BASELINE STUDY AND RISK ANALYSIS OF LANDFILL LEACHATE – Current State-of-the-Science of Computer Aided Approaches

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Abstract

For the successful completion of a risk analysis process, its foundation (i.e. a baseline study) has to be well established. For this purpose, a baseline study needs to be more integrated than ever, particularly when environmental legislation is increasingly becoming stringent and integrated. This research investigates and concludes that no clear evidence of computer models for baseline study has been found in a whole-system and integrated format, which risk assessors could readily and effectively use to underpin risk analyses holistically and yet specifically for landfill leachate. This is established on the basis of investigation of software packages that are particularly closely related to landfills. Holistic baseline study is also defined along with its implications and in the context of risk assessment of landfill leachate. The study also indicates a number of factors and features that need to be added to baseline study in order to render it more integrated thereby enhancing risk analyses for landfill leachate.

Keywords: risk assessment; risk analysis; baseline study; waste disposal sites; landfill leachate; literature review; computer models.

1.0 INTRODUCTION

Risk analyses are increasingly being applied to landfill sites, at planning, operational and completion stages (Butt et. al., 2014; SEPA, 2005; Environment Agency, 2003a; 2003b; 2004; DETR et. al., 2000). In various countries, environmental legislation is also becoming a main driver of the employment of risk assessment. For example, a risk assessment (RA) requirement for the protection of groundwater from landfill leachate has been legislatively introduced in the UK since 1st May 1994, through Regulation 15 of the Waste Management Licensing Regulations, 1994 (SI, 1994; 2005a). However, for a risk assessment to be productive, it needs to be based on a strong preliminary investigation generally that is called baseline study. This is because the information gathered in the baseline study is used as an input to subsequent stages of the risk assessment process throughout (Figure 1).

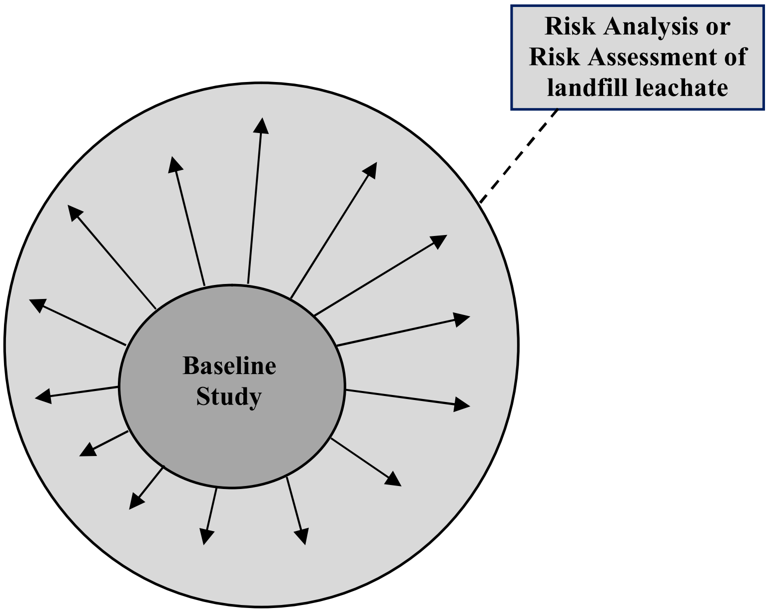

Figure 1: A baseline study holistically informing risk analysis of landfill leachate

Furthermore, environmental legislation is increasingly becoming not only stringent but also inclusive, versatile, and integrated (Butt et. al., 2009; 2014). For instance, the Water Framework Directive includes new requirements for protection and restoration not only of ground waters but also surface waters and dependent ecological systems (EC, 2000; Environment Agency, 2003a). Similarly, the Landfill Directive and Regulations take it even beyond surface and ground waters only, thereby, including air, soil, global environment, greenhouse gases, and human health (EC, 1999; SI, 2002; 2004; 2005b; Scottish Executive et. al., 2005). Another directive, generally referred to as the Habitat Directive (EC, 1992), brings legal obligation to combat hazards in order to guard and enhance natural habitats and wild fauna and flora. On the basis of these environmental legislation which are tending to be increasingly more holistic than ever before, it can be established that an even more holistic approach towards risk analysis is required. This necessitates baseline study for risk assessment to be correspondingly more inclusive and holistic. Therefore, particularly in the case of landfills, the baseline study has to account for a wide range of disciplines e.g. geology, hydrology and hydrogeology (Environment Agency, 1997, 1999, 2003a; Butt et. al., 2016).

This research note has a twofold aim. Firstly, the paper investigates current computer models that are associated with landfills one way or another, in order to establish where the current state-of-the-science stands in terms of a holistic baseline study. Secondly, based on this investigation the paper also briefly highlights a number of knowledge gaps and aspects of baseline study that if included, can render the baseline study more comprehensive. This way the paper indicates with evidence that current computer models regarding landfills do not offer an integrated risk analysis system or even a holistic baseline study framework, either as a standalone entity or in combination with subsequent risk assessment stages. The purpose of this paper, being a short communication, is to quickly and yet effectively disseminate the state-of-the-science of baseline study to diverse range of stakeholders (from the landfill industry in particular, and the fields of waste management and environmental management in general).

From the perspective of landfill risk analysis, a baseline study process is described as that fundamental and initial stage of a risk assessment exercise of landfill leachate in which all basic information and / or data are collected, organised and analysed. *The term 'holistic' in this paper implies an overall framework or system, covering all aspects and factors of the baseline study from the start to the end and specifically in the context of landfill leachate.* Further details are contained in Section 2.0, below.

2.0 ELEMENTS OF A HOLISTIC BASELINE STUDY

There are a number of elements that are needed to be integrated to form a holistic framework of the baseline study to more effectively support risk assessments (see Figure 2 which outlines a conceptual whole-system framework). Some of these elements are listed below as examples. A study of currently available software packages is described in Section 3.0, which establishes that these elements are either entirely and / or partly absent in current computer models.

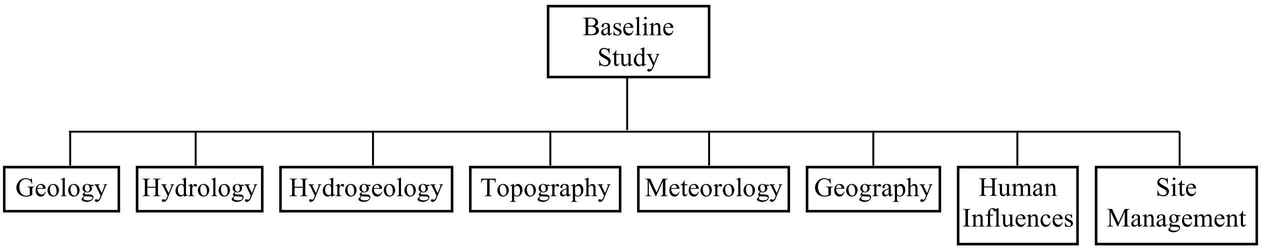

Figure 2: The Eight Modules of the Holistic Baseline Study – A conceptual model outline

1. The authors do not find any evidence of a computer model which contains a detailed, algorithmic, ready-to-use, sequentially, categorical, user-friendly, continual and step-by-step baseline study system. Such an organised and standardised baseline study system does not exist which a risk assessor could follow from the start to the finish in a self-guiding fashion to identify and classify all landfill site characteristics that are needed in different subsequent stages of a risk assessment process specifically for landfill leachate.

2. Keeping in view multi- and inter-disciplinary nature of the baseline study for landfill leachate, the authors divide it into eight modules which are: geology, hydrology, hydro-geology, topography, geography, meteorology, human influence and site management (Figure 2) and elaborated below with examples. Current computer models are found not to have included all of these eight modules along with their individual respective aspects (examples below) in an integrated manner. As a result of this shortcoming a baseline study cannot fully categorically inform subsequent stages of the risk assessment to be rendered holistic:

   i. *Geology*: top soil, drift, rock, porosity, effective porosity, fissures, density, geological materials and minerals, depth and width or volume of the geological materials, and other geological properties. This module can assist the follow-on stages of a risk analysis in a number of ways. For instance, establish the length of unsaturated zone of the pathway leading from the landfill to a given environmental receptor; chemical reactions that may take place between leachate contents and geological materials; etc.

ii. *Hydrology*: evaporation, transpiration, interception, surface runoff, infiltration, percolation, and groundwater ingress. This module can help to estimate, for instance, the net quantity of leachate generation for a specific landfill; leachate head to which the landfill base can be subjected; etc. Where leachate quantity can itself be regarded as a type of hazard whose implications will be identified in the subsequent 'hazard identification and categorisation' stage of the risk assessment of landfill leachate.

iii. *Hydrogeology*: vadose and phreatic (also called unsaturated and saturated) zones, perched groundwater, hydraulic gradient, permeability, groundwater speed and direction, and other hydrogeological properties. The information from this module can inform the exposure assessment stage of a risk assessment in terms of identifying pathways leading from hazards to receptors. This module can also be useful to establish the direction of leachate flow, length of the saturated zone, and groundwater fluctuation round the year. The groundwater itself may be regarded as an environmental receptor and in which case, this module can help determining the sensitivity of the groundwater as an environmental receptor.

iv. *Topography*: landforms and inclinations (to assist in measuring runoff to or from a given landfill); natural environment; habitats (e.g. a lake that feeds a food chain); built environment (e.g. residential area, a football stadium); water-courses; etc.

v. *Geography*: latitudes, longitudes, geographic zones, for instance, tropical and other geographic properties (e.g. arid and semi-arid) that can also help in estimating other baseline study parameters (such as expected rainfall). For instance, in an arid area such as Saudi Arabia the rainfall is minimal (insignificant to form leachate in large amounts) as opposed to the UK where precipitation occurs around the year which can contribute to large amount of leachate generation.

vi. *Meteorology*: precipitation (duration, frequency, intensity), wind speed and direction, wet and dry bulb temperatures, humidity, and degree of sunniness and cloudiness. For instance, precipitation can directly contribute to estimate maximum possible leachate quantity. In this case, this module and the Geography module can complement each other.

vii. *Human Influences*: past, present or future potential anthropogenic activities like quarrying, water abstraction, construction, and development. For instance, in a given environmental scenario, if groundwater is of good quality, that may be employed for human consumption in future. This can contribute to determine the level of criticalness of the groundwater in a risk assessment exercise.

viii. *Site Management*: site history, site type, site location, site design, and engineering (e.g. liners, drainage system), waste management activities, environmental monitoring, waste types, leachate type and its constituents. For instance, waste types and landfill design together can help determine the degree and nature of hazards (and corresponding risks) more effectively in the ‘hazard identification and categorisation’ stage of risk assessment. Similarly, the information on leachate type and its constituents can contribute to the Geology module to figure out what chemical, physical and biological reactions are like to occur.

More specific examples to elaborate on some of the above aspects are described below:

Example 1:

A topography module should be able to depict a model of where potential receptors (whether biotic / the living or non-biotic / the non-living) exist, so that these could be further explored in one of the follow-on stage of risk assessment called exposure assessment. No computer model regarding baseline study specifically for landfill leachate was found to cater for this feature.

Example 2:

The human influence module should be added to the current computer models in order to enable them to inform the follow-on risk assessment modules on matters such as follows: which potential developments are likely to take place within the potentially impacted environmental-sphere of a given landfill or which existing or past developments could cause what impacts on the landfill (whether existing or proposed).

Example 3:

A given landfill can be at pre-operation stage (i.e. planning, design, and development phase), in-operation stage and / or post-operation stage (i.e. completed and post closure phase). In current computer-aided approaches, there is a lack of consideration of issues regarding the three landfill stages that can be well accommodated in the Site Management module (that is in number viii above).

3. There is a lack of significance assessment and uncertainty assessment for various characteristics and parameters that are covered in the baseline study of a landfill leachate risk assessment. For instance, hydraulic gradient, water-table, evapo-transpiration, precipitation, interception, groundwater ingress, etc.

4. There is insufficient employment of statistical descriptions particularly in the context of maximum, minimum, and most-likely values of various parameters (e.g. evapo-transpiration, precipitation, interception, groundwater ingress, etc.). Such statistical descriptions can be helpful to figure out worst-case and most-likely risk scenarios.

3.0 CURRENT COMPUTER-AIDED APPROACHES OF RISK ANALYSIS AND BASELINE STUDY

Computer models' development is not only important for all areas of human endeavour, but have particular relevance to environmental issues where the risks involved are increasingly seen as substantial. However, in the investigation of current computer models no evidence has been revealed of such a software package of risk assessment that integrates all necessary elements in a sequential, algorithmic and yet holistic manner (McMahon et. al., 2001; Butt et. al., 2006). One of the factors which is found to be substantially absent in all the studied computer-aided models of risk analysis is an integrated baseline study itself, which is the main focus of this paper.

Below is a list of computer models that are found to be, more closely related to landfills than others:

1. LandSim (Environment Agency, 1996; 2001; 2003b),
2. HELP – Hydro-geological Evaluation of Landfill Performance (Schroeder et. al., 1994; FPLC, 1997; Scientific Software Group, 1998; UCF, 2001),
3. GasSim (Attenborough et. al., 2002; Golder Associates, 2003; 2016),
4. GasSimLite (Environment Agency, 2002),
5. RIP – Repository Integration Program (Landcare Research, 2003; Golder Associates, 1998), and
6. 3MRA – Multi-media, Multi-pathway, and Multi-receptor Risk Assessment (EPA, 2004)

In the list above, the first four computer programs are specifically designed for landfills, although the features of RIP (number 5 above) were subsequently extended to take landfills into account on a comparatively large scale and 3MRA (number 6 above) is not only for landfills but other waste management issues as well. Some other software packages were also examined but they are not demonstrably related to landfill risk analysis, although they could be used to underpin some of the aspects of landfill risk assessment. For instance, RockPlot 2D and RockPlot 3D (RockWare, 2016) and Drill Guide (Scientific Software Group, 1997/98) are useful in the sense that they can be included in the geology module of the baseline study of a given landfill, which consequently will help in the risk assessment process. Similarly, WinDes is a software package which is employed to estimate runoff from a given site area, and such an information can be used in the hydrology module of the baseline study of a landfill risk assessment to determine how much water can runoff a landfill site to establish net leachate generation. InfoWorks (CS – Collection Systems or RS - River Systems), and WinDes also, can be used to estimate surface water runoff for a given catchment (Micro Drainage Ltd, 2007; Wallingford Software Ltd, 2007). Thus, they can be used in the hydrology module of baseline study to work out how much water in a catchment could runoff towards a landfill to contribute to the leachate generation. The Flood Estimation Handbook (FEH) gives guidance on estimation of rainfall and river flood frequency in the UK. It is also available in the form of a software to support the implementation of the FEH procedures (CEH, 2008; 2002). Thus, the rainfall estimation aspect of FEH can be useful in the hydrology module of a landfill baseline study to calculate how much rain will directly fall on a landfill site. Similarly, Flood Studies Report (FSR) is another tool, also available in software format, that can be applied for rainfall runoff analysis and consequently to measure surface runoff (Morris and Simm, 2000). Like WinDes, this facet of FSR can be employed to measure the amount of runoff to or away from a given landfill to assist in estimating net or effective quantity of landfill leachate. However, like WinDes and InfoWorks, both FEH and FSR can be employed only to some hydrological and meteorological aspects of the baseline study in a landfill risk assessment, and these do not and cannot address other modules and facets of the baseline study.

The afore-listed six software packages do not holistically encapsulate various elements of risk analysis and specially the baseline study for landfill leachate. For example, the LandSim software which is purely for landfill risk assessment, does not offer a total risk assessment system. It can only contribute as a part of a total risk analysis process (Robinson, 1997). The software probabilistically estimates likely concentrations of leachate pollutants that can reach a given point in the ground (e.g. a groundwater abstraction point) in a certain time in terms of years. However, specifically from the baseline study perspective, the software does not offer a comprehensive system encompassing all the elements indicated above in Section 2.0. Although, the software can use various input data to prepare a site conceptual model for a given landfill, the software does not completely describe what data to find and how to organise, process and collate to draw what information to be used in later stages of the risk assessment, and yet not for all the eight modules (Figure 2). This means, that for various follow-on stages of risk assessment a full spectrum of information will not be available of which some examples are described in Section 2.0.

Similarly, the HELP program contains only some aspects of landfill risk assessment. These are mainly the design features of landfill (such as liners, capping) and some of other aspects (like precipitation, surface runoff). All these aspects can form part of the baseline study for a given landfill being assessed. However, the model does not and is not to offer a comprehensive baseline study system encapsulating many other facets indicated in Section 2.0 above, that could be applied as a complete preliminary investigation or foundation for the risk assessment of a given landfill. The three more specific examples 1, 2 and 3 in Section 2.0 also apply to this case.

The software GasSim, which is a probabilistic model, although deals with relevant risk assessment modules, including gas generation, migration, impact and exposure; but as its name suggests, is designed for assessing landfill gas only and not leachate. The GasSimLite is also developed from the perspective of landfill gas only and is used for calculating gas emissions. As with the other models mentioned above, both GasSim and GasSimLite do not offer a 'total' baseline study approach in a categorical and algorithmic manner even for landfill gas.

On the other hand the RIP package, which is an integrated probabilistic simulator for environmental systems, has not been specifically originally developed for landfill risk assessment. It has been designed generally for any potential pollutant source in the ground such as a chemical storage tank. So with the RIP package, which is a generic software, risk assessors have to adapt it to their specific problems including landfills. This adaptation is time consuming and not easy (Miller, 1998). Although RIP can be applied to landfills for issues like contaminant release and transport, it does not readily provide such a straightforward total procedure either for risk analysis or baseline study for landfill leachate, which a risk assessor could readily follow in a sequential and systematic fashion.

The Multi-media, Multi-pathway, and Multi-receptor Risk Assessment (3MRA) allows for evaluation of five waste management unit types and landfill is one of them. The other four are waste pile, aerated tank, surface impoundment, and land application unit (Leavesley and Nicholson, 2005). Thus, this renders the model more general than if it had been only specific to landfill leachate. The model encapsulates a host of biotic receptors but does not appear to mainly include non-biotics as standalone receptors, though may be indirectly covered as part of ecological systems (CEAM, 2005; Weinberg et. al., 2003). This software concentrates on exposure analysis section of risk assessment and not the baseline study part. Thus, the software despite relating to landfills, does not present a comprehensive baseline study for landfill leachate with all the factors indicated in Section 2.0 above.

In summary, from the above review of various computer models, it is established that there is no holistic computer model for a baseline study for landfills that contains all the required parameters and aspects (listed in Section 2.0) in an algorithmic and categorical manner in order to assist landfill risk assessors to execute a preliminary investigation comprehensively, and yet concisely. A model, in which various factors and features of landfill baseline study are put in such a format of categories that they could be linked and / or related to other appropriate modules of a given risk assessment process in the later stages, simply does not exist.

4.0 CONCLUDING REMARKS

Despite having the potential to pollute the environment, landfills are inevitable and required. Landfilling is still the predominant waste management option in many countries around the globe. The same is the case with the UK (Adu-Gyamfi et. al., 2010; DEFRA, 2006). Risk assessment is used as a tool to guard the environment against landfill hazards. However, there does not exist such an integrated methodology of landfill risk analysis, which could perform the process of risk assessment for landfill leachate from the start (i.e. baseline study) through to the end (i.e. hazard indices and risk quantification). A number of knowledge gaps have been identified in the literature reviewed to date and a computer model of the holistic baseline study is one of them. The baseline study is not only one of the most important factors but also the most fundamental initial stage of a risk assessment, as the effectiveness of the overall risk assessment correspondingly depends on how comprehensive is the baseline study.

Current software packages are just about adequate in meeting risk assessment requirements of the present environmental legislation. Future environmental regulations are going to be more stringent and wider in scope, and will encapsulate more environmental receptors such as various food chain links, ecological systems, terrestrial and aquatic flora and fauna. Therefore, more comprehensive, concise and robust risk analysis systems underpinned by more strategic baseline study approaches will be needed. This paper briefly reports on necessity and significance of the baseline study and identifies current models' limitations and knowledge gaps. This, therefore, establishes a base for developing a more complete and algorithmic computational procedure for the baseline study in an integrated fashion specifically for landfill leachate.

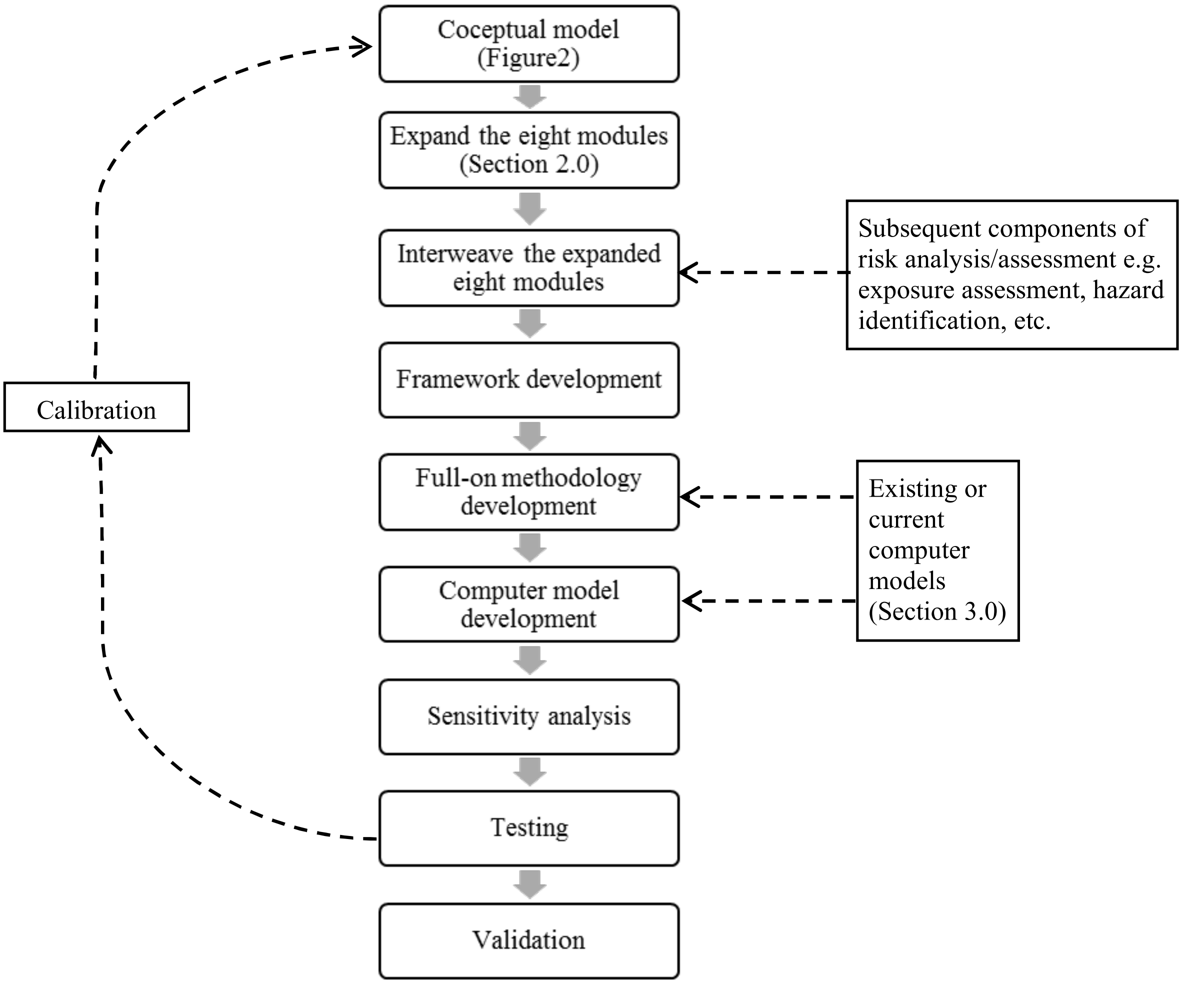

Figure 3: A conceptual flowchart diagram of the development of the proposed holistic baseline study to help improve the efficiency and effectiveness of existing computer models of landfill assessment.

This paper has concisely presented an account of elements (Section 2.0) that if assembled together in the form of a holistic baseline study can help meeting growing demands for integrated approaches of risk assessment required by the environmental legislation. A conceptual model of such a holistic baseline study is presented in Figure 2.0 which clearly shows a set of eight modules. These now need to be further divided exhaustively and yet categorically into sub-modules and parameters (examples given in Section 2.0), thereby interwoven in a multi- and inter-disciplinary manner. This way the presented conceptual model can be further researched and developed into a systematic structure / framework and then into a full-on holistic methodology of the baseline study. This methodology can then be transformed into a corresponding computer software as an e-tool. In order to assist landfill risk assessors to execute a preliminary investigation comprehensively, and yet concisely; this proposed software will have to be not only holistic but also categorical, sequential, well-structured, user-friendly, easily manoeuvrable within, interconnected and integrated. Figure 3 illustrates a sketch in the form of a flow chart diagram that how such a holistic computer aided-model of landfill baseline study can be generated. This software could be either an entirely stand-alone computer model or constructed in such a way that it can cater for the existing appropriate software packages of landfill assessment (identified in Section 3.0). This way the current state-of-the-science of baseline study can be enhanced to inform landfill risk assessments rendering them more whole-system. Such a holistic baseline study can also help to unify current approaches, thereby enhancing communications between consultants and regulators.

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