Groundwater Risk Evaluation of Several Landfill Sites in the Province of Vicenza (Veneto Region, Northern Italy)

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1. INTRODUCTION

A study on environmental conditions of a large number of landfills, in which waste storage has occurred in '70-'80s, has begun on behalf of the Province of Vicenza. The main purpose of the work, resumed on this paper, is to draw up an inquire priority list and, subsequently, to design monitoring networks in order to test groundwater chemical conditions. Based on the results, a site-specific risk analysis for the groundwater shall be performed. The identified sites are a total of 43, distributed throughout the Province of Vicenza. **Site locations** are shown in the table enclosed to this paper.

The work consists of three stages, each of them characterized by methodological approaches and different purposes:

- Step I - Screening (December 2008 - August 2009). Aimed at:
  - upgrade the knowledge framework through the collection of historical documentation and execution of official visits to verify the site assessment,
  - identify priorities for monitoring sites, by relative risk analysis;
- Step II – implementation of monitoring networks for groundwater (under development). Monitoring wells networks will also be designed and implemented in the priority sites identified by step I. Monitoring of groundwater levels and chemistry will also be conducted during a minimum representative period of time.
- Step III – site specific risk analysis (to be later developed): if the data achieved during the step II of the investigation will reveal environmental issues for groundwater, caused by the presence of waste storage, an absolute site specific risk analysis will be performed to quantify the effective risk for the groundwater resources. The data acquired during step II will be also integrated with the results of preliminarly geological and environmental surveys.

2. SOME BASIC CONCEPTS ABOUT RISK ANALYSIS

The health and environmental risk analysis is a tool that has been used for several decades in the U.S. and in Europe. Only recently it has also been adopted in Italy by environmental regulamentations. It allows to:

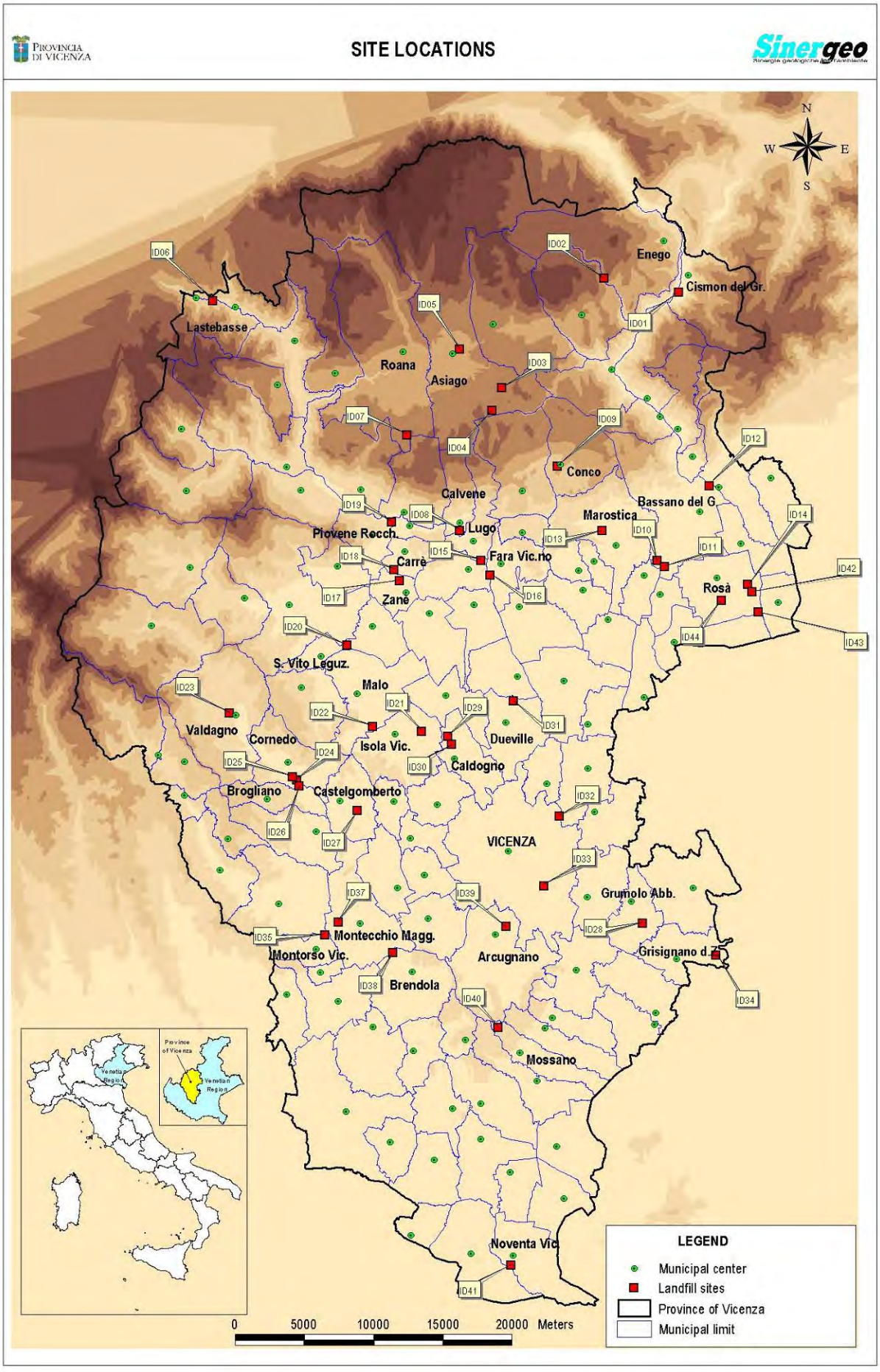
- assess the likelihood of a potentially harmful event to actually cause harm to human health and the environmental compartments of interest,
- setting priorities for action.

Risk (R) is commonly defined as the product between the probability of occurrence of a harmful event (P) and the extent of the damage that these events can cause (D):

$$R = P \times D$$

In the case of potentially contaminated sites the probability of occurrence is known to occur (P = 1) while the potential for harm is essentially linked to the toxicity of pollutants (T) and chronic daily intake exposition for receptors (E). In this case Risk can be defined by the following expression:

$$R = E \times T$$


PROVINCIA DI VICENZA
SITE LOCATIONS
Sinergeo
N
W
E
S
ID06
Lastebasse
ID02
Enego
Cismon del Gr.
ID01
ID05
Roana
Asiago
ID03
ID07
ID04
ID09
ID12
Conco
Calvene
ID19
ID08
Lugo
Marostica
Bassano del G.
ID14
Piovene Rocch.
ID13
ID10
ID18
ID15
Carrè
Fara Vic.no
ID11
ID42
Rosà
ID17
Zanè
ID16
ID20
ID44
ID43
S. Vito Leguz.
Malo
ID23
ID21
ID29
ID31
ID22
Valdagno
Cornedo
Isola Vic.
Dueville
ID24
ID25
ID30
Caldogno
Brogliano
Castelgomberto
ID32
ID26
ID27
VICENZA
ID33
Grumolo Abb.
ID37
ID39
ID28
ID35
Montecchio Magg.
Montorso Vic.
Arcugnano
Grisignano d. Z.
ID38
Brendola
ID40
ID34
Mossano
Province of Vicenza
Venetian Region
Noventa Vic.
ID41
LEGEND
Municipal center
Landfill sites
Province of Vicenza
Municipal limit
0
5000
10000
15000
20000 Meters

The risk is further distinguished in non-carcinogenic and carcinogenic. The results, in terms of degree of importance of potential risks, require a comparison with the threshold values of risk under the referring laws, which consists in Italy of Legislative Decree 152/2006. The significance of the results of risk analysis, as with any application modelling, critically depends on the quality and representativeness of input data used in the models. Methodologies for risk analysis currently used are able to evaluate quantitative (absolute analysis) or semi-quantitative (relative analysis) risk levels:

- Absolute Risk Analysis (ARA): it's a quantitative analysis, through which one can calculate the risk and danger indexes associated with a potentially contaminated site, through a mathematical model of the source of contamination, the migration paths of pollutants and targets' rate exposure. It is encoded by operating protocols, the most internationally known is the ASTM standard (also called RBCA - Risk Based Corrective Action). It is based on three different levels of analysis in which each subsequent tier of analysis represents a different level of complexity. Risk analysis is structured in two logical steps:
    - setting of the conceptual site model (soil, subsoil, air, groundwater, geometry of the contamination sources, possible routes of migration, exposure mode, risk target site-specific parameters);
    - analytical calculation, whereby one can determine the concentrations of contaminants at the exposure/compliance point (forward-mode) or residual concentrations eligible (backward-mode).
- Relative Risk Analysis (RRA): screening is a method by which one can define a priority list of corrective actions to be planned for a certain number of cases, even with limited financial resources. RRA models provide a score that expresses the degree of dangerousness of the site in relation to a specific scale of the model itself. Although this method does not give ratings on a scale of absolute risk or about the acceptability of risk, the scores obtained are useful to allow comparisons between sites and therefore for any ranking of opportunity for intervention. It requires the application of the same degree of accuracy for all parameters in order not to "distort" the model. The end result of the MRA can be expressed and codified in tables and histograms showing the entire logic path made, partial and total scores achieved and the reference sources used for data. The methodology is particularly useful when:
    - there is al large number of sites (in case study 43 areas are considered);
    - site types are the same (e.g. Municipal Solid Waste landfill or inert landfill);
    - a single administrative body control (Province of Vicenza in the case study) manages all sites and will presumably adopt consistent strategies;
- sites are located in a relatively low extended region (provincial level),
- the available information is insufficient for application of an ARA protocol.

3. CASE STUDY

3.1. SITE ASSESSMENT ANALYSIS

The documentation was initially concerning a survey conducted by third parties in the late 90s on the same sites on behalf of the Province of Vicenza. In agreement with the environmental engineers of all the municipalities involved, a search was then launched to find any deposited documents in the municipal archives concerning the history, management of landfill sites and other maybe interesting items (e.g. geological and hydrogeological investigations, chemical analysis, reports or complaints of persons living in surrounding areas). As the use of the areas has been stopped since several decades, the information collected most often has been poor and fragmentary. In fact there has been quantitative knowledge gap in the technical data of almost all sites, about:

- the structure of the areas used for waste disposal (bottom and lateral waterproofing, proportion between waste and muddy matrix, final capping...),
- years of activity,
- type of the waste (no records),

- spatial extension of the body waste,
- emissions (lack of points for the collection and monitoring of leachate and biogas),
- groundwater flow and regime (absence of monitoring well networks)
- environmental conditions of the surrounding matrix (only few non updated chemical soil and groundwater analysis were found).

The information gaps have seemed likely to undermine any attempt to quantify the absolute risk associated with the presence of landfills in the area.

3.2. ON SITE INSPECTIONS

From December 2008 to May 2009 special inspections in all landfill sites were carried out to integrate information from technical correspondence. A total of 43 areas were visited, distributed in 33 municipalities in the territory of Vicenza Province. The first part of the documented information during field visits is concerning the state of fact in each landfill (e.g. accessibility of places, presence / absence of fences, service roads, surface coverage, size and functionality of eventual monitoring networks, morphology of land, standing water, and structural failure). Such information, as well as being useful from a purely descriptive point of view, provides additional evidence of pre-judgment conditions of sites general safety and the degree of protection for the surrounding environmental media (e.g. soil, subsoil, air, groundwater and surface water), of any visitors (occasional or frequent) and buildings or near existing structures. Another important section of data collected during inspections is about contamination sources (waste) and typical landfill emissions (e.g. leachate, biogas, smelly exhalations, dust, evidence of other potential impact). Such information was not always available as, most often, waste material was completely covered and it was impossible to observe liquid or gaseous emissions phenomena coming from waste storage.



The visits also allowed to collect further evidence of the historical memory of the areas, both as documents examined or, sometimes, through interviews with owners and operators on the sites, neighbour residents, public administration engineers, factory holders, all identified near and upon landfills. Field sheet, prepared to be filled out during inspections, was provided with a census and registration data section about any existing groundwater, leachate or biogas monitoring control systems. During field tests every significant environmental element was also evaluated in order to identify:

- the overall site context (e.g. agriculture, green area, commercial-industrial, residential),
- other potentially impacting elements, apart from the presence of degraded sites in question (e.g. industrial, purification plant, other landfills)
- potential preferential contaminant ways of transport (e.g. sloping surfaces, major morphological elements, primary and secondary rivers),
- any evidence of environmental pressure (e.g. suffering vegetation, colorimetric changes in soil and water).

About potential target of risk, besides groundwater elements, even other factors and receptors that may be variously affected by the presence of waste have been identified and listed (e.g. residential buildings, density of population, rivers and streams, commercial/industrial areas, agricultural areas, protected areas).



The current situation found in each landfill was properly documented through photographs and placing the visual cones in layout. The captured images, besides to be an evidence of the visits that took place, are actually useful to update the elements of the state of things, to help to compare the present situation with a future updated one and to provide a visual memory of the environmental elements used to define the conceptual model of site.



4. RELATIVE RISK ANALYSIS PROTOCOL

Since that absolute quantification of environmental risk is not possible because of the significant deficiencies in knowledge about the examined sites, a relative methodology for the landfills potential risk to be assessed has been carried out, in order to define a priority list for actions. The choice of the main parameters to be used in this approach had to necessarily contemplate the most important geological, hydrogeological and environmental aspects that can influence the levels of groundwater risk. These parameters were derived from specialist papers and sometimes by a thorough knowledge of the Venetian Region:

- inherent areal vulnerability where landfills are located → evaluation of the area sensitivity, in probabilistic terms, be impacted by a contamination event,
- relative value of potentially impacted water resources → importance (significance) of the potential damage.

The resulting overall picture has been then improved through the addition of corrective factors resulting from the main field evidence and existing documentation. The protocol chosen for the purpose has been inspired, with appropriate adaptations, to nationally and internationally validated existing models such as the Italian protocol ARGIA (APAT 2004) and the Canadian model NCSCS. For the selection and parameterization of the most important factors a survey work has been consulted, done by others in 1998, concerning the same sites, on the behalf of the Province of Vicenza. The procedure was carried out to meet the following requirements:

- careful and considered management of the limited available information,
- easy applicability through the use of special operational information sheets;
- traceability of logical / methodological followed paths;
- hierarchy of the results.

Conservative criteria were used during the application of the method to always ensure the protection of the targets, while maintaining adherence to the real site-specific conditions. As this is a relative risk analysis method, it is always subjected to a component of forced and partially subjective approximation, related to the use of a few synthetic indicators to describe the contamination source, the mechanisms of transport of potentially hazardous substances and receptors at risk. The more complex issue appeared to be the choice of numerical values for each

parameter, since it depends on the quality of the correlation between the assigned indexes and derived risk. Specifically, the procedure used was divided into the following steps:

- Characterization, in which the system has been set by defining its characteristics and application limits, to obtain a SCM sufficiently representative and applicable to different locations;
- Preliminary preparation of the format, in which values corresponding to actual case studies have been attributed to the parameters of concern;
- Calibration, to minimize the differences between the model responses at the same request and the real system,
- Verification, in which representativeness of the results was assessed referring to the general framework of knowledge acquired at each site.

4.1. METHOD DESCRIPTION AND SCORES ATTRIBUTION

The three typical components categories, relevant for the definition of the conceptual site model, were considered for scoring:

- contaminant sources,
- pathways
- targets.

Each category, in turn, includes some site-specific programmable elements, which were selected as representative to characterize the environmental systems on Earth. Four classes were identified for every element, each of them distinguished by a condition or a range of verifiable values in the area. A score between 1 and 4 has been associated to each parameter, increasing with rising of risk level for the examined condition. The considered sources in the model are represented by the volumes of land affected by buried waste, from which it is assumed that emissions of contamination substances can be produced. The parameters taken into account are, therefore, those recognized as more suitable to describe this type of source in relation to its likely to exert environmental pressure or to be mitigated by limitation factors of potential pollutant mass:

- areal size of the landfill (parameter indicating the contamination potential),
- waste depth (parameter indicating the amount of contaminants),
- waste type (parameter indicating the toxicity of pollutants).

The receptor exposure, which in the case study is the groundwater resources, is essentially on the vertical of the contamination source. It was therefore necessary to consider the mechanisms that regulate the migration of the substances of concern upon surface and under subsurface, using those factors that most affect transport conditions and contaminants distribution, defined as below:

- coverage (affects actual infiltration and, therefore, gravitative way of percolation),
- surface morphology (affecting superficial runoff and possibility of stagnation),
- characteristics of the subsurface (describes the ability of the subsoil to being permeated by fluids),
- rainfall (affects actual infiltration).

There are only two types of sensitive receptors considered, groundwater and superficial water, whose characteristics can be summarized by the following indexes:

- distance from the aquifer to waste body (and therefore to contaminants);
- distance to watercourses and / or springs (able to operate pollutant transport);
- aquifer type (in terms of intrinsic value of first aquifer for drinking purposes).

Scores were summed and then calibrated through the adoption of appropriate “safety” or “reduction” factors, in order to enhance or mitigate the potential effects of the most sensitive risk indexes. According to these criteria the final scores can be included in a range between 0 and 65. Looking at the final ranking of the site scores 3 different model index were finally identified (higher frequency score), around which all values were distributed. These modal scores are:

- 37, frequency of 3,
- 28, frequency of 4,

- 23-24, both with frequency of 3 (average value = 23.5).

The mean values between successive modal indexes were therefore taken as limits to define priority classes in the score ranking. The classes are thus identified as the following:

- ≥ 32.5: priority sites for monitoring;
- 26 – 32.5: not immediate priority sites for monitoring;
- <26: not priority sites.

5. DISCUSSION OF THE RESULTS

The results of risk analysis are presented in the **histogram of risk scores distribution**, which shows all of the scores assigned to each considered site, according to a criterion of decreasing risk, highlighting, on the basis of ranking, priorities category within which each landfill falls. The analysis results show that:

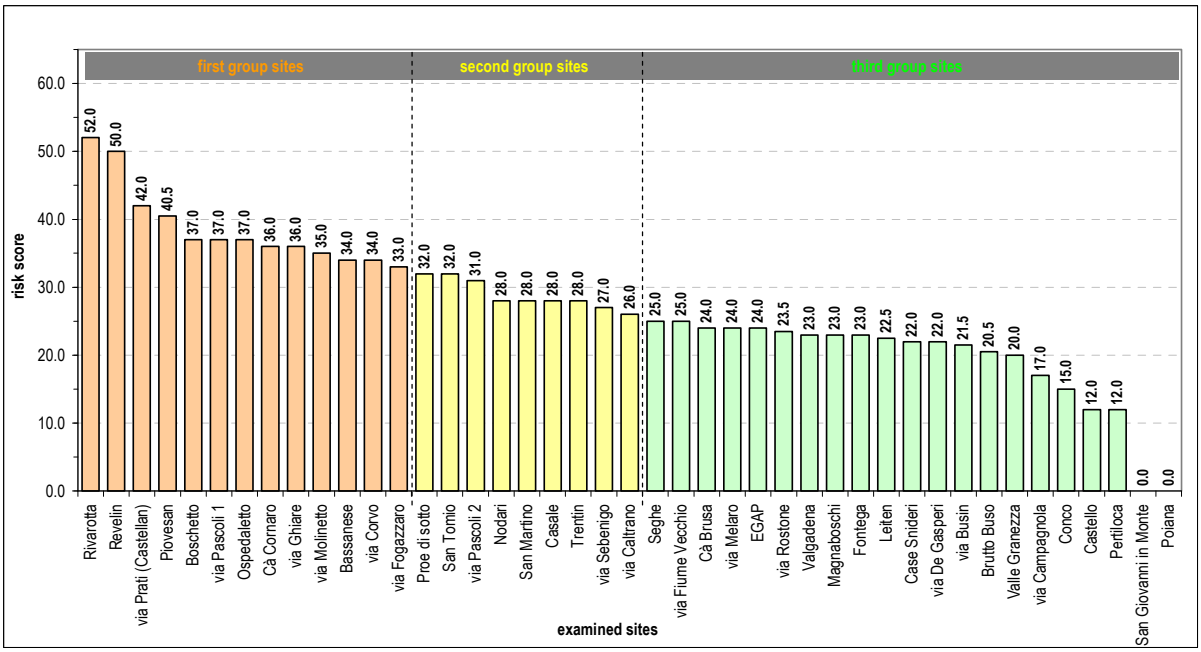
- the first group sites, with a score ≥ 32.5, that require priority attention are 13 at all. Landfills that stand out among them are the ones with larger area and thickness of the body waste, usually placed in a vulnerable and / or significant geological context or those with greater likelihood of a direct contact with groundwater. For these areas it is crucial to deepen the existing knowledge framework, through design, sizing and construction of groundwater control points. Only trough groundwater monitoring the preliminary relative risk scores will be completely confirmed or denied.
- in the second risk group (score between 26 and 32.5) there are 9 degraded areas, showing lesser but still significant possibility to cause negative impacts on groundwater resource. For these sites today it appears not to be a priority to realize any water control systems even if increasing the overall knowledge trhough ambiental and geological surveys and preliminary characterization of the potential source of contamination (waste) would be advisable and precautionary indeed.
- about the 21 landfills classified in the third group (score <26), it has been considered more likely a reasonable absence of an immediate risk to groundwater according to the acquired data and the current situation found during inspections.

Datasheets synthesizing the geological and environmental background and reporting the consistency of the proposed aquifer monitoring networks has been prepared only for the first group landfills.

PROVINCIA DI VICENZA

RISK SCORE DISTRIBUTION HISTOGRAM

Sinergeo



6. FIRST GROUP LANDFILLS – PRELIMINARY DESIGN OF GROUNDWATER MONITORING WELLS

Considering the 13 sites with RRA scores higher than 32.5 (relative risk limit), a preliminary design of groundwater monitoring networks was performed to initiate, organize, and if necessary, enable any mitigative or corrective actions. In this preliminary step the monitoring networks design for priority action sites has been performed taking into account only the hydrological and morphological criteria and information, as:

- direction of groundwater flux,
- average depth of the groundwater from the surface,
- average annual piezometric level excursion,
- access possibility for drilling machines and other working equipment.

For each landfill was, therefore, prepared a plan containing the synthetic hydro-geological factors, the location of any existing monitoring point and the preliminary location for the new monitoring wells, an example shown in figure **groundwater monitoring wells**. In another technical chart the details of the monitoring network implementation, the preliminary calculation of the meters and the cost analysis are then summarized. It will also include a hydrochemical groundwater monitoring through periodic sampling of aqueous samples and laboratory analysis. Initially it will be considered a wide spectrum of analytes. In a subsequent monitoring step, a more restricted analysis set, appropriate to each specific site, will be most likely identified. Chemicals of concern are those one listed in Italian Legislative Decree 152/2006, Annex 5, Table 2:

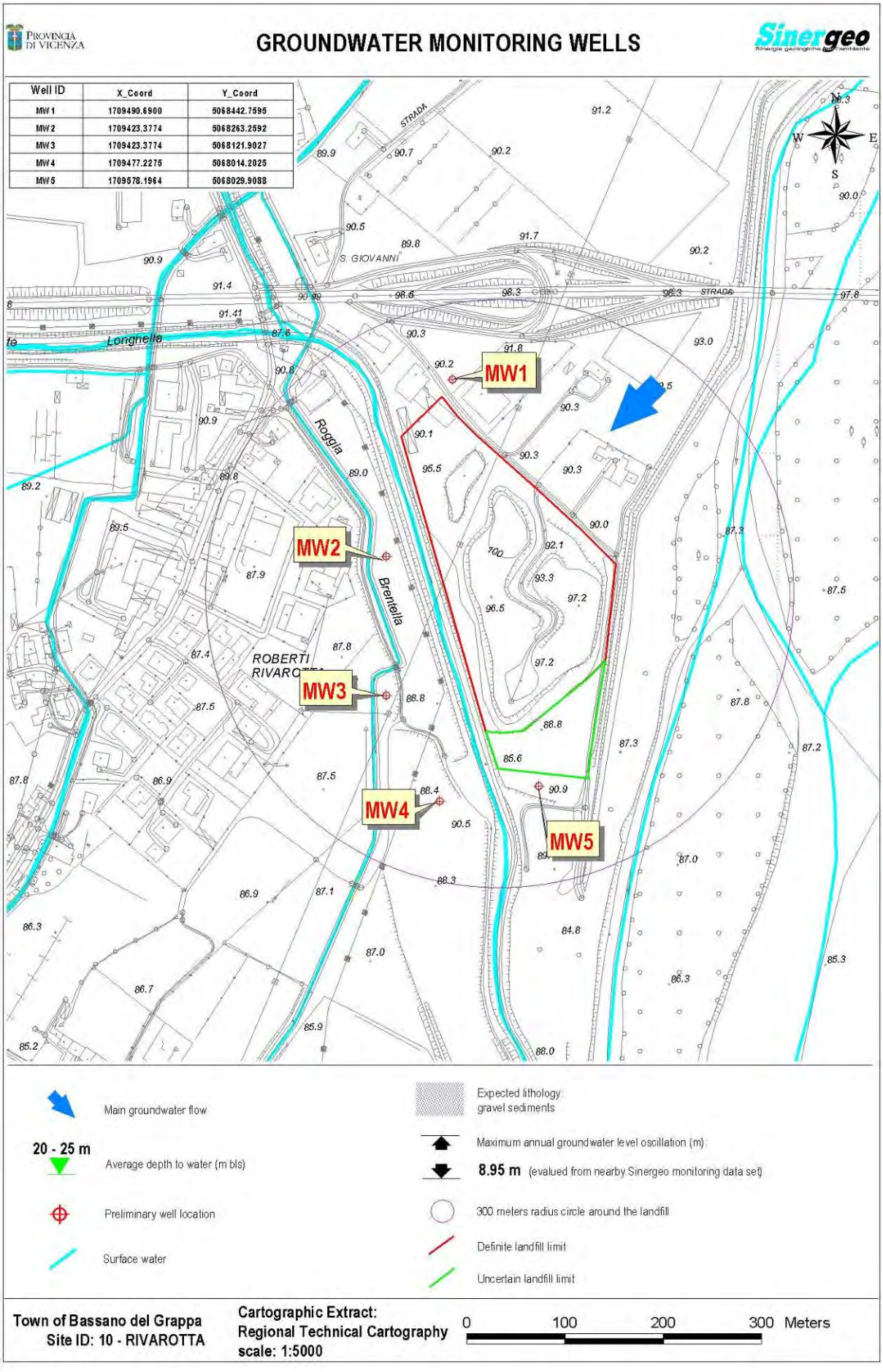
- metals and inorganic pollutants,
- aromatic organic compounds,
- polycyclic aromatic hydrocarbons,
- non-carcinogenic and carcinogenic chlorinated aliphatic
- carcinogenic and non-carcinogenic halogenated aliphatic
- nitrobenzene,
- chlorobenzenes,
- phenols and chlorophenols,
- aromatic amines,
- hydrocarbons (n-hexane)

About the minimun monitoring time interval, it was assumed to consider an initial trial period of 6 months, in which 2 quarterly groundwater sampling operations will be carried out.

7. SECOND GROUP LANDFILLS

About the median group landfills (scores between 32.5 and 26), it was considered that, without any other evidence and/or risk warnings, groundwater monitoring networks were not priority objectives. However, this assessment should not be a reason for being absolute thoughtless and neglecting all the possible public health and groundwater protective actions. In fact many natural or anthropogenic elements may potentially trigger not currently active pollutant sources or migration pathways. It can not be ruled out even the possibility for future new targets to be placed hydraulically downgradient and close enough to such sites to deserve attention and need of groundwater risk analysis (e.g. new private or public drinking water wells). Because of these considerations, and as a reasonable compromise between proper public health protection and limited available economic resources, it was so suggested to perform some geological and environmental surveys, for instance throughout digging machine and waste/soil sampling and analysis, in order to verify:

- waste type,
- waste chemical characteristics,
- ability of pollutant for leaching and affect groundwater,
- soil underlying waste chemical characteristics.


PROVINCIA DI VICENZA
GROUNDWATER MONITORING WELLS
Sinergeo
Well ID | X_Coord | Y_Coord
MW1 | 1709490.6900 | 5068442.7595
MW2 | 1709423.3774 | 5068263.2592
MW3 | 1709423.3774 | 5068121.9027
MW4 | 1709477.2275 | 5068014.2025
MW5 | 1709578.1964 | 5068029.9088
MW1
MW2
MW3
MW4
MW5
Roggia
Brentella
Longhella
S. GIOVANNI
STRADA
ROBERTI
RIVAROTTA
N
W
E
S
Main groundwater flow
20 - 25 m
Average depth to water (m bls)
Preliminary well location
Surface water
Expected lithology: gravel sediments
Maximum annual groundwater level oscillation (m):
8.95 m (evalued from nearby Sinergeo monitoring data set)
300 meters radius circle around the landfill
Definite landfill limit
Uncertain landfill limit
Town of Bassano del Grappa
Site ID: 10 - RIVAROTTA
Cartographic Extract:
Regional Technical Cartography
scale: 1:5000
0
100
200
300 Meters

8. THIRD GROUP LANDFILLS

Regarding the third group landfill sites, characterized by scores under 26, need for knowledge resuming fades more or less noticeably. The now availaible information about these sites argue in favor of little or none environmental grounwater hazard. Therefore it was not considered necessary, in absence of new and more specific information, to promote further cognitive actions.

9. SUBSEQUENT STUDY STAGES

Future study and analysis stage, at least for first group landfills, will critically depend on the data-set collected during hydrochemical groundwater monitoring period. Experimental chemical concentrations obtained will be first compared to italian legal reference values (CSC – Contamination Treshold Concentration) and, if higher, it will be likely for proper environmental procedures to be activated.

In this context, the existing legal provisions uniquely leads up to preliminary environmental investigations and/or further implementations (Environmental Characterization Plan and deeper investigations). Once technical and administrative process will be complete, a site-specific environmental and health risk analys would be finally adopted.