GROUNDWATER PROTECTION AROUND LANDFILLS: FROM EU REGULATION TO SITE-SPECIFIC ACTION PLANS

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SUMMARY: In 2003, Wallonia (Belgium) transposed the Landfill Directive 1999/31/EC onto regional legislation. However, regarding the control and monitoring procedures to be followed to ensure groundwater protection, some aspects were missing, ie. the definition of trigger levels leading to corrective measures to be taken in case of adverse environmental impact on groundwater. In 2010, the regulation was deeply amended on this particular topic, including the obligation to realize a site-specific groundwater intervention and protection plan (GWIPP) in case of endogenous and persistent groundwater contamination. A particularly comprehensive and well-constructed GWIPP has recently been implemented on the Tenneville MSW landfill in Wallonia, following the endogenous and persistent contamination report in 2013.

1. LEGAL FRAMEWORK

1.1 Sectoral conditions for the exploitation of sanitary landfills

Directive 1999/31/EC (European Commission, 1999), Annex III, section 4, gives recommendations about control and monitoring procedures to be followed by every landfill operator in the EU to ensure groundwater protection. As mentioned in Articles 12 and 13, "significant adverse environmental effects" should lead to "corrective measures". Regarding groundwater, “trigger levels”, representative of a “significant change in water quality”, must be set "taking account of the specific hydrogeological formations in the location of the landfill and groundwater quality". Transposition of EU Directive onto Walloon regional legislation has been implemented in two steps:

- The regional authorities (Walloon Government, 2003) formalized the groundwater monitoring system into a first version of sectoral conditions. The law requires every landfill operators to analyse a defined set of parameters in a relevant selection of wells and on a bi-annual basis. However, this law did not set any trigger levels as provided by the Directive.
- Seven years later, the groundwater protection chapter has been deeply modified (Walloon Government, 2010) namely to optimize the set of chemical parameters to be periodically controlled in the groundwater and to introduce first-order threshold levels, called "vigilance values" (Lebrun *et al.*, 2011).

A wide-scale environmental monitoring program around landfills, initiated by the Government in 1998 (Bietlot *et al.*, 2011) is still running. It allowed to define the groundwater geochemical footprint in case of leachate pollution of aquifers, and to determine the minimal set of parameters to be monitored. Vigilance values take also into account the natural geochemical background computed from the regional groundwater database built according to 2000/60/CE

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Water Framework Directive (European Commission, 2000). The setting of vigilance values is important insofar it allows the competent authorities (Environmental Policy) to dispose of a repressive tool: the exceeding of a vigilance value, accompanied by an exceeding of 3 times the upstream concentration, triggers a more sustained control during a limited time. If this enhanced vigilance confirms that groundwater is affected by an endogenous and persistent pollution, the operator have to implement a groundwater intervention and protection plan (GWIPP). It is assumed that corrective actions should be taken if and only if the pollution is not yet stabilised in time and space (spreading risk) or if it generates a risk for environment or human health. Consequently, operators have to undertake a detailed risk assessment, at a local scale, with the objective of setting trigger values above which corrective measures are to be implemented. A decision-making flowchart corresponding to this procedure has been established and already published in 2011 (Lebrun *et al.*, 2011).

1.2 Progressive implementation of the new normative system

Prior to the entry into force of the new legislation, it was well known that most of the existing authorized landfills were, at least partially, responsible for an historical pollution. Indeed, Walloon sanitary landfills have often been built close to (or on) old waste dumps. When their controlled operation began, groundwater was already polluted by these former uncontrolled (or illegal) deposits. Since 2010, every "historically polluted groundwater under landfills" have been progressively subject to the new procedure. Diagnostics about the presence of an endogenous and persistent pollution have been officially done for each landfill or dumpsite. The implementation of the two subsequent steps is still in progress (section 1.3 and 1.4). The state the procedure differs from one site to another. However, it is already possible to draw up a provisional assessment of this normative work. The two following sections try to synthesize the results of the first groundwater intervention and protection plans (GWIPP), and to list the main permit modifications implemented on the basis of their conclusions.

1.3 Groundwater intervention and protection plan (GWIPP)

GWIPP have been achieved for 6 main landfills and are still in progress for 2 other ones. During the realization of these plans, a lot of additional investigations, tests and risk assessments have been achieved by experts, including:

- Historical researches and investigations about former waste management;
- Assessment of hydrogeological background concentrations;
- Trend analysis of concentrations measured in monitoring wells;
- Identification of potential leachate transport paths from landfills to targets ;
- Search for potential receptors and quality assessment (surface water, sources, drinking water production wells...);
- Pump-tests on existing wells and building new wells for hydrogeological containement;
- Review of best available remediation techniques, adapted to each particular pollution/aquifer;
- Reverse modeling with the aim of computing risk-based trigger values to be applied on some compliance points (monitoring wells).

During the realization of these key phases of the GWIPP procedure, technical committees including experts and competent authorities have been constituted. Periodic meetings of these committees allowed the progressive drawing up of the protection plans, with a kind of continuous approval of technical actions by Walloon administration. This facilitated the subsequent drafting of the new operating conditions or monitoring programs to include in the amended permits.

1.4 Permit amendments

The last step of the procedure, which consists in translating the recommendations of the plans into permit conditions, is in progress since among two years. The amendments that have already been accepted by the authorities are, of course, site-specific. However, it is possible to list the main particular conditions implemented up to now:

- Selecting monitoring wells in the polluted zone(s) of the aquifer;
- Restraining monitoring to the parameters detected in the polluted aquifer;
- Adding monitoring wells to control the quality of deeper aquifers;
- Adding water quality control at some target points (sources, pumping wells, surface water);
- Setting trigger values and/or particular vigilance values obtained by reverse modeling;
- Defining compliance points where these values have to be respected;
- Description of possible corrective actions to be taken when exceeding one of the values;
- Allowing hydrogeological groundwater containment (pumping in protective barriers of wells).

Recently, two industrial waste landfills and two municipal solid waste landfills get their modified authorization. One of them has been chosen to be presented as a case study.

2. CASE STUDY: TENNEVILLE MSW LANDFILL

2.1 History and trigger elements

The Tenneville site is owned by the public intermunicipality AIVE (Association Intercommunale pour la Valorisation de l'Environnement). It was operated as a MSW treatment unit from 1979 to 2006 (hereafter called the old dumpsite or the tumulus, see Figure 1). The site is originally a forest area. In 1979, a household waste collection and sorting plant is installed in the eastern part of the site. Non valorisable waste is dumped in the northeastern part of the site, directly on the natural ground without any bottom protecting layer. From 1984 to 2006, non-dangerous and inert waste is dumped. A peripheral drainage system (maximum depth of 1.5 m) is placed on the north and west sides of the tumulus to collect emerging leachate (at least partially). Until 1996, leachate and runoff water collected in the peripheral drain are directly discharged in a small creek, the Pisserotte, located just below the tumulus. In 1997, the drain is connected to a waste water treatment plant built near the creek. The rehabilitation of the tumulus is performed in 2006 by mean of a semi-permeable clay layer and the installation of a biogas collection system. A new sanitary landfill area is then built according to the 2003 landfill regulation, located close to the waste water treatment plant in the north-west part of the site.

Since 2004, ISSeP, the scientific institute of Wallonia, periodically performs monitoring campaigns of landfill emissions (leachate, biogas) and their impact on potential receptors on the Tenneville site. Based on the ISSeP controls and owner's compulsory monitoring campaigns, some local anomalies in groundwater are hightlighted: the concentrations of several parameters are more than 3 times higher compared to the local background and exceed the vigilance values. In accordance with the brand new 2010 legislation, it triggered a one-year enhanced monitoring. In 2013, the suspicion of an endogenous and persitent contamination of groundwater straight downstream of the old dumpsite is confirmed, requiring the implementation of the GWIPP (Jodocy, 2016). A follow-up committee is set up, including the owner, the expert mandated by the owner to carry out the study, the competent authorities and ISSeP, in order to validate each stage of this site-specific procedure.

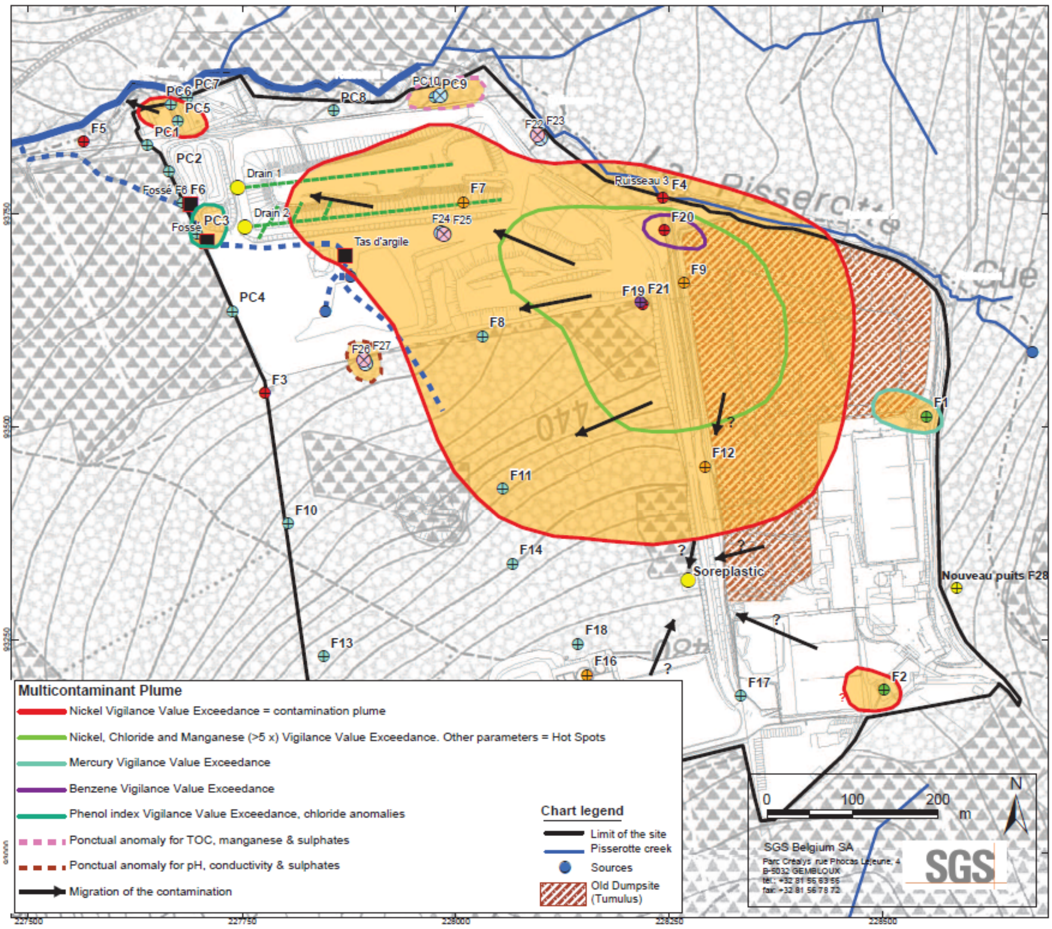

Figure 1. Location of facilities and extension of multicontaminant plume (Jodocy, 2016)

2.2 Elaboration and content of the groundwater intervention and protection plan (GWIPP)

2.2.1 Additional field investigations

Additional field investigations (new wells and sampling campaigns) were carried out in order to delineate the contamination plumes in groundwater and to provide additional useful information for the further risk assessment. Six new wells were installed downstream of the old dumpsite. Specific sampling campaigns were carried out on these new wells but also existing wells, leachate and surface water. The analyzed parameters were in line with the landfill legislation and mainly focused on the substances for which trigger values has to be set (chloride, nickel, mercury and benzene).

2.2.2 Groundwater quality

Groundwater downstream of the tumulus exceeds threshold values for conductivity, chloride, total organic carbon (TOC), nickel, iron, manganese and occasionally ammonium, AOX and the phenol index. There are also higher sulphate concentrations compared to the natural background. Most of these parameters are found in the leachate collected from the old dumpsite. Locally, exceedances of vigilance values are recorded in separate wells for mercury, benzene, and zinc.

The different highlighted contaminations can be linked to several distinct sources (Figure 1), the main one being the former dumpsite due to the absence of a bottom protecting layer, resulting in the migration of leachate in the subsoil then in the aquifer.

The highest concentrations of contaminants are encountered in four wells (F4, F19, F20 and F21, Figure 1) located directly downstream of the old landfill. At longer distances, exceedances of vigilance values are also observed but they only concern the most mobile compounds (chloride, nickel and manganese - dissolved fractions). As far as they are concerned, TOC and sulphate only present anomalies with respect to local background. All these parameters are considered as the main tracers of contamination. Among these, only chloride and nickel legally require the definition of trigger values. In addition, trigger values also have to be defined for mercury detected in F1 (upstream of the old dumpsite) and benzene (F20), both contaminations being considered as historical and probably endogenous.

It must be stressed that the local aquifer is naturally poor in chloride and sulphate, which help to trace the extent of the contamination plume even if these parameters do not exceed the vigilance values. On the other hand, natural nickel and manganese background concentrations are particularly high, close to the vigilance values, which may complicate the distinction between natural and anthropogenic origin.

Focussing on the main plume from the old dumpsite and looking at the temporal evolution of the contamination, it appears that the concentrations in the F4 well, located at the heart of the plume, remained relatively low and in any case below the vigilance values until around 2000. At that time, the well did not seem impacted by leachate contamination flowing from the old dumpsite. The concentrations then started to increase significantly until around 2006 and then at a lower rate until a more recent period. This well, located at a certain distance from the source (200m), was only affected by the contamination plume after a certain period of groundwater migration (maximum 20 years). It means that the current situation is not yet fully stabilized.

The F19, F20 and F21 wells have been present for a shorter time (since 2011). Over a more recent period, the F19 shows an increasing trend similar to that of F4 well. On the other hand, F20 and F21 show a quite stable trend.

At longer downstream distances, concentrations remained low in F8 (350m) and in the groundwater drainage system (D1 and D2) under the current sanitary landfill. From 2008, the situation starts to deteriorate, with a clear trend to increase until the current time. However, a relative stabilization seems to be reached again since 2014 in this well.

2.2.3 Surface water quality

The available historical informations show a significant impact of the site on surface water quality (the Pisserotte creek) until 2010. Before this date, the crude leachate and then the discharge of the sewage treatment plant were carried out in this small creek. Subsequently, the wastewater was discharged into a larger river, the “Wamme”, which shows no signs of impact. The displacement of the discharge point had a direct positive effect on the quality of the Pisserotte which rapidly recovered a good ecological quality, complying with quality standards for priority substances.

Nickel and cadmium exceedances of environmental quality standards for surface water were observed in some samplings during this study. These concentrations were higher at the source of the Pisserotte creek, then decreased in such a point that they reach the quality standards downstream of the site. Additional surveys have demonstrated that these concentrations could be linked to the analysis of the total fraction (unfiltered water) and the presence of suspended particles naturally rich in nickel and cadmium. In this case, the observed standard exceedances would not be a real problem considering surface water contamination. Even if linked to dissolved fractions, these higher upstream concentrations would probably not be related to an influence of the site but rather to background variations due to natural causes.

The sources of small tributaries of the Pisserotte emerging in the western part of the site show the same contamination signature compared to the F8 well. This impact is local and only affects a tributary of little ecological interest inside the site.

2.2.4 Risk assessment

As required by the GWIPP procedure, the risks associated to the groundwater contamination have to be assessed for:

- Human health, in case of harmful vapor emissions and if water is intended for human consumption (relevant targets: workers on site, users of pumping wells),
- Fauna and flora living in or near natural resurgences of contaminated groundwater (relevant targets: Pisserotte and Wamme creeks).

The general principles of this risk assessment is in line with the Soil Decree (Service Public de Wallonie, 2008) and more precisely with the reference guide for risk assessment.

The risks have been assessed according to the current situation and the expected evolution of the contamination level. For this purpose, simulations were performed using mathematical modeling of flows and transport in groundwater. Figure 2 shows the simulated nickel plume over a 100 years period keeping the same current operating conditions.

This modeling was carried out on the basis of the information known or acquired during the first step of the GWIPP. The parameters have been calibrated in order to check and validate historical and current field observations, which allows predictive simulations with a higher degree of confidence. It gives a simplified representation of reality dependent on assumptions and uncertainties. This tool however is intended to offer a better understanding of the possible evolution of groundwater site contamination and a decision-making aid.

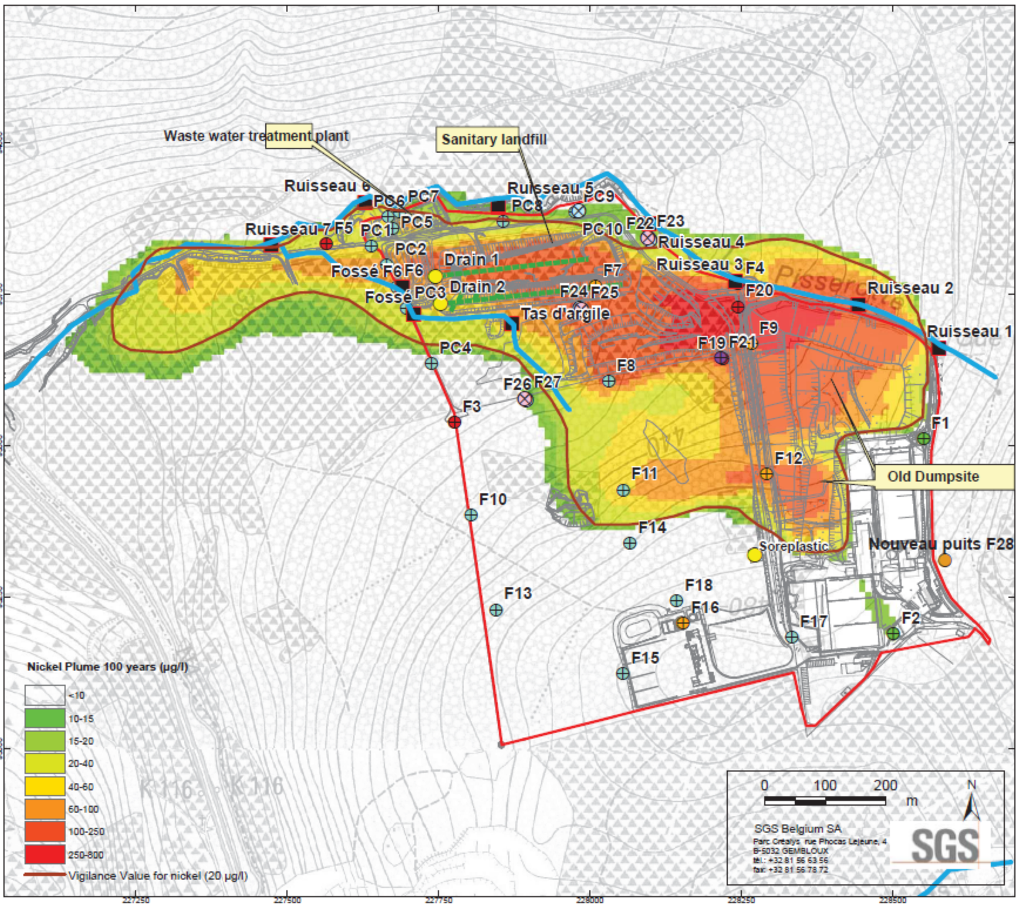

Figure 2. Simulated nickel plume (100 years) in current operating conditions (Jodocy, 2016)

The current contamination level, hydrogeological conditions and operating conditions were used for the first predictive simulation. Subsequently, additional simulations were carried out to assess the influence of active measures on the site (capping, modification of pumping flow rates in existing wells on site...) on the migration of contamination plumes.

2.2.5 Trigger values and monitoring program

The mathematical model is used to find the most relevant compliance points as part of the future adaptation of the monitoring network. These compliance points are supposed to be located on the preferential transport paths from the tumulus towards the target (Pisserotte creek). Trigger values for each compliance point are set for every parameters of concern: chloride, nickel, benzene, mercury and zinc. Values are computed using the model, by performing iterative reverse modeling. Given the fact that the simulation taking account the current contamination level does not pose a threat to the Pisserotte quality, even in the future, the expert simulated scenarii where the contaminant load would be higher compared to the current one. The flow of pollutants at the source (old dumpsite) is gradually increased until the simulations predict that, within 100 years, a quality objective is exceeded in the Pisserotte creek. Finally, trigger values at the compliance points are deduced from the corresponding modeled scenario. Several compliance points were selected immediately downstream of the old dumpsite. In this way, in case of trigger value exceedance, corrective actions can be taken before the concentration increase leads to exceedance of quality standards in the Pisserotte. As an additional precautionary measure, particular vigilance values are set, aiming to alert the owner in case of anomalies in the groundwater. If so, exceeding a particular vigilance value may also trigger actions such as enhanced monitoring, counter-analysis,... Pumping wells are also monitored and affected by trigger values to avoid any risk to human health related to the use of water on site. Because of its location, the site is actually not connected to the public distribution network.

It is also planned to monitor some wells downstream of the main contamination plume and just upstream of the Pisserotte creek. The purpose of these compliance points is to assess the risk of allowing the main contamination plume to spread outside the site and a possible increase in the pollutant load reaching the creek from the groundwater. Some of these wells are also affected by plots of more local contaminations which still deserve some attention. Furthermore, they are located at the downstream edge of the current sanitary landfill and will therefore be useful to monitor some possible new impacts on groundwater related to the sanitary landfill.

As an illustration, Table 1 shows the particular vigilance values and trigger values that have been defined for nickel and chloride in 4 relevant wells. Legal vigilance values for groundwater are given for comparative purposes (ie. chloride: 150 mg/l and nickel: 20 µg/l).

Table 1. Trigger values and particular vigilance values at 4 representative compliance points

Compliance points (monitoring wells)	Current concentrations		Trigger values		Particular vigilance values	
	Chloride (mg/l)	Nickel (µg/l)	Chloride (mg/l)	Nickel (µg/l)	Chloride (mg/l)	Nickel (µg/l)
F4	73	79	-	150	350	-
F8	31	56	-	255	350	-
F19	100	64	-	240	350	-
F20	442	245	-	540	880	-

Legal vigilance values : 150 mg/l (Chloride) ; 20 µg/l (Nickel)

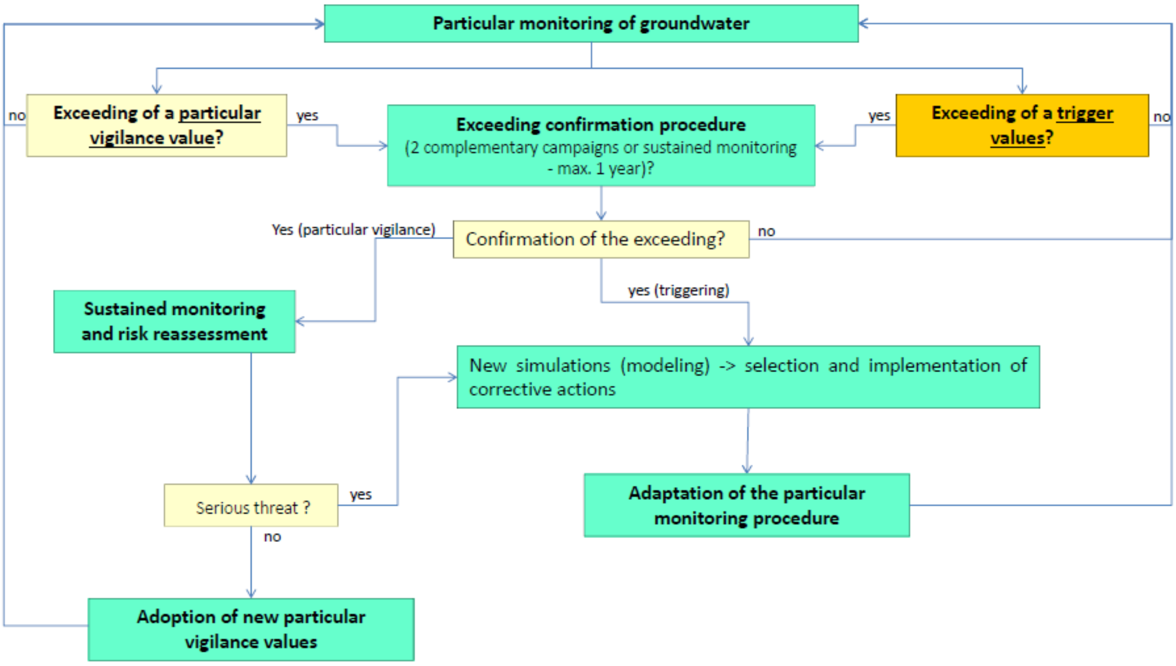

Figure 3. Decision-making flowchart – Monitoring program and action plan (Jodocy, 2016)

A routine monitoring on tracer parameters is carried out on a biannual frequency and an extended one every two years, with a wider set of parameters.

At the end of GWIPP procedure, a decision-making flowchart has been established on the basis of the new monitoring program and the risk management action plan (Figure 3).

2.2.6 Risk management and corrective action plan

According to the 2010 legislation, corrective actions have to be implemented in case of exceedance of a trigger value at a compliance point. These actions aim to reduce concentrations to a level below the trigger values. Actions can be potentially taken:

- Either on the source of contamination generating the exceedance;
- Either on the target concerned by a potential impact;
- Or on the transfer routes between the two above mentionned elements.

The mathematical model was used by the expert to perform different simulations in order to assess the effect of each considered option:

- The early implementation of a definitive top cover on the old dumpsite (action on the source);
- Leachate collection in biogas wells (action on the source);
- Reduction of leachate flow in the subsoil by pumping groundwater in new or existing containment wells (action on the transfer paths);
- Pumping and treating groundwater near the creek, or installing a water treatment plant directly on the creek (actions on the target).

Since the effectiveness of each option can not be predicted in a fully reliable way, due to the uncertainty associated to the nature/intensity/location of a potential problem, it was not deemed necessary to include theses actions in the future permit validating the GWIPP. Competent authorities chose to maintain the follow-up committee even after the approval of the GWIPP. Its task is very crucial insofar it will take decision about the best action plan in case of threshold value exceedances. In this respect, the operator is required to maintain the mathematical model, as it may still be available and updated for timely simulations in order to size and optimize the envisaged remediation systems.

2.3 Amendment of the permit

At the time of writing this paper, the groundwater intervention and protecting plan is in the last approval phase. It has been approved by the competent authorities, which followed its development for almost 2 years. The next step is to modify the existing permit to incorporate the new site-specific conditions of groundwater and surface water monitoring as well as the trigger values and corrective action plan.

3. CONCLUSIONS

Seven years ago, the Walloon reglementation has established a procedure that requires the implementation of an intervention and protection plan in case of endogenous and persistent contamination of groundwater due to a landfill site. This procedure is fully in line with the European landfill directive. This paper presents the multi-step procedure that led to the development of an intervention and protection plan following groundwater contamination by MSW leachate on the Tenneville site (Wallonia). Field investigations and risk assessment for potential targets led to the definition of site-specific trigger values and to propose corrective actions in the event of an aggravation of the environmental situation of groundwater.

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