"Capacity Building and Strengthening Institutional Arrangement"

Workshop: Quantitative risk assessment of oil and gas plants"

Analysis of Environmental Consequences of Major Hazards

Mr. Francesco Astorri

APAT

Agency for Environmental Protection and Technical Services

Overview

Brainstorming based on experience

- Italian Regulatory System
- Objectives and Technical Criteria
- Technical Procedure Description

Case Studies based on experience

- Description of an italian case study
- Spill prevention countermeasure
- Spill protection countermeasure

Working group

Environmental Consequences Assessment

- Exercise Pattern

"Seveso" EU Directives and Italian Regulations

"Seveso" European Directives and their implementation in Italian Regulatory System (L.D. 334/99 and Ministry of Transports and Infrastructures Decree - M.D. 2001/05/9) extends risk analysis issues to an explicit evaluation of environmental consequence of major accidents caused by accidental release of dangerous substances.

Reference 1: L.D. 334/99-Annex VI

Not-reversible or long term harms produced to terrestrial habitats:

- Protected by national or local Regulations: 5,000 square meters or more

- Including crop areas: 100,000 square meters or more

Relevant or long term harms produced to freshwater or seawater habitats

- Rivers or channels: 10 Kilometers or more

- Lakes or ponds: 10,000 square meters or more

- River outlets (deltas): 20,000 square meters or more

- Coastal Areas: 20,000 square meters or more

Relevant harms produced to aquifers (groundwater)

- 10,000 square meters or more

Reference 2: M.D. May 9 , 2001

A more detailed definition of relevant harms produced to environmental features is described in appendix 1 of M.D. May 9, 2001 :

Relevant Harms: Generated by accidental releases that require less than two years for their remediation

Severe Harms: Generated by accidental releases that require more than two years for their remediation

A Major accident for Environment is intended as the event which produces a release of eco-toxic substances whose magnitude, expressed in time necessary for their removal from affected environmental features, overrides two years.

Critical aspects of EU and Italian regulations

Not-Easy evaluation in advance of:

- **Eco-toxic substance/s mass released**
- **Rate and area extent of contaminants dispersion**
- **Negative effects produced by contamination on environmental components**
- **Time of remediation**
- **Additional harms caused to environmental features by a major accident compared with the presence of existing pollution condition**

Critical aspects of EU and Italian regulations

Criteria reported in appendix 1 of M.D. 09/05/2001 are applicable only in the case we are able to reproduce or simulate the effects of an uncontrolled dispersion of eco-toxic substances on environmental features.

This might be possible only by using sophisticated models that needs for running a previous collection of large number of parameters

The above described scenario would be applicable in a “Seveso” context (prevention not remediation) by a preliminary identification of those critical situations really capable to produce severe damages to environmental features in case of eco-toxic substances releases.

Team of Experts: APAT/ARPA/CNVVF

Definition of the problem:

Identification of simplified procedures or methodologies aimed to provide support to authorities in environmental consequence assessment

The methodology is focused on the evaluation of environmental impact generated by accidental liquid hydrocarbons releases on soil, subsoil and groundwater potentially affecting environmental feature like natural habitats and water bodies (freshwater o seawater) hydraulically connected with source of contamination.

Base criteria

- Compliance with present regulation as far as major accident for environment definition and risk assessment methodologies are concerned.
- Reduced number of parameters to be used
- Easy identification of risk attenuation control measure on the base of a tier-based risk analysis (IRA/ARA)
- Ensuring results objectivity during evaluation of industrial plant and geo-environment feature
- Simplified model calibration
- User-friendly procedure
- Honor conservative statement

Methodological approach

A methodological approach based on semi-quantitative and simplified operative criteria aimed to the identification of diagnostic and "*geo-gnostic*" variables (factors) related to the tendency of generating a major accident with high consequence on environment rather to the research of an effective mathematical relationships between frequency and events magnitude (P*M).

This due to a lack of statistical data on accidents occurred in the past (oil releases) combined to the natural complexity of those factors (facility-related and territorial) involved in the generation of accidents with high consequence to the environment.

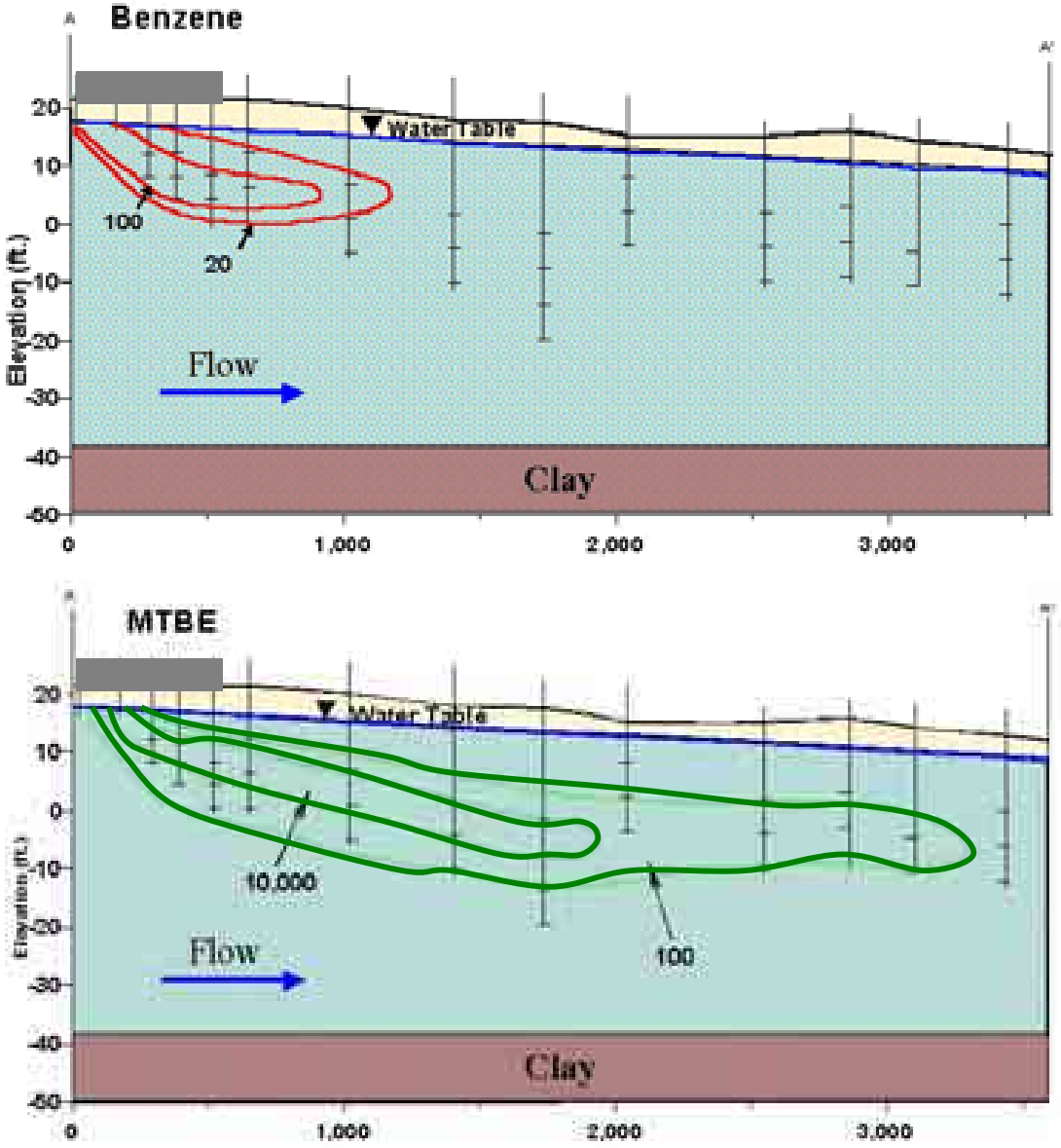
Fate & transport of hydrocarbons in groundwater

Fate and transport of contaminated substances in groundwater are strictly related to chemical-physical characteristics of substances and intrinsic properties of porous media.

Transport of chemicals in subsoil and groundwater shows different behaviors in relation to different subsoil zone:

- the un-saturated zone (vadose zone)
- the saturated zone (aquifer).

Behaviors of hydrocarbons in saturated zone



Retardation Factors: 1.033

MTBE moves a the same velocity of groundwater (RF = 1) and is twice faster than benzene (RF = 2)

Once in water table MTBE will move at the same velocity of ground water and tends to be permanent in it.

Constant of Henry: 0.02-0.05

Ten times less volatile than Benzene (liquid phase / vapor phase

Relationships with magnitude of consequences

The presence of hydrocarbons with characteristics similar to water combined with high rates of groundwater seepage velocity involves:

- Higher probability to reach a receptors
- Developing countermeasures aimed to reduce spills probability and/or prevent hydrocarbons flow toward vulnerable environmental receptors

Implementation of hydrocarbons recovery systems (hydraulic barriers, recovery wells and draining trench) located in direction of ground water flow to intercept contaminants plume

Building-up index

Factors related to the tendency of generating a major accidents with high consequence for environmental feature have been analyzed and organized into two main indexes:

- Release Tendency Index (RTI)
- Propagation Tendency Index (RTI)

Release Tendency Index

Express the tendency of a plant unit to release a certain amount of eco-toxic substances (hydrocarbons) with high rates of mobility and persistence in sub-soil and aquatic environment. (Reference M.D. October '98 *"Safety Reports Evaluation Criteria applied to inflammable/toxic liquid storage plants"*)

Main related factors :

- Amount and intrinsic characteristics of substances (rate of toxicity, mobility and persistence in aquatic environment)
- Applied technologies (Process Plants, Control Systems)
- Safety Management Systems (maintenance and operative procedures, authorities inspection)

Factors affecting Release Tendency Index

			Factors
RTI	Penalties	Substances	Eco-toxicity (Risk Phrases)
			Persistence
			Mobility
			Mass Released
		Plant	Processes connected Risk
			Particular Risk
			Layout Risk
	Corrective		Containing
			Processes Control
			Prevention Policy
			Protection Policy
			Substances Elimination or Isolation
			Emergency Response

RTI Classification:
-Very Low
-Low
-Medium
-High.

Propagation Tendency Index

Express the tendency of the land portion where an oil and gas facility is located to favor contaminants diffusion in subsoil and groundwater causing water quality to be compromised and hydraulically connected environmental features to be damaged. It describes the environmental vulnerability

Main related factors:

- Seepage Velocity
- Flow Direction
- Time of travel

(Ref., *"L. Decree, May 1999 , Nr. 152 Guidelines for drink-water conservation and general criteria for water resources protection areas identification)*

Evaluation of vertical time arrival

Ratio between vertical seepage velocity and water table depth allow the determination of contaminants time arrival to groundwater (t) classified on the base of *De Luca* and *Verga* approach (1991) modified.

Time arrival (t):

High, > 6 months

Medium, 1 month- 6 months

Low, 96 hours-1 month

Very Low, < 96 hours

Horizontal seepage velocity

The horizontal seepage velocity express the tendency of groundwater in transporting and diffusing contaminants not considering any retardation factor or oil degradation effects.

The selection of velocity intervals take on account the average groundwater velocities registered in many aquifers in Italy.

Horizontal Vulnerability	Seepage velocity mt/day
Very low	< 0.5
Low	0.5 – 1
Medium	1- 3
High	> 3

Propagation Tendency Index Matrix

By combining in a matrix vertical time arrival and seepage velocity intervals allow the identification of related risk level by grouping homogeneous values of:

- distance covered in 6 months
- time of travel needed to cover a distance of 50 meters along horizontal direction (by taking also on account vertical time arrival)

Two grouping criteria have been defined on the base of type of receptors potentially impacted:

1 Risk level for vulnerable receptors hydraulically connected with groundwater

2 Risk level for groundwater alone

Propagation Tendency Index Matrix

	Ground water seepage velocity (mt/day)			
	Very Low	**Low**	**Medium**	**High**
	<0.5	0.5- 1	1–3	>3
Time arrival to water table	**Time of travel to cover a distance of 50 meters (days)**			
	> 100 gg	100-50	50 -15	<15
High: > 6 months	**Level 1/I** *>180+100 = 280 gg* *almeno 280gg* *0 metri*	**Level 1/I** *180+100gg= 280gg* *180 + 50 = 230gg* *almeno 230gg* *0 metri*	**Level 2/I** *180 + 50 = 230gg* *180 + 15 = 195gg* *almeno 195gg* *0 metri*	**Level 2/I** *>180gg* *<180+15 = 195gg* *almeno 6 mesi* *0 metri*
Medium: 1 months -6 months	**Level 3/II** *30+100 = 130 gg* *180+100 = 280* *almeno 130 gg* *75 metri*	**Level 4/II** *30+100gg* *30 +50 = 80gg* *180+100=280gg* *180+50=230gg* *almeno 80gg* *150 metri*	**Level 5/III** *30 +50 = 80gg* *30+15=45 gg* *180+50 = 230gg* *180+ 15 = 195gg* *almeno 45gg* *450*	**Level 5/III** *>30+0gg=30gg* *<30 + 15 = 45gg* *>180+0gg=180gg* *<180 + 15 = 195gg* *almeno 30gg* *> 450*
Low: 96 hours – 1 months	**Level 3/II** *4+100 = 104 gg* *30+100 = 130* *almeno 104 gg* *88 metri*	**Level 4/III** *4+50gg =54* *4+100 =130gg* *30+100= 130gg* *30+50 = 80gg* *almeno 54gg* *176 metri*	**Level 5/IV** *4+50=54* *4+15= 19* *30+50= 80gg* *30+15= 45gg* *almeno 19 gg* *518 metri*	**Level 5/IV** *>4gg* *<4+15 = 19 gg* *> 30gg* *<30+15=45gg* *almeno 4gg* *sicuramente meno di 19gg* *> 518metri*
Very Low: < 96 hours	**Level 3/II** *>100gg* *almeno 100gg* *90 metri*	**Level 4/III** *>50gg* *almeno 50gg* *180 metri*	**Level 5/IV** *>15gg* *50-54 gg* *almeno 15 gg* *540 metri*	**Level 5/V** *>0gg* *<15 gg* *> 540metri*

Propagation Tendency Index – Vulnerable receptors

¤	Velocità·effettiva·di·migrazione·orizzontale·(metri/giorno)·IPO¤			
	Molto·Bassa¤	Bassa·¤	Media¤	Alta¤
	<0.5¤	0.5-·1¤	1–3¤	>3¤
Tempo·di·arrivo·in·falda¶ IPV¤	Tempo·per·percorrere·50·metri·(gg)¤			
	>·100·gg¤	100-50¤	50-·15¤	<15¤
Alto:·¶ >·6·mesi¤	Livello·1/I¶ ¤	Livello·1/I¶ ¤	Livello·2/I¶ ¤	Livello·2/I¶ ¤
Medio:¶ 1·mese·-·6·mesi¤	Livello·3/II¶ ¤	Livello·4/II¶ ¤	Livello·5/III¶ ¤	Livello·5/III¶ ¤
Basso:¶ 96·ore·—·1·mese¤	Livello·3/II¶ ¤	Livello·4/III¶ ¤	Livello·5/IV¶ ¤	Livello·5/IV¶ ¤
Molto·Basso:¶ <·96·ore¤	Livello·3/II¶ ¤	Livello·4/III¶ ¤	Livello·5/IV¶ ¤	Livello·5/V¶ ¤

Propagation Tendency Index – GroundWater

⊠	Velocità effettiva di migrazione orizzontale (metri/giorno) IPO⊠			
	Molto Bassa⊠	Bassa⊠	Media⊠	Alta⊠
	<0.5⊠	0.5 - 1⊠	1–3⊠	>3⊠
Tempo di arrivo in falda IPV⊠	Tempo per percorrere 50 metri (gg)⊠			
	> 100 gg⊠	100-50⊠	50 - 15⊠	<15⊠
Alto: ⊠ > 6 mesi⊠	Livello 1/I⊠ ⊠	Livello 1/I⊠ ⊠	Livello 2/I⊠ ⊠	Livello 2/I⊠ ⊠
Medio: ⊠ 1 mese - 6 mesi⊠	Livello 3/II⊠ ⊠	Livello 4/II⊠ ⊠	Livello 5/III⊠ ⊠	Livello 5/III⊠ ⊠
Basso: ⊠ 96 ore — 1 mese⊠	Livello 3/II⊠ ⊠	Livello 4/III⊠ ⊠	Livello 5/IV⊠ ⊠	Livello 5/IV⊠ ⊠
Molto Basso: ⊠ < 96 ore⊠	Livello 3/II⊠ ⊠	Livello 4/III⊠ ⊠	Livello 5/IV⊠ ⊠	Livello 5/V⊠ ⊠

Vulnerable environmental features - categories

Category	Vulnerable Environmental features (Receptors)
A	Natural Habitats, National or Regional Parks, Natural Reserves, Oasis, etc. protected by state or local regulation,
B	Lakes, Ponds, agricultural or drinking wells, springs, groundwater recharge areas, etc.
C	Deltas, Coastal Areas, Rivers or Channels.

Critical Matrix - Vulnerable Categories

	Propagation Tendency Index evaluated for vulnerable receptors (PTIVR)				
Release Tendency Index (RTI)	1	2	3	4	5
Very low	ABC	ABC	A>200 m BC>100 m	A>400 m BC>200 m	A>1500 m BC>500 m
Low	ABC	ABC	AB>200 m C>100 m	AB>400 m C>200 m	AB>1500 m C>500 m
Medium	ABC Applicable for existing facilities otherwise ARA	ABC Applicable for existing facilities otherwise ARA	AB>200 m C>100 m	AB>400 m C>200 m	ARA
High	ARA	ARA	ARA	ARA	ARA

Critical Matrix – Groundwater

	Propagation Tendency Index evaluated for groundwater (PTIGW)				
Release Tendency Index (RTI)	**I**	**II**	**III**	**IV**	**V**
Very Low	**F**	**F**	**F**	**F**	**F**
Low	**F**	**F**	**F**	**F**	**F(0-1)***
Medium	**F**	**F**	**F**	**F(0-1)***	**F(0)**.**
High	**F**	**F**	**F(0-1)***	**F(0)****	**F(0)****

Land-use category (*)
2- Residential, Commercial, High grade Agricultural
1- Low rate Agricultural
0- Industrial

Rate of aquifer exploitation
2- High
1- Medium
0- Low

Aquifer Remediation Capability
0. Low: Fractured or carst rocks
1.Medium: Multi-layered homogeneous aquifer and/or single-layered heterogeneous aquifer
2.High: single-layered homogeneous aquifer

Corrective Parameters selection criteria

Determination of groundwater critical levels make it the mutual presence of other factors affecting water resource value and/or remediation time to be taken on account.

1. *Hydro-geologic structure complexity is a parameter directly proportional to remediation or intervention time.* Porous or fractured media with high levels of un-homogeneity and the presence of preferential pathways in groundwater flow make it harder remediation or emergency response action to be implemented.
2. *Groundwater rate of exploitation can be expressed in terms of aquifer trasmissivity*;
3. *Facility neighboring areas land use category* is another relevant parameter related to water resource value and could represents the loss of usability in relation to an established groundwater state of contamination due to oil releases

Evaluation of environmental consequences Procedure Step 1

Collection of geological and hydrological data (on an industrial facility scale) aimed to select parameters for propagation index building-up:

1) Vertical infiltration velocity

2) Seepage horizontal velocity

3) Evaluation of time arrival to water table

T(vert) = WaterTableDepth/vertical infiltration velocity

V(horiz) = Ki/n (effective porosity)

Evaluation of environmental consequences

Parameters to be used in Darcy Law $V = Ki/\eta$

1) K= Hydraulic Conductivity

2) i= Hydraulic gradient

3) η = Effective Porosity

Alternatively field collection of:

- V (horizontal)
- V (vertical) in situ collected

4) Depth of water table

5) Aquifer typology

6) Aquifer thickness

7) Land Use Maps

8) Evaluation of vulnerable receptors distances from facility (use of digital maps or GIS Systems)

Evaluation of environmental consequences
Procedure Steps 2-3

Step 2

Determination of related groundwater (PTIGW) and vulnerable receptors (PTIVR) propagation tendency indexes on the first matrix.

Step 3

Comparison between two calculated index (Propagation Tendency Indexes and Release Tendency Index) on the second matrices, to support the identification of critical scenarios ether for vulnerable receptors and groundwater.

Evaluation of environmental consequences
Procedure step 4

Results should be scheduled in order to:

a) Make a synthesis of output scenarios for each analyzed logical unit

b) Determination of critical scenarios

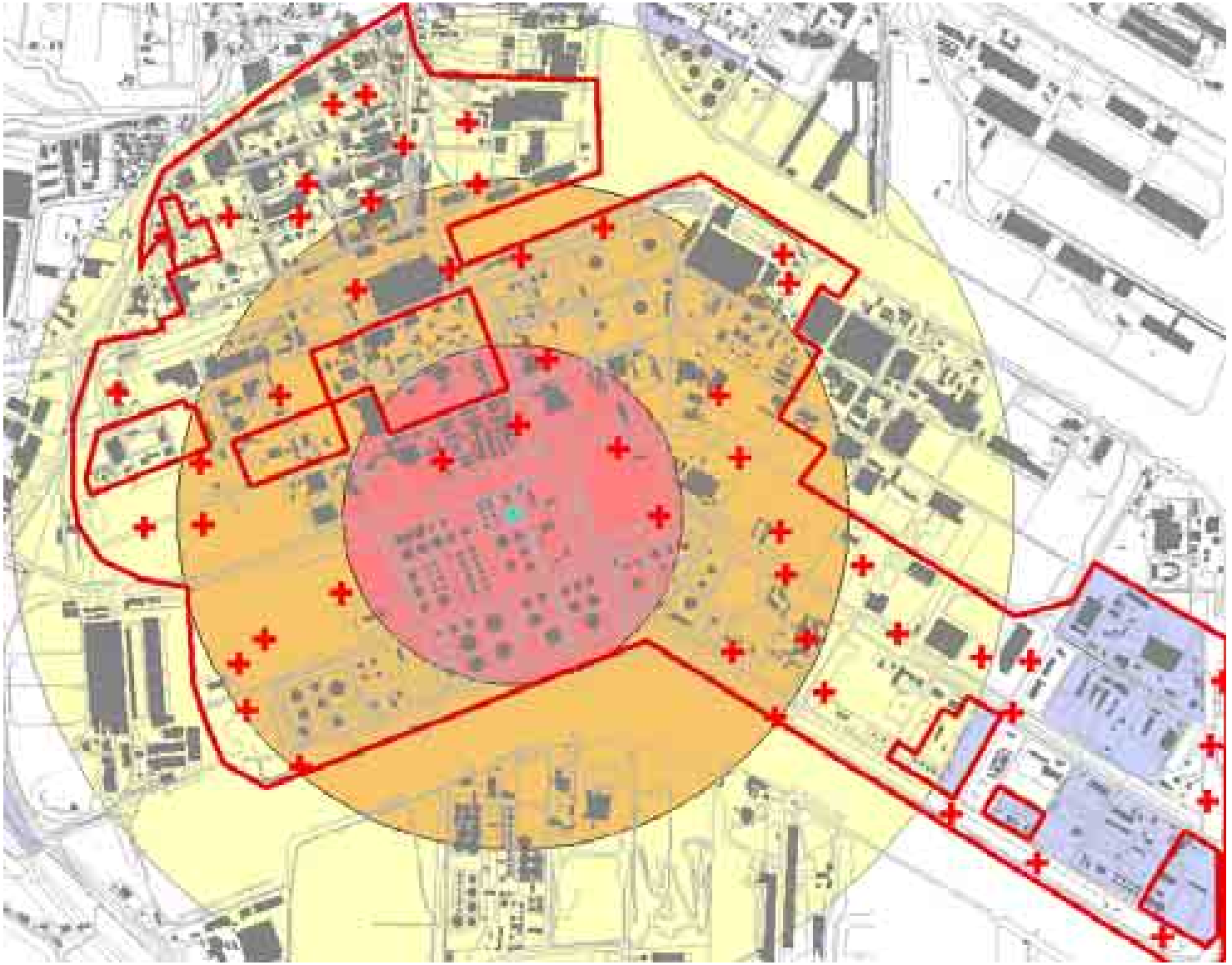
c) Definition of corrective actions (prevention/protection) aimed to risk attenuation.

	Responso di criticità e intervento					
Unità Logiche	Falda	Bersagli			Tipologia intervento	
		A	B	C	Prevenzione	Protezione
Aree di stoccaggio in serbatoi fissi						
Aree di carico e scarico						
Aree di pompaggio						
Aree dove sono presenti additivi pericolosi						
Aree di tubazioni e condotte di trasferimento						

Spatial Analysis tools - Neighborhood analysis

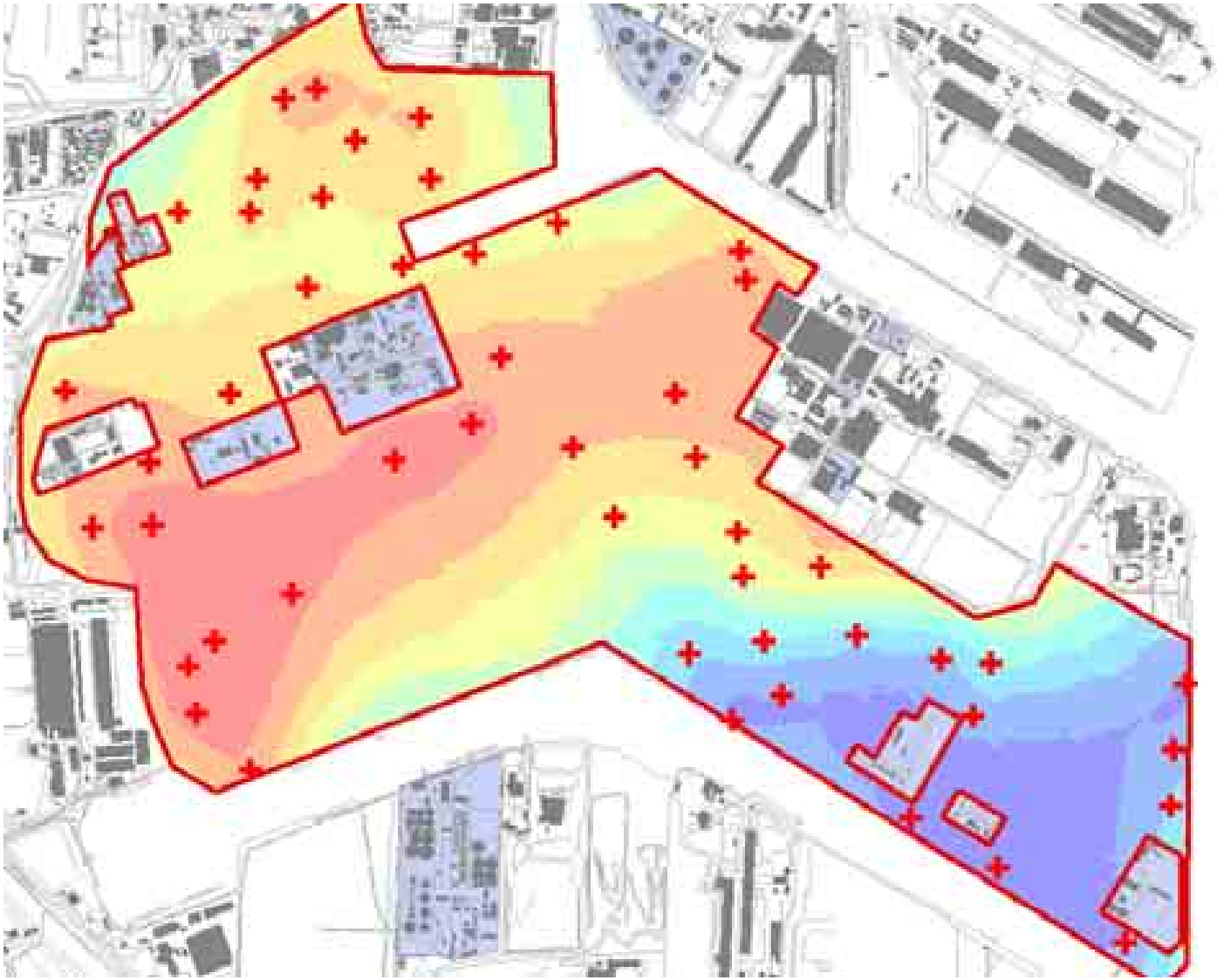
Capability of identification of environmental features (vulnerable receptors) that fall inside buffer areas.

Distance can be expressed in terms of time of travel (TOT) from source of pollution (i.e. TOT contour line 180 days)

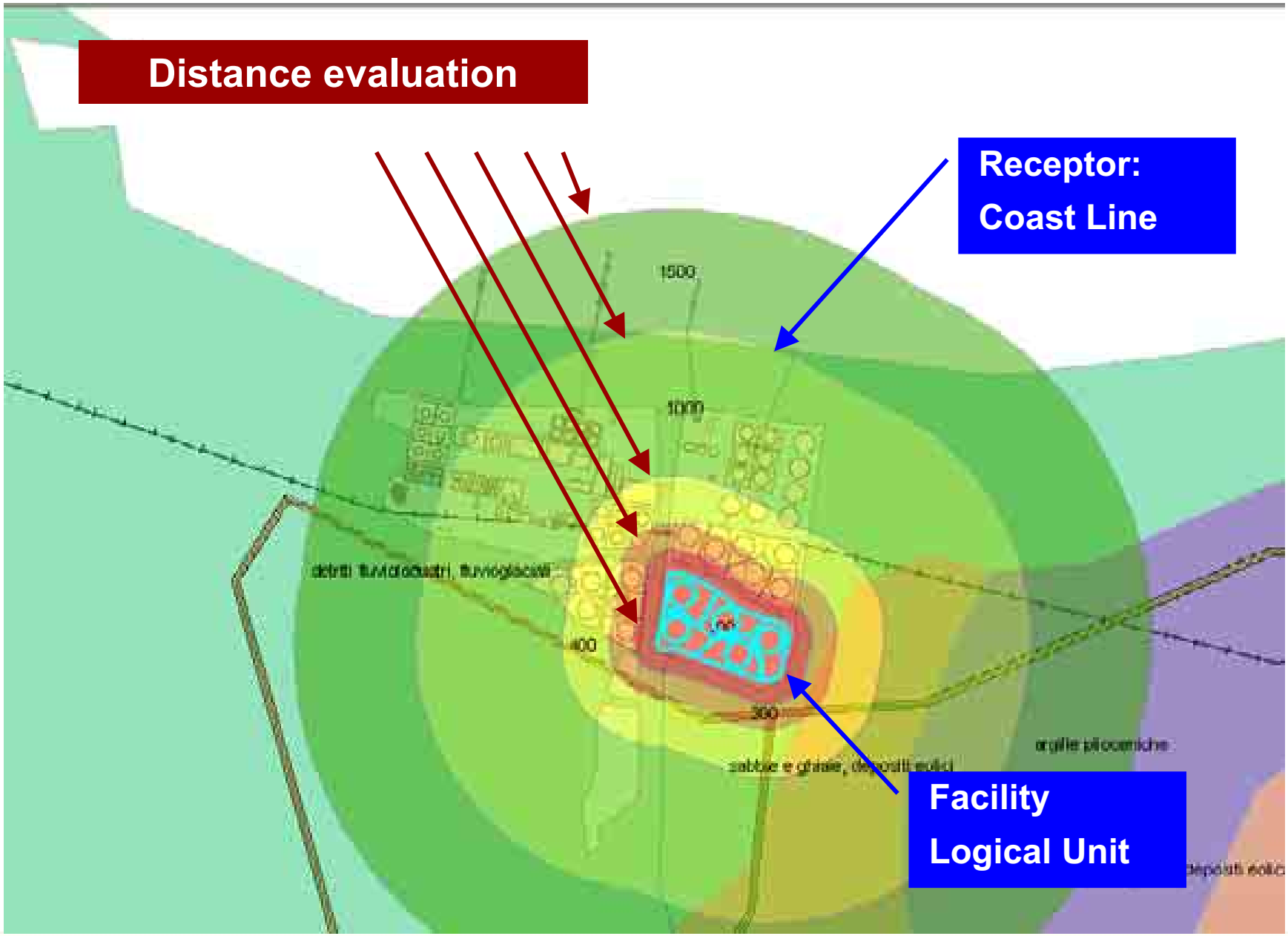


Spatial Analysis tools - Surface Model Generation

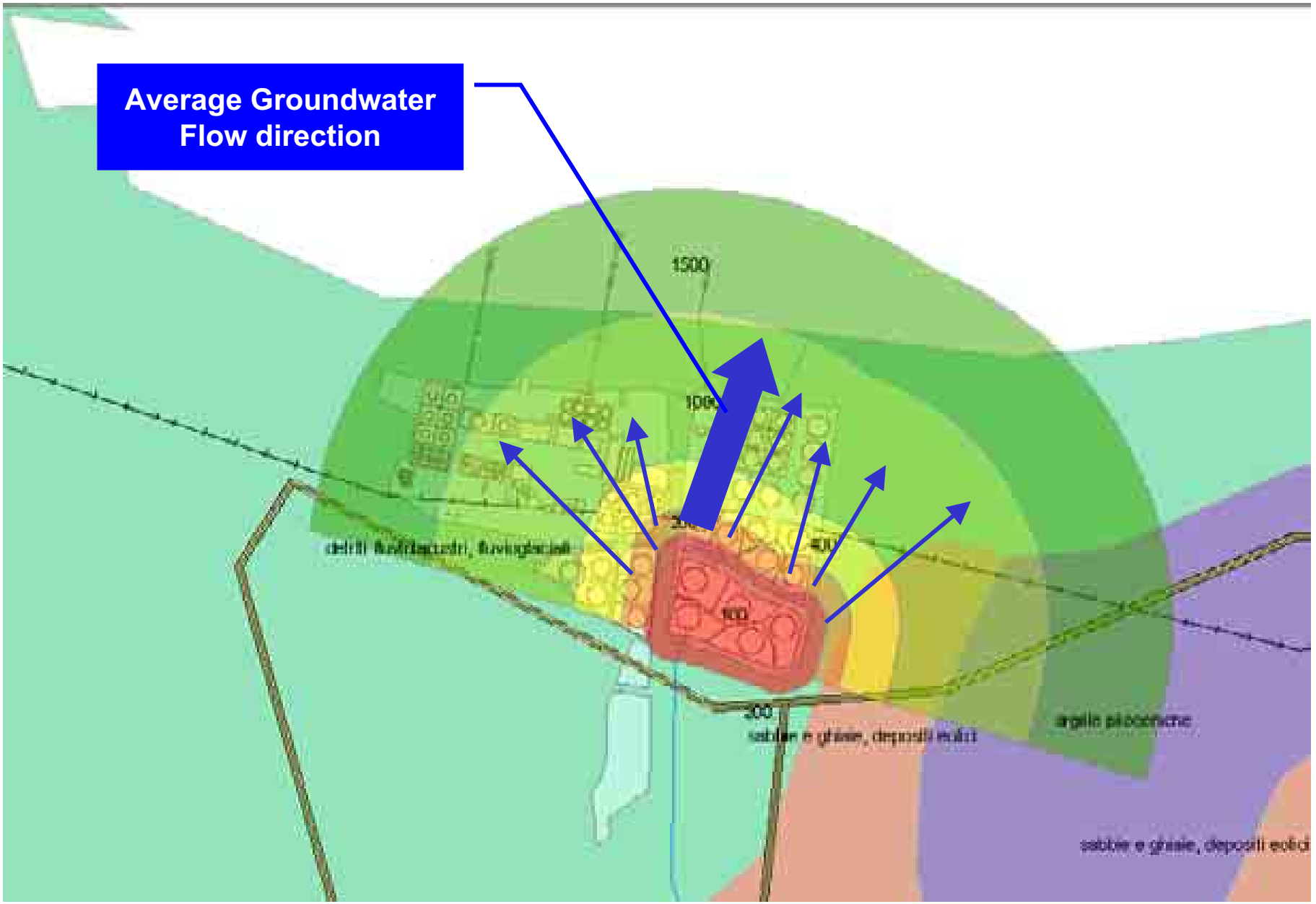
Using monitoring wells make it easier the ground water head elevation surface model to be generated as well as the estimation of TOT and pathways of contamination



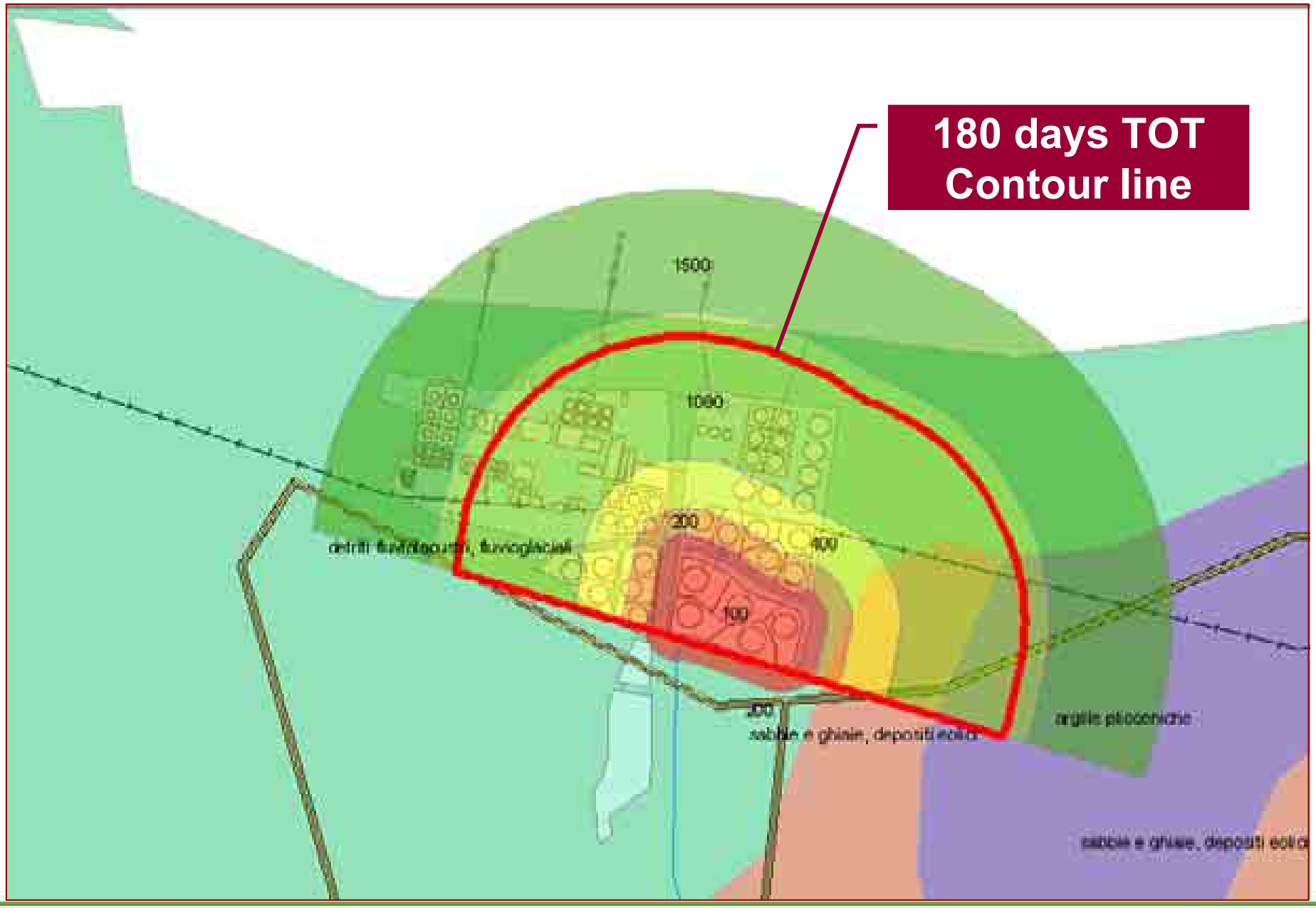
Graphical tools



Groundwater average velocity vector



Not-Critical Scenario



ARA (Advanced Risk Assesment) o Protection Measures Set-up