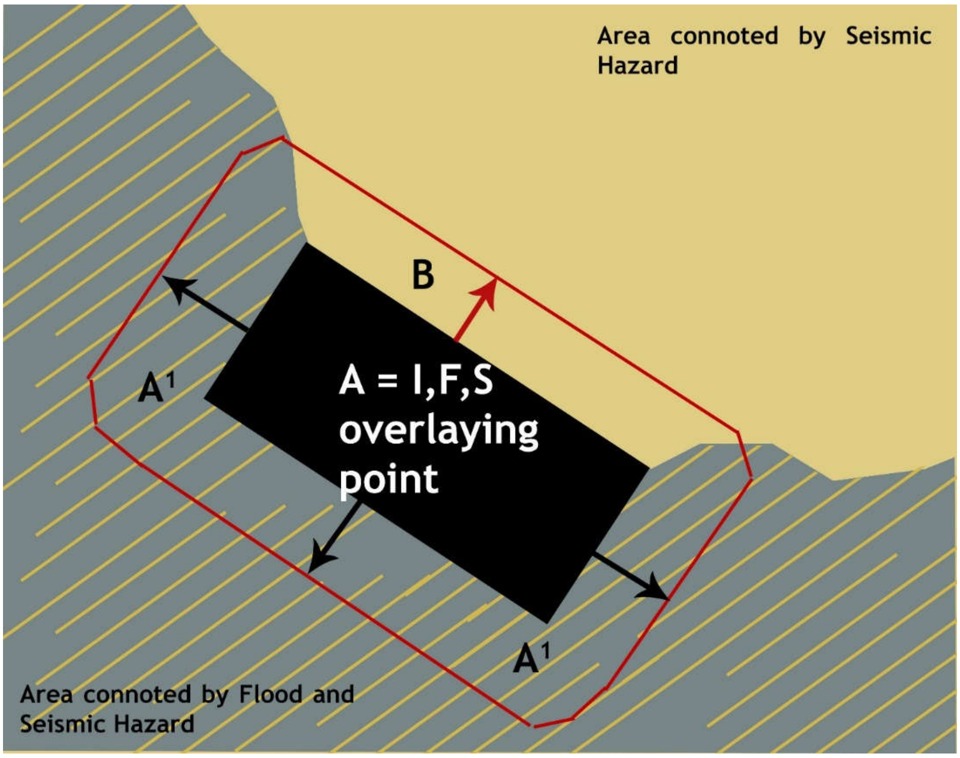


Figure 17: Assessment of the territorial compatibility in the buffer zone

Therefore, in the buffer zone, the compatibility assessment is based on multiple elements: on one hand, the projection of the interaction effects provoked by the industry, on the other hand, the local characteristics of the risk. All the following values have to be evaluated, in order to check if they remain or not below the threshold of 2.5:

- The values of the interactions projected from the industry
- The values of the macro-categories S.E. and H.E. of the industry
- The local values assumed by the macro-categories S.E. and H.E. of the not-industrial risk in the buffer zone.

3.7.2 Environmental compatibility

As far as it concerns the environmental compatibility, the D.M. 09/05/2001 only marginally defines a method to assess it: as reported by (Menoni et al., 2006), the Decree merely states that Public Authorities have to verify the compatibility between dangerous plants and environmental resources, checking if the environmental damage can be qualified as Significant or Severe on the basis of the foreseen time for the recovery. According to the DM 09/05/2001 "*In case of potential impact on the environmental elements (Significant damage), the Master Plan should introduce provisions for the building and planning activities, or preventive and protective measures including specific arrangements and territorial, infrastructural and organizational intervention, in order to protect the surrounding* *environment. These actions shall be defined on the basis of their feasibility and of the characteristics of the plants, with the aim of reducing the category of damage*". No further indications on the possible measures to be adopted were given.

Nevertheless, as reminded in Chapter 1, some Italian Regions and Provinces made an improvement with respect to the national regulations as far as it concerns the environmental compatibility: in particular, Turin Province defined a list of incompatibility depending on the substances detained by the plant and the environmental vulnerabilities encountered in the area of analysis. Also, it required to the existing plants to develop a further compatibility research, based on the analysis of the peculiar characteristics of soil and water in the area interested by the plant. The presence of the following elements should be investigated:

1) the depth and the direction of the phreatic aquifer nearby the plant, in a sector with 30° degrees of amplitude and 3 kilometres of extension, measured from the possible point of release in the direction of the aquifer flow;
2) the presence of wells inside the same sector, within an extension of 500 metres;
3) the presence of drains in superficial creeks or canals.

If the three conditions reported are all verified, the owner has to adopt a specific list of preventive and protection measures (reported in Paragraph 3.3, **Table 8**).

However, for the proposed methodology, the environmental compatibility should be assessed not only in relation to industry, but also with reference to other risks; therefore, its assessment presents more difficulties, because the same exposed element can present a different level of vulnerability to different risks.

Table 17 constitutes an indicative Guide to identify the influence that each hazard can have on the different environmental receptors; the level of influence was assigned on the basis of literature data and surveys on natural and combined events, and in comparison with the hazard which exercises the highest influence (industry). The "influence" is intended as the capacity of a determined hazard to provoke permanent negative changes to the analysed receptor, which could also bring to its complete loss.

As far as it concerns the interactions, if the industrial risk is involved, the estimation of the possible influence will have to take into account the presence of the plant; otherwise it will be necessary to evaluate the influence on the vulnerable element for each risk involved, and adopt for the compatibility assessment the most impacting.

Table 17: Risk influence on environmental vulnerable elements

VULNERABLE ELEMENTS	RISKS			
	SEISMIC	FLOOD	INDUSTRIAL	CLIMATE EVENTS
Extreme vulnerability				
Protected natural areas (national, regional, provincial)	Reduced influence	From reduced to moderate influence	High influence (environmental /toxic/ flammable substances)	From reduced to moderate influence (for lightning, drought)
Natura 2000 ex Direttiva 92/43/CEE "Habitat" areas	Reduced influence	From reduced to moderate influence	High influence (environmental /toxic/ flammable substances)	Reduced influence
Landscapes protected by D.Lgs.42/2004 s.m.i. art. 142, letters: b, (300 m. areas around the lakes), d (mountains higher than 1600 m), m (archaeological areas)	From moderate to high influence	From moderate to high influence (on areas around the lakes and archaeological zones)	High influence (environmental / flammable substances)	Moderate influence (on mountains)
Relevant vulnerability				
Historical monuments, protected landscape / environmental archaeological areas	High influence	High influence	From moderate to high influence (depending on the substances detained)	Moderate influence
Geological-geomorphological elements of interest	High influence	High influence	Moderate influence (flammable substances)	Reduced influence
Landscapes protected by D.Lgs.42/2004 s.m.i. art. 142, letter g: (wood areas)	Reduced influence	Moderate influence	High influence (flammable, environmental)	Moderate influence (lightning, drought)
Area subjected to hydrogeological restrictions ex l.r. 45/1989.	-	-	-	-
Landscapes protected by D.Lgs.42/2004 s.m.i. art. 142, letter c, (150 m. areas around rivers and public creeks)	Reduced influence	From moderate to high influence	From moderate to high influence (environmental substances)	Moderate influence
Environmental passageways	Reduced influence	Reduced influence	From moderate to high influence (environmental substances)	Reduced influence
Land use capacity categories 1 and 2	Moderate influence	From moderate to high influence	High influence	From moderate to high influence

VULNERABLE ELEMENTS	RISKS			
	SEISMIC	FLOOD	INDUSTRIAL	CLIMATE EVENTS
Typical / specialized agriculture	Moderate influence	From moderate to high influence	High influence	From moderate to high influence
Underground water with very high or high vulnerability	See Note[10] below		High influence (environmental, toxic)	
Aquifer recharge areas				
Underground water depth > 3 m.				
Underground water depth from 3 m. to 10 m., sandy or loamy soils				

As a consequence of the previous mentioned "variability" of the environmental vulnerability, the compatibility assessment for environmental elements should be assessed in two steps: for an area connoted by Extreme or Relevant vulnerable elements, after verifying if the risks and interaction values overcome the threshold of 2.5., the specific relations between the risk analysed and the vulnerable element shall be investigated.
Table 17 above represents an attempt to drive this process, but clearly the situations have to be evaluated case by case.

3.8. Planning phase

The last step of the methodology is dedicated to the studies and actions to be carried out when possible incompatibilities are encountered. The overcoming of the threshold of 2.5. in areas with potential territorial or environmental incompatibilities, is an alert signal for the Municipalities, indicating that it is necessary to concentrate here economical and technical resources.
The first step to be planned is an analysis in detail of the potential incompatible situation, both as far as it concerns the hazards and the vulnerabilities: i.e. for the territorial

[10] Seismic and flood hazards and climate events clearly have repercussion on the aquifers, mainly consisting in fluctuations in the levels, however the actual occurring of a possible negative permanent influence could be extremely variable and strictly related or to local conditions or to factors which scale is wider than local. For this reason, it was not expressed a judgement on the relationship between these hazards and the exposed elements. However, usually a flood provokes a sudden increase in the level of the water in the rivers, that brings also the phreatic water to increase. For the earthquakes, the relationship with underground water fluctuation is still matter of investigation; the anomalies of levels observed during seismic events can be related both to a level-raising (as observed in Emilia Romagna in 2012), and to level-decreasing. It depends on the characteristics of the soil which hosts the aquifer, that can be subjected to dilatation or compression. The size of the anomaly encountered depends also on other variables, like the distance from the earthquake epicenter.
The fluctuations do not present an expression of a negative influence per se, but they could have further repercussions on other elements, like i.e. territorial vulnerable elements.

vulnerability, the exposure of the elements menaced by seismic, flood and climate risk, could be integrated analysing the characteristics of the buildings.
After this first level of investigation, aimed at confirming and verifying the characteristics of the incompatibility encountered, the Municipality will have to identify preventive or protective measures that could be adopted.

Table 18, **Table 19**, **Table 20**, **Table 21** collect the possible actions for the in-depth analysis and the adoption of measures of prevention and protection, and constitute a path to help the Municipalities in the planning phase. The indications are mainly referred to existing Manuals and Guidelines, diffused by the government or other public authorities, or settled by research groups, which in many cases do not have binding value, and therefore are little known and applied.
The first two tables report the measures related to natural risks and their interactions, the second two are referred to industrial risk. This is the risk with the highest influence on environmental elements, and at the same time, it is the most subjected to external influences; the application of HSSM and ALOHA software give a first idea of the consequences of the interactions, but an in-depth analysis is necessary.

As far as it concerns the preventive and protective measures, usually they are ascribable to 4 different categories: hazard, exposure, vulnerability or risk oriented (Menoni et al., 2006):

- Hazard: structural interventions aimed at reducing the hazard severity or probability (i.e. levees and dams, consolidation and drainage systems, barriers, etc.);
- Exposure: relocation of the exposed elements, or in some cases of the threat (i.e. industrial plants); they are rarely applied because of the high costs;
- Vulnerability: based on the concept of resilience. Improvement of the qualities and characteristics of the exposed elements to increase the passive resistance to the hazards.
- Risk: the damage is not reduced, but the impact on the community is mitigated through financial strategies, to permit quick recovery at reasonable costs (i.e. insurance).

The measures proposed for this last step of the methodology are mainly hazard-oriented, and in some cases vulnerability-oriented. In fact, as far as it concerns the measures exposure-oriented, the relocation, even if suggested by E.R.I.R. and applied to peculiar cases of cities menaced by landslides, never had a wide application in Italy. Also, the risk-oriented measures, like insurance, are normally not integrated in land-use plans.

Table 18: In-depth analysis for natural risks and interactions

RISK	*Measures*	
	In presence of: Punctual / areal elements and infrastructure cat. A, B	*In presence of: Environmental elements subjected to a high influence*
Earthquake	Draft of 0 and 1 level data sheets in compliance with the OPCM 3274 (Presidente del Consiglio dei Ministri, 2003), starting from the public buildings and infrastructures classified as A.	For the archaeological and historical monuments, and protected landscapes: development of an in-depth analysis in compliance with (Ministero dei Beni e delle Attività culturali e del Turismo, 2010)
Flood	For the buildings classified A and B, the characteristics of the pavement, walls etc. should be analysed and on the basis of the indication of (A.D.B.Po e Università degli Studi di Pavia, 2009): i.e. ground level should be higher than that of the reference flood or levee height For the bridges (linear element), it is recommended the compilation of the vulnerability sheet proposed by (Provincia di Torino, 2004), an Operative manual on the hydraulic vulnerability of bridges.	Case by case assessment of the specific vulnerabilities for the elements subjected to high influence
Climate	No guidelines are available for climate-related events. In this case, the in-depth analysis could be more focused on the study of the local climate trends, therefore, depending on the specific climatic risk identified, different investigations on the vulnerability can be carried out: i.e. on the roofs resistance etc.	-
Interactions Flood-Earthquake, Flood-Climate	The interactions between risks could cause an increase of the effects; in case the threshold of interaction is higher than 2.5, it could be useful to proceed with an in-depth analysis related to the probability of occurrence and the assessment of the spatial distributions of the possible effects. In this case maybe it would be necessary to involve experts with precise skills in matter of Seismic / flood and other hazards.	

Table 19: Measures for Natural risks and interactions

RISK	*Measures*	
	In presence of: Punctual / areal elements and infrastructure cat. A, B	*In presence of: Environmental elements subjected to a high influence from the analysed risks*
Earthquake	The interventions suggested in this case are vulnerability-oriented: the *NTC - Norme tecniche per le costruzion*i provide indications for the seismic adaptation and improvements when the buildings are in area where the acceleration overcome certain threshold. The application of these measures could be evaluated for buildings A and B for which the in-depth analysis evidenced particular fragilities.	The protection of the archaeological, historical monuments, protected landscapes can be improved through the adoption of the measures contained into (Ministero dei Beni e delle Attività culturali e del Turismo, 2010) and NTC - Norme tecniche per le costruzioni.
Flood	If the characteristics of the buildings located in areas menaced by flood demonstrate to be not compliant with those suggested by (A.D.B.Po e Università degli Studi di Pavia, 2009) or, for bridges, by (Provincia di Torino, 2004), several actions could be carried out. On one side, it is possible to directly intervene on the vulnerable elements themselves through the improvement of their resistance to the hazard; otherwise hazard-oriented measures can be adopted. In fact, structural interventions adapt to improve the hydrogeological protection can be implemented: three manuals released by APAT - Agenzia per la Protezione dell'Ambiente – Agency for the Environment protection, related to river and coastal arrangement, and landslides, can be used as guidelines for the actions (APAT, 2002) (APAT, 2003) (APAT, 2007). The choice of hazard-oriented measures could also protect the vulnerable environmental elements, even if in this case the impact of the protective interventions should be carefully evaluated.	
Climate	Depending on the specific climatic risk identified, different actions can be carried out.	-
Interactions Flood-Earthquake, Flood-Climate	The efficacy of the implemented measures towards a possible interaction should be object of a specific evaluation.	

Table 20: In-depth analysis for industrial risks and interactions

RISK	*Measures*	
	In presence of Punctual / areal elements and infrastructure cat. A, B	*In presence of Environmental elements*
Industrial	When the threshold values are overcome, it is necessary to verify the characteristics both of the vulnerable elements present in the area and of the plant. The position of the most dangerous items and substances has to be checked, and the topics of the area, linear or punctual elements in the vicinity have to be investigated: are they outside or inside? Which is the specific scenario that could interest them and which are the protective measures already in place? etc.	When the thresholds are overcome, the plants should carry out further investigations on their environmental impact in compliance with the prescriptions of the Turin province Guidelines (Provincia di Torino, 2010). The analysis, mainly related to water and soil conditions, aims at verifying: 1) depth and direction of the phreatic aquifer nearby the plant, in a sector with 30° of amplitude and 3 kilometers of extension, measured from the possible point of release in the direction of the aquifer flow; 2) presence of wells inside the same sector; 3) presence of drains in superficial creeks or canals. For other types of exposed elements, it is necessary to verify their compatibility with the substances detained by the plant, therefore analyzing in depth to which influence the element could be exposed.
Interaction with other industries	When the buffer zones of two industries are overlaid, it is necessary to verify if effectively there are items which could generate an interaction in the areas involved; it is suggested for particularly severe situations to contact experts for the application of the assessment of domino effects as developed by Antonioni et al. (2009)	
Interactions with other risks	When the interaction involving industrial risk overcomes the threshold value of 2,5, the application of quantitative methodologies for the assessment of the NA-TECH risk, aimed at verifying the possible damages and probabilities of occurrence is suggested. The integrated Q.R.A. developed by Cozzani et al. (2014) or the methodology by Chiaia et al. (2016) for the seismic verification of industrial structures are examples of the possible methods to be adopted.	

Table 21: Measures for Industrial risks and interactions

<table>
<tr><th rowspan="2">RISK</th><th colspan="2">Measures</th></tr>
<tr><th>In presence of Punctual / areal elements and infrastructure cat. A, B</th><th>In presence of Environmental elements subjected to a high influence from the analysed risks</th></tr>
<tr><td>Industrial</td><td rowspan="2">No A and B elements should be allowed in the damage areas, or in a "Exclusion binding zone", whose extension is calculated in 200 m from the limits of the plant for energetic events, or 300 m for toxic events. In case of incompatibility, the plant or the vulnerable element should be relocated, or the safety level of the structure or of the plant shall be increased: i.e. for flammable accidents, it is possible to require the plant to construct walls. The Municipality can also require to the industrial activity: the modification of the internal traffic; assets modification aimed at reducing the probability of accident, etc. In order to increase the protection against Na-tech events, it could be also possible to require the adoption of some of the measures indicated by Cruz et al. (2004), to increase the protection of the assets which could be more at risk in case of interaction.
It is necessary to strictly monitor all the interventions on the transformation areas included in the damage areas, and in the Exclusion areas, in order to avoid to have A and B categories in these areas.</td><td rowspan="2">In the areas connoted by a Very high vulnerability, no plants should be admitted;
In the areas with a Relevant vulnerability, the following plants should not be admitted:
• Energy plants in wooden areas
• Toxic plants in areas with specialized agriculture
Environmental plants in areas with vulnerable aquifers, underground water recharge, aquifer depth from 0 to 10 m.
Further prevention and protection measures have to be adopted following the in-depth analysis reported in the Table above: if the three conditions are all verified, or the plant is on an area with vulnerable aquifer, the owner will have to adopt the measures recommended by Turin province, points 1, 2, 3 (see Table 8). When the plant has wells inside its boundaries, or drains in superficial waters, the measures of Points 1 and 2 shall be adopted. In all the other cases, it is recommended at least the adoption of the measure of Point 1.
As far as it concerns the effects of the interaction, if the simulations prove possible environmental damages, the adoption of all the measures of the table should be imposed, in addiction to specific measures evaluated case by case.</td></tr>
<tr><td>Interactions with other risks</td></tr>
</table>

The studies and measures reported should be mandatory in case the threshold is overcome, however, even for risk levels and interaction levels below the threshold, a careful evaluation should be carried on. As illustrated in Chapter 4 and 5, the Municipalities could decide to go in depth in any case with further studies, in order to clarify some uncertainties.

3.8.1 Questionnaire for industrial in-depth analysis

Table 20 and **Table 21** suggested, in case of industrial incompatibilities, the execution of further risk assessment, and the application of the environmental analysis and measures of Turin province guideline.

However, risk assessment is not executable in case of non-Seveso plants or abandoned plants, that could represent a threat for the population and the environment (see Chapter 5). The type of storage, the prevention and protection measures adopted, the case history can deeply influence the possible consequences of the interaction of non-Seveso plants with natural events, but the information collected about these plants' assets are often inexistent or insufficient. In fact, they have no legal obligation to provide information about the substances detained or the possible external risks deriving from their activities. This lack of obligation and monitoring could in some cases enhance the level of risk in comparison to a Seveso plant.

As reminded in Paragraph 1.2.1, till now only Piedmont region has extended the E.R.I.R. analysis to non-Seveso plants, including:

1) Seveso "sub-threshold plants", detaining an amount of hazardous substances equal to 20% of the inferior threshold fixed by the Decree no. 334/1999 for the application of Seveso regulation;
2) Plants detaining carcinogenic substances; with high pressure / high temperature processes; ionizing radiations; hazardous biological agents.

In order to identify Sub-thresholds plants and other dangerous plants, the Municipalities have to undertake the following steps:

1) Require the list of potential dangerous plants to the Chamber of Commerce on the basis of their ATECO code (code identifying the activity).
2) Analysis of the list, and rejection of the plants considered not dangerous for the type of activity / number of employees

A detailed questionnaire (**Table 22**) is sent to the potential dangerous plants, to verify the quantity of hazardous substances stored, the presence of high pressure/high temperature processes or ionizing radiation, the protection and prevention measures adopted.

Table 22: Piedmont region questionnaire for Sub-threshold Seveso plants

SECTION 1: PRODUCTION				
1) Short description of the main activities conducted in the plant				
2) Is the production process continuous?				
3) Does the production process involve? - High temperature (≥ 100°C) - High pressure (≥ 10 bar) - Ionizing radiation				
SECTION 2: GENERAL PREVENTION AND PROTECTION				
Is the plant equipped with the following structural and installation devices? - Division walls between the departments, or production chains - Fire prevention systems (specify) - Full perimeter walls (no iron-grids)				
SECTION 3: ENVIRONMENTAL PROTECTION MEASURES				
1) Is the plant equipped with the following measures for the protection of the environment? - Devices for the monitoring and abatement of gas effluents - Retaining basins in the working and pouring areas - Waterproof service areas - Rain fall drainage system with accumulation basin/emergency basin				
2) Is the plant is equipped with two different drainage systems, one for the rainfall and the other for the water employed in the productions?				
3) Are the drainage systems equipped with interception valves?				
SECTION 4: VIABILITY				
1) Typology of vehicles which arrive to the plant: 18-wheelers, tank trucks, vans				
2) Arrivals/departures per month				
3) Main goods transported				
SECTION 5: HAZARDOUS SUBSTANCES INVENTORY				
With reference to the Legislative Decree no. 105/2015, Annex I, Parts 1, 2, compile a list of the hazardous substances detained/ employed in the plant.				
Substance	Category	Hazard statements	Maximum quantity	Storage methods

The questionnaire proposed by Piedmont region represents an essential step for the analysis of the non-Seveso plants, however it still leaves some information gaps, particularly evident when NaTech aspects and risk interaction are concerned (see Chapter 5). Therefore, some other tools should be integrated for the last phase of the proposed methodology, related to the In-depth studies and planning measures, to collect the necessary knowledge for better contextualizing the consistency of the industrial risk and its impact.

The proposed solution to recover this in-depth information is a second questionnaire (see **Table 23)**, that should be sent to the plants identified as potentially incompatible; it is composed by 3 sections that investigate about storage methods and items exposed to NaTech risk; case history; environmental impact (extracted from (Provincia di Torino, 2010)). The in-depth questionnaire can provide effective answers on the dangerousness of the plant and its exposure to NaTech risk, guiding the Municipalities in better identifying the possible actions and priorities of intervention; it represents a valid tool also to investigate Seveso plants for which the simulations with ALOHA and HSSM are not executable.

Table 23: In-depth questionnaire for plants

A) STORAGE CONDITIONS & NA-TECH ITEMS					
1) With reference to the hazardous substances detained, please indicate in detail the storage conditions of each hazardous substance, describing type, capacity, quantity and containment measures adopted.					
Hazardous substance	*Stored in (container type)*	*Number of containers or total capacity*	*Single Container Capacity*	*Position: Inside, outside, outside under coverage, underground, etc..*	*Containment measure adopted for the container (basin, waterproof ground etc.)*
2) Please report if the following items are present:					
Underground pipelines, pipelines passing on not-waterproofed soil.			*Description (length, width, substance transported, protection measure)*		
Long and slim structures (torches, chimneys, cooling and distillation towers etc)			*Description of the structure and its function*		
Open-air water treatment basin / liquid waste storage			*Description of the installation and related preventive measures*		
Hazardous waste storage			*Description of the quality and quantity of stored waste, and related containment measures*		
B) CASE HISTORY					
3) Please report a list of the accidents occurred in the last 20 years that have provoked release of hazardous materials					
Date		*Item interested*		*Accident description*	
4) Please signal eventual damages provoked by: flood events, extreme climate events, earthquake.					
Date		*Item interested*		*Accident description*	
C) ENVIRONMENTAL ANALYSIS[11]					
5) For the environmental protection, the owner shall demonstrate to have adopted the protective and preventive measures recommended by Turin Province Guidelines (Table 8); *OR* 6) Proceed with a vulnerability analysis of the conditions of water and soil around their plants:					
➢ Indicate the depth and the direction of the phreatic aquifer nearby the plant, in a sector with 30° degrees of amplitude and 3 kilometres of extension, measured from the possible point of release in the direction of the aquifer flow;					
➢ Indicate the presence of wells inside the same sector, within an extension of 500 metres					
➢ Indicate the presence of drains in superficial creeks or canals.					

[11] Turin Province guidelines; If the three conditions reported are all verified, the owner shall adopt all the measures of points 1, 2, 3 (although the Municipality could in some cases relieve the owner of the application of point 3).

Chapter 4

Case study 1

4.1 Introduction

The Test case study for the methodology should have been a Municipality interested by at least three risks, that simultaneously affect the same areas. The city of Mantua, located in the Po valley, in Lombardy region, demonstrated to be a good example: a huge Seveso area raised in a zone both interested by flood and seismic hazards.
Mantua is a famous historical city: its entire centre was recognized as UNESCO site in 2008. Three lakes, formed by the slow flowing of the Mincio river, surround the city; they were created in the medieval age to avoid the creation of marshes. Mincio river flows into Po river few kilometres after Mantua, therefore it is classified as one of the city on Po left bank. Po floods repeatedly interested the city during the years, particularly provoking the return surge of Mincio river flow from the confluence point.
In 2012, Mantua was marginally interested by the earthquakes that affected Emilia and portions of Lombardy and Veneto regions; the epicentre of the second shakes, Mirandola, was located at only 50 kilometres from Mantua. However, while Mirandola and the adjacent municipalities were hit by an earthquake with a peak ground acceleration by far higher of that assigned according to the national classification - also amplified by the particular typology of sedimentary soils which provoked multiple phenomena of liquefaction -, Mantua did not register such problem, and the consequent damages consisted only in fissures to the buildings, particularly those of the historical centres. However, after 2012 Emilia Romagna and Lombardy regions reviewed their seismic classifications, in order to better describe the effective seismic impact in the areas (Regione Lombardia, 2014). The Municipalities nearby the epicentre were shifted to Class 1, and detailed micro-zoning studies were undertaken. Mantua classification was increased from the 4th class to the 3rd one.

Mantua has an important chemical hub located on the lakes banks opposite to the city: the former refinery was built in 1947, while the petrochemical plant raised in 1956; around these two Seveso plants, many other industries were aggregated. As lately explained, the long years of industrial exploitation determined a serious pollution for soil and water: currently the entire zone is classified as Recovery site of National interest (SIN). The SIN has an extension of 9.519.678 m2, equal to 15% of Mantua territory, and includes, in addition to the productive zones, also the Median and Inferior lakes, and the Vallazza regional reserve.

Figure 18 shows Mantua city; the city centre and the industrial areas are evidenced, together with the Mincio lakes.

Figure 18: Mantua main elements (GoogleMaps®)

4.2 Hazard characterization

The characterization phase aims at improving the information on the impact of each hazard verifying the possible elements of influence. The following paragraphs show, through the illustration of the test Case-study, the application of the first steps of the methodology previously explained, and namely: the hazard identification and characterization; the rating attribution; the drafting of thematic GIS maps.

The collection phase was autonomously realized by the Candidate on the basis of documents broadly available; Mantua Municipality and Lombardy region provided basic maps of the territory for the GIS drafting. For each hazard, the sectorial plans constituted the starting point for the analysis:

- For Earthquake → the geological study annexed to Mantua City plan (Comune di Mantova, 2012)
- For Flood → Plan for the evaluation and management of flood hazard, monographic data sheet related to Mantua (A.D.B.Po, 2016)
- For Industry → Mantua E.R.I.R. (Comune di Mantova, 2012)

4.2.1 Seismic hazard characterization

1) Data collection

The seismic hazard characterization was carried out on the basis of the local Geological study related to the City Plan (Comune di Mantova, 2012), of the Provincial Seismic Emergency Plan (Prefettura di Mantova, 2012), and of other documentation available on the website of Lombardy Region.

HISTORICAL EVENTS: Mantua is located in an area of Po valley with a reduced seismicity; however, intense earthquakes, provoked by two different tectonic movements, can interest its surroundings. Verona, the Garda Lake and the foothill areas under the Alps can be hit by the seismic shakes generated by the subduction of the European plate under the African plate, which also generated the Alps. Emilia Romagna hosts another subduction zone, where the Adria plate flows under the European plate; furthermore, in this zone, a complex system of faults, able to generate earthquakes like that in 2012, was identified. Mantua raises nearby the north-west border of the faults called "Pieghe ferraresi", as shown in **Figure 19.**

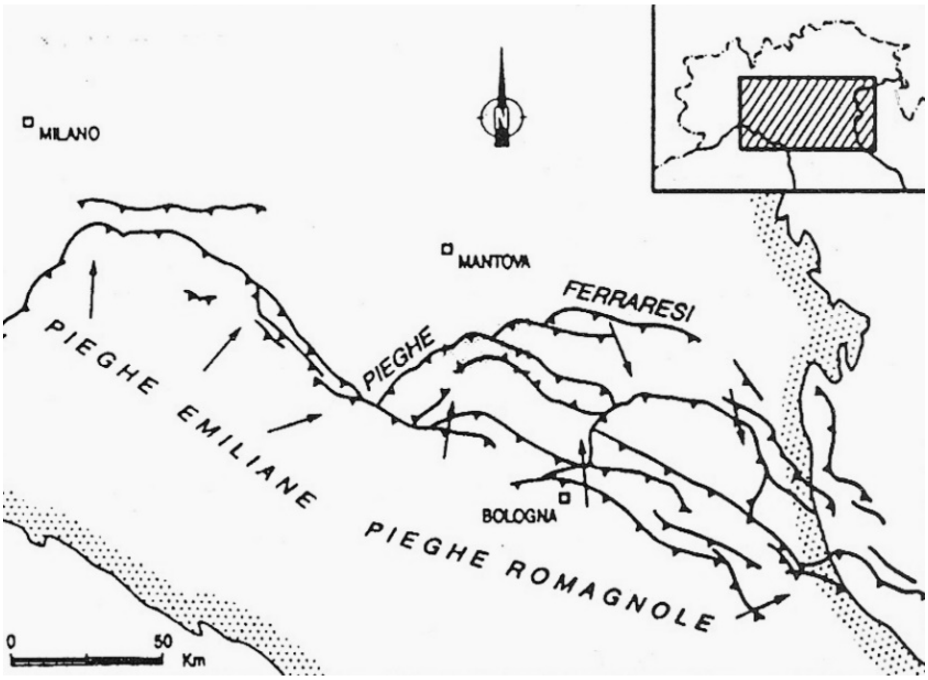


Figure 19: Seismic faults named "Pieghe ferraresi"

Until now, despite of the earthquakes that repeatedly interested the areas above mentioned, the seismic hazard in Mantua maintained low levels, both as far as it concerns the frequency of the events, the distance from the epicentres, and the quantity of energy released. **Table 24** reports the consequences on Mantua of some of the most important earthquakes that affected Po valley in the last centuries.

Table 24: Main seismic events in Mantua

Date	Intensity scale	Epicentre	General consequences	Consequences in Mantua
238-984	≥ VIII Mercalli	Cremona, Brescia, Garda Lake, Verona Baldo mountain	n.a.	n.a.
1693	n.a.	Province of Mantua	The earthquake was perceived in Ferrara, Padua and Venice.	The area most hit was the province of Mantua, where the earthquake cause the fall of many chimneys, and the collapse of some buildings.
25/12/ 1786	n.a.	Province of Rimini	The province of Rimini was interested by deaths and building collapse. The earth shake was perceived also in Geneva.	The shake in Mantua was brief, and only lasted some seconds.
1834-36	n.a.	Apennines in the area of Piacenza	n.a.	The earthquake was barely perceived in Mantua
1841	n.a.	Sanguinetto (26 km from Mantua)	n.a.	n.a.
1983	VI-VII Mercalli	Province of Parma (50 km from Mantua)	n.a.	The earthquake was perceived in Mantua, without any consequence on people or building
1996	VI-VII Mercalli	Reggio Emilia (50 km from Mantua)	n.a.	The earthquake was perceived in Mantua, without any consequence on people or building
2004	5.2 Richter	Salò (52 km from Mantua)	n.a.	No relevant consequences
2008	5.1 Richterd epth: 26 km	Canossa and Neviano degli Arduini (73 km from Mantua)	Spotted damages nearby the epicentre, damages in the Municipality of Quingentole (Mantua province)	n.a.
25-27/12/ 2012	4.9 and 5 Richterd epth: km 33,2 km and 60, 8 km	Brescello, Poviglio and Castelnuovo di sotto (Reggio Emilia province – 50 km from Mantua); Corniglio, Berceto, Monchio delle Corti and Palanzano (Parma province – 80 km from Mantua)	Reduced damages	The earthquake was perceived in Mantua, without any consequence on people or building
20/05/ 2012	5.9 Richterd epth: 6,3 km	Finale Emilia (MO) and Sant'Agostino (FE) (50 km from Mantua)	Victims, injuries and people evacuated in the zones close to the epicenters; in the province of Mantua, churches and	Minor damages to Palazzo Ducale

Date	Intensity scale	Epicentre	General consequences	Consequences in Mantua
			architectonic heritage were damaged	
29/05/ 2012	5,8 Richterd epth: 10,2 km	Mirandola (MO) (35 km from Mantua)	Victims and injuries. In Province of Mantua damages to historical and modern buildings (Moglia, Quistello, Schivenoglia e Quingentole)	Damages to the artistic and architectonic heritage: cracks in Palazzo Ducale, collapse of the bell tower of Santa Barbara church; damages to Palazzo Te and Palazzo della Ragione.
10/2012	4.5 Richterd epth: 30 km	Apennines of Piacenza	No effects for the people	The earthquake was perceived in Mantua, without any consequence on people or building

As far as it concerns the earthquake swarm of 2012, in Mantua no variation of the seismic classification assigned was registered: the P.G.A. maintained a low level, between 0.003 and 0.004, as shown in **Figure 20.** This is extract of the "shaking map of 2012 earthquake" (*Mappa dello scuotimento*), available online on Lombardy region website, represents Mantua in blue colour, corresponding to low P.G.A. value. However, as previously mentioned, Mantua was included in the seismic re-classification of Lombardy Municipalities (Regione Lombardia, 2014).

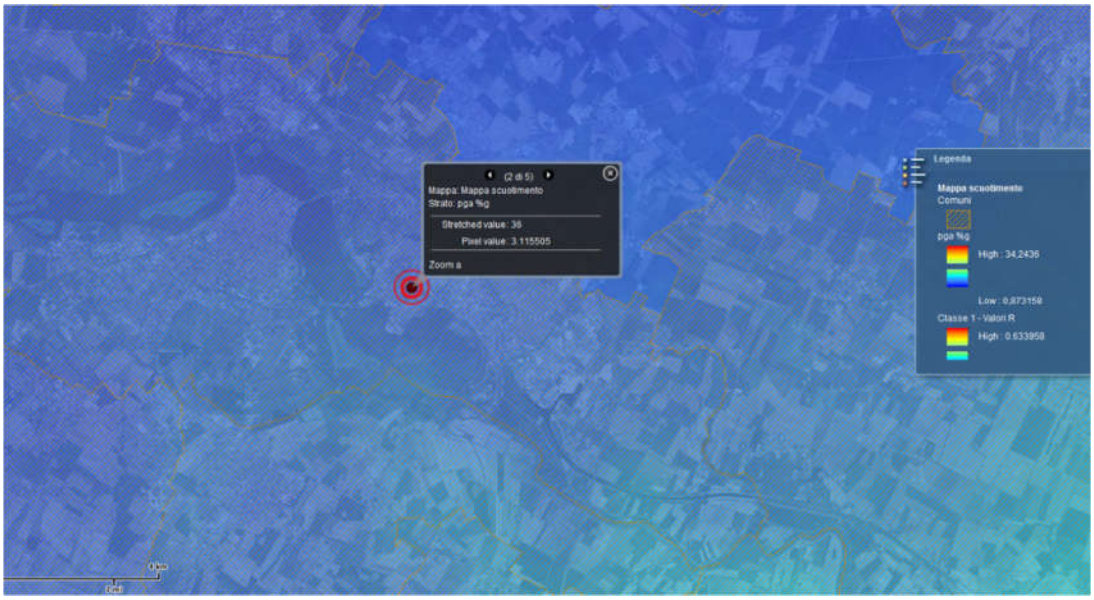


Figure 20: ***Mappa dello scuotimento* for Mantua**

STRENGTHENING EFFECTS: (Regione Lombardia, 2011) imposed a mandatory First level micro-zoning study to the Lombard municipalities, called *P.S.L. Pericolosità sismica locale* - Local Seismic Dangerousness. As reported in Table 25, P.S.L. should identify:

- *Site or local amplification effects*: topographical or lithological amplification caused by: 1) complex superficial morphologies or irregular topography, which favours the concentration of the seismic waves nearby the crests of the elevations; 2) deep morphologies or stratigraphic unites with specific mechanical properties.
- *Instability effects:* instable behaviour of the soil under seismic solicitation. 1) slopes with unstable equilibrium, which can generate landslides; 2) areas interested by the presence of specific geological structures (active faults), where differential movements can take place; 3) soils with poor physical and mechanical properties, which can produce permanent soil deformation, or saturated granular soils, which provoke liquefaction; 4) territories interested by karst phenomena, that can originate subsidence.

Table 25: Scenarios of local seismic dangerousness (Regione Lombardia, 2011)

Code	Local seismic dangerousness	Effects
Z1a	Zones connoted by active landslide movements	Instability
Z1b	Zones connoted by quiescent landslide movements	
Z1c	Zones potentially subjected to landslides or exposed to landslides	
Z2a	Zones with particularly poor saturated foundation soils	Collapse
Z2b	Zones with saturated grainy and little sediment	Liquefaction
Z3a	Border zones with h>10 m. (scarp, quarry edge, stream terrace, ecc.)	Topographic amplifications
Z3b	Crest or peak zones	
Z4a	Plain zones with presence of alluvial and/or fluvio-glacial sediment, grainy or cohesive	Lithological and geometrical amplifications
Z4b	Foothill zones, characterized by alluvial or lake fans	
Z4c	Moraine zones, with grainy or cohesive sediment	
Z4d	Zones with eluvio-colluvial clays	
Z5	Zones where lithotypes with different physical and mechanical features are in stratigraphic or tectonic contact	Differential behaviour

As far as it concerns Mantua P.S.L. (Comune di Mantova, 2012), its soils are mainly sediments formed by floods occurred in Pleistocene and Holocene, caused by the rivers born from the Garda glacier. Therefore, the municipal territory is composed by sand, clay and loam sediment, distributed in 4 different zones: 1) right bank of the superior lake, formed by sandy and loamy sediment alternated; 2) city centre, where sandy and pebbly material prevails; 3) right bank of the Inferior lake, connoted by clays and peatlands; 4) the ancient Paiolo lake, characterized by thick peatlands. The main type of potential effects derives from site or local amplification, while only few areas of the Municipality seem subjected to instability. Therefore, almost the entire municipal territory is defined as Z4a soils "*Plain zones with alluvial or fluvio-glacial sediment, grainy or cohesive*". Some limited areas (left bank of Superior lake, ancient riverbed of the Paiolo Basso creek, Vallazza) are classified as Z2 soils because of the presence of peat and marshy terrains, which can provoke instability effects due to the poor mechanical and physical characteristics. A Second level micro-zoning analysis was carried out on 4 sample areas of the municipal territory; however, according to the seismic re-classification (Regione Lombardia, 2014), this 2nd level analysis shall be extended to all the urbanized zone. The sample areas were: Valdaro harbour (B1); Te Brunetti neighbourhood (B2); S. Giorgio castle (B3); industrial zone (B4). Their location is reported in **Figure 21**.

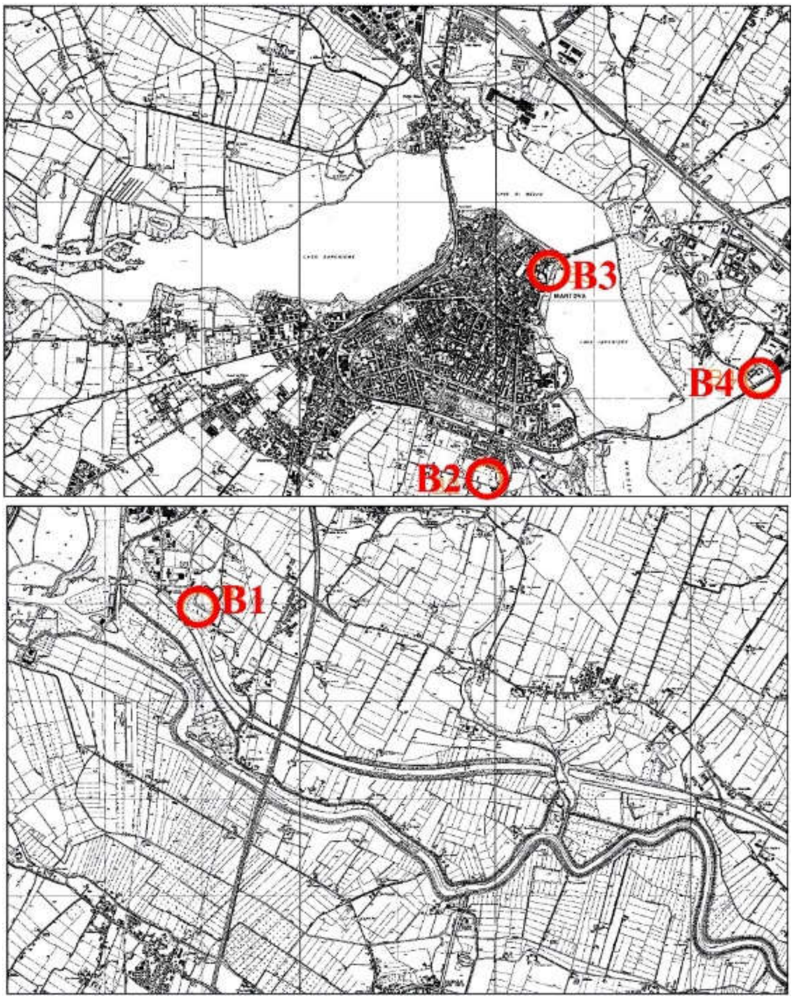


Figure 21: Sample areas in Mantua territory

In the chosen areas, the underground propagation of the shear seismic waves was verified with a refraction test, in order to quantify the Amplification Factor Fa given by the Z4 and Z2 soils. The calculation demonstrated that the amplification could overcome the threshold values estimated for Mantua area. Therefore, the technicians recommended to execute a 3rd level micro-zoning analysis in these areas, before any new strategic construction.

PROTECTION MEASURES: no intrinsic hazard-oriented measures can be taken against earthquake.

2) *Macro-categories and Ratings assignation*

Table 26 shows the ratings assignation: only two types of soils determine the strengthening effects, while the historical recurrence of the events has a uniform distribution overall territory. No direct protection measures can be adopted towards seismic hazard; it is only possible to enhance the resilience of the vulnerable elements exposed.

Table 26: Rating attribution for seismic hazard in Mantua

Element considered	[S.E.] Strengthening effects		[P.M.] Protection measures	[H.E.] Historical events
Municipal territory	Z4a soils Lithological and/or geometric amplifications	Fa, local amplification factor, overcame the values the reference regulations in 4 sample zones.	-	Seismic class = 3 In 2012, the seismic system called the Ferrara fault lines reactivated, but the registered P.G.A. remained low. Reduced damages (i.e. falling cornices). Seismic risk in Mantua territory is low, both for local seismic capacity; distance from the epicentre of the most powerful earthquakes; frequency of the events; energy releases.
SCORE	***2***		***0***	
Right banks of Superior lake, ancient riverbed of Paiolo Basso drain, area Vallazza	Z2a soils: instability.		-	
SCORE	***3***		***0***	***1***

The macro-category H.E. was evaluated as LOW = 1 because, even if seismic episodes can be quite frequent in Mantua area, these events always demonstrated to have a low impact, in line with the low seismic classification (Class 3).
For Strengthening Effects, the micro-zoning studies of 1st and 2nd level demonstrated that the soils do have the possibility to enhance and worsen the effects of an earthquake. Therefore, for the Z4 soil, a value of MEDIUM = 2 was assigned, while the Z2 soils, capable of more negative effects, were evaluated as a potential HIGH = 3 impact element.

As far as it concerns the GIS map, the polygons of the layer seismic hazard trace the perimeters of the different types of soil, in order to return the different values assumed by the portions of territory analysed; all these polygons have the same values for HE (1) and MP (0), and different values for SE (2, 3). **Figure 22** is an extract of the GIS mapping, representing the layer Seismic Hazard – Strengthening effects theme.

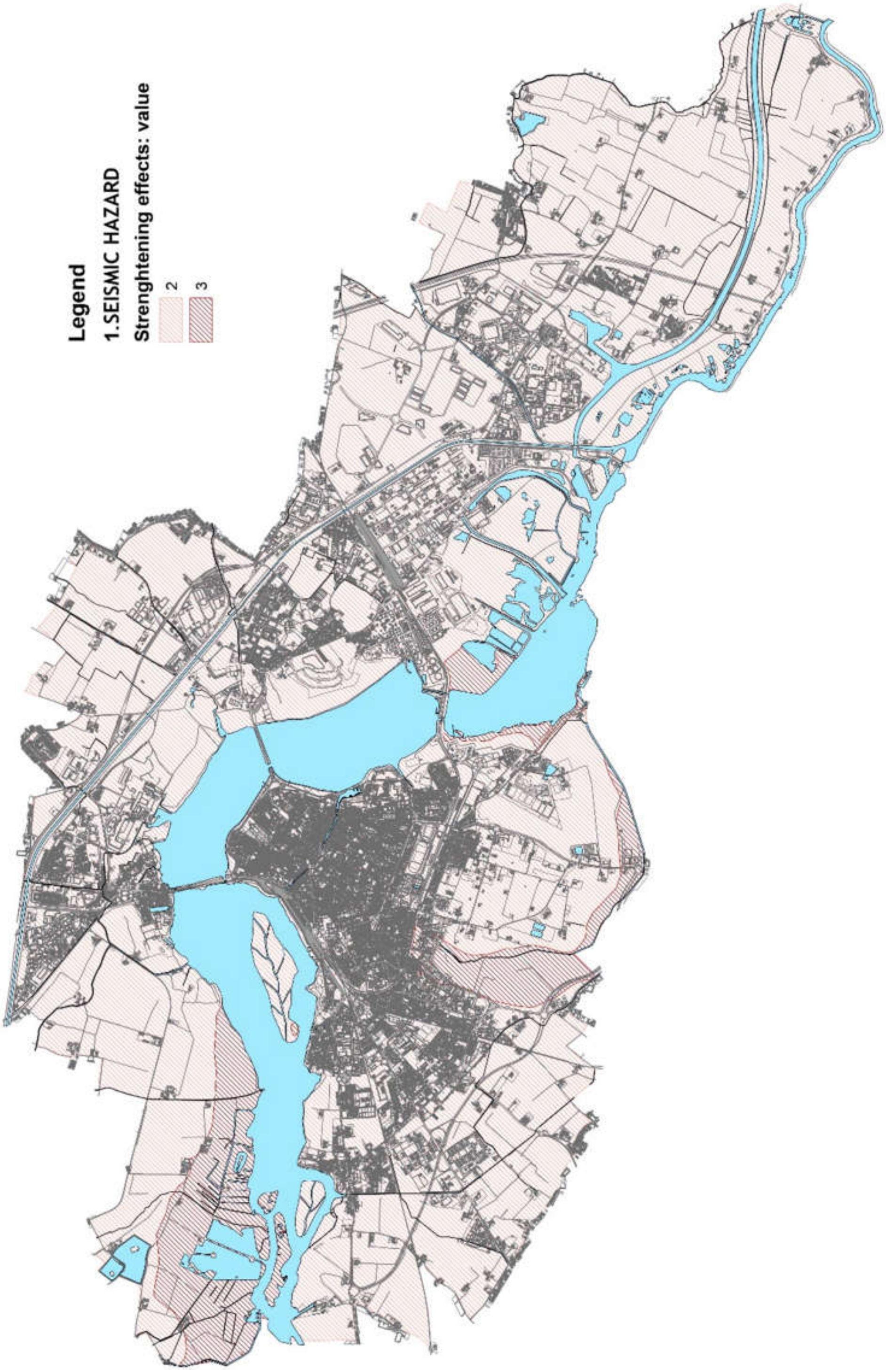


Figure 22: Thematic map of the seismic hazard layer, S.E.

4.2.2 Flood hazard characterization

1) Data collection

The flood hazard characterization was based on documents produced by several authorities, like the ADBPO (Authority for Po river), the Mincio consortium, and the Municipality itself. This paragraph introduces the main features related to history, hydraulic regulation and criticalities of Mincio river.

HISTORICAL EVENTS: Mantua was repeatedly afflicted by floods provoked both by Mincio and Po river, which is located at only 20 km from the city. in addition, nearby the city, Mincio river tends to slow down, forming marshy and unhealthy areas. The attempts to arrange these situations started in the Medieval Age: in 1189, the engineer Alberto Pitentino realized a system of dikes to transform the marshes in 4 lakes, also aimed at defending the city from external assaults (Superior, Median and Inferior lakes, and the Paiolo lake). In order to protect the city from the return flow caused by Po river floods, Pitentino also designed the Governolo sluice, located in the village of Governolo where the Mincio river flows into Po. Despite of these hydraulic interventions, the floods continued to hit Mantua city; i.e. two huge events caused by Po river hit the city in 1801 and 1807, while in 1879 Mincio river provoked an inundation. Thus, after II World War, a permanent hydraulic transformation was executed, to finally protect Mantua from floods. The system, later explained, functioned without criticalities even during the major Po floods in 1994 and 2001.

(A.D.B.Po, 2016) mapped the scenarios for high and medium probability (A and B) on the basis of the existing levees or natural terrace, while the scenario with low probability (extreme event) was mapped on the basis of all the areas historically flooded. Mincio determines scenarios with high (10-20 years) and medium probability (100-200 years) that are almost completely overlaid, and which have a brief distance from the river; while the scenario with low probability (500 years) involves wider areas. Also 4 creeks of the secondary water network produce some limited potential flooded areas, with a return time calculated in 20/50 years (Fosso della Posta, Fosso Magistrale, Fossamana, Agnella).

PROTECTION MEASURES: The hydraulic settlement of Mincio river, carried out from 1965, led to a river flow completely artificialized, from the origin to the mouth. AIPO, Interregional Agency for Po river, is currently in charge for the management of Mincio river; telemetering and remote control are located in 4 points of the river (Casale, Vasarone, Formigosa and Governolo); and act on the electric hydraulic floodgates. The implementation of remote control is still on course. The re

Mincio river origins in Peschiera del Garda, in the northern limit of Garda lake, at around 40 km from Mantua; the flow rate from the lake is regulated by the Salionze barrage, composed by three floodgates. The maximum flow rate released in this point is equal to 200 m^3/s, which is also the flood rate on which the reference-flood scenario was settled (200 years). During

the major flood events in the last 30 years, the maximum flow rates registered after the Salionze barrage were between 150 m^3/s and 185 m^3/s.
Near to Pozzolo village, another important hydraulic arrangement is present: a divider addresses the major part of the rate flow (130 m^3/s) to a drain, named Canale scaricatore Pozzolo Maglio. In Mincio river, a maximum flow of 70 m^3/s is left; however, in this portion, the river receives the contribution of the plain northern-west water network, and in particular of the channel Caldone (max 40 m^3/s).
In the vicinity of Casale di Goito, one of the most important hydraulic artefact is located, composed by the divider of Casale and the drain called the Diversivo Mincio. The latter bypasses Mantua city and, in case of floods, can collect the entire flow rate remained in Mincio riverbed (70 m^3/s); the Casale floodgate is closed and Diversivo Mincio releases the water to Mincio after Mantua and Formigosa barrage.
Mantua city defence system is able to bear a maximum flow rate of 50 m^3/s, that can be entirely reach by the sum of the tributaries that flow into Mincio riverbed before Mantua (Solfero-Goldone and Osone), and inside the Municipal territory (Naviglio, Cavo San Giorgio, Paiolo). In addition, Mantua drainage network can contribute, but the exact share has not been calculated yet. As a consequence of these contributions, the maximum amount of flow rate left into Mincio river at the Casale divider is usually around 10-20 m^3/s.

Figure 23 shows the hydraulic system of Mantua city: in the northern part, it is highlighted the path of Diversivo Mincio, while Mincio river surrounds the city creating three lakes. The Superior lake is contained by the dyke-bridge named Ponte dei Mulini, which is equipped with two floodgates (named Vasarone and Vasarina); this artefact maintains the water level in the lake at 17,40 m. The maximum foreseen water level is 18.40 m. The following lakes and the Vallazza are maintained at 14.20-14.40 m. by the barrage of Governolo; indeed, the Masetti dyke could act as a regulatory artefact for the levels of Median and Inferior lake, but it is not employed. Inside the Municipal territory, some channels flow into the lakes, and in some cases, they are equipped with lifting plants to help the water in trespassing the different heights of the lakes (i.e. Rio di Mantova, Fossa Magistrale, Fosso Paiolo Basso, Angeli Cerese).

The crucial hub of Formigosa is located after the zone of Vallazza, which hosts also a protected natural area. It is constituted of a barrage with two floodgates, a lifting plant (Valdaro), and the drainage channel “Scaricatore Vallazza-Fissero”, which is connected with the starting point of the navigable channel named Canal Bianco. During the Po floods, the barrage of Formigosa is closed, in order not to allow the water returning from Governolo to increase the water levels in the lakes and inundate Mantua city. However, the water collected by Mincio before Formigosa needs to be discharged in some way: both Valdaro lifting plant and Vallazza-Fissero drain are designed for this scope. Valdaro can discharge in the Diversivo Mincio a flow rate of 50 m^3/s; alternatively, the water can be addressed to the so-called Canal Bianco through the Vallazza-Fissero drain, which has a capacity of 30 m^3/s. **Figure 24** shows in detail the Formigosa hub and its components.

Figure 23: Hydraulic artefacts in Mantua city

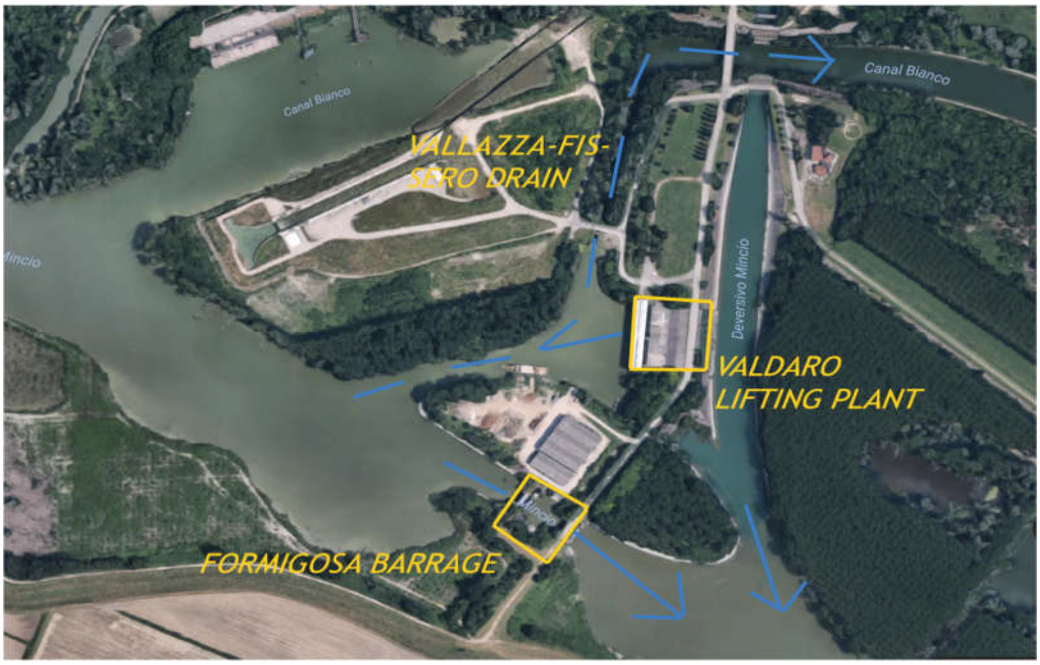


Figure 24: Formigosa hydraulic hub

The last portion of Mincio river, from Formigosa to the barrage and navigation lock of Governolo, is completely contained by levees on both the banks. Mincio river flows into Po in Governolo, where a barrage maintains the level of the river higher than that of Po.
Figure 25 (A.D.B.Po, 2016) provides the complete scheme of all the Mincio hydraulic arrangement previously described.

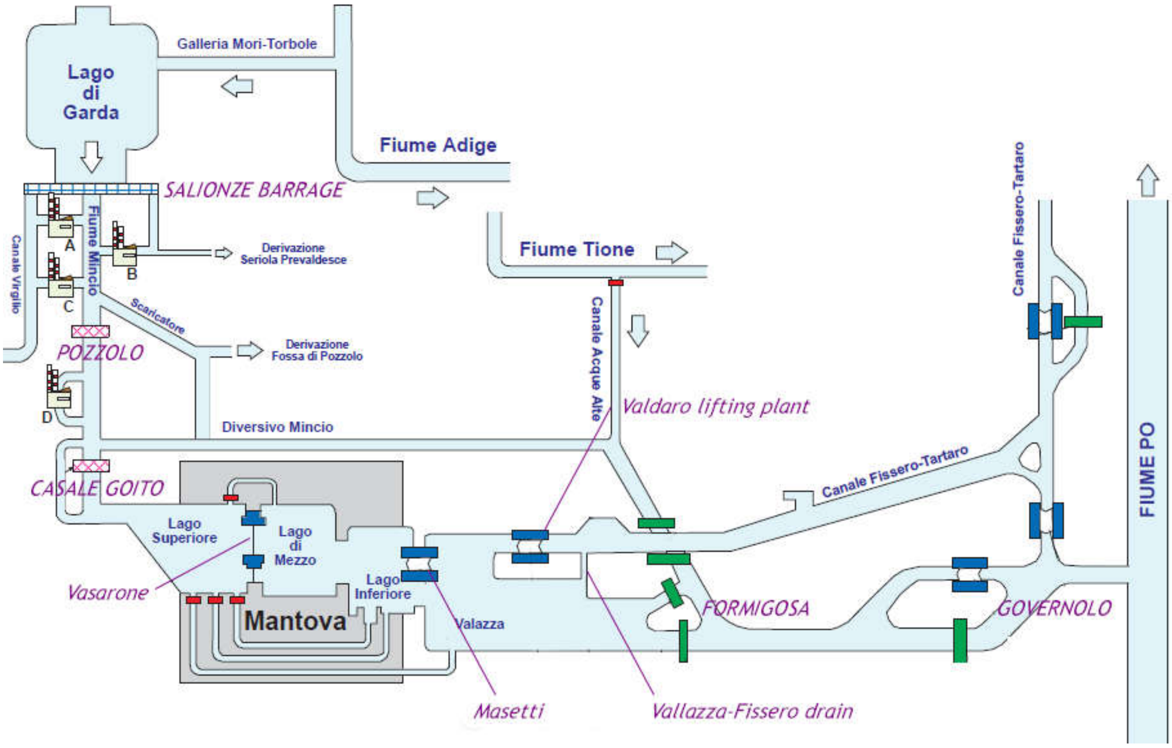


Figure 25: Scheme of the hydraulic settlement of Mincio river

STRENGTHENING EFFECTS: (A.D.B.PO, 2016) demonstrated that some minor criticalities of the complex Mincio hydraulic system need to be addressed:

- The contributions of the secondary water network, in particular in the portion between Pozzolo divider and Mantua, together with the urban water drainage system, can influence the balance and correct functioning of the system. Two drainage channels were designed to divert the water of Osone, Marchionale, Birbesi and Goldone from Mincio, the so called North-west and North-East drains, but still they were not constructed.
- The obsolescence of the hydraulic artefacts, in particular: Valdaro lifting plant, Casale di Goito divider, Vasarone dyke, and Formigosa hub
- Phenomena of erosion and riverbed lowering in the dammed portion between Formigosa and Governolo.

In the light of the complex situation above exposed, Mantua was identified by (A.D.B.Po, 2016) in its Plan for the evaluation and management of flood hazard as “Area with relevant flood risk", that means a critical hub of strategic importance where conditions of high or very high risk involve relevant urbanized areas or productive plants.

2) Macro-categories and ratings assignation

Table 27 shows the ratings assignation for Flood risk. In order to attribute the ratings, it was first of all necessary to recognize homogenous zones of the river: the upstream portion of the river was distinguished from the portion in the Municipal territory. For the first one, an overall evaluation was carried out, in order to verify if there were major criticalities that could increase the dangerousness of flood also inside the Municipality. For the municipal river portion, a deeper analysis was developed, evaluating all the hydraulic artefacts, the differences in heights, and the elements whose presence could have repercussion on the hydraulic behaviour.

Table 27: Ratings assignation for Flood

Element considered	**[S.E.] Strengthening effects**		**[P.M.] Protection measures**	**[H.E.] Historical events**
	Interactions with other elements of the water network	*Criticalities of the hydraulic artefacts*	*Hydraulic artefacts / levees etc.*	
Mincio upstream portion outside Mantua	Secundary water network can increase the Lakes level. Diversivo Mincio receives the Acque alte channel, that could generate unforeseen flow rates.	Casale divider needs maintenance and consolidation interventions.	**Salionze barrage:** length 72 m, multiple openings with planar metallic floodgates; max. flow rate = 200 m^3/s **Pozzolo divider and drain**; max capacity 130 m^3/s. **Casale di Goito divider and Diversivo Mincio:** deviates the water of Mincio, bypassing Mantua and protecting it from floods. Floodgates regulated with remote control.	No floods after 1965. Flow rates almost reached the maximum thresholds in 1985 2000, 2001, 2002, 2010, 2013 (150-185 m^3/s released in Salionze).
SCORE	***1***		***-3***	***1,2,3***
Mincio in Mantua, Superior lake	Secondary water network and drainage could raise the Lakes level.	Vasarone dyke needs maintenance and consolidation interventions.	**Porta dei mulini or Vasarone dyke and flood gates**, maintains the level of Superior lake at 17,40 m., Floodgates can be open in case of high water	*See first cell*
SCORE	***1***		***-3***	***1,2,3***

Element considered	[S.E.] Strengthening effects		[P.M.] Protection measures	[H.E.] Historical events
	Interactions with other elements of the water network	*Criticalities of the hydraulic artefacts*	*Hydraulic artefacts / levees etc.*	
Mincio in Mantua, Median and Inferior lake, Vallazza	Contribution of the city drainage system not calculated. Vallazza Fissero could discharge to Canal Bianco channel its maximum capacity in conjunction with other floods contribution, generating problems for the channel.	Formigosa barrage needs maintenance and consolidation interventions; the Valdaro lifting plant and its regulation system are obsolete	**San Giorgio bridge Masetti bridge-dyke:** employed only as bridge **Formigosa hub:** Closed for lakes height ≥ 16.5 m. Valdaro lifting plant activated for water ≥ 16.8 m. (flow rate = 50 m^3/s) Vallazza-Fissero drain discharges water into Canale Bianco, max flow rate 30 m^3/s, it works alternatively to Valdaro lifting plant. Syphon of the Diversivo Mincio, passes under Vallazza-Fissero .	*See first cell*
SCORE	***1,5***		***-3***	***1,2,3***
Mincio downstream – from Formigosa to Governolo	Potential break of the left Po levee; in 1951, Po reached here 22,5 m. Return flow in Mincio riverbed provoked by high level of Po.	Banks erosion and lowering of riverbed could threat the stability of the levees and of Governolo and Pozzolo bridges.	1) **Continuous levees** from Formigosa to Governolo 2) **Governolo barrage and navigation lock**, maintain the level of Mincio median and inferior lakes, and Vallazza	*See first cell*
SCORE	***2***		***-3***	***1,2,3***
Secondary creeks to drain stagnant water.	n.a.	n.a.	Lifting plants of Paiolo, Fossa Magistrale, Rio di Mantova and Angeli	Little floods: Fosso Posta, Magistrale, Fossamana, Agnella return time: 20-50 years.

Some considerations on the rating attributed: first, as far as it concerns the measures of protection, it is possible to observe that in all the cases they received the maximum ratings. Indeed, the artificialized system of flow regulation and all the hydraulic artefacts demonstrated to be adequate in facing flood events, despite of the minor criticalities encountered, and their high efficacy was expressed with the value attributed.

For the Historical events, it is clear that from the hydraulic arrangement, no major floods hit Mantua, and no documents are available on return times and areas different from those reported in (A.D.B.Po, 2016). Therefore, the values attributed for the historical recurrence fully reflect the plan scenarios for high probability (=3), medium probability (=2), low probability (=1).

For Strengthening effects, the superior lake assumes values slightly different from the other lakes and Vallazza, which are regulated by Governolo barrage and can be more influenced by the functioning of Formigosa hub. Therefore, lower values were assigned to the upstream portions, where the contribution of the secondary networks can be managed through the deviation of the water into Diversivo Mincio. Then, S.E. values slightly increase in the portion regulated by the complex hub of Formigosa, whose efficacy is essential for the protection of the city. In the portion from Formigosa to Governolo, the value of S.E. rises again, because this area is more subjected to the influence of Po river. However, the values attributed remain in a low range, because no explicit proofs of the criticalities above mentioned are reported.

In relation to the secondary water networks, this system can produce a great influence on the potential flood hazards, provoking unexpected floods in turn; however, the municipal secondary network is not connoted by particular criticalities. Outside the Municipality, some creeks could increase Mincio flow rate, however until now this contribution has been managed by deviating Mincio river into Diversivo Mincio, giving the possibility to its riverbed to receive the waters of its tributaries. Unfortunately, for the secondary network, it was not possible to carry out a local in-depth analysis because of the lack of more in-depth data, therefore no values were attributed.

Figure 26 and **Figure 27** report two thematic maps representing the values assigned to the categories S.E. and H.E.

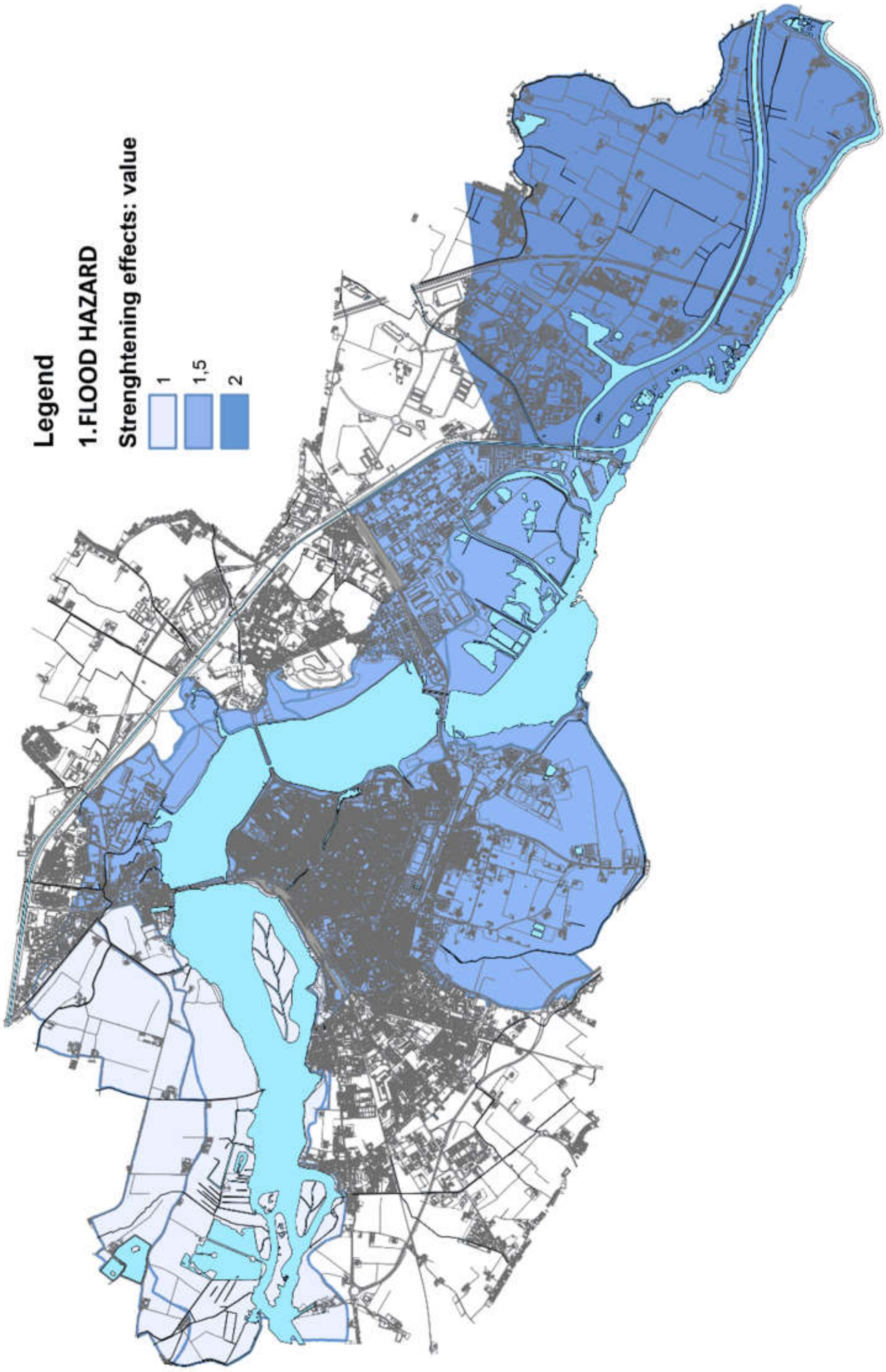


Figure 26: Thematic map of the flood hazard layer, S.E.

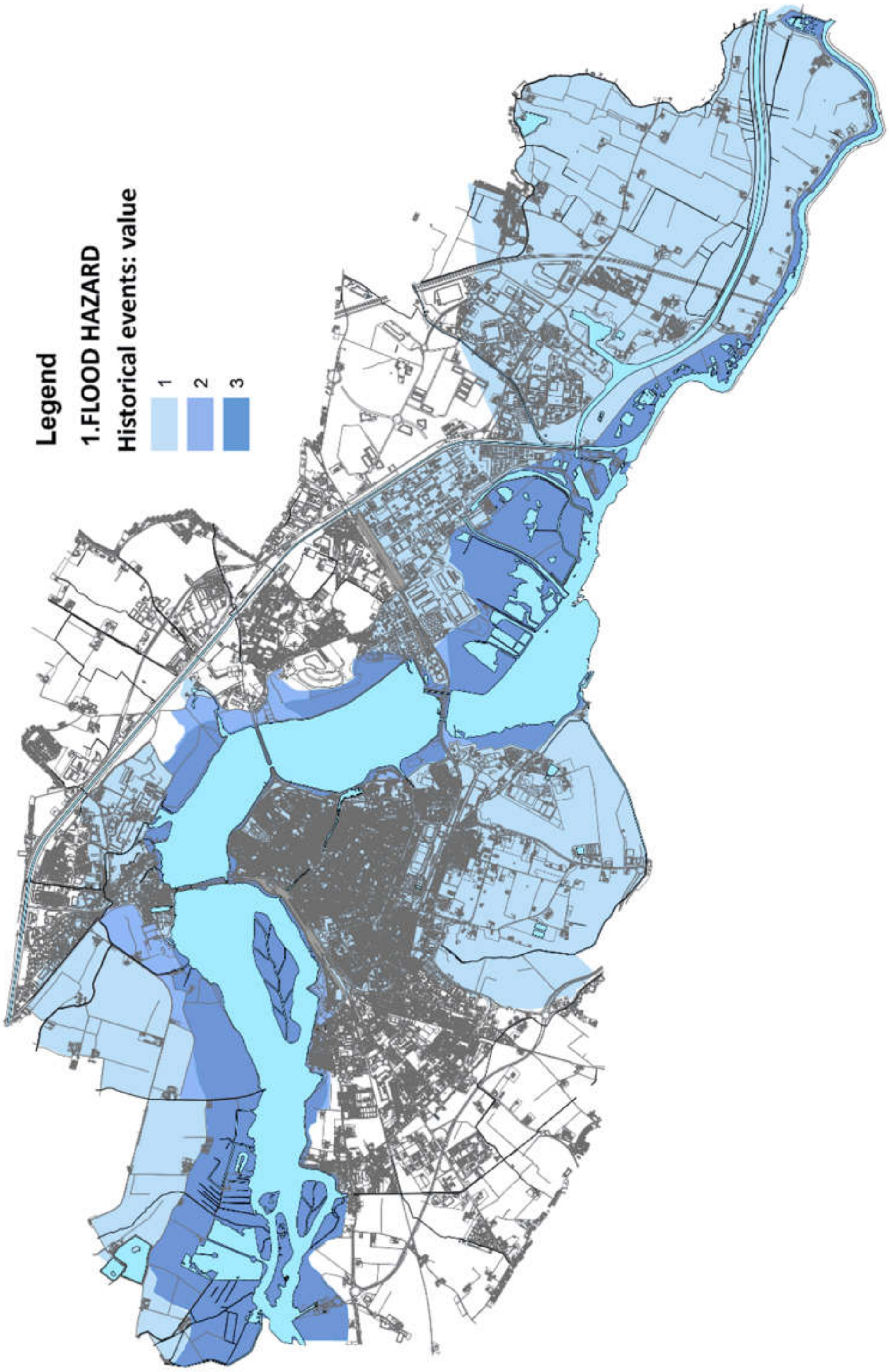


Figure 27: Thematic map of the flood hazard layer, H.E.

4.2.3 Industrial hazard characterization

1) Data collection

The information related to the industrial hazards were collected on the basis of several documents, like i.e. the E.R.I.R. planning for the city of Mantua 2012, the municipal Emergency Plan (2014), the external Emergency plans of the Seveso companies, etc. Due to confidentiality issues, it was not possible to obtain the Safety reports of the Seveso companies of Mantua; however, they were in phase of revision to be compliant with the Legislative Decree no. 105/2015, recently issued. The information on the Companies were recovered from Emergency plans, IPPC authorisations, the Services Conferences related to the environmental recovery, Environmental relations drafted by the Companies etc.

As far as it concerns the so-called Seveso sub-thresholds plants and other hazardous non-Seveso companies, this kind of industries should be always considered in the proposed methodology because, even if they do not detain a huge quantity of Seveso substances, they are subjected to a minor control with respect to the Seveso companies, and therefore could produce unforeseen events, also as a consequence of an external activation. Mantua hosts several industrial activities that would merit a further investigation (i.e. ex Burgo paper factory, paint factory Industria Colori Freddi San Giorgio, etc.), but unfortunately, they were not investigated because the process would have need a strict and long cooperation with the Municipality, not possible outside E.RI.R. drafting.

INTRODUCTION

Mantua industrial hub is located on the left bank of Mincio river, near to the Vallazza area, and includes 4 Seveso plants:

- the petrochemical plant Versalis;
- the gasoline and diesel deposit IES;
- the plant for the production and storage of oxygen and hydrogen SAPIO
- the plant for the production and storage of oxygen and hydrogen SOL.

The area is crossed by two main roads, connoted by an intense traffic of hazardous goods: Provincial road SP28 (via Brennero), which links Mantua centre and the industrial zone with the A22 highway (direction East-West); and Provincial road SP482, which represents Mantua north bypass. The industrial area is also crossed by the railway and served by a dedicated station, from which railroad switches address the rail tankers to IES and Versalis plants. Both IES and Versalis plants supply their raw materials not only through roads and railways, but also via river and pipeline. Each plant has a dedicated dock; furthermore, Versalis is reached by three pipelines transporting benzene, ethylbenzene and cumene, while IES was formerly served by a pipeline for crude oil coming from Porto Marghera.

Outside the industrial hub, another important industry can be found: the ex Burgo paper factory, in the San Giorgio neighbourhood. Despite Burgo was not taken into account by the E.R.I.R., the information contained in the IPPC document documents suggest that it could be at least a Sub-threshold Seveso plant (Regione Lombardia, 2008). It produced recycled paper, bleached through a de-inking process based on the use of chlorine.

Mantua E.R.I.R. (Comune di Mantova, 2012) reported the information and accidental scenarios extracted from the Safety reports of the 4 Seveso plants:

- the petrochemical plant Versalis detains about 87.000 t of hazardous substances, mainly flammable, toxic and carcinogenic substances. The predominant scenarios are toxic releases, with probabilities from 10^{-4} to 10^{-6}, whose IDLH can reach a maximum distance of 290 m. The extension of the reversible injuries areas reaches 1200 m. However, these scenarios barely outcome the boundaries of the plant, and interest areas with no human activities, except for some industrial areas on the south-east limit.
- The plant IES worked as a refinery until 2014, and the information of E.R.I.R. were still related to that phase. It had an amount of hazardous substances of 500.000 t., mainly flammable. The scenarios consisted of pool fires related to the gasoline tanks, and of flashfire caused by the GPL tanks located in the north portion of the plant. In this case, the area for beginning of lethality reached 121 m., hitting a residential area adjacent to the plant; this incompatibility was pointed out by the E.R.I.R., therefore IES proceeded with the construction of a dedicated wall to protect the neighbourhood. In March 2014, the decommissioning of the refinery plant began, and only a portion of the storage was maintained. The crude oil was no more received and stored, so that the remained substances were mainly gasoline and diesel (IES, 2014).
- SAPIO plant, located in front of Versalis, detains about 16 t. of hydrogen and oxygen, that means flammable and combustive agents. They can provoke jet fire scenarios with a medium probability, between 10-3 and 10-4, which do not overcome the plant boundaries, except for one, very reduced.
- SOL is located inside Versalis area, and produces oxygen and other technical gases for the petrochemical plant; it detains about 3700 t. of oxygen. The scenarios are related to vapours releases, and are contained inside the plant boundaries.

Figure 28, extracted from Mantua E.R.I.R., shows the spatial extension of the Seveso scenarios; it has to be noticed that those of IES still reflects the refinery asset.

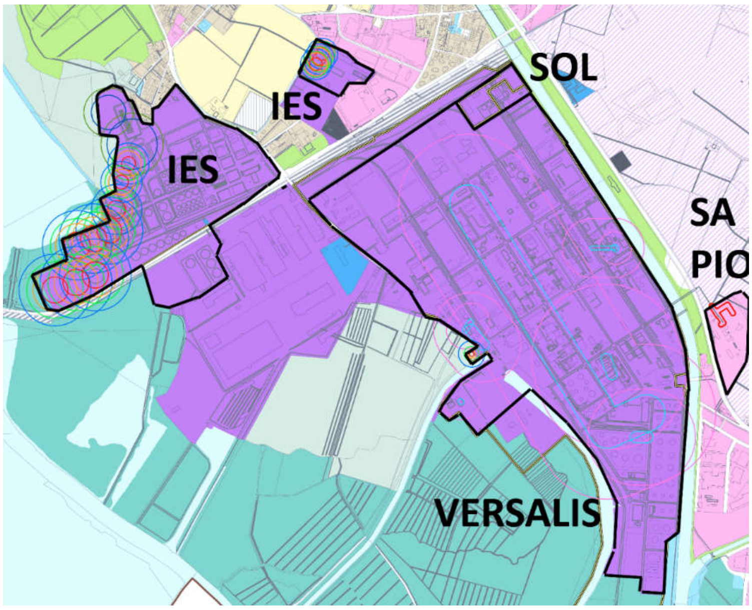


Figure 28: Mantua E.R.I.R. tavola 3, accident scenarios

In the end, with the exception of the GPL flash fire for IES, no incompatibilities were encountered and pointed out by the E.R.I.R.. In particular, no environmental scenarios are reported or analysed in this document, therefore they were probably excluded for their low probability in the Safety reports of the plants.

However, concerning environment, the last two decades of analyses, conferences organized by the Ministry for the Environment, and surveys vouch for a completely different situation (Ministero dell'ambiente e della tutela del territorio e del mare, 2015) and (Ministero dell'ambiente e della tutela del territorio e del mare, 2016). The industrial hub, together with the Median, Inferior and Vallazza lakes, and portions of Mincio river, was declared with the law 172/2002 as Site of recovery of national interest (SIN), because of the severe situation of pollution encountered both in soil and waters. The SIN includes all the Seveso industries previously described, and other minor industrial activities, that also contributed to the pollution (i.e. the paint factory Industria Colori Freddi San Giorgio). The contamination observed for soil and subsoil is related to heavy metals, BTXEs (benzene, toluene, ethylbenzene and xylene), light and heavy hydrocarbons, dioxin. The underground waters present traces of aliphatic compounds, carcinogenic chlorinated compounds, heavy metals, IPA (polycyclic aromatic hydrocarbons), MTBE (Methyl tert-butyl ether), ETBE (ethyl tert-butyl ether). The light hydrocarbons created a supernatant spot extended for about 105.000 m^2 (according to 2015 survey campaign), which interests the underground waters under Ies, Versalis and the Industry Belleli Energy. Mincio river and the adjacent wetlands, included in the SIC-ZPS "Vallazza", are the final receptors of the pollution in progress; indeed, there is an interchange with the underground waters, and furthermore, the Diversivo Mincio canal acts as a draining system for the phreatic waters, conducting the pollutants to the river. In fact, even if the canal is entirely made of concrete, the investigations have reveled several fractures and areas of permeability.

Starting from 2002, the implementation of a network of piezometers was financed and carried out by Government agencies, and entrusted to the interested companies and to ARPA (Regional Agency for the Enviroment Protection), for a coordinated monitoring of the underground water. Annual survey campaigns should be carried out, but not all the companies or private societies demonstrated the same level of commitment. The industries Ies, Versalis, Belleli Energy and Syndial (a society of ENI group which manage the Versalis areas to be recovered) also have the specific charge of measuring the thick of the supernatant spot. The following pollutants were observed:

- mercury in the underground water under the ex chlorine-soda plant of Versalis and, downstream to this area, in the wet zone owned by Syndial, called the “Poison hill”, delimited by the petrochemical water intake from Mincio and the sewer canal of the plant, named “Sisma”. Mercury was also found in the riverbed of Sisma;
- pollutants in the Versalis piezometers and wells located along the Diversivo Mincio;
- chlorinated solvents in the area between the Versalis units ST20 and CER;
- chlorinated solvents in the underground water under the painty factory Clorificio san Giorgio;
- supernatant spot under the properties Ies, Belleli Energy, versalis and Syndial.

Both Versalis and Ies were required by the authorities in charge to design dedicated systems to improve the environmental quality of their area; the Companies activated hydraulic barriers constituted by drainage wells to drain the supernatant, and Syndial carried out recovery activities in the areas of the Sisma canal, Diversivo Mincio and the “poison hill” of Versalis. The wider hydraulic barrier network belongs to IES: 64 wells, partly destined to the water drainage, partly equipped with the dual pump system, are dedicated to the suction of the supernatant spot. The water is treated in a dedicated plant (TAF), which has a capacity of 50 m^3/h. Other 10 new wells, and the doubling of the treatment capacity from 50 m^3/h to 108 m^3/h, are on progress.

Despite of the above-mentioned measures, (Ministero dell’ambiente e della tutela del territorio e del mare, 2016) pointed out that the hydraulic barriers are not sufficient: the elevated pollutant concentration remained stable, and the contamination was detected also downstream the barriers. I.e., one of the piezometer Versalis showed a benzene concentration of 177.000 µg/l, while the accepted threshold values should be $\leq$ 1 µg/l. The severe situation of pollution currently present in the SIN is mainly a heritage of the past productions and management of the industrial area, however it cannot be excluded that some sources of contamination are still present today.

The consequences of the contamination are not only problematic for the environment, but also for the people’s health; some studies have already been carried out in Mantua, to verify the possible impact. (ASL Provincia di Mantova, 2007) studied the dioxin concentration in plasma for Mantua population, in particular for that of the neighborhoods near to the industrial hub, and the incidence of a peculiar type of sarcoma associated to it. In the Nineties, during the years of activity of Versalis chlorine-soda plant, and of the ex Burgo paper Factory, both the incinerators of the two factories burnt chlorinated residuals, producing dioxin. The study concluded that for the people living near to the industrial hub, the association between the exposition to the industrial emissions and the sarcoma arising appeared credible.

IES

STRENGTHENING EFFECTS: the quantity of detained hazardous substances, the presence of assets particularly exposed to NaTech risks (i.e. tanks, pipelines etc.) and the identified scenarios were taken into account.
Ies is dedicated to the storage of oily products, mainly gasoline and diesel; certain data on the quantity of substances detained are not available, however the plant has a large number of atmospheric tanks, which are considered the item more exposed to NaTech risk. The storage park is composed of 87 atmospheric tanks, whose capacity varies from 60.000 m^3 to 1000 m^3; the majority of the tanks has a floating roof. 8 horizontal underground tanks host LPG – liquefied petroleum gas. The whole storage capacity is around 680.000 m^3.
The products arrive through rail tankers, tanker trucks, and river barges, that constitute other items sensitive to possible NaTech events.
Finally, IES has a plant for the treatment of the drained water (TAS), with open collection basins, exposed to potential overflow.

Figure 29 represents the layout of IES plant, with the relevant hazardous substances detained: Green = gasoline; Purple = diesel fuel; Red = LPG; Acid green = biodiesel, kerosene, MTBE/ETBE; Brown = heating oil; Black = slop (residuals of oil products)
The areas defined with the orange line belong to the former refinery, decommissioned in 2014; the grey areas are tanks no more in use; the light blue area is the water treatment plant. The tanks whose colour is not full are those destined by the plant management to "Stand-by": they are not normally operative, but can be used to manage the variations in the quantity of products stored.

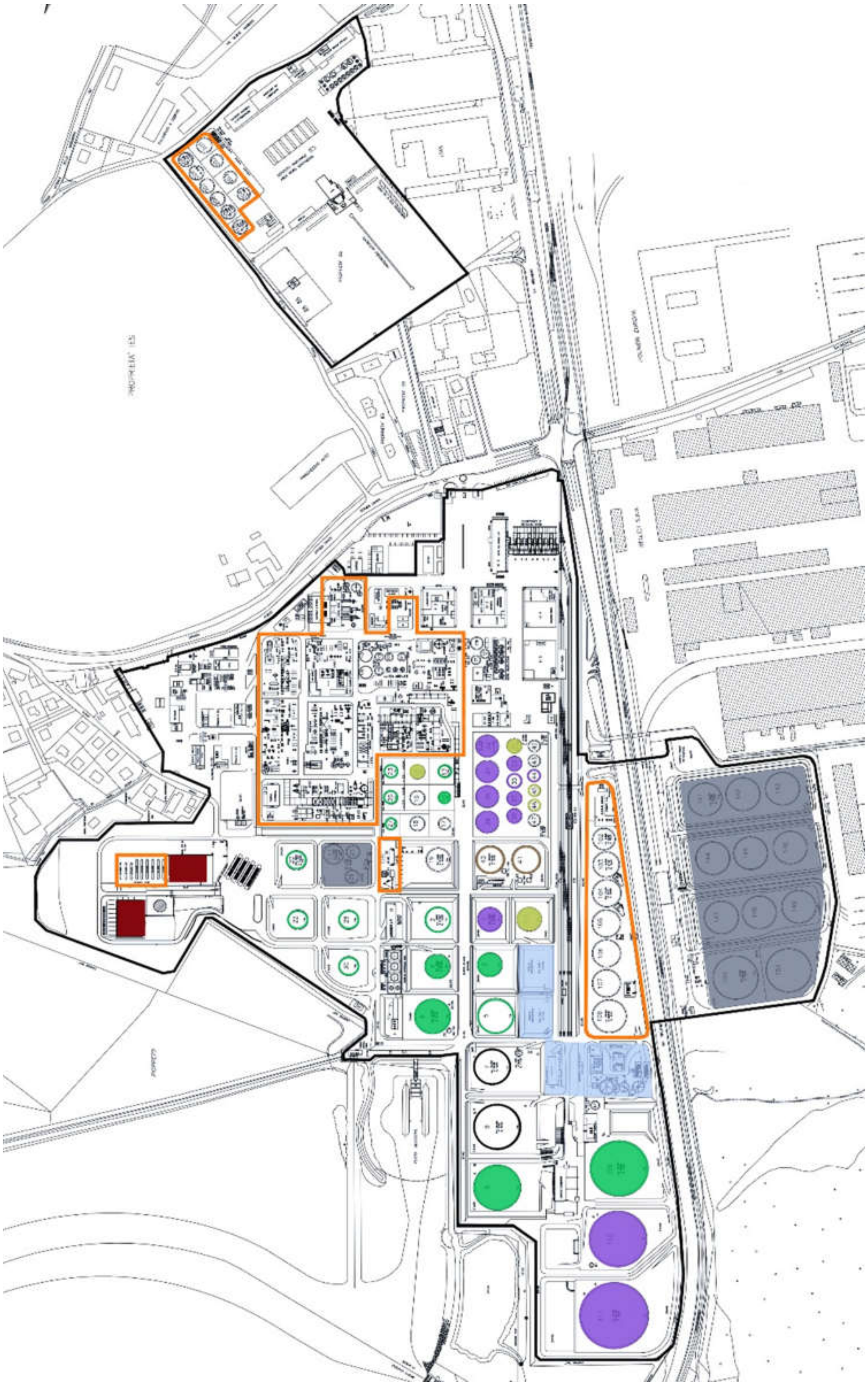


Figure 29: IES storage layout

The available scenarios are still related to the refinery phase, but according to (IES, 2014), those for gasoline and LPG remained valid after the decommissioning (see Table 28). Only fire consequences were identified.

Table 28: IES scenarios for gasoline and LPG

Substance	Event	Scenario	Frequency/year	Probability class	High lethality	Beginning of lethality	Irreversible wounds IDLH	Reversible wounds
Gasoline	Release in basin SR5-6 due to overfilling of the floating roof tanks	Pool fire	$<10^{-6}$	$<10^{-6}$	35	61	77	98
	Release in basin SR202-203-204 due to overfilling of the floating roof tanks	Pool fire	$4*10^{-6}$	10^{-4} - 10^{-6}	25	45	50	60
LPG	Release from the coupling pipeline/pump	Flash fire	$1,2*10^{-4}$	10^{-3} 10^{-4}	67	96	-	-
	Release for break of the loading arm	Flash fire	$5,9*10^{-6}$	10^{-4} 10^{-6}	98	121	-	-

HISTORICAL EVENTS: Besides the presence of the supernatant spot, whose extension was not reduced by the hydraulic barrier, the case history produced by (IES, 2013) showed releases from tanks, pipelines, TAS with minor consequences for the environment.

- 25/12/1994, gasoline release from S13 tank, accumulation in the containment basin not waterproofed, penetration into the ground;
- 25/06/1999, kerosene release from a flanged coupling on a pipeline inside the waterproof containment basin of tank 150;
- 13/09/2008, the intense rainy event caused the overflowing of the API separator system of the TAS, which interested some adjacent containment basins;
- 07/04/2010, release from an underground pipeline between the tanks 5 and 7;
- 08/08/2012, release of water contaminated by hydrocarbons from S39 tank, during maintenance operations.

A program to equip the tanks with dedicated systems to detect overfilling started in 2015; periodic checks are carried out to verify the integrity and seal through acoustic emission (EA test). However, it was not possible to verify, from the available documents, if the tanks are provided or not with double bottom. The main criticality encountered is the lack of a waterproof containment basin that is missing for all the biggest tanks.

PROTECTION MEASURES: The protection measures are described in the following lines; all the information collected were inserted into the checklists reported in **Table 8** and **Table 9** to check their efficacy against pollution and NaTech events (See Annex II – Versalis and Ies protection measures).

- *atmospheric tanks:* 1) fire detection system, constituted by thermosensitive cables located near the seal of the roofs; 2) foam discharge devices on the roof, to address the foam exactly in the area where usually the gas releases, and the consequent fire takes place. The foam discharge device can be fed with a fixed system or through tanker trucks. 3) Shell plating externally cooled. 4) Installation on progress of logic solvers able to detect and activate dedicated emergency procedures for: fire / roof inclination / overfilling or over emptying / isolation. For the fixed roof tanks, it was foreseen the detection of overfilling. 5) Containment: trip system related to high and low levels. Presence of basins of containment, or dykes, also to avoid accidental collisions; tanks equipped with an external concrete logline, connected to a cockpit with a dedicated pump, aimed at collecting minor releases or operational discharge to draining system.

- Pipelines: The pipeline paths are developed in protected areas, to avoid collisions with vehicles. The major part is located on open racks, to be more easily inspected.
- *LPG tanks and LPG loading areas:* thermosensitive cables for fire detection, and gas release detection system placed in loading areas, tanks and pumps. For gases, sensors are present at the entry and exit points of the pipelines from the mounds, and inferior portions of the mounds. Since the tanks are entombed, as required by the Ministerial Decree D.M.13.10.94, they would not need cooling system or fixed foam discharge devices; however, they are equipped with a water fixed plant. The LPG loading area, the control room, the pumps and their surroundings are protected with pulverized water, and foamy systems. The whole area is also equipped with portable fire extinguishers and hoses.
- *Dock:* the area is protected by 4 fire-fighting monitors, that can be fed with water or foam, which are distributed on the 2 loading/unloading piers. The measures to avoid releases are: reduction of flanged couplings; motorized valves on the transport lines; jacketed pipelines in the underground portions.
- *Tank trucks and rail tankers loading areas:* the loading areas for trucks are equipped with a fixed cooling system and with a fire-fighting system with automatic activation. The latter is constituted by 2 water-foam cannons; 5 fire hydrants. The loading areas for rail tankers are equipped with cooling system and fire-fighting foamy system with manual activation.

<u>*Ratings assignation*</u>

Table 29 shows the ratings assignation for IES. The first column reports the macro-category Strengthening effects, evaluated on the basis of the items, type and quantity of substances (toxic (T), flammable (F), dangerous for the environment (N)), and scenarios. The second column is related to the Protection measures, both adopted for the single item, or general for pollution and NaTech events. The third column is related to all the accidental events registered for the plant. The impossibility to consult the Safety Reports introduced some uncertainties in the evaluation; in case of lack of information, a precautionary judge was attributed.

Table 29: Ratings assignation for IES plant

S.E. STRENGTHENING EFFECTS				P.M. PROTECTION MEASURES		H.E. HISTORICAL EVENTS
Assets / items with potential NaTech risk No	Item description	Substance	Scenarios	Protection measure related to the item	Protection measures for Na-tech / pollution events	
31	Fixed roof tank, 2000 m^3	Biodiesel (F, N)	n.a.	Unique waterproof containment basin, for the tanks 31- 46 (excepted 40, 41). Trip for high and low levels. Cooling system for the external coating and roof.	POLLUTION the plant adopted many measures foreseen by (Provincia di Torino, 2010). However, it was not possible to verify if there are system of automatic block of the water discharge into Mincio, and many tanks have no waterproof pavement. NATECH: No specific measures result adopted against NaTech events; unfortunately, many information are not available, however the documents for IPPC did not mention a plan for area events, and consequent dedicated actions.	POLLUTION: IES is included in Mantua national area of recovery (SIN), which is affected by a at least 30-years of pollution. The supernatant spot of hydrocarbons detected on the underground water of the industrial area originated under Ies plant, and then expanded towards Versalis and Belleli energy. Despite of the containment barriers activated by the plant, in 2015 the surveys made through the piezometers for monitoring the water table show no decrease in the values of the pollutants. Some accidents related to release took place in the plant, but no releases are considered in the safety report. EVENTS: the area is included in the ADBPO area for catastrophic flood (C), some parts of the tanks 9 and 8 are included in the A areas, were the flood could be more likely. No events in the last years hit the area. The area is connoted by seismic soil Z4, where it was encountered a level of amplification higher than the thresholds. Past intense rainy events cause problem to the drainage and water treatment system.
32	Fixed roof tank, 5750 m^3	Diesel fuel (F,N)	n.a.			
33	Fixed roof tank, 2000 m^3					
34	Fixed roof tank, 5750 m^3					
35	Fixed roof tank (standby), 2000 m^3					
36	Fixed roof tank, 5750 m^3					
37	Fixed roof tank, 2000 m^3					
38	Fixed roof tank, 5750 m^3					
39	Fixed roof tank, 2000 m^3					
44	Fixed roof tank (standby), 1000 m^3					
45	Fixed roof tank, 1000 m^3	Kerosene (F, N)	n.a.			
46	Fixed roof tank, 1000 m^3					
40	Fixed roof tank (stand-by), 10000 m^3	Burning oil (F, N)	n.a.	Unique waterproof containment basin. Trip high and low levels. Cooling system for external coating, roof.		
41	Fixed roof tank (stand-by), 10000 m^3					
109	Floating roof tank, 40000 m^3	Gasoline (F, N)	Release for overfilling (Tanks 5-6)	Each tank has its not-waterproof containment basin, with circumference concrete curbs with raceways to collect minor releases. Trip for high and low levels. Cooling system for the external coating and roof. Foam discharge devices along the roof sealing.		
2	Floating roof tank (stand-by), 7000 m^3					
3	Floating roof tank, 7000 m^3					
4	Floating roof tank, 7000 m^3,					
5	Floating roof tank (stand-by), 10000 m^3					
6	Floating roof tank, 10000 m^3					
9	Floating roof tank, 28000 m^3					
13	Floating roof tank (stand-by), 1000 m^3					
20	Floating roof tank (stand-by), 5000 m^3					
22	Floating roof tank (stand-by), 5000 m^3					
23	Floating roof tank (stand-by), 2250 m^3					
25	Floating roof tank (stand-by), 2250 m^3					
27	Floating roof tank (stand-by), 1000 m^3					

S.E. STRENGTHENING EFFECTS				P.M. PROTECTION MEASURES		H.E. HISTORICAL EVENTS
Assets / items with potential NaTech risk						
No	Item description	Substance	Scenarios	Protection measure related to the item	Protection measures for Na-tech / pollution events	
28	Floating roof tank (stand-by), 5000 m^3	Gasoline (F, N)				
30	Floating roof tank (stand-by), 5000 m^3					
110	Floating roof tank, 40000 m^3	Diesel fuel (F, N)	n.a.	Equal to gasoline tanks		
111	Floating roof tank, 60000 m^3					
1	Floating roof tank, 7000 m^3					
14	Floating roof tank, 2000 m^3	MTBE/ ETBE (F)	n.a.			
122	Horizontal tank (stand-by), 252 m^3	LPG (F)	Release for rupture loading arms, or coupling pipeline -pump	Underground tanks		
123	Horizontal tank (stand-by), 252 m^3					
124	Horizontal tank (stand-by), 252 m^3					
125	Horizontal tank (stand-by), 252 m^3					
126	Horizontal tank (stand-by), 252 m^3					
137	Horizontal tank (stand-by), 252 m^3					
138	Horizontal tank (stand-by), 252 m^3					
139	Horizontal tank (stand-by), 252 m^3					
–	Pipelines for product transfer	Hydrocarbon and other products (F, N)	n.a.	Pipelines above-ground, or with coating for inspection		
-	Quay for the uploading and downloading	Various (F)	n.a.			
-	Water treatment system for oily drainage	Polluted liquids	Overflow of the basins			
SCORE						
2,5				-1		2

The score assigned to IES for the Strengthening Effects is between moderate and high (2,5), because of the detained quantity of flammable and pollutant substances (136.500 m^3 of gasoline, 139.000 m^3 of diesel fuel), and the considerable quantity of items vulnerable to external events (atmospheric tanks). Similarly, a medium value was assigned to the Historical Events (2): the severe pre-existing conditions of pollution, confirmed by the periodical surveys carried out every year, may suggest that some sources of pollution are still active; also, the case accident collection from the plant showed multiple cases of releases in the soil. In addition, even if no flood events or seismic damages hit the plant after its construction, the plant is located in an area that could be affected by unforeseen consequences, i.e. because the amplification factor of the soil is high. Intense rainy events have already caused some problems.

For the Protection measures, it was assigned a reduced value (-1). Even if the plant adopted many measures requested by (Provincia di Torino, 2010), no particular measures seemed to be addressed to possible NaTech events (see Annex II). Since it was not possible to go in-depth with the specific provisions adopted by the plant, a precautionary low value was assigned in this case. The absence of waterproof pavement for the containment basins, a factor that facilitate the pollutant penetration in the soils, was also taken into account.

Versalis

Versalis is a petrochemical plant active from the end of the Fifties; its production is organized in three different cycles: 1) styrene monomer; 2) styrene polymers; 3) intermediate products (phenol, acetone, hydrogenated). The productive cycle of “styrene monomer” employs as raw materials ethylene and benzene, transforming them into ethylbenzene and finally into styrene monomer. This substance is the raw material for the cycle “Polystyrene”: it is polymerized, also with acrylonitrile and rubber, to obtain several types of Styrofoam, addressed to automotive, house and packaging sectors. The productive cycle “Intermediate products” is based on cumene and hydrogen (obtained from the de-hydrogenation of ethylbenzene), whose transformation returns phenol, acetone, alpha-methylstyrene, acetophenone, cumene hydroperoxide, cyclohexanol, cyclohexanone.
The plant has a storage park with capacity equal to 170.000 m^3; it also hosts a research center with pilot equipment, a plant for the water treatment connected to an incinerator, plants for the production and distribution of water (demi, industrial). Table 30 shows the main departments of Versalis plant (Ministero dell’ambiente e della tutela del territorio e del mare, 2011); their location is reported in **Figure 30**.

Table 30: Versalis main departments

ID	Description	Department	Description
1	Styrene production	ST20	Styrene production
		ST40	Styrene production
2	Raw chemical production	PR7	Phenol and other raw chemicals production
		PR11	Hydrogenated phenol production
3	Polymers production and storage/transportation of solid products	ST12	Crystal and expandable polystyrene (GPPS and EPS) production
		ST14	Expandable polystyrene (EPS) production
		N8 ST8	Rubber dissolution in styrene
		ST15	Anti-collision polystyrene (HIPS) production
		ST16	Co-polymer ABS/HIPS and crystal polystyrene (GPPS) production
		ST17	Co-polymer SAN and crystal polystyrene (GPPS) production

ID	Description	Department	Description
		ST18	Co-polymer ABS and Anti-collision polystyrene (HIPS) production
		SG12	Storage and transportation of solid products
		MS2	Warehouse
4	Storage/transportation of liquid products	LCE/MSL	Storage/transportation of liquid products
5	Waste incineration	SG30	Waste incineration
		Other activities	
		SG40	Water treatment
		GSA	Auxiliary services

STRENGTHENING EFFECTS: Versalis detains huge quantities of hazardous substances, reported in **Table 31** and **Table 32** (Comune di Mantova, 2012), (Prefettura di Mantova, 2012). The substances are toxic, flammable and dangerous for the environment.

Table 31: Main hazardous substances detained by Versalis plant

Substance	Max. quantity (t)	Classification ex CEE 67/548	Classification ex CLP 1272/2008	Description
Styrene	16688	R10	H226, H332 H315 H319	flammable liquid and vapors
Alpha-methylstyrene	959	R10 R51/53 R36/37	H226 H319 H335 H411	toxic to aquatic life with long lasting effects, is a flammable liquid and vapors,
Acrylonitrile	1645	R23/24/25 R11 R51/53	H225 H350 H331 H311 H301 H335 H315 H318 H317 H411	Toxic if swallowed, toxic in contact with skin, toxic if inhaled, may cause cancer, toxic to aquatic life with long lasting effects, highly flammable liquid and vapors,
Phenol	6561	R68 R48 R24, R25	H314 H341 H373 H311 H331	toxic if swallowed, Toxic in contact with skin, toxic if inhaled, toxic to aquatic life with long lasting effects.
Acetone	9433	R11	H225 H304 H316 H320	highly flammable liquid and vapors
Cumene	21305	R10	H226 H304 H335 H411	toxic to aquatic life with long lasting effects, flammable liquid and vapors
Benzene	22476	R11 R23/24/25	H225 H315 H319 H304 H340 H350 H372	may cause genetic defects, may cause cancer, highly flammable liquid and vapors, harmful to aquatic life with long lasting effects.
Cyclohexanol, cyclohexanone	7781	R10	H226 H332	highly flammable liquid and vapors

Table 32: Overall quantities of hazardous substances detained by Versalis

Categories of substances or compounds	Maximum quantity (t)	Superior Threshold D.Lgs. 334/1999 (t)
Toxic	59626,719	200
Oxidising	551	200
Explosive	5,78	200
Flammable	60915,269	50000
Highly flammable	517,456	200
Liquids highly flammable	64773,065	200
Extremely flammable	352,507	50
Dangerous for the environment	220,594	200
Dangerous for the environment	30143,005	200

Items exposed to NaTech: Versalis storage park is located in its southern portion; 80 tanks store: acrylonitrile 1.500 m^3, benzene 27.500 m^3, ethylbenzene 15.000 m^3, gasoline 10.000 m^3, dehydrogenated mixture 5.000 m^3, nonene 2.000 m^3, acetone 12.000 m^3, cyclohexanone 8.000 m^3, olone 2.000 m^3, cumene 26.500 m^3, styrene 16.000 m^3, pentane 351 m^3, phenolic water 5.000 m^3, oily water 10.000 m^3. 25 tanks are pressurized, while the others are atmospheric with floating roof (benzene and derivates) or fixed roof; since December 2014, they are all equipped with double bottom. Every department also has process tanks, with smaller dimensions. Other sensitive items are:

- the three pipelines from Porto Marghera, containing: 1) cumene, benzene, ethylbenzene, separated by water; and the internal pipelines of the plant used for the products transfer.
- The loading/unloading areas are both for rail tankers, tank trucks and barges; they are located in the following zones, reported in **Figure 30**: zone XXXI – loading of styrene acetone cyclohexanone olone; zone XXVIII – loading of oily and chemical products; zone XXV: loading of pentane; dock - loading of acetone / styrene /ethylbenzene.
- Basins of the oily and acid water treatment systems, located nearby the storage plant and in the east part of the plant, close to the incinerator. Different drainage networks are present in the plant, one for acid process water, the second for oily process water (which include those extracted from the underground water for the recovery of the supernatant), and the last two for the cooling water and rainy water. After the treatment, all the networks are addressed to the drain canal called "Sisma", that flows into Mincio river before Formigosa.
- The incinerator tower, the three plant torches, and the distillation towers are high and thin structures sensitive to earthquake effects. The first is authorized for the thermic destruction of 6.132 t/y of liquid and solid wastes; it also burns the residuals of the water treatments. The torches are connected to the emergency and safety vents of the departments PR11, PR7, ST14, ST20, ST40, and of the storage park. The distillation towers treat phenol and styrene.

Figure 30 reports the layout of Versalis plant, with the main productive departments; the relevant hazardous substances are identified with: red for flammable substances; green for substances dangerous for the environment; purple for toxic substances; grey for the tanks not in use, and acid green for the tanks and basins containing drainage oily and acid waters.

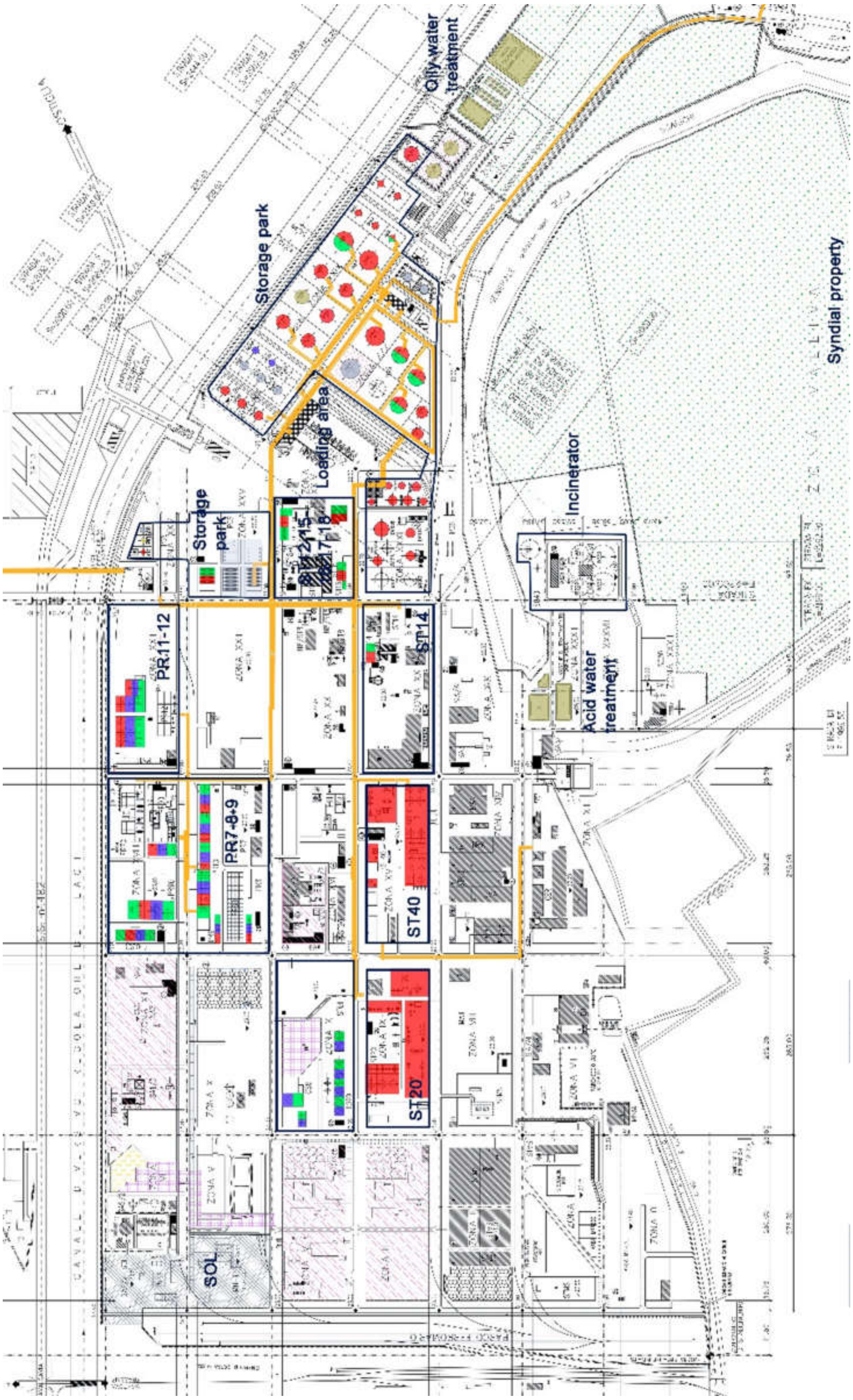


Figure 30: Versalis layout

Versalis scenarios are related to toxic releases (see **Table 33**); the distances of the damage areas (IDLH) are moderate and slightly overcome the plant boundaries. According to the Safety report, cited in Mantua E.R.I.R. (Comune di Mantova, 2012), in the process areas there is no risk of relevant environmental accidents, because all the equipment and tanks are placed on a waterproof concrete slab, and the possible releases are collected by the drainage system. The loading/unloading areas have waterproof pavement too, while no substances dangerous for the environment are treated at the dock. Possible releases could take place in the areas where no waterproof pavement is present, i.e. along the pipeline paths of cumene, benzene, ethylbenzene, pentane; but the occurring of serious consequences was excluded in the Safety report.

Table 33: Versalis scenarios

Substance	Dep.	Accidental event	Scenario	Yearly frequency	Probability class	High lethality LC50	Beginning of lethality	Irreversible wounds IDLH	Reversible wounds
Acrylonitrile	CER	Release from pipeline arriving to CER	Toxic release	$2,54*10^{-5}$	10^{-4} 10^{-6}	22	-	145	1200
Benzene	CER	Release from pipeline arriving to CER	Toxic release	$4,6*10^{-5}$	10^{-4} 10^{-6}	11	-	73	440
Acrylonitrile	Storage park	Release from flexible pipe for rail tankers unloading	Toxic release	$1,31*10^{-5}$	10^{-4} 10^{-6}	22	-	187	715
Benzene	Storage park	Release from transport pipeline	Toxic release	$2*10^{-5}$	10^{-4} 10^{-6}	72	-	270	1550
Separated product[12]	PR7	Release from sending pipe from pump GA-1110	Toxic release	$3,34*10^{-5}$	10^{-4} 10^{-6}	8	-	115	740
Separated product	PR7	Release from the sealing of pump GA-1110	Toxic release	$5*10^{-4}$	10^{-3} 10^{-4}	13	-	62	512
Flammable liquid hydrocarbon	SAU	Overfilling accumulator D20	Toxic release	$2,49*10^{-5}$	10^{-4} 10^{-6}	10	-	70	430
Acrylonitrile	ST16	Release from feeding lines	Toxic release	$3,34*10^{-5}$	10^{-4} 10^{-6}	20	-	290	1205
Flammable liquid	ST40	Explosion in torch B-1700	Confined explosion	$3,09*10^{-6}$	10^{-4} 10^{-6}	8	15	28	50

More in-depth information on the environmental events were provided for the IPPC procedure: (Versalis, 2015) identified the possible "Dangerous points" for release of cumene, benzene, ethylbenzene, pentane, in accordance to the Ministerial Decree 272/2014 (internal

[12] Phenol, acetone, alpha-methylstyrene, cumene

transport pipelines). In addition, a survey campaign was carried out on the piezometers: the presence of cumene and benzene in the underground water resulted by far higher than the thresholds established by the legislative Decree 152/2006. (Versalis, 2015) ascribed these parameters to the previous Company management, but did not excluded a possible on-going contamination, given the particular hydrogeological characteristics of the site.
It has to be highlighted that, as for long portions of the pipelines, the tanks of the storage park are not equipped with a waterproof pavement; they only have a circumference concrete logline aimed at addressing minor releases to the oily drainage system.

In relation to IPPC procedures, (ENI Versalis, 2012) also evaluated possible Area events, earthquake, flood and energy shutdown. As far as it concerns the flood, it was simulated the maximum level reachable by the lakes, with the drain canal Vallazza correctly functioning; it resulted in 19,45 m. Since the ground levels of Versalis plant beyond Sisma canal are between 21 and 23 meters, the possibility of flood was excluded, and no dedicated measures against flood were adopted. For seismic events, Versalis prepared and transmitted to the competent authorities the 0 level seismic data sheets, aimed at give a basic idea of the seismic vulnerability of some equipment and buildings of the plant. Finally, for the electric supply, the plant in case of necessity can pass from a 380kV feeding to a 220 kV one; the areas of production of the polymers are also equipped with 3 generators, similarly to the firefighting system, which has 1 generator.

PROTECTION MEASURES: The main protection measures and procedures adopted in the plant are described in the following lines; all the information collected were inserted into the checklists reported in **Table 8** and **Table 9** to check their efficacy against pollution and NaTech events (See Annex II).

- *Firefighting system:* underground water network composed by 256 hydrants, pressure 10 bar, fed by two electric pumps (capacity 250 m^3/h and 500 m^3/h) and two motor pumps with capacity 1000 m^3/h. In normal condition, the 250 m^3/h electric pump maintains pressure. A generator starts the motor pumps in case of electric shutdown.
- *Containment:* the tanks of the storage park are equipped with double bottom; the Company is progressively equipping also 50 department tanks with double bottom. The storage tanks containing acrylonitrile, styrene, acetone, cyclohexanone, olone are insulated to reduce the heat exchange and the emissions. All the tanks are equipped with level monitoring, transmitted to DCS and alarmed; within 2019, a second high-level detector, with block for too high level, shall be installed. For the acrylonitrile tanks, a gas chromatograph is installed in the double bottom to immediately detect a potential release. Monitoring program: for the double bottom tanks → absence of product between the two bottoms verified every 3 months; external inspection every 5 years; complete inspection every 20 years. For the single bottom tanks → the integrity tested with EA test every 5 years; bottom sealing tested with tracer test every 2 years; external inspection every 5 years; complete inspection every 10 years.

Process areas and the loading / unloading areas are placed on waterproof concrete pavement, equipped with curbs which address potential releases to the drainage system. There are not underground tanks or underground pipelines containing process fluids.
The pipelines, placed on racks, and the equipment are also subjected to periodical monitoring campaigns: an external inspection is carried out every 5 years, but also ultrasonic surveys of thickness, magnetic examination and other surveys are carried out. The portions of racks crossing the plant rail or roads are monitored through a dedicated coating, which allows detecting eventual releases. From 1990, the lines are inserted in an Inspection Manager tool, which keeps under control the monitoring activities and the needs of maintenance.

HISTORICAL EVENTS: No information on Versalis case history is available, but the plant is partially responsible of the severe pollution encountered in the area.

Ratings assignation

Table 34 shows the ratings assignation for Versalis. The first column reports the macro-category Strengthening effects, evaluated on the basis of the items, type and quantity of substances (toxic (T), flammable (F), dangerous for the environment (N)), and scenarios. The second column is related to the Protection measures, both adopted for the single item, or general for pollution and NaTech events. The third column is related to all the accidental events registered for the plant. The impossibility to consult the Safety Reports introduced some uncertainties in the evaluation; in case of lack of information, a precautionary judge was attributed.

Table 34: Ratings assignation for Versalis plant

S.E. STRENGTHENING EFFECTS				P.M. PROTECTION MEASURES		H.E. HISTORICAL EVENTS
Assets / items with potential NaTech risk		Substance	Scenarios	Protection measure related to the item	Protection measures for Na-tech / pollution events	
No	Item description					
421	Fixed roof tank, 750 m^3	Acrylonitrile (T,F,N)	Toxic release: flexible duct for unloading	Waterproof containment basins, concrete curbs connected to DA405. Double bottom, insulation.	NATECH: No specific measures were adopted for flood events. Concerning the table reported in (Cruz et al., 2004), only 10/31 measures can be considered adopted; no structural interventions were made on the tanks, like anchoring or construction of containment walls. No intervention is mentioned against lightening	VERSALIS is included in Mantua national area of decontamination (SIN), which is affected by a at least 30-years of pollution. Despite of the containment barriers and protective measures imposed by the Government, the piezometers still register parameters for benzene and other hazardous substances higher than the thresholds. As far as it concerns floods, according to (ENI Versalis, 2013), the maximum height reachable by Mantua lakes during an exceptional raining
422	Fixed roof tank, 750 m^3					
401	Floating roof tank, 5000 m^3	Benzene (F)	n.a.	Non-waterproof containment basins, concrete curbs connected to DA405. Double bottoms.		
403	Floating roof tank, 5000 m^3					
404	Floating roof tank, 5000 m^3					
409	Floating roof tank, 10000 m^3					
415	Floating roof tank, 2000 m^3					
406	Floating roof tank, 5000 m^3	Ethylbenzene (F)	n.a.			
407	Floating roof tank, 10000 m^3					
431	Floating roof tank, 1000 m^3					
432	Floating roof tank, 1000 m^3					
416	Floating roof tank, 2000 m^3	Semi finished toluene (F)	n.a.			
417	Floating roof tank, 2000 m^3					
450	Floating roof tank, 2000 m^3					
451	Floating roof tank, 2000 m^3					

S.E. STRENGTHENING EFFECTS				P.M. PROTECTION MEASURES		H.E. HISTORICAL EVENTS
Assets / items with potential NaTech risk		Substance	Scenarios	Protection measure related to the item	Protection measures for Na-tech / pollution events	
No	Item description					
428	Floating roof tank, 1000 m^3				POLLUTION: 15/22 measures recommended by (Provincia di Torino, 2010) were adopted	event, with return time = 100 years and last d = 96 ore, could go from m 18,50 to m 19,00. Since Versalis plant is located on a river terrace whose heights vary from m 22,00 to m 23,00, the hydraulic risk for the plant was excluded. However, the calculation did not take into account the possible obstruction of Scaricatore Vallazza-fissero
429	Floating roof tank, 1000 m^3					
402	Floating roof tank, 5000 m^3	Styrene dehydrogenated mixture (F)	n.a.			
1001	Fixed roof tank, 2000 m^3	Cyclohexanone (F)	n.a.	Non-waterproof containment basins, concrete curbs connected to DA405 (Double bottoms, insulation).		
1002	Fixed roof tank, 1000 m^3					
460	Fixed roof tank, 5000 m^3					
1003	Fixed roof tank, 1000 m^3	Olone - KA oil cyclohexanol and cyclohexanone (F)	n.a.			
1004	Fixed roof tank, 1000 m^3					
408	Floating roof tank, 10000 m^3	Cumene (F, N)	n.a.	Non-waterproof containment basins, concrete curbs connected to DA405. Double bottoms		
430	Floating roof tank, 1000 m^3					
452	Floating roof tank, 5000 m^3					
453	Floating roof tank, 5000 m^3					
455	Floating roof tank, 5000 m^3					
1005	Fixed roof tank, 2000 m^3	Styrene (F)	n.a.	Ground containment basins, concrete curbs connected to DA405. Double bottom; insulation		
1006	Fixed roof tank, 2000 m^3					
1007	Fixed roof tank, 1000 m^3					
1008	Fixed roof tank, 5000 m^3					
1010	Fixed roof tank, 2000 m^3					
1013	Fixed roof tank, 2000 m^3					
1014	Fixed roof tank, 2000 m^3					
1017	Floating roof tank, 500 m^3	Benzene (F)	n.a.	Ground containment basins, concrete curbs connected to DA405. Double bottom;		
1018	Floating roof tank, 500 m^3	Cumene (F, N)	n.a.			
482	Horizontal tank, 117 m^3	Pentane (F, N)	n.a.	Ground containment basins, concrete curbs connected to DA405. No double bottom		
483	Horizontal tank, 117 m^3					
484	Horizontal tank, 117 m^3					
ST20	10 tanks with fixed roofs, capacity from 75 to 770 m^3	Styrene, benzene (F)	n.a.	Waterproof basins, concrete curbs addressed to DA405. No double bottom for some tanks		
ST40	8 with fixed roofs, capacity from 45 to 1000 m^3	Styrene, benzene (F)	n.a.	Waterproof basins, connected with the drainage system		
PR7	30 tanks with fixed roofs, capacity from 100 to 1000 m^3 (phenol)	alpha methyl styrene, phenol, cumene, Hydrocarbons (T,F,N)	Releases from the ducts of the pump GA1110	Waterproof basin with containment walls, connected with the oily drainage system		

S.E. STRENGTHENING EFFECTS				P.M. PROTECTION MEASURES		H.E. HISTORICAL EVENTS
Assets / items with potential NaTech risk		Substance	Scenarios	Protection measure related to the item	Protection measures for Na-tech / pollution events	
No	Item description					
PR11	14 tanks with fixed roofs, capacity from 100 to 1000 m^3	alpha methyl styrene, phenol (T, F, N)	n.a.	Waterproof basin with containment walls, connected with the oily drainage system		
ST12-15-16-17-28	20 pressurized tanks, capacity from 4 to 120 m^3 (styrene)	alpha methyl styrene, styrene, ethylbenzene (F,N)	n.a.	Waterproof pavements, connected to the oily drainage system		
ST14	9 pressurized and fixed roof tanks, capacity from 0,15 to 10 m^3 (pentane)	Styrene Pentane (F,N)	n.a.	Waterproof pavements, connected to the oily drainage system		
S.G.A.	9 fiberglass tanks, capacity from 28 to 150 m^3 (pentane)	Hydrochloric acid, sodium hypochlorite (T, N)	n.a.	Containment basin in concrete		
-	Pipelines from Porto Marghera, diameter 150 mm 2 - Pressurized pipeline ethylene, towards areas ST20 e ST40	Cumene benzene ethylbenzene (F, N)	n.a.	n.a.		
-	Pipelines on racks - 5 m.; inside the Tank Park they are at ground level	Various (F, N)	Potential leaks and toxic releases: cumene, benzene, ethylbenzene, pentane.	n.a.		
-	7 Distillation towers	Phenol, styrene (T, F)	n.a.	n.a.		
-	1 Quay for the uploading and downloading	Acetone, styrene, ethylbenzene (F)	n.a.	n.a.		
-	Incinerator and torches	Hazardous wastes	n.a.	n.a.		
-	Drainage oily and acid basins and tanks	Polluted liquids	n.a.	n.a.		
SCORE						
3				**-1**		**2**

Versalis received a high score for the Category Strengthening effects (3): in fact, it detains a huge amount of hazardous substances (toxic, carcinogenic, hazardous for the environment and flammable), representing a multiple source of hazard; in addition, many items are particularly vulnerable in case of an external impact (tanks and pipelines of the storage park, in large part located on a non-waterproof basement, the multiple distillation towers that could be hit in case of earthquake, the open sky basins for the water treatment etc.)

A medium-high value (2) was assigned for the Historical Events; indeed, even if the most dangerous productions are ceased, and the plant adopted more precautionary measures with respect to the past, the yearly surveys demonstrated no sensible diminution of the pollutants, in particular for benzene. The plant still represents a source of pollution, located in a zone which could be affected by external events.

For the Protection measures, as illustrated in the following tables, Versalis adopted a large part of the measures suggested by (Provincia di Torino, 2010). The information available on the interventions to safeguard the plant from NaTech events do not allow to go in-depth with the analysis, however only 10 on 31 measures by (Cruz et al., 2004) were implemented (See Annex II). For a precautionary reason, it was decided to assign a low value to PM macro-category, in particular considering the problem related to the non-waterproof areas of the plant (i.e. the storage park). Also, the lack of preventive measures against flood interest some crucial departments of the plant that are very close to Mincio river (i.e. the incinerator, the water treatment plant etc.).

Sol and Sapio

Both the Companies produce technical gases, mainly for the adjacent companies Versalis and Ies.
Sapio is located in front of the loading / unloading area of Versalis, beyond "Diversivo Mincio"; it is composed by two parallel lines which produce hydrogen from methane steam reforming, and a line for the purification and liquefaction of CO2. The hydrogen was sent to IES refinery through a gas pipeline DN200; however, it is not clear if this conduct is still active, or maybe is used by Versalis. The plant stores gas cylinders containing hydrogen, oxygen, acetylene and GPL, and has an area for the parking and supply of cylinders trucks.
STRENGTHENING EFFECTS: The hazardous substances present in the plant are reported in Table 35, taken from Mantua E.R.I.R.: the plant overcomes the inferior threshold of the Legislative decree no. 105/2015 for only one substance, hydrogen (threshold = 5 t).

Table 35: Sapio hazardous substances

Substance	Maximum quantity (t)	Classification ex CEE 67/548	Classification ex CLP 1272/2008	Description
Methane	0,3	R12	H220	Extremely flammable gas
Hydrogen	9,56	R12	H220	Extremely flammable gas
Oxygen	7,144	R8	H270	Oxidiser
Acetylene	1,5	R5-6-12	H220	Extremely flammable gas
Ethylene	0,55	R11	H220 H336	Extremely flammable gas
LPG	0,55	R12	H220 H340 H350	Extremely flammable gas, may cause cancer
Dimethyl disulphide	0,531	R11 R51/53	H302 H312 H315 H319 H330 H335 H411	toxic if inhaled, toxic to aquatic life, with long lasting effects, highly flammable liquid and vapour

The hydrogen is present in the process areas and in the loading areas for cylinders trucks and cylinders warehouse. The first is composed by 18 concrete boxes, equipped with flexible

pipes with non-return valves and anti-tear device; the latter is a concrete-building that can contain cylinders for an equivalent hydrogen quantity of 23400 Nm^3. The warehouses for the acetylene and LPG cylinders, and for the oxygen cylinders are placed at an appropriate distance from the process areas and the hydrogen warehouse.
Sapio scenarios are reported in Table 36, extracted from Mantua E.R.I.R.; only one damage area (highlighted) overcomes a little the boundaries of the plant. All the scenarios are related to jet-fires; environmental scenarios can be excluded because of the type of substances.

Table 36: SAPIO accidental scenarios

Substance	Department /equipment	Event	Scenario	Yearly frequency of occurrence	Length of the jet fire
Hydrogen	Flanged coupling prereformer	Release	Jet fire	$3{,}53*10^{-6}$	1 m
	Flanged coupling degasser	Release		$6{,}16*10^{-6}$	7,4 m
	Transfer pipelines	Release for rupture		$1{,}06*10^{-3}$	9,5 m
		Release from flanged coupling		$4{,}64*10^{-4}$	1,2 m
	Flexible pipes to cylinders trucks / cylinders	Release for rupture		$1{,}17*10^{-3}$	6,2 m
		Release from flanged coupling		$1{,}05*10^{-2}$	1,2 m
	Flanged coupling reactor	Release		$2{,}5*10^{-4}$	1 m
	Flanged coupling converter	Release		$1{,}09*10^{-3}$	1,1 m
	Flanged coupling degasser	Release		$2{,}82*10^{-5}$	0,9 m
	Emergency vent	Release from torch		$4{,}69*10^{-4}$	21 m
	Transfer pipelines	Release for rupture		$2{,}18*10^{-3}$	9,5 m
		Release from flanged coupling		$3{,}35*10^{-4}$	1,2 m
	Flexible pipes to cylinders trucks / cylinders	Release from rupture		$1{,}03*10^{-2}$	6,2 m
Methane	Pipelines	Release	Jet fire	$2{,}84*10^{-3}$	6,4 m
	Pipelines	Release		$3{,}61*10^{-4}$	6,4 m

PROTECTION MEASURES: As far as it concerns the measures of protection, the plant is equipped with 1 underground water basin (150 m^3) and 1 external basin (150 m^3), both with electric pump and diesel pump; a network of distribution of the water to hydrants and sprinklers. The areas for truck loading and acetylene storage are cooled off with vaporized water systems.

Sol plant produces nitrogen, oxygen and argon through an air splitting up process by distillation; the liquid products are stored in 2 tanks with capacity 3000 m^3. Nitrogen and oxygen are sent to Versalis through a gas pipeline, or loaded on tanker trucks. The plant detains 3736 t. of oxygen, an oxidizer, which overcomes the superior thresholds established by the Legislative Decree no. 105/2015 (2000 t). The plant has also 280 kg of fuel oil.
Sol scenarios are reported in Table 37. They do not overcome the plant boundaries, and there are no environmental scenarios, because of the type of substances.
Concerning the Measures of protection adopted, the firefighting system is manual; the plant is equipped with control alarm and trip systems.

Table 37: SOL accidental scenarios

Substance	Equipment	Accidental event	Scenario	High lethality LC50	Beginning of lethality	Irreversible wounds IDLH	Reversible wounds	High lethality LC50
Oxygen	Transfer pump from tank to evaporators	Partial rupture of the exit pipe	Gas release (gravity dispersion)	$1,6*10^{-3}$	-	-	4,7	-
		Complete rupture of the exit pipe		$1,8*10^{-5}$	-	-	7,4	-
	Pipe for tankers uploading	Partial rupture		$9,4*10^{-5}$	-	-	3	-
		Complete rupture		$1,1*10^{-7}$	-	-	13	-
	Transfer pump from column to tank	Partial rupture		$1,15*10^{-3}$	-	-	-	-
		Complete rupture		$2,5*10^{-5}$	-	-	4,7	-

<u>Ratings assignation</u>

Table 38 and **Table 39** report the ratings for the Seveso plants Sol and Sapio; they not owe substances that are hazardous for the environment, therefore the hazard is exclusively due to flammable and oxidant substances. The two plants have only pressurized tanks, which according to (Krausmann et al., 2011) should have a major resistance against external triggered events.

Table 38: Rating assignation for Sapio plant

[S.E.] STRENGTHENING EFFECTS							*[M.P.] PROTECTION MEASURES*		*[H.E.] HISTORICAL EVENTS*
Assets / items with potential NaTech risk		*Hazardous substances*	*T*	*F*	*N*	*Credible events / scenarios RDS*	*Protection measure related to the item*	*Protection measures for Na-tech / pollution events*	
No.	*Item description*								
	Pressurised tank, 351000 lt, 0,35 barg Pressurised tank, 301000 lt, 0,4 barg Hydrogen cylinders' warehouse	Hydrogen		F		n.a.	Firefighting water network, fed by two basins (150 m^3, and 175 m^3, both served by an electrical and a motorized pump. The network serves both automatic sprinkler devices, and monitors and hydrants.	POLLUTION : the plant does not detain hazardous substances for the environment, however containment basins and curbs are adopted for the possible areas of release. NATECH: Information not available.	No information on the plant accidents are available. EVENTS: the plant borders the area for catastrophic flood (C). It is located in an area with Z4 seismic soil.
	Oxygen warehouse	Oxygen		F		n.a.			
	Acetylene and LPG warehouse	Acetylene and LPG		F		n.a.			
	Internal lines and Gas pipeline DN 200, 19 barg, 40°C	Hydrogen		F		Partial or total rupture transfer pipelines (probability range 10^{-3} - 10^{-4})			

[S.E.] STRENGTHENING EFFECTS							[M.P.] PROTECTION MEASURES		[H.E.] HISTORICAL EVENTS
Assets / items with potential NaTech risk		Hazardous substances	T	F	N	Credible events / scenarios RDS	Protection measure related to the item	Protection measures for Na-tech / pollution events	
No.	Item description								
	9 Hydrogen absorber beds	Hydrogen		F		n.a.			
	Stripping columns	-				n.a.			
	Box for the stop/recharge of cylinders trucks	Hydrogen		F		Partial or total rupture flexible pipes for the loading (probability range 10^{-3} - 10^{-2})			
SCORE									
1,5							-1		1

Table 39: Rating assignation for Sol plant

[S.E.] STRENGTHENING EFFECTS							[MP] PROTECTION MEASURES		[HE] HISTORICAL EVENTS
Assets / items with potential NaTech risk		Hazardous substances	T	F	N	Credible events / scenarios RDS	Protection measure related to the item	Protection measures for Na-tech / pollution events	
No.	Item description								
7201	Pressurized tank 60 mbar, 3000 m^3	Liquid OXYGEN (F)		F		Credible scenarios related to the partial or complete rupture of the pumps serving the oxygen transfer line (probability range = 10^{-3} - 10^{-5}	Alarm and trip systems; manual firefighting system	POLLUTION: the plant do not detain hazardous substances for the environment. NATECH: The information on the measures implemented is not available; however the biggest tank bottom is placed at +3 m. with respect to the ground level.	No information on the plant accidents are available. EVENTS: the area is included in the ADBPO area for catastrophic flood (C), adjacent to its boundaries. Therefore, the quote of the ground level is here at 23,50 m.; according to the Emergency External Plan, this quote is too high to be reached both by a flood from the lake or Po river.
7401	Pressurized tank 1bar, 3000 m^3								
7701	Back up tank, 10 m^3								
-	8 other pressurized tanks, capacity from 3000 m^3 to 200 and 10 m^3	Nitrogen and argon (not hazardous)							
35	Tower for the air fractioning	Oxygen, nitrogen, argon		F		n.a.			
SCORE									
1,5							-1,5		1,5

The scores assigned to Sol and Sapio were affected by lack of information about the items and the adopted measures. However, both the plants received low ratings for S.E. and H.E., because of the reduced presence of hazardous substances (lack of toxic substances and pollutants), and of items with a higher resistance to external events (pressurized tanks).

However, the presence of high and tiny structures, like distillation and stripping towers, or the purge gas tanks for Sapio, could represent a problem in case of earthquake. For P.M., very little information was available, so that the evaluation was based on the contents of the external emergency plans. Both the plants have a firefighting system adequate to their necessities, but that of SOL is manual; this could be a partial criticality. However, SOL is also the only plant which adopted a specific measure against an external event, that means the super-elevation of the bottoms of the biggest tanks with respect to the ground levels. Due to the lack of more in-depth information, the rating attributed to the capacity of protection remained low.

Figure 31 represents the Industrial Hazard layer. Thematic GIS map for S.E.; the buffer-zones of 500 m generated by each Mantua plant is also reported (see Paragraph 3.4.4.).

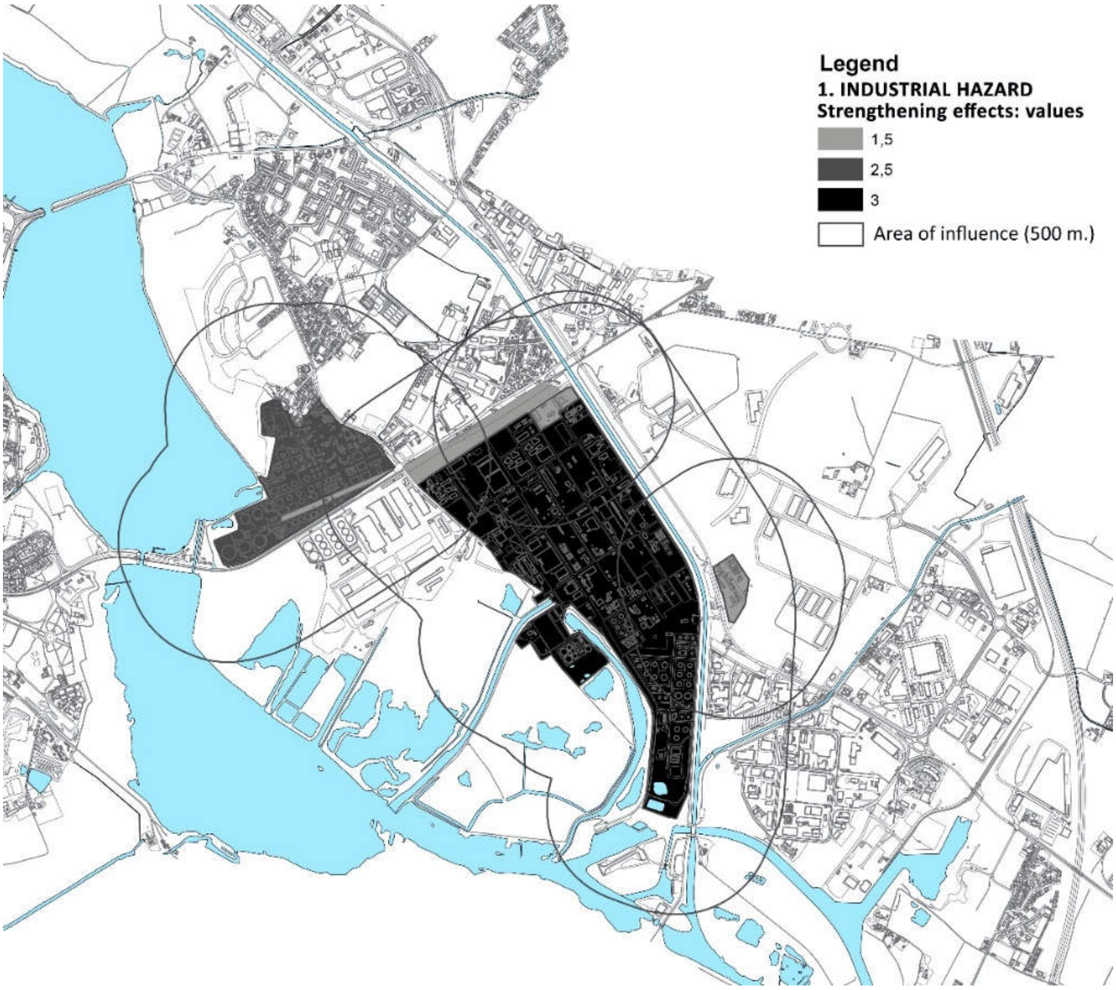


Figure 31: Industrial hazard layer, ratings attributed to S.E.

4.2.4 Local extreme climate events

The inclusion of climate in risk assessment practices or in land use planning is a relatively new discipline, and still has a reduced spread; for the present methodology, it was important to introduce indexes related to climate extreme events, because they can be a hazard source themselves or produce a great influence on other risks. However, as reported in (Schmidt Thomé and Klein, 2011) the local trends of climate are the most difficult to be assessed, because of the great variations of local phenomena which can influence them.

The data for rain, temperature, extreme rainy events available for Mantua were collected to constitute a general basis of information, but, without major expertise and in-depth research in the field, it was not possible to verify the presence of local trends. Therefore, it was decided to adopt the simplified approach reported in **Table 7**, aimed at reflecting the common tendencies for the entire Po valley. The following ratings were therefore assigned to each macro-category for the Climate related events (**Table 40**):

Table 40: Rating assignation for Local climate events

[S.E.] Strengthening effects	***[H.E.] Historical events***	***[P.M.] Protection measures***
Mantua area is located in the area defined as southern Europe, where a diminution of rainy events was observed, against the increase of extreme stormy/rainy events. However, given to its position in the northern Italy, the phenomena are slightly attenuated with respect to other Italian areas.	The area is a plane zone characterized by continental climate.	-
	Score	
2	***1***	***0***

4.3 Assessment of the interactions

The possible risk interactions for Mantua were assessed in the areas where 4 hazards overlaid, corresponding to the 4 Seveso industries. A further Interaction table was applied in the area of the city center, which is connoted by the highest density of people and vulnerable elements.

VERSALIS: the possible risk interaction on the area of Versalis is described by two different interaction tables, because the plant raises on areas connoted by different levels of flood risk. The first interaction table (Table 41) includes the majority of the plant, where the values of Flood risk are = H.E. 1; S.E. 1,5; P.M. -3. The second table (Table 42) is related to the Incinerator and some empty areas in the southern portion of the plant, whose ground level is lower, and that are included in a flood risk zone where = H.E. 3; S.E. 1,5; P.M. -3.

Table 41: Versalis interaction table (1)

HAZARDS & Macrocategories			Seismic			Flood			Industrial			Climate		
			SE	HE	PM	SE	HE	PM	SE	HE	PM	SE	HE	PM
			2	1	0	1,5	1	-3	3	2	-1	2	1	0
Seismic	**SE**	2												
	HE	1		No interaction			1,00			1,75			No interaction	
	PM	0												
Flood	**SE**	1,5												
	HE	1		No interaction			No interaction			1,42			No interaction	
	PM	-3												
Industrial	**SE**	3												
	HE	2		No interaction			No interaction			-			No interaction	
	PM	-1												
Climate	**SE**	2												
	HE	1		No interaction			1,00			1,75			No interaction	
	PM	0												

Table 42: Versalis interaction table (2)

HAZARDS & Macrocategories			Seismic			Flood			Industrial			Climate		
			SE	HE	PM	SE	HE	PM	SE	HE	PM	SE	HE	PM
			2	1	0	1,5	3	-3	3	2	-1	2	1	0
Seismic	**SE**	2												
	HE	1		No interaction			1,67			1,75			No interaction	
	PM	0												
Flood	**SE**	1,5												
	HE	3		No interaction			No interaction			2,08			No interaction	
	PM	-3												
Industrial	**SE**	3												
	HE	2		No interaction			No interaction			-			No interaction	
	PM	-1												
Climate	**SE**	2												
	HE	1		No interaction			1,00			1,75			No interaction	
	PM	0												

As far as it concerns the possible multiple interactions and simultaneous occurring of risks in the area of Versalis, the following values were obtained for the zone of Table 41:

(C) → (F)→ (I) = 1 + 1,42 = 2,42 "From moderate to high" influence

(S) → (I) + (F) → (I) = 1,75 + 1,42 = 3, 17 "High" influence

(C) → (F) → (I) + (C) → (I) = 2,42 + 1,75 = 4,17 "Very high" influence

(S) → (F) → (I) = 1 + 1,42 = 2,42 "From moderate to high" influence

(S) → (I) + (F) → (I) = 1,75 + 1,42 = 3, 17 "High" influence

(S) → (F) → (I) + (S) → (I) = 2,42 + 1,75 = 4,17 "Very high" influence

IES: as for Versalis, the area of IES is interested by different values of Interaction (**Table 43** and **Table 44**), because a marginal portion of the plant is included in an area more frequently interested by flood. In this area, a risky item is located (tank 9, containing gasoline).

Table 43: IES interaction table (1)

HAZARDS & Macrocategories			Seismic			Flood			Industrial			Climate		
			SE	HE	PM	SE	HE	PM	SE	HE	PM	SE	HE	PM
			2	1	0	1,5	1	-3	2,5	2	-1	2	1	0
Seismic	SE	2	No interaction			1,00			1,67			No interaction		
	HE	1												
	PM	0												
Flood	SE	1,5	No interaction			No interaction			1,33			No interaction		
	HE	1												
	PM	-3												
Industrial	SE	2,5	No interaction			No interaction			-			No interaction		
	HE	2												
	PM	-1												
Climate	SE	2	No interaction			1,00			1,67			No interaction		
	HE	1												
	PM	0												

Table 44: IES interaction table (2)

HAZARDS & Macrocategories			Seismic			Flood			Industrial			Climate		
			SE	HE	PM	SE	HE	PM	SE	HE	PM	SE	HE	PM
			2	1	0	1,5	3	-3	2,5	2	-1	2	1	0
Seismic	SE	2	No interaction			1,67			1,67			No interaction		
	HE	1												
	PM	0												
Flood	SE	1,5	No interaction			No interaction			2,00			No interaction		
	HE	3												
	PM	-3												
Industrial	SE	2,5	No interaction			No interaction			-			No interaction		
	HE	2												
	PM	-1												
Climate	SE	2	No interaction			1,67			1,67			No interaction		
	HE	1												
	PM	0												

The following values were obtained for possible multiple interactions and simultaneous occurring of risks in the area of **Table 43**:

(C) → (F) → (I) = 1 + 1,33 = 2,33 “From moderate to high” influence

(S) → (I) + (F) → (I) = 1,67 + 1,33 = 3 “High” influence

(C) → (F) → (I) + (C) → (I) = 2,33 + 1,67 = 4 “Very high” influence

(S) → (F) → (I) = 1 + 1,33 = 2,33 “From moderate to high” influence

(S) → (I) + (F) → (I) = 1,67 + 1,33 = 3, 17 “High” influence

(S) → (F) → (I) + (S) → (I) = 2,33 + 1,67 = 4 “Very high” influence

SOL: **Table 45** describes the values of the interactions of the natural hazards with SOL plant.

Table 45: SOL interaction table

HAZARDS & Macrocategories			Seismic			Flood			Industrial			Climate		
			SE	**HE**	**PM**	**SE**	**HE**	**PM**	**SE**	**HE**	**PM**	**SE**	**HE**	**PM**
			2	1	0	1,5	1	-3	1,5	1,5	-1,5	2	1	0
Seismic	**SE**	2	No interaction			1,00			1,29			No interaction		
	HE	1												
	PM	0												
Flood	**SE**	1,5	No interaction			No interaction			0,96			No interaction		
	HE	1												
	PM	-3												
Industrial	**SE**	1,5	No interaction			No interaction			-			No interaction		
	HE	1,5												
	PM	-1,5												
Climate	**SE**	2	No interaction			1,00			1,29			No interaction		
	HE	1												
	PM	0												

SOL multiple interactions and simultaneous occurring:
(C) → (F) → (I) = 1 + 0,96 = 1,96 "From low to moderate" influence
(S) → (I) + (F) → (I) = 1,29 + 0,96 = 2,25 "From moderate to high" influence
(C) → (F) → (I) + (C) → (I) = 1,96 + 1,29 = 3,25 "Very high" influence
(S) → (F) → (I) = 1 + 0,96 = 1,96 "From low to moderate" influence
(S) → (I) + (F) → (I) = 1,29 + 0,96 = 2,25 "From moderate to high" influence
(S) → (F) → (I) + (S) → (I) = 1,96 + 1,29 = 3,25 "Very high" influence

SAPIO: in the area of Sapio, only three hazards are overlaid: earthquake, industry and climate, therefore the Interaction table has a row and a column less than the other tables. Climate and earthquake have no direct correlation.

Table 46: SAPIO interaction table

HAZARDS & Macrocategories			Seismic			Industrial			Climate		
			SE	**HE**	**PM**	**SE**	**HE**	**PM**	**SE**	**HE**	**PM**
			2	1	0	1,5	1	-1	2	1	0
Seismic	**SE**	2	No interaction			1,16			No interaction		
	HE	1									
	PM	0									
Industrial	**SE**	1,5	No interaction			-			No interaction		
	HE	1									
	PM	-1									
Climate	**SE**	2	No interaction			1,16			No interaction		
	HE	1									
	PM	0									

SAPIO simultaneous occurring:
(C) → (I) + (F) → (I) = 1,17 + 1,17 = 2,34 "From moderate to high" influence.

The values obtained for the effects of the binary interactions that involve Mantua plants are between Low and moderate; they can be considered as credible, because they reflect the low incidence of the natural hazards in the zone analyzed. In fact, the historical and recent seismic events proved that the peak ground acceleration for Mantua remained low, while the artificialization of Mincio drastically reduced the possibilities of intense flooding. Furthermore, considering the ground level of the industries analyzed with respect to Mincio river, a possible flood would reach a moderate height, with a reduced impact. These conditions are well represented by the value of interaction obtained.

The multiple interactions or simultaneous occurring reach higher values in comparison with those of the binary interactions, expressing the increase of hazard that could be caused by several natural hazards acting simultaneously.

4.4 HSSM and ALOHA simulations

HSSM and ALOHA simulations were carried out to verify the possible spatial consequences of natural events impacting on the industrial areas of IES and Versalis. This optional step was executed to acquire more in-depth information for the compatibility assessment in relation to the two industries with the highest values for the category Strengthening Effects. Both the plants reported low values of interaction for earthquake and flood; in fact, the natural dangers have low impacts, and low recurring rates (with the exception of the little portions where the flood can have a stronger impact – see **Table 42** and **Table 44**).
The damage state associated to the interactions corresponds to R3 both for seismic and flood risk: *continuous spill from a hole with diameter 10 mm*. ALOHA simulations were executed for possible R2 and R3 damage states provoked by Earthquake (S) and Flood (F). HSSM was executed only for a R3 damage state provoked by Earthquake (S), due to the software limitations (paragraph 3.5.4).

Table 47 resumes the parameters settled to carry out HSSM and ALOHA simulations in Mantua. The following paragraphs show in detail: 1) the items on which the simulation was executed; 2) the specific parameters adopted for Mantua case study.

Table 47: Parameters for HSSM and ALOHA simulations in Mantua

Damage state	***ALOHA***	***Natural risk***		***HSSM***	***Natural risk***	
	Parameters	***S***	***F***	***Parameters***	***S***	***F***
R3 (binary interactions)	*Source*: tank *Release hole:* 1 cm-3 cm	✓	✓	*Source:* puddle for 1 cm release. *Depth*: 0,5 cm (conventional ALOHA depth)	✓	×
R2 (multiple interactions)	*Source:* tank *Release hole:* 15 cm-22,5 cm-30 cm	✓	✓	*Not executed*	×	×

4.4.1 Items exposed

In order to speed up the simulation process, the characteristics of the items more exposed to possible NaTech risk were listed (Table 48 and Table 49). The items were mainly tanks: both IES and Versalis have a wide storage park, which evidence criticalities due to the lack of waterproof pavement. Versalis also owes several productive departments, but little data were available for the items in these areas. Only two simulations were carried out outside the storage park: one for the rail tankers that enter the plant in the zone nearby Frassine station, and the other for the tank containing phenol located in the Phenol treatment department (PR7-PR9). The pipelines were signalled in (Versalis, 2015) as capable to produce environmental consequences but, due to the scarcity of information about their dimensions and characteristics of the soil, it was not possible to carry out a valid simulation.

Table 48: Versalis items for ALOHA and HSSM simulations

Substance	*Density (g/cm^3) Viscosity (Cp)*	*Item*	*Roof: Fixed (FI) or Floating (FL)*	**(t)**	*Volume (m^3)*	*Diameter (m)*	*Area (m^2)*	*Height (m)*	*Contain. basin area (m^2)*	*Eq. basin radius (m)*	*Waterproof basin*
Acrylonitrile	0,81 0,34	DA422	FI		750	10	79	10	736	15,31	Y
		DA421	FI		750	10	79	10	736	15,31	Y
Benzene	0,87 0,696	DA401	FL	34	5000	22	380	13	2100	25,85	N
		DA403	FL	34	5000	22	380	13	2100	25,85	N
		DA404	FL	34	5000	22	380	13	2100	25,85	N
		DA409	FL	68	10000	30	707	14	3474	33,25	N
		DA415	FL	14	2000	14,5	165	12	1040	18,19	N
		DA1017	FL	3	500	8	50	8	386	11,08	N
Ethylbenzene	0,86 0,68	DA406	FL	34	5000	22	380	13	2100	25,85	N
		DA407	FL	68	10000	30	707	14	2774	29,71	N
		DA431	FL	7	1000	11	95	11	1005	17,89	N
		DA432	FL	7	1000	11	95	11	1005	17,89	N
Semifinished toluene	0,86 0,6	DA416	FL	14	2000	14,5	165	12	1040	18,19	N
		DA417	FL	14	2000	14,5	165	12	1040	18,19	N
		DA450	FL	14	2000	16	201	10	729	15,23	N
		DA451	FL	14	2000	16	201	10	797	15,92	N
		DA428	FL	7	1000	11	95	11	845	16,40	N
		DA429	FL	7	1000	11	95	11	845	16,40	N
Cyclohexanone	0,94 2,2	DA1001	FI		1000	14	154	12	246	8,85	N
		DA1002	FI		1000	11	95	11	285	9,52	N
		DA460	FI		5000	24	452	11	1418	21,24	N
OLONE - KA OIL	0,94 2,2	DA1003	FI		1000	11	95	11	246	8,85	N
		DA1004	FI		1000	11	95	11	305	9,85	N
Cumene	0,86 0,79	DA408	FL	68	10000	30	707	14	3474	33,25	N
		DA430	FL	7	1000	11	95	11	845	16,40	N
		DA452	FL	34	5000	27	572	12	1928	24,77	N
		DA453	FL	34	5000	27	572	12	1992	25,18	N
		DA455	FL	34	5000	27	572	12	1784	23,83	N

Substance	*Density (g/cm³) Viscosity (Cp)*	*Item*	*Roof: Fixed (FI) or Floating (FL)*	(t)	*Volume (m³)*	*Diameter (m)*	*Area (m²)*	*Height (m)*	*Contain. basin area (m²)*	*Eq. basin radius (m)*	*Waterproof basin*
		DA1018	FL	3	500	8	50	8	392	11,17	
Styrene dehydrogenated mixture	0,9 0,696	DA402	FL	34	5000	22	380	13	2100	25,85	N
Stryene	0,9 0,696	DA1005	FI		1000	14	154	12	246	8,85	N
		DA1006	FI		1000	14	154	12	246	8,85	N
		DA1007	FI		1000	11	95	11	235	8,65	N
		DA1008	FI		5000	24	452	11	1276	20,15	N
		DA1010	FI		2000	15	177	11	696	14,89	N
		DA1013	FI		2000	15	177	11	1054	18,32	N
		DA1014	FI		2000	15	177	11	1196	19,51	N
Pentane	0,63	DA482	Horizontal tanks		117	n.a.	53	n.a.	431	11,71	N
		DA483			117		53				N
		DA484			117		53				N
Phenol	1,06	Generic tank	n.a.		1000	10	78	12,7	22	-	Y
Benzene and acrylonitrile	*See cells above*	Rail tankers	Assimilated to horizontal, length 10,8 m.		73	-	-	2,93	-	-	N

Table 49: IES items for ALOHA and HSSM simulations

Substance	*Density (g/cm3) Viscosity (Cp)*	*Item*	*Roof: Fixed (FI) or Floating (FL)*	(t)	*Volume (m³)*	*Diameter (m)*	*Area (m²)*	*Height (m)*	*Contain. basin area (m²)*	*Eq. basin radius (m)*	*Waterproof basin*
Diesel fuel	0,84 2,5	110	FL	270	40000	60,96	2917	15,00	4464	37,69	N
		111	FL	405	60000	73,15	4200	15,00	7811	49,86	N
		1	FL	47	7000	27,50	594	11,79	818	16,14	N
		32	FI		5750	24,00	452	12,78	9200	54.12	Y
		33	FI		2000	15,24	182	10,68			
		34	FI		5750	24,00	452	12,78			
		35	FI		2000	15,24	182	10,68			
		36	FI		5750	24,00	452	12,78			
		37	FI		2000	15,24	182	10,68			
		38	FI		5750	24,00	452	12,78			
		39	FI		2000	15,24	182	10,68			
		44	FI		1000	12,28	118	9,14			
Kerosene	0,81	46	FI		1000	12,28	118	9,14			
		47	FI		1000	12,28	118	9,14			
Biodiesel	0,85	31	FI		2000	15,24	182	10,68			
Burning oil	0,98	40	FI		10000	30,50	730	14,40	2352	27,36	Y
		41	FI		10000	30,50	730	14,40			
Gasoline	0,72 0,8	109	FL	270	40000	60,96	2917	15,00	4752	38,89	N
		2	FL	54	8050	27,50	594	13,85	1379	20,95	N

Substance	***Density (g/cm3) Viscosity (Cp)***	***Item***	***Roof: Fixed (FI) or Floating (FL)***	**(t)**	***Volume (m^3)***	***Diameter (m)***	***Area (m^2)***	***Height (m)***	***Contain. basin area (m^2)***	***Eq. basin radius (m)***	***Waterproof basin***
		3	FL	47	7000	27,50	594	11,79	1301	20,35	N
		4	FL	68	7000	27,50	594	12,19	1497	21,83	N
		5	FL	68	10000	38,40	1158	9,14	751	15,47	N
		6	FL	68	10000	38,40	1158	9,14	1997	25,22	N
		9	FL	189	28000	50,00	1963	15,00	2316	27,15	N
		13	FL	7	1000	12,50	123	8,15	698	14,91	N
		15	FL	7	1000	12,50	123	8,15	698	14,91	N
		20	FL	34	5000	21,34	357	15,00	1565	22,32	N
		22	FL	34	5000	21,34	357	15,00	1871	24,40	N
		23	FL	15	2250	13,71	148	15,24	591	13,72	N
		25	FL	15	2250	13,71	148	15,24	591	13,72	N
		27	FL	7	1000	12,50	123	8,15	361	10,72	N
		28	FL	34	5000	21,34	357	15,00	1790	23,87	N
		30	FL	34	5000	21,34	357	15,00	1453	21,50	N
Mtbe /Etbe	0,75 0,35	14	20 00	FL	2000	15,34	185	10,83	610	13,94	N
		122			250		89			0,00	-
		123			250		89			0,00	-
		124			250		89			0,00	-
LPG	0,5	125	Underground tanks		250		89			0,00	-
		126			250		89			0,00	-
		137			600		178			0,00	-
		138			600		178			0,00	-
		139			600		178			0,00	-

4.4.2 Parameters for the simulation

The simulations were carried out on the items reported in **Table 48** and **Table 49**, which were grouped and analyzed depending on different criteria. The two paragraphs below expose the parameters employed for the execution of ALOHA and HSSM on Versalis and IES plants.

ALOHA:

Climatic conditions:

The data on humidity, wind speed and wind direction were recovered from the weather station located in the area of Frassine-Lunetta.

Two different climatic conditions were hypothesized, aimed at reproducing the actual conditions of a sunny day and of a rainy day in Mantua. The first was associated to possible seismic events (S), that can take place independently from the weather conditions, the second to flood events (F), which could probably follow adverse weather conditions.

- S = wind speed (2 m/s), wind direction (286 degrees), Cloud cover (clear), Temperature (20° C), Humidity (medium)

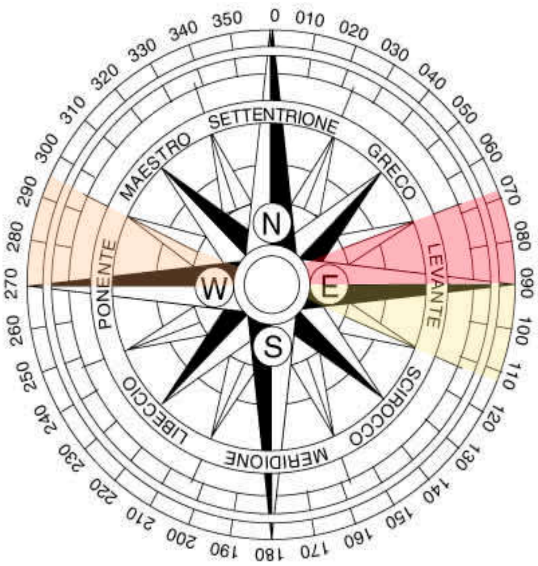
- F = wind speed (5 m/s), wind direction (286 degrees), Cloud cover (complete cover), Temperature (20° C), Humidity (wet)

The wind direction was established on the basis of the prevalent directions registered in a year, shown in Table 50: E-NE (78 degrees), E-SE (91 degrees), W-NW (286 degrees). The latter was adopted for ALOHA simulation, because it can push eventual release of pollutants towards urban areas external to the plants.

Wind speed: the analysis of 1 year of daily surveys revealed low values of wind speed: spring = 2.01 m/s, summer = 1,93 m/s, fall = 1,5 m/s, winter = 1,75 m/s. The maximum value reached in Mantua is equal to 10,5. The values of the two stability classes B and D (2 and 5 m/s) were adopted, because they result in line with the general values encountered in Mantua.

Table 50: Assessment of the wind main directions in Mantua

Wind rose sectors (degrees)	**Recurrence / year (hours)**	**Percentage (%)**	**Sector Median value (degrees)**
0-22,5	225	2,6	
22,5-45	311	3,6	
45-67,5	771	8,9	
67,5-90	1443	16,6	78
90-112,5	1016	11,7	91
112,5-135	347	4,0	
135-157,5	189	2,2	
157,5-180	202	2,3	
180-202,5	216	2,5	
202,5-225	374	4,3	
225-247,5	558	6,4	
247,5-270	771	8,9	
270-292,5	1217	14,0	286
292,5-315	583	6,7	
315-337,5	245	2,8	
337,5-360	226	2,6	



Sources of release:

The settled source of release was "Tank": ALOHA simulates the creation of a Puddle, whose extension can be unlimited or limited by containment basins or other obstacles.

- For Seismic event conditions: limits of the puddle = containment basin of the tank analysed. Ground type = dry sandy soil
- For Flood event conditions: no boundaries specified (flood wave can overcome the basin limits). Ground type = water.

The items analysed in ALOHA were picked from **Table 48** and **Table 49** depending on:

- the proximity to the borders of the plant (they represent a major threat towards external targets)
- the exposure to natural external events. For seismic events all the items can be considered exposed at the same level, because the quality of the soil remains the same

under the entire plants. For Flood events, the vulnerability is strictly correlated to the ground elevation.

For Versalis, the ground elevation varies from 18 m. (incinerator) to 23,5 m. (areas located in the north-eastern corner of the plant). Since the maximum flood height reachable could be around 22,3-22,5 m. (in case of floods provoked by Po river), the simulation was carried out only for items with reduced ground elevation (tanks located on the south-western border of the plant, in front of the Sisma drain). For seismic events, the simulation was carried out for all the tanks located on the borders of the plant, for the rail tankers and for the Phenol tank located in PR7 department.

IES has a lower ground elevation, and the plant is located nearby the passage from Inferior lake to Vallazza; the simulations, both for seismic and flood events, were carried out for the tanks nearest to the riverside (biggest plants in front of via Brennero).

Events:

For each source of release selected, ALOHA provides multiple scenarios, shown in Table 51, but they were not all suitable for the low damage state R3 associated to the Interactions in Mantua (i.e. BLEVE simulations was not carried out).

Table 51: Scenarios developed by ALOHA

Initiating event	***Scenarios***
Leaking tank, chemical is not burning and forms an evaporating puddle	Toxic area of vapour cloud
	Flammable area of vapour cloud (Flashfire)
	Blast area of Vapour Cloud Explosion (VCE)
Leaking tank, chemical is burning and forms a pool fire	Poolfire
BLEVE tank explodes and chemical burns in a fireball	BLEVE

Toxic area of vapour cloud, Flashfire, Poolfire and VCE were modelled; for each scenario, threshold values related to the impact (Level of Concern) had to be inserted in ALOHA. In fact, ALOHA provides default values for LOCs, but the user can modify them: for the current case study, the threshold values indicated by the Ministerial decree 09/05/2001 were inserted (Table 52).

Table 52: LOC thresholds inserted in ALOHA

Scenario	***High lethality***	***Beginning of lethality***	***Non-reversible wounds***	***Reversible wounds***	***Damage to structures / Domino effects***
Pool-fire (stationary thermal radiation)	12,5 kW/m^2	7 kW/m^2	5 kW/m^2	3 kW/m^2	12,5 kW/m^2
BLEVE/Fireball (Variable thermal radiation)	Radius of the fireball	350 kJ/m^2	200 kJ/m^2	125 kJ/m^2	200-800 m (depending on the type of tank)

Scenario	*High lethality*	*Beginning of lethality*	*Non-reversible wounds*	*Reversible wounds*	*Damage to structures / Domino effects*
Flash-fire (instantaneous thermal radiation)	LFL[13]	½ LFL	-	-	-
VCE (peak overpressure)	0,3 bar (0,6 for open spaces)	0,14 bar	0,07 bar	0,03 bar	0,3 bar
Toxic release (adsorbed dose)	LC50[14]	-	IDLH[15]		

Leakage: The damage state associated to the level of interaction for Ies and Versalis plant corresponds to R3; 2 possible hole sizes were tested for all the tanks analysed (1 cm and 3 cm). In addition, a bigger hole dimension was simulated to verify a R2 damage state, related to possible multiple interactions: the dimension was defined on the basis of (HSE, 2012): 15, 22,5 or 30 cm (see **Table 12**). The R1 damage state, equivalent to a catastrophic rupture with immediate release of the entire content, was tested only for the two Versalis tanks containing acrylonitrile.

HSSM:

For Mantua case study, KOPT and OILENS models were run, in order to check: 1) the time of arrival of the pollutant to the aquifer; 2) the extension reachable by the LNAPL lens. TGSPLUME running, related to the dispersion of the dissolved constituents in the water, needed data not available.

Leakage: R3 damage state = 1 cm was simulated, with the pond depth given by ALOHA. *Data:* The input data required to run HSSM tables are more complicated than for ALOHA, and could imply local surveys. However, HSSM manual (Weaver et al., 1994) contains useful indications. The data collected for Mantua were organized through excel tables reproducing the contents of HSSM Input boxes (**Table 53**), conceived to constitute a useful help for future users of the methodology, because:

- the column *Notes* explain how and where to find each value required;
- the lines in grey evidence the parameters that have to be filled for OILENS model only.

[13] LFL = Lower Flammable Limit

[14] LC50 = lethal concentration 50, Standard measure of the toxicity of the surrounding medium that killS half of the sample population of a specific test-animal in a specified period through exposure via inhalation (respiration)

[15] IDLH = Immediately Dangerous to Life or Health condition, defined by the National Institute of Occupational Safety and Health (NIOSH) as a situation "that poses a threat of exposure to airborne contaminants when that exposure is likely to cause death or immediate or delayed permanent adverse health effects or prevent escape from such an environment." The IDLH limit represents the concentration of a chemical in the air to which healthy adult workers could be exposed (if their respirators fail) without suffering permanent or escape-impairing health effects.

Table 53: Criteria for HSSM running

HSSM Parameter		***Generic value***	***Value in Mantua***	***Notes***
1st INPUT BOX: HYDROLOGIC PARAMETERS				
Water dynamic viscosity (cp)		1	1	The values inserted are default values provided by HSSM manual (Weaver et al., 1994)
Water density (g/cm3)		1	1	
Water surface tension (dyne/cm)		65	65	
Maximum krw during infiltration		0,5	0,5	
Recharge rate	*Average annual recharge (m/d)*	-	-	Local source data
	Or Saturation	0,35	0,35	Local source data: to be calculated starting from volumetric moisture content and porosity. For Mantua: 35% of the pore space filled with water, taken from the examples provided by the HSSM manual (Weaver et al., 1994) .
Capillary pressure curve model (Brooks and Corey)	*Pore size distribution index (λ)*	*See HSSM Manual, Table 92*	0,398	Table 92 of HSSM manual (Weaver et al., 1994) provides the values for λ and air entry head, depending on the type of soil. Residual water saturation calculated on the basis of table 92, starting from the values of residual water content Θ_{wr} and porosity $\eta = \Theta_{wr}/\eta$. In order to identify the type of soil, the Italian classification should be adapted to the USDA textural soil classification, using the textural triangle. According to (Comune di Mantova, 2012), the soils in the area of Versalis and IES are mainly sandy: sand 46 - 89%, loam 10-39%, clay 1-18%. USDA textural triangle identifies these soils as "Sandy loam", therefore the values for λ, air entry head and residual water saturation of sandy loam soils were adopted.
	Air entry head (m)		0,29	
	Residual water saturation		0,24	
Saturated vertical hydraulic conductivity K (m/d)		*See HSSM Manual, Table 96*	8,64	Table 96 of HSSM manual (Weaver et al., 1994) presents Literature datasets for the different types of soils, but it is highly recommended to use directly measured values, because k_{sat} has an extremely high variability. For Versalis area, (Ministero dell'ambiente e della tutela del territorio e del mare, 2014) provided the following values for K_{sat}: between $5*10^{-4}$ m/s (43,2 m/d) and $1*10^{-4}$ (8,64 m/d). In HSSM simulation was adopted the lowest value.
Ratio of horizontal /vert hyd cond.		*See HSSM Manual,*	2,5	The parameter is related to anisotropy. For soils slightly anisotropic, like the sandy one, it is adopted the value of 2,5, indicated in HSSM manual (Weaver et al., 1994) examples.
Porosity		*See HSSM Manual, Table 92*	0,2	Table 92 of HSSM manual provides the values for porosity η. For Mantua, the value provided by (Ministero dell'ambiente e della tutela del territorio e del mare, 2014) was used.
Bulk density (g/cm³)		*To be determined (Tbd)*	1,5	Parameter related to the soil porosity and density; it is possible to find online some data: i.e. Sandy soils have a bulk density = 1.500-1.600 kg/m³ = 1,5 g/cm³ Clay and loamy soils have a bulk density = 1.200 kg/m³.

HSSM Parameter		***Generic value***	***Value in Mantua***	***Notes***
				Peaty soils have a bulk density = 900-1.000 kg/m^3.
Aquifer saturated thickness (m)		*Tbd*	20	These data could be find in the geological report that is usually associated to the Urban plan. For Mantua, values taken from (Ministero dell'ambiente e della tutela del territorio e del mare, 2011)
Depth to water table (m)		*Tbd*	8	
Capillary thickness parameter (m)		0,01	0,01	Default value provided by HSSM manual (Weaver et al., 1994)
Ground water gradient (m/m)		0,01	0,01	Typical maximum natural gradients range from 0.005 to 0.02. In HSSM examples it is always used 0,01
Aquifer dispersi vities	*Longitudinal (m)*	10	10	According to HSSM manual (Weaver et al., 1994), the dispersion coefficients are not fundamental parameters, but they are characterized by scale dependence: horizontal transverse dispersivities are typically from 1/3 to almost 3 orders-of magnitude lower than longitudinal dispersivities. Vertical transverse dispersivities are typically 1-2 orders-of-magnitude lower than horizontal transverse dispersivities. The values reported for the case study are those used in HSSM examples.
	Transverse (m)	1	1	
	Vertical (m)	0,1	0,1	
2ND INPUT BOX: HYDROCARBON PARAMETERS				
NAPL density (g/cm^3)		*Tbd*	Table 48 Table 49	For OILENS simulation, the density values should be minor than water density. Some density and viscosity data are reported in Table 10 of HSSM manual (Weaver et al., 1994), however they could be easily found online or in the Safety data Sheets of the substances.
NAPL dynamic viscosity (cp)		Tbd		
Hydrocarbon (NAPL) solubility (mg/l)		10	10	According to HSSM manual (Weaver et al., 1994), this is not a critical parameter, however it should be greater than zero. Here the value 10 is employed, as in the examples provided by HSSM manual.
Aquifer residual NAPL saturation S_{ors}		0,15	0,15	S_{orv} is assumed as a known constant; for hydrocarbons, it can vary from 0,10 to 0,20. S_{ors} for hydrocarbons varies from 0,15 to 0,50. HSSM examples for OILENS running report for S_{ors} 0,15, for S_{orv} 0,05
Vadose zone residual NAPL saturation S_{orv}		0,1	0,1	
Soil water partition coefficient (l/kg)		0,083	0,083	According to HSSM manual (Weaver et al., 1994), like the solubility of the NAPL phase, listed above, this parameter could be considered not critical. The value adopted is that reported in HSSM examples.
NAPL surface tension (dyne/cm)		*See HSSM Manual, Table 11*	35	Some values are provided in Table 11 (Weaver et al., 1994): typically, for hydrocarbon products, the values range from 26 to 32. In our simulations, we adopted the value 35 employed in the examples.
Hydroca rbon release	*NAPL flux: q_0 (m/d)*	-	-	HSSM provides 4 possible alternatives to simulate the leakage; as far as it concerns the case of a slowly leaking tank or a leaking tank within an embankment, HSSM manual (Weaver et al., 1994) suggests to choose the option "ponded LNAPL ", options 3 or 4. Option 3: the ponding abruptly goes to zero at the end of the ponding period. Option 4: the ponded depth decreases gradually at the end of the ponding period. In our simulation, we adopted the third option, inserting the default ponding depth used by ALOHA = 0, 5 cm
	NAPL volume/area (m) lower depth of NAPL zone (m)	-	-	
	Constant head ponding: depth (m)	0,005	0,005	
	Variable ponding after a	-	-	

HSSM Parameter		*Generic value*	*Value in Mantua*	*Notes*
	constant period: depth (m)			
	Beginning time (d)	0	0	Usually, 0 days beginning time is adopted.
	Ending time (d)	TBD	2-3 hours	The ending time represents the period in which the pond remains on the soil and therefore its pollutant agents are free to penetrate it. Repeated simulations with different ending times were carried out for Mantua items, in order to test the minimum time of release necessary for the different pollutants to reach the water table; for the majority of the substances analysed, an ending time between 2 and 3 hours was sufficient.
3RD INPUT BOX: SIMULATION PARAMETERS				
Radius of oil lens source R_s				For KOPT simulation it could be inserted a standard value: 0,5642. For OILENS, the value inserted was the radius calculated by ALOHA
Radius multiplication factor		1,001	1,001	Standard value provided by HSSM manual (Weaver et al., 1994)
Maximum NAPL saturation in the NAPL lenz, S_0 (max)		TBD	See note	Parameter related to the thickness of the lens, it should be calculated using the NTHICK utility provided together with HSSM software - see detailed instructions at page 188 of the Manual (Weaver et al., 1994). Unfortunately, because of a bug of the utility NTHICK, we could not calculate the exact value; after many simulations to verify the influence of the parameter, it was decided to adopt that indicated in HSSM examples.
Simulation ending time (d)		From 25 to 2500	From 25 to 2500	The parameter depends on the characteristics of the substance and on the model that the user is running: for KOPT, it should be an interval of time related to the foreseen time of arrival to the water-table (i.e. 25-30 days). For OILENS model, HSSM example suggests to insert a time much greater than that expected for the NAPL lens to form (i.e. 2500 days)
Maximum solution time step (d)		From few hours to 25 or less	From few hours to 25 or less	It is proportionally related to the simulation ending time; for OILENS it should be high as possible: values of up to 25 days are acceptable.
Minimum time between printed time steps (d)		0,1-0,25	0,1-0,25	Standard value provided by HSSM manual (Weaver et al., 1994)
Simulation ending criterion	*User specified time*			4 alternatives are provided by HSSM. Since the contaminant dispersion was not analysed for Mantua, the first option was adopted for KOPT running, the second for OILENS.
	NAPL lens spreading stops			
	Max contaminant max flux into aquifer			
	Contaminant leached			

HSSM Parameter		*Generic value*	*Value in Mantua*	*Notes*
NAPL lens profiles	*from the lens*			
	Number of profiles	Max 10	Max 10	Up to ten profiles are allowed.
	Time of profiles (d)			Enter up to ten profile times in days. They are obviously correlated to the chosen simulation ending time.
Receptor location	*Number of wells*	1	1	If no HSSM-T is run, it is enough to specify that there is one receptor located in 0,0-0,0.

- *First input box (hydrologic parameters):* the values remained the same for all the simulations executed, in particular for: *Saturated vertical hydraulic cond.* (m/d) = 8,64, *depth to the water table* = 6 m and *Aquifer saturated thickness* = 20 m.
  The saturated vertical hydraulic condition is a parameter that can hugely influence the results of the model: it expresses the permeability of the ground and can assume a wide range of values, strictly correlated to the local characteristics of the soil. In Mantua, the values of the saturated vertical hydraulic condition provided by (Ministero dell'ambiente e della tutela del territorio e del mare, 2014) are very high, that means that the soil in the industrial area is particularly vulnerable to pollutant penetration.
- *Second Input box (Hydrocarbon properties):* Only substances located in tanks or rail tankers without waterproof pavement were analyzed. The values changed in relation to the substance analyzed, however, substances with the same density and viscosity produce the same results in terms of time to reach the water-table and expansion of the oil lens. Therefore, the simulations were conducted for groups of substances with similar viscosity and density: i.e. benzene simulations are valid also for ethylbenzene, toluene, cumene and styrene. Cyclohexanone, gasoline and diesel required individual simulations.
  As far as it the source of release, the diameter and depth of the pond calculated by ALOHA for 1 cm release hole was adopted, as explained in Par. 3.5.4. 1 cm, the minimum measure associated to damage state R3, was not sufficient to produce consequences in terms of fire/toxic events. Thus, it was particularly important to explore the consequences on the environmental side: if such a minimum release was able to produce pollution, clearly the environmental vulnerability of the place could not be neglected.
  Finally, different durations of release from the pond were tested in order to verify the time necessary to the different substances to reach the water-table: since the substances analyzed were characterized by low density and low viscosity, usually a pond remaining on the soil for three hours was sufficient to push the pollutants into the aquifer.
- *Third Input box (Simulation parameters):* the ending time and the adopted profiles remained constant for all the simulations executed:
  - For KOPT, 25 days simulation ending time, 5 profiles (0,25; 0,5; 1; 2; 5 days)
  - For OILENS, 2500 days simulation ending time, 7 profiles (25; 50; 75; 100; 125; 150; 200 days)

4.4.3 ALOHA and HSSM results

Annex III - *ALOHA and HSSM results* reports the simulations executed for each tank of Versalis and IES, and their outcomings. The most significant results of the simulations are shown in this Paragraph, through graphics related to ground penetration and oil lens expansion for HSSM, Google Earth® maps with the spatial extension of the scenarios (ALOHA).

For Mantua plants, the simulations identified the most dangerous substances, and the threatened areas that could be associated to a NaTech event with low impact, corresponding to a R3 damage state.
As far as it concerns the energetic/toxic consequences, ALOHA pointed out that Versalis tanks and rail-tankers containing acrylonitrile and benzene could generate toxic external consequences. While for acrylonitrile tanks, the protection measures implemented (survey of leakages through gas chromatograph, double bottom etc) could grant a rapid intervention to avoid the scenario, the railway indeed could be the most vulnerable area in case of interaction effects, because no containment basins or direct control are available.
For IES plant, the R3 damage state can produce a diesel pool-fire, which remains inside the plant boundaries; the tank 9, containing gasoline, for which the binary interaction value F→I reaches a R2 damage state, produces a pool-fire too, that does not reach critical targets. However, rail-tankers containing gasoline could be exposed to the same consequences of those of Versalis.
However, the most alarming scenario associated to Na-Tech interactions both for Versalis and Ies is related to environmental pollution. HSSM demonstrated that a very small release hole (1 cm), and 3 hours of release from the puddle on the ground are sufficient to cause pollution for the aquifer. Further interactions with external factors like flood, extreme climate events (storms, raining) can spread pollutants to unforeseeable distances. The surveys in the industrial area confirm the data obtained with HSSM; considering that such a small release could also not being detected in time by the monitoring and protection devices, it is very important to duly take into account this scenario for the compatibility phase.

Damage state: R3 – release hole: 1 cm

The simulations carried out for a 1cm hole did not produce meaningful results in terms of toxic or fire events; even in case the Levels of Concern were reached, the extension of the incidental areas did not overcome the basins of containment. However, given the high hydraulic conductivity of the Mantua soils, this little leakage - for substances characterized by a low density and low viscosity - was sufficient to provoke pollution.

VERSALIS: For tanks containing benzene and substances with similar density and viscosity, the pond produced by a 1 cm hole, after three hours of stay on the ground, can reach 6 m. deep in 5 days. The extension of the Hydrocarbon lens formed on the aquifer surface in 200

days can reach 25 meters from the point of release; for major releases of pollutant, it can vary from 90 to 120 meters.
The tanks containing Cyclohexanone and olone are less dangerous for the environmental effects: the viscosity of these substances is equal to 2.2, therefore the penetration of the pollutant flux in the soil is slower. Both for the 5000 m^3 and 1000 m^3 tanks, a release time of 12 hours would be necessary for the pollutant to reach the aquifer.
Figure 32, **Figure 33**Errore. L'origine riferimento non è stata trovata. and **Figure 34** show HSSM results for the biggest tank of Benzene, 10.000 m^3 (valid for tanks DA407, DA408, DA409). **Figure 32** shows KOPT simulation: flux penetration into the ground after 3 hours of release from the puddle. The 5 time- profiles evidence the depth reached by the pollutant after 6 hours – first curve on the right – and after 5 days – first curve on the left. Since the depth of the aquifer in the area of Versalis is between 4 and 8 m., it appears clear that the pollutant can reach the water table in a brief period.

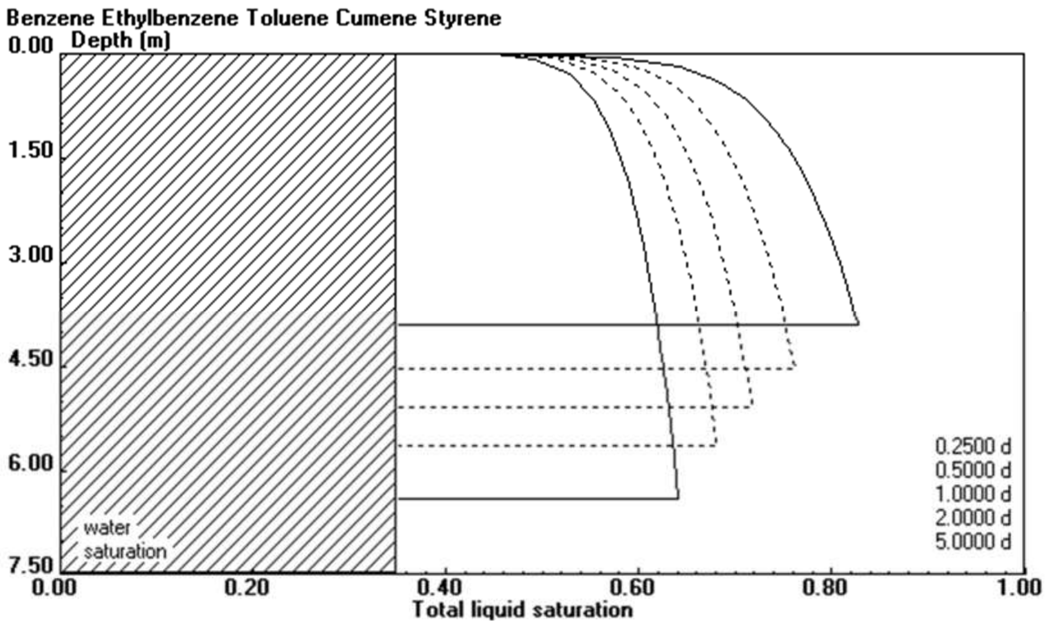


Figure 32: KOPT results for benzene and similar substances

Figure 33 and **Figure 34** show OILENS model: formation of a lens of hydrocarbon substance on the surface of the aquifer, after the arrival of the pollutant to the water table. In this case, the time profiles analyzed are longer than in KOPT model and go from 25 days to 200 days.

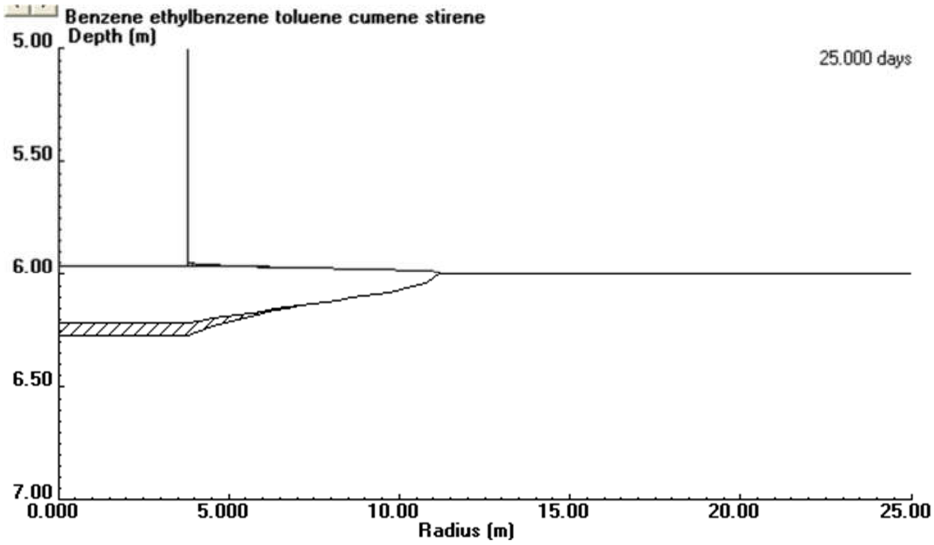


Figure 33: OILENS results for benzene and similar substances (25 days)

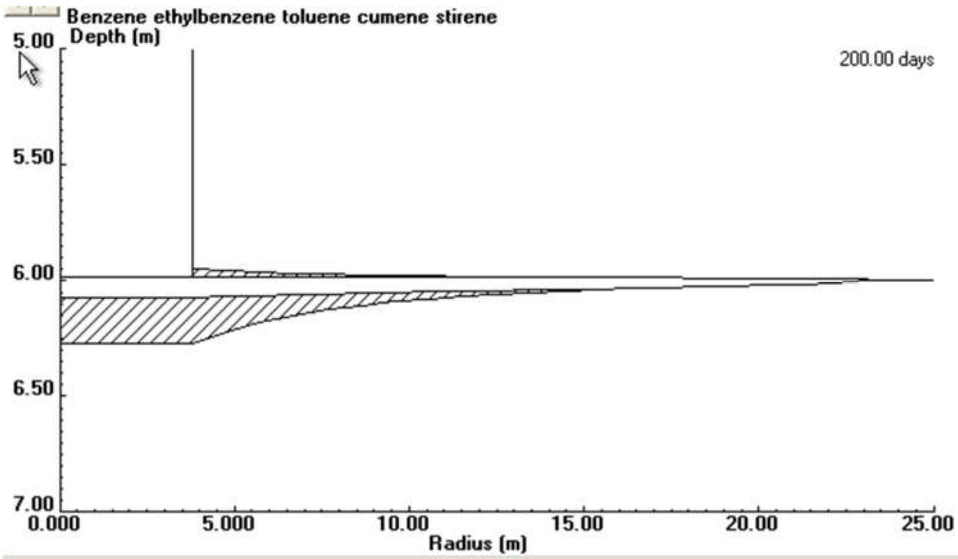


Figure 34: OILENS results for benzene and similar substances (200 days)

IES: the tanks without waterproof basins contain gasoline and diesel. The first showed a behavior similar to that of benzene, reaching the water table in 5 days after three hours of release from the puddle; however, given the major dimension of the tank, and the consequent major dimension of the puddle and of released pollutant, the oil lens can reach distance from the starting point of about 40 m. On the contrary, the viscosity of diesel fuel, equal to 2.5, slows down its penetration into the ground: after 4 hours, it reaches only 2,50 meters deep, and in order to reach the water table, 14 hours of uninterrupted leakage from the puddle are required.

In addition, the tank of MTBE / ETBE was analyzed: the viscosity in this case is very low, therefore only 2 hours of release from the puddle are sufficient for the pollutant to reach the aquifer; the lens can arrive to 40 meters in 200 days.

Damage state: R3 – release hole: 3 cm (Seismic events)

VERSALIS: **Figure 35** shows that a possible minor rupture (3 cm) caused by an earthquake could lead to a critical event in the storage park provoked by the tanks containing acrylonitrile. The toxic release would reach some areas outside the plant, mainly industrial, and a civil house. The same damage on the benzene tanks can generate a vapor release limited to internal areas of the plant; benzene is not classified as toxic substance, but it is recognized as a carcinogenic one.

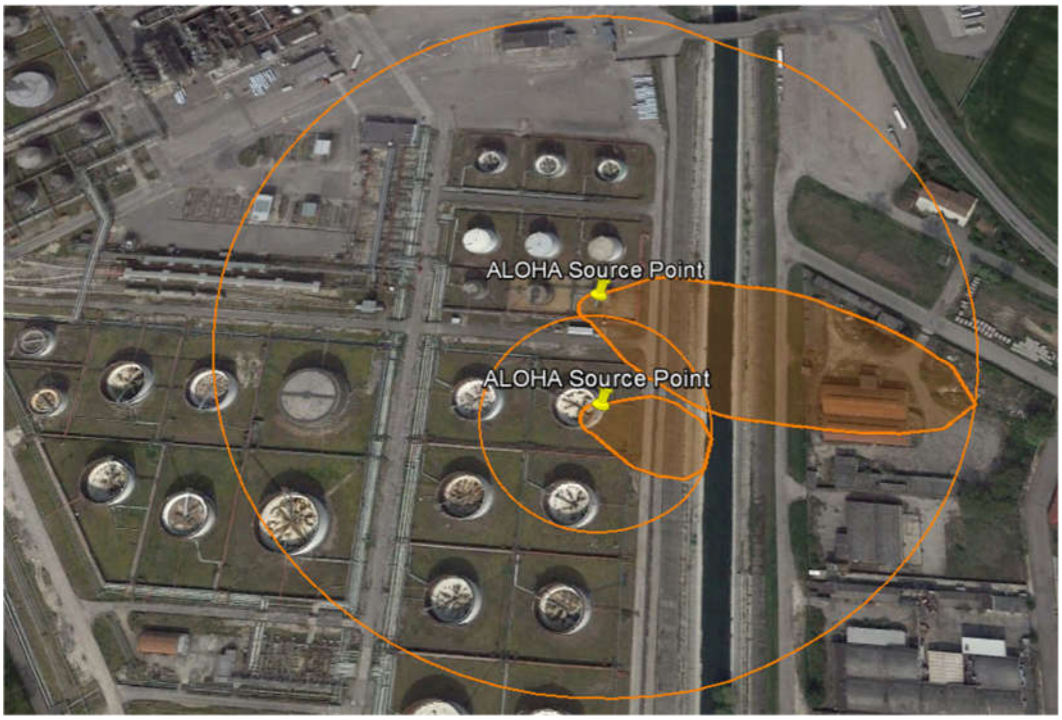


Figure 35: Seismic R3 damage state on acrylonitrile and benzene tanks

As far as it concerns the productive departments and the Frassine railway, another potential risky situation was identified for the rail tankers. Possible leakages of acrylonitrile and benzene could generate toxic releases (**Figure 36**) involving the residential zones located along the railway.

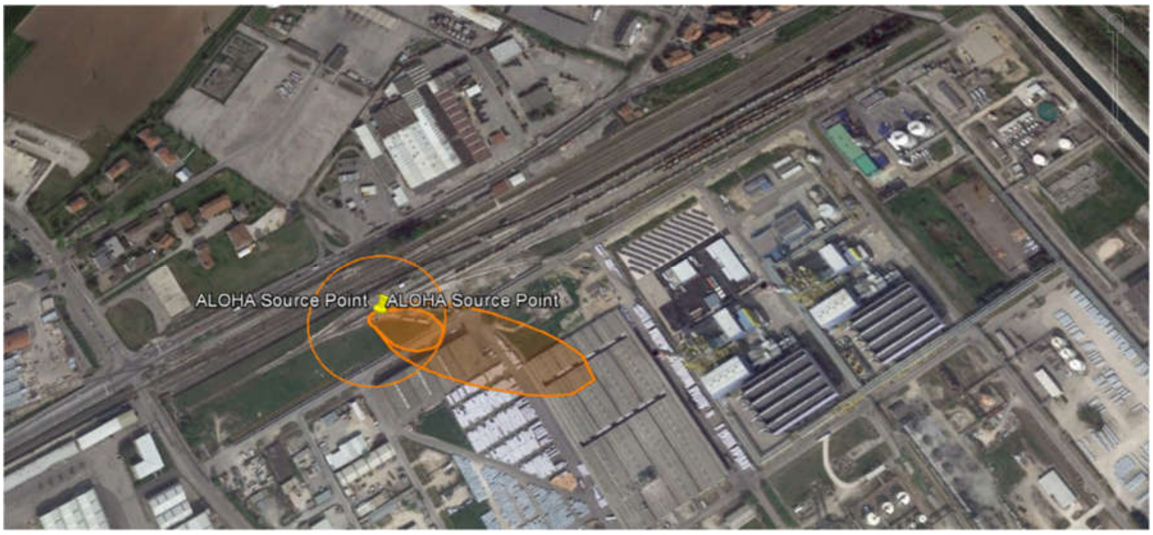


Figure 36: Seismic R3 damage state on acrylonitrile and benzene rail-tankers

IES: the possible scenario caused by a minor leakage provoked by an Earthquake consists of a pool-fire from the biggest tank of diesel fuel, which in any case remains confined inside the tank basin (**Figure 37**).

Figure 37: Seismic R3 damage state on acrylonitrile and benzene rail-tankers

Damage state: R3 – release hole: 3 cm (Flood events)

The simulations developed for a R3 damage state provoked by a possible flood impact evidenced little or negligible scenarios both for Versalis and IES.

VERSALIS: the tanks located in the lowest portion of the plant, in front of the Sisma drain, were analysed: they contain cumene, cyclohexanone, toluene and styrene. **Figure 38** shows that the leakage provokes minor poolfires, contained inside the containment basins.

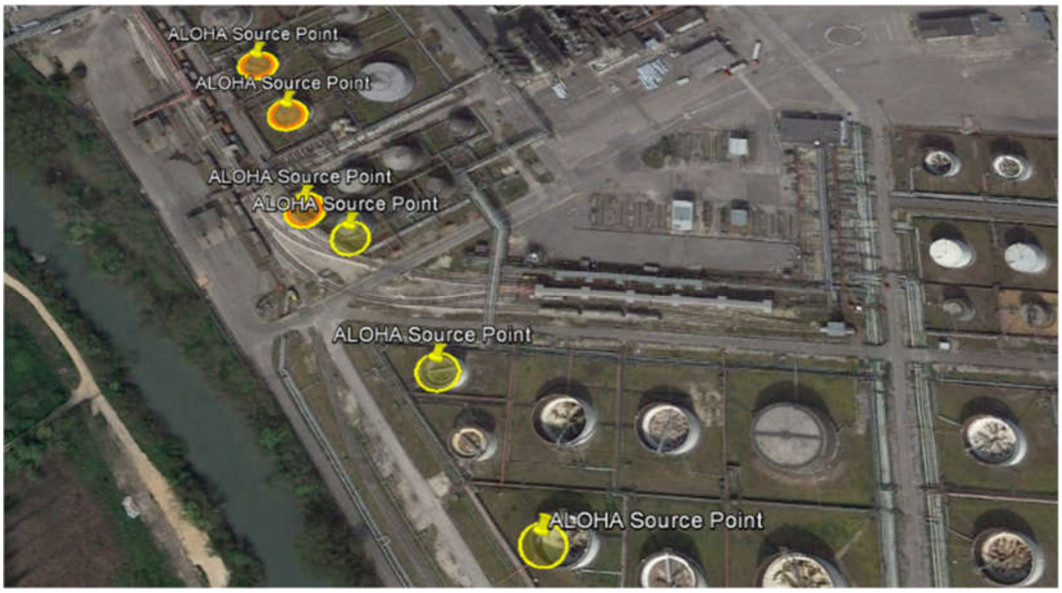


Figure 38: Flood R3 damage state on cumene, cyclohexanone, toluene, styrene tanks

Damage state: R2 – release hole: 15-30 cm (Seismic events)

Some simulations for R2 damage state were conducted in order to verify the possible scenarios related to multiple interactions. Different dimensions of the leakage holes, compliant to those provided by (HSE, 2012) were tested.

VERSALIS: all the tanks analysed could produce pool-fires; they do not overcome the plant boundaries, but could provoke domino effects on the adjacent tanks. As far as it concerns the possible toxic release (orange areas), once again the tank containing acrylonitrile could provoke the largest toxic area outside the plant; it includes one residential building. The release from benzene tank could overcome the plant boundaries and reach the industrial buildings in front of Versalis (**Figure 39**).

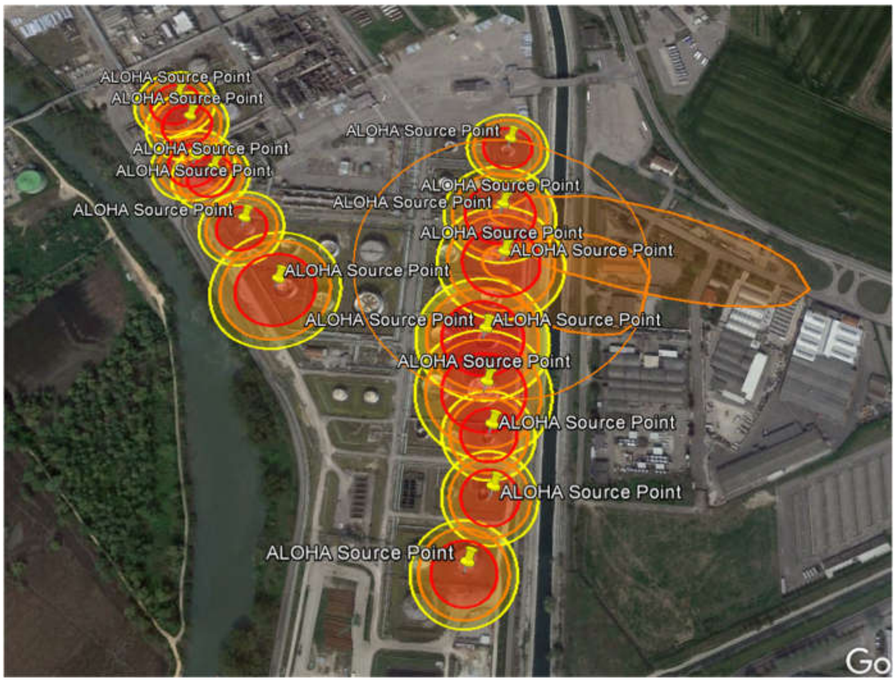


Figure 39: Seismic R2 damage state on Versalis tanks

IES: the R2 damage state applied to the biggest tanks of diesel fuel and gasoline could bring to major pool-fires, which include via Brennero (**Figure 40**). However, it has to be considered that the perimeter wall of the plant partially protects the street.

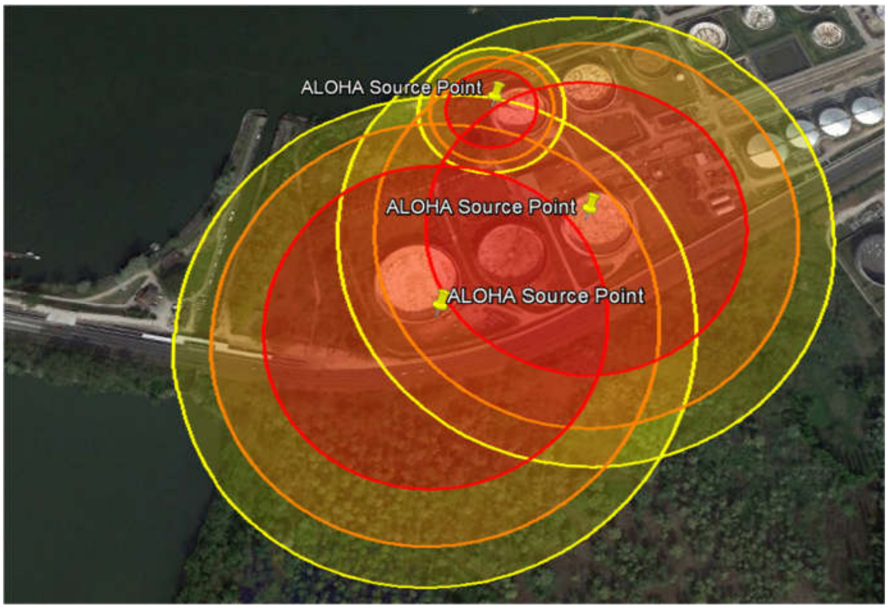


Figure 40: Seismic R2 damage state on IES tanks

Damage state: R2 – release hole: 15-30 cm (FLOOD)

The scenarios related to a R2 damage related to Flood events are once again Pool-fires; however, considering that ALOHA cannot simulate Pool-fires on water, the extension of the area could be very different from the map.

VERSALIS: the scenarios are produced by the tanks with a low ground elevation; they overcome the plant boundaries, but do not reach areas of interest (**Figure 41**).

Figure 41: Flood R2 damage state on Versalis tanks

IES: the R2 damage state for the gasoline tank 9 could be the result of a simple binary interaction Flood→Industry (**Table 44**), as a consequence of the major hazard value that the flood risk has in that area. On the contrary, for gasoline tank 109, R2 damage state is a remote event, that could be provoked by multiple interactions.

In any case, the areas generated by 9 do not reach sensible targets, while the poolfire from 109 could involve the Brennero street (**Figure 42**).

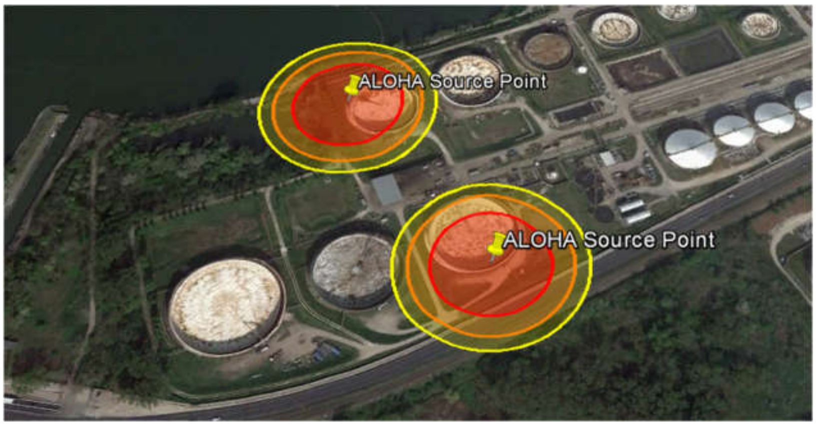


Figure 42: Flood R2 damage state on IES tanks

4.5. Territorial and environmental vulnerabilities

The territorial vulnerability for Mantua was assessed through the identification of areal, linear and punctual vulnerabilities (Regione Piemonte, 2010), classified according to Ministerial decree DM 09/05/2001. The territorial vulnerable elements and the assigned classes are reported in Annex III; 3 thematic layers were also drafted in Arcgis, as shown by **Figure 43.**

1) *Areal vulnerabilities:* the vulnerability classification was based on the building ratio indexes defined by Mantua City plan (Comune di Mantova, 2012). Usually, the city plan defines the building ratio index for each urban function, specifying the allowed density of construction; but this index is not indicated for the most ancient areas. For Mantua city centre, the class was assigned on the basis of the urban density; normally the city centers could assume categories between A and B.

   In relation to areal analysis, the E.R.I.R. approach recommends to investigate only the residential areas; however, in order to obtain a good knowledge of the territory, the analysis was extended also to other urban functions, i.e. commercial and tertiary areas, green public areas, parks, and areas destined to the transformation. These spaces were attributed to a C category, because of their average people frequentation; an in-depth research was then carried out to verify the correct attribution and verify the presence of vulnerable punctual elements.
2) *Punctual vulnerabilities*: all the buildings with public functions or connoted by high frequentation were analyzed; in particular schools, hospitals, churches, museums, nursing homes, stations, commercial malls etc. For Mantua, the lists provided by the local E.R.I.R. (Comune di Mantova, 2012) and Emergency plan (2014) were assumed, and then expanded through to a closer investigation of the territory. Since many dates related to the frequentation of the buildings were not available, precautionary categories were assigned on the basis of the specific functions and dimensions of the building analyzed.
3) *Linear vulnerabilities and strategic elements*: railways, main roads, gas ducts were identified (etc.). In addition, the strategic elements for emergency, and key infrastructures for the functioning of the city were pointed out: areas signalled in Mantua Emergency Plan as shelter areas, and storage places for the civil protection; buildings related to public services, police and strategic civil protection; power plants and infrastructures for water regulation.

Annex III also reports the environmental vulnerabilities encountered in Mantua: several elements are connoted by Extreme and Relevant environmental vulnerability. The entire city centre and the surrounding lakes are classified as Unesco area, because of their unique historical, artistic and landscape characteristics. At the same time, the Mincio river, in spite of its artificial flow, still constitutes a fundamental natural element for the biodiversity safeguard: two "Natura 2000" areas are defined inside Mantua municipality, for the host and reproduction of wild birds and other species.

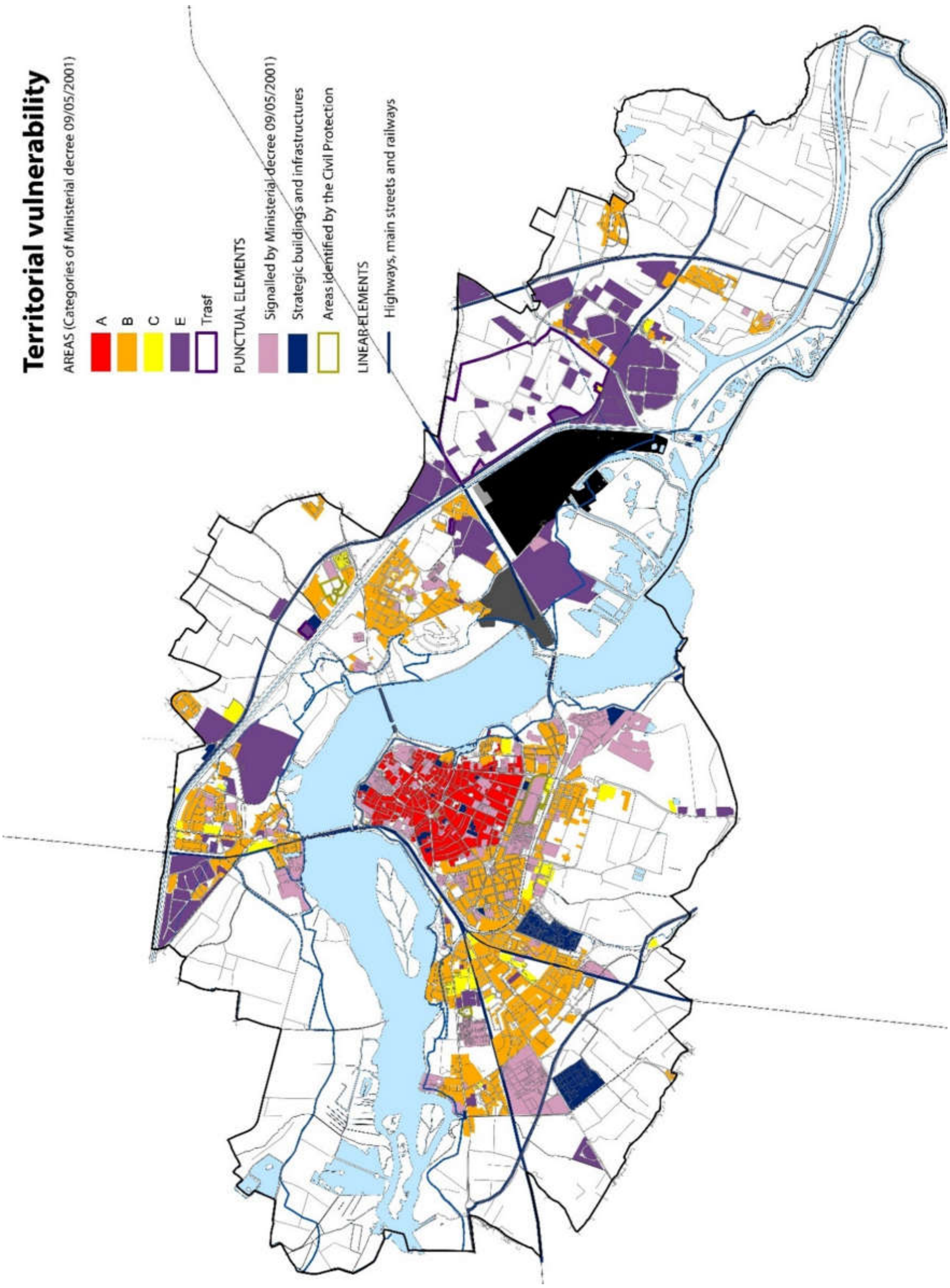


Figure 43: Territorial vulnerable elements in Mantua

4.6. Compatibility and planning actions

The risks encountered in Mantua and the effects of their possible interactions were superimposed to the vulnerabilities listed in Annex III in order to verify the presence of possible incompatibility situations. Studies and interventions to grant the protection of people and environment have to be activated for these areas.

Two different zones of Mantua were chosen for the compatibility assessment:

- the city centre, the area with the highest concentration of vulnerabilities, both of territorial and environmental type. Flood, seismic and extreme climate events can overlay in this zone, but they present homogenous low values.
- Industrial area of Frassino-Lunetta, where Versalis and IES are located, together with the other Seveso plants Sol and SAPIO and other industrial activities. 4 different risks (Industrial, hydrogeological, seismic and climatic) are concentrated here. In this case, the assessment of the compatibility was based on further considerations deriving from the estimation and mapping of the potential consequences of the interaction, produced with ALOHA and HSSM software.

The two compatibility assessments are resumed in the following paragraphs, that follow each step of the process: 1) the assessment of the interaction levels and effects, through the interaction tables, and the simulations with ALOHA and HSSM; 2) the list of the vulnerabilities encountered in the analysed zone; 3) the identification of the possible incompatibilities or alert situations, and the recommended in-depth studies and interventions.

4.6.1. Central area

The area analysed consists of the entire city centre of Mantua, included the more recent urban areas of via Donati and via Nenni, that delimitate the southern border of the centre. Two hazards are overlaid (seismic and flood), together with the overall influence of the Climate; the ratings assigned for the Earthquake and the Flood maintain the same values for the whole central area, with the exception of a little zone in via Nenni, where the seismic risk results higher. Even if the low values encountered do not require further studies and interventions, some recommendations were given to increase the general safety of the area.

1. Risks and interactions

Flood Risk: SE 1,5, HE 1, MP -3

Seismic Risk: SE 2, HE 1, MP 0 (via Nenni = SE 3, HE 1, MP 0)

Climate: SE 1,5, HE 1, MP 0

Risks in central area			Flood			Seismic			Climate		
			SE	HE	PM	SE	HE	PM	SE	HE	PM
			1,5	1	-3	2	1	0	2	1	0
Flood	SE	2									
	HE	1		-			-			-	
	PM	0									

Seismic	**SE** 1,5 **HE** 1 **PM** -1		1	-	-
Climate	**SE** 2 **HE** 1 **PM** 0		1	-	-

2. Territorial vulnerability

Areal vulnerabilities (A and B urban functions):
D14 - A1 Città della prima cerchia (A), D15 - A2 Suburbio della prima e seconda cerchia (A), D16D16 - A3 Aree di continuità con area Unesco (A), D18 - Area resid. Valletta Paiolo Valsecchi (B), D19 – aree residenziali (B)
Punctual elements classified as A or B:
Schools: Mons. Martini (+ Institute Casa Pace), Leon Battista Alberti, Pomponazzo, Ferrari e Bertazzoli, Montessori, Chaplin, D'Este e Nievo, D'Arco e Pitentino, Redentore, Mantegna, Romano, Istituti Santa Paola, Ardigò e Sacchi, Virgilio, Campogalliani e Martiri di B., Politecnico di Milano, UniMantova, Conservatorio
Hospital, hospices, etc: Istituti Geriatrici Mazzali, Poliambulatorio, Casa di riposo Sereno Soggiorno, Casa di riposo Isabella d'Este.
Other elements: Palazzo ducale, Duomo di Mantova
Linear elements and strategic areas / building / infrastructures: Railway; Impianto idrovoro Valsecchi; Area di ricovero R3; Polizia di stato e polizia stradale; Questura; Corpo forestale dello stato; Comune di Mantova; Prefettura; Tribunale di Mantova; Casa circondariale Mantova; Palazzo Soardi - uffici comunali; Guardia di Finanza; Polizia locale; Regione Lombardia – STER; Carabinieri; VVF Mantova

3. TERRITORIAL COMPATIBILITY

Many A and B vulnerable elements were identified in the City centre, but neither the values assigned to the risks, nor the interactions overcome the critical threshold of 2,5, therefore no further actions should be taken. However, some recommendations are given in relation to:
Flood and the possible effects provoked by its interactions → the protection of the central area majorly depends on the efficacy of the hydraulic defence system, composed by the integrated functioning of several elements. In order to continue to ensure this safety, a periodic maintenance and test of the entire system should be applied.
Earthquake → the S.E. value = 2, due to sandy soils, does not reach the threshold for further analysis; in any case, since this soil would increase the effects of an earthquake, it is recommended to verify the state of progress in the compiling of the vulnerability seismic sheets (level 0), and to evaluate if it is convenient to deepen the analysis for the most important public buildings. A clear incompatibility is identified only in the area of via Nenni: the macro-category S.E. for earthquake is equal to 3, and many buildings with public functions raise on this soil with very poor structural characteristics. In particular, two vulnerable elements classified as B were identified: a residential area, and the centre for the treatment of drug dependences (SERT). Further investigations should be carried out for the B elements, and possibly for the entire area: first of all, it is necessary to precisely identify the frequentation and number of people in the zone, at least for each public building. Therefore, further micro-zoning analysis are advocated and at

least the level 0 vulnerability seismic sheet should be arranged for the public buildings. On the basis of the results of these further studies, appropriate measures for the construction and restoration activities in the area could be introduced in the City plan.

2bis. Environmental vulnerability

As mentioned in Paragraph 3.7.2, the compatibility of the environmental elements has to be analysed case by case, in relation to the peculiar characteristics of the element analysed and of the risk and risk interactions. Below the environmental vulnerable elements identified for Mantua city centre are reported, together with the analysis of the possible influence from the risks identified.

Extreme vulnerable elements:	***Flood risk***	***Seismic risk***	***Climate***
Archaeological area in the city centre (not an excavation area; zone where the presence of archaeological vestiges is known and recognized, as centre of the ancient roman city).	Given the fact that the vulnerable element is underground, the influence of a flood could be considered REDUCED. Possible conditions of digging out could be produced by major flood, but this scenario would require more in-depth verifications.	The nature of the archaeological vestiges analysed, which do not constitute an organic compound, can led to consider the effects of the seismic risk as REDUCED	The same considerations as for the flood risks are given.
Protected park of Mincio river (the coastal green banks of the lakes are inserted in the area of the park)	The possible impact of a flood on these areas could be considered MODERATE; indeed, a flood could hit the organization of these areas, bringing mud and waste; however, they are naturally predisposed to flood.	REDUCED INFLUENCE	REDUCED INFLUENCE
300 m. areas around the Inferior, Superior and Median lakes)	FROM MODERATE TO HIGH INFLUENCE	FROM MODERATE TO HIGH INFLUENCE: an earthquake could impact on the built part of the landscape that constitutes the lake coast	REDUCED INFLUENCE

Relevant vulnerability elements:	***Flood risk***	***Seismic risk***	***Climate***
Historical monuments and Landscape: Mantova e Cittadella, Lago Mezzo e Inferiore, Fiume Mincio	HIGH INFLUENCE	HIGH INFLUENCE	REDUCED INFLUENCE
Little wood area near to via Nenni and the railway	REDUCED INFLUENCE	REDUCED INFLUENCE	MODERATE INFLUENCE (lightning)

The coastal areas and the southern areas nearby via Nenni are subjected to hydrogeological restrictions ex l.r. 45/1989:	FROM MODERATE TO HIGH INFLUENCE, because of the reduced altimetry of the analysed areas	HIGH INFLUENCE in the area of Via Nenni, characterized by Z4 type of soil	MODERATE INFLUENCE
Mincio river and lakes constitutes a passageway for several wild species, in particular birds	REDUCED INFLUENCE	REDUCED INFLUENCE	REDUCED INFLUENCE
Only two plots of land with land use capacity 1 or 2 are included in the area analysed	REDUCED INFLUENCE	REDUCED INFLUENCE	FROM MODERATE TO HIGH INFLUENCE
The vulnerability of the aquifers under the city centre goes from Very high to High	Mincio river and lakes are very close, and have high possibility to influence the underground water level	The fluctuation of the underground water could favour the liquefaction for Z2 soils	
The entire city centre has a level of the aquifer between 2 m. and 4 m.; in the area of via Nenni the depth level decrease to 1 m.			

3bis. ENVIRONMENTAL COMPATIBILITY

On the basis of the previous analysis of vulnerability, flood and earthquake and possible interactions have the highest influence on the monumental heritage. However, both the interactions and the strengthening effects values are low; therefore, no further measures can be imposed. Anyway, an accurate maintenance of the hydraulic control system is suggested.

The threshold is overcome only for the area of via Nenni, where the macro category Strengthening effects for earthquake is equal to 3. The following vulnerable environmental elements were identified nearby via Nenni: a wooden area, a hydrogeological restriction, and a vulnerable aquifer whose depth is between 1 and 2 m. The wooden area is subjected to a low influence from seismic events, but earthquake can provoke some repercussions on water behaviour: there is no a direct environmental compatibility, but this particular situation should be considered as a further reason to conduct seismic verifications on the buildings present in the area.

4.6.2. Lunetta-Frassino neighbourhood

The neighbourhood of Lunetta-Frassino is connoted by a wide industrial presence, hosting all the Seveso plants of Mantua. Portions of the neighbourhood are included in the buffer zones identified by (A.D.B.Po, 2016) as exposed to flood risk, and the soils belong to the class Z2 (possible amplification effects). ALOHA and HSSM simulations were executed for the two most dangerous Seveso plants, Versalis and IES, to verify the possible spatial consequences of interactions with natural risks. The vulnerable elements were investigated inside a radius of 1 km from the industries, that are the zone were 4 risks overlay.

1. Risks and interactions

Flood Risk: SE 1,5, HE 1, MP -3

Seismic Risk: SE 2, HE 1, MP 0

Industrial Risk: Versalis SE 3, HE 2, MP -1, Ies SE 2,5, HE 2, MP -1

Climate: SE 1,5, HE 1, MP 0

Risks in Versalis area			Industrial			Flood			Seismic			Climate		
			SE 3	HE 2	MP -1	SE 1,5	SE 3	HE 2	MP -1	SE 1,5	SE 3	HE 2	MP -1	SE 1,5
Industrial risk	**SE**	3												
	HE	2		-			-			-			-	
	MP	-1												
Flood risk	**SE**	1,5												
	HE	1		1,42			-			-			-	
	MP	-3												
Seismic risk	**SE**	2												
	HE	1		1,75			1,00			-			-	
	MP	0												
Climate	**SE**	2												
	HE	1		1,75			1.00			-			-	
	MP	0												

Risks in Ies area			Industrial risk			Flood risk			Seismic risk			Climate		
			SE 2,5	HE 2	MP -1	SE 1,5	SE 2,5	HE 2	MP -1	SE 1,5	SE 2,5	HE 2	MP -1	SE 1,5
Industrial risk	**SE**	2,5												
	HE	2		-			-			-			-	
	MP	-1												
Flood risk	**SE**	1,5												
	HE	1		1,33			-			-			-	
	MP	-3												
Seismic risk	**SE**	2												
	HE	1		1,67			1,00			-			-	
	MP	0												
Climate	**SE**	2												
	HE	1		1,67			1.00			-			-	
	MP	0												

2. Territorial vulnerability (1 km from the plants)

Areal vulnerabilities: the following B urban functions are included: D19 – residential areas (B); some of them are inside the buffer zone of 500 m from the Seveso industries. The City Plan identified a huge area adjacent to the east border of Versalis for the placement of commercial and industrial activities.

Punctual elements classified as A or B: only few C punctual elements were identified.

Linear elements and strategic areas / building / infrastructures: railway, Mantua orbital road, methane pipe line, services line to the plants

3. TERRITORIAL COMPATIBILITY

The buffer zones of 500 m. for the 4 Seveso industries (Versalis, Ies, Sapio and Sol) are almost completely overlaid, and include some residential zones classified as B. The values attributed to the macro-categories of Sapio and Sol are low, as their possible interactions with natural events; on the contrary, Ies and Versalis obtained high values both for S.E. and H.E. The interaction values are low, because of the low levels of the natural risks; however, they tend to medium level. Given these initial conditions, ALOHA software was employed to obtain more defined scenarios

deriving from the interaction. A R3 damage state, corresponding to the low levels of interaction calculated for both plants, was adopted for the simulation → continuous leakage from a hole of 3 cm.
The scenarios obtained through ALOHA were superimposed to the territorial vulnerable elements identified: two incompatibilities along Versalis North and East borders were encountered, in relation to potential accidents provoked by the release of acrylonitrile and benzene from tanks and rail tankers. In particular, along the railway, the impact of natural external events could cause minor damage to the rail-tankers, producing release that could interest the residential areas classified as B. As far as it concerns the east border, releases from the tanks of acrylonitrile and benzene could interest some adjacent industrial activities and a residential house results involved. For IES, the only consequence for R3 damage state is related to diesel fuel, but remains inside the plant boundaries. Therefore, no incompatibilities were detected.
The potential incompatibility identified for the railway zone requires further analyses: first, on the quantity and characteristics of the people living in the B residential areas nearby the railway, on the type of use of Frassine station, frequency of the arrivals of the dangerous goods etc. More detailed simulations on the possible scenarios should be carried out too. Finally, possible integrative protection measures could be taken, like i.e. improvement of the emergency procedures of Versalis and Ies plants, check of the openings of the residential houses pointed towards the railway, automatic lock of the ventilation systems etc.

2bis. Environmental vulnerability (1 km from the plants)

Below are reported the environmental vulnerabilities encountered in the area of analysis of 1 km., and the potential influence of the various risks. The influence of the plants Versalis and IES always result very high, because they both detain different kind of substances (toxic, flammable, dangerous for the environment) that can consequently affect different types of vulnerabilities.

Extreme vulnerability elements:	***Industrial risk***	***Flood risk***	***Seismic risk***	***Climate***
Protected area SIC/ZPS Vallazza and Mincio coastal banks belonging to Mincio protected park (both included in the 500 m. buffer zone of Versalis and Ies)	HIGH INFLUENCE	The possible impact of a flood on these areas could be considered MODERATE; they are naturally predisposed to flood.	REDUCED INFLUENCE	MODERATE INFLUENCE
300 m. protected area generated by the Inferior lake (included in IES buffer zone)	FROM MODERATE TO HIGH INFLUENCE	MODERATE INFLUENCE (on the built landscape)	MODERATE INFLUENCE (on the built landscape)	REDUCED INFLUENCE

Relevant vulnerability elements:	*Industrial risk*	*Flood risk*	*Seismic risk*	*Climate*
Wooded areas pertaining to Mincio park included both in Ies and Versalis buffer zones	HIGH INFLUENCE	REDUCED INFLUENCE	REDUCED INFLUENCE	MODERATE INFLUENCE
Area subjected to hydrogeological restrictions ex l.r. 45/1989: coastal banks of Mincio River	REDUCED INFLUENCE	HIGH INFLUENCE	HIGH INFLUENCE (Z4 soils in certain areas)	MODERATE INFLUENCE
Mincio river and the lakes constitutes a passageway for several wild species, in particular birds	HIGH INFLUENCE	REDUCED INFLUENCE	REDUCED INFLUENCE	REDUCED INFLUENCE
Many soils with Lnd Use Capacity 1 or 2 are included in the buffer zones	HIGH INFLUENCE	REDUCED INFLUENCE	REDUCED INFLUENCE	FROM MODERATE TO HIGH INFLUENCE
The vulnerability of the aquifers in the area is High *The level of the aquifer is between 4 m. and 8m.*	HIGH INFLUENCE	Mincio river and lakes are very close, and have high possibility to influence the underground water level	The fluctuation of the underground water could enhance the possibility of liquefaction phaenomena in case of earthquake	

3bis. ENVIRONMENTAL COMPATIBILITY

Sapio and Sol are plants connoted by the presence of flammable substances, that do not overcome the alert threshold; no environmental elements (like woods or architectural heritage) vulnerable to energetic events were found in their proximity, therefore they can be considered compatible.
The highest influence on the vulnerable environmental elements of the area Lunetta-Frassino is associated to the presence of the industries Ies and Versalis, whose interaction with the Natural risks can widen the risk of pollution. In fact, even if the estimated level of interaction is quite low, the simulations with HSSM demonstrated that minor incidents to the tanks provoked by an external event (damage state R3 → 1 cm hole of release) could easily bring to dispersion of pollutant in the aquifer, a situation that is confirmed by the current state of severe pollution of the area. An evident environmental incompatibility is therefore associated to these plants; the current

protective measures adopted (i.e. hydraulic barrier) seem to be not sufficient to face this situation. The adoption of the measures recommended by Turin province Guidelines should be verified by the Municipality; some integration could be required to the plant. Monitoring and plans for the recovery are currently on course for the procedures related to the national Site of Recovery, leaded by the Ministry for the Environment. They can be considered as sufficient, even if the most adequate procedure to avoid the continuation of the pollution should be the complete impermeabilization of the storage parks and pipelines paths; since this is a costly operation, it could be at least proposed for the tanks and pipelines that transport the substances whose presence still result further over the thresholds in the surveys campaign (like i.e. benzene).

Chapter 5

Case study 2

5.1 Introduction

The second case study analysed is a small town in the Piedmont region; it allowed taking into account risks produced by sources considered as "minor" or “secondary”; these risks, in some cases neglected or not accurately described in the existing sectorial plans, demonstrated to have a relevant impact on the municipal territory, therefore a wider analysis of their possible interactions was needed.
A Seveso plant was identified on the Municipal territory by the Regional authorities: it was an abandoned factory, closed for not being compliant with the requests for the Environmental Authorization – Autorizzazione Integrata Ambientale (AIA). No proved recovery operations were undertaken; neither the Municipality was able to verify if the building were secured or not. Other two potential Seveso plants not identified by Piedmont Region were found: both detained a quantity of hazardous substances higher than the thresholds established by Annex I of the Legislative Decree 105/2015. Other factories, even if below the Seveso thresholds, were analysed because they employed or stored of toxic substances and substances dangerous for the environment in vulnerable areas. No one of these plants was subjected to any specific regulations related to risk assessment.

The particular hydrologic and morphologic condition of the case study made the presence of these industries potentially incompatible; indeed, the town rises on a flat land area connoted by high vulnerability due to flood events. The flood problem is not provoked here by a major river, but by a network of secondary artificial canals and creeks, for which no maintenance was carried out across the years. More specifically, the Municipality, together with the adjacent ones, rises on a mega alluvial fan (**Figure 44**) crossed by a large number of irrigation canals. The increasing urbanization and the industrialization brought to the abandon of the canals - which in many cases were covered - and to the complete waterproofing of areas formerly destined to agriculture and farming activities. Consequently, the hydric system is currently no more able to drain the water surplus, and during intense rain events, it produces floods that affect the entire fan.
During Piedmont major flood events in 1994, 2004, 2008, the areas affected by flood in the Case study area were definitely wider than those identified by (A.D.B.Po et al, 2016): this plan mapped the flooding areas generated by one hydric element, but the minor hydrographic

network provoked unforeseen overflows in areas that were unmapped. Even if the water reached moderate heights (between 30 cm and 80 cm.), this was sufficient to cause several damages.

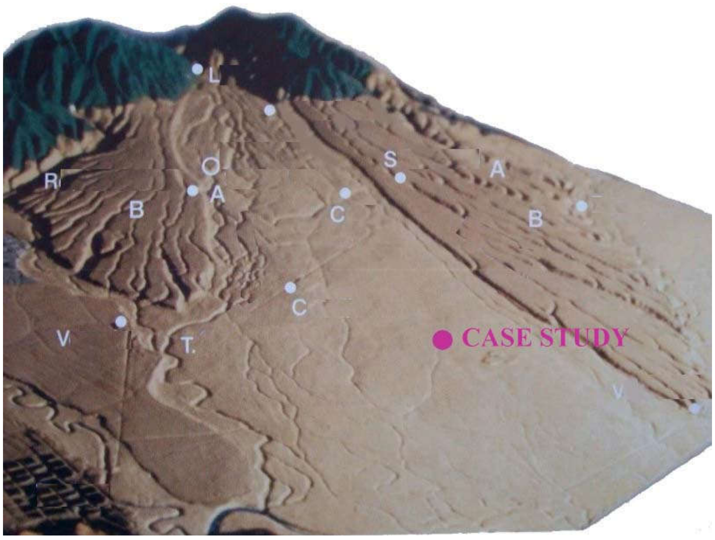


Figure 44: Mega-alluvial fan (Provincia di Torino, 2009)

The relation between industries and nature obviously is not unidirectional: flood can represent a problem for the factories, but the plants constitute a high risk for the environment too. The alluvial fan is characterized by soils constituted by sand and sinters with an extremely high permeability; in the area of the case study, the phreatic waters can be found within 0 and 3 meters from the ground level. This means that the aquifer is extremely vulnerable to industrial pollution.

In the end, the risk for Case study 2 is produced on one side by industries that are not subjected neither to Seveso regulation nor to the Ministerial decree 09/05/2001, and on the other side by canals, which are not taken into account in the Flood sectorial plan. Therefore, the application of the methodology could constitute a helpful step to better describe the actual risk and define possible preventive measures.

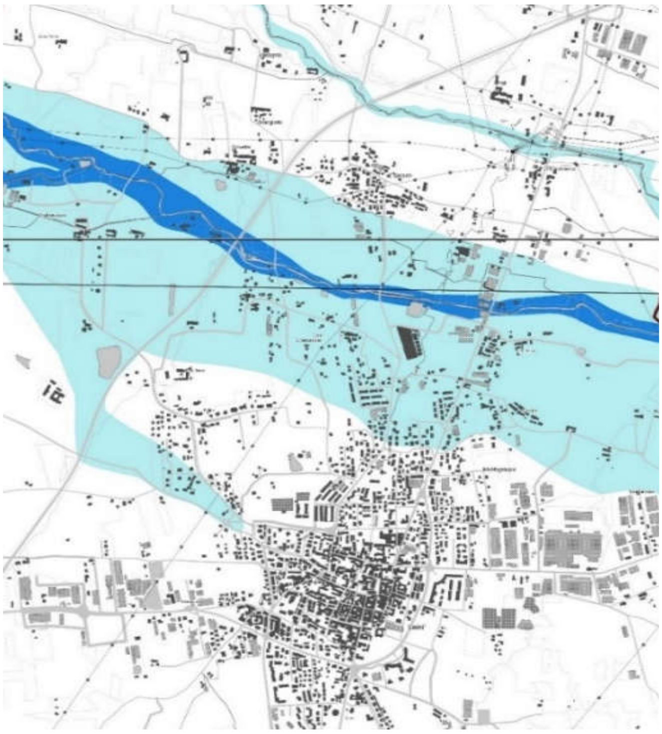


Figure 45: Flooding buffer-zone of *Creek β*, defined by (A.D.B.Po et, al 2016).

5.2. Hazard characterization

The following paragraphs describe the characteristics of the Flood and Industrial hazards; in comparison to Mantua (Case Study 1), less information was available, because of the "minor" features of the hazards themselves. The seismic hazard was not taken into account because the entire Municipal territory was connoted by Class 4, corresponding to a "Negligible" value. The collection phase was autonomously realized by the Candidate on the basis of:

- For Flood → Piano Gestione del Rischio alluvioni - Plan for the evaluation and management of flood hazard (A.D.B.P.O., 2016) and (A.D.B.Po et al., 2016), surveys of the flood events from 1994 to 1996 (Regione Piemonte, 1998), feasibility studies issued by (Politecnico di Torino, 2009 and (Provincia di Torino, 2009), studies on the secondary water network by the Municipalities.
- For Industry → E.R.I.R. draft documents (2015)

5.2.1. Flood hazard

Case study 2 rises on a mega-alluvial fan, that starts from the left side of *River α* and is delimited on its east portion by *Creek β*; **Figure 46** shows the area examined. The alluvial fan occupies 174 km^2, and is mostly constituted by flat land; during the years, many irrigation canals were derived from river to support the development of agriculture. These canals flow towards East and South and constitute a dense network which provide water to the fields. The return of the water to *River α* was not foreseen, because the main function of the canals was to water the crops; therefore, some of them flow into *River γ*, but the majority simply end in the meadows.

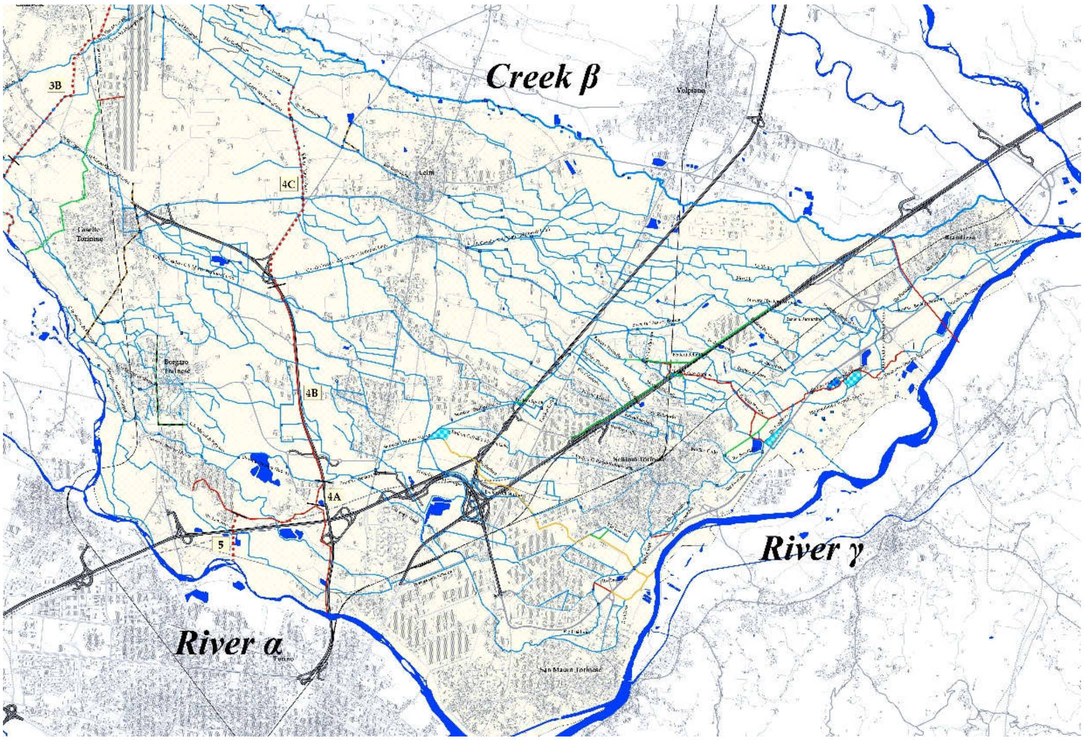


Figure 46: Minor hydraulic network between *River α* and *Creek β*

In ancient times, when the urbanised areas where limited, the hydraulic framework could bear also intense rainy events; the canals were constantly monitored, therefore the water intakes on α river were immediately closed; also, in case of overflowing, the water was free to run into meadows and crops without provoking serious damages. However, starting from 1950, a relevant part of the land was urbanised and therefore made waterproof; furthermore, the construction of transporting routes and other infrastructures created artificial barriers to the water overflowing. All these infrastructures were equipped with systems of drainage for the rainy water, which ended conferring other water to the irrigation canals.

Nowadays, the hydraulic system is unable to grant the security in case of intense rainy events; the overflowing of canals and creeks can provoke damages to the towns, as demonstrated by the floods occurred in 1994, 2000 and 2008. In particular, during the flooding event that took place between the 4th and the 7th November 1994, β creek overflowed in several points. Even if buffer zones connoted by low-medium dangerousness Em (return-times 300-500 years) were identified, the flood covered wider areas, with features typical of the 200 return times events, for rainfall lasting 24 hours. The conformation of β creek was found not adequate for channelling peak discharges, even for reduced water quantities (Politecnico di Torino, 2009).

After 1994 event, the Municipalities belonging to *Creek β* basin decided to constitute a Consortium for the prevention and control of the flood risk. In 1998, a General Plan for fitting-out works to *Creek β* was released by the Consortium. Three main activities were planned: 1) the execution of a floodway canal upstream, to address the exceeding flow of *Creek β* to *River α*; 2) the execution of one overflow basin downstream; 3) the execution of two overflow basins in the last portion of the creek. In 2000, the floodway canal started operating; during the same years, some activities of river bank defense and riverbed restoration were executed.

In 2009, two significant coordinated studies were executed on *Creek β* and the secondary network, to identify the most urgent and convenient interventions to be executed: the first, realized by (Politecnico di Torino, 2009) tested the efficacy of the overflow basin designed; the second, executed by (Provincia di Torino, 2009) identified the artefacts and activities to be carried out to reduce the flood risk caused by the canals.

The following hazard characterization is extracted from the two studies previously mentioned.

STRENGTHENING EFFECTS:

Creek β → β riverbed is connoted by a reduced width, while the riverbank has a limited height; these characteristics are uniformly distributed along all the creek path. In particular, these hydraulic inefficiencies are more frequent in correspondence to the crossing artefacts of the urbanized areas, where the riverbanks can result also lower than 2 m. The presence of bridges, combined with the scarce width of the riverbed, make *Creek β* unable to bear peak discharges, even in case of reduced flows like 30 m^3/s.

The floodway canal built in 2000 partially contributes in reducing the volume of peak discharges, but the residuals transported by *Creek β* progressively obstruct its intake, and it has very low riverbanks. Therefore, for rate flows equal to 40-45 m^3/s, the hydric section of the floodway results inadequate, producing a severe hydraulic risk.

The portion of *Creek β* in the territory of the second case study is connoted by fluvial terraces with height between 1 and 3 m; the riverbed has scarce slope (<1%). 5 critical sections (crossing bridges) were identified, with maximum tolerable rate-flows of 20 m^3/s; 40 m^3/s; 40 m^3/s; 10 m^3/s and 50 m^3/s.

In case of intense rate-flow, *Creek β* can feed its tributaries (the secondary channels network).
Channels network → in addition to the massive urbanization and the increasing land waterproofing, other factors favour the overflowing of the network of irrigation canals:

- the network is not equipped with flood-ways able to return the exceeding water into *River α*. In addition, the majority of water intakes from *River α* is not controllable, because they are not equipped with any shutter.
- the entire network has a reduced slope, aggravated by the state of scarce or non-existent maintenance. These problems, summed up with the presence of extended portions covered or diverted to comply with the building needs, obviously reduce the flowing sections, facilitating the overflowing.
- the raised roads, often perpendicular to the flowing direction of the network, act as a barrier towards the expansion of the waters, enhancing their level.

The Municipalities as Case Study 2, located in the downstream portion of the alluvial fan, constitute the most fragile part of the territory, because they collect the water arriving from the entire fan.

HISTORICAL EVENTS
Creek β → *Creek β* was responsible of several inundations, coinciding with intense rainy events; the floods were characterized by low energy, with height between 60-100 m. The western portion of Case study 2 territory was interested by *Creek β* flooding.
Channels network → Both in 1994 and 2008, the secondary network provoked flood wider than those reported in P.A.I plan: a covered canal was responsible of the inundation of the city centre. Other extensive flooding interested the southern areas of the Municipality, interesting a wide industrial area. **Figure 47** (Provincia di Torino, 2009) reports the areas interested by flood in 1994, 2000 and 2008 (blue and light blue areas); the buffer zones of *Creek β* identified by P.A.I. are represented with yellow color.
In spite of the detailed surveys realize both by Piedmont region and by the studies promoted by the Consortium, the new Piano Gestione del Rischio alluvioni (AD.B.P.O, 2016) that substituted P.A.I. in compliance with the European directive, reported only the buffer zones of *Creek β* (see **Figure 45**). The dangerousness of the secondary water network and its combined effects with *Creek β* in case of intense rainy events were not analyzed, and the areas interested by the floods in 1994, 2000 and 2008 were not mapped.

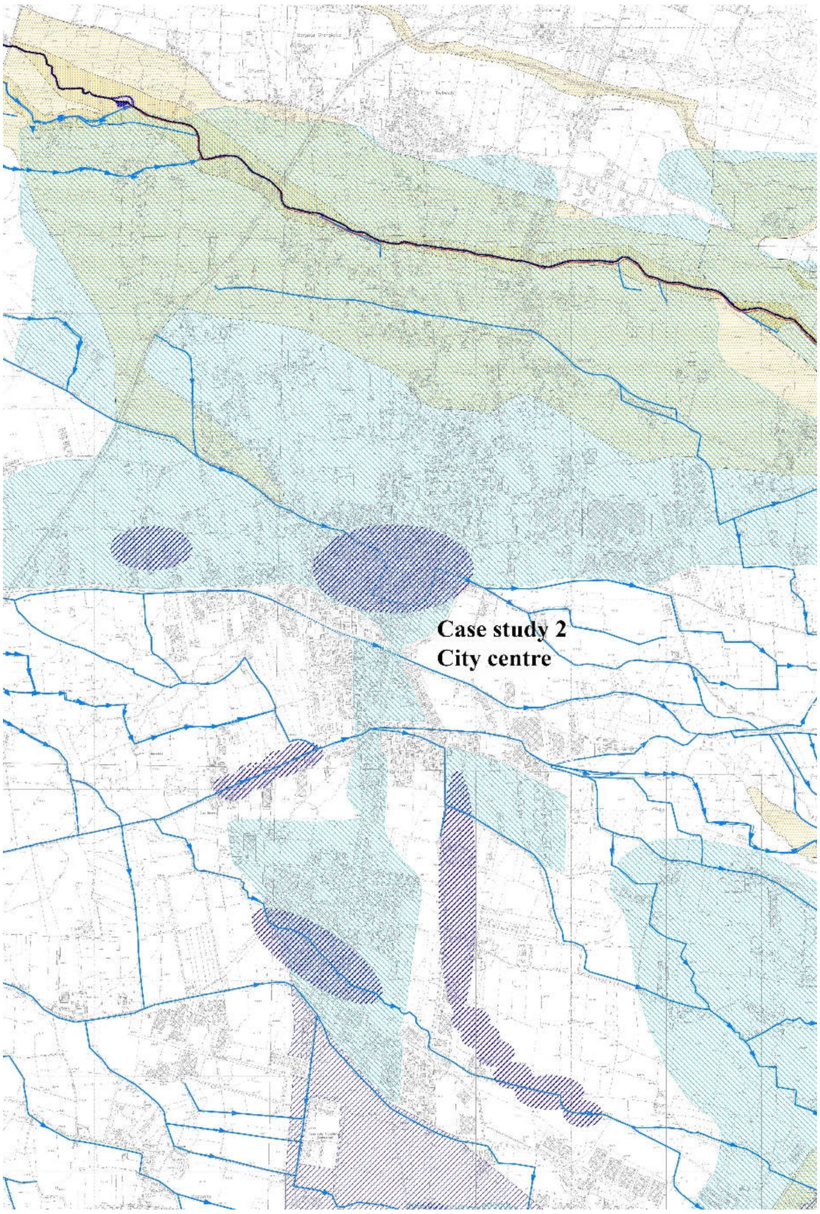


Figure 47: Case-study 2 - regional survey of the areas interested by flood

PROTECTION MEASURES:

Creek β → with reference to the interventions programmed by the Consortium in 1998, only the upstream floodway canal was executed.

The preliminary plan for the realization of the first overflow basin is currently on progress. However, (Politecnico di Torino, 2009) demonstrated that the advantages coming from the construction of this basin have moderate effects on the farer downstream portions of the creek. The intervention was considered effective, but not sufficient to grant the security along the entire path of the creek. According to Politecnico experts, only the execution of a detailed hydraulic-hydrologic model of the entire basin could allow to program coordinated interventions to grant protection from floods.

Channels network → The feasibility study by Provincia di Torino, 2009 proposed the realization of 5 floodway canals to return the exceeding waters of the secondary network into *River α (*one in the territory of Case-study 2), but no one of the above-mentioned interventions was executed till now.

The need of further protection measures and studies is advocated by the new Piano Gestione del Rischio alluvioni (A.D.B.Po, 2016): the following measures were identified:

Table 54: Measures suggested by (A.D.B.Po, 2016):

Objectives	***Measure name***	***Authority in charge***	***Progress***	***Priority***
IMPROVING THE RISK KNOWLEDGE – Updating and improving the knowledge related to flood hazard and risk	Completion of the hydraulic study for the entire creek, to define the criticalities and the priority interventions.	Consortium for *creek β*	Ongoing constructio n	High
IMPROVING THE PERFORMANCE OF THE EXISTING DEFENCE ELEMENTS – Execution of interventions for the control of flooding through overflow basins	Planning and execution of the overflow basin		Ongoing constructio n	High
GRANT MAJOR EXPANSION AREAS TO RIVERS – Preserving side areas of the rivers for expansion	Proposal of new buffer zones for the creek, for the risk reduction in the Municipalities	Piedmont region	Not started	Critical

Ratings assignation

As reminded in the previous chapters, the rating assignation to rivers and creeks requires to identify portions connoted by homogenous characteristics and behaviour.

As far as it concerns *Creek β*, the first partition adopted, like in Mantua, was: “Upstream not-municipal portion” and “Municipal portion”. The latter was treated as a unique element because (Politecnico di Torino, 2009) identified the plain portion of the creek as a unique sub-basin, uniformly connoted by very small slopes of both riversides and river course.

For H.E. ratings, the flood buffer zones identified by the Piano di Gestione del Rischio Alluvioni (A.D.B.Po, 2016) were taken into account: the areas with higher probability of flood obtained a higher rating. However, the several floods events of the last 20 years showed return times not exactly compliant with those defined by the sectorial flood plans, in particular for medium-low flood hazard. The study by (Politecnico di Torino, 2009) reported that the 1994 flood had an intensity equal to the events with 200 years return time, also in areas where the flood was considered rare (300-500 years). This discrepancy was also recognized by (A.D.B.Po, 2016) - see **Table 54**.

The inadequacy of the actual flood buffer zones was kept into account in the rating assignation: the areas with Very high flood hazard (Ee) and High flood hazard (Eb) respectively obtained 3 and 2, as indicated in **Table 7** but the rating of the areas with medium-low flood hazard (Em) was raised to 2, instead of 1.

In relation to the secondary network, given the complexity of the interactions and interdependencies between the canals, it was decided to consider them as a unique element, also because all the main canals identified were equally responsible of several overflowing. (A.D.B.Po, 2016) did not assign buffer zones, therefore only the case history could help in attributing the rating: the hydraulic secondary network participated in all the major flood events of the last 20 years, and in particular in 2008 it was interested by a proper breakdown, according to (Politecnico di Torino, 2009). For this reason, a medium value = 2, corresponding to that of a flood buffer zone "*High flood hazard Eb (100-200 yrs) = not frequent flood scenario*" was assigned.

Table 55: Ratings assignation for Case-study 2 water-network

	[SE] Strengthening effects		**[PM] Protection measures**	
Element considered	*Interactions with other elements of the water network*	*Criticalities of the hydraulic artefacts*	*Hydraulic artefacts / levees etc.*	**[HE] Historical events**
Creek β (upstream not-municipal portion)	Possibilities of inverted flow from the creek main course to the tributaries or upstream.	Portions with riverbanks height < 2 m. Reduced width of the riverbed Critical sections due to crossing bridges uniformly distributed along the river course Floodway canal: obstruction due to scarce maintenance inadequate hydric section for peak discharge	Unique protection artefact = floodway canal. The realization of the overflow basin could enhance the security of the upper course of *Creek β*, but its effect decreases for the farthest portions of the creek.	3 flood buffer zones 1) Very high flood hazard Ee (20-50 yrs) = frequent flood scenario 2) High flood hazard Eb (100-200 yrs) = not frequent flood scenario 3) Medium-low flood hazard Em (300-500 yrs) = rare flood scenario. In the last 20 years, several important flood events occurred; the one in 1994 reached an intensity correspondent to return times of 200 yrs, even in areas where return time = 300, 500 yrs (Em).
SCORE	3		Depending on the portion analyzed	**Em 2 Eb 2 Ee 3**
Creek β creek	Possible interactions	5 critical sections (bridges)	2 areas for flood expansion and a stone riverbank	2 flood buffer zones: 2) Very high flood

Element considered	**[SE] Strengthening effects**		**[PM] Protection measures**	**[HE] Historical events**
	Interactions with other elements of the water network	*Criticalities of the hydraulic artefacts*	*Hydraulic artefacts / levees etc.*	
(municipal portion)	with other canals	producing hydric insufficiencies were identified.	were planned; only the riverbank was realized, after the flood event in 2000.	hazard Ee (20-50 yrs) = frequent flood scenario 3) Medium-low flood hazard Em (300-500 yrs) = rare flood scenario. In the buffer zone classified as Em, in 1994 *Creek β* overflowed, reaching municipal sectors outside the buffer zones. The water height reached 1 m.
SCORE	**3**		**0**	**Em 2 Ee 3**
Secondary municipal water network, right side of Creek β	Water intakes from *River* α cannot be regulated; *Creek β* can act as a feeder of the channels network during flood events	Geomorphologic features: aquifer close to the ground level, reduced slope of the soil and canals Scarce maintenance: obstructions, riverbeds not defined, inadequate crossing artefacts Forcing of the network due to building needs: covered portions, diversions (even with 90° curves) Raised roads block the natural flow of the hydric network	5 floodway channels were planned to return the exceeding flows to *River* α, but no interventions were executed.	No flood buffer zones and return times are assigned to the secondary network, except for a little portion in an agricultural area, that is classified as Em. However, the network provoked overflowing in 1994, 2000 e 2008, reaching water heights between 30-80 cm in the city centre, and in southern and western municipal areas.
SCORE	**3**		**0**	**2**

5.2.2. Industrial hazard

This paragraph introduces the description of the hazardous plants identified for Case study 2; as previously stated, only one Seveso plant was present; other 8 potential dangerous plants were investigated and identified thanks to the questionnaire reported in Table 22.
E.R.I.R. was drafted during the initial stage of application of the new Seveso legislative decree (no. 05/2015), which introduced modifications in the parameters for Seveso classification; therefore, the investigation on the non-Seveso plants pointed out some Companies not yet in line with the new requirements.

The analysis of the Sub-threshold Seveso plants introduced some uncertainties for the ratings assignation phase because, in spite of the compilation of the questionnaire, some essential information related to case history, storage conditions and preventive and protection measures were missing. In example, in relation to the macro-category Historical Events, the surveys realized after the floods in 1994, 2000 and 2008 demonstrated that the majority of the plants was affected; but no information was available on the effects provoked. Also, no data on the previous accidents of the plants were available.
Therefore, a common indicative value of 1,5, corresponding to a low-medium impact, was assigned to the plants interested by the flood events. In fact, since the registered water heights were not so relevant, it could be possible that the damages suffered by the factories were limited. A negligible H.E. value, equal to 0,5, was given to the plants not hit by flood events located in proximity of canals, to take into account the possibility overflowing water.

The ratings for S.E. and P.M. were assigned on the basis of the information provided by the owners in the questionnaires, and of the data contained in the procedures for the release of the Environmental authorization - AIA. Google maps and Google street view were employed to check if outdoor storage was present, if there were items like tanks more exposed to NaTech risk, which delimiting systems were adopted for the perimeter (full wall or railings), and the presence of waterproof apron.
Unfortunately, the environmental analysis on soil and water required by Turin province guidelines is mandatory for Seveso sub-thresholds plants and the non-Seveso plant only in case of modifications with risk increase; therefore, it is not possible to require this information in a "level 0" condition for the existing plants.
Consequently, the ratings assigned to the macro-category P.M. were maintained generally low because of cautionary reasons.

'A' (Seveso plant)
'A'plant was closed in 2011, after several recalling from the authorities aimed at obtaining the integration of unavoidable safety, preventive and protective measures. After the closure, the Municipality required to the plant owner to secure the factory, but this was never verified on site. For this reason, the plant was still included by Piedmont region in its Seveso plants regional list.

The information on the substances detained and the scenarios were extracted from the Emergency plan (Prefettura di Torino, 2007), the Environmental Authorization - AIA (Provincia di Torino, 2007) and the Notification of the plant. No external damage areas were identified in 2007; however, the risk analysis could be too obsolete, considering the actual conditions of abandon and absence of monitoring.

Rating assignation

S.E. → Plant 'A' represents the most hazardous plant, mainly for its permanent condition of unmanned abandon. The plant still has 10 underground basins, whose conditions would require an on-site inspection; some of them were not equipped with any containment system. Rating assigned to S.E. = 3
H.E. → Plant 'A' is included in an area of potential overflowing of *Creek β*, identified with medium-moderate dangerousness (Em) by the Piano di Gestione del Rischio alluvioni. The plant was reached by the water in 1994. The indicative value for H.E. = 1,5 was assigned.
P.M. → the documents related to AIA authorization demonstrated that the measures adopted were completely inadequate, and this problem brought to the closure of the activity. The information is not sufficient to establish if there are some NaTech measures. Rating assigned to P.M. = 0

Table 56: Ratings assignation for plant 'A'

[S.E.] STRENGTHENING EFFECTS				***[M.P.] PROTECTION MEASURES***		***[H.E.] HISTORICAL EVENTS***
Assets / items with potential NaTech risk		***Hazardous substances***	***Credible events / scenarios RDS***	***Protection measure related to the item***	***Protection measures for Na-tech / pollution events***	
Item type	***Item description***					
5 underground basins	Overall capacity: 296, 1 t.	(T, N)	No external scenarios identified. Factory closed, situation not monitored.	Required level alarms for basins, measures for the safe disposal of rainy water. Implementation not verifiable. Factory closed for its not compliance.	POLLUTION: measures for environmental protection not adopted NATECH: information not available	No information on accidents case history; plant closed under unsafe conditions. EVENTS: the area is included in the area classified with medium-moderate dangerousness (Em) by the Piano di Gestione del Rischio alluvioni. It was interested by the flood of 1994 .
5 underground basins	Overall capacity: 180,4 t.	(N)				
Storage barrels	3,5 t. + 1	(T, N)				
SCORE						
3				**0**		**1,5**

'B' (potential Seveso plant)

Plant 'B' hosts 30 reactors with capacities from 4 to 25 m^3. Processes with temperature > 100°C and pressure > 10 bar are carried out; mobile firefighting systems and systems for the monitoring and abatement of gaseous discharges are adopted.

The plant has different collection lines for process and rainy water, respectively addressed to the Municipal drain and to the canal adjacent to the north border. Retaining basins for possible leakages are present in the working and pouring areas; an emergency basin before the discharge is also present.

Plant 'B' is subjected to Environmental Authorization - AIA, therefore it adopted several protection and preventive measures, like i.e. for the tanks, the implementation of high level alarms, and the construction of dedicated containment basins.

Plant 'B' can be considered a potential Seveso plant because the quantity of substances categorized as H2 - Acute toxic overcomes the Lower-tier requirements of Annex I of the Legislative decree 105/2015. In addition, the substances classified as hazardous for the environment overcome the 20% of the Lower-tier requirements of Annex I of the Legislative decree 105/2015, therefore Plant 'B' is also an environmental hazardous Sub-threshold plant.

Rating assignation

S.E. → As Seveso plant, Plant 'B' should be subjected to the commitments of the Legislative decree 105/2015. Plant 'B' storage is located in its external apron; several tanks of hazardous substances are placed here, without a cover, and can therefore be exposed to extreme climate events. Turin province required, for the release of the Environmental Authorization - AIA, high-level alarms and basins of containment for the tanks with hazardous substances, however the implementation of these measures cannot be verified. Considering the presence of items potentially subjected to NaTech and the absence of specific Seveso regulations, the rating assigned for S.E. = 2,8

H.E. → Plant 'B' was interested by the flooding of the adjacent canal in 1994 and 2008; however, the heights of the water and the damages provoked are unknown. The indicative rating assigned was = 1,5

P.M. → Adoption of the measures of Turin Province guideline and of NaTech measures not verifiable. The Plant is equipped with separated lines for rainy and process water; the Plan for Rainy water, requested by Piedmont region, was fully implemented. The plant has a drain in the adjacent canal, whose condition should be more investigated. For these reasons, the rating assigned = -1,8

Table 57: Ratings assignation for Plant 'B'

[S.E.] STRENGTHENING EFFECTS				*[M.P.] PROTECTION MEASURES*		*[H.E.] HISTORICAL EVENTS*
Assets / items with potential NaTech risk		*Hazardous substances*	*Credible events / scenarios RDS*	*Protection measure related to the item*	*Protection measures for Na-tech / pollution events*	
Item type	*Item description*					
Tanks	Overall quantity: 27 t	(T)	Quantity of toxic substances > lower tier Legislative Decree 105/2015. No Safety report. Outdoor unprotected storage areas, some tanks seem to have the containment basin.	AIA authority recommended adopting for the tanks: level alarms, containment basins.	Plant subjected to AIA; Plan for the management of rainy water. Collection system for accidental spills; different drainage lines for rainy and process water; emergency basin. NaTech: Information n.a.	No information on the plant accidents are available. The plant was repeatedly interest by the flooding of the adjacent canal.
	Overall quantity: 50 t	(T)				
	Overall quantity = 25 t.	(F, N)				
	Overall quantity = 27 t.	(F)				
Bags	Overall quantity = 22 t.	(F)				
SCORE						
2,8				**-1,8**		**1,5**

'C' (potential Seveso plant)

Plant 'C' employs processes with temperature > 100°C. The plant is subjected to Environmental Authorization - AIA; in compliance with this regulation, the plant has systems for the monitoring and abatement of gaseous discharges; retaining basins for possible leakages in the working and pouring areas; waterproof aprons, and separated drain lines for the rainy and process waters. The deposition basin is equipped with a shutter that allows interrupting the flow towards the Municipal drain in case of dispersion of pollutants. The quantity of substances categorized as H1 - Acute toxic overcome the Lower-tier requirements of Annex I of the Legislative decree 105/2015.

Rating assignation

S.E. → the plant overcame the lower tier-requirements of Annex I of the Legislative decree 105/2015; it should be subjected to the commitments of the Legislative decree 105/2015, which were not respected. Even if the quantity of substances detained is not particularly significant, the absence of specific Seveso regulations leads to assign a medium-high rate for S.E. = 2,5

H.E. → Plant 'C' was not interested by any major floods, but it is near to two irrigation canals. Since the entire network of irrigation channels has problems of scarce maintenance, a possible flood cannot be completely excluded. A very low rating was assigned to keep into account this possibility = 0,5.

P.M. → Adoption of the measures of Turin Province guideline and NaTech measures not verified for lack of information. The Plant is equipped with separated lines for rainy and process water, the discharge to the Municipal sewer can be controlled with a shutter, and the Plan for Rainy water requested by Piedmont region was fully implemented. Also, the apron is waterproof. For these reasons, the rating assigned = -2

Table 58: Ratings assignation for plant 'C'

[S.E.] STRENGTHENING EFFECTS				*[M.P.] PROTECTION MEASURES*		*[H.E.] HISTORICAL EVENTS*
Assets / items with potential NaTech risk		*Hazardous substances*	*Credible events / scenarios RDS*	*Protection measure related to the item*	*Protection measures for Na-tech / pollution events*	
Item type	*Item description*					
Storage barrels	Overall quantity: 4,6 t	(T)	Quantity of toxic substances > lower tier Legislative Decree 105/2015. No Safety report.	Waterproof pavements; the storage of raw materials and wastes is under cover, and the area for trunks loading and unloading too.	Plant subjected to AIA; Plan for the management of rainy water. Collection system for accidental spills; different drainage lines for rainy and process water; sedimentation basin, shutter. NaTech: information n.a.	No information on the plant accidents are available. EVENTS: the area is very close to those interested by the flood in 1994 and 2008.
	Overall quantity: 5 t	(T, N)				
	Overall quantity = 0,2 t.	(T)				
	Overall quantity = 0,8 t.	(T, F)				
	Overall quantity =0,7 t.	(F)				
	Overall quantity = 17, 4 t.	(N)				
	Overall quantity = 0,3 t.	(N)				
	Overall quantity = 1 t.	(F)				
Bags	Overall quantity = 5 t.	(F)				
SCORE						
2,5				**-2**		**0,5**

'D' (Seveso sub-threshold)

Plant 'D' is equipped with mobile and fixed firefighting systems, systems for the monitoring and abatement of gaseous discharges; retaining basins for possible leakages in the working and pouring areas; waterproof aprons. Process cooling water and rainy water are addressed to a unique authorized discharge.

Plant 'D' is a toxic Sub-threshold plant because the quantity of substances classified as Acute toxic overcome the 20% of the Lower-tier requirements of Annex I of the Legislative decree 105/2015.

Rating assignation

S.E. → The plant is a Seveso sub-threshold for category H1 (Acute toxicity). No outside storage is present. The rating assigned is medium, tending to low = 2

H.E. → Plant 'D' was interested by the flooding in 1994 and 2008. The indicative rating assigned was = 1,5

P.M. → The adoption of the measures of Turin Province guideline, and of the NaTech measures cannot be verified. The plant is equipped with retaining basins for possible leakages in the working and pouring areas; waterproof aprons. Process cooling water and rainy water are addressed to a unique authorized discharge. Due to the uncertainty related to the measures for the environmental protection, the rating assigned = -1,5

Table 59: Ratings assignation for Plant 'D'

[S.E.] STRENGTHENING EFFECTS				***[M.P.] PROTECTION MEASURES***		***[H.E.] HISTORICAL EVENTS***
Assets / items with potential NaTech risk		***Hazardous substances***	***Credible events / scenarios RDS***	***Protection measure related to the item***	***Protection measures for Na-tech / pollution events***	
Item type	***Item description***					
Tank on containment basin	Overall quantity: 2,8 t	(T)	The plant is not subjected to the Legislative decree 105/2015; no external storage	Waterproof storage areas	Collection system for accidental spills. Rainy and process water addressed to the public sewer. NaTech: Information n.a.	No information on the plant accidents are available. EVENTS: the area was interested by the flood in 1994 and 2008.
	Overall quantity: 3,7 t	(N)				
Tins in a fireproof box	Overall quantity: 0,1 t	(F,N)				
	Overall quantity: 0,19 t.	(F)				
SCORE						
		2			**-1,5**	**0,5**

'E' (Seveso sub-threshold)

Plant 'E' is equipped with mobile firefighting systems, retaining basins for possible leakages in the working and pouring areas; waterproof aprons. It owes a dedicated drain line for rainy water, that is discharged into a canal adjacent to the plant.

Plant 'E' is classified as an environmental hazardous Sub-threshold plant, because the quantity of substances classified as hazardous for the environment overcome the 20% of the Lower-tier requirements of Annex 1 of the Legislative decree 105/2015.

<u>Rating assignation</u>

S.E. → The plant is a Seveso sub-threshold for category E1 (Environmental hazard). Outside, uncovered storage is present, that could be subjected to effects of extreme climate events or floods. The rating assigned is = 2,5

H.E. → Plant 'E' was not interested by any major floods, but it is near to one irrigation canal. Since the entire network of irrigation channels has problems of scarce maintenance, it cannot be completely excluded a possible flood. A very low rating was assigned to keep into account this possibility = 0,5

P.M. → The adoption of the measures of Turin Province guideline and of NaTech measures cannot be verified. The plant is equipped with retaining basins for possible leakages in the working and pouring areas; waterproof aprons. Rainy water is addressed to an adjacent canal. Due to the uncertainty related to the measures for the environmental protection, the rating assigned = -1

Table 60: Ratings assignation for Plant 'E'

[S.E.] STRENGTHENING EFFECTS				***[M.P.] PROTECTION MEASURES***		***[H.E.] HISTORICAL EVENTS***
Assets / items with potential NaTech risk		***Hazardous substances***	***Credible events / scenarios RDS***	***Protection measure related to the item***	***Protection measures for Na-tech / pollution events***	
Item type	***Item description***					
Bags	Overall quantity: 90 t	(N)	The plant is not subjected to the Legislative decree 105/2015. External covered storage of materials	waterproof storage areas	Collection system for accidental spills. Rainy water addressed to a channel. NATECH: Information not sufficient	No information on the plant accidents are available. EVENTS: the area is very close to those interested by the flood in 1994.
Tank	Overall quantity: 0,38 t.	(F,N)				
Underground tank	Overall quantity: 0,88 t.	(F)				
SCORE						
		2,5		**-1**		**0,5**

'F'

Plant 'F' has a surface of 70.000 m^2; 11.000 m^2 are dedicated to storage. The plant is subjected to Environmental Authorization - AIA.

The plant is equipped with mobile firefighting systems, systems for the monitoring and abatement of gaseous discharges; retaining basins for possible leakages in the working and pouring areas; waterproof aprons; drain line for the collection of rainy water with dedicated basin. Process water and rainy water are collected in a series of basins and discharged to the Municipal drain; a shutter allows stopping the flow in case of presence of pollutants. A portion of the rainy water is discharged in an adjacent canal.

<u>*Rating assignation*</u>

S.E. → Plant 'F' carries out an activity with high risk for the environmental matrixes. Also, there are items potentially exposed to NaTech risk, like opencast treatment basins. For these reasons, the rating assigned was = 2,8

H.E. → Plant 'F' was not interested by the last major floods. However, it is very close to an area of potential overflow classified as medium-moderate dangerous (Em), by the Piano di Gestione del Rischio alluvioni. Therefore, the indicative value = 0,5 was assigned.

P.M. → The adoption of the measures of Turin Province guideline and of the NaTech measures cannot be verified. However, the plant integrated all the AIA indications, and the discharge to the public sewer is controlled through a shutter. The value assigned was = - 1,5.

Table 61: Ratings assignation for Plant 'F'

[S.E.] STRENGTHENING EFFECTS				***[M.P.] PROTECTION MEASURES***		***[H.E.] HISTORICAL EVENTS***
Assets / items with potential NaTech risk		***Hazardous substances***	***Credible events / scenarios RDS***	***Protection measure related to the item***	***Protection measures for Na-tech / pollution events***	
Item type	***Item description***					
Tank on containment basin	Overall quantity: 5 t	(N)	The plant did not declare the quantities of the hazardous substances treated. Outdoor basin for the treatment of liquid wastes, surrounded by a not	Waterproof storage areas	Subjected to AIA; Plan for the Management of rainy water. Rainy and process water to the public sewer, after 3 collection and sedimentati	No information on the plant accidents are available. EVENTS: Plant close to an area classified with medium-moderate dangerousness (Em), or low dangerousness by P.G.R.A.

[S.E.] STRENGTHENING EFFECTS				*[M.P.] PROTECTION MEASURES*		*[H.E.] HISTORICAL EVENTS*
Assets / items with potential NaTech risk		*Hazardous substances*	*Credible events / scenarios RDS*	*Protection measure related to the item*	*Protection measures for Na-tech / pollution events*	
Item type	*Item description*					
	Overall quantity: 0,4 t	(N)	waterproof surface. Outdoor tanks		on basins, controlled through a shutter. Collection system for accidental spills. NaTech: Information n.a.	
SCORE						
2,8				**-1,5**		**0,5**

5.3. Assessment of the interactions

The industrial and flood characterizations made clear that Case-Study 2 is not interested by extremely high hazards; the risk derives from little lower-tier Seveso plants or Sub-threshold plants, and flood events with low energy. However, the interaction of plants, mostly detaining toxic and environmental hazardous substances, with the recurrent overflowing events could produce unexpected and severe conditions for people and environment, because of the lack of adequate protection and prevention measures. In order to verify possible impacts, the interaction tables were realized for each area where flood areas and plants overlay. **Figure 48** shows the location of the plants ‘A’, ‘B’, ‘C’, ‘D’, ‘E’, ‘F’.
Possible local extreme climate events were also taken into account, for their possible impact on industries and influence on flooding; they were rated according to the simplified approach exposed in Chapter 3.

The interaction assessment was carried out also for the plants that were never interested by flood (‘C’, ‘E’, ‘F’), because of a cautionary reason. In fact, these plants are close or adjacent to canals whose slope, maintenance and riverbed conditions are not different from those of the canals provoking the past overflowing. Future flood events could not be completely excluded. In this case, the following ratings were attributed to the FLOOD RISK: S.E. = 1, H.E. = 0, P.M. = 0; while to H.E. of the industries the value of =0,5 was assigned.

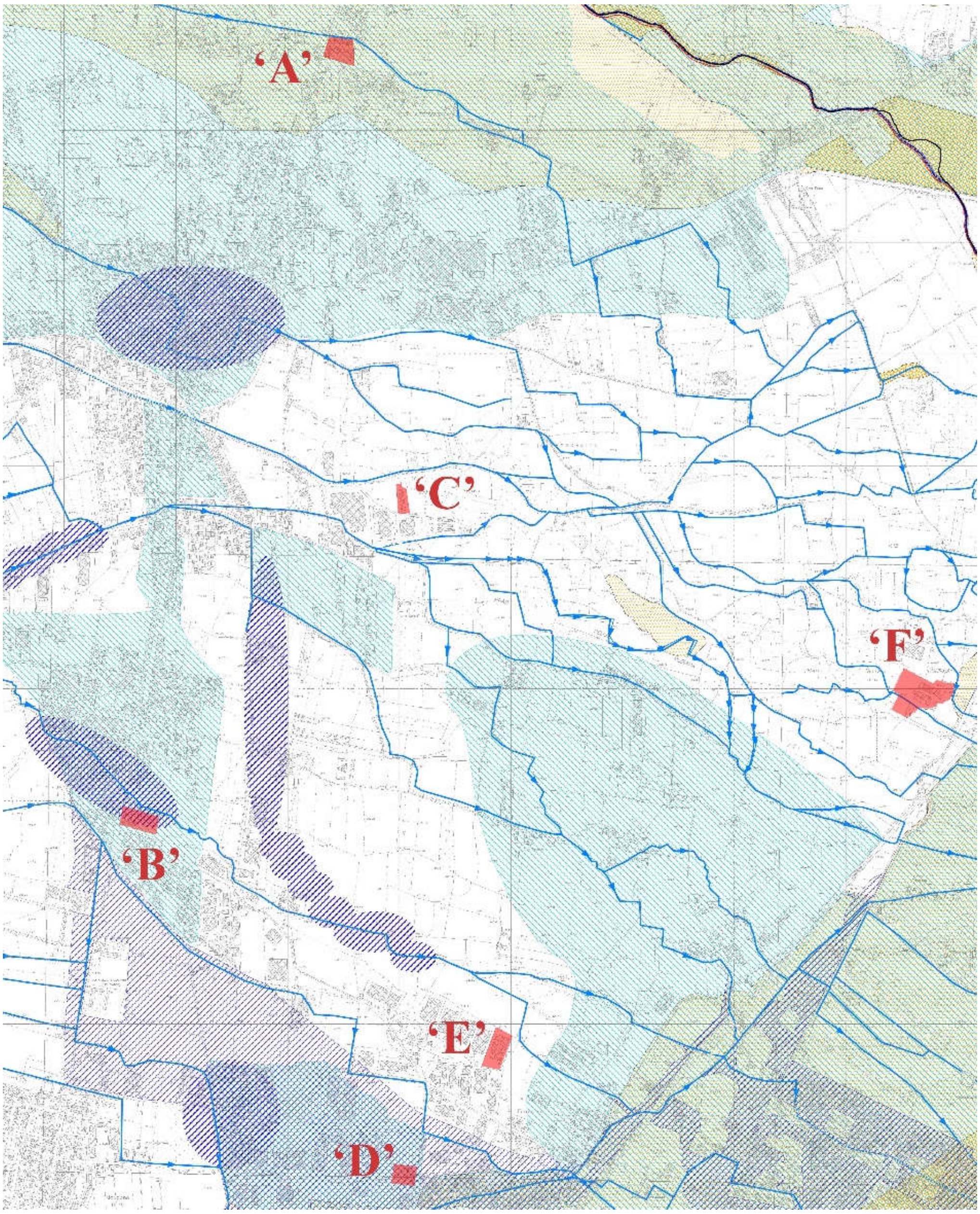


Figure 48: Areas for the assessment of the interaction ('A', 'B', 'D')

Table 62: Interaction tables for plants exposed to flood risk

Plant 'A' (Seveso)			FLOOD			Industrial			Climate		
			SE	HE	PM	SE	HE	PM	SE	HE	PM
			3	2	0	3	1,5	0	2	1	0
FLOOD	SE	3									
	HE	2		No interaction			***2,17***			No interaction	
	PM	0									
Industrial	SE	3									
	HE	1,5		No interaction			-			No interaction	
	PM	0									
Climate	SE	2									
	HE	1		1,83			1,67			No interaction	
	PM	0									

Plant 'B' (Potential Seveso)			FLOOD			Industrial			Climate		
			SE	HE	PM	SE	HE	PM	SE	HE	PM
			3	2	0	2,8	1,5	-1,8	2	1	0
FLOOD	SE	3									
	HE	2		No interaction			***1,98***			No interaction	
	PM	0									
Industrial	SE	2,8									
	HE	1,5		No interaction			-			No interaction	
	PM	-1,8									
Climate	SE	2									
	HE	1		1,83			1,48			No interaction	
	PM	0									

Plant 'D' (sub-threshold)			FLOOD			Industrial			Climate		
			SE	HE	PM	SE	SE	HE	PM	HE	SE
			3	2	0	2	1,5	-1,5	2	1	0
FLOOD	SE	3									
	HE	2		No interaction			**1,88**			No interaction	
	PM	0									
Industrial	SE	2									
	HE	1,5		No interaction			-			No interaction	
	PM	-1,5									
Climate	SE	2									
	HE	1		1,83			1,38			No interaction	
	PM	0									

Table 63: Interaction tables for plants not exposed to flood risk

Plant 'C' (potential Seveso)			FLOOD			Industrial			Climate		
			SE	HE	PM	SE	SE	HE	PM	HE	SE
			1	0	0	2,5	0,5	-2	2	1	0
FLOOD	SE	1									
	HE	0		No interaction			***0,58***			No interaction	
	PM	0									
Industrial	SE	2,5									
	HE	0,5		No interaction			-			No interaction	
	PM	-2									
Climate	SE	2									
	HE	1		0,83			1,08			No interaction	
	PM	0									

Plant 'E' (sub-threshold)			FLOOD			Industrial			Climate		
			SE	HE	PM	SE	SE	HE	PM	HE	SE
			1	0	0	2,5	0,5	-1	2	1	0
FLOOD	SE	1									
	HE	0		No interaction			**0,67**			No interaction	
	PM	0									
Industrial	SE	2,5									
	HE	0,5		No interaction			-			No interaction	
	PM	-1									
Climate	SE	2									
	HE	1		0,83			1,17			No interaction	
	PM	0									

Plant 'F'			FLOOD			Industrial			Climate		
			SE	HE	PM	SE	SE	HE	PM	HE	SE
			1	0	0	2,8	0,5	-1,5	2	1	0
FLOOD	SE	1									
	HE	0		No interaction			***0,68***			No interaction	
	PM	0									
Industrial	SE	2,8									
	HE	0,5		No interaction			-			No interaction	
	PM	-1,5									
Climate	SE	2									
	HE	1		0,83			1,18			No interaction	
	PM	0									

The interaction values obtained for the possible influence flood → industries correspond to a medium-low impact of interaction for plants 'A', 'B' and 'D', in line with the registered low energy of the flood events. For the other industries analysed for cautionary reasons, the interaction values can be considered as negligible.

The results obtained are strongly influenced by the indicative medium-low level assigned to the industrial macro-category H.E. (1,5); an in-depth analysis could produce different and more accurate results for the interaction.

5.4. Territorial and environmental vulnerabilities

The following paragraph reports the categorization of the territorial and environmental vulnerabilities of Case-study 2; the first are classified in compliance with the Ministerial decree 09/05/2001, the second are identified according to Piedmont Regional Guidelines.

5.4.1 Territorial vulnerabilities

3 types of territorial elements were identified and classified:

- *Areal vulnerable elements.* They were categorized on the basis of the building ratio index reported in the Technical standards of the City plan. The urban density was quite low: the majority of the residential areas was categorized as C and D. The areas addressed to *public services* and the areas addressed to *transformations with commercial o tertiary*

destination were individually investigated to verify if punctual vulnerable elements were present; the parcels not occupied by punctual elements obtained the conservative C category. Monitoring the transformations of these areas, in particular in case of risk exposure, is particularly important.
The list of urban functions and related categories is showed in Annex IV.

- *Punctual vulnerable elements.* They were identified and categorized on the basis of the capacity, type of attendance (daily, weekly, monthly), type of exposure (inside, outside), etc. Several schools and 1 nursing home were classified as A; structures for leisure like i.e. a mall, a discotheque, a bowling center obtained a B. The list of the punctual vulnerable elements is reported in Annex V.
- *Linear vulnerable elements*. The following elements were identified: Highway and Provincial route / Energy lines arriving from the energy production center / Methane pipeline.

Figure 49 is an extract of the vulnerable territorial map of the city centre: the areal elements are colored in different ways depending on their classification (B = red, C = yellow, D = light green, E = light blue), while the punctual elements are identified in dark blue and accompanied with their ID number. The linear elements are also traced in dark blue.

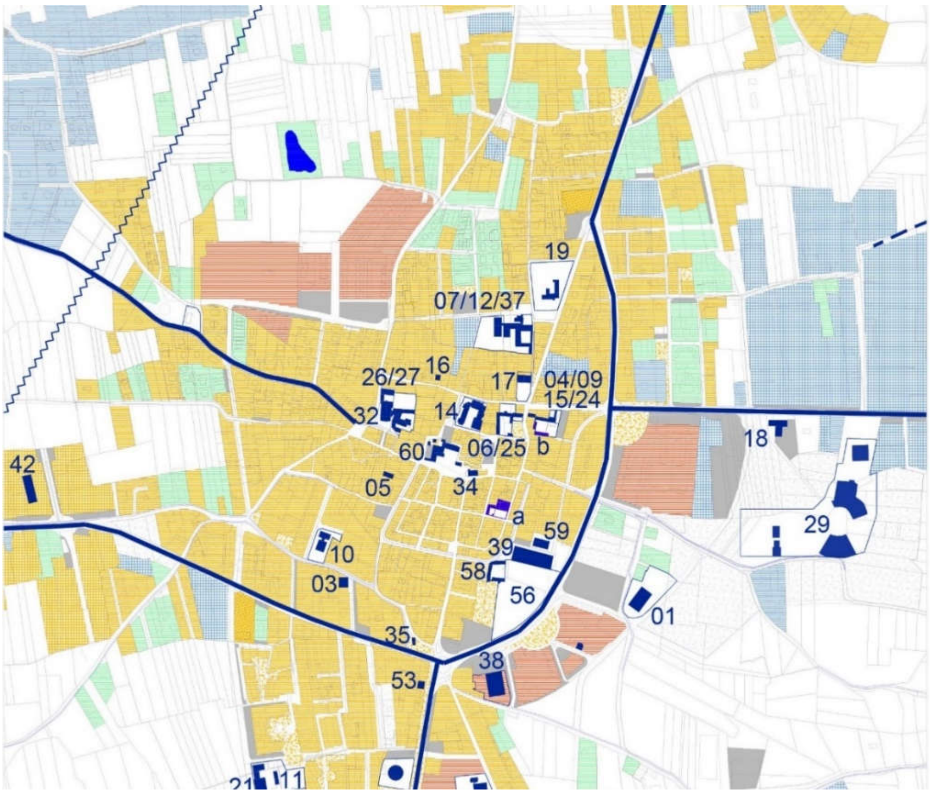


Figure 49: Case-study 2 Extract of the map of territorial vulnerabilities

5.4.2 Environmental vulnerability

No Extreme environmental elements were encountered for Case study 2; however, many Relevant vulnerable elements typical of flat land areas are present. In particular, the depth of the aquifer from the ground level is between 0 and 3 meters, and the soils are connoted by Land use capacity class between 1 and 2. Therefore, the territory is very vulnerable towards possible pollution events. The complete list of vulnerable elements can be found in Annex V. **Figure 50** reports an extract of the map for environmental vulnerabilities: the green uniform color represents the depth of the aquifer 0-3 m., uniformly distributed in the municipal territory. The cross layer represents the distribution of soils cap. 1 and 2. On the top of the figure, *Creek β* appears, with the two-landscape protected areas of 150 m. on each side. The red buildings are the protected historical heritage.

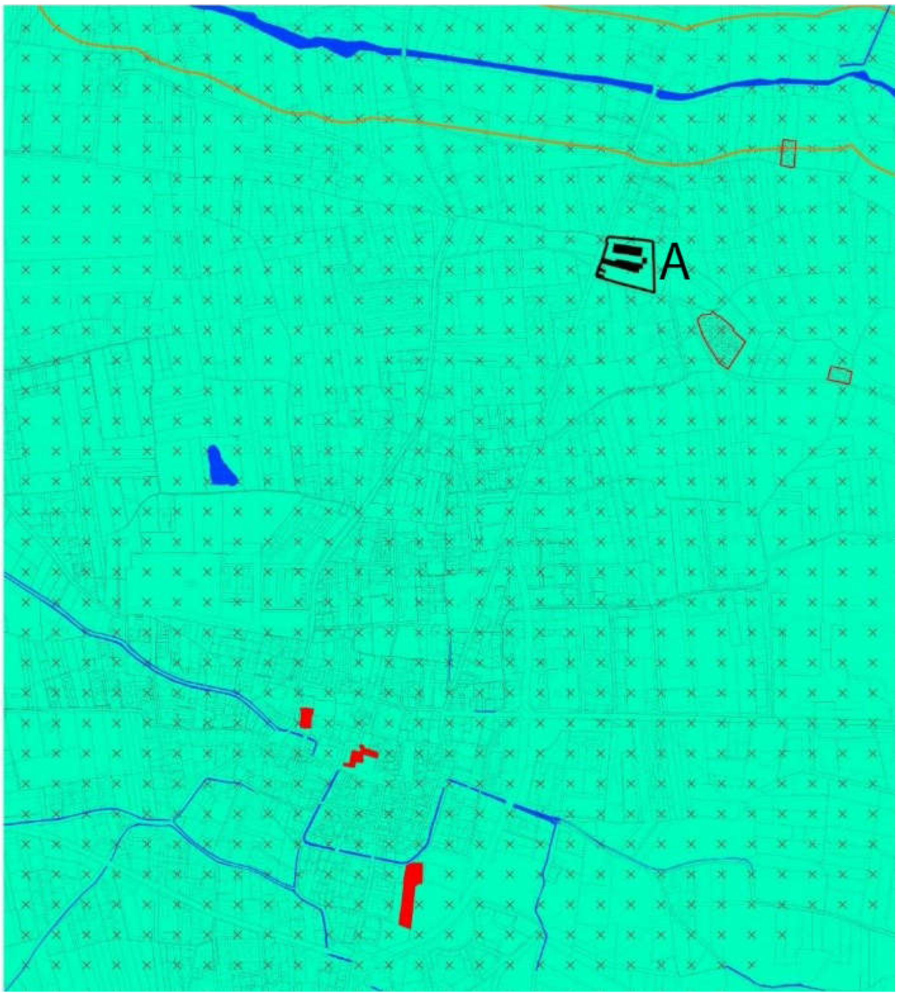


Figure 50: Case study 2 - environmental vulnerabilities

5.5. Compatibility and planning actions

The areas of risk interaction (flood → industry) were located in correspondence of plants; therefore, the assessment of the environmental and territorial compatibility was carried out drawing a buffer zone of 500 m. around each plant. The values of the Industrial macro-categories and of F/I interaction were projected here, and the possible variations of the Flood macro-categories were verified.
The condition of compatibility can be considered satisfied if no vulnerable areas of A and B categories are present inside buffer zones where H.E., S.E. or Interaction values are higher than 2,5.
As far as it concerns the environmental vulnerability, the same threshold of 2.5. was adopted, but first the specific relation between the threats analysed and the environmental vulnerable element was considered.

The assessment of the territorial and environmental compatibility for each plant is reported in the next Paragraph 5.5.1. **Figure 51** and the following lines shows an example of the Territorial compatibility analysis, carried out inside the buffer area of 500 m. for plant 'A':

Figure 51: Plant 'A' buffer zone overlaid with the territorial vulnerabilities

- FLOOD RISK. *Creek β* appears in the top portion of **Figure 51**; it is surrounded by two blue buffer zones. The nearest and darkest area is that of frequent risk flood scenario (Ee), the furthest and wider area is that of the rare scenario (Em), and includes plant 'A'. They received a rating for H.E. = 3 and 2, S.E. = 3 (see Paragraph 5.2.1). The areas in light blue in the bottom of the Figure are those repeatedly hit by the floods caused by the secondary water network in 1994, 2000 and 2008, as identified by Piedmont region and Province. The ratings are =H.E. 2, S.E. 3

- INDUSTRIAL RISK: Plant 'A' is represented in black in the middle of **Figure 51**. The ratings for S.E. and H.E. were 3 and 1,5, even if the latter is an indicative value attributed in the absence of in-depth data.
- INTERACTION: the interaction F → I in the area of overlaying returned a value = 2,17.
- The values for INDUSTRIAL RISK and INTERACTION were projected inside the buffer zone of 500 m. (red circle) to verify their impact on the vulnerable elements. The variations of ratings for FLOOD RISK were considered too.

COMPATIBILITY: inside the buffer zone some residential areas in C, D and E category are located. They have no explicit incompatibility neither with the Industrial risk and the Flood risk, because the density of people is limited; however, the fact that S.E. overcomes the threshold of 2,5 both for Industrial and Flood risk is an alert signal that should not be neglected.

5.5.1 Punctual provisions

Table 64: Plant 'A' (Seveso) Compatibility and planning actions

Ratings	***Territorial vulnerabilities inside 500 m.***	***Environmental vulnerabilities inside 500 m.***
Interaction 2,17 *Industrial risk* SE 3, HE 1,5 *Flood risk* SE 3, HE 2 *Variations inside the buffer area* SE 3, HE 3 (Flood risk on the northern border)	*1)* C and D Residential areas. 3 productive areas (E) destined for reconversion to commercial function, whose transformation has to be monitored, also because two are interested by levels of HE for flood = 3 *2) O*nly few C punctual elements are included; 3) No linear elements and strategic areas / building / infrastructures	RV – land use soil capacity 1st and 2nd classes (agricultural areas around the plant) RV – water table depth < 3 m. RV – historical urban areas Presence of a canal for irrigation adjacent to the northern border of the plant, probably used in the past to drain the rainy water. Presence of a well inside the plant.
Judgement of compatibility & possible further steps	***Territorial compatibility*** The ratings for the macro-categories of Flood and Industrial risks overcome the threshold of 2,5, but there is no manifest incompatibility because of the low people density. However, the state of abandon of the plant, without implementation of safety measures, represents a potential threat for all the territorial elements. This condition can be potentiated by a flood event, as evidenced by the medium value of interaction, which would contribute in spreading the pollutants and toxic substances. Further analysis should be carried	***Environmental compatibility*** A potential incompatibility is detected for the plant, detaining toxic substances and substances dangerous for the environment: the threshold for industrial S.E. is overcome in an area where the environmental elements are particularly sensitive to pollution. The interaction value is medium: flood events, even with their low energy, could cause unexpected consequences of spreading and diffusion of pollutants towards the underground water and superficial water. No prevention and protective measures for the environment have never been adopted.

	out, in particular to verify the state and filling of the containment basins, and protection measures should be adopted. As far as it concerns the areas addressed to future transformations, it has to be considered the compatibility with the High-risk level of flood, avoiding high density of people and adopting specific constructive parameters.	An onsite visit is recommended to verify the actual conditions of the plant, and to organize a recovery procedure.

Table 65: Plant 'B' (potential Seveso) Compatibility and planning actions

Ratings	***Territorial vulnerabilities inside 500 m.***	***Environmental vulnerabilities inside 500 m.***
Interaction 1,98 *Industrial risk* SE 2,8, HE 1,5 *Flood risk* SE 3, HE 2 *Variations inside the buffer area* Area not entirely interested by Flood risk	1) C residential areas. 2 productive areas (E) destined for reconversion to commercial function, whose transformation has to be monitored. 2) 2 punctual elements in B (commercial centre/ bowling; church) 3) Energetic lines	RV – water table depth < 3 m. Presence of a canal for irrigation adjacent to the northern of the plant
	Territorial compatibility	***Environmental compatibility***
judgement of compatibility & possible further steps	Potential incompatibility in case of toxic release with the two punctual elements classified as B (threshold for S.E. > 2,5). An in-depth analysis is recommended for: 1) the specific activities of the 2 vulnerable elements classified as B; 2) the storage methods and protection and preventive measures of the substances classified as TOXIC (H2)	The plant, detaining toxic substances and substances dangerous for the environment, is not compatible with the vulnerable element identified. S.E. = 2,8 overcomes the compatibility threshold; the interaction with flood events, even if connoted by a low-medium value (1,98), could enhance the threat. Further analysis on the possible pollution scenarios and prevention and protective measures against flood should be carried out.

Table 66: Plant ‘C’ (potential Seveso) Compatibility and planning actions

Ratings	***Territorial vulnerabilities inside 500 m.***	***Environmental vulnerabilities inside 500 m.***
Interaction 0,58 (negligible) *Industrial risk* SE 2,5, HE 0,5 *Flood risk* SE 1, HE 0 *Variations inside the buffer area* On the border of the buffer zone, the flood risk increases (S.E =3, HE. = 2)	1) E productive areas. 2) No A and B punctual elements 3) No linear elements and strategic areas / building / infrastructures	RV – water table depth < 3 m. RV – land use soil capacity 1st and 2nd classes (agricultural areas around the plant) Two canals for irrigation are close to the plant
	Territorial compatibility	***Environmental compatibility***
Judgement of compatibility & possible further steps	No incompatibilities were encountered with respect to the territorial vulnerabilities.	An incompatibility is detected, threshold for S.E. overcome in an area where the environmental elements are highly sensitive to pollution. Adequate Protection measures but, since the plant is not in line with the Seveso regulation, an in-depth analysis on the storage methods and protection and preventive measures should be carried out.

Table 67: Plant ‘D’ (Sub-threshold) Compatibility and planning actions

Ratings	***Territorial vulnerabilities inside 500 m.***	***Environmental vulnerabilities inside 500 m.***
Interaction 1,88 *Industrial risk* SE 2, HE 1,5 *Flood risk* SE 3, HE 2 *Variations inside the buffer area* -	1) E Productive areas; little C and D residential areas on the extreme border of the buffer zone. 2) No punctual elements classified as A or B 3) No linear elements and strategic areas / building / infrastructures	RV – water table depth < 3 m.
	Territorial compatibility	***Environmental compatibility***
Judgement of compatibility & possible further steps	Neither the macro-categories of the industrial risks nor the interaction with flood overcome the threshold of 2.5; no incompatibilities were encountered.	The plant detains both toxic and dangerous for the environment substances, to which the environmental elements identified are vulnerable. Even if the threshold of 2.5. is not overcome, a further investigation on the storage methods and protective measures could be developed.

Table 68: Plant 'E' (Sub-threshold) Compatibility and planning actions

Ratings	***Territorial vulnerabilities inside 500 m.***	***Environmental vulnerabilities inside 500 m.***
Interaction 0,67 (negligible) *Industrial risk* SE 2,5, HE 0,5 *Flood risk* SE 1, HE 0 *Variations inside the buffer area* On the border of the buffer zone the flood risk increases (SE.E =3, HE. = 2)	1) E productive areas; on the border of the buffer zone, C and D residential areas 2) No A and B punctual elements 3) No linear elements and strategic areas / building / infrastructures	RV – water table depth < 3 m. One canal for irrigation is close to the plant
Judgement of compatibility & possible further steps	Territorial compatibility No incompatibilities were identified on the basis of the substances detained.	Environmental compatibility An incompatibility is detected, because the threshold for S.E. is overcome in an area where the environmental elements are highly sensitive to pollution. An in-depth analysis on the storage methods and protection and preventive measures should be carry out.

Table 69: Plant 'F' Compatibility and planning actions

Ratings	***Territorial vulnerabilities inside 500 m.***	***Environmental vulnerabilities inside 500 m.***
Interaction 0,68 (negligible) Industrial risk SE 2,8, HE 0,5 Flood risk SE 1, HE 0 Variations inside the buffer area Nearby the plant the flood risk increases (S.E. =3, HE. = 2)	*1) E* productive areas. 2) No A and B punctual elements 3) Torino-Val d'Aosta highway	RV – water table depth < 3 m. RV – land use soil capacity 1st and 2nd classes (agricultural areas around the plant) Canals for irrigation are close to the plant
Judgement of compatibility & possible further steps	***Territorial compatibility*** The data on the substances detained are too scarce to determine the compatibility.	***Environmental compatibility*** The activities of hazardous waste treatment represent a potential risk for the aquifer and the irrigation channels. S.E. overcomes the compatibility threshold; an in-depth analysis on the storage methods and protection and preventive measures should be carry out.

The incompatibilities identified were mainly related to the presence of the industries themselves; in fact, the level of interaction with flood events did not overcome the threshold of 2,5. However, for two cases (Plants ‘A’ and ‘B’, Seveso plants), medium levels of interaction were reached and this should be interpreted as an alert signal, as explained further on.

As far as it concerns territorial compatibility, a general compatibility was found for all the plants, because they were located in areas connoted by low people density or industrial use. The only exception was represented by plant ‘B’, whose buffer zone includes two punctual vulnerable elements; their characteristics of attendance and use shall be investigated to confirm the incompatibility encountered.

The environmental compatibility presents more issues: the entire Municipal territory hosts environmental receptors very sensitive to pollution, and the majority of the industries analysed overcome the compatibility threshold of 2,5 because of the presence of toxic and environmental hazardous substances. A potential environmental incompatibility was encountered for plants ‘A’, ‘B’, ‘C’, ‘E’ and ‘F’, while plant ‘D’’ remained under the compatibility threshold. For plants ‘A’ and ‘B’, the environmental incompatibility can be aggravated by the interaction with flood events, that could provoke spreading of substances and other unforeseen consequences.

In conclusion, the compatibility analysis signalled that for Case study 2 is particularly important to focus the attention on two plants, ‘A’ and ‘B’; both present aspects not sufficiently analysed in E.R.I.R. and other industrial plans, and could cause unexpected scenarios deriving from the interaction with Flood events. In order to enhance the general safety and protection for the population and the territory, the two situations need to be investigated, to verify in detail NaTech vulnerabilities of the two plants. For this purpose, the application of the environmental analysis foreseen by Turin Province guidelines is proposed, together with the dedicated in-depth questionnaire for the plants developed by the candidate (see Paragraph 3.8.1).

Chapter 6

Discussion of results

6.1 Advantages of the methodology

The methodology exposed in the previous chapters focuses on three types of risk, which are those majorly diffused in Italy and in Europe (Flood, earthquake, industry). In Italy, these risks are managed in a separate way, through dedicated sectorial plans which adopt different methodologies for the risk assessment. The only “meeting point” of these risk sectorial plans are the municipal City plan and Emergency plan, which however do not operate an integrate analysis of the possible risk mutual influences.
The multiplication of plans and responsibilities related to risk, together with the scarcity of financial resources, often constitute an obstacle for a proper risk management and land use-planning, most of all at a local scale. As already evidenced, Municipalities are in front line for risk management and are also those more exposed to the direct consequences of risks, but they have not adequate tools to face multiple risks impinging the same territory.

The proposed methodology represents an attempt to fill the current gap, focusing on the augmented risk impact caused by possible interactions. It is an easy-to-use and simple tool that can be adopted at a local scale to enhance the knowledge and security of the territory, waiting for the implementation of an official multi-risk methodology, recognized both by the European and national laws.
Therefore, the proposed methodology does not substitute existing plans or LUP structure, but acts as a collector of the overall available information on risks, integrating them in a unique framework directly usable by the Municipal technicians. In particular, through this methodology, they can identify the areas more exposed to risks and risk interactions, and concentrate here further studies and financial resources. Thanks to a clearer vision of the several threats on the territory, LUP and risk management actions can keep into account possible extreme events deriving from risk interactions, that at the moment the separate sectorial plans do not consider.
The methodology is explicitly designed for local planners not expert in risk assessment, that are called to assume a more active role on their territory: on one side, they directly analyze the contents of the sectorial plans and acquire a major awareness, but at the same time, they can integrate missing information or imprecisions using their direct knowledge of the territory. The direct management by local technicians allows to spare resources, which at the

moment is one of the main obstacles for local government; these same resources can be better addressed after the risk pre-screening made by the methodology.

The implementation of the methodology should be executed independently from contingent situations, because its purpose is to orient the strategic decisions that underpin the local plans (City plan and emergency plan), providing the Municipalities with a huge and systemic know-how on risks and risk interactions that affect their territory. The in-depth studies and the planning actions that compose the “planning phase”, last step of the methodology, can be executed each time that a revision of the city plan, or the development of determined project is programmed.

The methodology was developed to be used by a task force of Municipality technicians, coming from different Municipal offices and functions (Environment, Urban planning, etc.); however, as later specified, local experts and other entities should join the panel for the assessment.

The development requires between 6-12 months, like an E.R.I.R. draft; it can be almost completely developed on documents that are already owed by the Municipality, so that the major effort consists of the systematization and organization of the data, in order to be able to assign the ratings.

6.2 Main innovations

The main innovative elements of the methodology are here resumed, together with a short explanation. The inspiring criteria for all these elements was to maintain a simple approach, accessible for users not expert in risk analysis.

1) *Common index scale for risk and risk interactions.* The scale should be directly used by the Municipal technicians to evaluate the risks; it measures also the possible impacts of the interactions.
2) *Risk characterization through macro-categories*. The macro-categories help the user to focus on the different aspects that determine the final impact of a risk: not only the recurrence, but also other elements can have influence. Perhaps they are better known at a local scale than at the wider scale of the sectorial plans.
3) *Introduction of the macro-category Strengthening effects*. This macro-category was entirely dedicated to aspects not analyzed or superficially treated in the sectorial plans: i.e. for seismic risk, the quality of soil, that is usually not investigated, because in Italy the micro-zoning studies are mandatory only for Municipalities included in seismic class I. For flood, the local scale allows to better detect critical sections and interactions of the hydraulic network; in many cases, they are already known, but not adequately evaluated and reported in the plans. For industries, this macro-category helps focusing the attention on an aspect left out from ERIR, like i.e. the presence of items, storage conditions and substances that make the industries more vulnerable towards NaTech events.

4) *Assessment of the interactions*. The methodology particularly focused on the interactions, that currently are completely neglected in the plans: a simple formula, deriving from the macro-categories, was settled to return a possible impact of the interaction. The interactions are calculated in the areas of risk overlaying through the Interaction table. The calculation can be also directly managed through GIS.
5) *Employment of ALOHA and HSSM for the spatial consequences of the interaction*. Existing simple modelling programs were employed to obtain a first esteem of the spatial consequences of interaction involving industries. Even if a buffer zone of 500 m. around the plants is adopted to project possible interaction consequences, the simulations can return a clearer and more precise vision of possible scenarios.
   Specific parameters were fixed to simulate the initial damage conditions produced by an interaction; the data to be inserted in HSSM and ALOHA were clearly detailed in dedicated data-sheets in order to guide the utilization also for not-expert users.
6) *Development of a questionnaire for an in-depth analysis of the NaTech vulnerability of the plants*. This questionnaire aimed at integrating the information on the plants collected during the ERIR drafting, through the collection of further data on items, storage conditions, past events etc. with a special attention to their NaTech vulnerability. The questionnaire is particularly important to investigate hazardous plants that do not reach Seveso thresholds.

6.3 Case-studies

The methodology was developed and tested on two different Italian case-studies, which were connoted by risks with different characteristics, and by different levels of data availability:

1) *CASE STUDY 1: MANTUA.*
   Choice → Famous Italian city with several vulnerabilities, both territorial and environmental; it was chosen because three different risks were superimposed, besides local extreme climatic events: flood, earthquake, and 4 Seveso industries (2 with huge dimension).
   The probabilities of occurrence for the risks analyzed were quite low; i.e. because of the complete artificialization of Mincio river, and of industrial scenarios that did not or slightly overcome the plants' boundaries. However, the presence of extremely important vulnerable elements (Unesco historical centre, protected SIC-ZPS natural areas, etc), together with the persistence of a severe situation of environmental pollution, raised doubts on the possible unexpected consequences of risk interactions, even if with low levels. The application of the methodology tried to answer these issues.
   Data → Mantua Municipality and Lombardy region provided the basic GIS maps; the other data were autonomously collected by the Candidate and they are all publicly available.
2) *CASE STUDY 2:*

Choice → Little outlying city in Piedmont, 2 main risks with low impact: flood risk (P.G.R.A. identified the return times for a creek crossing the municipal territory) and industrial risk (1 Seveso plant, a former factory closed in unsafe conditions). The plant was included in the flood areas of the creek.

The necessity to investigate the interactions raised from conditions not adequately investigate and represented, neither in the sectorial plans, nor in the City plan. Surveys by Piedmont Region demonstrated that the secondary hydraulic network, not analyzed by P.G.R.A., was responsible of the recent flood events as much as the creek represented as the solely source of risk in P.G.R.A. Two plants, not identified by the authorities in charge but classifiable as Seveso, were included in the areas flooded by the secondary network.

The methodology was applied to compensate this lack of information, and to test possible unexpected consequences of risks not correctly reported or known by the Authorities. In addition, this second case study gave the opportunity to test the methodology on industrial risk not only caused by Seveso plants.

Data → the Candidate participated in the ERIR drafted for the Municipality, made in compliance with (Regione Piemonte, 2010). Therefore, the investigation on the municipal territory entailed also Sub-threshold plants, whose main information were collected through the questionnaire reported in **Table 22.** The identification of the territorial and environmental vulnerabilities was very detailed, thanks to the support of the Municipality. With respect to the first case-study, more data were available, but the information on the industrial risk were less precise, due to the fact that the plants were not Seveso.

The application of the methodology on both the case studies returned positive results, signaling risky situation that currently are not adequately described neither in the sectorial risk plans nor in the Municipal city plan. In spite of the initial low values for risk and risk interactions, potential incompatibilities were identified for both the case studies:

1) CASE STUDY 1. A possible problematic situation was identified for the rail-tankers that serve Seveso plants and transport acrylonitrile and benzene. Since in this area the protection measures adopted are minor than for the tanks of the storage parks, in case of damage caused by external events, some unforeseen consequences could arise. HSSM simulation demonstrated that a very little damage caused by external events could produce environmental pollution, because the soil is highly permeable and many areas in the storage parks are not waterproofed. The result of the simulation confirmed the data of the surveys campaigns carried out by the authorities for the recovery of the industrial zone: the concentration of benzene and other hydrocarbon substances remained very high in the aquifer, in spite of the hydraulic barriers built by the plants.

   In the city centre, some further studies were recommended for an area where a poor quality of soil was identified.

2) CASE STUDY 2. The application of the methodology signaled several potential incompatibilities due to the presence of industries detaining pollutants; they are included in areas interested in the past by flood provoked by the minor hydraulic network, and the methodology signaled the need to investigate in detail the items of the plants to correctly evaluate possible NaTech events.

The values of the interaction obtained for the two case studies demonstrated that the procedure adopted for the calculation and the weights attributed to the macro-categories were able to produce credible results, in line with the initial global values of the risks (that in those cases were low).

6.4 Possible shortcomings

The application of the methodology to case studies connoted by different situations and risk sources allowed to test its functioning towards different contexts, facing at the same time possible operational difficulties.

The following lines evidenced some possible shortcomings or aspects to be addressed:

1) IMPLEMENTATION.

- The lack of data could decrease the efficacy and the precision of the results; for both the case studies, some data resulted missing, mainly because of the impossibility to recover them in absence of a stronger cooperation with the Municipalities. I.e. for Mantua, the Sub-thresholds plants were not analyzed because E.R.I.R. did not include them, therefore no data were available, even if some critical situations related to environmental pollution were known. Also, the analysis focused only on Mincio river because of the unavailability of data on the secondary water network in the municipal territory. Finally, Safety reports of the Seveso plants were not available, even if the huge collection of documents related to the A.I.A. releases and to the process of recovery of the lakes provided very detailed information.
- Some problems could arise also during the phase of assignation of the ratings, because of uncertainties due to a correct interpretation of the data themselves and possible doubts arising from the users' scientific background.
- The implementation of the methodology will add an adjunctive commitment to the Municipalities, for which they should be adequately supported by the central authorities.
- A possible problem related to the implementation can derive from external influences or unforeseen "contaminations" on the Municipality technicians; in order to compensate and monitor possible problems, the panel of technicians could be extended to include external experts, like those of the Environmental Protection Agency for the Environment. They could check the implementation of the procedure through collegial conferences, analogous to those already employed for other LUP procedures.

2) TECHNICAL ASPECTS.
   Although the weights assigned to the macro-categories produced for both the case studies results in line with the expectations and with the initial risk values, the weights assigned actually reflect a conservative position, in which the macro-category HE received the higher weight because of its major reliability. Variations in the weights assigned could vary the final value of the interaction; given the importance assigned by many experts consulted to the macro-category SE, the procedure of weights assignation could be strengthened through an enlargement of the panel of experts and the adoption of an AHP procedure.

Chapter 7

Conclusions

The data presented by Cred (Centre for the Epidemiology of Disaster) in 2017 showed an increase of natural disasters related to droughts, floods and earthquakes; Italy resulted the seventh nation in the world for number of victims and expenses for the recovery of damages. One of the identified causes, besides the climate change, is the lack of prevention actions; as already discussed in the previous chapters, Italy scarcely implements maintenance and prevention actions in land use planning, neither possible actions to increase the resilience of the exposed vulnerable elements are defined. Earthquake is the only sector in which a more structured regulation was adopted; however, the draft of the sheets for the estimation of seismic risks, and the execution of the microzoning studies are proceeding too slow to avoid dramatic consequences, as for Amatrice and the central Apennine in 2016.
In addition to a scarce diffusion of a prevention culture, and to the bureaucratic difficulties, the reason most frequently indicated for the lack of prevention and maintenance action is identified in the absence of sufficient financial resources. This issue is particularly felt by the Municipalities, which have to answer to several necessities of maintenance and protection of the territory, with limited available funds.
In absence of specific measures voted to the prevention, the actual situation is expected to increasingly worsen: in fact, the augmented violence and recurrence of the natural events could also influence the probability of multi-risk events, involving more hazardous sources, and causing more extensive damages. This possible scenario currently is not addressed by any regulations.

The objective of this thesis was to help the Municipalities in facing risk management in a more adequate way, making them more aware of the possible consequences of the climate change and more prepared towards multi-risk events. In particular, the aim was to build a quick and easy to use methodology, able to support the Municipalities in:
1) identifying the areas more exposed to high levels of risk and risk interactions;
2) addressing the available funds to further studies and interventions on the areas identified.
A dedicated semi-quantitative methodology, based on indexes meant to be directly assigned by the Municipality technicians, was developed and applied to two test case-studies, that produced plausible results in terms of representation of the intensity of the risk interactions. Both the towns had risks with some worrisome features (included and evaluated in the macro-category S.E.), but that - for intensity or recurrence – did not have a strong impact

on the vulnerable elements (as expressed by H.E. macro-category). The application of the weighted sum and the interaction tables, proposed to verify the possible impact of multi-risk events, returned low-medium values of interaction, that were reasonably in line with the starting conditions and the case-histories of the areas. In spite of these low values, the simulations with ALOHA and HSSM demonstrated that unforeseen multi-risk events, even with low intensity, could be able to provoke hazardous consequences, in particular as far as it concerns the environmental aspects.

The results obtained from the case studies highlighted some possible risky situations neglected in the risk sectorial plans, guiding the Municipalities in better addressing further studies or interventions. They completely met the initial objective of the methodology, aimed at pointing out eventual problems related to risk interactions and aspects neglected by the sectorial plans.

Therefore, the methodology represents an advance with respect to the state of the art, because local authorities can deal with risk and risk interactions at a local scale, from a perspective aimed at enhancing their participation and involvement. It has to be reminded that, even if local planners usually do not have a strong background in risk analysis, in the end they are responsible for the governance and safety of the territory; the municipality-centered approach "force" local administrators to recover an active role towards the risks, overcoming the fragmentation of the sectorial plans and the delays in the implementation. This allows on one side to increase the local technicians' awareness about the contents and information of the sectorial plans, and on the other side to exploit the major direct knowledge of the local administrators.

The methodology treats the risks in an integrating and systemic way, acting as a pre-screening instrument that orient future choices: it does not substitute existing plans or methodologies, but brings the users to take into account their contents in a wider context, focusing better on the areas where further studies and interventions are required.
The simple framework proposed represent a starting point of a path towards the increase of the safety that can be applied worldwide, to make local authorities more conscious for risks and their interactions. Indeed, the current guidelines developed for the ratings of the macro-categories H.E., S.E. and P.M. can be adapted to the laws and procedures in use among other countries; the calculation of the interaction remain the same, while the list of measures suggested for the planning phase once again can be explicitly drawn for the country interested.

Some further steps could be hypothesized to widen and promote the use of the methodology:

1) Development of the rating guidelines for other territorial risks, defining the levels for the three macro-categories in cooperation with experts of each specific discipline (landslide, volcanic risk, sea risk etc.)
2) Strengthening of the approach in relation to the local extreme events caused by climate change, with a wider local data collection and definition of the phenomena.

3) Enhancement of the representation of the spatial consequences. At the moment the simulations related to the interactions were essentially focused on industrial assets; however, a major involvement of experts of other disciplines could allow to set tools and instruments to analyze and study the consequences of all the types of interaction, creating an all-inclusive and more powerful tool.
4) Strengthening of the approach in relation to the vulnerability analysis, in order to evaluate the different aspects of susceptibility presented by the vulnerable elements, and trying to settle possible solutions to enhance the resilience.
5) Developing a participative process to improve the application of the methodology among the Municipalities, to reinforce the cooperation between the users and external authorities. In this context, also the adoption of a Multi-criteria Decision Analysis (MCDA) could be useful, to better guide and support the choice of the possible planning actions, as proposed by (Nivolianitou & Papazoglou, 2014) for LUP around Seveso plants.
6) Integrating the methodologies with procedures related not only to structural interventions, but also to emergency management, i.e. taking into account the guidance for flood disaster management with the use of AHP by (Nivolianitou & Synodinou, 2015).

In conclusion, the methodology tried to address the wide-spread problem of dealing with risk interactions in contexts where risks are usually managed in a separate way, considering this issue from the point of view of the local authorities. The results obtained from the case studies confirmed the simple usability of the methodology to quickly identify the areas more exposed to risks and risk interactions; therefore, this approach can constitute a valid pre-screening, able to orient the application of further more precise and quantitative methodologies, both for risk and for multi-risk. The framework can be extended to other risks and countries with an opportune enforcing of some aspects.

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Annex I: Experts' judgement

The process of validation of the weights assigned to the macro-categories was conducted through experts' judgement, collecting the experts'opinions through a dedicated questionnaire.
The selection of the experts was made on the basis of the suggestions by (Crispen & Hoffman, 2016): experts should be identified depending on the career analysis, performance analysis and socio-metric analysis; they should have 5 years of full-time professional experience, and be recognized as "go-to persons" for the field analysed.
The expert panels employed by other Multi-risk projects were evaluated: i.e. for ESPON project (Schmidt-Thomé, 2006), a sufficient scientific background in the work with hazards, and with multi-hazard approaches was required; 12 people were selected, with different geographical provenience. For PRIM Lombardia (Lari et al, 2009), 15 experts coming from different disciplines were identified: geologists dealing with flood, landslide, and avalanche risk, Civil Protection officers in charge of economic resources for mitigation projects, environmental researchers and public administrators.
As far as it concerns the size of the panel, the problem of the definition of a "correct size" was deeply treated by (Crispen & Hoffman, 2016), who questioned the common scientific concept that a wider sample of experts can return more robust, dependable and believable results. The authors observed through repeated experiments that the amount of knowledge elicited from experts' panel increases with a decreasing rate, that means that the marginal utility for each added expert is about 5%. In case of small group of interest and limited generalization, and when the goal is related to "practical significance more than statistical significance", the authors recommend to employ panels composed by 3-4 experts, whose contribution should be evaluated measuring the marginal utility.

For the proposed research, size and composition of the panel recovered the practices used in other Multi-risk projects: 11 experts were consulted, mainly pertaining to Engineering field and dealing with industrial risk and NaTech risk; however, 3 LUP experts and 1 environmental engineer were also involved. The geographical provenience covers some of the main EU countries. The experts were asked to express their opinions on the role of the risk macro-categories, in terms of influence on a possible risk-interaction, and of reliability, intended as data available and supporting proofs. Furthermore, an opinion on the threshold adopted to evaluate the compatibility of risks and risk interaction with vulnerable elements was required.

The following table reports the content of the questionnaire; the questions were introduced by a brief explanation related to the adopted methodology.

The methodology developed aims at providing the local authorities, which are responsible for land use planning, with a rapid guide to the risks impinging on the territory, able to point out the areas more exposed to risks and taking into account explicitly the possible interactions among the risks. The purpose is to have a complete picture of the risks and some numerical indications supporting the decision making in terms of intervention on the territory and/or request for further and more detailed studies.
In order to reach this objective, the Municipality technicians will have to follow a semi-quantitative methodology, through the assignation of indexes, which express the impact of the risk and risk interaction: the scale proposed goes from 0 to 3 and onwards (in absolute values); values between $0 \leq I < 1$ are considered negligible.
$1 \leq I < 2$ From low to medium impact
$2 \leq I < 3$ From medium to high impact
$I \geq 3$ From High to extremely high impact
The risks taken into account are: Flood risk, seismic risk, industrial risk.

1st step of the methodology: RISK RATING.
Each risk identified on the Municipal territory is described and rated in accordance to three specific macro-categories, which aim to bring the users to think about all the possible elements that can potentially influence the risk intensity.

- HISTORICAL EVENTS, HE: recurrence of the risk analysed, based on the information provided by the existing plans, studies and surveys
- STRENGTHENING EFFECTS, SE: elements that could enhance the final impact of the risks, and that could have been neglected by the existing plans (i.e. quality of the soil for earthquake, type of items and substances for Seveso industries etc.)
- PROTECTION MEASURES, PM: existing protection measures adopted for the specific risk (i.e. levees for flood, hydraulic barriers etc.)

A guideline was developed to drive the Municipality technicians in the rating attribution.

2nd step of the methodology: ASSESSMENT OF THE INTERACTION AMONG THE RISKS.
In order to assess the interaction of two different events impacting on the same area at the same moment, an arithmetic average between the risk rates was proposed:
$$[(H.E._{haz1} + H.E._{haz2}) * w1 + (S.E._{haz1} + S.E._{haz2}) * w2 + (P.M._{haz1} + P.M._{haz2}) * w3] / 6$$
However, it was necessary to attribute some weights (w1, w2, w3) to the three macro-categories to obtain credible values for the binary interaction.
The weights were attributed on the basis of two parameters:

- on one side, the overall reliability of the macro-category, related to the reliability of the information available and potential uncertainties (i.e., the attribution of the values to the macro-category H.E. is based on existing studies and surveys, while for S.E. the identification and rating of the potential strengthening elements could be more uncertain);
- on the other side, the possible final influence of the macro-category on the interaction was taken into account (i.e. for P.M., literature data demonstrated that the in many cases the protection measures failed when extreme unforeseen events occurred; therefore P.M. capacity to reduce the impact of the interaction is low).

3rd step of the methodology: COMPATIBILITY ASSESSMENT
The values attributed to the macro-categories and the values obtained for the binary risk interactions are super-imposed to the vulnerabilities encountered on the Municipal territory to assess the compatibility.
An alertness threshold was identified for values of impact that overcome 2.5 (medium-high impact);
if vulnerable elements connoted by high density of people, or environmental vulnerable elements are included in zones where the macro-categories of the risks, or the risk interactions overcome the threshold, the Municipality will have to carry out further studies and/or actions to analyse in-depth the compatibility and improve the situation.
The purpose of this short questionnaire consists of:

- the validation of the weights assigned to the macro-categories
- the validation of the chosen alertness threshold for the compatibility.

I kindly ask you to answer the following questions, on the basis of your knowledge and previous experiences:

1) In assessing the interaction within two risks, which macro-category do you think will be more relevant between:

☐ HISTORICAL EVENTS ☐ STRENGHTENING EFFECTS

why?

----

2) In assessing the interaction within two risks, which macro-category do you think will be more relevant between:

☐ HISTORICAL EVENTS ☐ PROTECTION MEASURES

why?

----

3) In assessing the interaction within two risks, which macro-category do you think will be more relevant between:

☐ STRENGHTENING EFFECTS ☐ PROTECTION MEASURES

why?

----

4) In a scale from 0 to 4, which weight would you attribute to each macro-category, in relation to its reliability and capability to influence the final interaction impact?

	No importance	*Low importance*	*Medium importance*	*Discrete importance*	*High importance*
HISTORICAL EVENTS	☐0	☐1	☐2	☐3	☐4
STRENGHTENING EFFECTS	☐0	☐1	☐2	☐3	☐4
PROTECTION MEASURES	☐0	☐1	☐2	☐3	☐4

5) In a scale from 0 (N) to 4 (Y), do you consider appropriate to adopt as alertness threshold for the compatibility a value corresponding to a 2,5 (medium-high impact)?

No	Quite disagree	Indifferent	Quite agree	y
☐0	☐1	☐2	☐3	☐4

6) If no, could you suggest which would be in your opinion an appropriate vale for the threshold, and why?

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8 experts answered the questionnaire; the following lines report a summary of the answers received for each question.

<table>
<tr><td colspan="5">QUESTION 1: Macro-category more relevant for risk interaction between</td></tr>
<tr><td colspan="5">HE | 4 | SE | 4</td></tr>
<tr><td colspan="5">QUESTION 2: Macro-category more relevant for risk interaction between</td></tr>
<tr><td colspan="5">HE | 6,5[16] | PM | 1,5</td></tr>
<tr><td colspan="5">QUESTION 3: Macro-category more relevant for risk interaction between</td></tr>
<tr><td colspan="5">SE | 5,5 | PM | 2,5</td></tr>
<tr><td colspan="5">QUESTION 4: Level of importance of the macro-category in terms of reliability</td></tr>
<tr><td>No importance (0)</td><td>Low importance (1)</td><td>Medium importance (2)</td><td>Discrete importance (3)</td><td>High importance (4)</td></tr>
<tr><td></td><td></td><td>3 SE</td><td>2 SE</td><td>3 SE</td></tr>
<tr><td></td><td></td><td>2 HE</td><td>3 HE</td><td>3 HE</td></tr>
<tr><td></td><td>1 PM</td><td>4 PM</td><td>2 PM</td><td>1 PM</td></tr>
<tr><td colspan="5">QUESTION 5: agreement on the threshold level chosen for the compatibility:</td></tr>
<tr><td>No</td><td>Quite disagree</td><td>Indifferent</td><td>Quite agree</td><td>y</td></tr>
<tr><td></td><td></td><td>2</td><td>5</td><td>1</td></tr>
</table>

The results obtained showed a substantial equivalence between the macro-categories Strengthening effects (SE) and Historical events (HE) in terms of importance attributed by the experts, with a slight advantage of the macro-category Historical events. HE was judged as the most important and reliable category by the majority of the risks analysts, because they considered it more capable to return a correct idea of the possible NaTech events on the territory. On the contrary, experts from other disciplines attributed a major importance to SE, underlining the possible variations of HE in terms of probability of occurrence of events related to climate, and the difficulties related to correctly identify and report all the events.

Questions 2,3 and 4 make evident that the macro-category Protection measures was judged as the less relevant to describe the possible effects of an interaction: 4 experts attributed it a medium importance, and 1 a low importance. The explanations provided by the experts are mainly related to the fact that the Protection measures are designed on the basis of the Historical events for a specific single risk, and they could be inadequate in case of interaction; PM can be ineffective, work badly or be broken.

The results of the experts' judgment confirmed the importance of HE (2) and SE (1) in evaluating a possible interaction impact; however, for the weights assignation, the candidate decided to attribute a major weight to the Historical events (=2), more in line with the judges of the risk analysts. Since the proposed methodology did not adopt a probabilistic approach, the major weight assigned to the macro-category Historical events, deriving from the existing sectorial plans, allows to take in due account the solid data and probabilistic analyses

[16] The rating 6,5 and 1,5 is obtained because one expert considered the two macro-categories analysed equally important, so his/her vote was equally divided between the two. The same happened for Question 3.

developed in the risk plans. The macro-category Strengthening effects, that can be helpful in determining the final effects of the interaction, could be interested by major uncertainties, as lack of data and a minor objectiveness in the evaluation by the Municipal technicians, because the elements that compose it are not formalized by specific laws (with the exception of the types of soil for the earthquakes). Therefore, for a conservative reason, SE received a minor weight (=1). In the end, the macro-category Protection Measures received the lowest value (=0,5) to remain in line with the evaluations of the experts: even if it is based on secure data, many problems related to design, maintenance and efficacy could affect this category, therefore the presence of Protection measures could not be sufficient to properly reduce the possible effects of an interaction, also because they are usually designed for single risk effects.

As remarked in the chapters related to the Case studies and in the Conclusion, the adoption of the proposed weights returned positive results for the two case-studies analysed; possible problematic areas were identified, but the threshold alert was not overcome. Thanks to the weights attributed, the results obtained for the interactions were reasonably in line with the low initial risk levels of the two case studies.

Annex II: Versalis and Ies Protection measures

The following tables report the checklists of Protection measures by (Provincia di Torino, 2010) and (Cruz et al., 2004), completed with the information of Versalis.

Table 70: Versalis environmental protection measures

PREVENTIVE/PROTECTIVE MEASURES	VERSALIS FULFILMENT	
	Y/N	**Description**
POINT 1a		
Identification of the supply and lines with a label containing the name of the substances and safety information	**Y**	Probably yes (prescribed by the law)
Formalisation of a schedule to check and maintain the entirety of tanks and basins	**Y**	Three-monthly verification of the double bottoms of the tanks; every 5 years external inspection; every 20 years complete inspection. Single bottom tanks: verification with tracer test every 2 years.
Formalisation of a schedule to check and maintain the entirety of pipes and lines, included the drainage lines and interception valve	**Y**	The pipelines are monitored through the informatic Manager tool, which programmes the maintenance interventions and the recovery of the metallic portions. The drainage system is yearly inspected.
Constant updating of the documents, capable to demonstrate the physical and chemical compatibility of the substances chosen	**Y**	Probably yes (prescribed by the law)
Provision of a system for the collection of the small releases (adsorbing materials and pads nearby wells, sewer covers etc.)	**?**	Information not available
POINT 1b		
Separation of the areas potentially involved by releases from the other areas, using containment basins and dedicated collection lines	**Y**	The process areas are located on a concrete waterproof basement; all the tanks are provided with containment basins, and have circumferential curbs collected to the process drainage for the adsorption of the minor releases. For critical equipment, the pavement is equipped with slopes and curbs with allow to contain the release and facilitate its collection. For critical lines, interception devices are available at the beginning and at the arrival to the user.
Arrangement of two different drainage lines for the rainfall water and the water employed in the process or interested by potential releases.	**Y**	3 drainage systems are present in the plant: - 1 drainage system for the meteoric water and the cooling water, which are directly returned to the river without treatment; - the acid process drainage system - the oily process drainage system
Reduction of the areas interested by potential releases and provision of protection devices, such as waterproof paving, dedicated collection lines, etc.	**Y/N**	The adoption of the waterproof paving is not extended to the entire plant; therefore, some areas of the park storage and product transfers result not protected yet.
Elimination or reduction of the junctions with flanges, and adoption of completely soldered lines	**?**	Information not available (even if it has to be observed that in case of earthquake, flexible junctions could be safer)

PREVENTIVE/PROTECTIVE MEASURES	VERSALIS FULFILMENT	
	Y/N	**Description**
Provision of devices for the registration and alarm related to unexpected loss of level of the tanks and basins	**Y**	A monitoring system for the level of resting tanks is implemented; the levels are transmitted to DCS and alarmed. A second tool of alarm and trip was in course of installation on all the plants containing Hazardous substances.
Substitution or renovation of the underground tanks, according to the decree 20/10/1998 n. 260	**Y**	No underground tanks are present.
POINT 2		
Definitive lock of the unused wells located inside the plant, and external protection of those still in operation	**N**	The wells which compose Versalis hydraulic barrier and all its piezometers are still in operation; no information is available on external protections
Arrangement of the devices and measures foreseen by of the Regional regulation 20/2006 n 1/R on rainfall water collection.	**?**	Information not available
Provision of emergency devices (Adsorbing material, pads..) nearby wells and sewer covers in order to obstacle the access of the pollution agents to the municipal sewer	**?**	Information not available
Arrangement of devices for an automatic lock of the drainage lines whether is detected the presence of pollution agents.	**?**	There is no information on automatic devices for the lock of the drainage lines; however, the drainage systems are monitored both in their paths and in the points of delivery, through devices which allow a continuous analysis
Arrangement of emergency management procedures	**Y**	
POINT 3		
Assessment of the hydrogeological conditions nearby the plant and the points of possible release	**Y**	The hydrogeological and soil conditions are at least monitored once a year, in relation to the operations required by the recovery of the SIN area
Assessment of the times employed by the pollution agents to arrive to the sensitive elements	**-**	Some hypotheses were made for the Safety Report, judging the type of soil as slightly permeable; however, the analysis carried out by ARPA showed higher levels of permeability, also demonstrated by the stability of the pollution levels in the water, despite of the hydraulic barriers.
Arrangement of emergency safety measures (Hydraulic barrier)	**Y**	The hydraulic barrier for Versalis was implemented during the Nineties, however its efficacy seems to be partial
Employment of off-ground tanks instead of those underground	**Y**	
Paving of the area for the new plant with layers of waterproof materials	**Y/N**	aSomeprocess and storage areas of the plant still lack of waterproof pavements.
Employment of off-ground lines instead of those underground	**Y**	

Table 71: Versalis NaTech protection measures

NA-TECH SAFETY AND MITIGATION MEASURES	VERSALIS FULFILMENT	
	Y/N	**Description**
Use of structural design codes or retrofitting	**N**	
Containment dikes or walls	**N**	
Use of structural design codes or retrofitting of walls and dikes	**N**	

NA-TECH SAFETY AND MITIGATION MEASURES	VERSALIS FULFILMENT	
	Y/N	**Description**
Anchoring mechanisms of tanks and equipment (e.g. anchor bolts, bracing)	**N**	
Bracing of pipes and connections	**Y**	The pipelines are located on racks or trenches; in the areas of intersections they are reinforced with jackets, which are monitored for possible losses.
Flexible connections for pipes	**?**	Information not available
Restraining straps or chains for barrels or pressure vessels	**?**	Information not available
Strapping and anchoring of emergency equipment	**?**	Information not available
Emergency shut off/safety valves	**Y**	
Emergency water systems, and foam spraying systems	**Y**	The plant is equipped with an underground firefighting water network, served by Mincio river, and fed by 4 pumps, both electrical and motorized, which progressively activate on the basis of the request. In case of electric default, a generator can activate one of the motorize pumps. No information on the presence of foam sytems is available.
Adequate siting of emergency water and foam spraying systems to avoid damage from falling debris	**?**	Information not available
Redundancy in pipeline systems, particularly emergency water	**?**	Information not available
Warning systems	**Y**	
Emergency power generators designed to maintain critical equipment housing hazardous chemicals in safe condition for extended periods of time	**?**	The information available is not sufficient: Versalis has adopted specific structural measures to fix possible electrical defaults, reducing their probability and duration, however it is not clear if there are measures specifically adopted for the critical equipment and installations.
Routine inspection and maintenance for corrosion and deterioration	**Y**	The installations, pipelines and tanks are periodically inspected.
Inventory control (e.g. minimizing the amount of hazardous materials used)	**?**	
Strategic placement of substances inside plant in order to avoid chemical incompatibility	**Y**	
Placement of storage tanks with hazmats above the maximum height reachable by water	**N**	No explicit measures were adopted against a possible flood, because according to some documents of the plant, it could not be reached by water.
Construction of drainage system	**Y**	
Interruption of production process	**Y**	
De-inventory of main processing units	**?**	Information not available
Giving transport priority to most dangerous chemicals (those that react violently with water)	**?**	Information not available
Verification of storage tank seals	**Y**	
Hermetic sealing of silos and underground storage tanks	**?**	Information not available
Wrapping of substances in watertight packing and labelling	**?**	Information not available

NA-TECH SAFETY AND MITIGATION MEASURES	VERSALIS FULFILMENT	
	Y/N	Description
Raising of electrical equipment such as motors, pumps and control panels to avoid water damage and system failure	**?**	Information not available
Maintaining na-tech emergency response plan	**N**	
Construction of retaining walls and levees or dykes	**N**	
Drills and Training	**Y**	
Plan to allow workers to check on family	**?**	Information not available
Training plan for external responders on management of hazardous chemicals onsite	**?**	Information not available

Table 72: Ies environmental protection measures

PREVENTIVE/PROTECTIVE MEASURES	IES FULFILMENT	
	Y/N	Description
POINT 1a		
Identification of the supply and lines with a label containing the name of the substances and safety information	**Y**	Probably yes (prescribed by the law)
Formalisation of a schedule to check and maintain the entirety of tanks and basins	**Y**	- Plan for the inspection of the tanks, and integrity check with EA test for tanks without double bottom - Periodic check of the tank and critical pipelines according to a yearly program, to verify integrity, functionality and corrosion - Underground tanks equipped with cathode protection
Formalisation of a schedule to check and maintain the entirety of pipes and lines, included the drainage lines and interception valve	**Y**	Plan for inspection and prevention of the pipelines; the underground pipelines were progressively reconstructed as above ground pipelines on rack or, if not possible, located in trenches or provided with inspectable coating. The oil pipeline from Porto Marghera is equipped with cathode protection. For the drainage system: the oily network is entirely above-ground, and inspectable.
Constant updating of the documents, capable to demonstrate the physical and chemical compatibility of the substances chosen	**Y**	Probably yes (prescribed by the law)
Provision of a system for the collection of the small releases (adsorbing materials and pads nearby wells, sewer covers etc.)	**?**	Information not available
POINT 1b		
Separation of the areas potentially involved by releases from the other areas, using containment basins and dedicated collection lines	**Y**	The tanks of the plant are provided with containment basins, the loading areas are pavemented and equipped with perimeter curbs

PREVENTIVE/PROTECTIVE MEASURES	IES FULFILMENT	
	Y/N	**Description**
Arrangement of two different drainage lines for the rainfall water and the water employed in the process or interested by potential releases.	**Y**	IES has a double drainage network: - White sewer, for process water, vapor condensation, rainy water - Oily sewer, for the water coming from the tanks and process areas, containing hydrocarbons. This water is stored in a dedicated tank, from which is addressed to the TAS (biologic and physical chemical treatment) system.
Reduction of the areas interested by potential releases and provision of protection devices, such as waterproof paving, dedicated collection lines, etc.	**Y/N**	According to the documents release by the plant for AIA, the risk of soil and water contamination is limited because of specific containment measures: • installation of double bottoms on progress; periodical EA tests • the storage areas are connected to the oily drainage system, which addresses possible releases to TAS • the pipelines transporting hydrocarbons are above ground or easily inspectable • the oily sewer pipelines are entirely above ground • there are not underground tanks containing hazardous substances However, the containment basins have not a waterproof paving
Elimination or reduction of the junctions with flanges, and adoption of completely soldered lines	**?**	In the area of the dock, it was applied the reduction of the flanged couplings. No indication for the other parts of the plant.
Provision of devices for the registration and alarm related to unexpected loss of level of the tanks and basins	**Y**	The tanks are equipped with trip system for high and low levels. It is in progress the installation of logic solvers for the protection of the floating roof tanks from overfilling/overemptying.
Substitution or renovation of the underground tanks, according to the decree 20/10/1998 n. 260	**Y**	The only underground tanks are those for LPG, compliant with the provisions of Ministerial Decree 13.10.94
POINT 2		
Definitive lock of the unused wells located inside the plant, and external protection of those still in operation	**N**	The wells and piezometers composing the hydraulic barrier are all active and cannot be locked
Arrangement of the devices and measures foreseen by of the Regional regulation 20/2006 n 1/R on rainfall water collection.	**?**	Information not available
Provision of emergency devices (Adsorbing material, pads..) nearby wells and sewer covers in order to obstacle the access of the pollution agents to the municipal sewer	**?**	The water discharge is in Mincio; there is a continuous check of the water discharged by TAF (treatment of the water sucked by the hydraulic barrier). From the document, available, it is not clear if it is present an automatic lock of the drainage lines.
Arrangement of devices for an automatic lock of the drainage lines whether is detected the presence of pollution agents.	**?**	
Arrangement of emergency management procedures	**Y**	
POINT 3		
Assessment of the hydrogeological conditions nearby the plant and the points of possible release	**Y**	The hydrogeological conditions are periodically monitored by the plant and public authorities in relation to the project of recovery of the SIN area
Assessment of the times employed by the pollution agents to arrive to the sensitive elements	**?**	Information not available
Arrangement of emergency safety measures (Hydraulic barrier)	**Y**	64 wells act as an hydraulic barrier for the containment and removal of the supernatant hydrocarbon spot present in the underground water; a dedicated water treatment system (TAF) is present.

PREVENTIVE/PROTECTIVE MEASURES	IES FULFILMENT	
	Y/N	Description
Employment of off-ground tanks instead of those underground	Y	The only underground tanks are those for LPG, compliant with the provisions of Ministerial Decree 13.10.94
Paving of the area for the new plant with layers of waterproof materials	Y/N	Only some loading areas and some containment basins have waterproof paving
Employment of off-ground lines instead of those underground	Y	

Table 73: Ies NaTech protection measures

NA-TECH SAFETY AND MITIGATION MEASURES	IES FULFILMENT	
	Y/N	Description
Use of structural design codes or retrofitting	N	
Containment dikes or walls	N	
Use of structural design codes or retrofitting of walls and dikes	N	
Anchoring mechanisms of tanks and equipment (e.g. anchor bolts, bracing)	N	
Bracing of pipes and connections	N	
Flexible connections for pipes	?	Information not available
Restraining straps or chains for barrels or pressure vessels	?	Information not available
Strapping and anchoring of emergency equipment	?	Information not available
Emergency shut off/safety valves	Y	
Emergency water systems, and foam spraying systems	Y	- The firefighting water network encloses all the plant, distributing water to the protection points near the tanks and process units. The water is taken from the Inferior lake through electrical or diesel pumps; it can also be partially reintegrated with the water produced by the TAF. - The floating roof tanks are equipped with foam discharge devices along the roof sealing; all the tanks are equipped with cooling system for coating and roof. - The LPG tanks are provided with water firefighting pipelines. The entire LPG areas is equipped with dedicated firefighting system, using both pulverized water and foam. - the loading area for tanker trucks is equipped with firefighting automatic system, based on foam and water - the loading area for rail tankers is equipped with manual firefighting system, based on foam and water - 4 monitors are present for the protection of the dock area.
Adequate siting of emergency water and foam spraying systems to avoid damage from falling debris	?	Information not available
Redundancy in pipeline systems, particularly emergency water	?	Information not available, the redundancy is certainly active for the pumps
Warning systems	Y	
Emergency power generators designed to maintain critical equipment housing hazardous chemicals in safe condition for extended periods of time	?	Information not available
Routine inspection and maintenance for corrosion and deterioration	Y	Periodical inspection and maintenance, non-disruptive checks through ultrasounds, x-ray etc.

NA-TECH SAFETY AND MITIGATION MEASURES	IES FULFILMENT	
	Y/N	**Description**
Inventory control (e.g. minimizing the amount of hazardous materials used)	**?**	Information not available
Strategic placement of substances inside plant in order to avoid chemical incompatibility	**Y**	
Placement of storage tanks with hazmats above the maximum height reachable by water	**N**	
Construction of drainage system	**Y**	Double drainage system, equipped with emergency tanks and basins to adsorb an excessive charge
Interruption of production process	**Y**	The trip is foreseen for certain anomalies
De-inventory of main processing units	**?**	Information not available
Giving transport priority to most dangerous chemicals (those that react violently with water)	**?**	Information not available
Verification of storage tank seals	**Y**	Periodical checks of the integrity of tanks
Hermetic sealing of silos and underground storage tanks	**?**	Information not available
Wrapping of substances in watertight packing and labelling	**?**	Information not available
Raising of electrical equipment such as motors, pumps and control panels to avoid water damage and system failure	**?**	Information not available
Maintaining na-tech emergency response plan	**N**	
Construction of retaining walls and levees or dykes	**N**	
Drills and Training	**Y**	
Plan to allow workers to check on family	**?**	Information not available
Training plan for external responders on management of hazardous chemicals onsite	**?**	Information not available

Annex II: ALOHA and HSSM results

ALOHA and HSSM simulations and results for the items of Versalis and IES are showed. The scenarios for Toxic release, Flash-fire, pool-fire and environmental pollution are reported; VCE is not present because all the simulations returned results in which the Level of Concern was not exceeded.
The simulations aimed at reproducing the possible effects of the interactions between the industries and the natural events (Flood, Earthquake), but the Flood conditions were not tested for the items whose ground elevation made them safe from the flood wave.

The measures of the puddles obtained through ALOHA, and those reported as Input for HSSM are also shown. In case the basin of containment is settled as boundary (E), the maximum extension reached by the puddle coincides with the diameter of the basin, while in F conditions the puddle is allowed to expand on the water without boundaries, and therefore reaches bigger sizes.

Table 74: ALOHA and HSSM results for Versalis

VERSALIS								
		Damage areas						
Substance & item	**Damage state**	**Toxic release (IDLH)**		**Flash-fire 1) LFL 2) 60%LFL)**		**Pool-fire 1) 12,5 Kw/m² 2) 7 Kw/m² 3) 5 Kw/m²**		**Environmental pollution**
		F	**S**	**F**	**S**	**F**	**S**	
Benzene DA404, 5000 m³ Containment basin Ø = 52 m.	R3 10 mm	-	10 m (Puddle Ø = 6,9 m.)	-	1) and 2) < 10 m.	-	1) = 10 m. 2) < 10 m.	*R3 – 1 cm hole Puddle Ø:* 7,6 m, *r* = 3,8 m (median between puddle Ø obtained for benzene, ethylbenzene, cumene, toluene, styrene). KOPT: After a 3 hours release from the puddle, the pollutant can reach the underground water depth (6 m.) in 5 days. In half day, it overcomes 3 m. OILENS = around 10 m. in 25 days, 25 m. in 200 days
	R3 30 mm	-	57 m (Puddle Ø = 21 m.)	-	1) = LOC not exceeded 2) > 10 m	-	1) < 10 m. 2) < 10 m.	
	R2 225 mm	-	160 m (Puddle Ø = 52 m)	-	1) 15 m 2) 29 m	-	1) 43 m 2) 59 m 3) 71 m	
Acrylonitrile DA422, 750 m³ Containment	R3 10 mm	-	29 m (Puddle Ø = 7,3 m)	-	1) and 2) < 10 m.	-	1)<10 m 2)<10 m	Waterproof containment basin
	R3 30 mm	-	195 m (Puddle	-	2) level of	-	1)<10 m 2)<10 m	

VERSALIS								
Substance & item	**Damage state**	**Damage areas**						**Environmental pollution**
		Toxic release (IDLH)		**Flash-fire 1) LFL 2) 60%LFL)**		**Pool-fire 1) 12,5 Kw/m² 2) 7 Kw/m² 3) 5 Kw/m²**		
		F	**S**	**F**	**S**	**F**	**S**	
basin Ø = 30 m			Ø = 22 m)		concern never exceeded			
	R2 150 mm	-	347 m (Puddle Ø = 30 m)	-	2) level of concern never exceeded	-	1) 19 m 2) 27 m 3) 32 m.	
	R1[17]	-	358 m.	-	1) and 2) Level of Concern never exceeded	-	1) 41 m. 2) 55 m. 3) 65 m.	
Cumene DA408, 10000 m³ Containment basin Ø = 66 m	R3 10 mm	-	< 10 m (Puddle Ø = 8,1 m)	-	1) and 2) < 10 m	-	1)<10 m 2)<10 m	*R3 – 1 cm hole Puddle Ø:* 7,6 m, *r* = 3,8 m (median between puddle Ø obtained for benzene, ethylbenzene, cumene, toluene, styrene). KOPT: After a 3 hours release from the puddle, the pollutant can reach the underground water depth (6 m.) in 5 days. In half day, it overcomes 3 m. OILENS = around 10 m. in 25 days, 25 m. in 200 days
	R3 30 mm	-	12 m (Puddle Ø = 24 m)	-	1) 12 m. 2) 12 m	-	1)<10 m 2)<10 m	
	R2 225 mm	-	33 m (Puddle Ø = 66 m)	-	1) 17 m. 2) 17 m.	-	1) 44 m 2) 60 m 3) 71 m	
Cumene DA453, 5000 m³ Containment basin Ø = 50 m.	R3 10 mm	< 10 m (Puddle Ø = 12,6 m)	< 10 m (Puddle Ø = 8 m)	1) and 2) < 10 m	1) and 2) < 10 m	1)<10 m 2)<10 m	1)<10 m 2)<10 m	
	R3 30 mm	19 m (Puddle Ø = 38 m)	12 m (Puddle Ø = 24 m)	1) 19 m. 2) 19 m	1) 12 m. 2) 12 m	1)<10 m 2)<10 m	1)<10 m 2)<10 m	
	R2 225 mm	144 m (Puddle Ø = 289 m)	25 m (Puddle Ø = 50 m)	1)144 m 2)145 m	1) 17 m. 2) 17 m	1) 42 m 2) 58 m 3) 69 m	1) 44 m. 2) 60 m. 3)71 m.	
Ethylbenzene DA431,1000 m³ Containment basin Ø = 18 m	R3 10 mm	-	10 m (Puddle Ø = 7,9 m)	-	1) and 2) < 10 m	-	1) and 2) < 10 m	*R3 – 1 cm hole Puddle Ø*: 7,6 m, *r* = 3,8 m (median between puddle Ø obtained for benzene, ethylbenzene, cumene, toluene, styrene). KOPT: After a 3
	R3 30 mm	-	12 m (Puddle Ø = 24 m)	-	1) 12 m 2) 12 m	-	1) and 2) < 10 m	
	R2 150 mm	-	18 m (Puddle	-	1) 18 m 2) 18 m	-	1) 29 m 2) 40 m 3) 48 m	

[17] R1 damage state – catastrophic rupture, is simulated through a puddle source, having the same area of the containment basin (736 m²), and the same volume of the tank (750 m³).

VERSALIS								
		Damage areas						
Substance & item	Damage state	Toxic release (IDLH)		Flash-fire 1) LFL 2) 60%LFL)		Pool-fire 1) 12,5 Kw/m^2 2) 7 Kw/m^2 3) 5 Kw/m^2		Environmental pollution
		F	S	F	S	F	S	
			Ø = 36 m)					hours release from the puddle, the pollutant can reach the underground water depth (6 m.) in 5 days. In half day, it overcomes 3 m. OILENS = around 10 m. in 25 days, 25 m. in 200 days
Ethylbenzene DA406, 5000 m^3 Containment basin Ø =26 m	R3 10 mm	-	< 10 m (Puddle Ø = 7,9 m)	-	1) and 2) < 10 m	-	1) and 2) < 10 m	
	R3 30 mm	-	12 m (Puddle Ø = 24 m)	-	1) 12 m 2) 12 m	-	1) and 2) < 10 m	
	R2 225 mm	-	22 m (Puddle Ø = 52 m)	-	Level of concern never exceeded	-	1) 49 m 2) 60 m 3) 71 m	
Cyclohexanone DA460,5000 m^3 Containment basin Ø = 42 m	R3 10 mm	-	< 10 m (Puddle Ø = 7,9 m)	-	1) and 2) < 10 m	-	1) and 2) < 10 m	*R3 – 1 cm hole* *Puddle Ø:* 7,9 m. KOPT: After a 3 hours release from the puddle, the pollutant arrives around 3 m. underground. It can reach the water-table only with a release of 12 h. from the puddle. OILENS = around 10 m. in 25 days, 30 m. in 200 days
	R3 30 mm	-	12 m (Puddle Ø = 24 m)	-	1) 12 m 2) 12 m	-	1) and 2) < 10 m.	
	R2 225 mm	-	21 m (Puddle Ø = 42 m)	-	1) 21 m. 2) 21 m.	-	1) 41 m 2) 56 m 3) 66 m	
Cyclohexanone DA1001, 2000 m^3 Containment basin Ø = 36 m.	R3 10 mm	< 10 m (Puddle Ø = 12,9 m)	< 10 m (Puddle Ø = 7,9 m)	1) and 2) < 10 m.	1) and 2) < 10 m.	1) and 2) < 10 m.	1) and 2) < 10 m.	
	R3 30 mm	19 m (Puddle Ø = 39 m)	12 m (Puddle Ø = 24 m)	1) 19 m 2) 19 m	1) 12 m 2) 12 m	1) and 2) < 10 m 3) 11 m	1) and 2) < 10 m.	
	R2 150 mm	98 m (Puddle Ø = 196 m)	18 m (Puddle Ø = 36 m)	1) 98 m 2) 98 m	1) 18 m 2) 18 m	1) 26 m 2) 36 m 3) 43 m	1) 27 m 2) 37 m 3) 45 m	
Toluene DA417, 2000 m^3 Containment basin Ø = 36 m	R3 10 mm	-	< 10 m (Puddle Ø=7,4 m)	-	1) and 2) < 10 m	-	1) and 2) < 10 m	*R3 – 1 cm hole* *Puddle Ø:* median measure between those obtained for benzene / ethylbenzene /cumene / toluene / styrene = Ø 7,6 m, r = 3,8 m. KOPT: After a 3 hours release from the puddle, the pollutant can reach the underground water depth (6 m.) in 5 days. In half
	R3 30 mm	-	53 m (Puddle Ø = 22 m)	-	2) level of concern never exceeded	-	1)<10 m 2)<10 m	
	R2 150 mm	-	79 m (Puddle Ø = 36 m)	-	1) and 2) < 10 m	-	1) 28 m 2) 40 m 3) 47 m	
Toluene DA428	R3 10 mm	-	< 10 m (Puddle Ø=7,4 m)	-	1) and 2) < 10 m	-	1) and 2) < 10 m	

VERSALIS								
Substance & item	**Damage state**	**Damage areas: Toxic release (IDLH)**		**Flash-fire 1) LFL 2) 60%LFL)**		**Pool-fire 1) 12,5 Kw/m^2 2) 7 Kw/m^2 3) 5 Kw/m^2**		**Environmental pollution**
		F	**S**	**F**	**S**	**F**	**S**	
1000 m^3 Containment basin Ø =.33 m	R3 30 mm	-	53 m (Puddle Ø = 22 m)	-	2) level of concern never exceeded	-	1) and 2) < 10 m	day, it overcomes 3 m. OILENS = around 10 m. in 25 days, 25 m. in 200 days
	R2 150 mm	-	71 m (Puddle Ø = 33 m)	-	1) and 2) < 10 m	-	1) 28 m 2) 40 m 3) 47 m	
Toluene DA450 & DA451, 2000 m^3 Containment basin Ø = 31 m	R3 10 mm	< 10 m (Puddle Ø = 9,4 m)	< 10 m (Puddle Ø = 7,4 m)	1) and 2) < 10 m	1) and 2) < 10 m	1) and 2) < 10 m.	1) and 2) < 10 m	
	R3 30 mm	25 m (Puddle Ø = 29 m)	53 m (Puddle Ø = 22 m)	1) 14 m 2) 14 m	2) level of concern never exceeded	1) and 2) < 10 m 3) 12 m	1) and 2) < 10 m	
	R2 150 mm	122 m (Puddle Ø = 152 m)	66 m (Puddle Ø = 31 m)	2) level of concern never exceeded	2) level of concern never exceeded	1) 28 m 2) 39 m 3) 46 m	1) 28 m 2) 40 m 3) 47 m	
Styrene DA1007,1000 m^3 Containment basin Ø = 18 m	R3 10 mm	< 10 m (Puddle Ø = 12,4 m)	< 10 m (Puddle Ø = 7,9 m)	1) and 2) < 10 m.	1) and 2) < 10 m	1) and 2) < 10 m	1) and 2) < 10 m	*R3 – 1 cm hole* *Puddle Ø:* median measure between those obtained for benzene / ethylbenzene /cumene / toluene / styrene = Ø 7,6 m, *r* = 3,8 m. KOPT: After a 3 hours release from the puddle, the pollutant can reach the underground water depth (6 m.) in 5 days. In half day, it overcomes 3 m. OILENS = around 10 m. in 25 days, 25 m. in 200 days
	R3 30 mm	19 m (Puddle Ø = 38 m)	< 10 m (Puddle Ø = 18 m)	1) 19 m 2) 19 m	1) and 2) < 10 m	1) and 2) < 10 m 3) 12 m	1) and 2) < 10 m	
	R2 150 mm	95 m (Puddle Ø = 190 m)	< 10 m (Puddle Ø =18 m)	1) 95 m 2) 95 m	1) and 2) < 10 m	1) 28 m 2) 39 m 3) 47 m	1) 29 m 2) 40 m 3) 48 m	
Styrene DA1013 & DA1014, 2000 m^3 Containment basin Ø = 36 m	R3 10 mm	< 10 m (Puddle Ø = 12,4 m)	< 10 m (Puddle Ø = 7,9 m)	1) and 2) < 10 m.	1) and 2) < 10 m.	1) and 2) < 10 m.	1) and 2) < 10 m.	
	R3 30 mm	19 m (Puddle Ø = 38 m)	12 m (Puddle Ø = 24 m)	1) 19 m 2) 19 m	1) 12 m 2) 12 m	1) and 2) < 10 m 3) 12 m	1) and 2) < 10 m.	
	R2 150 mm	95 m (Puddle Ø = 190 m)	18 m (Puddle Ø = 36 m)	1) 95 m 2) 95 m	1) and 2) < 10 m.	1) 28 m 2) 39 m 3) 47 m	1) 29 m 2) 40 m 3) 48 m	
Benzene	R3 10 mm	-	< 10 m (Puddle Ø = 6,6 m)	-	1) and 2) < 10 m	-	1) and 2) < 10 m	Not executed (see results for the benzene tanks)

VERSALIS								
		Damage areas						
Substance & item	**Damage state**	**Toxic release (IDLH)**		**Flash-fire 1) LFL 2) 60%LFL)**		**Pool-fire 1) 12,5 Kw/m² 2) 7 Kw/m² 3) 5 Kw/m²**		**Environmental pollution**
		F	**S**	**F**	**S**	**F**	**S**	
Rail tanker[18]	R3 30 mm	-	67 m (Puddle Ø = 20 m)	-	1) and 2) < 10 m	-	1) and 2) < 10 m	
Acrylonitrile	R3 10 mm	-	33 m (Puddle Ø = 7 m)	-	1) and 2) < 10 m	-	1) and 2) < 10 m	
Rail tanker	R3 30 mm	-	220 m (Puddle Ø = 21 m)	-	1) and 2) LOC never exceeded	-	1) and 2) < 10 m	
Phenol	R3 10 mm	-	< 10 m (Puddle Ø = 14,7 m)	-	1) and 2) < 10 m	-	1) and 2) < 10 m	
FB1319, 1000 m³ Containment basin Ø = 22	R3 30 mm	-	11 m (Puddle Ø = 22 m)	-	1) 11 m 2) 11 m	-	1) 11 m 2) 11 m	Not executed (DNAPL)
	R2 150 mm	-	P11 m (Puddle Ø = 22 m)	-	1) 15 m 2) 29 m	-	1) 43 m 2) 59 m 3) 71 m	

Table 75: ALOHA and HSSM results for IES

IES								
		Damage areas						
Substance & item	**Damage state**	**Toxic release (IDLH)**		**Flash-fire 1) LFL 2) 60%LFL)**		**Pool-fire 1) 12,5 Kw/m² 2) 7 Kw/m² 3) 5 Kw/m²**		**Environmental pollution**
		F	**S**	**F**	**S**	**F**	**S**	
Diesel fuel 111, 60000 m³ Containment basin Ø = 100 m.	R3 10 mm	Not toxic	Not toxic	*The chemical sinks in the water*	1) and 2) < 10 m (Puddle Ø = 19,5 m)	-	1)<10 m 2)<10 m 3) 10 m.	*R3 – 1 cm hole Puddle Ø:* 19, 5 m. KOPT: After a 3 hours release from the puddle, the pollutant reaches 2 m. underground. It arrives to the water

[18] For the rail tankers simulations, generic dimension typical of the rail tankers for hydrocarbon products were employed: length 10,8 m., width 2,87 m., height 4,6 m, internal volume 73 m³. The rail tankers are usually employed by Versalis for the transportation of its raw materials; benzene and acrylonitrile were chosen because they are among the most dangerous substances detained. The point of release was settled nearby the Lunetta Frassine station, in order to verify the risk for the urban functions around the railways. No limits for the puddle were imposed.

Substance & item	Damage state	IES Damage areas: Toxic release (IDLH)		Flash-fire 1) LFL 2) 60%LFL)		Pool-fire 1) 12,5 Kw/m² 2) 7 Kw/m² 3) 5 Kw/m²		Environmental pollution
		F	S	F	S	F	S	
	R3 30 mm	Not toxic	Not toxic		1) 29 m 2) 29 m (Puddle Ø 58 m)	-	1) 19 m 2) 26 m 3) 30 m	depth (6 m.) in 5 days after 14 hours of release. OILENS = around 30 m. in 25 days, 65 m. in 200 days
	R2 300 mm	Not toxic	Not toxic		1) 50 m 2) 50 m (Puddle Ø 100 m)	-	1) 148 m 2) 193 m 3) 224 m	
Gasoline 109, 40000 m³ Containment basin Ø = 80 m	R3 10 mm	Not toxic	Not toxic	1) and 2) < 10 m (Puddle Ø = 11,6 m)	1) and 2) < 10 m (Puddle Ø = 10,2 m)	1) and 2) < 10 m	1) and 2) < 10 m	*R3 – 1 cm hole* *Puddle Ø*: 10,2 m. KOPT: After a 3 hours release from the puddle, the pollutant can reach the underground water depth (6 m.) in 5 days. In half day it overcomes 3 m. OILENS = around 15 m. in 25 days, 40 m. in 200 days
	R3 30 mm	Not toxic	Not toxic	1) 18 m 2) 18 m (Puddle Ø = 36 m)	1) 15 m. 2) 16 m (Puddle Ø = 31 m)	1) and 2) < 10 m	1) and 2) < 10 m	
	R2 300 mm	Not toxic	Not toxic	Puddle Ø = 390 m level of concern never exceeded	Puddle Ø = 80 m level of concern never exceeded	1) 42 m 2) 57 m 3) 67 m	1) 144 m 2)190 m 3) 222 m	
Gasoline 9, 28000 m³ Containment basin Ø = 54 m	R3 10 mm	Not toxic	Not toxic	1) and 2) < 10 m (Puddle Ø = 11,8 m)	1) and 2) < 10 m (Puddle Ø = 10,4m)	1) and 2) < 10 m	1) and 2) < 10 m	Not executed
	R3 30 mm	Not toxic	Not toxic	1) 18 m. 2) 18 m (Puddle Ø = 36 m)	1) 16 m. 2) 16 m (Puddle Ø = 31 m)	1) and 2) < 10 m	1) and 2) < 10 m	
	R2 300 mm	Not toxic	Not toxic	LOC never exceeded (Puddle Ø = 390 m)	LOC never exceeded (Puddle Ø = 54 m)	1) 42 m. 2) 57 m. 3) 67 m	1) 43 m 2) 58 m 3) 69 m	
	R2 1000 mm	Not toxic	Not toxic	1) 18 m 2) 18 m Puddle Ø = 36 m	1) 16 m. 2) 16 m (Puddle Ø = 31 m)	1) 173 m 2) 227 m 3) 225 m	1) 98 m 2) 130 m 3) 153 m	

IES								
		Damage areas						
Substance & item	Damage state	Toxic release (IDLH)		Flash-fire 1) LFL 2) 60%LFL)		Pool-fire 1) 12,5 Kw/m² 2) 7 Kw/m² 3) 5 Kw/m²		Environmental pollution
		F	S	F	S	F	S	
MTBE/ETBE 14, 2000 m³ Containment basin Ø = 28 m.	R3 10 mm	Not toxic	Not toxic	-	1) and 2) < 10 m (Puddle Ø = 4,9 m)	-	1) and 2) < 10 m	*R3 – 1cm hole* *Puddle Ø:* 4,9 m. KOPT: After a 2 hours release from the puddle, the pollutant can reach the underground water depth (6 m.) in 1 day. In half day it overcomes 3 m. OILENS = around 23 m. in 25 days, 40 m. in 200 days
	R3 30 mm	Not toxic	Not toxic	-	1) 12 m 2) 19 m (Puddle Ø = 15,2 m)	-	1) and 2) < 10 m	
	R2 150 mm	Not toxic	Not toxic	-	1) 31 m 2) 41 m (Puddle Ø = 28 m)	-	1) 52 m 2) 72 m 3) 86 M	

Annex III: Territorial and environmental vulnerabilities in Mantua

Table 76: Territorial vulnerable elements in Mantua (AREAL)

Mantua City Plan (P.G.T.) – urban zones			DM 09/05/2001 category	
Article	**Definition**	**Building ratio index**	**Category assigned**	**Notes**
D14	"Civitas vetus", area included in the first town-walls	Not specified	A	The category assigned for these functions was A, because of their dense urban pattern and high frequentation
D15	Area include in the second town-walls	Not specified		
D16	More recent areas, with values analogous to those of the historical centre	Not specified		
D17	Ancient Borgo Angeli	Not specified	B	The category for this little village outside walls was chosen according to its architectural characteristics and to the category of the surrounding residential areas
D18	Residential areas Valletta Paiolo, Viale Risorgimento, Valletta Valsecchi	1,05 m^2/m^2	B	-
D19	Residential areas	0,75 m^2/m^2	B	-
D20	Areas for economic activities	1,10 m^2/m^2	B C E	The article D20 include areas with very different functions, both commercial and productive. Therefore, the areas were explored one by one in order to assign the right category: the industrial areas were classified as E, the biggest shopping centres obtained a category B, while other selling activities were classified as C
D21	Areas for productive and industrial activities	Not relevant	E	-
D22 D23 D24	Areas subjected to transformations into residential or productive functions	Variable	Variable	The Building ratio index is defined by the PGT for each area; they were classified in accordance to their future function

Table 77: Territorial vulnerable elements in Mantua (PUNCTUAL)

Function	Element	DM 09/05/2001 category
Schools	Scuola dell'Infanzia CALVI; Scuola primaria Allende; Scuola dell'infanzia Berni; Scuola primaria Tazzoli; Scuola dell'infanzia Pacchioni; Scuola secondaria I grado Leon Battista Alberti; Scuole Mons. Martini e Istituto casa Pace; Liceo Ginnasio Virgilio; Istituto privato Redentore; Liceo Scienze Umane I. D'Este + primaria Nievo; For.ma CFP + primaria Ardigò + media Sacchi; Scuola dell'infanzia "Casa dei Bambini"; Istituti Santa Paola; Scuola dell'Infanzia V. Da Feltre; Asilo nido Charlie Chaplin; Scuola Inf. Ferrari + secondaria Bertazzoli; Scuola Infanzia Strozzi Valenti; Scuola infanzia Montessori; Scuola infanzia Visentini; Scuola Infanzia Rodari; Istituto superiore Mazzolari; Scuola Infanzia A.Frank; Scuola primaria Don Mazzolari; Scuola infanzia Collodi; Scuola primaria De Amicis; Scuola Infanzia Sawyer, primaria Don Leoni; Scuola inf. Campogalliani, primaria Martiri di B.; Scuola infanzia Ricordo c. + primaria D. Minzoni; Asilo nido Kelder Asilo nido Soncini; Scuola primaria Pomponazzo; Succursale liceo Belfiore	A
Cultural/cult and sport centers	Museo archeologico, Palazzo ducale, S. Barbara	
Social assistance centers	Casa di riposo Sereno Soggiorno; Casa di riposo Isabella d'este; Casa di cura San Clemente; Azienda sanitaria locale Mantova; Istituti Geriatrici Mazzali; Poliambulatorio	
Schools	ITG "D'Arco" e ITC "Pitentino"; Istituto tecnico A. Mantegna; Istituto tecnico A. Mantegna – succursale; Conservatorio; Istituti industriali FERMI e DA VINCI; Istituto tecnico agrario; Fondazione Università di Mantova; POLIMI - polo Mantova; Istituto d'Arte Romano; Liceo scientifico Belfiore	B
Cultural/cult and sport centers	Sala concerti e centro polifunzionale PalaBam; Società Canottieri del Mincio; Duomo di Mantova e Seminario vescovile	
Social assistance centers	Villaggio SOS; SERT Lombardia; Azienda ospedaliera Poma - centro Salute Mentale; Casa di cura Villa al Lago	
Others	Campo nomadi; stazione centrale	
Cultural/cult and sport centers	Palazzo Tè; Biblioteca colle Aperto e Circoscrizione Nord; Museo diocesano; Teatro scientifico Bibiena e accademia virgiliana; Biblioteca comunale; Biblioteca - mediateca Baracca; Teatro Minimo; Centro sociale Valletta Valsecchi; Museo di Palazzo d'Arco; Teatro sociale Mantova; Palazzo Cantoni Marca; Palazzo Museo della Città; Palazzo S. Sebastiano del Mago; Casa del Mantegna; Circolo ARCI; Parrocchia B.V. Maria e S. Urbano; Parrocchia di s. Maria dei miracoli; Congregazione Suore di Gesù Buon pastore; Parrocchia di S. Ruffino e Beato G. Bono; Parrocchia di San Michele Arcangelo; Basilica di Sant'Andrea; Rotonda di san Lorenzo; Parrocchia di Santa Maria della carità; Parrocchia di San Barnaba; Chiesa Santa Teresa e convento Carmelitani; Parrocchia di Sant'Egidio; Parrocchia di Santa Caterina; Parrocchia di Santa Maria del Gradaro; Chiesa SS. Simone e Giuda; Parrocchia di S.Pio V e pertinenze; Parrocchia s. Giuseppe Artigiano; Parrocchia s.Filippo Neri; Chiesa SS. Gervasio e Protazio; Chiesa di San Francesco; Chiesa di Sant'Orsola; Chiesa di San Maurizio; Chiesa San Luigi Gonzaga; Sala del Regno testimoni di Geova; Chiesa di Sant'Apollonia; Chiesa s. Maria degli Angeli; chiesa di San Leonardo; Chiesa di San Sebastiano; Chiesa di S. Spirito; Campi da calcio Filippi; Ippodromo e stadio comunale; Centro sportivo comunale Neolù; Tennis club Poggio Reale; Campi da calcio; Campo da basket; Pista atletica e campo basket; Tennis club Mantova; Campi da calcio Cugola; Centro sportivo Migliaretto e U.S. Rugby; Circuito motocross; Piscina comunale Dugoni; Area sosta camper di Sparafucile; Centro polisportivo San Lazzaro; La Spiaggetta; Aree verdi attrezzate Piazza Virgiliana; Aree verdi attrezzate Piazza dei Mille; Aree verdi attrezzate Giardini valentini; Giardini Tazio Nuvolari	C
Offices and public services	Centro direttivo TEA s.p.a.; Camera di commercio; Consorzio di bonifica Territori del Mincio; CISL sindacato; Istituto zooprofilattico; Provveditorato agli studi; Comune Settore Lavori pubblici; ENAIP Lombardia e Centro per l'impiego; Polizia postale e telecomunicazioni; API associazione piccole e medie industrie; INPS; Poliambulatorio veterinario	
Others	Stazione Borgochiesanuova; Stazione Frassine	
Others	Cimitero di Formigosa; Cimitero di Frassine; Cimitero di San Giorgio; Bosco Virgliano e Parcobaleno; Cimitero monumentale	D

Table 78: Territorial vulnerable elements in Mantua (OTHERS)

LINEAR ELEMENTS	
Power line	
Methan pipeline	
Services pipelines for the plants Versalis and IES	
Main road: E45 Brennero highway, Mantua orbital road	
STRATEGIC ELEMENTS	
Civil protection areas	Area di ricovero R1; Area di ricovero R2; Area di attesa A; Area di ricovero R3; Area stoccaggio mezzi/materiali S1; Area stoccaggio mezzi/materiali S2
Strategic infrastructures[19]	Impianto idrovoro Valsecchi; Depuratore; Impianto idrovoro Paiolo Basso; Impianto idrovoro Ponte Arlotto; TEA cabina metano; Centrale elettrica; Impianto di sollevamento Quattro venti
Strategic buildings	Polizia di stato e polizia stradale; Questura; Corpo forestale dello stato; Comune di Mantova; Prefettura; Tribunale di Mantova; Casa circondariale Mantova; Palazzo Soardi - uffici comunali; Guardia di Finanza; Polizia locale; Ospedale Carlo Poma; Caserma militare San Martino; Caserma polizia di Stato; Regione Lombardia – STER; Carabinieri; VVF Mantova

Table 79: Environmental vulnerable elements in Mantua

EXTREME VULNERABILITY	DOCUMENT SOURCE	Presence in Mantua
1. Protected natural areas (national, regional, provincial)	Comune di Mantova, Piano di Governo del Territorio, Rapporto Ambientale, Carta delle Sensibilità, nov. 2012	**YES** Mincio natural park
2. *Natura 2000 ex* Directive 92/43/CEE "*Habitat*" areas	Comune di Mantova, Piano di Governo del Territorio, Rapporto Ambientale, Carta delle Sensibilità, nov. 2012	**YES** SIC IT20B0017 Ansa e Valli del Mincio SIC IT20B0010 Vallazza
3. Landscapes protected by D.Lgs.42/2004 s.m.i. art. 142, letters: *b*, (300 m. areas around the lakes), *d* (mountains higher than 1600 m), *m* (archaeological areas)	Comune di Mantova, Piano di Governo del Territorio, Rapporto Ambientale, Carta delle Sensibilità, nov. 2012	**YES** Area 300 m. around Mincio lakes Archaeological site in the city centre
4. *A and B* zones from PAI plan, areas with very high or high hydrogeological instability	Comune di Mantova, Piano di Governo del Territorio, Rapporto Ambientale, Carta delle Criticità, nov. 2012	**YES** A and B zones Mincio river
5. Landslides	Comune di Mantova, Piano di Governo del Territorio, Rapporto Ambientale, Carta delle Criticità, nov. 2012	**NO**
6. Residential areas to be transferred or consolidated according to legge 9 luglio 1908 n. 445 e s.m.i.	Comune di Mantova, Piano di Governo del Territorio, Rapporto Ambientale, Carta delle Criticità, nov. 2012	**NO**

[19] not listed as Protection Measures for the hazards

RELEVANT VULNERABILITY	DOCUMENT SOURCE	Presence in Mantua
1. Historical monuments, protected landscape / environmental archaeological areas	Comune di Mantova, Piano di Governo del Territorio, Rapporto Ambientale, Carta delle Sensibilità, nov. 2012	**YES** Historical monuments L. 1089/1939; Landscape areas protected by L. 1497/1939: Mantova e Cittadella, Lago Mezzo e Inferiore, Fiume Mincio; area subjected to Hydrogeological protection by the PTC Plan for Mincio park
2. *geositi*	Comune di Mantova, Piano di Governo del Territorio, Rapporto Ambientale, Carta delle Sensibilità, nov. 2012	**NO**
3. Landscapes protected by D.Lgs.42/2004 s.m.i. art. 142, letter *g*: (wood areas)	Comune di Mantova, Piano di Governo del Territorio, Rapporto Ambientale, Carta delle Sensibilità, nov. 2012	**YES**
4. Area subjected to hydrogeological restrictions ex l.r. 45/1989.	Geoportale Regione Lomabardia, Aree vincolo idrogeologico 2013	**NO**
5. Landscapes protected by D.Lgs.42/2004 s.m.i. art. 142, letter *c*, (150 m. areas around rivers and public creeks)	Comune di Mantova, Piano di Governo del Territorio, Rapporto Ambientale, Carta delle Sensibilità, nov. 2012	**YES**
6. *Environmental passageways*	Geoportale Regione Lombardia. Rete Ecologica Regionale, 2011	**YES**
7. *Land use capacity categories 1 and 2*	Geoportale Regione Lombardia, Basi informative dei suoli, 2013.	**YES**
8. *Typical / specialized agriculture*	Geoportale Regione Lombardia. Aree di pregio vitivinicole	**NO**
9. C zones from PAI plan, areas with moderate hydrogeological instability	Comune di Mantova, Piano di Governo del Territorio, Rapporto Ambientale, Carta delle Criticità, nov. 2012	**YES** C zones Mincio river
10. fasce di rispetto fluviali a media probabilità di inondazione, indicate da studi della Provincia	-	-
11. *Underground water with very high or high vulnerability*	Geoportale Regione Lombardia. PTUA – Piano di Tutela e Uso delle Acque, 2013	**YES** The entire Mantua territory is characterized by a vulnerability high or very high
12. Aquifer recharge areas	Geoportale Regione Lombardia. PTUA – Piano di Tutela e Uso delle Acque, 2013	**NO**
13. Underground water depth > 3 m.	Comune di Mantova, PGT - Studio Geologico-Tecnico, Parte Prima – Relazione Geologica Generale, 2012 Comune di Mantova, PGT - Studio Geologico-Tecnico, Tavola 4.1 Carta Idrogeologica e della Vulnerabilità, 2012	**YES** The available documents do not allow to draw a complete mapping on ArcGis; however, in many parts of Mantua the underground water depth is very scarce. The specific depth below the Seveso plants could is between 4 and 20 meters.
14. Underground water depth from 3 m. to 10 m., sandy or loamy soils		

Annex IV: Case-study 2, territorial and environmental vulnerabilities

Table 80: Territorial vulnerable elements (AREAL)

City Plan (P.R.G.) – urban zones			DM 09/05/2001 category	
Code	**Definition**	**Building ratio index**	**Category assigned**	**Notes**
R1/1	Historical city center and hamlets	Not specified	C	The building ratio index is usually not provided for historical areas; the category was established in cooperation with the Municipal technicians on the basis of the type of buildings and attendance of the zone.
R 1/2		Not specified		
R 1/3		Not specified		
R 1/4		Not specified		
R 2/1	Consolidated residential areas	0.35 m^2/m^2	C	
R 2/2		0.35 m^2/m^2		
R 3/1	Areas for urban completion (residential use)	0.30 m^2/m^2	D	
R 3/2		0.20 m^2/m^2		
R 3/3		0.45 m^3/m^2	C	
R 3/4		0.45 m^2/m^2		
R 4	Area for urban completion in agricultural context	0.10 m^2/m^2	E	
R 5	Areas subjected to transformation with residential purposes	0,50 m^2/m^2	B	
R 5/1		0,50 m^2/m^2		
R 5/2		0,50 m^2/m^2		
R 6/2		0,60 m^2/m^2		
R 6/3		0,50 m^2/m^2		
P 1/1	Existing Productive areas	Not relevant	E	
P 1/2		Not relevant		
P 1/3	Existing productive areas, potentially subjected to transformation for commercial or tertiary purposes	Not relevant	C	A precautionary "C" value was assigned because of the future transformations. The interventions shall be monitored, and the category will be modified in accordance to the future settlements.
P 1/4	Saturated productive areas	Not relevant	E	
P 1/5		Not relevant		
P 1/6		Not relevant		
P 2		Not relevant	C	A precautionary "C" value was assigned because of the future transformations. The

City Plan (P.R.G.) – urban zones			DM 09/05/2001 category	
Code	**Definition**	**Building ratio index**	**Category assigned**	**Notes**
P 2/1	Productive areas for completion and new installations, also for tertiary use	Not relevant		interventions shall be monitored, and the category will be modified in accordance to the future settlements.
P 3/1		Not relevant		
P 4	Productive areas for completion and new installations	Not relevant	E	
P 5		Not relevant		
T 1/1	Existing commercial / tertiary areas	Not relevant	C	A precautionary "C" value was assigned; however, each area was punctually investigated to identify possible Punctual vulnerable element.
T 1/2		Not relevant		

Table 81: Territorial vulnerable elements (PUNCTUAL)

N	Element	Address	Maximum capacity	Attendance	Inside/outside exposure	Category
			INSTRUCTION SERVICES			
	A Nursery		60 pupils	Daily	Inside / outside	B.2
	Nursery		24 pupils	Daily	Inside / outside	B.2
	Nursery		25 pupils	Daily	Inside / outside	B.2
	Nursery		20 pupils	Daily	Inside / outside	B.2
	Nursery		12 pupils	Daily	Inside / outside	B.2
	Nursery		100 pupils	Daily	Inside / outside	A.2
	preschool		50 pupils	Daily	Inside / outside	B.2
	preschool		125 pupils	Daily	Inside / outside	A.2
	preschool		26 pupils	Daily	Inside / outside	B.2
	preschool		136 pupils	Daily	Inside / outside	A.2
	2 preschool		46 pupils	Daily	Inside / outside	B.2
	primary school		550 students	Daily	Inside / outside	A.2
	primary school		108 students	Daily	Inside / outside	A.2
	secondary school		397 students	Daily	Inside / outside	A.2
	University of the third age		480 students	Daily	Inside	C.2
	training centre		20 students	Weekly	Inside	C.2
	Tsecondary private school		20 students /year	Daily	Inside / outside	C.2
			HEALTHCARE AND SOCIAL ASSISTANCE SERVICES			
18	Free clinic and other healthcare and assistance services		Max 800 users	Daily	Inside	B.4
19	nursing house		45 places	Daily	Inside	A.2
20	nursing house		12 places	Daily	Inside	B.2
21	Physiotherapy center		10 places	Daily	Inside	C.3
22	social assistance center		12 places	Daily	Inside / outside	B.2
23	SER.T ASL		12 places	Daily	Inside / outside	B.2
24	Library and multimedia center		40 places	Weekly	Inside	C.3
25	Municipal senior center		55 places	Daily	Inside	C.3
26	Parish Cinema - Auditorium		203 seats	Weekly	Inside	C.3
27	Oratory		80 places	Daily	Inside / outside	B.2
28	Sporty center		90 users	Daily	Outside	C.3
29	Sport city		4500 users	Daily	Inside / outside	B.4
30	Jehovah's Witnesses center		2000 places inside, 4000 outside	Weekly	Inside / outside	B.5
31	bowls club		Max 90 users	Weekly	Inside / outside	C.3
32	parish		Max 320 users	Weekly	Inside	C.3
33	church		Max 75 users	Weekly	Inside	C.3
34	church		Max 120 users	Weekly	Inside	C.3

N	Element	Address	Maximum capacity	Attendance	Inside/outside exposure	Category
35	church		Max 50 users	Occasional	Inside	D.2
36	church		Max 620 users	Weekly	Inside	C.3
37	sanctuary		Max 50 users	Occasional	Inside	D.2
	COMMERCIAL CENTRES, HOTELS					
38	Supermarket		Max 340 users	Daily	Inside	C.2
39	Commercial mall		Max 220+140 users	Daily	Inside	C.2
40	Commercial mall		Max 870 users	Daily	Inside	B.4
41	shop		Max 180 users	Daily	Inside	C.2
42	Supermarket		Max 190 users	Daily	Inside	C.2
43	Supermarket		Max 150 users	Daily	Inside	C.2
44	Supermarket		Max 170 users	Daily	Inside	C.2
45	Shop		Max 300 user	Daily	Inside	C.2
46	Bowling + dancing hall		Max 1400 users	Daily	Inside	B.5
47	discotheque		Max 1800 users	Daily	Inside	B.5
48	dancing hall		Max 740 users	Daily	Inside	C.3
49	fishers' club		-	Weekly	Outside	C.3
50	Hotel		130 beds	Daily	Inside	C.2
51	Agritourism		40 beds	Daily	Inside	C.2
52	Agritourism		35 beds	Daily	Inside	C.2
53	restaurant		21 beds	Daily	Inside	C.2
54	Hotel		14 beds	Daily	Inside	C.2
55	B&b		68 beds	Daily	Inside	C.2
56	Public Market		1000 users	Weekly	Outside	B.5
57	Cemetery		40/50	Daily	Outside	D.2
58	museum		90	Daily	Inside	C.2
59	Postal office		90	Daily	Inside	C.2
60	Municipality		36-90	Daily	Inside	C.2

Table 82: Territorial vulnerable elements (OTHERS)

LINEAR ELEMENTS	
Highway	
Provincial roads	
Power lines	
Methane gas line	
STRATEGIC ELEMENTS	
Strategic infrastructures	Electric power plant
Strategic buildings	Caserma carabinieri, Polizia Municipale

Table 83: Environmental vulnerable elements

EXTREME VULNERABILITY	DOCUMENT SOURCE	Presence
1. Protected natural areas (national, regional, provincial)	Provincia di Torino, P.T.C. 2 – Tavola 3.1 Sistema del Verde e delle Aree libere, 2011	**NO**
2. *Natura 2000 ex* Directive 92/43/CEE "*Habitat*" areas	Provincia di Torino, P.T.C. 2 – Allegato 3: Quaderno Sistema del verde e delle aree libere. Core areas, 2011 Provincia di Torino, P.T.C. 2 – Allegato 3: Quaderno Sistema del verde e delle aree libere. Buffer zones, 2011 Provincia di Torino, P.T.C. 2 – Schede comunali	**NO**
3. Landscapes protected by D.Lgs.42/2004 s.m.i. art. 142, letters: *b*, (300 m. areas around the lakes), *d*	Provincia di Torino, P.T.C. 2 – Tavola 3.1 Sistema del Verde e delle Aree libere, 2011 Comune di xxxx, Piano Regolatore Generale, 2000	**NO**

(mountains higher than 1600 m), *m* (archaeological areas)		
4. *A and B* zones from PAI plan, areas with very high or high hydrogeological instability	Provincia di Torino, P.T.C. 2 – Tavola 5.1 Quadro del dissesto idrogeologico, dei Comuni classificati sismici e degli abitati da trasferire e consolidare, 2011 Provincia di Torino, P.T.C. 2 – Allegati cartografici del Servizio Difesa del Suolo e Attività Estrattiva, Area Risorse Idriche e qualità dell'Aria: Tavola DS2a, Carta dei Dissesti – Ambito Nord 4, Riquadro 2, 2011 Provincia di Torino - Messa in sicurezza del reticolo idrografico del territorio posto tra il T. …. e il T. …..: Studio di fattibilità. Tav. GEO-2E, Carta geomorfologica e delle opere di difesa idrauliche censite, 2009	**YES**
5. Landslides	Provincia di Torino, P.T.C. 2 – Tavola 5.1 Quadro del dissesto idrogeologico, dei Comuni classificati sismici e degli abitati da trasferire e consolidare, 2011	**NO**
6. Residential areas to be transferred or consolidated according to legge 9 luglio 1908 n. 445 e s.m.i.		**NO**
RELEVANT VULNERABILITY	**DOCUMENT SOURCE**	**Presence**
1. Historical monuments, protected landscape / environmental archaeological areas	Comune di xxxx, Piano regolatore generale, 2000	**YES** Proposed by Turin province a new protected area. Monumental heritage buildings: 5
2. *geositi*	Regione Piemonte, Piano Paesaggistico regionale, Elenchi delle componenti e delle unità di paesaggio, 18 maggio 2015 (adozione)	**NO**
3. Landscapes protected by D.Lgs.42/2004 s.m.i. art. 142, letter *g*: (wood areas)	Provincia di Torino, P.T.C. 2 – Tavola 3.1 Sistema del Verde e delle Aree libere, 2011 Provincia di Torino, P.T.C. 2 – Schede comunali, agosto 2013	**NO**
4. Area subjected to hydrogeological restrictions ex l.r. 45/1989.	Provincia di Torino - Difesa del Suolo e Attività estrattiva, cartografia in formato webgis disponibile all'indirizzo http://gis.csi.it/vidrwbw/	**NO**
5. Landscapes protected by D.Lgs.42/2004 s.m.i. art. 142, letter *c*, (150 m. areas around rivers and public creeks)	Comune di xxxx, Piano regolatore generale, 2000	**YES**
6. *Environmental passageways*	Provincia di Torino, P.T.C. 2 – Allegato 3: Quaderno Sistema del verde e delle aree libere. Corridors, 2011	**NO**
7. *Land use capacity categories 1 and 2*	Provincia di Torino, P.T.C. 2 – Tavola 3.1 Sistema del Verde e delle Aree libere, 2011 Provincia di Torino, P.T.C. 2 – Schede comunali, agosto 2013	**YES**
8. *Typical / specialized agriculture*	Comune di xxxx, Piano regolatore generale, 2000	**NO**
9. C zones from PAI plan, areas with moderate hydrogeological instability	Provincia di Torino, P.T.C. 2 – Allegati cartografici del Servizio Difesa del Suolo e Attività Estrattiva, Area Risorse Idriche e qualità dell'Aria: Tavola DS2a, Carta dei Dissesti – Ambito Nord 4, Riquadro 2, 2011	**YES**

<table>
<tr><td></td><td>A.I.P.O., Regione Piemonte, ARPA – Carta della pericolosità da alluvione, Tavola 135SW, Giugno 2014
A.I.P.O., Regione Piemonte, ARPA – Carta della pericolosità da alluvione, Tavola 156NW, Giugno 2014
Provincia di Torino - Messa in sicurezza del reticolo idrografico del territorio posto tra il T. … e il T. ….: Studio di fattibilità. Tav. GEO-2E, Carta geomorfologica e delle opere di difesa idrauliche censite, 2009</td><td></td></tr>
<tr><td>10. fasce di rispetto fluviali a media probabilità di inondazione, indicate da studi della Provincia</td><td>PROVINCIA DI TORINO, P.T.C. 2 – Tavola 5.1 Quadro del dissesto idrogeologico, dei Comuni classificati sismici e degli abitati da trasferire e consolidare, 2011</td><td>NO</td></tr>
<tr><td>11. Underground water with very high or high vulnerability</td><td>Regione Piemonte, Piano di Tutela delle Acque, MS06 Pianura torinese – Macroarea idrologica di riferimento acquiferi superficiali, Tav. 3 Elementi di assetto idrogeologico
Comune di xxxx – 14° Variante non strutturale al PRG, Relazione di compatibilità geologica, 2011
Provincia di Torino - Messa in sicurezza del reticolo idrografico del territorio posto tra il T. ….. e il T. …..: Studio di fattibilità. Tav. GEO-2E, Carta geomorfologica e delle opere di difesa idrauliche censite, 2009</td><td>YES</td></tr>
<tr><td>12. Aquifer recharge areas</td><td>Regione Piemonte, Piano di Tutela delle Acque, Allegato D: Tavole di Piano, 8, Zone di protezione delle acque destinate al consumo umano, 2007</td><td>NO</td></tr>
<tr><td>13. Underground water depth > 3 m.</td><td rowspan="2">REGIONE PIEMONTE, Piano di Tutela delle Acque, MS06 Pianura torinese – Macroarea idrologica di riferimento acquiferi superficiali, Tav. 3 Elementi di assetto idrogeologico
COMUNE DI xxxx – 14° Variante non strutturale al PRG, Relazione di compatibilità geologica, 2011
PROVINCIA DI TORINO - Messa in sicurezza del reticolo idrografico del territorio posto tra il T. … e il T. ….: Studio di fattibilità. Tav. GEO-2E, Carta geomorfologica e delle opere di difesa idrauliche censite, 2009</td><td rowspan="2">YES</td></tr>
<tr><td>14. Underground water depth from 3 m. to 10 m., sandy or loamy soils</td></tr>
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