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Diplomarbeit

Collaboration in the risk assessment of small-sized old deposits within the framework of EU – LIFE project EVAPASSOLD

EU Life-Projekt ENV/99/A/000390

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Kurzfassung

Collaboration in the risk assessment of small-sized old deposits within the framework of EU – LIFE project "EVAPASSOLD"

EU Life-Projekt ENV/99/A/000390

Der Projektbereich Abfallwirtschaft des EU-Life-Forschungsvorhabens "Evaluierung und Erstabschätzung von Altablagerungen- EVAPASSOLD", untersuchte in den Bundesländern Nieder- und Oberösterreich 14 Altablagerungen hinsichtlich ihres Emissionsverhaltens. Bei den Altablagerungen handelt es sich größtenteils um mit Hausmüll und Bauschutt verfüllte Gruben aus der Schotter-, Lehm- oder Sandgewinnung und natürliche Geländemulden, welche seit den 50er Jahren, bis in die frühen 90er hinein, als Deponien genutzt wurden. Entsprechende Oberflächen- oder Basisabdichtungssysteme sind nicht vorhanden. Das Ablagerungsvolumen der untersuchten Standorte beträgt zwischen 4.000 m³ und 60.000 m³. Neben den aktuellen Zustandsbeschreibungen bezüglich der jeweiligen Stoffgefährlichkeit, sollten die kurz- und. langfristig noch zu erwartenden Emissionen der 14 ausgewählten Altablagerungen abgeschätzt werden. Hierbei fand eine Evaluierung der Zusammenhänge von Stoffinventar, Ablagerungsgröße (Mächtigkeit), Beschaffenheit der Oberflächenabdeckung und Emissionspotenzial, hinsichtlich der Modifizierung eines geeigneten Bewertungsschemas, statt. Im Zuge des EU-Life Projekts EVAPASSOLD konnte eine neue Anwendungsformel für Altablagerungen < 50.000 m³ entwickelt werden.

Abstract

Collaboration in the risk assessment of small-sized old deposits within the framework of EU – LIFE project “EVAPASSOLD”

EU Life-Project ENV/99/A/000390

The section waste management of the EU-Life research project “Evaluation and Preliminary Assessment of old deposits” has investigated 14 old deposits in the Federal States of Lower Austria and Upper Austria concerning their emissions behavior. These deposits contain mainly domestic waste and construction waste, filled in pits remaining from gravel, loam, clay, and sand excavation locations and filled in natural morphology depressions. The filling period of the deposits was approx. between the years 1950 and 1990. Surface coatings and base liners usually do not exist. The deposition volume of the investigated locations is in the range of 4,000 m³ and 60,000 m³. Beside the description of the actual state concerning material hazard, the expected medium term and long term emissions of the 14 old deposits should be estimated. An evaluation of the correlations of material, volume, surface coating and emission potential was made with the objective to obtain a general valid assessment scheme. In the course of this EU-Life Project EVAPASSOLD a new evaluation guideline for old deposits < 50,000 m³ was obtained.

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1 Introduction

Environmental endangerment and restrictions concerning urban development as well as land development due to old deposits are a widespread problem in Europe. After years and even decades, the emissions from the deposited waste may lead to a pollution burden on soil, a contamination of groundwater and surface waters as well as air pollution as a result of gas emissions. Various risks may thus arise for the environment and for the people living in the surroundings of old deposits, often resulting in restrictions where regional planning and land development are concerned.

Available basics, such as the development of an improved preliminary assessment of the possible endangerment of old deposits on an Europe-wide significance, are not sufficiently available. Regarding to the hundred thousands of small deposits found across the region. Within the range of the EU-LIFE project EVAPASSOLD ("Evaluation and Preliminary Assessment of Old Deposits"), these fundamental actions shall be developed by means of examining representative areas of suspicion. An innovative procedure for the determination of the risk potential of old deposits of different kinds shall be developed and examined in a pilot experiment carried out in two Austrian regions.

In two consecutive investigation stages, a larger amount of old deposits is examined regarding to their risk potential, using reliable methods in an interdisciplinary fashion in combination with innovative investigation techniques:

- Preliminary tests: preliminary assessment, e.g. multi-temporal aerial view evaluations
- Main investigations at the site (characterisation of the actual conditions)
- Main investigations in the laboratory (characterisation of the danger potential of the substances and future emission behaviour)
- Compilation of the results and conclusions with regard to the revision and realisation of guides with Europe-wide transferability

In the state of Lower Austria, the results and the experience gained will be evaluated, with revised and supplemented to an already existing guideline for a preliminary assessment of areas of suspicion. Apart from the improvements in environmental protection for the surroundings of old deposits with a high risk potential, the aim is to realize a more significant of after-use of old deposits which show a low or no risk potential with a differentiated assessment. By transferring results to other, especially Southern European regions, the Europe-wide applicability of the method shall be realised.

By means of numerous publications, conference contributions, workshops and status seminars, the methodical procedure and the achieved results will be presented and thoroughly discussed with representatives of authorities, universities and other specialised institutions.

1.1 Initial situation and objectives of this project

Former non-engineered landfills (dumps or old deposits) are a widespread European problem as they pose risks to the environment as well as restrict spatial planning and land use. As a result of insufficient or not existing liner systems leachate emissions to an unknown extend still migrate into soil and groundwater. In addition uncontrolled biogas emissions occur.

Within the EVAPASSOLD- project, a method for the evaluation of potential risks of different types of sites (small old landfills in rural areas and old landfills with larger waste catchment areas) had been developed on the basis of selected, representative suspected sites. The already existing manual for the “Preliminary Evaluation of old Deposits / Leitfaden Verdachtsflächen” of the province of Lower Austria [1], which is based on the guideline “Expert based control of suspected and actual contaminated sites as well as cases / Fachtechnische Kontrolle von altlastverdächtigen Flächen, Altlasten und Schadensfällen” of the German federal state of Baden Württemberg [2] was evaluated.

Figure 1: Typical old landfill in a Lower Austrian region [1]

Beside the indication of the array of current emissions via the pathways groundwater, surface water, soil, and air a detailed evaluation of old deposits, which show little or presumably no potential hazard has been carried out with the attempt of developing sites for future land use.

For these hundreds of thousands of small waste deposits within Europe there are only insufficient scientific and legal information available in order to enable an improved preliminary assessment of hazards possibly posed by old deposits.

1.2 Objectives

The success of the EU-Life project EVAPASSOLD depended inter alia on the communication of the individual project team partners.

Main objective of this degree thesis was to cover the communication between the individual project partners and the project organisation. Therefore, it was important to make the required information available in time in the required language. Therefore, it was import to work out and translate the reports of the project teams.

An other objective was to participate on the project meetings and to collaborate on the project results.

2 Overview of the EU-Life project EVAPASSOLD

The EVAPASSOLD project was developed into two project phases:

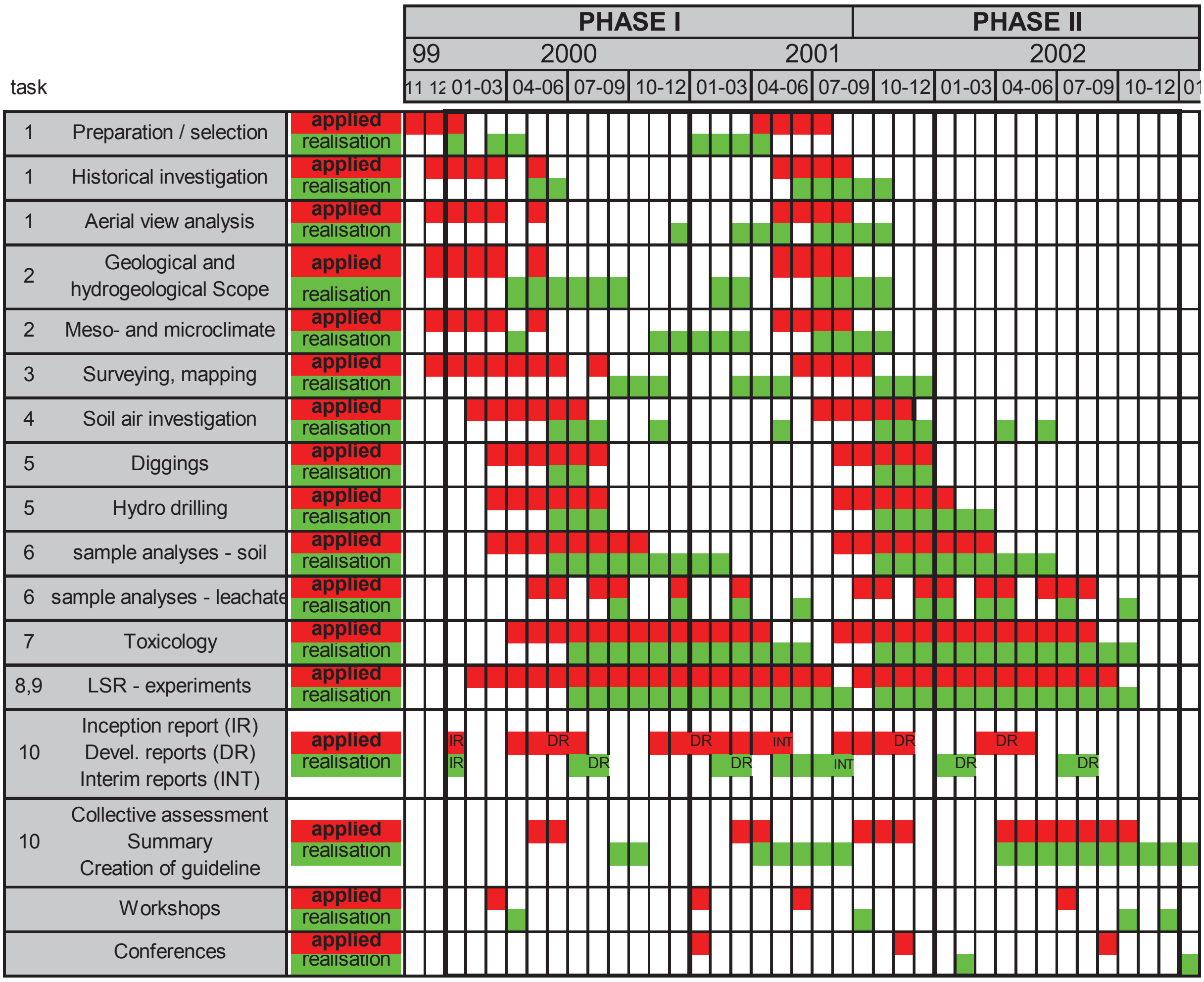
- **Project phase I:** Investigation of 8 out of 12 selected small and rural old deposits
- **Project phase II:** Investigation of 6 out of 8 selected larger old deposits

For both phases, the following activities were carried out:

- **Task 1:** Historical investigation and aerial view analysis
- **Task 2:** Geological and hydro-geological scope, meso- und microclimate
- **Task 3:** Surveying and mapping
- **Task 4:** Soil air investigations
- **Task 5:** Prospect and drilling investigations
- **Task 6:** Investigations of solid samples, groundwater, leachate, soil samples
- **Task 7:** Toxicological examinations
- **Task 8:** Elution tests and bio-tests
- **Task 9:** Emission tests in landfill simulation reactors
- **Task 10:** Compilation and evaluation of the results, reporting of results

The project was planned to last for a period of 3 years (1999 - 2002, prolongation until 02/2003). The project is completed as it can be seen in Table 1. The following chapter presents a further description of the EVAPASSOLD project.

Table 1: Time table of the EU Life-Project EVAPASSOLD. Chronological planning and implementation of processing steps [3]



2.1 Partners and organisation of the project

The beneficiary is the Niederösterreichische Landesakademie (National Academy of Lower Austria), which is also responsible for the administration and the general management of the project. The institutions executing the project are

- Joanneum Research, Graz (Univ. Prof. Dr. Zojer),
- University of Natural Resources and Applied Life Sciences, Vienna (Ass. Prof. Dr. Braun),
- Technical University TU Hamburg-Harburg (Prof. Dr.-Ing. Stegmann)
- University of Padova (Prof. Cossu).

They are assisted by specially-allocated advisory boards consisting of representatives of other universities, various authorities and sponsors. A complete overview is presented in Figure 2.

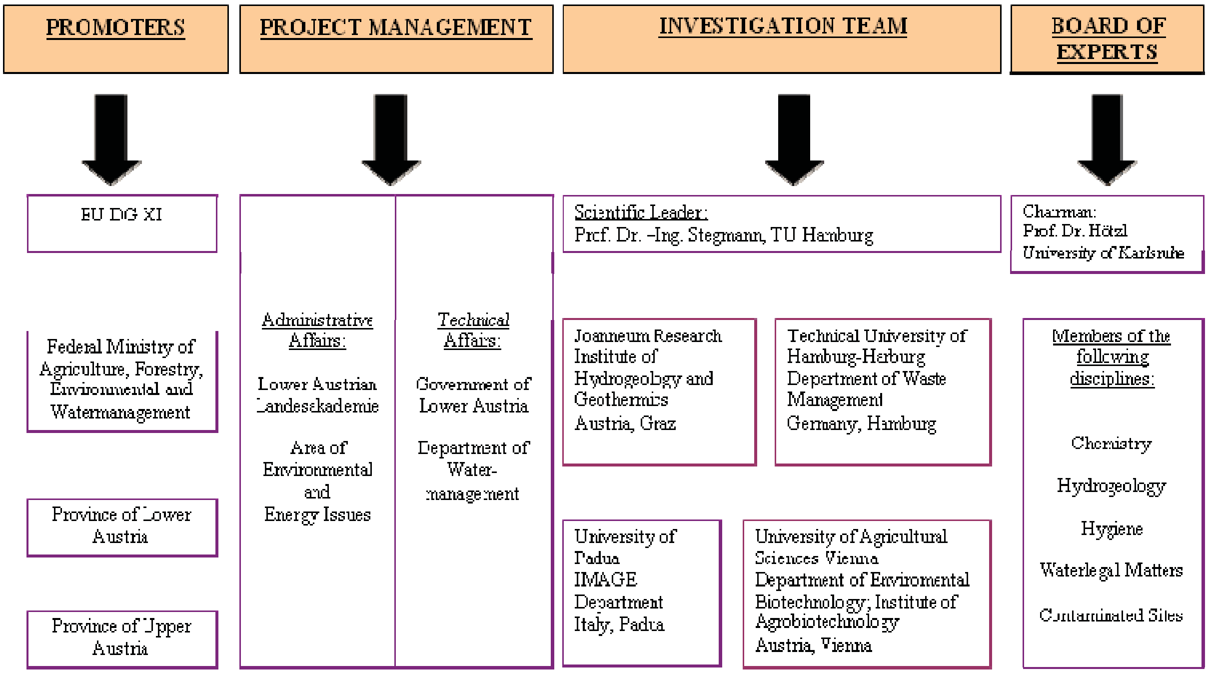


Figure 2: Project Organisation of EVAPASSOLD [3]

2.2 Modifications of original project application

There have been a few modifications to the former application. All modification's applications were allowed by EU Life. These are the mentioned modifications:

- Runtime prolongation of the project execution time for 3 months to complete all processing steps successfully.
- Technical modification of aerial view screening (project-phase II): As the generation of altitude models by aerial view screening seemed not to be useful, this part of task 1 was cancelled. Therefore, the investigation of surface coverage was improved to get a better estimation of precipitation input into the waste body.
- Technical modification in task 4 and 6 concerning control analysis and parameter list of solid samples (project phase II): Due to the results of project phase I some control analyses of soil-air and leachate turned out to be and dispensable and were cancelled. Three analysis parameters of solid samples were also cancelled because of that reason.
  Instead of these tasks, extended ecotoxicity tests were submitted.

These modifications are optimising the project in sense of the project goals. The European Community confirmed their approval on 03.06.2002.

2.3 Description of the investigated old deposits

In compliance of the described methodology a pre-selection in the first project phase reduced the 50 at first considered sites to 12 inspected sites. Finally the list of 12 sites was reduced to 8 old deposits in the state of Upper Austria and in the state of Lower Austria to be investigated in detail. The main reduction criterion was to receive representative data with maximum likelihood. Sites expecting significant difficulties for the determination of the flow direction of the groundwater as well as sites documenting an atypical content were not taken into consideration. The considered criteria were:

- Spreading of the sites over areas with varying annual precipitation
- Spreading of the sites over areas with different geological and hydro-geological conditions (type of subsoil and size of the groundwater flow)
- Approximate equal spreading amongst old deposits with indication of potentially dangerous content, or converse rather harmless contents. The old deposits should contain waste from households and should not include atypical industrial or hazardous waste.

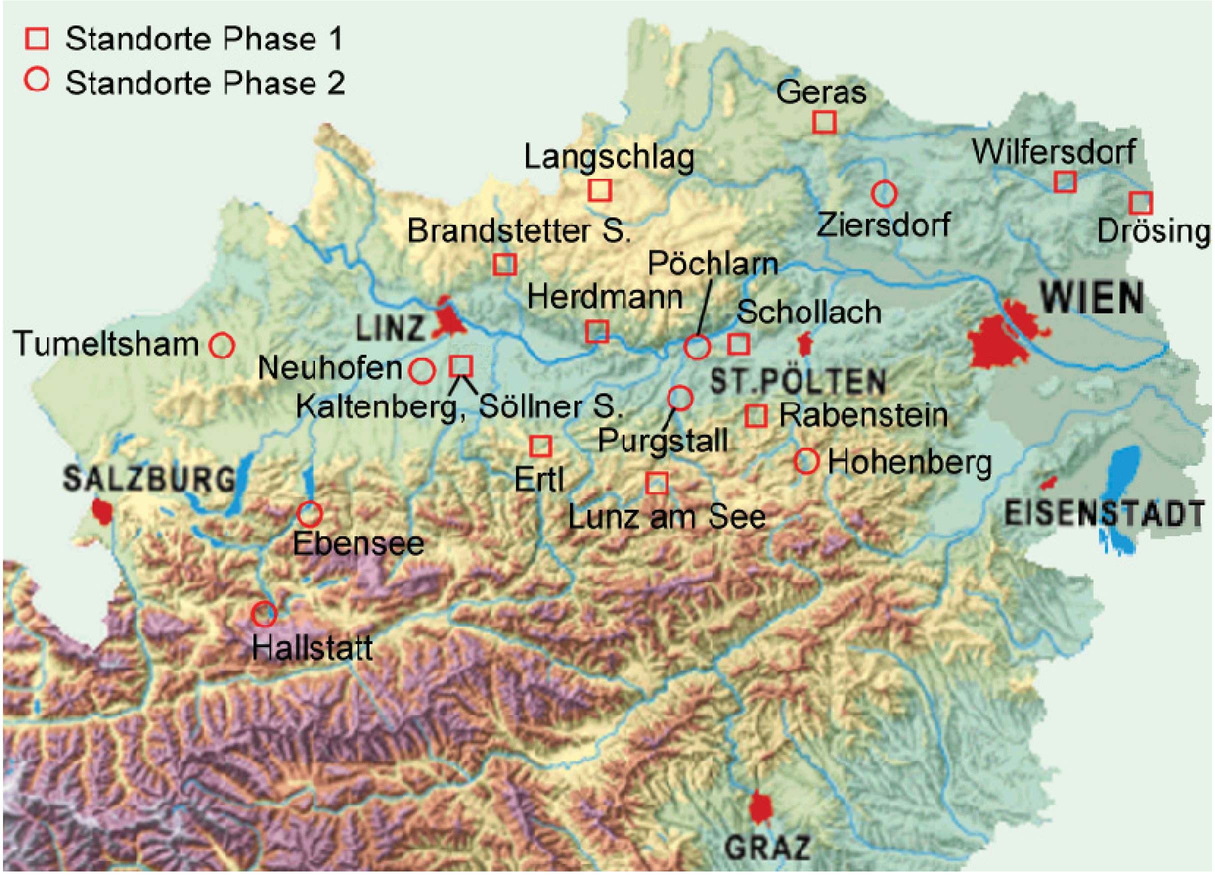


Figure 3: Location of the investigated old deposits in Austria [4]

Figure 3 gives an overview about the geographical locations of the investigated sites. Table 2 describes the filling periods, the deposit age, the size of deposition and the precipitation of these locations.

Table 2: Position of the investigated old deposits in Austria [5]

Location		state	Filling period	size	precipitation [mm]	Volume [m³]
LS	Lunz am See	LA	1972 – 1980	25	> 1,500	4,000 - 8,000
ER	Ertl	LA	1973 – 1979	25	> 1,000	4.000
LA	Langschlag	LA	ca.1970 – 1990	ca. 21	< 700	< 10,000
GR	Grein	UA	1970 – ca.1975	ca. 29	> 800	ca. 5,400
SF	St. Florian	UA	1971 – 1991	20	> 700	ca. 30,000
HO	Hofkirchen	UA	ca.1960 – 1971	ca. 36	> 700	ca. 10,000
DR	Drösing	LA	1968 – 1980	27	< 600	ca. 15,000
RP	Rabenstein a. d. Pielach	LA	1965 – 1981	28	< 900	10,000 - 15,000
HA	Hallstatt	UA	1971 – 1988	22	> 1,500	20,000
TU	Tumeltsham	UA	1967 – 1975	30	> 900	50,000
NF	Neuhofen / Fischen	UA	1980 – 1988	17	> 700	30,000
HB	Hohenberg	LA	1973 – 1983	23	< 900	9,000
PU	Purgstall	LA	1966 – 1976	30	> 800	39,000
EB	Ebensee	UA	1958 – ca.1975	ca. 35	> 1,500	25,000

LA state of Lower Austria (Niederösterreich)
UA state of Upper Austria (Oberösterreich)

3 Methods

The applied technologies and methods may be described by means of 10 tasks. The following flowchart shows the interaction of the applied technologies.

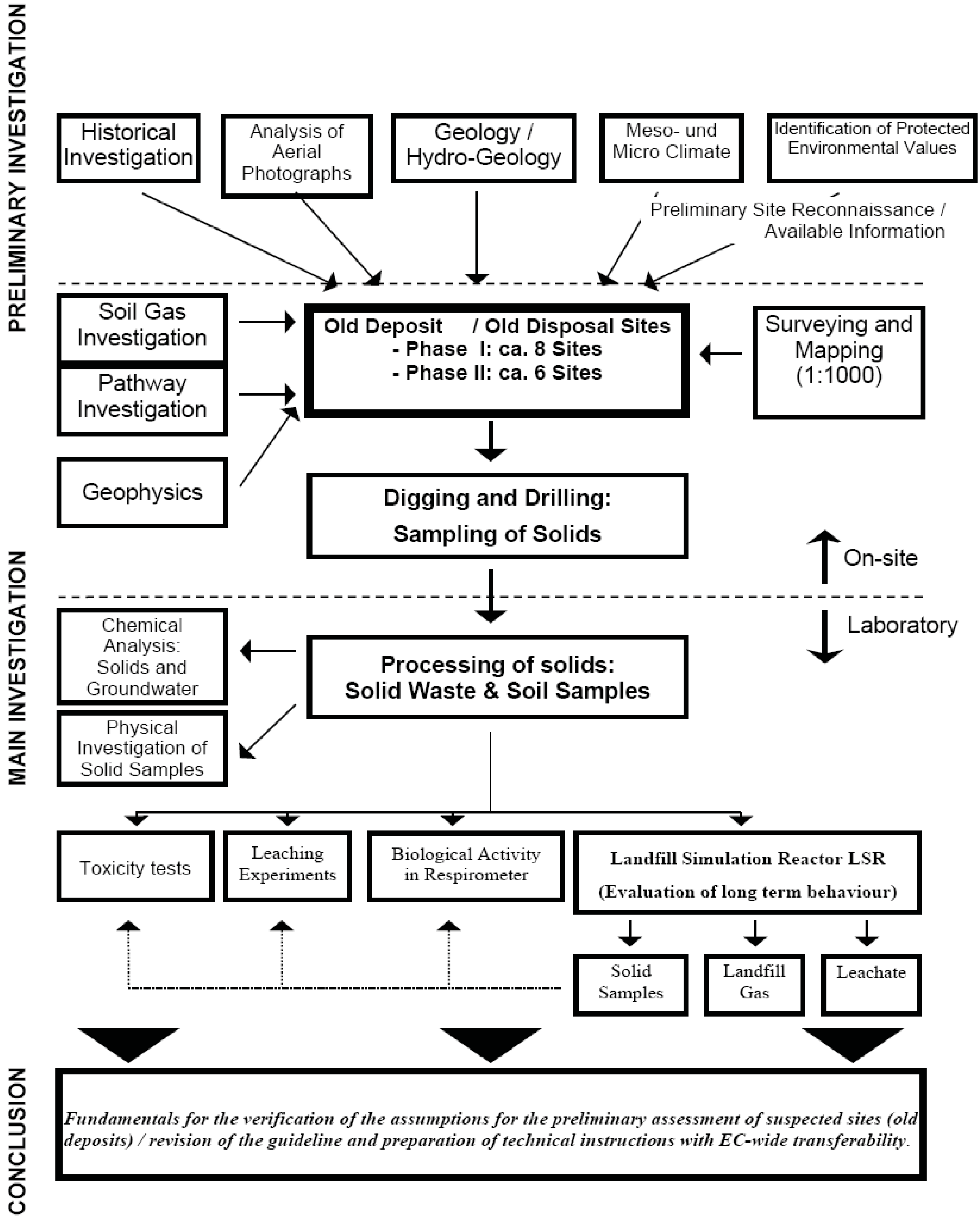


Figure 4: The complete program of the project EVAPASSOLD, flow chart of the tasks and proceedings [3]

3.1 Task 1: Historical investigation and analysis of the aerial view

3.1.1 Historical investigation

Similar to the questioning, the historical investigation is an indirect method of investigating old deposits. The examined locations differ in terms of size of files and in available information. The inspection of old deposits is basic for the questioning and for the planning of soil-air probes distribution and prospecting locations. During inspection, the vegetation was examined for damage indicating emissions of landfill gas. The morphology of the area and the shape of deposit (pit, slope) are also acquired.

3.1.2 Analysis of aerial view

By screening aerial views, the chronological development of the waste deposition was investigated (boundaries of the single deposition areas at different moments). Using the interpretation of the aerial photographs, digital images of the height of the deposit are calculated photogrametrically, in order to get the cubing of the landfill body. The raster data resulting from the multi-temporal aerial view survey are transformed into three-dimensional models. Further information from the development works like position of drillings and prospectings, groundwater level and geology are integrated in the models.

3.2 Task 2: Geological and hydro-geological scope, climate

The geological and hydro-geological conditions of all 20 prospected locations were investigated by examining files and available geological data of the area. At the 14 locations investigated in detail, the results of drillings and diggings were additionally applied.

The climatic conditions prevailing in the area of the old deposit are of great importance for the determination of the water balance when it comes to the calculation of the input of precipitation into the waste body. For all 14 in detail investigated old deposits, the data of the nearest climate station and the water balance were used to calculate the evapo-transpiration and climatic leachate-formation.

3.3 Task 3: Surveying and mapping

All 20 prospected locations were mapped. At the 14 old deposits investigated in detail, the locations of drillings and diggings were surveyed and mapped. As far as possible, the vertical layers of the deposits were also recorded.

3.4 Task 4: Soil-air investigations

At the 14 locations the soil-air investigations were performed for determining main components such as methane, carbon dioxide, oxygen, nitrogen and other selected trace substances. Exhausting experiments were effected in 4 old deposits to determine the total gas quantity.

3.5 Task 5: Prospect and drilling investigations

In project phase I the working program provides one drilling in the upstream flow of the ground water and two drillings downstream. In the course of the historical investigations and the first visual inspections, a development program for each old deposit depending on geological and hydro-geological situation was evolved. Any observed groundwater level was considered.

The prospectings in the waste body were made by backhoe excavator. In the first project phase 3 – 5 prospects per location were made, in the second phase 8 – 12 until feasible depth (in most cases 4 - 5 meters). Numerous solid waste samples (from 1 to 100 kg) were taken from the central waste body and from the boundary layer to the subsoil.

3.6 Task 6: Investigations on solid samples, groundwater, leachate, soil samples

By drilling into the groundwater level, water samples were drawn. As far as possible, short pumping tests for the determination of some hydraulic parameters were made. The evaluation of hydraulic parameters was based on quasi-stationary and/or transistent flow conditions.

During drillings and prospectings, representative sediment samples were drawn for further investigations in laboratory:

- Radiographic clay-mineral investigations (phase I)
- Cationic exchange capacity (phase I)
- Fine grit distribution of soil

To make the results of the analytics comparable, the processing of solid samples was standardised.

3.6.1 Examinations of the solid material, waste solids, soil samples

Parameters: Metals, cyanide in solids, sum of hydrocarbons, sum of 16 EPA-PAK, PCB, dry residue, loss on ignition, carbon, nitrogen, water content and maximum water absorption capacity.

3.6.2 Groundwater and leachate investigations

Parameters: anions, DOC, metals, mercury, AOX, phenols, LVHH, benzene, toluene, xylene, ethyl benzene, total HC, PAH, cyanide. In project phase II the groundwater was additionally analysed for isotopes.

3.6.3 Statistical calculations

The analysis results were statistically evaluated. At multivariate analysis, the procedures are differated by examining the structure (regression analysis, variance analysis, discriminate analysis) and discovering the structure (factor analysis, cluster analysis). As multivariate analysis methods, the discriminate analysis, the factor analysis and the cluster analysis were used for records. In the first project phase the analysing application was SPSS 7.5 and the application of the second project phase was SPSS 10. The graphics application therefore was S-PLUS.

3.7 Task 7: Toxicological examinations

Toxicological investigations serve to assess the effects of several pollutants on subjects of protecting human beings, animals and plants. Thus, the 14 sites were assessed considering ecotoxical aspects. Mainly the chemical investigations and the results of ecotoxical tests were used for assessment. Furthermore, results of geological and hydro-geological investigations, of historical examinations, of the landfill simulation tests and of the respirometer tests were taken into account. In addition, each site was investigated for distinctive biocoenosis features.

The following tests were most in these investigations:

- Plant test,
- Earthworm test,
- Luminescent bacteria test,
- Algae test,
- Daphnia test, acute,
- Daphnia test, chronic,
- SOS chromo-test

3.8 Task 8: Elution experiments and tests for biological activity tests

3.8.1 Elution experiments

The eluates were made according to the standard DIN DEV S4, both single and multiple elution. The elution test is determining the mobility of different substances in dissolved state.

The parameters of the test are:

- Conductibility
- pH value

- Chloride
- Nitrate
- Sulfate
- Nitrite
- Ammonium
- Phosphate
- AOX
- COD
- BOD_5
- TOC
- HCO_3
- Cyanide
- Fluoride
- Heavy metals, e.g.: Pb, Cd, Zn, As, Hg, Ni, Cr and Cu.

3.8.2 Biological activity tests

Goals of the test methods are the determination of the biological activity using respirometer tests and the determination of the gas formation potential.

3.9 Task 9: Emission tests in landfill simulation reactors

A main point of the EVAPASSOLD project are the Lysimeter tests in “Landfill Simulation Reactors” (LSR), describing shortly the fundamental medium-term and long-term degradation processes in the waste body under anaerobic and aerobic conditions. By adjusting the optimal boundary conditions the LSR effects an acceleration of the physical, chemical and microbiological processes. Future long-term evolutions of the waste substances in the landfill body become assessable.

3.10 Task 10: Compilation and evaluation of the results, reporting the results

The results of treatment stages according to tasks 1 – 9 were discussed at regular meetings in order to reach conclusions and to develop recommendations. At the end of the second project phase the fundamental results, conclusions and recommendations were transferred to European circumstances.

Parts of this task are substances of the diploma thesis on hand.

4 Project results

4.1 Old assessment procedure

The overriding objective of the EVAPASSOLD project is the evaluation of a guideline for areas of suspicion, leading to an mimproved systematic proceeding for the first assessment of old deposits risk potentials.

Guidelines for areas of suspicion have an evaluation system for the risk potential assessment that mainly considers the emission potential (the dangerousness of the constituent substances), the diffusion behaviour and the respective environmental goods. With this system, the explained predominant treatment should be made possible (detection of dangerous deposits with high risk assessment for further investigation, securing / redevelopment if necessary, exclusion of harmless deposits with a low risk assessment from further observation and high grade afteruse, if possible). Currently, the preliminary assessment is often completed by scrutinising documents, and in special cases by the inspection of the site, questioning or multi-temporal aerial view evaluation.

According to a standard methodology, the decisive risk potential (r_4) is determined as follows for every environmental good (see existing Guide for areas of suspicion of the Department of the Lower Austrian Provincial Government) [1]:

$$r_4 = r_0 \cdot m_1 \cdot m_2 \cdot m_3 \cdot m_4 \qquad (1a)$$

r_4	Decisive risk respectively risk potential
r_0	Dangerousness of the substances
m_1	Pollutant discharge
m_2	Pollutant introduction
m_3	Pollutant transport and effect
m_4	Relevance of the environmental good (groundwater, surface water, air, soil)

The evaluation and further development of the guideline within the EVAPASSOLD project was changed. The project showed, that this model is obsolete. Detailed descriptions can be found in the guideline „Leitfaden Verdachtsflächen“ [1].

4.2 Results of the University of Agricultural Sciences, Vienna [5]

4.2.1 Institution

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4.2.2 Assessment on existing data and Interview

This chapter describes the study of recorded data and knowledge of the population living on the investigated locations.

4.2.2.1 Historical investigation

The information complexity was different on each location. The files recorded by the government were easy to obtain. Data from performed analyses cannot be expected, but four of the eight examined deposits had actually meaningful chemical test results. In some cases there were even results of trial analyses for the determination of the compositions available. Nevertheless it remains questionable how far these old records are representive of the current state of the landfill body, particularly in the case of opened landfills.

Beside the chemical analysis data, the obtained documents showed partly whether the old deposit is either a potentially emitting or an inert type. Specialists can interpret hydrogeological and geological information. Even the form of deposition (e.g. dump-filling or slope filling) can be roughly measured out of the material map. This kind of information is not always easy to find, and sometimes the related information can be found in general phrases like „filling of a clay-tray“ or „filling of a spring syncline“. In individual cases data concerning soil and surface indications can be found. For their interpretation the references, like “former gravel pit“ or “former narrow pass“, “covered with loam“ have been used.

4.2.2.2 Visual inspection

The inspections of the areas were performed as basis for the interviews and for roughly planning of the distribution of soil-air sensors and digging positions. It was important to acquire information about the location and the appearance of the area. On inspectioning it was especially attended to determine the presence of damages on the natural cover indicating discharges of landfill gas. The morphology of the deposits (e.g. cavity, inclination) was also specified at this time.

Committing the locations is as an extremely informative procedure. Particularly the investigation of the surface cover in phase II took only approx. 30 to 45 minutes in every case, delivering very useful information concerning type and quality of surface coverage and type of landfill. The attempt of evaluating a vegetational damage seemed less meaningful. Agricultural damage at monocultures often looked clear at first. With additional investigations it could not be recognized if there are damages more often as usual compared to agriculture.

In the second phase of the EVAPASSOLD project the permeability of the surface coat was also assessed. Therefore a small investigation cavity of about 30 cm was digged with a shovel. The granularity of the excavated material was estimated by finger-assay according to BLUM.

4.2.2.3 Interviews

The most important aspect of this project is the validity of the obtained results. Each interview is a unique event, where the maximum on information should be obtained. Considering this, the questionnaire from the guideline was revised.

With the questioning on „former depositions“ the priority goal is avoiding answers inhibited. These results serve for the genesis and not for the examination of theories. A bad example would be: “The garbage composition of the landfill is dangerous, isn’t it?“. It will be worked explorative, i.e. the results are rated as an overview of the location’s situation, neither examining nor regarding existing speculations. Experience shows that qualitative interviews bring better results. The group of the interviewed persons demands a large heterogeneity concerning different social characteristics (education, profession, age etc.). These differences can affect the understanding and interpretation of questions. For people who naturally are using very different language codes, an adapted language style raises comprehension and understanding. Not all asked persons have the equal articulation level concerning their opinions. Even if the interviewer has an absolutely uniform behaviour, it would cause different reactions when interacting with the different socio-cultural education levels of the asked persons. It appears more useful to accept such reciprocal effects and therefore trying to apply the interview properly.

The interview situation should be partly structured, i.e. questions are prepared, but can be adapted if necessary, depending on each situation. “Everyday life discussion” should be seeked. The valid communication monitoring system is when both, the asked person and the interviewer have to adapt themselves to the situation. The interrogation situation should be as trustful and relaxed as possible. Girtler (1974) writes: "*The respondent may never receive the impression of getting entrapped or feeling just like a respondent. You have to transmit the feeling of being interested in his world, that you want to discover his world and that you will not cause him any damage*". In familiar surroundings and in a well-known topic the interviewed person gets almost an expert-status. It should be emphasised that his personal opinions are interesting. More reliable data regarding sensible topics can be obtained, if the respondent does not feel like asked by an inquisitor.

The questionnaire was intended to confirm the basic principles of empiric social research. Nevertheless the reliability of the interviews had a low level. Though the interviews in most cases have been essential for getting an exact demarcation of the areas, it was unacceptable to use the interviews as assessing method for hazardousness of smaller landfills. Statements concerning landfill volume and possible hazardous containments were practically always wrong (see Table 3). The same happened to the statements concerning the period of landfilling operations.

Table 3: Overview of the obtained data on the volume of deposits. The first row shows the data found in historical records, the last two rows shows the estimation of the conducted interrogations. The additional cell information shows, which person was interviewed. [5]

VOLUME OF LANDFILLS			
LOCATION	**Volume data from documents**	**data from interview 1st person**	**data from interview 2nd person**
Drösing	15,000 m³	major 40,000 m³	vice major 8,000 m³
Ertl	4,000 m³	major 150,000 m³	Owner: 20,000 m³
Langenschlag	10,000 m³	Owner (jun.): 3,000 m³	Owner (sen): 35000 m³
Lunz am See	4,000 - 8,000 m³	Secretary: 64,000 m³	Owner: 6,000 m³
Rabenstein	10,000 - 15,000 m³	vice major: 30,000 m³	employee of community 15,000 m³
Grein	5,400 m³	major: 20,000 m³	Owner: 140,000 m³
Hofkirchen	10,000 m³	Owner: 8,000 m³	employee of community 15,000 m³
St. Florian	3,000 m³ (70,000)	officer: 96,000 m³	Owner: 8,000 m³

This table shows, that it is not possible to get reliable information about the volume of the landfills. The same experience was occurred concerning landfilling period.

4.2.3 Analyses

4.2.4 Statistic procedures

In the first project phase the analysing application was SPSS 7.5 . The analysing application of the second project phase was SPSS 10, some graphics were created by the application S-PLUS.

For the evaluation of the analysis results from phase II it has to be mentioned, that the sample size appears to be very small. Only two repetitions gave unsafe results. Nevertheless it is very important to try out different methods of research, even if some results seem to be contradictory. A comparison between the cluster analyses and the discriminance analysis should not take place. These are two totally different factors.

4.2.4.1 Discriminance analysis

The classification of the data based on the discriminance analysis worked reasonable good, especially for the unusual data record. As the amount of variables exceeded the amount of repetitions for the tenfold the function of discriminance could be estimated. Especially the content of heavy metals is the important indication to distinct the different locations. In the reference to the data evaluation out of the solids of LUNZ AM SEE and ERTL lie near each other. This underlines the interpretation that these two locations are open ones. RABENSTEIN AN DER PIELACH, HOFKIRCHEN and DRÖSING are based on similar solid data material. ST. FLORIAN, LANGSCHLAG and GREIN are found besides the other locations. These are landfills with partly reacting contents of different composition (GREIN has more organic pollutants, LANGSCHLAG heavy metals, and ST. FLORIAN has a mixed load of both).

From the evaluations of the Eluate analysis results it can be seen that LANGSCHLAG and RABENSTEIN AN DER PIELACH are lying close together. As with the data of the groundwater research the relation of the variables is very broad, elasticising the force of expression of the very appropriate and suitable discriminance functions. Out of the results of the soil-air analysis, mislead can happen as especially the values of methane show the location-typical picture. But the most important aspect to make a difference between locations is the content of oxygen and carbon dioxide.

4.2.4.2 Cluster analyses

Here it is important to prove how representative the mixed samples are for the single samples of a landfill. The acceptance that it is not possible to take representative mixed samples out of the old deposits was confirmed. The samples mass were very similar among each other. The few outliers could not be assigned to the appropriate location on a sufficiently low level. Therefore it was possible to evaluate the mixed sample in the same way as the single sample. This procedure assumed from a unordered random sample, so that for clarifying these procedure seemed to be better than the discriminance analysis.

4.2.4.3 Factor analyses

The goal of the factor analysis is to achieve independent influence coefficient out of many possible variables.

4.2.5 Soil-air analyses

The results of soil-air investigations were very useful for a preliminary assessment of hazardousness of the deposited material. The locally measured contents of methane and carbon dioxide permitted conclusions on the biological activity of the landfill body. For the first time the vaguely derived data from the survey was confirmed with concrete data (potentially emitting, inert). The contents were analysed with substantial laboratory expenditures. Traces of particular gases gave punctual refers to dangerous contents. However, they could not be generalized and did not correspond with the results from on-site measurements.

In the second project phase the measurements of drill core material's conductivity represented valuable additional information to the soil-air composition results. With small additional expenses the existence of two differently leached out waste layers could be verified in PURGSTALL. This fact explains the collected soil-air data at the location.

The methane to carbon dioxide ratio could be included in the evaluations as suggested by ÖNORM S 2088-3. By using qualified literature, a supposable classification can be made for most landfills.

Table 4: Allocation of the old deposits of the phase II due to their average CH_4/CO_2 ratio of conditions to the landfills long-term phases[5]

notation	long-therm phase	MIN	MAX	old depositions (average CH_4/CO_2)
stable methane phase	I	1.25	1.5	
long-term phase	II	1.7	2.3	
air intrution phase	II	2.3	2.4	NF (2.64)
methane dioxyd phase	IV	0.2	2.4	PU (0.61 north) PU (1.09 south) TU (0.47)
carbon dioxyd phase	V	0.08	0.2	EB (0.2)
air phase	VI	0	0.08	HB (0.01) HA (0)

4.2.6 Digging and sample analysis

According to EVAPASSOLD there were planned 3 – 5 diggings in the first project phase, and 8 – 12 diggings in the second project phase. The diggings reached in most cases until approx. 5 meters. It was important to formulate:

- Type and thickness of surface coating
- Thickness of waste body
- Homogeneity of waste body
- Estimated content of domestic waste
- Type of underground, if possible.

Goal of this description was to get information of the waste composition. So it is possible to recombine information about pollutant content, imminent pollutant discharge (rain infiltration, elution of mobile fraction in the waste body, discharge through underground).

All diggings were made by local contractors with two excavators of different fabricate and type, supervised by team members. Surveying, mapping and documentation took place immediately after finishing the diggings. For each digging, 2 – 5 samples were taken in phase I and 5 - 9 per location in phase II, each sample 15 – 20 kg of weight. Additional samples of 70 – 100 kg per location were taken for the landfill simulation reactor. At locations LUNZ AM SEE and Langenschlag the edge layer of the diggings caved in because of the instable waste bodies. In these cases it was not possible to take pure samples of waste. The surveying of waste layers was also deficient at those locations.

It is a common question of assessing old deposits, if the obtained results represent the on-site situation with an adequate reliability. The following are some common problems related to sampling:

- **Number and distribution of digging,**
- Choice of homogenisation (gathering volatile pollutants versus good mixing for representative sub-samples)
- Weak spots of individual analysis methods, etc.

It is nearly impossible to estimate how far an eluate out of a laboratory corresponds with the location-specific conditions of leaching process in the landfill body.

Considering digging operations at old deposits as independent method is a very interesting aspect. The temporary and financial input would be within limits. The sensory indications (e.g. smell) of the newly excavated material are very helpful for experts to find indices concerning environmental impact of the deposited materials. The real coating thickness is visible, which is important for estimating its permeability. Experts can also recognise if the materials are wet and decomposed or if there does still exist partly decomposable material in conserved form.

If the deposition type is closed, excavation operations can cause malfunctions in landfills. Microbiologic of activity could be reanimated as it happened in Rabenstein.

Current norm (ÖNORM S 2088-1) and guideline for assessing suspected areas consider results of chemical analysis of solid-samples as main factor concerning hazardousness. This is the reason why the comparing significance and plausibility of results of all other investigation methods were relativated to the chemical analysis. The analyses of the few obtained leachate gave clear results. Pollutant discharges have been clearly verified. Nevertheless, water from unknown pipes was inhibiting the analysis of leachate. The results must be analysed whether the analysed data comes from leachate or from water of unknown pipes.

The analyses of the contents of unstable compounds (e.g. phenol and cyanide) appear less important for deposits older than 15 years. Analysis of eluates on heavy metals and organic pollutants (PAH, CHC etc) can be left out.

4.2.7 Groundwater analysis

The main two questions to be answered in this stage were:

- How far do the actual critical value and the measured threshold values agree with the generally small discharges of deposits older than 15 years?
- To which extend can such minimum entries in the groundwater be analysed.

The differences of the groundwater composition in the examined surfaces, between the upstream and downstream taken samples, were marginal and can be seen as analytic uncertainty. It was clear, that it could only be obtained through the comparison with results from later deposits. Groundwater analyses at landfills in this state of development cannot be very meaningful. If it is an inert type of deposit, the leaching of pollutants has already been finished. If it is a potentially emitting type of deposit, there is almost no contact with neither the surrounding areas nor with the groundwater, and therefore no contamination is expected.

Clearly recognizable contamination of the groundwater could only be verified at the deposit of Rabenstein. This was a reaction to the interference of excavation works for taking samples. The closed systems (intact garbage bags) are broken, so there was a new elution of garbage contents. The slight entries of easily dissolvable inorganic ions in the downstream of the groundwater (especially Na, K, Ca, Mg, ammonium, chloride, nitrate and sulphate) could be regarded as uncritical. A statistical significant entry of toxicological relevant contents did not take place in any case.

Based on the data of both project phases, the groundwater analysis has only little importance for the evaluation of small and medium sized old deposits. These analyses seem to be much more important for the proof of emissions in the first few years. There are no more significant values expected more than 15 years after finishing landfilling. The analysis can only be used to prove or to exclude punctual leakages of a potentially emitting old deposit. Even in this case the results are very difficult to interpret because there are only very little differences between the upstream and downstream groundwater. If high differences are verified, the material is classified as highly dangerous (conclusion from the emissions). In some cases the groundwater analysis causes the only way to determine the leachate influence of an actual emitting old deposit. The meaning of the groundwater body should be proven before.

The groundwater contamination around the location of NEUHOFEN (OÖ, phase II) could not be explained with the project type and complexity of investigations. It is not clear, how only the verified LVHHs (lightly volatile halogenated hydrocarbons but no other mobile pollutants) reached the groundwater. The samples from the upstream groundwater were also contaminated but just slightly. Additional investigations on the special mobility of halogenated hydrocarbons should be made.

4.2.8 Analyses of ecotoxicity

Ecotoxicity and screening tests were scheduled to identify direct material hazardousness of deposited material. Except of the algae no assigned organism showed significant and clear arranged reactions by the contact with the deposition material. The algae test supplied reactions difficult to interpret. It remained unclear which sample parameters caused inhibitions, same, as there are reactions on an unknown, not analysed parameter (e.g. on herbicides). With plant tests the physical structure of samples were proved (grain size, water retention) because it affects the root penetration and the plants growth. From reanalysing sieved samples smaller 4 mm from project phase I, there was no more significant inhibition. In some cases the increased nitrogen parameters had a compensating influence on growth (manuring effect) and adjusted possible inhibition effects. Even the worm tests, the Daphna tests and the lumination-bacteria tests did not give clear results. This was not an inefficiency of the testing systems, but a result derived from the constitution of typical domestic waste. In TUMELTSHAM the presence of toxic content materials could be verified with ecotoxicity tests, the samples caused clearly higher inhibitions compared to the other 13 deposits. It is remarkable that in some landfills the measured values excessed the measure threshold value (MTV) of particular parameters according to ÖNORM S 2088-1, without that bio-tests would have indicated clear toxicity. So the question came up, if the used ecotoxicity test were too little sensitive or if the limit values regarding the hazardous potential should be rethought.

4.2.8.1 Statistical evaluation of ecotoxicity tests

Old deposits are always a disturbance of the original ecological system. It does not matter if it is inert or not. If some not adopted organism is confronted with the waste material as in case of the ecotoxic screening methods, it will always have a reaction. In most project cases not exceeding a certain point, these disturbances were attributed to other toxic reactions. According to the statistic evaluation the ecotoxic differentiation between inert and potentially emitting is only a small factor of influence. The cluster analysis could identify the extreme samples of the location TUMELTSHAM. A cross validation does not lead to no discriminance function, which would make a clear separation between the different types of landfills. With the main component analysis it was cleared up that the first three factors could explain the big part of the variance. But it was not possible to explain one of the factors with the background knowledge of the existence of landfill types. Above all the following factor charges were significant: the algae correlated well with factor 2 while plant species, worms and luminating bacteria reacted very strong along factor 1 of the statistical analysing methods.

4.2.9 Statistical Assessment for hazard estimation

4.2.9.1 Soil-air analysis

In the soil-air analysis the relation between the variables and cases is in the direct opposite to the ground water analysis. Many repetitions are leading to a clear grouping. TUMELTSHAM was classified as very similar to other locations. There was a special grouping for the values of the NEUHOFEN (L-CHC). Also inert locations (HOHENBERG) were considered into that group. In the discriminance analysis the relation between original cases and the cross-valuated cases was very close. So the soil-air analysis was specified as a good investigation procedure.

The same applies to the results on main component analysis. Here the component 1 could be explained as an important factor of influence to the landfill phase. The factor charge of oxygen correlated clearly and negatively with methane as well as with carbon dioxide. L-CHC and VTX approached to factor 2 also correlating negatively.

4.2.9.2 Solid analysis

Cluster analysis was the first procedure used for a big amount of data showing a clear system behind the data. TUMELTSHAM was clearly declared as an extreme location. While the other samples differentiated in a range of 5 measurement units, the three samples of TUMELTSHAM differentiated in 25 measurement units.

The results of the solid analyses showed a huge group of samples from all locations except TUMELTSHAM. This big group was separated in two other groups. One with samples of EBENSEE, HALLSTATT and HV, the second with samples of PURGSTALL and NEUHOFEN. The results of the solid analyses indicated an inert group of locations. This group did not differentiate much from smaller parts of potentially emitting depositions. The third part of this grouping shows samples of potentially emitting locations. Excepting TUMELTSHAM the analyses showed three big clusters. One group was with samples from potentially emitting locations, one with inert samples of HOHENBERG and a third group with samples of the locations HALLSTATT and EBENSEE.

The univariate ANOVA showed which parameters contributed significantly to a diversification in those groups. The biggest force of separation had arsenic, like in the first phase of the project. Also the content of lead and hydrocarbons had a big influence on the groupings. According to the discriminance analysis the determination of zinc and cadmium was particularly unnecessary for the differentiation of deposits.

The attribution of samples to one of the three landfill types was possible due to the solid analysis results. The 'extreme types' of deposits like HOHENBERG were hardly recognizable in cross validations. Using only some of the solid parameters (as for instance arsenic, lead and KW) in this discriminance analysis it would be unlikely in a future application that a sample would be unjustifiably assigned to an inert type. With the main component analysis only about 60 % of the variance could be explained. None of the first three factors affecting the distribution of samples could be explained by the influence of the different landfill types. The correlated factors in the second phase were different to the first phase factors.

4.2.9.3 Eluate analysis

Against all expectations the cluster analyses did not reach a good grouping results for the eluate analysis. After excluding the results of TUMELTSHAM some different types of deposits could be recognized. The group „inert" with some samples of „nearly emitting" could be best identified. Other clustering groups were less recognisable compared to solid analysis.

The discriminance analyses showed a quite good separation of different landfill types. The equality test on the groups mean values showed that the content of chloride, phosphate and aluminium were especially meaningful for the separation. Chloride is not a standardisable variable, which could be the reason for not showing the expected clearness in grouping by cluster analysis. The pH-value was the most separating parameter but only as long as differentiating the different types of landfills. In the discriminance analysis the separation of types was very well. Even in the cross validation a correct classification of the values (over 76 %) was reached. It is very remarkable that the inert type was only confounded with the mixed type. About 10 % of the samples of the potentially emitting types and of the actual emitting types were assigned to the inert type.

With the main component analyses data the first three factors explained less variance than with the solid data. Clearly correlating factors were COD, TOC, PAH and phenol which also seemed a plausible combination for PURGSTALL.

4.2.9.4 Groundwater analysis

Decisive was the relation of the unusual number of variables for the different cases. Only the first pass of the samples was taken for the analysis. All parameters that were relevant for the estimation of the material danger according to standard were included. Already the cluster analysis (even with the values of TUMELTSHAM) showed that some samples of NEUHOFEN were extreme values. But again the differences were within 5 distance steps, except both samples of EBENSEE and one sample of HALLSTATT. Those were more similar to leachate than to groundwater. The good classification results were debilitated by the bad cross validation results. With the ground water analysis the inert deposit type could be best identified. The difference between the total classification and the cross validation increased when the investigation procedures could not separate the different types of landfills. Boron had the largest separating force in the groundwater. In the main component analysis the first two factors explained a big part of the variance. Interpreting the factors load was built on the geogene location's condition.

4.2.10 Overview and classification of the used evaluation procedures

Table 5 shows the information about the danger of the deposited material (r_0) out of the individual investigations, partly analysed, partly derived from the deposit type. Table 6 shows an overview of the costs of the investigation methods.

Table 5: Classification of material's danger (r_0) out of individual preliminary investigations

location	files	inspection	interview	soil air	GW	analytic		ecotoxic
						solid	eluate	
DR, I	higher	lower	DW	DW	0	lower	lower	lower
ER, I	lower	DW	DW	lower	0	lower	lower	DW
LA, I	DW	lower	DW	lower	0	higher	lower	lower
LS, I	DW	DW	DW	lower	0	lower	lower	DW
RP, I	DW	higher	higher	higher	0	lower	lower	higher
HB, II	DW	lower	DW	lower	0	lower	lower	higher *
PU, II	DW	lower	DW	higher	0	higher	higher	DW
GR, I	DW	DG	DW	DW	higher	DW	DW	lower
HO, I	higher	lower	DW	lower	0	lower	lower	higher *
SF, I	DW	DW	DW	higher	0	higher	higher	higher
EB, II	DW	lower	DW	lower	higher	lower	lower	lower
HA, II	DW	DW	DW	lower	DW	lower	lower	lower
NF, II	DW	higher	DW	higher	0	higher	higher	DW
TU, II	higher	higher	higher	higher	0	higher	higher	higher

DW - Data related to average domestic waste (r_0 = 2)
* - inhibition caused by herbicides

Table 6: Cost / use balance of the applied investigation methods [5]

procedure	Info-content *	time exposure **	costs [€] **
	school grade	location	location
files	3	2 h	140
inspection	3	3.5 h	320
interview	4	7 h	570
soil-air	1	2 d	1.430
scrape	2	1 d	715
chem. Analyses	1	4 w	1.785
ecotoxicity	-	4 w	715
ground water	4	5 w	6.785
sum			**12.460**

* - composed of the quantity of the information and in agreement with chemical analytic
** - data including an average approach of 100 km and 1.5 h running time
*** - sum without costs for the determination of the ecotoxicity

4.2.11 Discussion on proposed modus operandi

4.2.11.1 Classification of old deposits into three different types

An important part for a first assessment of the material danger was the classification of the site to one of the following categories:

- **Leached out** (inert)
- **Potentially emitting**
- **Actually emitting**
- **Mixed type**

According to this classification it was already possible to estimate the expected material danger. The success was considered as good. The elution of water, leachate and groundwater resulted out of the individual history of the old deposit, the quality of the coverage and the contact with the groundwater. The water entry also determined the biological procedures of an old deposit. It was difficult but not impossible to make a classification without having data from the analysis.

Inert old deposits were eluted in the past by rainfall. At the time of investigation they did not have any soluble contents.

Potentially emitting types were characterised by waterproofed polymer coating and also by deposits of garbage in closed garbage bags and they kept their soluble contents for a long time. In the past they emitted only a little amount or even no pollutants. But a microbiological activity could be proved in all cases. It was verified by the existence of methane in the landfill-gas.

The mixed types could be recognised as actually emitting but only after getting more extensive data. They were characterised by zones with big elution, but also by zones without any discharge of water (this happened in deeper layers). So there were found zones with activity and zones that were inert at the time of investigation.

4.2.11.2 Consequences of the classification as preliminary assessment

Inert deposits contained neither soluble nor mobile pollutants in verifiable quantities. These were leached out in the past and the further infiltrating rainfall does not become heavily loaded. Non-mobile pollutants like heavy metals in insoluble compounds can be existing but they have no mentionable toxic potential. The organic waste compounds were mainly decomposed because of adequate water supply.

Even after its complete elution the material was still different to usual material of excavated earth. Nevertheless there is no acute call for action. There are no probable hazards for air, soil and groundwater.

Potentially emitting deposits still contained a big part of their mobile contents, eventually even soluble parts and pollutants. Because of the failure of water entry they were not eluted in the past. They remained in the dry parts of the garbage or were collected with the enclosed water in a big at the bottom of the deposit. The organic fraction of the garbage was only partly microbiologically abolished or it was not abolished at all. Organic pollutants like PAH, PCB and hydrocarbons could exist in high concentrations. The danger from this type of old deposit for air, soil and groundwater is nevertheless quite low as long as the surface coverage and the support layers are not changed or damaged. Soluble fractions could not be eluted unless in case of water entry. If this condition remains there is no further elution of mobile pollutants. Even if there is no important danger going out from this kind of old deposit the potential of methane emissions and mobile pollutant fractions still remains.

The risk of damage for air, soil and groundwater is comparatively low for this type of deposit as long as the surface coverage and the ground layer stays fully functional. There is no acute danger but the emission potential of methane and mobile pollutants is still high. Therefore potentially emitting old deposits should remain under observation but there is no need to make any clean up or assurance.

Actual emitting old deposits represented the group of mixed type. This type had inhomogeneities in the surface coverage or locally limited contact to spring water or groundwater streams. Dry material was next to fully leached out and inert areas. These inhomogeneities could arise sterically and also temporary. This could happen when some water streams under the surface arised only in certain periods or when the garbage body had contact to the groundwater in times of high level. The inert section adjoins directly to the potentially emitting sections. Regarding the contents and the emission the several sections had the same principles as the first two types. If water reached the non-leached out ranges in a slow way (diffusion, continuously) or in certain time intervals (groundwater high level, periodically) it was possible to mobilise the pollutants and to activate the microorganisms. Possibly methane was created and soluble contents and pollutants could leave the deposit by water flow. It was not possible to make a general forecast about frequency, concentration in leachate and pollutant load. The actual situation had to be cleared by expensive analysis. The potential of damage had to be determined analytically.

Depending on the meaning of the groundwater body it could be indicated if there was a call for action for the mixed types or not. The emissions taking place at the time of investigation could contain insignificant contents, like calcium and carbonates, but they could contain even more critical organic and inorganic pollutants. Decisions regarding assurance and decontamination could not be formulated in a general valid way.

4.2.11.3 General statements to pollutant contents

The results of the analysis showed that toxicological relevant concentrations and loads of pollutants occurred punctually and infrequently. Only one of the 14 investigated locations showed an analytically detectable contamination in the groundwater bounded on the halogenated hydrocarbons.

The toxicological danger of old deposits with pure domestic waste and/or waste similar to the domestic waste is low according to the data of this project. But for some more considerations it has to be mentioned, that the deposited waste still contains considerable concentrations of non-mobile heavy metals. The detected waste could rarely be classified as excavated earth or construction waste according to the Austrian landfill regulation (BGBl. 164/1996).

Mechanical characteristics as load-carrying capacity were not investigated in this project. Therefore the rededication of inert old deposit land to industry land or building land should be made on behalf of other criteria.

4.2.11.4 Consequences of type classification regarding the estimation of effort when investigating all old deposits in Austria

In a common reflection of all 14 investigated old deposits of both project phases it was visible, that the inert types of phase 1 (small deposits) were better leached out than those of phase 2. Smaller deposit layers and therefore a shorter way of elution for the rainfalls could explain this fact. On the other side it could also be explained by the more frequent local determinations (Hot-Spots) in combination with the clearly bigger amount of deposited waste. As a consequence of this awareness there is more often inhomogeneity when having bigger old deposits. Therefore mixed and actual emitting types occur more often. This thesis has to be taken as highly speculative, because it is quite probably that the investigation of the 14 old deposits cannot give a coherent image of the several thousands in Austria. But by extrapolating the results of this project it should be possible to make conclusions about the expected expenditure of human labour and the expected economisation. It has to be pointed at a considerable big misinterpretation.

4.2.11.5 Derived considerations for future investigations of material danger

This is not a guidance that must be obeyed literally, word by word. Even the expressions of the different recording clerks were not consistent. Also investigations on location took a different course every time and they lead to awareness that could not be seen as a concrete key. So it has to be mentioned that a classification of an old deposit to one of the three types implies a certain detective flair and professional knowledge of the enforcing person to interprete the information.

But nevertheless the classification leads to a quite good categorisation to assess the material danger in the old deposits. This estimation would have been right for 12 out of the 14 investigated old deposits after the inspection but even before performing other investigations. In two cases a first assessment had to be corrected after a first performance of soil-air measures. Afterwards the analytical situation would have been reflected.

Of course the recommendations are only valid for deposits older than 15 years. The volume should not be bigger than 50,000 m^3.

The investigations should be chronologically registered in the following way:

- Review of all existing files and records
- Inspection
- Inquiry
- Soil air investigations
- Digging investigation and sample drawing
- Analyses of solid samples (inclusive ecotoxicity)
- Analysis of ground water

The results and the reached awareness of each single step are the base for the necessary complexity of the next step. If some results from big and actual analyses already exist, it might be possible to reduce the complexity of the new analysis or even to skip them completely.

STEP 1 - START OF THE INVESTIGATION:

For covering the cognitions the first three steps (review of existing files, inspection, inquiry) have to be compulsory. The use of inquiries is more important to get in contact with the local population than to gain any information about the material danger. Analysis data out of files can consist of very varying significance and have to be handled carefully. Especially if they are already older it might be possible that they do not reflect the actual situation. Of course it is possible to see if deposited material contains pollutants and if they were eluable or if they migrated into the ground water. Especially in actual emitting old deposits it is possible that a discharge of pollutants years ago is already completed. Old deposits with water-soluble surface coverage emitting the soluble contents in the first few years after filling and they slowly change to an inert type afterwards.

Taking along a shovel and/or a drilling machine for inspection could be helpful to classify the surface coverage by making some profile-exploration diggings. But even the enquiry of the local soil type (at least after the categories: loam and sand) can help to estimate the dimension of the water permeability of the coverage. Out of the data of this project it can be seen that the surface coverage and the coverage in the meantime preferable were made of excavation material from the surrounding area.

The gained information together with meteorological data (amount and seasonal spread of precipitation) allows a preliminary assessment of the liquid to solid ratio (L/S). From the estimated L/S ratio the type of deposit can already be assigned to one of the three categories. Then the assessment has to be continued with step 2a, 2b or 3. If so far the clues indicate more a closed, potentially emitting type, the soil-air investigation might be more promising (go to 2a) In case of a leached out type a digging investigation might be more helpful (go to 2b). Assumed mixed types might still have emitting soluble contents, a groundwater investigation has to be made in advance. An endangerment of existing methane has to be cleared up with soil-air measurements. An endangerment for important groundwater has to be ensured by chemical analysis.

With a secured categorisation of the deposit into one of the types, inert or potentially emitting, the current material hazard can be assigned already with very high accuracy. If even a raw estimation of the L/S ratio is not possible because of the deficiency of data you will have to make further investigations and inquiries (go to step 3).

STEP 2a - SOIL AIR INVESTIGATION

Old deposits, with suspicion on rather well sealing surface layers and small L/S should be explored preferentially by measurement of soil air.

The composition measurements of the main landfill gas components are additionally an indirect measurement for the residual activity of the garbage body. The visual judging of the drilling core can determine the thickness of coverage very well. The variability of data gives further information on different areas and other inhomogeneities in the garbage body. Further representative impressions from the domestic waste can be expected.

Indices for a residual biological activity are the presence of methane in concentrations over approx. 15-vol%, the absence of oxygen and an increased conductivity of the material from the drill cores. As consequence of this the presence of mobile pollutant fractions must be expected. With the presence of clear indications of a potentially emitting type the classification and the exploration would be finished. The current material danger in this case should be assessed as high. Measurements for receiving the condition of the surface coverage and the support layer should follow.

If against all expectations there is no methane or there are only small concentrations (less than 2 % or inhomogeneously distributed) and the coverage layer seems to leak water, the deposit has to be classified as an inert type or an actual emitting type. The conductivity of the drill cores can simplify the further classification. Low values indicate the inert type and higher and inhomogeneous distributed values indicate the actual emitting type. A specifying investigation with further digging has to be made in every case. Possible inhomogeneities must be declared more exactly and it might be necessary to take some more samples for the laboratory (go to step 3).

Laboratory analyses of gas samples should take place for verifying any contamination with halogenated, aromatic and aliphatic hydrocarbons, which are not recognizable with other investigations. In case of positive reports digging investigations and continuing analysis are necessary (go to step 2b).

STEP 2b - DIGGING INVESTIGATION

Old deposits with suspicion of water leaking surface layers (with high L/S ratio) should be investigated with further diggings. The digging investigation should give clear indications of type and thickness of the coverage and also make type and quantity of the deposited material. The visual observation of the garbage must also be recorded, especially when organic fractions (herbal garbage, newspapers, etc.) or smell are present. If the underground is reached when digging (at smaller old deposits), the permeability of water should be estimated. Determination of conductivity of an aqueous eluate can be taken on site as additional decision aid.

If the coverage seems to leak water and if the typical organic components and their smell are missing and if the conductivity measurements gave only low values, the deposit can be classified as an inert type and the investigations can be closed. If the surface coverage is water impermeable, the smell of existing organic components is present as well as high conductivity, an actual emitting type is indicated. But when there are indications for an inert type at primary investigations it might also be a mixed type. When having unclear results or inhomogeneous distributions of characteristics or appearance of coverage and waste body seem to be different all over the area further investigations are necessary (step 3). With a high probability the soil air measurements after a digging investigation do not lead to meaningful results.

STEP 3 - HYDROGEOLOGICAL EVALUATION

In this project there were also locations investigated, where the waste body had no contact to the groundwater body, and where the leachate discharge directly to receiving stream respectively. The know how decides whether further investigations of the deposit's content should be followed in case of potentially contamination risk for the groundwater. The estimation of contamination risk by methane or other trace gases in the landfill remains unaffected and has to take place in case of suspicion (go to step 4).

STEP 4 - EXTENDED ANALYSES FROM SOLID SAMPLES

Depending on the current state missing investigations have to be realized for getting information about the composition of the landfill gas (inclusive trace gases) and about the garbage body after some chemical analysis. A first analysis of the ecotoxicity particularly with aquatic bio tests can help to plan the exact extent of further chemical analysis of the solid samples.

The results of the chemical analysis of the deposited material must deliver the ultimate indication of their actual material danger. The evaluation according to ÖNORM S 2088-1 is useful. Compliance of thresholds gets examined, e.g. Austrians Landfill Regulation or Drinking Water Regulation). Savings can be made on analyses of BTX, cyanide and fluoride of solid samples without losing any information. From the eluate only those parameters need to be analysed, which were actually not determined in the solid samples or which delivered a high value. Also analyses of heavy metals in aqueous eluate can be cancelled without losing any information except aluminium (soluble), iron and manganese as indicator for anaerobic conditions. The content of the nitrogen (nitrate, nitrite and ammonium) as well as conductivity and content of solved organic compounds (COD and/or TOC) are useful parameters and should never be spared from any investigation.

4.3 Results of the Technical University TU Hamburg/Harburg [6]

4.3.1 Institution

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4.3.2 Initial Situation

As a result of insufficient or not existing barrier systems an unknown leachate amount still leak into soil, groundwater and air. In addition uncontrolled biogas emissions occur. Due to the growth of cities and villages, these old small deposits are now more adjacent or even inside residential areas. This often results in restrictions in regional planning and land use. These suspected old deposit sites often remain unused or are alternatively used due to protection and restriction measures for a purpose of inferior value because of the cost intensiveness of risk assessments and treatment measures, which are generally have to be financed by the municipalities. Within the project, a method for the evaluation of the potential hazards from different types of small old landfills has been developed on the basis of selected, representative suspected sites. An already existing guideline of the province of Lower Austria for the preliminary assessment of suspected sites which is based on a guideline of the German federal state of Baden Württemberg was evaluated. Besides the indication of the array of current emissions via the pathways groundwater, surface water, soil, and air a detailed evaluation of old deposits, which show little or presumably no potential hazard was carried out with the attempt of developing sites for future land use. For these hundreds of thousands of small waste dumps within Europe there is only insufficient scientific and legal background available in order to enable an improved preliminary assessment of potential hazards from small old deposits. All cognitions of the project as well as the new developed assessment method are based on a multidisciplinary scientific cooperation of several international institutes from Germany, Austria and Italy.

4.3.2.1 Investigated old deposits

According to defined criteria, that are supposed to reflect the characteristics of typical small old deposits in rural areas, 14 representative sites in Lower and Upper Austria were selected for the investigations. Important selection criteria were the period of landfilling, the climatic conditions and the deposition volume. The criteria for the site selection are the following:

- The deposition of the waste should have been carried out between the years 1950 and 1980
- The annual average precipitation rate is set between 600 mm/a and 1,000 mm/a
- The deposition volume should amount from approximately 5,000 m^3 to app. 50,000 m^3
- The hydro-geological conditions should be in compliance with the central European characteristics (aquiferous quaternary sandstones, Flysch, Molasse)

4.3.2.2 Number and size distribution of old deposits in Germany and Austria

In the last years the existence of old deposits in Germany and Austria has been intensively registered. The investigation of the number of suspected sites has been performed on a state level. The Federal Environmental Office in Berlin reports a number of suspect areas of approx. 100,000 in Germany. However, this number is expected to grow due to the continuously development of the landfill register also in other states. At this time, there is an average of one suspected area per 822 inhabitants in Germany. According to latest information, there are approximately 10,000 old deposits in Austria; this means 1 abandoned landfill per 805 inhabitants.

Concerning size distribution of old deposits, there is a lack of information all over Europe. However, within the framework of this project, such data have been gained from the authorities of the states of Thüringen and Hessen in Germany. These data were supplemented by investigations of the state Lower Austria and evaluated statistically. As a result, about 80 % of all old landfills are in a category of smaller than 50,000 m^3.

It is also assumed that in 44 - 75 % of the evaluated old deposits, less than 10,000 m^3 of wastes have been deposed.

4.3.3 WORK PROGRAM

4.3.3.1 Investigation program

The following investigations and measurements were performed in the context of the European Union Life project EVAPASSOLD at the Department of Waste Management of the Technical University Hamburg-Harburg:

- Production of solid waste samples by drillings and diggings into landfills
- Physico-chemical characterisation (solid waste and leachate samples)
- Measurement of the biological activity of MSW- samples in respirometer
- Long-term investigations of waste samples in landfill simulation reactors (LSR)
- Sorting and classifying analysis of the waste samples up to a grain size of 0.063 mm
- Investigations on the water regime in individual disposals
- Evaluation of different water budget models, aiming to the best prediction of rainwater infiltration through the surface of the old deposits
- Evaluation of the deposition parameters volume, height, density, surface cover etc. using a simplified evaluation scheme

4.3.3.2 Landfill Simulation Reactors (LSR)

The emissions from landfills are highly controlled by the biological processes inside the waste deposit. The determination of the long-term behaviour of landfills and/or the estimation of the maximally mobilisable pollutant load (emission potential) has been investigated in landfill simulation reactors (LSR). These were already developed in 1981 and allow the simulation of the landfilling behaviour of landfilled waste under clearly-defined boundary conditions. Using the lysimeter it is possible to determine the “key parameters” for an optimisation of the degradation processes and the prognosis of the long-term behaviour of the landfilled MSW. The water flow through the lysimeter was about 2 – 22 times higher than in actual landfills which results in an acceleration of the emissions and thus in a time lapse effect. This is a consequence of an enhanced biological degradation and leaching of pollutants from the waste in the in the LSR. The microbiological degradation activity is optimised additionally by the control of a process temperature of 35 °C.

A regular analysis of the gaseous emissions (analyses of the permanent gases, ethyl benzene, CFC, trace materials) and leachate (analyses of the organic parameters: COD, BOD_5, nitrogen etc. and heavy metals) was carried out. Due to the high leachate exchange rate as well as by sampling for leachate analysis, 1 Litre per week of leachate has been removed and substituted by fresh water. This means that the degradation as well as the leaching processes in the landfill simulation reactors of the EVAPASSOLD project was about 2-22 times faster, than the examined old deposits.

4.3.3.3 RESULTS AND DISCUSSION

All investigated old deposits have no “technical” surface/base sealing systems. They are covered with regional-specific mineral material. These cover layers are more or less water permeable, which results in long term leachate emissions into the soil and groundwater. The long-term water regime in old deposits affects significant chemical, biological and physical processes that take place in the landfill body. The two most influential factors on the decontamination processes in old landfills are:

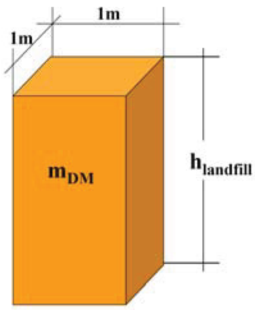
- **Biochemical degradation of the deposited organic materials**
  Regarding the anaerobic degradation processes in a landfill, the nutrient transport for the microorganism exclusively takes place via the liquid phase. Also the chemical conversion processes need sufficient water content. Investigations showed that already at a water content of less than 35 % strongly decreased biochemical degradation processes take place, which can even results in the termination of the conversion/degradation processes in the landfill body (preservation effects). In this case the pollutant content remains almost invariably available in the landfill over many years in the old deposits and can be re-activated with a renewed intensified water penetration into the landfill.

- **Elution via the leachate path (flushing effect)**
  Due to precipitation and snow melting, a water infiltration into the landfill body occurs. This leads to an elution and transportation of contaminated substances in the landfill body. This leachate emit from the landfills due to missing bottom liners, over long periods into the soil and/or groundwater.

If an optimum water content of 35 – 50 $\%_{DS}$ and sufficient corresponding processes prevail in a landfill body with sufficiently available organic substance, decontamination-promoting interactions between biological degradation and leaching processes can be provoke. In this case the most optimal pollutant degradation processes and highest emissions would be developed. Due to these facts can be understood that under conditions of comparable landfill compositions, thickness and deposit periods, a lower emissions potential will be exhibited in old deposits whereby a high water infiltration took place on a long-term basis, in comparison to those, at which smaller water entries took place.

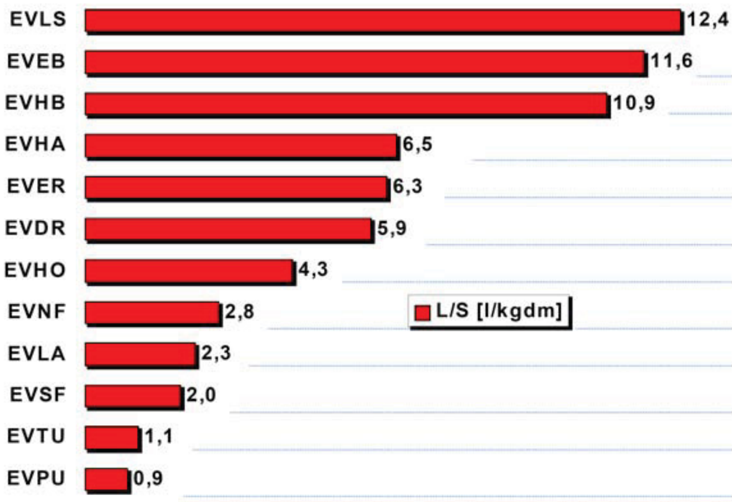
The parameter that best describes the amount of water that was in contact with the waste in the landfill is the Liquid/Solid ratio (L/S). Here the water infiltration in a landfill is set into relation to the dry weight of the deposited wastes. As the water/solid ratio is increasing, an increased leaching and intensified biochemical degradation in the landfill body takes place. The water-solid relationship is directly related to the kind of the surface cover system, the landfill height, the precipitation and the evaporation rates. With increasing Liquid/Solid ratio at the investigated small old landfills also the leachate contamination degreased. The test results (see Figure 2) produced in this research project show good correlations between the determined Liquid/Solid ratio in the landfill body and the corresponding leachate concentrations in the landfill simulation reactors (LSR) and in the elution tests.

$$L/S = \frac{(I_o * a_o) + (I_R * a_R)}{m_{TS}} \qquad (1)$$



L/S =	Liquid/Solid Ratio
I_o =	Infiltration into the *uncovered* landfill during operation [l/ a*m²]
I_R =	Infiltration into the closed/ *recultivated* landfill [l/ a*m²]
a_o=	Time period of waste disposal into the *uncovered* landfill during operation [a]
a_R=	Time period of the status closed/ *recultivated* landfill [a]
m_{DM}=	Dry- Weight (mass) of the landfill section of 1m² multiplicated with the estimated average height of the landfillbody [kg]

Figure 5: Model for the estimation of the Liquid/Solid ratio [6]



	COD [mg/l]	TOC [mg/l]	Cl [mg/l]	N_{tot} [mg/l]
EVLS	69	25	40	13
EVEB	200	80	29	54
EVHB	83	33	32	10
EVHA	200	77	40	10
EVER	84	33	27	10
EVDR	261	117	249	42
EVHO	99	37	91	17
EVNF	1138	450	632	300
EVLA	156	66	66	10
EVSF	833	306	676	356
EVTU	803	323	579	123
EVPU	1496	620	415	29

Figure 6: Estimated Liquid/Solid ratios of different waste samples from the investigated old landfills vs. different initial LSR-leachate compositions from the same samples. [6]

4.3.4 Gas and leachate emissions from the LSR investigations in the context of the L/S-ratio

For better demonstration of the influence of the individual water/solid ratios in the sample material on the emission behaviour, in Figures 3 & 4 the leachate and gas concentrations in the LSR versus determined L/S (at the time of sampling) are presented. These figures show typical examples for the LSR gas- & leachate production of material samples with very low & very high origin L/S-ratios.

Supplementing accomplished in-situ investigations at the individual locations (leachate composition and soil-air investigations.) have confirmed the results from the LSR investigations.

Therefore the different locations can be described regarding to their L/S-ratios:

High L/S (5.0 – 12 l / kg dry matter)

- No potential for gas emissions
- Elutions are lower than limit values
- Concentration of LSR – no more relevant heavy metal discharges in leachate flow.

Medium L/S (1.5 < L/S < 5.0 l / kg dry matter)

- Gas potentials possibly present
- With investigations on eluate emission potentials can still be verified
- Concentration of LSR-Leachate is higher than limit values accord. AAEV, no relevant heavy metal outputs

Low L/S (0.4 – 1.5 l / kg dry matter)

- Investigations on eluate still identify emission potentials
- Concentrations of LSR Leachate are high above limit values
- No relevant heavy metal outputs
- Relevant biogas production in LSR

Investigations in LSR showed that parameters as methane concentrations, biogas production, nitrogen and COD are relevant emissions at low water infiltration rates – even in small landfills. About 20 % of the landfills are potentially emitting types. Due to natural 'isolating process' (low permeable cover material) conservation of the waste took place in the landfill body. In this case, there remains an emission potential in these deposits. Emissions will not occur until a new initial event of biochemical processes caused by intensified water inputs (damaging of surface cover) starts. Using LSR-investigations the following results have been gained:

- Intensifying and shortening actual biological and elution processes in old landfills
- Verification of the relation between L/S-ratio and gas- potential in old landfills
- Prediction of the time period and potential of the emissions.

Results from the investigations regarding the L/S and from LSR- tests:

- **The Liquid/Solid ratio (L/S) gives indications about a set of old landfill characteristics**
- Long emission potentials for biogas, COD, organic and nitrogen compounds (>100 years)
- Old deposits with a very low L/S ratio (< 1.5 l / kg_{DS}) may still contain high emission potentials
- Old deposits can be categorised into the following types **stabilised**, **current emitting** and **potential emitting**.

On the basis the L/S ratio a statement regarding the existing emission potential can be made respecting the specific material danger of the landfilled waste materials.

4.3.5 Conclusions

It is possible to implement the parameter L/S- ratio into the risk assessment process for small old landfills.

In the existing Lower Austrian manual for the “Preliminary Evaluation of old Deposits” the current substance hazardousness of the landfilled domestic waste is mainly related by the parameter “age”. Further possible influences, which could have caused enhanced biological stabilization process and/ or intensified elution processes of the deposited wastes (water infiltration rate, geometry of the landfill etc.) are not considered!

By applying the L/S ratio factor instead of the factor age, it is possible to better estimate the current state of the waste emission potential of a small old landfill. Via a suitable model the water infiltration rate can be calculated. The model chosen during the EVAPASSOLD project is called BOHWALD.

For the calculation of the L/F ratio the following factors of influence have to be known:

Climate: Precipitation rate over the year, temperature, air humidity (if available on daily basis)

Landfill parameter:

- Kind of surface cover
- Kind of vegetation
- Landfill cover soil characteristics
- Surface slope
- Time period of landfill operation and closure
- Average landfill height
- Estimation of the waste dry mater (dry matter density)

A new, simple preliminary risk assessment model has been developed for small old deposits by the scientific team of the EVAPASSOLD- Project, which considers a maximum number of simple available factors which causes the degradation processes in the landfill body (see (1b).

$$(1b) \qquad G = r_0 * f(L/S) * f(\ )$$

G	Current risk potential of the old landfill
r_0	Substance hazardousness of the waste (at the time of deposition)
$f\ (L/S)$	Factor for the Liquid/Solid ratio
$r_0 * f\ (L/S)$	r_{now}: Current substance hazardousness of the waste
$f\ (\ )$	Factor for the site utilisation/protection

By using this model it is possible to rank small old landfills regarding the priority for the call for action.

The benefits of this model:

- High consideration of factors of influence on the long-term stabilisation processes in an old deposit.
- One evaluation scheme can be applied to all four media to be protected as there are groundwater, soil, air, surface water by means of the variable f() factor.
- Transfer of this model to other European countries should be possible due to the utilisation of the specific climatic relevant climatic factors (creation of data collections)
- Investigation for proving the applicability of this model should be initiated.

The boundaries for application can be so far defined as follows:

So far the suggested preliminary risk assessment model can be used only for small old deposits under climatic conditions similar to those in Austria.

- Deposit volume max. 60,000 m^3
- Maximum average landfill height of approx. 8 m
- No relevant (< 1 %) industrial waste deposits in the landfill body.
- “Middle European” climatic conditions

4.4 Results of the Institute of Hydro-Geology and Geothermy [8]

4.4.1 Institution

Institute of Hydro-Geology and Geothermy,
Joanneum Research Forschungsgesellschaft Graz (IHG), Austria
(http://www.joanneum.at/ing)

Univ.-Prof. Dr. Hans Zojer
Head of Institute for Hydrogeology and Geothermy at Joanneum Research Forschungsgesellschaft mbH, Graz
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4.4.2 The climate data are from climate stations next to the depositions

The Joanneum Research Forschungsgesellschaft mbH was one of the main investigating teams of the EVAPASSOLD project. The following list describes the performed tasks of the second project phase:

- Historical Investigation and visual inspection of 8 locations (Task 1)
- Analyses of aerial view on 8 locations (Task 1)
- Geological and hydro-geological scope (Task 2)
- Describing of climate conditions (Task 2)
- Estimation of leachate range (Task 6)
- Isotopic Investigations (Task 2)
- Geological and hydro-geological advise for soil-air measurements (Task 4)
- Supervision of drillings, diggings and pump-experiments (Task 5)
- Physical and chemical investigations of soil (Task 6)
- Supervision of field works and sampling

The aerial view screening and laboratory investigations of soil samples was delegated to authorised and qualified laboratories, as well as some isotopic investigations.

4.4.3 Comments on the investigation steps of the working program

4.4.3.1 Geological – hydrogeological characterisation

The study of recorded files and geological maps is important for the experienced geologist to get a rough estimation of the prospected location situation concerning geology and hydrogeology. In most cases field survey is inevitable. Therewith a classification into three main types of location can be made:

- Landfill at ***pore-aquifer*** (gravel fillings and sand pit fillings)
- Landfill on ***impermeable underground***
- Landfill on ***hydrologically undefinable aquifers***

4.4.3.2 Coatings

Climatic conditions and the surface coating of the landfill and its recultivation are important factors concerning leachate entry into the site's body. In most cases, the files give only little information about type and thickness of the coverage and recultivation. Data about thickness are predominating. There is a lack of soil-specific description of coating materials.

In connection with the geological situation of surroundings, useful interferences can be made about the surface material. Coatings of gravel pit are usually filled with the local sandy–gravel materials. Locations in granite – felt areas tend to be filled with well-permeable sandy and weathered granite. In areas of flysch or silt, the surfacial filling materials as silt and clay are low permeable or impermeable. The approximate time, when the deposit was closed by a final coating can also be estimated.

4.4.3.3 Visualising

<u>Aerophotographic screening and multitemporal aerophoto-analyses</u>

Screening is a useful method for reconstructing the location and extension of old deposits. Out of its area and waste layer thickness and the cubature are estimated, but only in case of pit-filling landfills with simple geometrical morphology, such result is actually useful. At backfilling of trench or similar complicate underground morphology, the results have high uncertainty. In this case, the expensive multitemporal-aerophoto-analysis delivers good results on volume and cubature of the waste layer.

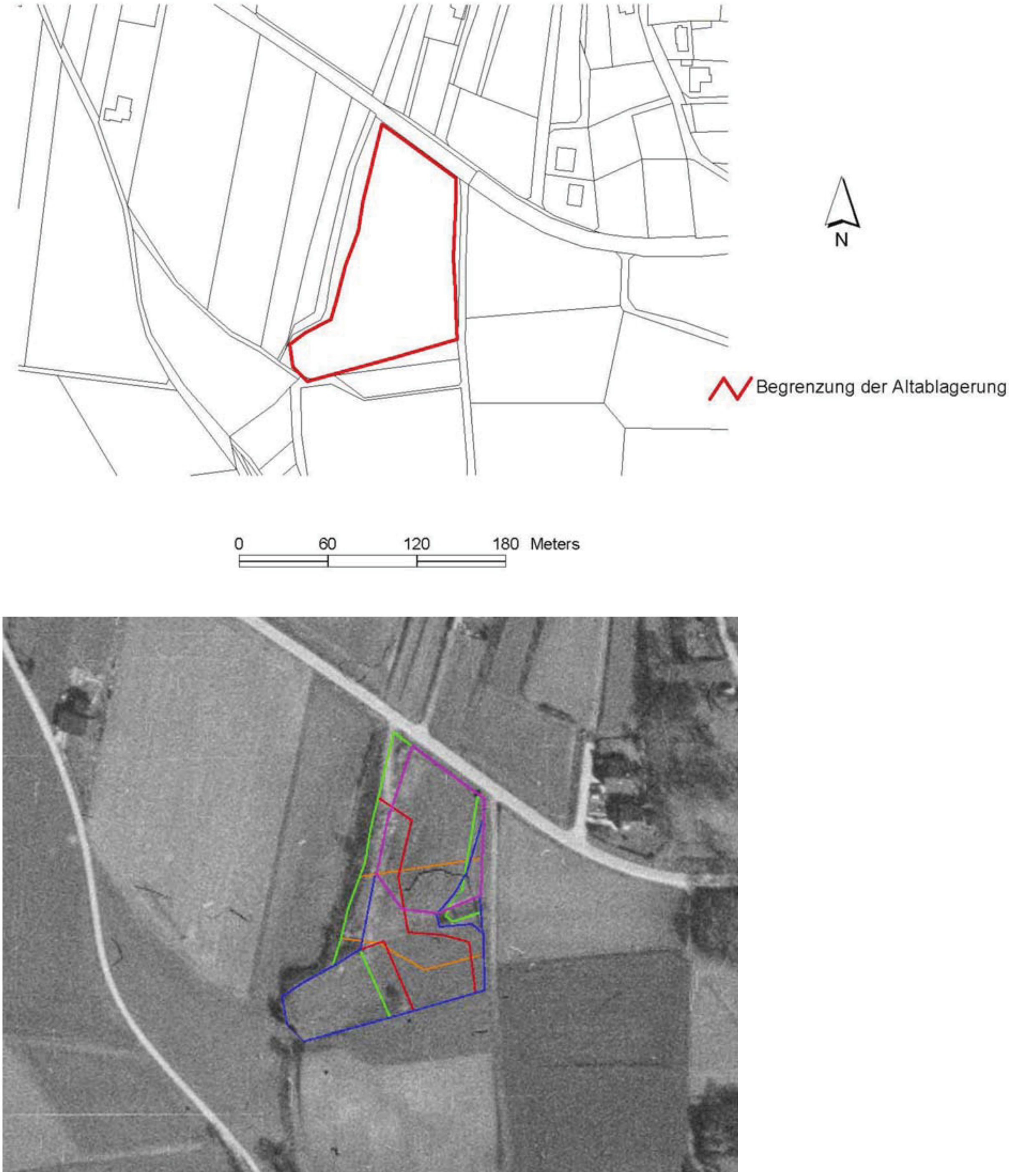

Figure 7: Example for aerial view screening with Orthophoto

4.4.3.4 Diggings and Drillings

The operations showed clearly that a systematic underground investigation by drillings with present instructions like *"two drillings upstream of the old deposit and three drillings dorwnstream"*, is not useful. The main reasons are:

- Generally, the experienced geologist can estimate the geological and hydrogeological conditions around the deposit without drilling. No essential cognitions concerning geological conditions at locations, waste ground-layer and aquifer in admission areas could be obtained compared to the information from historical investigation and inspection. Only at one location, the drillings showed an unexpected stacking of the subsurface (Herdmann, GREIN AN DER DONAU). In this site, the waste layer is bedded on impermeable silt and not from on-site inspection on granite as expected. For estimation of hazardousness, this fact is not significant.

- From morphologic diagnoses in most cases, the drilling results and a possible high soil-moisture content could be forecasted very well.

- It was the question if special underground conditions make the detailed ground layer investigations (especially on groundwater contamination) dispensable. Drillings on clayey and silty undergrounds and on granite or carbonate locations were not useful. In most cases, these cores were dry or sometimes they showed a local leachate entry from the surface layer without any contact to the waste layer. If there are no clearly indications for an aquifer in the landfill's ground layer, generally the drillings are not useful.

- In case of a pore-aquifer in the landfill's ground layer, the ideal positioned drillings combined with pump investigations for flow rate, direction, gradient and volume are some useful aquifer parameter that can be obtained. These parameters are a good fundament to estimate the aquifer's importance and to forecast any pollutants load of the groundwater downstream.

- Because there is less risk at this time for actual pollution of the groundwater at any investigated deposition, a systematic investigation of the landfill's ground layer is not recommended for any type of deposit (actually emitting, potential emitting). Exceptions are old deposits within the catchment areas of water supplies. The supplier is committed to control the water quality regularly.

4.4.3.5 Analytics of solids

Investigations on clay minerals and determination of the sediment's cation exchange capacity at the ground layer of the deposit were conducted in the first project phase. All institutions participating the EVAPASSOLD project estimated these results as without significance and not useful.

The detailed soil investigations of the landfill's recultivation layer (e.g. profile description on site for supporting the laboratory analyses) for determining the leachate entry into the waste body seemed to be very important.

4.4.4 Summering results

4.4.4.1 Locations under hydrogeological aspects

From a hydrogeological aspect, in general three types of location can be characterised:

- Old deposits on **pore aquifer**
- Old deposits on **underground with high density**
- Old deposits on **stone with less moisture content**

4.4.4.1.1 Old deposit over pore aquifer (e.g. fillings of gravel pits)

A pore aquifer can be differentiated hydraulically according to its flow direction, groundwater speed, groundwater gradient, sediment permeability etc. For the estimation of those parameters, level networks and evaluation of pumping tests are necessary.

From a hydrogeological aspect, pore aquifers are usually important for water supply. It must be assumed that water supplies are present in the downstream area of the old deposits. Usually leachate of such landfill types discharge into the aquifer directly under the waste body, being absorbed by the groundwater stream.

Here occurs a dilution effect that depends on permeability, thickness of aquifer etc. The results of the hydro-chemical analyses of water samples drawn from the near downstream area showed that there is nearly no verifiable contamination of the groundwater. Over the years, the old deposit leached out. Deductive complex investigations on the groundwater aquifer cannot be regarded.

In most cases the surface cover material was gathered locally, so the recultivation layer's permeability can be classified mainly between medium and high permeable. In most cases old gravel pit fillings can be attributed to the landfill type inert or actual emitting.

4.4.4.1.2 Old deposits on high density underground

Trench fillings with geology of tertiary clay or silt as well as cleftless rocks like Phyllite, different types of crystalline schist or gneiss. The waste either was filled directly on an impermeable rock or on a thin layered unconsolidated soil rock. In the first case, the leachate will leak from the landfill bottom due to the water-confining bed. In the case of weathered rocks, the leachate is leaking diffusely and can be detected by diggings.

Drillings for groundwater sampling are not useful. Surface coatings in most cases are filled with local material. This material, adequately compressed, is practically impermeable. An example of such landfill-type is Kaltenberg near St. Florian. Potential emitting landfills will be found predominantly in such regions (flysch, schlier).

4.4.4.2 Depositions on rocks containing low waterflow

These deposits can be found on not contiguous aquifers (i.e. cleft aquifers). At the bottom layer of the deposit water can be present is not contiguous or contiguity can only be detected by expensive investigations, which have to be adjusted to each individual case (e.g. drilling, hydrochemical investigations, pumping test).

It might be possible to find some water supplies in the sphere of influence. It has to be taken care if there are some water well-springs in the surroundings. The investigations at these locations have showed that most parts of the drillings were dry.

Deductive drilling investigations are not a suitable way for investigating the hydrological underground conditions. The detection of a possible contamination of groundwater should be based on investigations of well springs in the downstream area.

4.4.4.3 Locations seen by sight-leachate input

As in the first project phase the leachate input of old deposits was calculated with the single-layer balance model, enlarged by an interception. The results are summarised in Table 7.

Table 7: Overview of the water balance influencing data of the locations [8]

Open deposit area						
Location	**Period**	**Precipitation**	**Usable field capacity**	**Leachate input in deposition area**		
				Mean value	**Minimum**	**Maximum**
		mm	mm	mm	mm	mm
Hallstatt**	1973 - 1994	1,603	18	1,102	760	1,756
Ebensee	1961 - 1975	1,507	18	1,055	611	1,597
Hohenberg	1970 - 1982	919	18	552	249	784
Tumeltsham	1966 - 1972	793	18	398	204	641
Neuhofen	1975 - 1988	727	18	333	153	486
Purgstall	1966 - 1974	685	18	317	161	418
recultivated deposition area						
Hallstatt**	1996 - 2000	1,751	20	1,140	1,068	1,311
Ebensee	1977 - 2000	1,658	34	1,230	817	1,668
Hohenberg	1984 - 1993*	982	15	566	415	743
Tumeltsham	1974 - 2000	898	79	neglectable (< 15)		
Neuhofen	1990 - 1999	793	71	neglectable (< 15)		
Purgstall	1979 - 1999	867	104	neglectable (< 15)		

* climate data missing; **data only valid for shallow areas

The results of the leachate modeling have influence on the L/S-ratio. This is the ratio between the water entering the landfill, and the existing dry substance. This proportion is an indicator for the leaching process and the microbiological decomposition of the landfill body.

4.4.4.4 Result of EVAPASSOLD and remarks to the Lower Austria scheme for a first evaluation regarding the safety of groundwater

As with all assessment schemes, the Lower Austrian evaluation model assumes that the water input in the landfill and the consecutively leaching process of the waste and mobilisation of pollutants has to be assessed as negative.

- The coverage decreases the danger potential. On its presence the factor m_1 (pollutant output) decreases as following:

    - Minus 0.1 with a “state of the art” coverage

    - Minus 0.05 with a 30 – 50 cm merging material coverage

  This is not corresponding to the results of the EVAPASSOLD project circumstantiating the danger potential decreases when having a higher water input and over the years. Old deposits not covered or only covered with permeable material actually have no or less danger potential than the covered deposit with not permeable or thick material (emitting or potentially emitting).

- The evaluation of unsaturated horizon between the landfill base and the aquifer assumes that a delay of pollutant infiltration into the groundwater is positive. The multipliers of the old scheme are between 0.8 (horizon not permeable) and 1.25 (carste). If the old deposit is in the aquifer, the multiplier is 1.3. In addition, this proceeding does not correspond to the EVAPASSOLD project results.

- The weighting of the water management of the ground water appears in the old scheme in evaluation step m_4, another point that has to be critically rethought. It is always assumed that groundwater is present, which has to be saved. However, in many cases the old deposits are bedded on impermeable underground, and the landfill leachate discharges directly into the receiving stream without groundwater contact.

  Examples for this situation are the following old deposits:

  ERTL: The old deposit is bedded in a silty clay-rift of the flysh zone. Drillings were dry. Water of the landfill horizon discharges directly to the receiving stream.
  HALLSTATT: The biggest part of the old deposit is bedded on silty clays, in a rift of the Hallstatt lime. At the landfill bottom layer the leachate discharges into a surface pipe.

A similar situation occurs at locations where the landfill leachate discharges to a receiving stream. Examples are old deposits on riverbanks and old river arm backfilling, with the examples DRÖSING and LANGSCHLAG.

Due to these facts, the old evaluation model is only for limited use.

5 Evaluation of the project results and conclusions

5.1 The final assessing model of the EVAPASSOLD project

This chapter is intended to introduce a new first-evaluation model, performed by the EVAPASSOLD partners, for the assessment of small old deposits.

There are two important considerations before this evaluation model should be used:

- Is the old landfill < 50,000 m^3, with an average thickness of 8 m?
- Are we in the working range (R_0)?

If there are positive answers, it is possible to use the developed ranking system on this site. If one answer is negative, this ranking system cannot be used. A simple scheme regarding the use of this model is depicted in Figure 8.

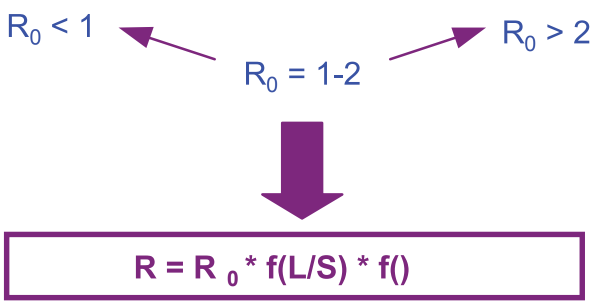

Figure 8: Support model for the first decision in the evaluation of a small old deposit

It has been stated that the Risk (R) model should contain three factors: R_0, f(L/S) and f(). R_0 deals with the historical background of the old deposits, as it will consider the kind of residues deposited as well as their deposited age. The liquid-to-solid ratio will also comply the information regarding the age and state of the old deposit. Therefore, these two parameters, when multiplied, conform what it has been called as „Actual material hazard“. Finally, the f() factor will consider all geological parameters regarding the subjects of protection (soil, air, groundwater, surface water).

5.1.1 The R_0 factor.

The R_0-factors value is changing linear between the range 1 and 2. Value 1 means 100 % construction waste and / or excavation waste. Value 2 means 100 % domestic waste. If there is a mix of those two different waste types the R_0 factor is set to the following rule:

- Construction waste, excavation materials with 10 % of domestic waste will have an evaluation of R_0= 1.1 (20 % = 1.2; 30 % = 1.3)

- 100 % domestic waste and domestic-like commercial waste: R_0= 2 (containing a maximum of 1 % hazardous waste),

In this evaluation model, when R_0 has a value inferior to 1, then the risk factor R will be considered equal to R_0. Moreover, if R_0 has a value superior to 2, then the old deposit is out of the range of the EVAPASSOLD model, and thus this evaluation procedure is not recommended.

- If $R_0 < 1$ then $R = R_0$

- If $R_0 > 2$ out of application-range of EVAPASSOLD

According to this scheme, R only gets evaluated, if R_0 has a value between 1 and 2 !

5.1.2 The f(L/S) factor.

In order to simplify the application of this model, the following scheme has been developed for the value determination of the function of the liquid-to-solid ratio.

$$F(L/S) = \begin{cases} 1 & \text{when } L/S < 1 \\ 1.2143 - 0.1429*(L/S) & \text{when } 1 < L/S < 5 \\ 0.5 & \text{when } L/S > 5 \end{cases}$$

Figure 9: Definition of the f(L/S) function

For detailed information see chapter *4.3 Results of the Technical University TU Hamburg/Harburg*

5.1.2.1 Calculation of the L/S ratio

According to Allgaier [6] the following equation shall be considered for the determination of the L/S ratio:

$$(3) \qquad L/S = \frac{(I_0 \cdot a_0) + (I_R \cdot a_R)}{m_{DS}}$$

I_0	Infiltration into „opened“ landfill [mm/a]
I_R	Infiltration into „closed“, recultivated landfill [mm/a]
a_0	duration of „opened“ deposit [a]
a_R	duration of „closed“, recultivated deposit [a]
m_{DS}	mass of dry substance in landfill-sector with base area 1 m². [kg_{DS}/m²] = 1m² * $h_{average}$ * $r_{DS\text{-}HM}$ (Figure 10)

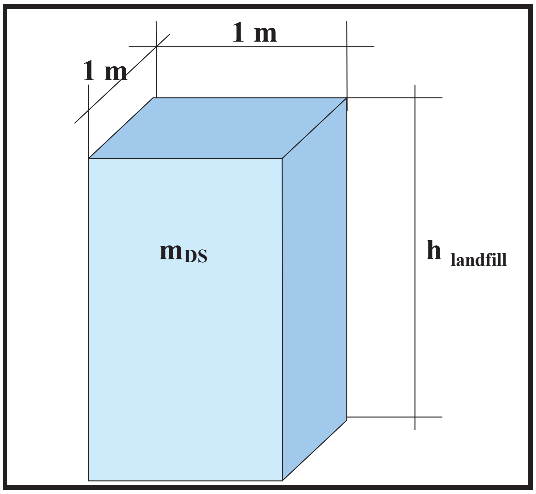

Figure 10: Scheme for the determination of the L/S coefficient [6]

5.1.2.2 L/S input-parameters

- **simulation program** develops water balance (climatic leachate formation, evaporation). Recommendation: BOHAWALD
- **climate: rainfall, temperature, air moisture** as far as available on day-base; in Austria available from: ZAMG [7]

- **Landfill parameters**
  - Surface coating
  - Vegetation
  - Surface characteristic value, thickness
  - Surface slope
  - Period (open/recultivated)
  - Average deposition thickness
  - Deposition dry density

5.1.2.3 The f( ) factors

This factor concerns to the hydrological aspects of the old deposit. Therefore, a risk evaluation can be performed on basis of groundwater, surface water, air and soil. Their correspondent evaluation parameters are presented in Table 8 to Table 11.

Table 8: Evaluation of the parameter f(G) – risk of contamination effects on groundwater

Parameters for the evaluation of f(G) for groundwater	
1	No utilisation possibilities for groundwater
1.3	Within influence area of water well
1.5	Run-off water, pore groundwater... sufficient only for individual and/or local water supplies.
1.7	Inside a (potential) area of regional and/or national drinking water supply
1.8	All declared sanctuaries and protected areas (phase III), groundwater body with national importance
2	All declared sanctuaries and protected areas (phase I + II)
> 2	In area of influence of an actual drinking water supply

Table 9: Evaluation of the parameter f(W) – risk of contamination effects on surface water

Parameters for the evaluation of f(W) for surface water	
1	No surface-water within 25 m surrounding and surface-water with possibility of contact to humans no more than after huge thinning of a potential emission and surface water without any special utilisation claim.
1.5	Surface water within directly urban areas or leisure areas (or in nature reserve), larger thinning possible.
2	Surface water within directly urban areas or leisure areas (or in nature reserve), no larger thinning probable resp. utilisation for in-shore filtration recovery or ground water-accumulation

Table 10: Evaluation of the parameter f(A) – risk of contamination effects on air

Parameters for the evaluation of f(A) for air	
1	No utilisation possible and/or contact with humans improbable.
1.2	Utilisation possible (e.g. grassland) and/or contact with humans possible
1.5	Actual agricultural utilisation (e.g. plant production) or location in a natural reserve, eventual fixtures in this area.
1.7	Single urban areas and/or other buildings or facilities for humans as well as leisure areas (parks)
2	Directly urban areas and/or areas with high sensible utilisation (e.g. children's playground)

Table 11: Evaluation of the parameter f(S) – risk of contamination effects on soil

Parameters for the evaluation of f(S) for soil	
1	No possible use of surface.
1.2	Agricultural utilisation of surface possible.
1.5	Agricultural utilisation of surface or situation within natural reserve.
1.7	In urban areas without possibility of direct contact to children.
2	Usage of area and/or usage of direct surrounding as leisure area (also children's playground).

6 Risk Assessment

This chapter was worked out by the IMAGE - Department of Hydraulics, Maritime, Environmental and Geotechnical Engineering, University of Padua. It was part of the Sardignia Symposium 2003, an international Waste Management and Landfill Symposium.

6.1 Fundamentals of Risk Assessment applied to the Aftercare Landfill Impact [9]

6.1.1 Introduction

Risk is an indication for damage caused by an accidental event. The system risk considers the hazard, intrinsic property of the system, and the occurrence probability. A system is not "risky" if it cannot cause damage on the universe. Everything outside the system is defined as "Universe". With other words, the universe is everything outside of the borders of the system landfill. For example, in a system damaging itself is not risky according to the given definition.

The universe can be classified in two effects of contamination:

- The environmental subject of protection water, air and soil;
- The biotic components of flora, fauna and humans.

The risk interaction on the environmental biotic components flora and fauna is called **Environmental Risk,** while **Sanitary Risk** describes the damage potential on human beings. The damage potential can be differently evaluated e.g. economic damage, loss of local species, concentration of the contaminants, damage to human health, lethality, etc.

Considering the risk as a function of the space to n+1 dimensions with n equals to the numbers of the different measuring units expressing the quantity of adverse effects. However, the problem of comparing the different damages and the subjectivity of decision processes still exists. The risk of the different events is expressed by a series of n-multiple. "n" is the number of possible measures of damage.

$$(2) \qquad R = \left\{ \begin{array}{l} \text{Economic damage in Euro} \\ \text{Concentration of contaminant in environment} \\ \text{Loss of life-expectancy} \\ \\ \text{Individual excess Lifetime cancer risk} \\ \text{Hazard Risk} \\ \ldots \end{array} \right\}$$

When deciding to use a unique describing unit for the system damage (e.g. human mortality), all the risk scenarios could be expressed similar.

According to the latest literature, a landfill system is multi-barrier, that means the system borders are not only the physical borders around the waste. In risk assessment, the attenuation of the barrier should also be evaluated.

In mathematical terms, the risk of a system is a function of the following parameters:

$$(3) \qquad R_i = f\ \{\ S_i, M_i(t), F_i(t, L), \varphi(M_i, F_i)\ \}$$

where:	
R_i	Risk of system due to event i
S_i	Event i
M_i	Magnitude of event i, function of time
F_i	Frequency of the event i, function of time and of the field scale of study
$\varphi(M_i, F_i)$	Parameter including uncertainties of magnitude and frequency

A problem of finding a general-valid risk-evaluation is the question, how to determine a function to evaluate all participating events. An easy way of solution is to use an additive function; but in this case the possible synergic effects cannot be considered.

In general, the global risk of a system is expressed by the following formula:

$$(4) \qquad R = \sum_{i=1}^{n} R_i + \sum_{i=1}^{m} R_i$$

where:	
R_i	Global risk of the system due to event i
n	Number of identified events
m	Number of unidentified events

The evaluation of the global risk depends on the experience of the assessing persons. More know-how leads to better will be the results.

The risk is a positive and limited indicator of the damage probability adequately applied:

$$(5) \qquad \lim_{M \to 0} R \to 0$$
$$\lim_{F \to 0} R \to 0$$

These situations represent the two theoretically cases defining the “no risk zone”:

- The magnitude (degree of damage of the landfill) is zero;
- The frequency of occurrence is zero.

Practical experience shows that these conditions are never reached in practice, except:

- After a long time and
- Very far away from the landfill.

The legislation should fix a tolerable level of risk. This existing limit will be discussed later, and could define the aftercare period. The following paragraphs describe the risk parameters of the system.

6.1.1.1 Events

There are many possible events of the landfill system differing from each other. These appearances derive from primary events, the so-called “Top Events”. They are at the top of a hypothetical risk tree:

- Uncontrolled biogas flow;
- Uncontrolled leachate flow;
- Solid waste flow.

Comparing these risks, the solid waste flow has low mobility. In this flow the pollutants are linked to the solid waste matrix and to the cover material. The damages made by the solid waste flow are applied to the system contiguous areas (e.g. the contamination of vegetation above the surface cover due to pollutants presence in the waste matrix, incorporation by dermal contact of the contaminated soil).

The solid waste flow has a low contamination potential, as a consequence it is very often omitted in risk assessment. In fact, the risk due to solid waste flow does not cover the whole life of a landfill, but it covers the aftercare period, when the polluting level has severely decreased (Table 12 and Table 13).

Every event is composed by a source, i.e. polluting flow (concentration and quality), by the way in which it moves from the systems boundaries (“fate” and “transport”), and by a target (children, men, fish, plants, etc). All these quantities define the exposure route. Generally risk assessment is conducted for a single substance. Studying the human risk, only the present landfill pollutants are taken into consideration that has a known toxicity to humans. At the moment less toxicity data of these chemicals are available, limiting in a considerable extent the human risk.

In general the event (S_i) is defined according to the following relation:

$$(6) \qquad S_i = S_{j,k}$$

where:

S_i	risk of system due to event i
j	exposure route
k	dangerous substance

In the system many chemical substances are present and they have different chemical, physical and toxicological behaviour. This presence makes the risk assessment complex. It has to consider many types of events, each referring to a contaminant.

Traditionally, the contaminants of the leachate and of the biogas are classified by physico-chemical parameters.

Leachate parameter:

- Organic dissolved parameter and organic hydrophobic parameter;
- Macroelements (Chlorine, Iron, Nitrogen compounds, etc)
- Heavy metals (Arsenic, Cadmium, Chromium, etc.)

In the biogas parameter:

- Methane and carbon dioxide.
- Traces of substances (H_2S, Vinyl Chloride, etc.).

In human toxicological context, a fundamental substance differentiation is made between carcinogenic substances (e.g. benzene) and non-carcinogenic substances (e.g. ammonia).

A methodology focussing on a unique substance like ammonia, that represents one of the most important landfill contaminants, is currently in a working progress. In fact, many authors have discovered that the toxicity of leachate is mainly due to the concentration of ammonia.

Table 12 and Table 13 show the probability of the most important events divided in the different exposure routes. The results are calculated for three different phases of the landfill life: exercise, aftercare and long period. In particular, the first table shows the environment risk, the second table shows the human risk.

It is pointed out how the risks of some events are still substantial in the aftercare period. In Italy the aftercare period is fixed with 30 years. The acceptable risk will be discussed later.

Other events describe a low risk during some landfill phases. It is necessary to define the landfill lifetime initially and the risk should be calculated at that time. In cases with low event occurrence probability the risk assessment can be neglected for this event.

Table 12: Probability of the accidental events during the life of a solid waste landfill. Aftercare means the management period of 30 years from landfill closure and long period means the following phase. [10]

TOP EVENT	EVENT	OCCURENCE PROBABILITY		
		Excercise	Aftercare	Long Period
Biogas Flow	**Biogas**			
	Hazardous concentration of contaminants	+++	++	-
	Inhibition to growth of vegetation	+++	++	-
	Inhibition to animal growth	++	+	-
Lechate Flow	**Contamination of Groundwater**			
	Overcoming of limit concentrations	+++	+++	++
	Contamination of Surface Water			
	Overcoming of limit concentrations	++	++	++
	Inhibition to growth of vegetation	++	++	++
	Inhibition to animal growth	+	+	+
Solid Flow	**Soil**			
	Overcoming of limit concentrations		++	+++
	Inhibition to growth of vegetation	+	+	+++
	Inhibition to animal growth	+	+	+++

+++ = high probability, ++ = medium probability, + = low probability, - = no hazard

Table 13: Probability of the accidental events during the life of a solid waste landfill. Aftercare means the management period of 30 years from landfill closure and long period means the following phase. [9]

TOP EVENT	EVENT	OCCURENCE PROBABILITY		
		Excercise	Aftercare	Long Period
Biogas Flow	**Biogas**			
	Inhalation of indoor gases	+++	++	-
	Inhalation of outdoor gases	+++	++	-
	Dusts			
	Inhalation of indoor dusts	++	+	-
	Inhalation of outdoor dusts	++	+	-
Lechate Flow	**Contamination of Groundwater**			
	Ingestion of contamined groundwater	+++	+++	++
	Dermal contact with contaminated groundwater (while showering)	+++	+++	++
	Inhalation of outdoor vapours	+++	+++	++
	Inhalation of indoor vapours	+++	+++	++
	Ingestion of home-grown vegetables irrigated with contaminated water	++	++	+
	Ingestion of irrigation water	++	++	+
	Dermal contact with irrigation water	+	+	+
	Inhalation of irrigation water spray (from sprinklers)	-	-	-
	Contamination of Surface Water			
	Ingestion of surface water (e.g. while swimming)	+	+	+
	Dermal contact with surface water	+	+	+
	Ingestion of home-grown vegetables irrigated with contaminated water	++	++	+
	Ingestion of irrigation water	+	+	+
	Dermal contact with irrigation water	+	+	+
	Inhalation of irrigation water spray (from sprinklers)	-	-	-
Solid Flow	**Soil**			
	Dermal contact with contaminated soil	+	+	+++
	Ingestion of contaminated soil	-	+	++
	Ingestion of home-grown vegetables grown in contaminated soil	+	+	+++
	Microbic risk	+	-	-
	Vapors			
	Inhalation indoor of gas	+	+	+
	Inhalation outdoor of gas	+	+	+

+++ = high probability, ++ = medium probability, + = low probability, - = no hazard

6.1.1.2 Magnitude (degree of damage)

As it was mentioned before, the magnitude quantifies the danger potential of the system. This potential depends on the typology of the deposited waste and can be decreased by sets of barriers.

The hazard is constituted by the characteristics of the present chemical substances in the waste body. The magnitude (degree of damage) is shown in the pollutant contents in the uncontrolled flows, i.e. leachate and biogas, and in up to a certain extent also in the solid flow. Physical, chemical and biological reactions, make the pollutant carrying vectors varying from time to time. Models of leachate and biogas production can evaluate these variations.

While the production models indicate the variations of the pollutant quantity inside the system, the transport models indicate the variations outside the system. The evaluation of mean flow rate of biogas and leachate and their transport can be executed by the use of analytical model. Simple models sufficiently accurate, obtaining both leachate and biogas. If the system is a homogeneous reactor CSTR, then the concentration of the pollutant will only depend on time. In general the system will be assumed as mixed reactor. If the waste typology and the surrounding conditions are different, several CSTR reactors for each landfill may be considered.

$$\lim_{t \to t_M} M \to 0 \quad (7)$$

where

t_M Specific system time which is independent from the exposure route and the target. It indicates the period in which the hazard associated to one of the main flows can be neglected (Table 14). That parameter may be determined knowing the long-term behaviour of the chemical substances that are present in the landfill.

Table 14: Average values for polluting flows in a traditional urban solid waste landfill. [9]

Flow	t_M (years)
Biogas	30
Leachate	100 - 500
Solid	100 - 500

For different landfill typologies like pre-treated solid waste or incineration waste landfills specific consideration must be taken into account.

6.1.1.3 Frequency

Frequency quantifies the possibility that the mentioned pollutant vectors exit the system and damage the universe. The universe is restricted to a characteristic dimension “L”, i.e. the landfill borders, the distance to the first residential building or drinking water supply. The choice of the conformity point is still argument of discussion.

The Frequency can be quantified by the transport models and distribution models and by damage potential models. Vulnerability models quantify the damage on the universe by estimating effects on base of concentration, i.e. the PNEC (Predicted No Effect Concentration). The vulnerability models are defined according to the target objects human (sanitary health) or abiotic environment including flora and fauna (ecological risk).

(8)	$\lim_{t \to t_F} F \to 0$

where:	
t_F	Does not depend on the system but on the followed route and on the target typology. For example, a certain quantity of benzene that would be transported to groundwater would be biologically degraded in the groundwater and after a period t_F the benzene concentration at the conformity point would be so low that every event referred to that pollutant could be neglected.

(9)	$\lim_{L \to \infty} F \to 0$

For example, the natural attenuation in the leachate plume limits the effect of contamination and then of the relative risk, around a maximum area of 1,000 m.

(10)	$\lim_{L \to \partial S} F \to 0$

∂S	Boundary system

In fact, from the definition initially mentioned, there is no risk if the universe is not damaged.

As it has been reported before, there are many uncertainties in the evaluation of risk assessment.

6.1.1.4 Parameters uncertainty

Risk is relative to the knowledge of the observer and presents a certain grade of uncertainty that today cannot yet be quantified. This does not permit to assess the risk in an absolute and deterministic sense. So, the possible damage made by an accidental event is a stochastic variable. The risk will be the expected value of this stochastic variable.

(11)	$R = E(R) = \int (x \cdot f_x(x)) \cdot dx$

E(R)	Expected risk

$f_x(x)$	Density function of stochastic variable damage

Figure 11 shows the density of the occurrence probability. In it 3 zones can be distinguished and they depend on the level of the damage (low damage X_m, high damage X_m):

- Zone of high probability and low damage;
- Zone of medium probability and medium damage;
- Zone of low probability and high damage.

The perception of risk varies very much in these three zones and becomes an important element for the management of the risk.

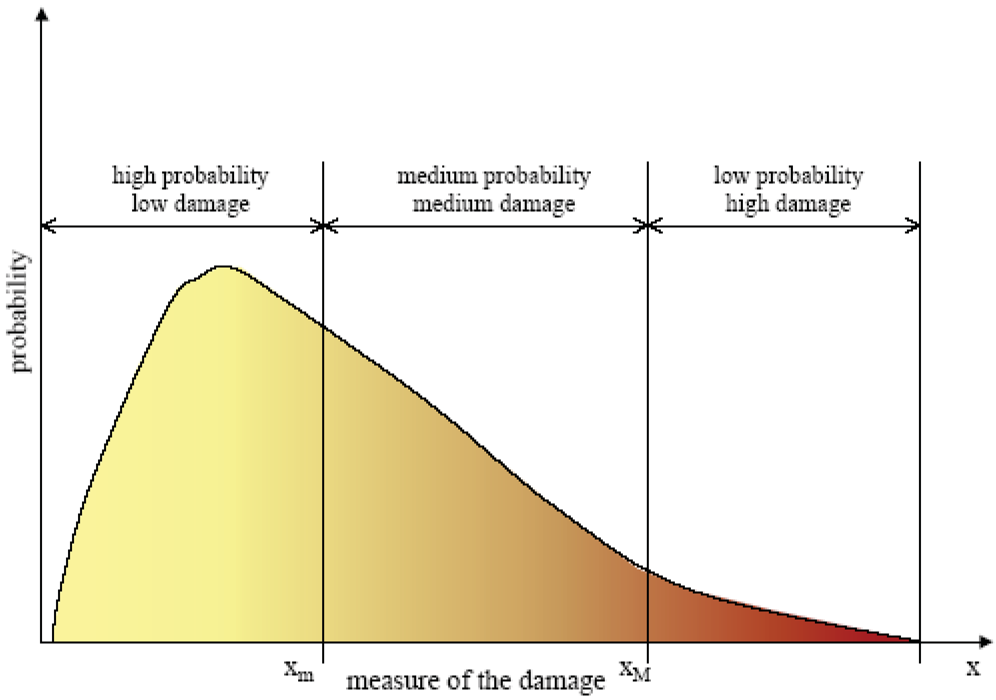

Figure 11: Representation of the distribution of risk probability [9]

The probabilistic characterisation of risk is commonly established as Monte Carlo method. The Monte Carlo method consents to quantify the risk numerically, starting from values of the casual input parameters in consensually with the assigned probability distribution. From the results of the iterations, the probability distribution of the total risk is obtained, and thus, a reference value, in general adopted in correspondence to the 95th percentile. If the iterations are carried out and only one input parameter varies, the Monte Carlo method allows verifying the sensibility of the models in relation to that specific parameter.

One more very important aspect of the no punctual overview above mentioned is the accurate study of the distribution tail, which can play a main role in the determination of the risk acceptability.

6.1.2 Barriers attenuation

The barriers are part of the overall landfill system and are everything that attenuates the potential hazards of the pollutant flow inside the boundaries of the system. Their function has dual importance:

- Containing the uncontrolled leakage of the pollutant flow into the universe because of passive (e.g. the geo-membrane impermeable cloak on the base) or active bearings (e.g. extracting leachate wells);
- Accelerate the processes of landfill configuration, by reducing the time t_m.

The barriers mainly carry out this task are those of the landfill body, the bottom barrier and the surface barrier (Figure 12).

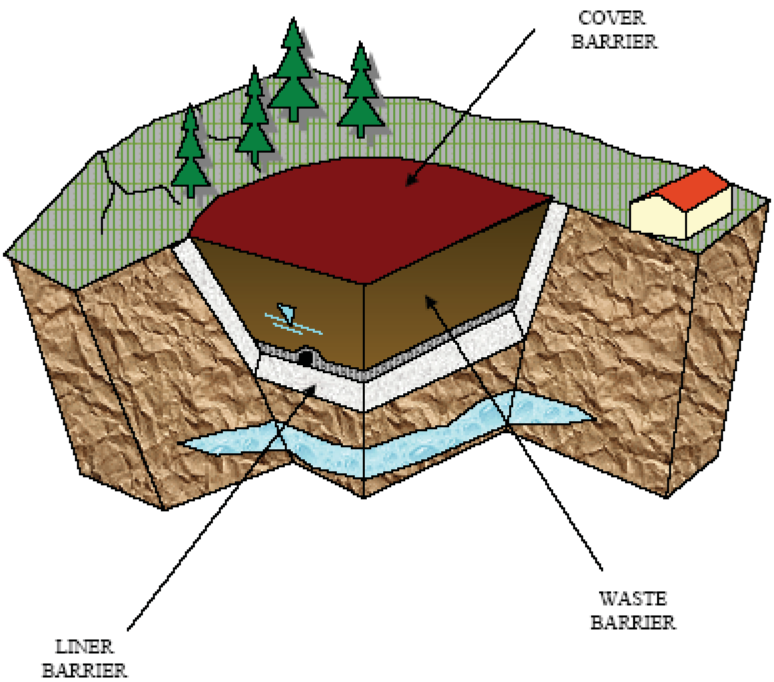

Figure 12: Representation of the barriers attenuating the potential hazard of the landfill system [9]

A different sort of natural attenuation (NA) occurs in the external environment and it is considered in the transport model. The natural attenuation has a central role in the risk assessment and the results are calibrated by monitoring data.

The hazard mitigations by extraction wells for leachate and biogas is part of the facility management and it is an intervention strategy going beyond the scope of our contribution, where this management is supposed to be known.

The main processes determining the attenuation of the landfill's hazard flows for each barrier are discussed as follows.

The **landfill body barrier** is constituted by the solid waste itself and by the material cover. Degradability and hydraulic conductivity to water and air is the key aspect of this barrier. At the same heights, if hydraulic conductivity is higher, the time that water takes to pass the waste body decreases, having influences on the degradation of the waste. Field surveys for the valuation of this element can open emitting paths for biogas and leachate.

The **surrounding conditions** of the landfill body (density and composition of waste, pore volume) are required for the determination of the distribution of the contaminant phases inside the system.

The **bottom barrier** substantially carries out a brake and delay action of the uncontrolled emissions of the liquid flow ($Q_{i,p}$), constituting the hazardous fraction of the flow.

$$Q_{i,p} = Q_{p,p} - Q_{c,p} \quad (12)$$

$Q_{i,p}$	Uncontrolled leachate flow from the landfill
$Q_{p,p}$	Leachate flow calculated by production models
$Q_{c,p}$	Collected controlled leachate flow

The **surface barrier**, on the one hand, attenuates the potential hazard of the uncontrolled biogas emissions, on the other hand, regulates the passage of infiltration water modifying the processes of production of leachate and biogas.

$$Q_{i,b} = Q_{p,b} - Q_{c,b} \quad (13)$$

$Q_{i,b}$	Uncontrolled biogas flow from the landfill. Partly attenuated by the barrier (e.g. methane is oxidized in the final cover liner)
$Q_{p,b}$	Biogas flow calculated by production models
$Q_{c,b}$	Collected and controlled biogas flow

As a result of natural processes in the system and of the barriers attenuation, few contaminants leave the landfill. A wide range of redox gradients from the landfill nearly always contains specific boundary conditions, necessary for biotransformation and precipitation of the contaminants.

6.1.3 Risk assessment of the landfill system

The proposed operative methodology follows the methodology indicated by the U.S. EPA, that is commonly recommended by the technical-scientific literature which subdivide the assessment of risk in different phases:

- **Hazard identification**: Identification of the present pollutants and assessment of their concentration and distribution. In this phase of risk assessment a provisional list of most hazards and its potential is established.

- **Hazard assessment**: evaluation of the material hazards. Classified in two complementally studies: the evaluation of both, exposure and effects.

    - **Evaluation of exposure**: Estimation of the pollutant concentration in the matrix contrasted with the exposure, considering the attenuating function of the barriers.

    - **Effects dependent on the dose**: Evaluation of the pollutant toxicity and determination of the risk effected by predefined doses. It can be observed that often the toxicity assessment step does not depend on the site-specific parameters.

- **Characterisation of risk**: Evaluation of the aggregate risk, including tolerability and the uncertainty of conducted estimations.

The attainment of the final risk estimation is conducted by following phases, gradually refined by calculation methods without reducing the accuracy.

6.1.3.1 Conceptual Model

The conceptual model from Figure 13 is under study. The input data essential for the evaluation of pollutant hazards are on the one hand the quality and quantity of the waste and of the penetrating rain, on the other hand the attenuation of the barrier’s function.

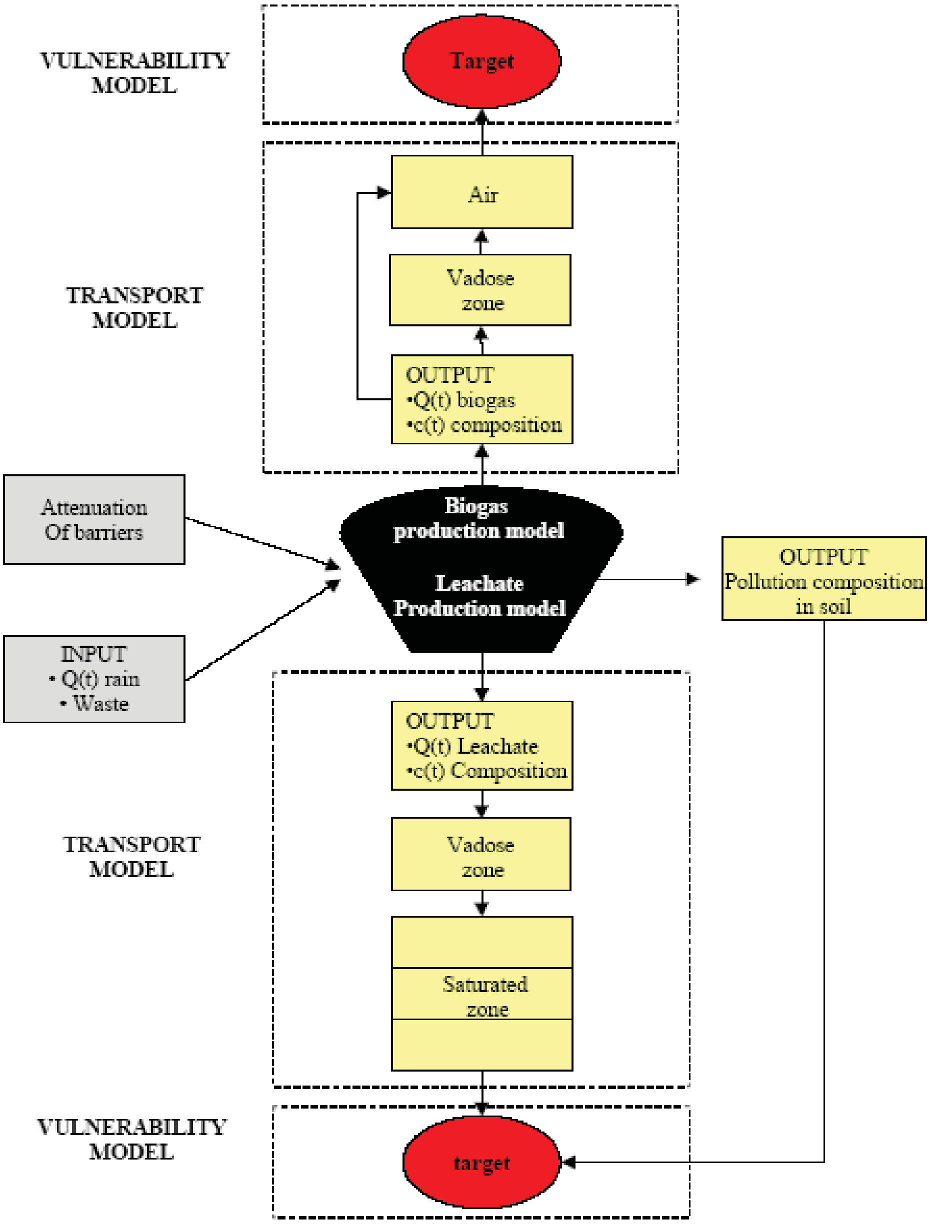

Figure 13: Conceptual model for the estimation of landfill risks according to the University of Padova. [9]

Distribution models calibrated by experimental data can obtain the determination of the pollutant concentrations in the different phases. The production models determine the time dependent quantity of liquid and gaseous flows.

The following step is the evaluation of the attenuation of the barrier's function inside the system. For example the biogas will be partly oxidised by the surface cover and the bottom cover will adsorb some pollutants in the entering leachate.

The calculated flows are spatially and temporally distributed in the external environment, and can be evaluated by means of the transport models. In case of the biogas flow, it might pass the surface cover directly, or it could pass the lateral cover and be adsorbed by unsaturated stratum. The case of incorporation (e.g. dermal contact with contaminated soil) is not considered as there is no natural attenuation. The determination of the damage in case of exposure is quantified by the vulnerability models.

6.1.4 Risk management applied to the aftercare period

Gradual emission reductions ordered by law are important from an ethical point of view. It is not acceptable to leave the following generation an inferior environmental state. This could cause unacceptable life conditions in short time.

In the middle eighties the “final storage” concept was defined by a Swiss landfilling working group. This term has evolved gradually. Different states of the waste are defined and the emissions are differated in short term (1-10 years), in the medium term (10-100 years) and in the long term (100-10,000 years). Acceptable impact means that the emissions do not change the flows, the natural composition of air and soil, and in the quality of water significantly. In other words, these emissions do not represent a “relevant” risk to the environment. Once this value of acceptable risk is set, the objective of the “Final Storage Concept” can be defined. The legislator will have to quantify this acceptability threshold, in order to define the aftercare period. For establishing regulations, the duration of the aftercare period has to be determined based on the remaining risk of the old deposit.

An acceptable risk is usually only reported for leachate, which causes emissions for a longer period of time than biogas. Although there are a lot of analysis for biogas and leachate emissions and the degrading activity of waste, there is insufficient knowledge of the processes of organic and not organic compounds in the long-term period.

The determination of the time (T_A) i.e. the period following the landfilling period where the obtained risk (R_A) is acceptable, causes significant problems. First of all some reference events should be defined for determining a value of acceptability. Afterwards the acceptable risk should be referred to standard conditions.

While in the first case it will be defined a value that will be similar to the value of (t_M) in the second case it will be similar to a value of the (t_F) type. The obtained results will be obviously very different and it will be possible to find an acceptability value according to the first method that is very much preventive for a specific case.

Once these first issues have been overcome, it should be known if the comparison between the determined value and the referring value has to be conducted in the deterministic or probabilistic ambits. The determination of the value of acceptability should be referred to standard conditions. In the next step the acceptable risk is compared with standard condition risks.

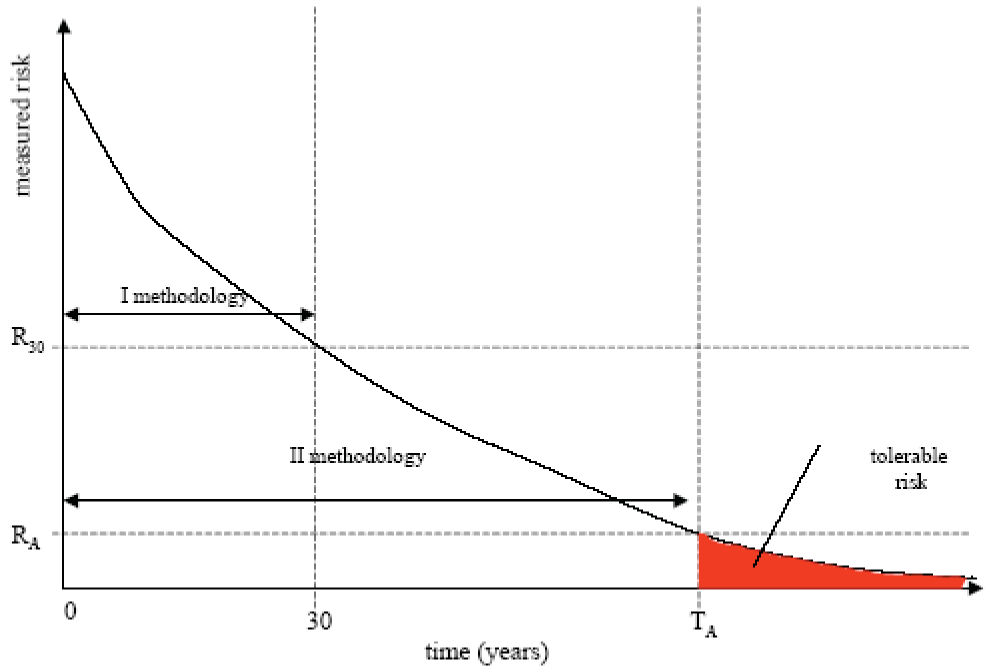

Figure 14: Comparison between the first methodology expressed by the Legislative regulation and the second methodology taken from the ‚Final Storage' concept. In the origin, time agrees with the landfill closing time.[10]

6.2 Preliminary risk assessment in Italy

6.2.1 Introduction

In the framework of the EU-Life Project EVAPASSOLD, the IMAGE Department of the University of Padova performed investigations for the evaluation of the current situation of old landfills in Southern Europe countries, especially in Italy.

In the first part of the program, contacts with local and central Italian administrations were established in order to:

- Discover, if detailed files of data on old landfills are recorded, containing information on characteristics of the landfill such as bottom liner, age of deposition, waste characteristics, geological situation around the deposit, leachate and biogas emissions, expected long term emissions etc.
- Discover, if any type of risk assessment has been executed.

The second part of the study was the application of the new model proposed by the EVAPASSOLD partners. This assessment was conducted not only for the landfills that have been investigated by the IMAGE Department, but also for other old landfills in Italy, where enough information was available. Due to the simple structure of the new assessment model, the application was possible. Some comments on the general procedure for risk management of old landfills are given in the next paragraph.

6.2.2 Institution

Department of Hydraulic, Oceanographic and Geotechnical Engineering, University of Padua, Italy (http://www.unipd.it)

Prof. Raffaello Cossu
Full Professor of Environmental Engineering, University of Padua

Collaborators:
Dr. Roberto Raga (raga@idra.unipd.it)

6.2.3 Risk management

According to the information obtained, in Italy no official risk assessment procedure has been set up and used for the preliminary evaluation of old waste deposits. Remediation is currently considered for deposits where at least one of the following conditions applies:

- There are indications of groundwater contamination;
- There are indications of uncontrolled biogas migrations into residential areas;
- New volumes for waste deposits are necessary and the remediation (i.e. landfill mining) would allow a better utilisation of the area and the construction of a new landfill.

However, no priority ranking list has been worked out. The decisions are made at local level, provided that the necessary funding can be obtained. The quantity of data required to accomplish a traditional risk assessment for landfills does not allow its implementation in the general context of the Italian situation, as the total costs for the necessary analysis and for the identification of the landfill system hazards would not be sustainable. In fact, thousands of old landfills in Italy represent a potential risk for the surrounding environment and for humans. However, as suggested by the EVAPASSOLD Project partners, it might be possible to select a number of old landfills where no more investigations are needed and a negligible risk can be considered. These cases have to be selected from those for which the situation is unclear and an evaluation of the potential risk has to be accomplished.

An instrument that may be useful to this aim is the preliminary risk assessment as it was proposed by EVAPASSOLD project partners, that allow to evaluate the magnitude of the system risk (i.e. the system hazard potential) and the vulnerability of the universe, with a low demand of initial data.

In the model the magnitude is evaluated considering the possible attenuation of the hazard potential of the waste caused by waste degradation and prolonged leaching due to rainfall infiltration. For the evaluation of vulnerability, information on general environmental condition and utilisation of the area are used. The two values (magnitude and vulnerability) provide a decision matrix that enables to select the situations needing further assessment (Table 15).

Table 15: Decision Matrix for risk assessment as proposed by EVAPASSOLD Project partners [9]

Magnitude	Vulnerability	Further Assessment
High	High	required
High	Low	not required
Low	Low	not required
Low	High	not required

The preliminary risk assessment is a decision tool applied to old landfills. For new landfills a risk assessment in new design should be considered. In fact, old landfills could have been attenuated by the natural degradation processes as well as leaching from rainfall.

Conversely, controlled landfills are hardly attenuated by leaching water. In consequence they are potentially more dangerous and must be studied in detail. In case of intermediate situations, where at the same place both, an old landfill and a landfill in operation are present, the two cases must be considered separately. This is visualised in Figure 15.

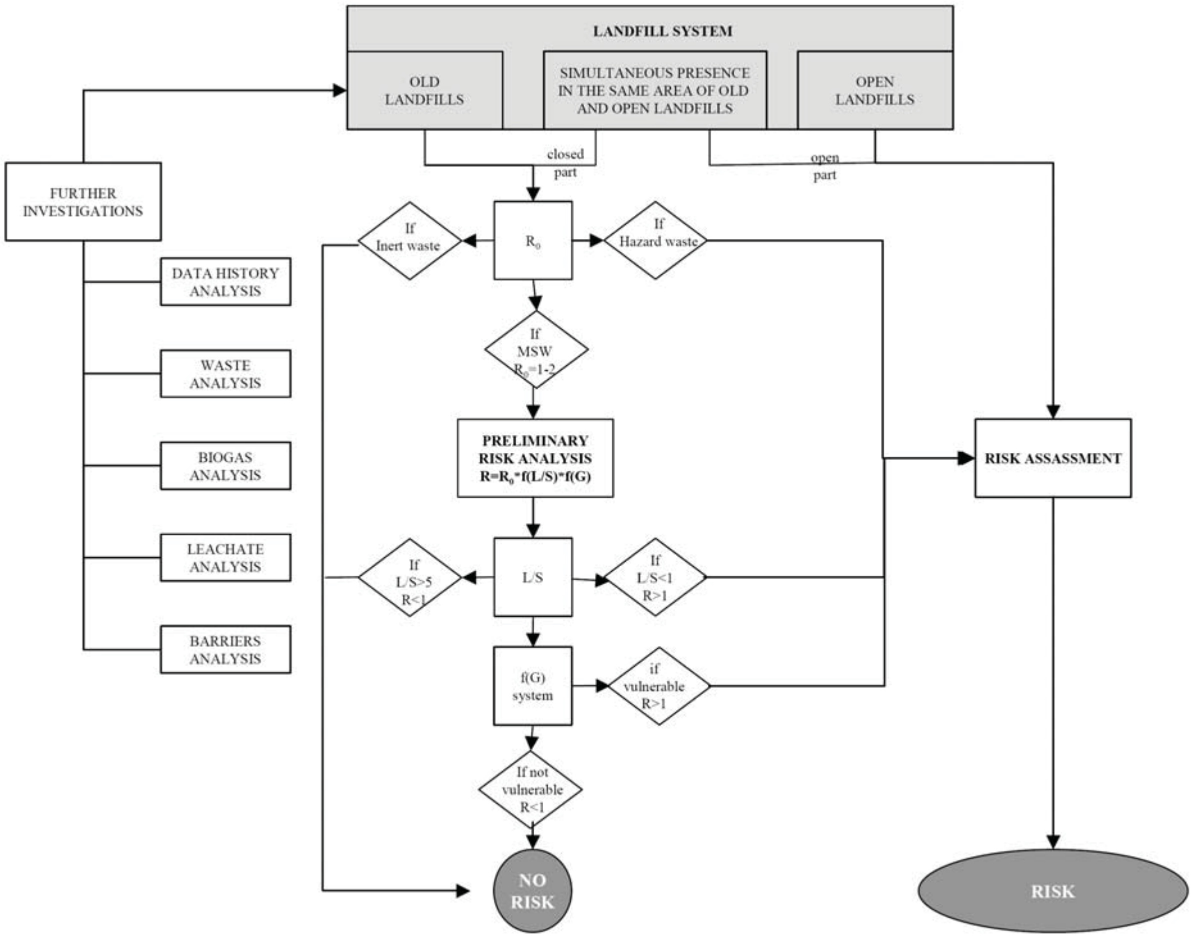

Figure 15: Preliminary risk assessment scheme [10]

6.2.3.1 Field investigations

A field survey is the base on which a risk assessment of the examined system is executed. In particular the following analysis for assessing the pollutant hazards and the attenuating, both internal (passing barriers) and external processes (natural attenuation) have to be accomplished.

- **Historical data analysis**: This research aims at compiling all the previous accomplished surveys (i.e. geo-physical site structure) and at identifying the typology and quantity of the landfilled waste;
- **Waste analysis**: respirometric tests, fermentation tests, test for eluates (pH, COD, BOD_5, BOD/COD, TKN, NH_3, Organic N, Nitrate, trace metals, toxicological tests), Black Index, composition and granulometric analysis;
- **Leachate analysis**: pH, COD, BOD_5, BOD/COD, TKN, NH_3, Organic N, Nitrate, trace metals, toxicological tests, pumping tests;

- **Biogas analysis**: biogas quality, assessment of uncontrolled gas migration through the landfill cover and the lateral barriers; assessment of the efficiency of the biogas extraction systems;

- **Barriers analysis**: analysis of the characteristics and of the attenuating capacity of the clay liner and top covers

The results of the investigations are needed for the calibration of the risk assessment model. For this purpose, five landfills (Modena, Legnago, Torino, Campodarsego and Chioggia) in northern Italy were extensively investigated.

6.2.3.2 Application levels of risk assessment

The prearranged procedures for the application of risk assessment take simplified intermediate levels into account, and in consequence a gradual approach, passing from one level to another:

- The protection level of health of human and the environment remains unchanged;

- The number of parameters and surveys increase;

- The quantity of technical and economical resources increase;

- Economic efficiency of the interventions;

- The conservative assumption decreases.

The preliminary risk analysis can be regarded as a Level Zero for the landfill system, where it is essential to identify only the hazard potential, with measurements easily available.

The Level One consists of confronting the contamination of the site with the screening values and locating the targets in the proximity of the source. The screening values consider the toxicological data of the substances and the diverse exposition ways that can be activated according to different land uses, but do not take into consideration the local data of the site. From the confrontation between the contamination of the site and the screening values it may be decided that either:

- The site can be dismissed as non contaminated;

- It is necessary to remediate up to the screening values.

In order to continue the surveys and assessments, it is required to pass to a successive level. In these steps it is planned to locate the exposition and conformity points beyond the polluting source and not immediately over it.

In Level Two the deeper surveys in the site provide information needed for:

- The conceptual model
- The chemical, physical and environmental parameters that determine the migration and the parameters of local exposition.

Level Three is applicable when neither Level Two nor Level Three are adequate for the specific conditions of the site. In this level the objectives of remediation are set by means of more complex analysis that may utilise more sophisticated models for the simulation of transport and fate of pollutants. In this level a probabilistic approach can be used.

6.2.4 Conceptual model for preliminary risk assessment

The EVAPASSOLD Project partners created the new first-evaluation model, in order to identify the environmental risk of the landfill system. In particular, the model was created for application to old landfills smaller than 50,000 m³ and with an average depth up to 8 m; but it was actually tested in case of higher volumes as well.

The Risk (R) is calculated considering three factors: R_0, f(L/S) and f(), as $R=R_0$*f(L/S) *f(). R_0 deals with the historical background of the old deposits, and its value is fixed according to the kind of deposited waste. The liquid-to-solid ratio is related to the age and waste biochemical stability in the old deposit. Finally, the f() factor considers the general environmental condition and utilisation of the area of the old deposit.

In this case the magnitude is represented by two parameters R_0 and f(L/S), while the vulnerability of the system by f().

6.2.4.1 The R_0 factor

R_0 is a parameter that considers the type of waste. This first model doesn't include two particular waste categories: completely inert waste (low magnitude) and waste with a percentage of hazardous waste higher than 1 % (high magnitude). In the other cases, for this parameter the following values can be considered:

Construction waste, excavation materials with 10 % of domestic waste:

- R_0= 1.1 (20 % = 1.2; 30 % = 1.3);
  100 % domestic waste and domestic-like commercial waste:
- R_0= 2 (containing a maximum of 1 % hazardous waste).

According to this scheme, R only gets evaluated, if R_0 has a value between 1 and 2.

6.2.4.2 The f(L/S) – Liquid-to-solid factor

In order to simplify the application of this model, Table 16 has been developed for the determination of the function of liquid-to-solid ratio.

Table 16: Summary of parameters for the evaluation of the Liquid / Solid factor [10]

L/S	f(L/S)
L/S < 1	1
1 < L/S < 5	1.2143 - 0.1429*(L/S)
L/S > 5	0.5

The actual water infiltration (L) into the landfill should be calculated; the mass of waste present in the old deposit (S) has to be estimated according to the information available. The calculation of L has been made by means of a model considering the most important factors influencing evapo-transpiration, surface run-off, and infiltration. The parameter S is the mass of waste inside the landfill. High values of the L/S ratio means that the deposited waste has been considerably leached out during the operative and post closure phase; in case of low values, a higher amount of degradable organics can still be expected to be found in the waste and the associated potential hazard is expected to be high.

6.2.4.3 The f() factors

The f() factors consider the general environmental condition and utilization of the area of the old deposit. Therefore, an evaluation can be individually performed for groundwater, surface water, air and soil. The corresponding evaluation parameters are presented in the previously in chapter 4.3. High values of the parameters f() are given in case of high vulnerability.

6.2.5 Application of the first evaluation model to landfills in Italy

The evaluation of the hazard potential of the different types of landfill sites has been carried out by means of the new first evaluation model proposed by the partners of the EVAPASSOLD project. The following landfills were considered as samples: Campodarsego, Chioggia, Legnago, Noale, Portogruaro (2 landfills) (north-eastern Italy); Torino, Cassolnovo, Zerbo (north-western Italy); Modena, Pisa (Central Italy); Gricignano, Succivo (2 landfills) Mondragone (southern Italy).

Risk (R) was calculated, according to the model, as $R=R_0*f(L/S)*f()$. The evaluation was possible considering the information available on the characteristics of waste and deposit and the environmental data.

The evaluation of f() was carried out in some cases thanks to information collected directly at the single municipalities; in other cases data from actual investigations carried out by the IMAGE Department were used.

The calculation of risk has been carried out and the results are given in the following graphics. Some remarks will be given in the discussion section.

Table 17: Values of parameters for risk calculation [10]

			actual material hazard	f()				R			
Location	**R0**	**f(L/S)**	**(R0 * F(L/S))**	**G**	**SW**	**A**	**S**	**G**	**SW**	**A**	**S**
Campodarsego	2.00	1.00	2.00	1.00	1.50	1.00	1.00	2.00	3.00	2.00	2.00
Chioggia	2.00	1.00	2.00	1.80	2.00	1.00	1.00	3.60	4.00	2.00	2.00
Legnago	2.00	1.00	2.00	1.50	1.00	1.00	1.00	3.00	2.00	2.00	2.00
Noale	2.00	0.50	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Portogruaro A	2.00	0.94	1.88	1.00	1.00	1.00	1.00	1.88	1.88	1.88	1.88
Portogruaro B	2.00	1.00	2.00	1.00	1.00	1.00	1.00	2.00	2.00	2.00	2.00
Torino	2.00	1.00	2.00	1.00	1.00	1.00	1.00	2.00	2.00	2.00	2.00
Cassolnovo	1.80	0.68	1.23	1.70	1.50	1.00	1.00	2.09	1.85	1.23	1.23
Zerbo	1.80	0.50	0.90	2.00	1.20	1.20	1.20	1.80	1.08	1.08	1.08
Modena	2.00	1.00	2.00	1.00	1.00	1.00	1.00	2.00	2.00	2.00	2.00
Pisa	1.80	0.75	1.35	2.00	2.00	1.20	1.20	2.70	2.70	1.62	1.62
Gricignano	2.00	0.50	1.00	1.00	1.00	1.20	1.20	1.00	1.00	1.20	1.20
Succivo A	1.80	0.50	0.90	1.00	1.00	1.50	1.50	0.90	0.90	1.35	1.35
Succivo B	1.80	0.50	0.90	1.00	1.00	1.20	1.20	0.90	0.90	1.08	1.08
Modragone	2.00	0.50	1.00	1.00	1.00	1.20	1.20	1.00	1.00	1.20	1.20

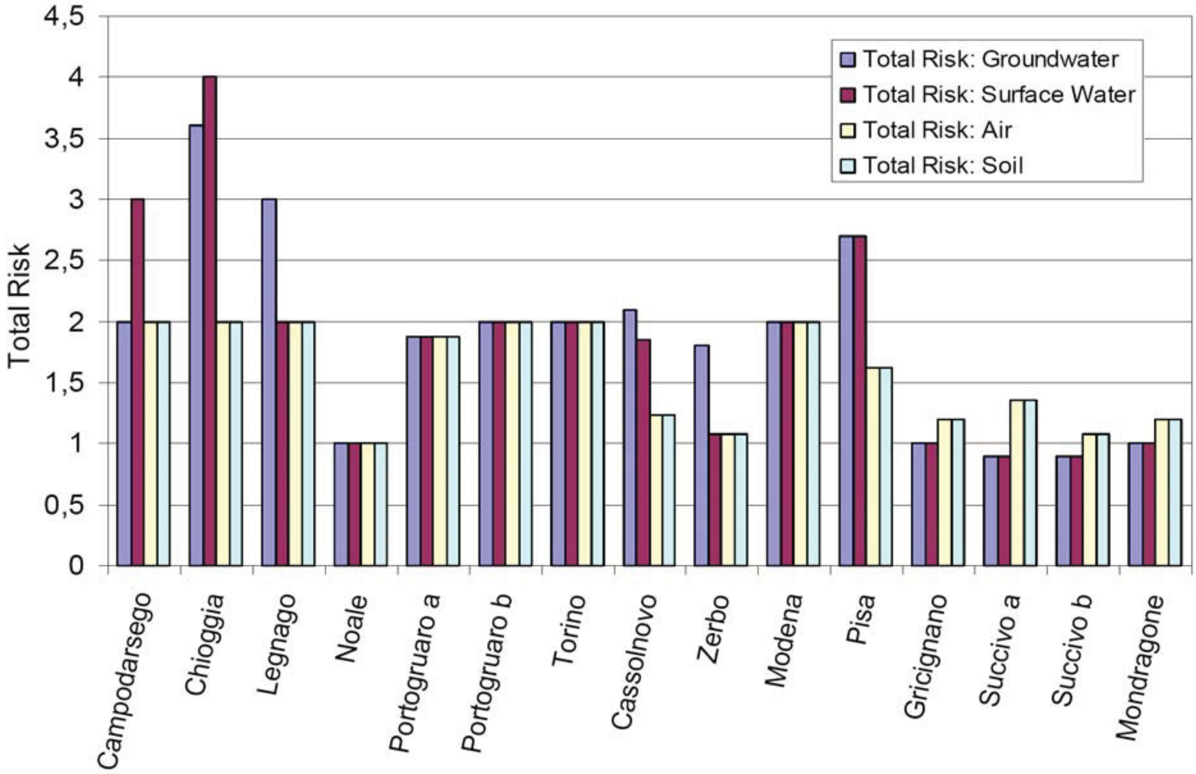

Figure 16: Overview of total risk of the considered landfills for subjects of protection Groundwater, Surface Water, Air and Soil [10]

6.2.6 Discussion of the results and conclusions

- According to the instructions for the application of the model, only landfills smaller than 50,000 m^3 and with an average depth up to 8 m should be considered. However, the model was tested with different landfills and seems to be applicable no matter what the size and depth of the landfills are.

- During the study, it was possible to collect information for 1,200 landfills in Italy but only for 20 % of them data on waste volume and depth was available. However, after the recent publication of the National Guidelines for the compilation of old landfill and contaminated sites data base in Italy, the local administration are making further steps in the acquisition of relevant data from the municipalities and they are organizing them by using appropriate software (geo-referred data will soon be available). Better possibilities for the application of the model can be expected in the near future.

- In order to improve its versatility, the use of the preliminary assessment model should be possible in the case of contemporary presence in the same area of old waste deposits and controlled landfills. The case of new landfills built as an extension of old waste deposits is very frequent in Italy (Basse di Stura, Campodarsego, Legnago, Modena, Portogruaro). In this situation, the evaluation of risk and the definition of strategies for intervention should be carried out considering the area as a whole. The preliminary assessment scheme might be applied to the old deposit and the risk assessment might be carried out as suggested in the flow chart in Figure 15.

- The application of the model gives the result that some landfills present values of R higher than 1, so they need further investigations.

- The laboratory and field analysis carried of for the landfills of Campodarsego, Legnago, Chioggia, Modena and Torino, produced results consistent with the results of the application of the model.

7 Conclusions

Within the EU Life-project EVAPASSOLD, the basics for an improved preliminary assessment of the possible danger posed by old deposits are developed by means of representative areas of suspicion. For this purpose, an innovative procedure for the determination of the danger potential of different types of old deposits was developed and examined in two Austrian regions as well as in Italy, a technology transfer as part of the project. Such application of these results to other, especially Southern European regions aim at an applicability of the method throughout Europe.

This report describes the main stages of investigations, results, conclusions and recommendations for a modified, improved preliminary assessment of old deposits.

Using different investigation and analysis methods for 14 closely-examined old deposits in Lower- and Upper Austria, a comprehensive picture regarding climatic, hydro-geologic and other deposition conditions has been gained – especially concerning the actual substance harmfulness of the deposited waste. Picking up this thread, further laboratory tests in landfill simulation reactors and ecotoxicology investigations show the future emission behaviour and the danger potential.

The informational content and the gained knowledge of the single investigation methods have been collected and evaluated with regards to the evaluation of an existing guideline. Based on these evaluations, a modified practice for the investigation and for a preliminary assessment facing the present practice has been developed:

$$\mathbf{R = (R_0 * f(W/F)) * f()}$$

where:

R	Decisive risk
R_0	Danger of the substances at the moment of deposition
f(W/F)	Derived factor of the water-solid ratio that characterises the stabilisation process of the landfill body and assesses with R0 the current danger
f()	Factor for the significance of the environmental good

This procedure facilitates a more conclusive preliminary assessment of old deposits and, in conjunction with the assessment of the affected environmental good, a validated risk assessment. The results show that old deposits can be classified into three types:

- **Potentially emitting old deposits** (with a low water permeable surface cover, therefore still high, mobility potential of harmful chemicals, but actually low discharge into biosphere)
- **Stabilised old deposits** (with a high water permeable surface cover, therefore in the past increased, but actually low discharge of harmful chemicals)
- **Mixed old deposits** (partly or slightly water-permeable surface cover, therefore at present both high and low discharge of harmful chemicals)

The characteristic of the modified procedure is the improved consideration of the actual substance harmfulness of old deposits by taking into account the water balance, the landfill shape and the age of deposition for the estimation of the course of stabilization via the factor L/S.

For a further validation of the preliminary assessment if required (further risk assessment) a concept of several successive analytical steps was created, based on the type of the old deposit. This provides a considerable cost-saving potential compared to conventional analytical programs with similar conclusions.

Moreover, an application of the modified procedure for the preliminary assessment to European conditions was carried out. This aims to promote comprehensive European initiatives for the protection of soil and water.

8 Indexes

8.1 Literature

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8.2 Abbreviations

8.2.1 Abbreviations

aa.	absolute altitude
ANOVA	ANalysis Of VAriance
AOX	Halogenated Organic Compounds
BOD_5	Biochemical Oxygen Demand within 5 days
BTXE	Benzene, Toluene, Xylene, Ethylbenzene (aromatic Hydrocarbons)
CFC	Chlorofluorocarbon
COD	Chemical Oxygen Demand
CSTR	contiuous stirred tank reactor
DOC	Dissolved Organic Carbon
DS	Dry Substance
EC	Electrical Conductivity
EPA	environmental protection agency
GC-MS	Gas Chromatography with Mass Spectronomy
HC	hydrocarbons
IMAGE	Dipartimento di Ingegneria Padua, Idraulica, Marittima, Ambientale, Geotecnico
IV	Inspection Value according to ÖNORM S 2088-1
LA	Federal State of Lower Austria
LOI	Loss on Ignition
L-REG	Austrian Landfill Regulation
LSR	Landfill Simulation Reactor
LVHH	Lightly Volatile Halogenated Hydrocarbons
MTV	measure threshold value

NA	natural attentuation
ÖNORM	Austrian Standard
PAH	Polycyclic aromatic Hydrocarbons
PCB	Polychlorinated Biphenyl
PNEC	predicted no effect concentration
Pre	Precipitation
SPSS	analytical software
TKN	total Kjeldahl nitrogen
TOC	Total Organic Carbon
TV	Threshold Value
UA	federal state of Upper Austria
W/S	Water to Solid ratio

8.2.2 Abbreviations of investigated old deposits

8 small old deposits investigated in Phase I:

DR	Drösing (NÖ)
ER	Ertl (NÖ)
HO	Hofkirchen (Söllner Schottergrube – gravel pit) (OÖ)
LA	Langschlag (NÖ)
LS	Lunz am See (NÖ)
GR	Grein (Herdmann) (OÖ)
SF	St. Florian (Kaltenberg) (OÖ)
RP	Rabenstein an der Pielach (NÖ)

6 bigger old deposits investigated in Phase II:

HB	Hohenberg (NÖ)

HA	Hallstatt (OÖ)
PU	Purgstall (NÖ)
TU	Tumeltsham (OÖ)
EB	Ebensee (OÖ)
NF	Neuhofen (OÖ)

8.3 Tables

8.4 Figures