The Life Cycle Assessment of Residential Onsite Wastewater Treatment Systems in Ontario

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ABSTRACT

THE LIFE CYCLE ASSESSMENT OF RESIDENTIAL ONSITE WASTEWATER TREATMENT SYSTEMS IN ONTARIO

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In Ontario, 1 million people rely on residential septic systems to treat their wastewater. The goal of the life cycle assessment (LCA) model is identify environmental hotspots of each of the five septic systems regulated under the Ontario Building Code. In the primary model, the Conventional Leaching Bed has the largest environmental burden in all ten midpoint impact categories. Overall, manufacturing and transportation contributed to majority of the environmental impacts. A sensitivity analysis showed that the native percolation time (T-time) of the soil is an important environmental consideration. The model was also tested for robustness by conducting four additional European-based life cycle impact assessments. The Conventional Leaching Bed had the largest environmental impacts in most midpoint impact categories, regardless of variation between units, while the Shallow Buried Trench or Sand Filter Bed typically had the least environmental impacts compared to the other three systems.

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ABBREVIATIONS

CML	Center of Environmental Science of Leiden University
CLB	Conventional Leaching Bed
DQI	Data Quality Indicators
GHG	Greenhouse Gas
GWP	Global Warming Potential
HDPE	High Density Polyethylene
HP	Horse Power
IMPACT	Impact Assessment of Chemical Toxics
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
ILCD	International Reference Life Cycle Data System
LCA	Life Cycle Assessment
LCCA	Life Cycle Cost Assessment
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory
MJ	Mega Joule
PM	Particulate Matter
PMA	Pedigree Matrix Approach
OBC	Ontario Building Code
OOWA	Ontario Onsite Wastewater Association
ReCiPe	Netherlands based LCIA
REPA	Resource and Environmental Profile Analysis
SFB	Sand Filter Bed
SBT	Shallow Buried Trench
SETAC	Society of Environmental Toxicology and Chemistry
TRACI	Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts
T-Time	Percolation Time in minutes per centimeter
Type A	Type A Dispersal Bed
Type B	Type B Dispersal Bed
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Carbons
WWTP	Wastewater Treatment Plants

1 INTRODUCTION

Current methods used in Canada and other developed countries for evaluating the consequences of wastewater treatment systems typically use economic and environmental criteria, which only consider the direct effects of treated effluent on receiving water. Stringent water quality regulations have allowed municipalities to design wastewater treatment plants without any consideration of the environmental effects that may be caused by the treatment processes such as aeration, an energy intensive process. The indirect and cumulative economic environmental effects are disregarded and as a result the true environmental, economic and social costs are not included in the decision-making process.

In order to understand the true environmental impacts, a broader, and more comprehensive environmental management technique must be used. Life cycle assessment (LCA) is a relatively new environmental management tool that assesses the environmental impacts from "cradle-to-grave" of a product, process or system. The general context of LCA is broad, allowing for various methodologies and interpretations. Multiple organizations have performed LCA on the same product, each generating different results and conclusions. To rectify these discrepancies, the International Standards for Organization (ISO), a globally recognized association, has provided ISO 14040:2006 and 14044:2006 to regulate the LCA methodology.

Results of LCA have numerous benefits, including assisting decision makers, product marketing (as there is an increase in consumer demand for "greener" products), and identifying and rectifying processes that contribute to large environmental impacts for a cleaner production. This methodology attempts to be holistic in terms of environmental evaluation and is largely quantitative by nature. Therefore, the full environmental cost can be considered while avoiding processes and practices that simply shift problems to another time, place, or sector. LCA is one of many environmental management techniques (e.g., environmental impact assessment, risk assessment, cleaner production, and environmental auditing), but is unique due to its broad and comprehensive analysis. A proper environmental assessment expands the evaluation scope beyond wastewater treatment criteria and assess the impacts at each stage of the process, including construction of infrastructure, operation and maintenance as well as material production and transportation.

Wastewater treatment can be classified into either centralized or decentralized. The former consists of a centralized collection system (i.e., sewers) that collects wastewater from multiple producers, such as residential, institutional, commercial and/or industrial, and treats large quantities of wastewater in large scale treatment plants. The treated effluent is then discharged off-site, usually far from the point of origin. Decentralized treatment systems are defined as the collection, treatment, and distribution of water and wastewater near the point of use or generation and consists of a variety of approaches for the collection, treatment and dispersal of wastewater for individual dwellings, industrial or institutional facilities, clusters of homes, businesses, and at larger scales, entire communities.

Decentralized systems range from simple to more complex mechanized approaches. Simple systems include passive treatments with soil dispersal, commonly known as onsite or septic systems. Whereas complex systems can consist of advanced treatment units that collect and treat wastewater from multiple buildings and discharge the effluent to surface waters or soil. In 2009, the Government of Canada found private septic systems served 12.4% of Canadians, and more specifically 12.2% of Ontarians, approximately 1.45 million Ontario residents. In Ontario, it is estimated that 30% of the one million septic systems are failing and not meeting the required effluent criteria. The objectives of this study are:

- Identify environmental hotpots in the life cycle stages of the five OBC regulated septic systems;
- Inform decision makers, such as OBC regulators, government officials, and home owners of the environmental impacts associated with septic systems; and
- Set a foundation for future comparative life cycle assessment of septic systems to larger decentralized and centralized wastewater treatment system

Therefore, a more complete environmental assessment through LCA was completed to better understand the indirect and cumulative impacts associated with septic systems.

1.1 Layout of Thesis

This thesis contains six chapters and three appendices. Chapter One briefly introduces LCA and the purpose of this study. Background information on LCA and onsite residential wastewater treatment (septic) systems, as well as a literature review on the application of LCA to decentralized wastewater systems is presented in Chapter Two. The methodology section (Chapter Three) primarily focuses on three of the four stages of the ISO 14044 LCA methodology, scope and goal, LCI and life cycle impact assessment (LCIA) as well as the procedure of how the five septic systems were modelled. This chapter includes the boundary conditions, the inventory sources, the five LCIA methods and midpoint impact categories used. Chapter Four focuses on the interpretation of the five LCIA results and identifying and comparing the environmental hotspots for each of the five septic systems. Sensitivity and uncertainty analysis are included for the primary and the only North American LCIA presented in this thesis, TRACI (Tool for Reduction and

Assessment of Chemicals and Other Environmental Impacts). The Fifth Chapter explains the engineering applications of this study. Lastly, Chapter Six concludes the LCA study by presenting the key findings and recommends possible next steps for future graduate students and LCA practitioners. References used in this thesis are provided in Chapter Seven in alphabetical order. Appendix A summarizes the Ontario Building Code (OBC) tables used in the design of the five septic systems. Appendix B and C provide detailed tables of the LCI data used and the raw and supporting LCIA results, respectively. Finally, Appendix D includes the general procedure of how the septic systems were modelled in SimaPro.

2 BACKGROUND AND LITERATURE REVIEW

2.1 History of Life Cycle Assessment

Similar to the environmental movement, the concept of LCA started in the 1960's. In 1963 Harold Smith presented the concept of cumulative energy requirements to produce chemical intermediates and products at the World Energy Conference (Curran, 2006). The next two notable LCAs were published in 1972, The Limits to Growth (Meadows et al., 1972) and A Blueprint for Survival (Goldsmith et al., 1972). Both works predicted the consequences of human interactions with the earth, with an exponentially growing population and the demand for finite resources. However, most people accredit the first LCA to Coca-Cola in 1969, in which they tried to determine if plastic or glass bottles had the lowest releases into the environment and the least amount of affects on the supply of natural resource. Coca-Cola's cradle-to-gate study quantified the raw materials and energy used, and the environmental consequences from the manufacturing processes of each container (Matthews et al., 2015). At the time of the study, one of the most innovative ideas at the time was to include the energy used to extract natural resources. In 1969, energy as an ecological issue was unheard of, as the U.S. was focused on increasing consumption of energy resources for economic gain. Coca-Cola saw that energy used for resources was connected to material use; hydrocarbons can be used as the primary material in plastic bottles and as energy to melt minerals to make glass bottles. The process of collecting and analysing the data was difficult and Coca-Cola recruited the Midwest Research Institute (MRI), a research organization (Curran, 2006).

Following Coca-Cola's study, subsequent LCA studies and concept development at MRI, and in the 1970's the U.S. began a practice called, a Resource and Environmental Profile Analysis

(REPA); the process of quantifying the resource use and environmental releases of products. A REPA was a synonym for environmental life cycle studies. In the late 1980's the environmental focus shifted to solid waste, with the demand of life cycle studies of waste produced by manufactures compared to postconsumer waste (Curran, 2006). As more life cycles were conducted, the methodology expanded to include the impact assessment, and not just the inventory. In 1974 the United States Environmental Protection Agency (USEPA) produced a comprehensive report, "Resource and Environmental Profile Analysis of Nine Beverage Container Alternatives". This report compared the different beverage containers, and considered 40 different materials, and developed energy and environmental data for national fuel, transportation and electricity operation. This was one of the most ambitions REPA's attempted due to the extensive data collection and methodology, but also was the first REPA to conduct an impact assessment.

While the modern concept of REPA/LCA took shape in the early 1970's, public interest dropped from 1975 until 1988, as hazardous waste was of an emerging concern. It was not until May 1990, that an invited panel publicly debated the future of the REPA in resource and environmental policy. Shortly after the first workshop hosted by the Society of Environmental Toxicology and Chemistry (SETAC), the term 'life cycle analysis (LCA)' was coined to delineate the REPA concept. Only since the 1990's has the history of LCA been well documented. Unfortunately, in 1991 LCA could no longer be used to make broad marketing claims. Eleven U.S. State Attorneys General denounced the use of LCA for marketing claims until a more uniform methodology was developed, and a consensus reached on how this research can be publicly presented non-deceptively. In addition to the marketing restrictions, other environmental organizations demanded for a standardized LCA methodology. The International Organization for Standardization (ISO) developed standards for LCA, known as ISO 14000 series (1997 through

2002). The most recent editions are ISO 14040 and 14044, which outline LCA principles and framework, and requirements and guidelines, respectively.

2.2 International Organization for Standardization Approach

The general context of LCA is broad, allowing for various methodologies and interpretations. Multiple organizations have performed LCA on the same product, each generating different results and conclusions. To rectify these discrepancies, the International Standards for Organization (ISO), a globally recognized association which has created over 21,000 standards, have provided ISO 14040:2006 and 14044:2006 to regulate LCA. Standards allow for a process or activity to be consistent or completed using common guidelines or methods. The 14040 LCA standard is recognized and practiced internationally and is the foundation of well-practiced LCA. Companies can be certified "ISO compliant" meaning their LCA study conforms to the ISO 14000 series standards. A complete LCA consists of the four phases delineated by ISO (ISO 14040: 2006):

1) *The goal and scope definition phase*: The scope outlines system boundaries and the level of detail of the study, which depends on the subject and its intended use. The depth of different LCA studies can differ greatly. The manufacture of a product or the complexity of a process can seem simple, however they consist of numerous, complicated steps below the surface level. For example, a LCA of a paper clip seems superficially simple, but consists of processes like coiling which requires steel, iron ore, and energy, all of which consist of sub-processes like machinery, and energy requirements to mine the iron ore. Energy requires fuel, which in turn requires a drilling rig and a pipeline to transport crude oil. Therefore, the location of the system boundary becomes extremely important and should be as transparent as possible.

2) *The inventory analysis phase:* The life cycle inventory analysis (LCI) phase is the inventory of the input/output data with respect to the goal and scope of the study. This depends on the data availability, and the amount of uncertainty/variability inherent to a given system. LCI involves the collection of data and the quality of data required should be outlined, and include the temporal, geographical, technology, and sources specified to complete a comprehensive LCI. For example, if the goal was to assess atmospheric emissions from a coal power energy plant, the LCI may require the collection of the type of emissions (e.g., carbon dioxide [CO_2], nitrogen oxides [NO_x], sulfur dioxides [SO_x]) and their respective concentrations.

3) *The impact assessment phase:* The life cycle impact assessment (LCIA) phase provides additional information to help assess the LCI results to further understand the environmental significance. For example, LCIA helps quantify the effect of CO_2 with regards to global warming potential and ozone depletion and how it will affect human health and ecosystems. There are numerous LCIA algorithms to help quantify LCI results, all with different scopes and outcomes. A LCA can consists of multiple LCIA, but a good LCA can use one LCIA method with a diverse set of impact categories which allows for relevant comparisons across inventory flows. Energy and global warming impacts are the most common LCIA methods, primarily due their straightforward approach and the large degree of scientific consensus on their use (Matthews et al., 2015). The LCIA phase is complicated and many studies stop at the LCI phase (ISO 14040:2006).

4) *The interpretation phase:* The last phase interprets the LCI and/or LCIA results and, summarizes them to provide the basis for conclusions, recommendations, and decision-

making with respect to the goal and scope the study. The interpretation phase should be unbiased and by ISO regulations companies must include all the results and cannot exclude impact categories for the study to be ISO compliant.

All four LCA phases are iterative and many studies require numerous iterations as the individual phases of a LCA affect the results of other phases. The comprehensiveness and consistency of a LCA study relies on the iterative approach within and between the phases. Figure 2-1 illustrates the LCA phases as defined by the ISO 14000 series of standards

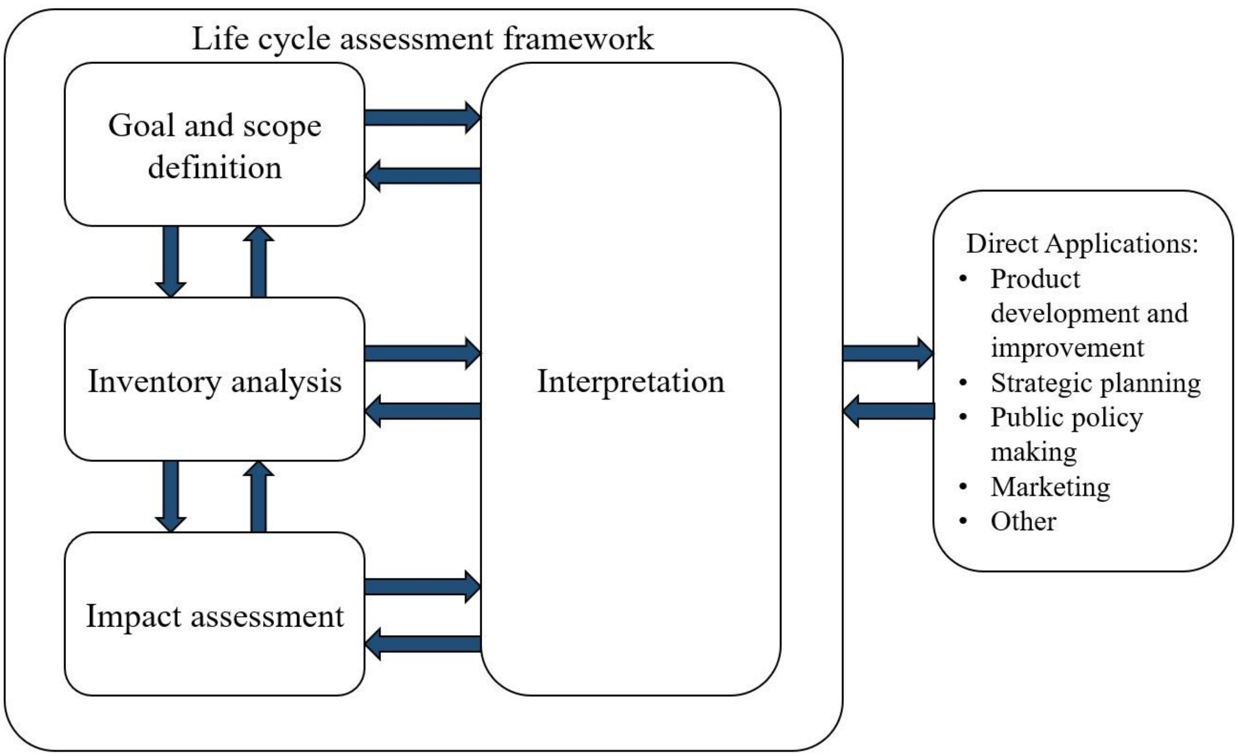

Figure 2-1: Stages of a Life Cycle Assessment (Adapted from ISO 14040)

There are two studies recognized under ISO 14040, LCI and LCIA studies. Due to the complexity of the impact assessment phase, many practitioners will exclude the third phase. It is only possible to compare the results of different LCI and LCIA studies if the assumptions and context of both studies are equivalent. Therefore, to overcome issues transparency is a major consideration of the ISO 14040 standard.

2.3 SimaPro

SimaPro has been the world's leading LCA software for the past 25 years and is currently used in over 80 countries (SimaPro, 2018). SimaPro allows users to choose from a wide range of premade science-based databases; allowing for a transparent approach and avoids black-box processes. Users can use the multiple databases or create their own processes. A few common applications include: sustainability reporting, carbon and water footprinting, product design, generating environmental product declarations and determining key performance indicators (SimaPro, 2018).

When building quantitative models such as LCIs, there are two sources: primary and secondary (SimaPro, 2018). Primary source data is first hand data collection and is preferable as it is a definitive source of information. A secondary source cites or reuses information from the primary source. Limitations to secondary sources includes, the use of the source's information in different ways that maybe inconsistent with the primary source's scope and goals. This may formulate a bias, and information of the primary source should be sought out. However, secondary sources are more prevalent due to the internet (Matthews et al., 2015).

One of the largest databases in SimaPro is ecoinvent. This leading database provides well documented processes for thousands of products, and was the main database used for this thesis project. The ecoinvent LCI datasets are intended as background data for LCA studies. The LCI and LCIA results of ecoinvent datasets may be used for comparative assessments, but the relevance and completeness of the data should always be considered. The third version of this database is restricted to the territorial boundary of the market. For example, if a dataset specifies a U.S. cement manufacturing process, the market activity dataset are calculated from the production volumes of the various cement-supplying activities located within the boundary of the market. However, many of the global datasets are extrapolated for one of the existing regional datasets (Treyer & Bauer, 2013). These extrapolated datasets are specified in the comment fields, and the quality of the data should be considered.

2.4 Uncertainty Analysis

As described in the ISO 14044, the last of the four steps is interpretation. All life cycle models have some uncertainty. The three main types are: (1) Variation in the data (2) Correctness/representativeness of the model, and (3) Incompleteness of the model. One parameter that is frequently overlooked in LCA studies is robustness (Guo & Murphy, 2012), specifically the lack of temporal information, and the lack of uncertainty analysis. For example, temporal effects such as landfill emissions for different time periods are rarely investigated (Guo & Murphy, 2012). Two prominent uncertainty analyses include the pedigree matrix (for the ecoinvent database) and the Monte Carlo analysis.

2.4.1 Pedigree Matrix Approach

The ecoinvent unit processes specify uncertainty through the pedigree matrix approach (PMA). The PMA uses data quality indicators (DQI) to quantify the uncertainty in LCI data (Matthews et al., 2015). Each LCI dataset contains 5 numbers in the description in square brackets (e.g., [1,4,5,3,2]), which is applied to another product system. The 5 categories of DQI are assigned a numerical score of 1-5, with scores of 1 being most favourable, indicating that the primary LCI data closely matches the product system of interest. Similarly, a score of 5 indicates the data may be a poor match for the product system of interest and may result in higher uncertainty. The PMA offers an easy and simple technique to understand the uncertainty associated with LCI data and is beneficial to those with limited backgrounds in quantitative uncertainty assessment.

Ecoinvent provides a standard value associated with the uncertainty information. This 'best guess' value is determined by sampling many different measurements and is usually the mean value of a lognormal distribution. Ecoinvent always assumes a lognormal distribution, which are characterized by a standard deviation. A common parameter for lognormal distribution is the square of the geometric standard deviation typically covers the 95% confidence interval. For example, a square geometric standard deviation of 1.4 confirms 95% of the values of interest are between the mean value multiplied and divided by 1.4. If all the measured values are the same, the geometric standard deviation is equal to 1. The ecoinvent databases uses the pedigree matrix which was originally developed in 1996 by Weidema to estimate the geometric mean and standard deviations. The total geometric mean for uncertainty (U_T) is given by Equation1, based on the 5 DQI parameters:

$$U_T = \sigma_g^2 = \exp\left(\sqrt{(\ln(U_b))^2) + \sum_i (\ln(U_i))^2)}\right) \qquad 1$$

Where U_b is the basic uncertainty factor, which can be found in the LCI dataset in SimaPro and is based on expert panel judgements, and U_i are the geometric deviations associated with the ranking of the 5 DQI as per Table 2-1:

Table 2-1: Pedigree Matrix (Adapted from Matthews et al., 2015)

Score	1	2	3	4	5
1. Reliability	Verified data based on measurements 1.00	Verified data partly based on assumptions OR non-verified data based on measurements 1.05	Non-verified data partly based on qualified estimates 1.10	Qualified estimate (e.g., by industrial expert); data derived from theoretical information 1.20	Non-qualified estimate 1.50
2. Completeness	Representative data from all sites relevant for the market considered over an adequate period to even out normal fluctuations 1.00	Representative data from >50% of the sites relevant for the market considered over an adequate period to even out normal fluctuations 1.02	Representative data from only some sites (<<50%) relevant for the market considered OR >50% of sites but from shorter periods 1.05	Representative data from only one site relevant for the market considered OR some sites but from shorter periods 1.10	Representativeness unknow or data from a small number of sites AND from shorter periods 1.20
3. Temporal Correlation	Less than 3 years of difference to the reference year 1.00	Less than 6 years if difference to the reference year 1.03	Less than 10 years of difference to the reference year 1.10	Less than 15 years of difference to the reference year 1.20	Age of data unknown or more than 15 years of difference to our reference year 1.50
4. Geographical Correlation	Data from area under study 1.00	Average data from larger area in which the area under study is included 1.00	Data from smaller area than area under study, or from similar area 1.02	Data from area with slightly similar production conditions 1.05	Data from unknown OR distinctly different area (North America instead of Middle East, OECD-Europe instead of Russia) 1.10
5. Further Technological Correlation	Data from enterprises, processes, and materials under study (i.e., identical technology) 1.00	Data from processes and materials under study (i.e., identical technology) but from different enterprises 1.05	Data on related processes or materials but same technology, OR data from processes and materials under study but from different technology 1.20	Data on related processes or materials but different technology, OR data on laboratory scale processes and same technology 1.50	Data on related processes or materials but on laboratory scale of different technology 2.00

Each data point is based on five criteria and the basic uncertainty factor, which is dependant on the type of data. The squared geometric standard deviation (95% confidence interval) is calculated using Equation 2 below:

$$\sigma_g^2 = \sum_{n=1}^{6} = \sigma_n^2 \qquad 2$$

Where σ_1^2 refers to the basic uncertainty factor, and σ_2^2 to σ_6^2 refer to the scores in the (1) reliability, (2) completeness, (3) temporal correlation, (4) geographical correlation, and (5) further technology. In addition, SimaPro has a sixth indicator, the sample size, but in the ecoinvent datasets used in this LCA study the sample size is unavailable. The PMA is only applicable to the LCI phase and does not consider midpoint or endpoint impacts. Therefore, the Monto Carlo simulation can be considered the most effective and quantifiable uncertainty analysis (Bieda, 2014).

2.4.2 Monte Carlo Simulation

The Monte Carlo simulation/analysis is a statistical method to characterize data quality and establish an uncertainty range and is the most commonly recommended approach (Guo & Murphy, 2012). In contrast to the PMA, the Monte Carlo analysis is used to analyze the uncertainties associated in different stages: LCI, LCIA, normalization and weighting processes. This simulation is a widely used approach to assess the influence that rises from the uncertainty within a specific variable or a set of variables and the uncertainties involved (Tu & McDonnell, 2016). There are multiple factors that affect the amount and type of substances released into the atmosphere. For example, if on average 10 kg of CO_2 is emitted for every 100 kg of wood burned in for a household fireplace, the CO_2 values could range between 5 kg and 15 kg. The fireplace produces 50 MJ of heat, but due to natural fluctuations, this value could vary 10%, therefore the actual value is between 45 MJ and 55 MJ. The chance that the best and worse case scenario of emitted emissions is extreme; the Monte Carlo analysis takes a random variable/factors for each value within the uncertainty range. The value of the specific scenario is stored and then repeated using different variables within the uncertainty range. This analysis can be repeated for instance 2000 times, and therefore there are 2000 answers which form an uncertainty distribution. SimaPro supports four types of distributions: uniform, triangular, normal and lognormal (Goedkoop et al. 2016).

Uncertainty associated with correctness of a model is subjective to modeling decisions and assumptions. For example, the assumptions regarding final waste disposal scenarios when the septic system will not be disposed of for decades. Factors such as these can often be difficult to account for and affect the results significantly, but sensitivity analysis sheds some light on these subjective assumptions and questions. Guo and Murphy (2012) found uncertainty combined with sensitivity analyses lead to a more transparent increase in confidence in LCA findings.

2.5 Life Cycle Cost Analysis

Life cycle cost analysis (LCCA) is the estimation of the total cost of operating a product or system over its life and has been used for decades (Matthews et al., 2015). For more important and costly decisions such as manufactured goods and structures (e.g., bridges and highways). LCCA allows for more efficient management of social resources used by these public structures and goods. Historically LCCA has been used for large-scale projects as future maintenance costs may affect early design and construction decisions. Recently this newer approach has been applied to individual products.

In addition to the environmental impacts of LCAs, LCCA broadens the scope by incorporating an economic aspect across the various life cycle phases. For LCCA to be effective, there must be a set of alternatives or alternative designs. In this LCA study, homeowners have five different septic systems that can be installed. It is assumed the average homeowner only wants two things when choosing a septic system, functional system and how much will it cost them. The latter is the scope and boundary of this LCCA. Therefore, the capital, installation, operation and maintenance costs for the homeowner over a lifespan of 25 years was accounted for.

Capital and installation fees were provided by a local designer and installer, the operation costs, the electricity to run the pump(s) will be applicable to every system except the filter bed which solely uses gravitational flow. The maintenance costs associated with pumping out the septic tank assumed to occur once every three years, in which the sludge in the septic tank must be pumped out. Septic systems can have a large capital cost, but the costs of the operation and maintenance can be a bigger hassle for homeowners, as once the system is in, it's out of sight, out of mind.

A benefit of using LCCA is allowing incorporation of costs by both the owner and other users. LCCA can help stakeholders make robust decisions that incorporate risk and uncertainty in both deterministic and probabilistic models. For this study we assume a deterministic model, where the LCI data is known and there is no chance of change.

2.6 Limitations of Life Cycle Assessment

Comprehensive assessments such as LCA aim to quantify all potential environmental effects. Conceptually, LCA is a simple tool, however, completing these extensive assessments requires a high level of simulation, sophistication and integration, which in turn require excessively large amounts of time, data, knowledge, and resources. Therefore, every LCA must be limited in some aspects of sophistication and/or comprehensiveness (Bare et al., 2012).

Directly, LCAs only address the environmental issues, however the environmental impacts can be used and integrated to address the social and economic issues. These three dimensions, environmental, economic and social are critical to avoid problem shifting of a product (Finnveden et al., 2009). Another large issue is the lack of standardization between several impact categories (Reap et al., 2008) and how one category may lack something important such as impacts on biodiversity and habitat alteration. In addition, some impact category results will receive much more attention (i.e., climate change) as seen in an US valuation exercise conducted by the National Institute of Standards and Technology (NIST) (Gloria et al. 2007).

Each impact assessment uniquely addresses the problems associated with the category selection, spatial variation, and time ranges. This lack of standardization poses three main problems for LCA practitioners: (1) a proper assessment cannot be preformed due to lack of data of that category, (2) the assumption that the category is not relevant in the study of interest, and (3) the lack of consideration in the impact assessment. Typically, in LCA studies there is little knowledge of other simultaneous emissions and it does not take into consideration the background emissions concentrations or the environment in which these emissions are released in. The impact assessment just reflects the potential contributions and is not a replacement for a risk assessment (Finnveden et al., 2009). Some LCI emissions such as nitrogen oxides (NO_X) may be 'double-counted' as it can affect multiple impact categories such as smog, acidification, and eutrophication (Reap et al., 2008). The same emission must not be assigned to different categories but should be allocated accordingly. Therefore, it is critical to consider the importance of each stages and sub-stages, as without a strong and credible LCI data, the impact results will be less valuable.

Ideally, decision makers prefer a simple, understandable, and clear LCA results especially in policy making or company management. In LCIA, there are two impact indicators, midpoint and endpoint. Midpoint impact categories are based on scientifically sound calculations. By further calculations, the midpoints can be reduced to a few endpoint impacts, such as damage to human health, damage to ecosystems and depletion of resources, as seen in Figure 2-2.

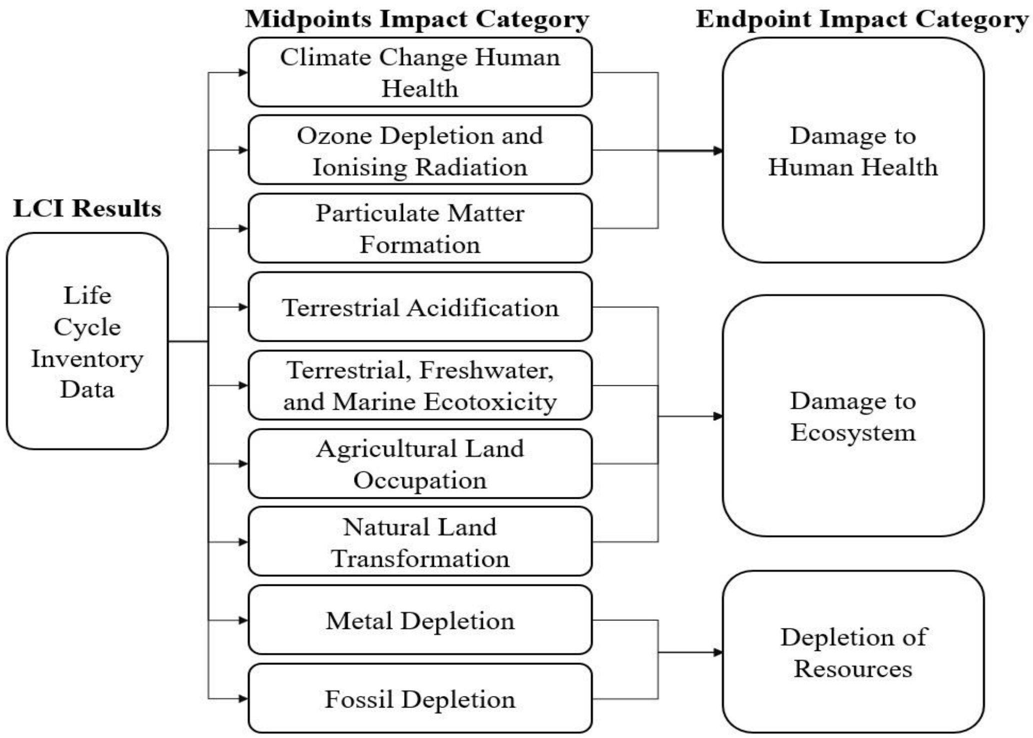

Figure 2-2: LCIA Midpoints and Endpoints (Adapted from SimaPro Database Manual, 2016)

However, endpoints methods add uncertainty due to a more complete modelling of impact pathways. For example, ReCiPe's impact assessment narrows 18 midpoint categories to three endpoint categories and presents them as a single or a total environmental score (SimaPro Database Manual, 2016). Weighting of midpoints categories to one single score adds uncertainty and bias and may result in counterproductive measures. ISO does not recommend endpoint indicators and decision makers should perform their own weighting and come to their own subjective conclusion. By presenting the results in one single score, the whole picture is captured into one number and the methodology and calculations behind that number is difficult to understand.

A growing body of literature demonstrates that in a decision driven context, external normalization masks the underlying uncertainty, the environmental trade-offs between alternatives, stakeholder preferences and may also result in the environmentally inferior for being chosen (Bare et al., 2006; Heijungs et al., 2007; White & Clark, 2010; Pardo et al., 2012). To clearly identify the environmentally preferable alternatives in a comparative LCA, some practitioners apply external normalization. External normalization relates the results of the LICA to an external database or normalization reference. This endpoint assessment is classified as an absolute scale, as it relies on information outside of the study and is intended to show the significance of a result proponent to a chosen reference system such as a regional scale. The normative concept is based in utility theory, which assigns a number value (ranking) to each alterative. However, there are several disadvantages when utilizing external normalization, including addition of uncertainty due to the lack of consensus in the data, masking significant aspects, compensating, boundaries issues, and divergence in databases.

Normalized impact categories with large annual per capita values, yield small normalized results and vice versa. This is referred to as "inverse proportionality" and can lead to confusion and unfavourable actions (Prado, et al., 2017). In addition, external normalization allows for various impact categories and units to be quantified into a single score and allows for a products poor performance in one category to be compensated by a good performance in another category. Lastly, spatial boundaries and time frames contribute to uncertainty or bias as the normalized reference data is typically compiled on a national basis, although not all environmental impacts have a national effect. For example, smog has a more localized effect than global warming and therefore all impacts outside of the spatial boundary will not be accounted for. Most external normalized reference data is collected on an annual basis and may not deal with emissions outside the designated timeframe (Prado et al., 2017). In ReCiPe's European impact assessment, each characterized result is divided by the annual environmental load of one European inhabitant. Therefore, only midpoint impact categories were presented in this study. LCAs are subjective by nature and ISO recommends LCAs to be as transparent as possible, midpoint indicators allow for a more science-based approach while minimizing uncertainty and bias.

2.7 Residential Onsite Wastewater Treatment Systems

2.7.1 Overview

Onsite residential wastewater treatment systems are regulated under the Ontario regulation 332/12, the Building Code Act (1992). Part 1 of Division A of the OBC defines sewage systems and Part 8 of Division B provides critical information regarding the design, construction, installation, operation, and maintenance of these systems. The OBC defines five classes of sanitary sewage systems, of which a Class 4 system (Figure 2-3) is defined as a leaching bed system, which can accept both greywater and human excrements.

Figure 2-3: Typical Septic System (Adapted from Muskoka Home Inspection, 2014)

Class 4 Onsite residential wastewater treatment systems, or septic systems are primarily composed of a septic tank, and a leaching bed, and in some circumstances a Level IV treatment unit and a pump chamber(s). The receiving soil is the most important component of the system, as it is the final treatment by which the effluent is treated to minimize contamination of groundwater. When first discharged from the tank, effluent clogs the surface soil (5-15cm), which forms a 'biomat', this helps aid in further aerobic digestion by the naturally occurring microorganisms in the soil, due to the decreases infiltration rates, allowing for the porous media to contain more oxygen. As the wastewater progresses through the soil, it is treated via chemical, biological, and physical processes. For example, some effluent particles may be absorbed through vegetation (i.e., grasses), others may be sorbed to the soil or diluted and treated as it passes through unsaturated soil.

2.7.2 Septic Tank

Settlement and anaerobic digestion of organic (primarily faecal) matter occurs in the septic tank, which is composed of at least two compartments (Withers et al., 2011). The first compartment (typically 66% of the tanks total volume) consists of a baffle or inlet tee to direct the influent downwards. As per Figure 2-4, the wastewater will travel towards the second compartment of the tank which is divided by a wall with perforated holes at about one third from the top, to help ensure larger particles settle to the bottom of the tank. Bacteria in the septic tank will decompose or liquefy some of the retained solid matter. The solids in the wastewater continue to settle as the wastewater travels through the second compartment of the tank (minimum 50% of the first compartment volume) and finally through an effluent filter out of the tank. Other septic tank stipulations include all piping in the tank must be continuous and have flexible watertight seals, the effluent filter at the outlet of the septic tank must have a minimum surface area of 550 cm^2. Lastly the septic tank must be accessible for pumping in all compartments. If the top of the septic tank is located less than 30 cm below ground, the access hatch does not require a riser, otherwise it requires a riser so that the access hatch is located within 30 cm of the ground surface.

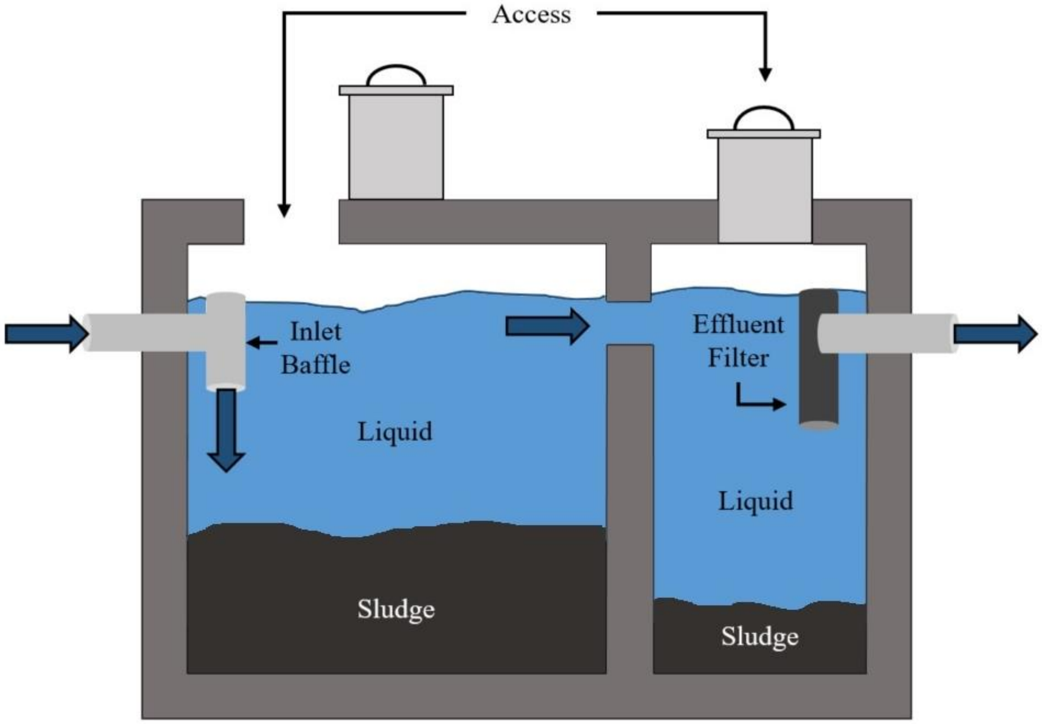

Figure 2-4: Septic Tank Cross Section

The design criteria for Class 4 sewage systems are outlined in Section 8.6 and 8.7 of the OBC. The primary design for a Class 4 septic system is dependent on the estimated daily flow of sanitary sewage from a building, the soil permeability, and the effluent quality. The estimated flow volume, also known as the total daily design sanitary sewage flow considers several factors such as the type and the size of the building (residential vs. non-residential), the number of bedrooms and fixture units, and the amount of sewage generated by the occupants of the building (residents, employees, patrons etc.). Table 2-2 below is adapted from Table 8.2.1.3.A of the OBC guidelines and was used to calculate the total daily design sanitary sewage flows for residential occupancies.

Table 2-2: OBC Daily Design Sanitary Sewage Flowrates for Residential Occupancy (Adapted from: O.Reg 332/12)

Residential Occupancy		Volume (liters)
Apartments, condominiums, or other multi-family dwelling, per person		275
Boarding houses	Per person, with meals and laundry facilities	200
	Per person, without meals or laundry facilities	150
	Per non-resident staff per 8-hour shift	40
Boarding school, per person		300
Dwellings	1-bedroom dwelling	750
	2-bedroom dwelling	1,100
	3-bedroom dwelling	1,600
	4-bedroom dwelling	2,000
	5-bedroom dwelling	2,500
Additional flow for	Each bedroom over 5	500
	Each 10 m^2 (or part of it) over 200 m^2 up to 400 m^2	100
	Each 10 m^2 (or part of it) over 400 m^2 up to 600 m^2 (1)	75
	Each 10 m^2 (or part of it) over 600 m^2	50
	Each fixture unit over 20 fixture units	50

For this LCA study a 3 bedroom, 240 m^2 residential dwelling was assumed, therefore the daily sewage flow is equal to 2000 L per day. As stated in the OBC, the septic tank must have the capacity of two times the daily sewage flow, with a minimum tank volume of 3,600 L. For this scenario, a tank of a minimum of 4,000 L must be installed. Septic tanks are manufactured in set sizes, and a 4,500 L, 35 MPa concrete septic tank will be installed for the purpose of this study, as the local manufacture does not produce a 4,000 L tank. Historically septic tanks are primarily made from concrete, but high-density polyethylene tanks are becoming more popular.

Section 8.7 of the OBC regulates the final treatment of the wastewater, the leaching beds. As mentioned above, one important design parameter is the permeability of the soil, the ability of the porous material to accept fluid through it. This parameter is known as the percolation time (T-time) which is measured in min/cm. Typically, a technician will dig a hole on the site of interest, pour water in the hole and measure how long it takes for 1 cm of water to infiltrate through the soil. A T-time of 40 min/cm was assumed for the primary model. The leaching bed must not backlog or reach the surface, and therefore should not be covered with any material having a hydraulic conductivity of less than 0.01 m/day. The covering/top layer should be permeable enough to ensure percolation from the ground surface, evaporation and aeration through the leaching bed. Additionally, the OBC requires a specific vertical clearance from the groundwater table, which is typically 90 cm for conventional leaching bed, filter bed, shallow buried trench, and 60 cm for Type A and B dispersal beds. Other OBC requirements include setback distances from dwellings, drinking wells, etc. It is assumed the theoretical residential lot meets all the OBC requirements regarding vertical and horizontal clearances.

There are five regulated leaching beds, all of which requires a septic tank (in some circumstances a septic tank can be replaced with a Level IV treatment unit). The five beds include: the conventional leaching bed (CLB), sand filter bed (SFB), shallow buried trench (SBT), Type A dispersal bed (Type A) and Type B dispersal bed (Type B). Each bed has their own constraints and criteria as defined by the OBC. In Ontario the most common installed leaching beds are the conventional and sand filter beds. The latter two leaching beds were later added to the OBC as alternatives to conventional and sand filter leaching beds. Shallow buried trench, Type A, and Type B are typically only installed when the lot is too small to install the two most common beds, or high groundwater table is present (less than 90 cm from the bottom of the trench). These three alternatives require a Level IV treatment unit before the effluent is dispersed to the smaller leaching bed. In addition to a septic tank, Level IV treatment unit, and a leaching bed, some of the septic systems requires pressurized or dosed effluent dispersal to the leaching bed. Table 2-3 summarized the general requirements for each of the five residential systems.

Table 2-3: Number of Components Typically Installed

	Number of Installed Components Over 25 Years				
	Septic Tank	**Pump Tank**	**Pumps**	**Level IV Treatment Unit**	**Leaching Bed**
Conventional	1	1	Optional[1]	-	1
Filter Bed	1	-	-	-	1
Shallow Buried Trench	1	1	3[2]	1	1
Type A Dispersal	1	1	3[2]	1	1
Type B Dispersal	1	1	3[2]	1	1

Note: [1] A pump or a siphon can be installed, as the system is required to be dosed (not pressurized) for distribution pipe length greater than 150 m.

[2]The beds are required to be pressurised and therefore require at least 1 pump, it was assumed a pump will last 10 years before it will need replacing.

2.7.3 Pump Chambers

Pump chambers are either made from concrete or plastic and contain a pump or a siphon. For the purpose of this study, a pump chamber refers to a concrete chamber that contains a 1/2 HP submersible pump. A diagram of a typical pump chamber can be seen in Figure 2-5.

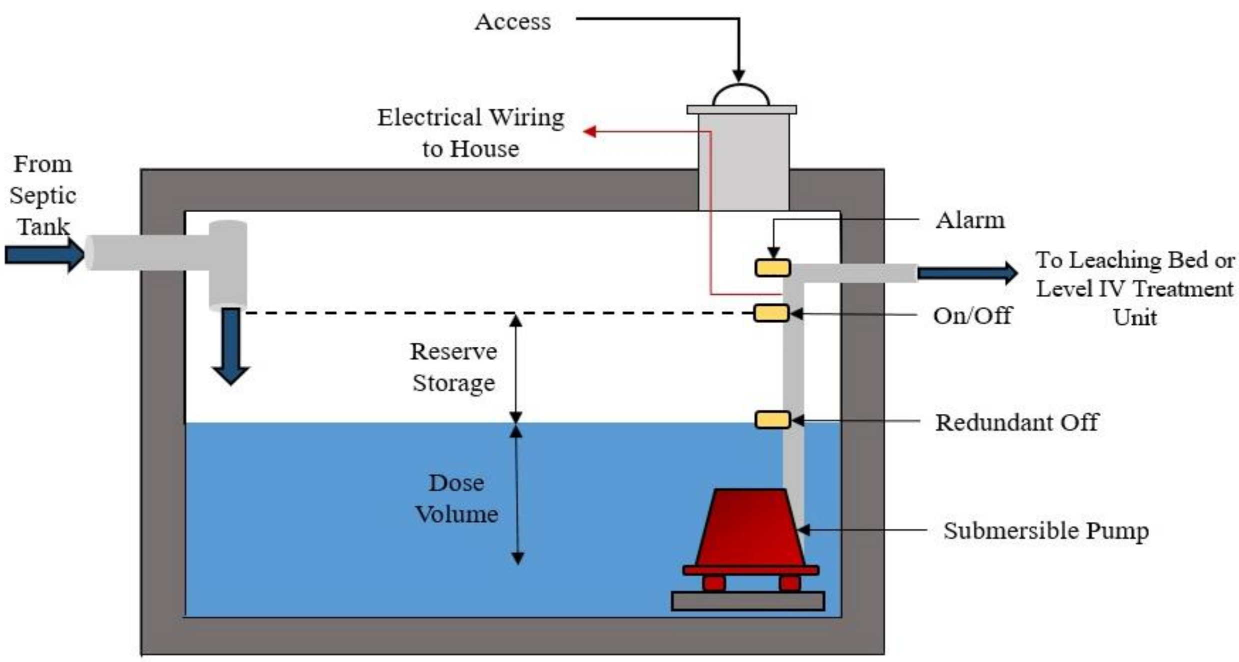

Figure 2-5: Concrete Pump Chamber

2.7.4 Level IV Treatment

There are three classifications of treatment units, Level II to IV. As of January 1, 2017, all treatment units must meet the requirements of CAN/BNQ 3680-600, "Onsite Residential Wastewater Treatment Technologies." Three of the five Class 4 septic systems require a Level IV treatment unit, which must not exceed the SS and CBOD5 requirements listed in Table 2-4.

Table 2-4: Level IV Treatment Unit OBC Requirements

Column 1	Column 2	Column 3
Classification of Treatment Unit [1]	**Suspended Solids [2]**	**CBOD5[2]**
Level II	30	25
Level III	15	15
Level IV	10	10

Note: [1] The Classifications of treatment units specified in Column 1 correspond to the levels of treatment described in CAN/BNQ 3680-600, "Onsite Residential Wastewater Treatment Technologies"

[2] Maximum concentration in mg/L based on a 30-day average

There are multiple Level IV treatment units on the market, however, the Model 20 HDPE Waterloo Biofilter, manufactured by the local company Waterloo Biofilter was chosen as an integrated component of the overall system. Waterloo Biofilter is among the few Level IV Treatment that has been recently certified according to the new regulations. Effluent from the pump chamber is distributed to the top of the Waterloo foam filter media. The wastewater slowly trickles down through the foam and is treated both physically and biologically. The treated water is then pumped to the leaching bed for further treatment. A general layout of a Waterloo Biofilter system can be seen in Figure 2-6.

Figure 2-6: Waterloo Biofilter Level IV Treatment Unit (Adapted from Waterloo Biofilter Systems, 2018)

2.7.5 Conventional Leaching Bed

A conventional in-ground leaching bed can be used if the T-time is between 1 to 50 min/cm and the bedrock or groundwater table is more than 90 cm of the bottom of the absorption trenches. Otherwise a raised leaching bed must be used. The T-time for the site of interest is 40 min/cm therefore an in-ground leaching bed is used. If the total length of the distribution pipe required is 150 m or more, a dosed distribution system is required. This is achieved either by a siphon or pump which sends a specified volume of effluent to the leaching bed in a single dose and is typically downgradient of the septic tank. Within 15 minutes, 75% of the pipe's total length must be dosed. In this case study, it was calculated a minimum of 400 m of PVC piping will be used with a diameter of 4 inches, and therefore the CLB must be dosed. Lastly, due to the required 400 m distribution pipe, the effluent should be distributed between two smaller beds, rather than one large bed. There are two main types of distribution components that are used, distribution box or the distribution header, as seen in Figure 2-7.

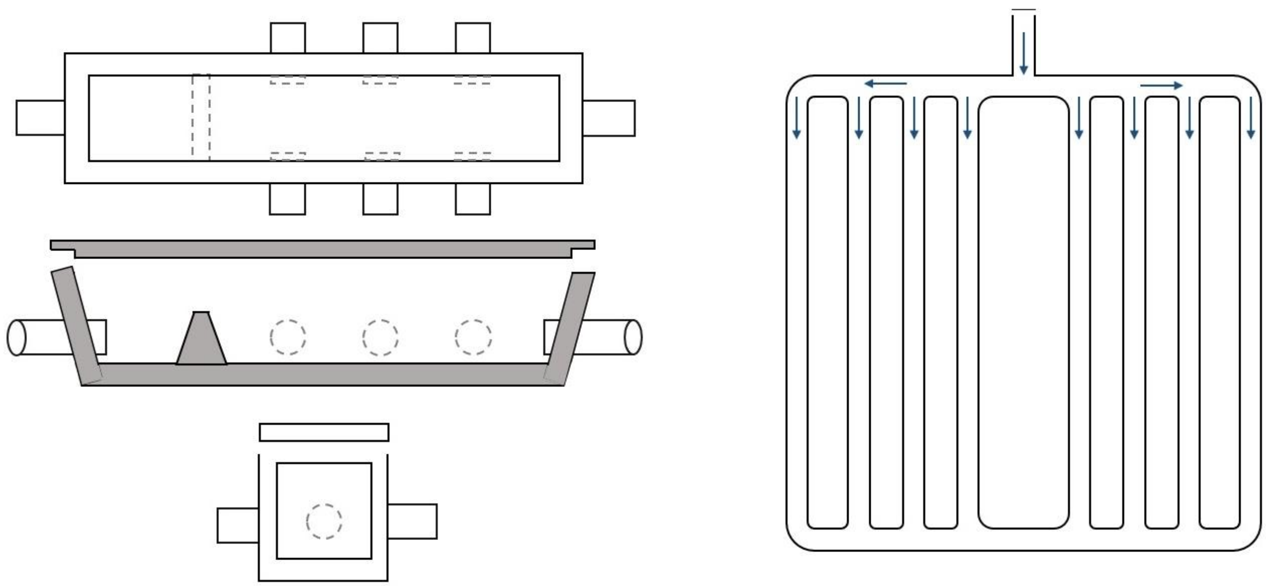

Figure 2-7: Distribution Box (left) and Header (right)

As distribution box or header is highly recommended, if more than 8 lines of distribution pipe are required. In general, a distribution box is recommended for larger systems as it can be inspected, cleaned, and adjusted after the bed is constructed. In contrast, a header is preferred for smaller systems that operate under gravitational flow. Two distribution boxes were modeled in this study for the CBL, while the other four leaching beds used headers due to smaller amount of distribution pipe. Figure 2-8 illustrates a cross-section of a typical absorption trench for a conventional leaching bed.

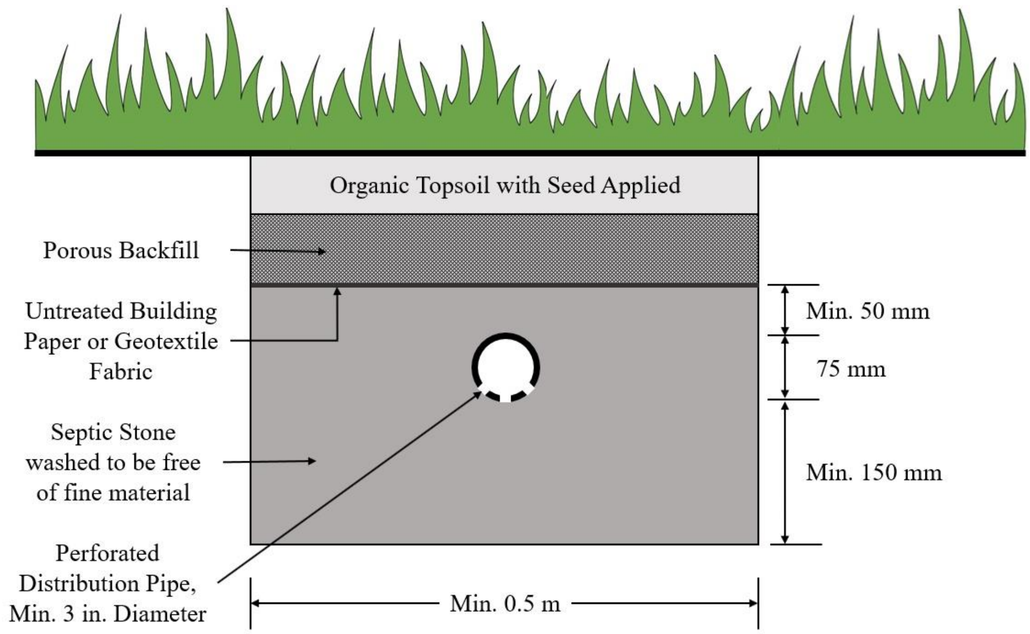

Figure 2-8: Typical Absorption Trench

2.7.6 Sand Filter Bed

A sand filter bed is an alternative to the CLB when there is limited space on a lot. The distribution pipes are set on a continuous layer of stone. As per Figure 2-9, in some circumstances, depending on the daily flow rate and T-Time of the native soil, an extended filter base maybe required. The filter sand cannot be native soil as the imported filter sand must meet the OBC's gradation limits (e.g., effective size and uniformity coefficient). There are no regulations regarding dosing of the SFB, however in one of the sensitivity analysis preformed on the model, a pump chamber was included, as dosed systems typically have more even dosing (Ontario Onsite Wastewater Association, 2016).

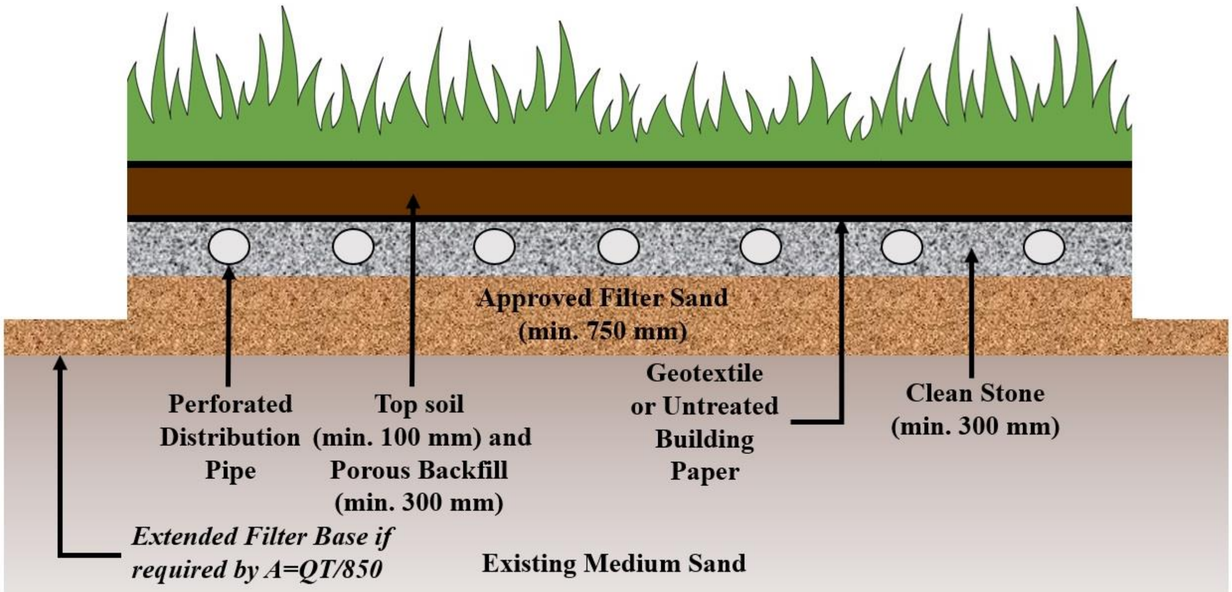

Figure 2-9: Sand Filter Bed

2.7.7 Shallow Buried Trench

A SBT is the only system that can be installed in soils with a T-time that exceeds 50 min/cm up to 125 min/cm. It requires the system to be pressurised and a Level IV treatment unit. Along with Type A and Type B dispersal beds, SBT are typically used for high groundwater tables (at least 900 mm from the top of the groundwater table to the bottom of the leaching bed) and/or smaller lots. Unlike the CLB and the SFB, SBT are required to be pressurized, not dosed. Pressurized systems are slightly different from dosed systems, as they have smaller pipes (minimum 1" diameter). A minimal pressure is maintained at the terminal end of all the lines of distribution pipe, which allow for an even distribution of effluent over the entire leaching bed area. Due to small size of the bed (Figure 2-10), the bed must be dosed every hour to maintain a low storage of effluent in the pump chamber.

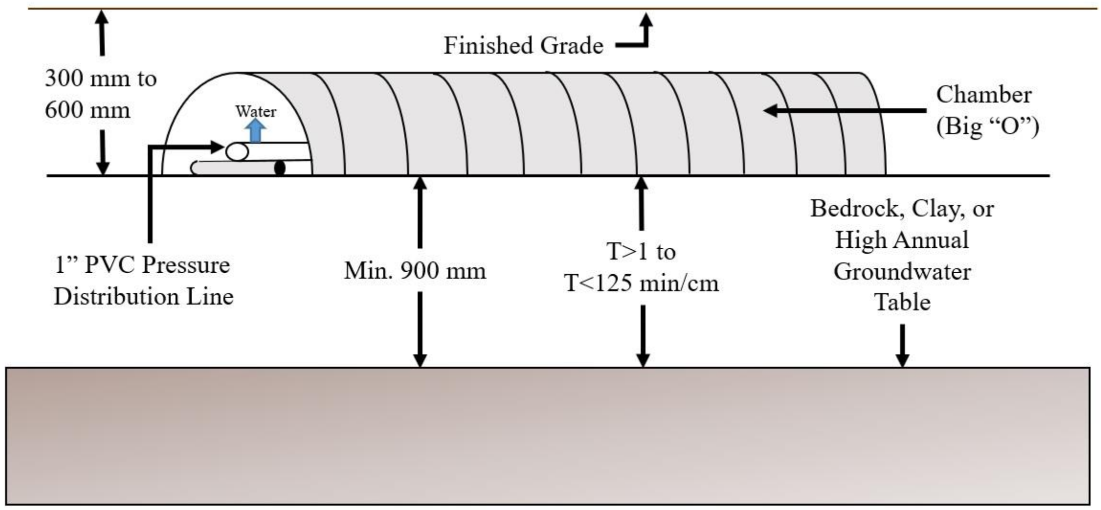

Figure 2-10: Shallow Buried Trench

2.7.8 Type A Dispersal Bed

Similar to a SBT, Type A dispersal beds receives effluent from a Level IV treatment unit. The leaching bed is comprised of a stone layer above an unsaturated sand layer. The bed is not required to be pressurized or dosed, therefore 3-4" distribution pipes are installed. However, the Waterloo Biofilter contains a pump, allowing for the bed to be dosed. A minimum depth of 0.5 m is required, comprised of a 0.3 m sand layer and a 0.2 m stone layer, as per Figure 2-11 and Figure 2-12 below.

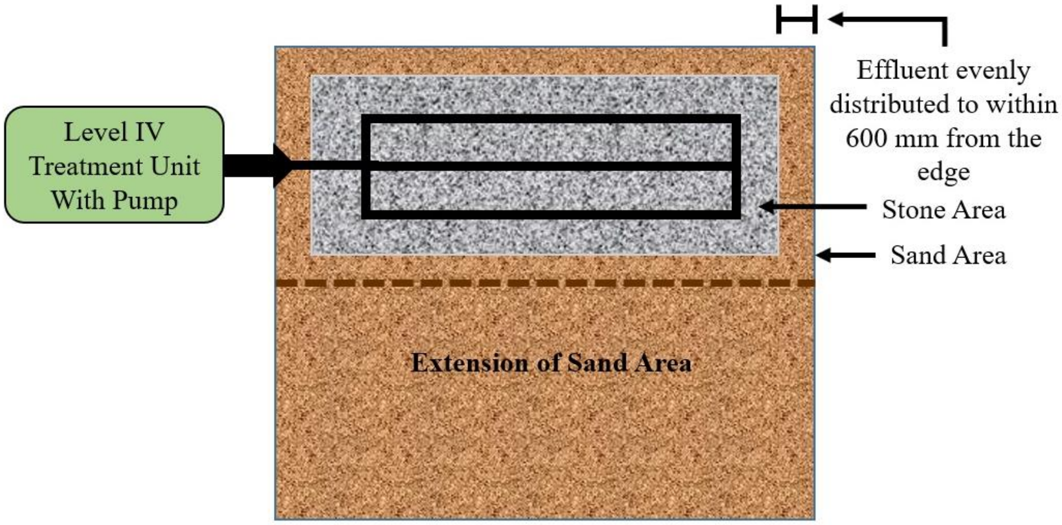

Figure 2-11: Top View of a Type A Dispersal Bed

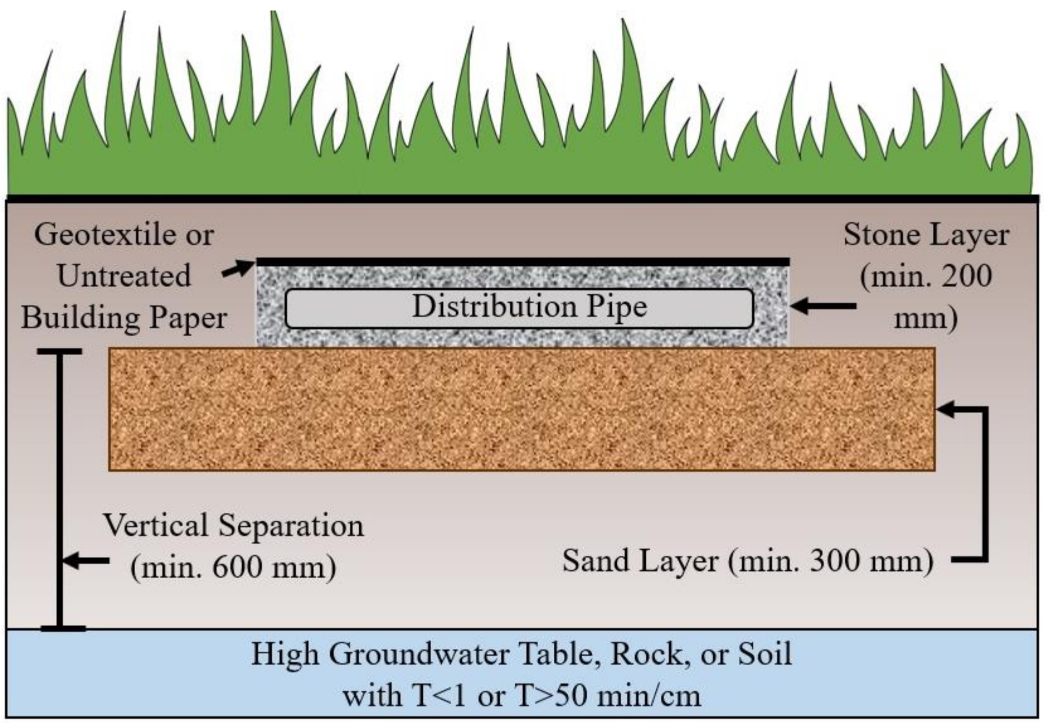

Figure 2-12: Cross-Section of a Type A Dispersal Bed

2.7.9 Type B Dispersal Bed

Type B dispersal beds are rectangular, with the effluent running parallel to the longer side minimum stone layer thickness of 0.3 m, as per Figure 2-13 and Figure 2-14. The leaching bed is pressurized and is dosed every hour, similar to the SBT.

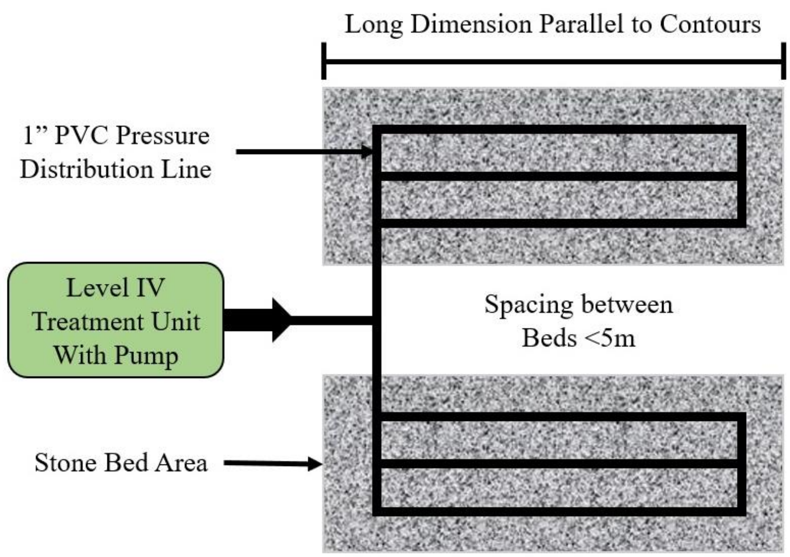

Figure 2-13: Top View of a Type B Dispersal Bed

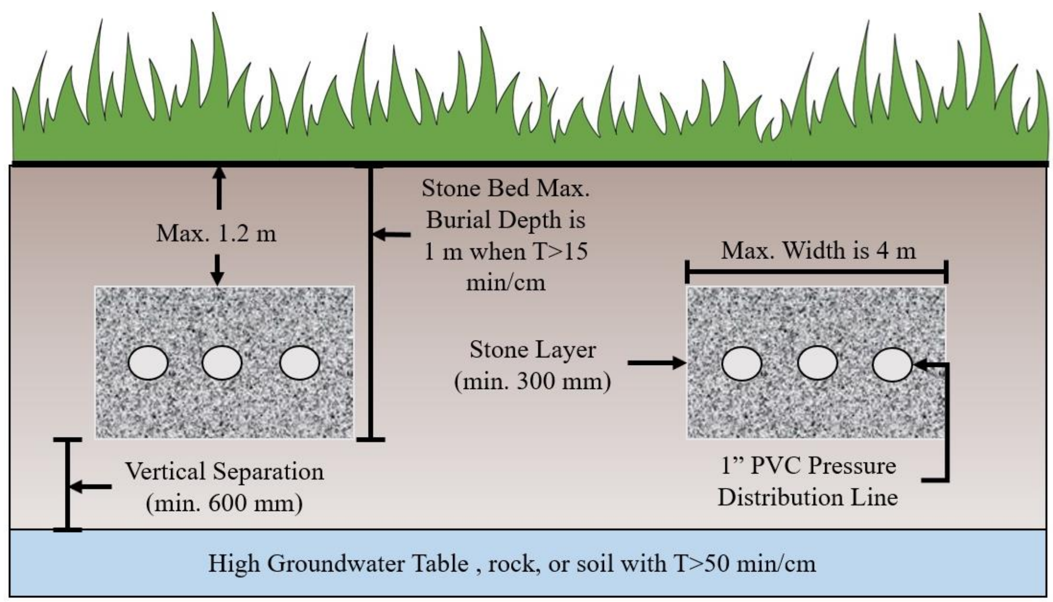

Figure 2-14: Cross-Section of a Type B Dispersal Bed

2.8 Applications of Life Cycle Assessment in Wastewater Treatment

With growing interest for more environmentally sustainable water and wastewater treatment, LCA is a valuable tool. Environmental assessments are more quantitative in nature, whereas LCA is a more qualitative approach. For example, an environmental assessment would list the amount of nitrogen in the wastewater effluent, while LCA will predict the effects of the nitrogen concentration in the wastewater on various impacts such as eutrophication, acidification and ecotoxicity. Conducting LCAs on wastewater treatment plants (WWTP) incorporates the environmental impacts associated with design and operation decisions. LCA and environmental assessments have been performed on different treatment processes, water reclamation feasibility, and overall sustainability of municipal wastewater treatment.

2.8.1 Energy

Drinking water and wastewater systems account for approximately 3 to 4% of the energy use in the United States, resulting in the annual emission of more than 45 million tons of greenhouse gases (Energy Efficiency, 2013). Energy used by water and wastewater utilities accounts for 35% of typical U.S. energy budgets (Energy Efficiency, 2013) and in typical mid-size cities, 30 to 40% of energy use results from water and wastewater treatment operations (Aeration Efficiency, 2013). Aeration processes can account for up to 25% of a cities total energy use (Aeration Efficiency, 2013). In addition to energy use, some water and wastewater treatment processes simply move pollutants around, such as the air stripping of ammonia, which converts the ammonia from the liquid phase to the gaseous phase before being discharged to the atmosphere (Ocean Arks International, 2005). Off-site impacts are typically neglected, as was the case with lime usage, which must be extracted and refined, resulting in the generation of air emissions and solid waste (Ocean Arks International, 2005).

Multiple studies found energy consumption during operation has a large overall environmental impact, specifically in greenhouse gas (GHG) production, global warming potential (GWP), and abiotic depletion (Emmerson et al., 1995; Beavis & Lundie, 2003; Dixon et al., 2003; Foley et al., 2010a; Gallego et al., 2008). Emmerson et al. (1995) found aeration treatment systems for activated sludge processes emitted more than three times the amount of CO_2 than biological filter plants. Approximately 60% of the emitted CO_2 is due to the operation of the aeration system, while the other 38% and 2% is due to the construction and maintenance respectively. The study concluded that over a 15-year lifetime, the biological filter plants were found to use on average 56% less energy than the activated sludge plants, while producing 35% fewer airborne emissions.

The operation of the WWTPs largely contributes to the environmental impacts since electricity demanding processes like aeration are more environmentally detrimental than other treatment technologies such as aerobic-anoxic treatments (Gallego et al., 2008) and sand filtration (Høibye et al., 2008).

2.8.2 Nutrients

However, some studies did not consider the trade-offs of energy intensive processes such as aerobic digestors and quality of effluent. The increase of nitrogen into waterbodies is due to the rapid increase in human activities, which has enlarged eutrophication and degradation in the natural water quality (Xin et al., 2010). Increased nutrient removal from wastewater treatment is an essential method to protect drinking water and decreased the growth of toxic cyanobacteria and algal blooms. With 20% of the world' fresh water contained in the Great Lakes, it is important water source for millions of Canadians and Americans. Uncontrolled growth of cyanobacteria has impacted human health in both Southern Ontario and the Midwest United States including gastrointestinal discomfort and liver damage if the contaminated water is ingested (Roelofs, 2015). Algal blooms have multiple effects on the local ecosystems as they block light for photosynthesis, which in turn reduce aquatic plant growth, and effects the food supply to aquatic species (Anderson, 2005). In addition, when algae decay it consumes oxygen and produces CO_2 which causes dead zones in the water where a widespread of plant and animals mortalities occur as very few organisms can live in the hypoxic conditions (National Geographic Society, 2011).

The smallest discharge of untreated wastewater can have a significant impact; therefore wastewater treatment should produce as high a quality of effluent as possible, especially in the removal of nitrogen and phosphorus (Roeleveld et al., 1997; Lassaux, Renzoni, & Germain, 2007). Venkatesh & Brattebø (2001) found over 70% of the eutrophication protentional of WWTP in Oslo, Norway was due to the nutrients in the discharged treated effluent. Eutrophication and terrestrial ecotoxicity were found to be of a significant concern in a WWTP in Spain, which were primarily due to ammonia (NH_3), phosphate (PO_4^{3-}), and the chemical oxygen demand (COD) in the treated wastewater, even when the concentrations were well below the legal limit (Hospido et al., 2004).

Beavis & Lundie (2003) examined the conversion from anaerobic to aerobic digestion. Anaerobic digestion was favourable in 6 of the 9 impact categories if the produced biosolids were used as a fertilizer. However, aerobic digestion minimizes the nutrients in the water. The infrastructure resources, operational energy, direct GHG emissions, chemical consumption, and biosolids production tend to increase with increased nitrogen removal (Foley, et al., 2010a; Beavis & Lundie, 2003; Kalbar et al., 2013). The environmental trade-off of increased energy consumption, but decreased eutrophication impact is highly recommended (Foley, et al., 2010a; Hospido, Moreira, & Feijoo, 2008). The removal of nitrogen through a nitrification-denitrification processes coupled with a biological aeration treatment system could lower the overall environmental impact (Hospido et al., 2008).

Two energy-saving wastewater treatment processes for small and decentralized communities were analyzed: constructed wetland with slow rate infiltration and, conventional activated sludge process (Machado et al., 2007). The constructed wetland has significant decrease in GHG emissions due to the low energy requirement and carbon sequestration. The activated sludge process requires large amounts of energy and is a main contributor to GWP and abiotic depletion. Operation and maintenance of the activated sludge WWTP significantly contributed to all six impact categories used in the study. The wetlands largest GHG contributor was the release of methane (Tangsubkul et al., 2005) however, constructed wetland has significant decrease in GHG emissions due to the low energy requirement and carbon sequestration (Machado et al., 2007). In contrast, Kalbar et al., (2013) found constructed wetlands had a negligible energy consumption and negative GWP.

Remy & Jekel (2008) compared conventional and source-separating urban sanitation systems. The source-separation does not necessarily result in a more environmentally system. If the energy consumption and nutrient removal are optimized, the conventional systems produced comparable environmental impacts to the source-separating system. However, the source-separation of urine and faecal matter can have ecological benefits due to the minimization of heavy metals in sludge applied to agricultural lands.

2.8.3 Biosolids

From LCA research, additional studies were performed on biosolids treatment. In some of the WWTPs, the sludge treatment and disposal had a larger environmental impact than the wastewater treatment. Reduction in water content in the sludge had a noticeable environmental benefit (Dennison et al., 1998). The treatment and disposal of sludge has a large environmental footprint, in midpoint categories such as global warming, eutrophication, and acidification due to high energy consumption and heavy metals concentrations (Dennison, et al., 1998; Kalbar, et al., 2013). Treatment of sludge through anaerobic was recommended as it was the more environmentally friendly compared to other processes including lime stabilization and composting (Suh & Rousseaux, 2002). Sludge-to-energy systems such as anaerobic digestion with fast pyrolysis for bioenergy conversion achieve net positive GHG emissions (Cao & Pawłowski, 2013). The environmental performance of the WWTPs would benefit from increasing the biogas production through improved anaerobic digestion of sewage sludge (Bravo & Ferrer, 2011). Additional benefits of anaerobic digestion include partially stabilized, significant volume reduction, and the impacts of soil application are minor (Hospido et al., 2008).

Newer wastewater treatment processes are also being compared through LCA. Foley, et al., (2010b) compared anaerobic digestion (with biogas generation) to two newer approaches, (1) microbial fuel cell treatment with direct electricity generation, and (2) a microbial electrolysis cell, with hydrogen peroxide production. The microbial electrolysis cell provided significant environmental benefits due to the decrease in GHG and the displacement of chemical production over conventional means. In contrast, the microbial fuel cell did not provide a noticeable environmental benefit compared to the conventional anaerobic digestion.

In addition to the reduction of biosolids, quality of biosolids for land application should be prioritized. High phosphorus removal in wastewater allows for the opportunity to increase resource recovery and reuse in biosolids for agricultural land (Foley et al., 2010a). In addition to keeping phosphorus within agricultural applications, heavy metals in the biosolids were of a significant environmental impact (Suh & Rousseaux, 2002; Remy & Jekel, 2008). Heavy metals due to off-gases from incineration and sludge application to farmland contributed the most to human toxicity and ecotoxicity respectively (Suh & Rousseaux, 2002).

The application of biosolids to agricultural land is known to increases nitrates in groundwater which poses a threat to human health (Almasri & Kaluarachchi, 2004). Typically, septic systems are installed in rural areas in which nutrient rich biosolids is applied, leaching into the local drinking water. The OBC does not regulate nutrient removal requirements for septic systems, which should be considered in further studies and regulations. Nutrient loading in both wastewater effluent and biosolids land application both pose a significant threat to human health and surrounding ecosystems.

From the studies mentioned above four general consensuses can be made in order to alleviate the environmental impacts of wastewater treatment systems: (1) minimize the discharge of untreated wastewater, (2) minimize the pollutant concentrations in the discharged treated effluent, specifically nutrient concentrations, (3) minimize energy consumption during the operation phase, and (4) minimize the quantity produced while maximizing the quality of the sludge. The LCA studies mentioned above have been conducted for both centralized and decentralized wastewater treatment systems. However, residential onsite septic systems are classified as decentralized wastewater treatment and there are no current LCAs applied to onsite septic systems, specifically in a Canadian context.

3 METHODOLOGY

3.1 Goal and Scope

The goal of this study is to perform a comparative LCA to identify environmental hotspots in each of the five provincially regulated septic systems. Due to multiple LCA and environmental studies (James, et al., 2014; Sowah, et al., 2014; Philips et al., 2015; Yang, et al., 2016; Mechtensimer & Toor, 2017; Yang, et al., 2017) assessing the impacts of treated septic effluent, only the material extraction, manufacturing, transportation, installation, electrical consumption (use), and final disposal will be scope of the study. The boundary conditions can be seen in Figure 3-1.

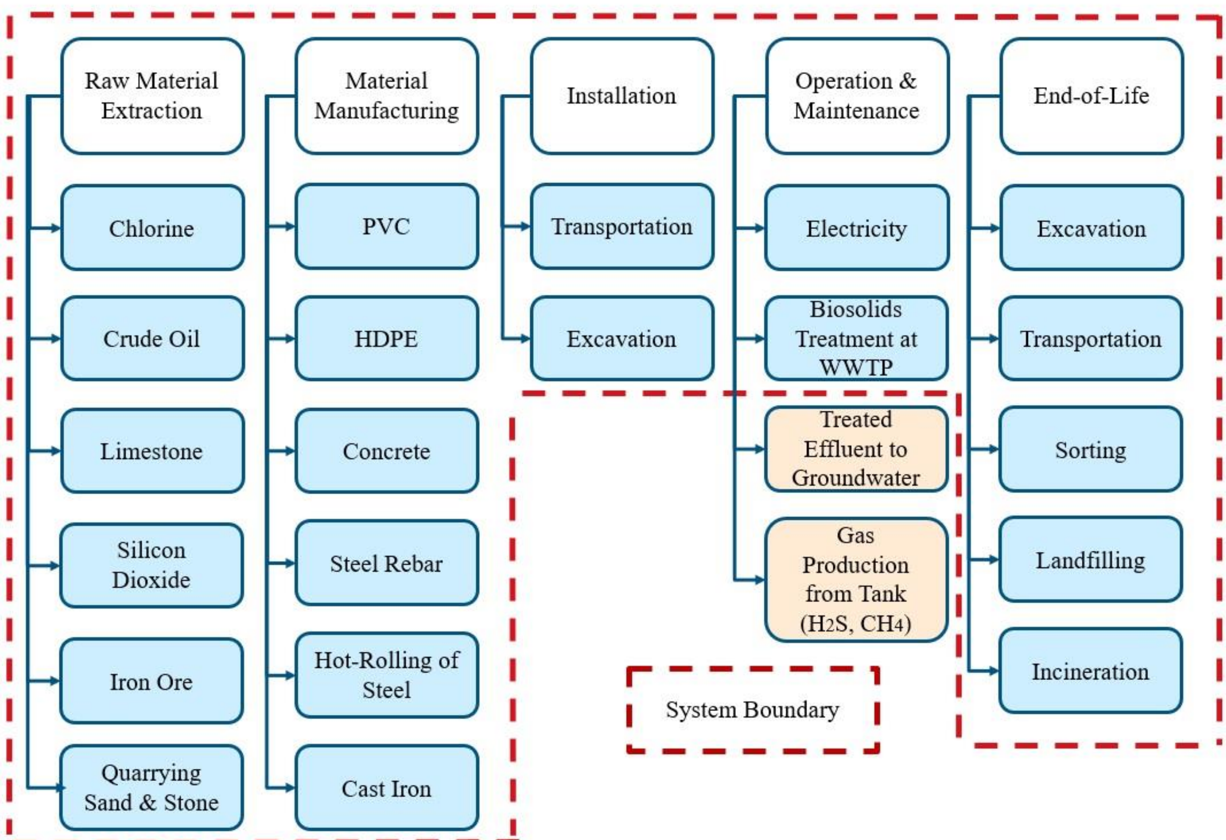

Figure 3-1: Boundary Conditions

3.2 Life Cycle Inventory

3.2.1 Primary Model

The Ontario Regulation 332/12 under the Building Code Act, 1992 was used to calculate the design parameters for the septic tank and the five leaching beds (conventional, filter bed, shallow buried trench, Type A and Type B dispersal bed). A 35 MPa, 4,500 L concrete septic tank CAD drawing was supplied by a local concrete supplier, Unit Precast located in Breslau Ontario. The CAD drawing included the dimensions and details regarding the pipe seals, reinforcing pipes. Unit Precast is redesigning the septic tank to incorporate plastic risers, therefore, it was assumed that 20" Polylok adapters, risers and lids were installed instead of the square concrete lids specified in the CAD drawings.

The distribution boxes and 2,700 L pumping chamber CAD drawings and specifications were acquired from Acton PreCast website, the riser adapters, risers, lids, effluent filter and baffles, and septic tank rubber boots were taken from Polylok's website. The smaller components (anchor bolts and screws), were calculated using specifications from home hardware stores (i.e., Home Depot). Lastly the 1,130 L pumping chamber CAD drawings are from Shaw Precast Solutions.

Shallow buried trench, Type A and B dispersal beds require a Level IV treatment unit. Therefore Waterloo Biofilter, a local and well-known tertiary treatment unit , who is certified under the CAN/BNQ 3680-600 was contacted and provided the necessary information and drawings.

The CAD drawings were used to calculate the volume of material and was converted to kilograms as SimaPro requires a weight for majority of the LCI inputs. In SimaPro transportation for transport trucks (lorries) are defined in tonnes-kilometer (tkm), where the weight of the product(s) is multiplied by the distanced traveled. In contrast smaller vehicles such as residential cars are defined in km. The following scenarios were assumed for the purpose of the model:

(1) sand and stone imported to the property was to be reused in the next system after 25 years, when the owners would replace the system;
(2) PVC piping was assumed to be sent to an incinerator 75 km from Guelph. The remaining components would be sent to the Twin Creeks Landfill in Watford Ontario, 180 km from Guelph;
(3) all septic tank components (i.e., the concrete tank, watertight seals, effluent filter and risers) were transported from one of the multiple local manufactures and a generic transportation distance of 50 km. The Level IV treatment unit, Waterloo Biofilter is located just outside of Guelph and therefore a generic transportation distance of 50 km was assumed;
(4) stone and sand were transported 50 km from the local quarries located in southwestern Ontario to the site; and
(5) the owner of the property would drive a medium sized vehicle to a local hardware store, 20 km (e.g., Home Depot) to pick up the PVC piping, the building paper and the pumps.

Another important parameter is the maintenance of the septic tank. The general guidelines recommend the tank should be pumped when it is 1/3 full of sludge or pumped 3 to 5 years depending on how many residents the tank is serving. It was assumed the tank would be pumped every 3 years and 1/3 of the tank was sludge (density = 1400 kg/m^3) and 2/3 full of water (density = 1000 kg/m^3). Therefore, the density of slurry mixture was assumed to be 1136.7 kg/m^3. It was found over 25 years 42.6 tonnes of sludge would be transported 30 km to a local wastewater treatment plant. Detailed LCI tables, can be found in Appendix B.

3.2.2 Sensitivity Analysis

Sensitivity analyses investigate system boundaries, allocation approaches, parameter values, and characterization methods (Guo & Murphy, 2012). Five parameters were considered to better understand the sensitivity of the model:

(1) Adding a pumping chamber and pump to the sand filter bed model for better effluent dispersal throughout the leaching bed, which can aid in better treatment (OOWA Best Practices Series, 2016).

(2) Doubling the lifespan from certain components 25 to 50 years, a concrete septic tank can last up to 60 years, and due to the costs of septic systems, most homeowners do not want to pay for a new septic system every 25 years. Therefore, the concrete septic tank and concrete pumping chambers were assumed to have a life span of 50 years, while the conventional leaching bed and the sand filter bed would have a lifespan of 25 years. Additionally, the Level IV treatment unit pre-treats the effluent before it is dispersed through the leaching bed allowing for less load to be put on the leaching bed. For the three systems that require the Level IV treatment unit, is was assumed only the treatment unit was replaced at year 25 and the other components, the septic tank, pumping chambers, and the leaching bed would last for 50 years.

(3) Changing the transportation distance by ± 25% and ±50%, Ontario is a large landmass therefore, a transportation sensitivity analysis is necessary.

(4) Changing the weight of the sand and stone by ± 10% and ± 20% due to the compaction when installing the leaching beds and various densities of sand and stone due to factors such as particle distribution.

(5) T-time of 10 min/cm, a more realistic assumption of the percolation time of soils in southwestern Ontario (Chan, personal communication, December 2017). The T-time only effects the design of the leaching beds; therefore a 4,500 L septic tank would still be required. However, the largest design change was the conventional leaching bed did not require a pumping chamber and a requires a much smaller bed, approximately 76% less than for a soil with a T-time of 40 min/cm. The sensitivity parameters tables can be seen in Appendix B.

3.3 Life Cycle Impact Assessment

The five septic systems were compared and assessed between five different LCIAs, with the primary and more in-depth focus in the North American LCIA, TRACI (Tool for the Reduction and Assessment of Chemical and other Environmental Impacts). A summary of the five LCIAs and their respective impact categories and units can be seen in Table 3-1 at the end of this section. Comparing the five septic systems between five LCIAs allows for evaluating model robustness. Between the five LCIAs, there are similar impact categories, however, the unit of measurement may vary. For example, TRACI presents freshwater ecotoxicity in CTUe (Comparative Toxicity Unit ecotoxicity), while ReCiPe uses the unit kg 1,4 DB equivalent (1,4 dichlorobenzene).

3.3.1 TRACI

Tool for the Reduction and Assessment of Chemical and other Environmental Impacts (TRACI) was developed by the USEPA and is a midpoint focused LCIA. Presently, TRACI is one the two North American impact assessments found in SimaPro. This impact assessment allows for the quantification expansion of stressors that have the potential effects on 10 various environmental, and human health factors:

Global warming	Human health cancer (carcinogenics)
Ozone Depletion	Human health noncancer (non-carcinogenics)
Acidification	Particulate effects
Eutrophication	Ecotoxicity
Photochemical smog formation	Fossil fuel depletion

Currently, TRACI does not include land and water use. The traditional pollution categories, ozone depletion, global warming, smog formation, acidification, eutrophication, and human health criteria correlates with various EPA programs and regulations (Bare et al., 2012). Human health was further subdivided into cancer (carcinogen), noncancer (noncarcinogen), and respiratory effects (particulate matter) to better communicate the intent of EPA regulations and develop a methodology consistent with US regulations, handbooks, and guidelines (Bare et al., 2012). Smog formation has been denoted as an important environmental issue within the US as it has separate regulations which addresses smog prevention, smog formation effects is kept independent and is not combined with other human health impacts, as the impacts of smog would be lost in combination of the other human health impacts. However, the other four European based impact assessments used in this thesis do not consider smog. TRACI's methodology focuses on the amount of chemical emissions and resources used and quantify the influence of the stressor.

3.3.2 CML-IA

For the baseline method, CML-IA (Center of Environmental Science of Leiden University) focuses on ecotoxicity (freshwater, terrestrial, and marine) and human toxicity, and generalizes other impact categories such as acidification, and eutrophication (SimaPro Database Manual, 2016). Overall there are 11 impacts:

Global warming potential	Freshwater aquatic ecotoxicity
Ozone depletion	Marine aquatic ecotoxicity
Human toxicity	Terrestrial ecotoxicity
Photochemical oxidation	Acidification
Abiotic depletion	Eutrophication
Abiotic depletion due to fossil fuels	

The baseline method includes the most commonly used LCIA categories, and is the most widely used, compared to its non-baseline approach, in which there are additional impact categories (SimaPro Database Manual, 2016).

3.3.3 ILCD 2011 Midpoint+

The International Reference Life Cycle Data System (ILCD) 2011 Midpoint+ was intended to identify and promote current best practices. Therefore, the midpoint categories were based off other impact assessment methods including: IPCC, USEtox model, CML 2002, and other peer-reviewed impact methods. The 16 impact categories include:

Climate change	Acidification
Ozone Depletion	Terrestrial eutrophication
Cancer effects (carcinogenics)	Aquatic eutrophication
Noncancer effects (noncarcinogenics)	Freshwater ecotoxicity
Particulate matter	Terrestrial ecotoxicity
Photochemical ozone formation	Land use

Ionising radiation human health	Water depletion
Ionising radiation ecosystems	Resource depletion (mineral, fossil, and renewable)

3.3.4 IMPACT 2002+

Impact Assessment of Chemical Toxics 2002+ (IMPACT) was originally developed at the Swiss Federal Institute of Technology (SimaPro Database Manual, 2016). At the midpoint level there are 15 impact categories: global warming, ozone layer depletion, respiratory effects, photochemical oxidation, ionizing radiation, mineral extraction, non-renewable energy (fossil fuel depletion), carcinogens, non-carcinogens, aquatic ecotoxicity, terrestrial ecotoxicity, aquatic acidification, aquatic eutrophication, terrestrial acidification, and land occupation. The characterization factors for human toxicity (carcinogens and non-carcinogens), and aquatic and terrestrial ecotoxicity are taken from the IMPACT 2002+ methodology, whereas the other 10 characterization factors are adapted from other LCIA methods, such as Eco-indicator 99, CML 2001, IPCC and the Cumulative Energy Demand (SimaPro Database Manual, 2016).

3.3.5 ReCiPe

Similarly, to the other LCIAs mentioned above, the precursor methods to ReCiPe are Eco-indicator 99 and CML-IA for their problem, and damage-oriented approach respectively. However, the focus of this study is the problem-oriented approach, the midpoint impact categories.

Of the 5 LCIAs in this study, ReCiPe contains the most (18) midpoint categories:

Climate change	Terrestrial acidification	Fossil fuel depletion
Ozone Depletion	Terrestrial ecotoxicity	Mineral depletion
Human toxicity	Marine ecotoxicity	Freshwater depletion

Ionising radiation	Freshwater ecotoxicity	Agricultural land occupation
Particulate matter	Marine eutrophication	Urban land occupation
Photochemical oxidant	Freshwater eutrophication	Natural land transformation

Comparatively to the other four LCIAs, ReCiPe is the only impact assessment that includes three perspectives, of which the second perception, Hierarchist was chosen for this study:

(1) Individualist (I): short-term interest, impact types that are undisputed, and is optimistic of technological advancement (e.g., 20-year GWP)
(2) Hierarchist (H): based on the most common policy principles with regards temporal and other issues (100-year GWP); and
(3) Egalitarian (E): the most cautionary perspective, considering the longest time-frame (e.g., 500-year GWP), and impact types that are not completely established (SimaPro Database Manual, 2016).

Of these three perspectives, the hierarchist was chosen for this thesis as it is considered to be the default model as it relies on medium timeframes (Matthews et al., 2015).

Table 3-1: Midpoint Impact Categories

Impact category	TRACI	CML-IA	ILCD 2011	IMPACT 2002	ReCiPe
Climate change/Global Warming	kg CO2 eq				
Ozone depletion	kg CFC-11 eq				
Photochemical oxidant formation	-	kg C2H4 eq	kg NMVOC eq	-	kg NMVOC eq
Smog	kg O3 eq	-	-	-	-
Ionizing radiation	-	-	-	Bq C-14 eq	kBq U235 eq
Ionizing radiation human health	-	-	kBq U235 eq	-	-
Ionizing radiation ecosystems	-	-	CTUe	-	-
Particulate matter/ Respiratory effects	kg PM2.5 eq	-	kg PM2.5 eq	-	kg PM10 eq
Respiratory organics	-	-	-	kg C2H4 eq	-
Respiratory inorganics	-	-	-	kg PM2.5 eq	-
Acidification	kg SO2 eq	kg SO2 eq	molc H+ eq	-	-
Aquatic acidification	-	-	-	kg SO2 eq	-
Terrestrial acidification	-	-	-	kg SO2 eq	kg SO2 eq
Eutrophication	kg N eq	kg PO4 eq		-	-
Freshwater eutrophication	-	-	kg P eq	-	kg P eq
Aquatic eutrophication	-	-	-	kg PO4 P-lim	-
Marine eutrophication	-	-	kg N eq	-	kg N eq
Terrestrial eutrophication	-	-	molc N eq	-	-
Ecotoxicity	CTUe	-	-	-	-
Freshwater ecotoxicity	-	kg 1,4-DB eq	CTUe	-	kg 1,4-DB eq
Aquatic ecotoxicity		-	-	kg TEG water	-
Marine ecotoxicity	-	kg 1,4-DB eq	-		kg 1,4-DB eq
Terrestrial ecotoxicity	-	kg 1,4-DB eq	-	kg TEG soil	kg 1,4-DB eq
Human toxicity	-	kg 1,4-DB eq	-	-	kg 1,4-DB eq
Carcinogenic Effects	CTUh	-	CTUh	kg C2H3Cl eq	-
Non-Carcinogenic Effects	CTUh	-	CTUh	kg C2H3Cl eq	-
Land Occupation	-	-	kg C deficit	m2org.arable	-
Agricultural land occupation	-	-	-	-	m2a
Urban land occupation	-	-	-	-	m2a
Natural land transformation	-	-	-	-	m2
Water depletion	-	-	m3 water eq	-	m3
Metal depletion	-	-	-	-	kg Fe eq
Fossil depletion/use	MJ surplus	MJ	-	MJ primary	kg oil eq
Mineral depletion	-	-	-	MJ surplus	-
Abiotic depletion	-	kg Sb eq	-	-	-
Mineral, fossil fuel, and renewable resource depletion	-	-	kg Sb eq	-	-

3.4 Midpoint Categories

3.4.1 Climate Change and Global Warming

The World Health Organization and Intergovernmental Panel on Climate Change (IPCC), define climate change as: any change in climate over time, whether due to natural variability or as a result of human activity (WHO, 2011). Since the industrial revolution the sources of GHG have increased, mostly due to the combustion of fossil fuels (Bare et al., 2012), while sinks have decreased (deforestation). With the concern of climate change being a forefront environmental concern, all five LCIAs used this study calculates the potency of various GHGs relative to CO_2. As recommended by the United Nations Framework Convention on Climate Change (UNFCCC), TRACI uses GWPs/climate change with a 100-time horizon.

3.4.2 Ozone Depletion

The stratospheric ozone layer provides protection from radiation which can lead to increased effects on plants, marine life, man-made structures and human health (i.e., increase in cataracts and cancers). Chemicals such as chlorofluorocarbons (CFCs) and halons have been linked to decreasing the stratospheric ozone level (Bare et al., 2012). The implementation of stricter laws has led to the reduction of emitted pollutants and the USEPA expects the ozone layer to recover in approximately 50 years (Bare et al., 2012). Similarly, to climate change, the five LCIAs calculate ozone depletion by calculation emitted gases relative to trichlorofluoromethane (CFC-11), which was widely used in refrigerants.

3.4.3 Acidification

The increased concentration of hydrogen ions (H+) due to the addition of acids (e.g., nitric and sulfuric acid) into the environment is known as acidification. In addition to the direct release of acids, other substances such as ammonia can increase acidity due to chemical reactions, biological activity, or by natural circumstances such as growth of local plant species which will change the pH of the soil. Acidic substances are often emitted into the air and may travel for long distances before wet (rain, fog, snow) or dry (dust, smoke, particulate matter) deposit the acidic chemicals on soil or water. The largest contributors are nitrogen oxides (NOx) and sulfur dioxide (SO2) due to the combustion of fossil fuels. Acidic chemicals can cause damage to man-made structures and all levels of ecosystems.

3.4.4 Ecotoxicity

Ecotoxicity accounts for both the environmental persistence, bioaccumulation, and the toxic effect of a chemical, or in TRACI's LCIA over 3000 chemicals (SimaPro Database Manual, 2016; Bare, Young, & Hopton, 2012). TRACI, ILCD, and IMPACT use similar calculation methods from the internationally collaborated and recognized model USEtox. The USEtox model is based on the most influential parameters and largest sources of differences between previously world leading human and ecotoxicity models. Overall the model accounts for 45 organic substances, due to their diversity in environmental persistence and partitioning, exposure pathway, and air transport (Bare, Young, & Hopton, 2012). Aquatic ecotoxicity refers to the emissions released to air, soil, and water that effect fresh water bodies. Similarly, terrestrial ecotoxicity refers to the emissions released to the three medias that impacts terrestrial organisms and plants.

3.4.5 Eutrophication

As previously defined in Chapter 2.3, Eutrophication is the enrichment of an aquatic ecosystem with nutrients (nitrogen and phosphorus) which promotes accelerated biological growth. Excessive release of nutrients affects both fresh and salt water ecosystems, however, phosphorus typically has a more negative effect on freshwater bodies, and nitrogen is more damaging to coastal bodies of water (Ecological Society of America, 1998).

3.4.6 Resource Depletion

Resource depletion, specifically fossil fuel depletion, is an important parameter for the development of LCA methodologies (Bare, Young, & Hopton, 2012). However, due to the multiple assumptions, it is one of the most challenging impact categories to quantify (Bare, Young, & Hopton, 2012). Impact categories that have legislation or control guides such as climate change are easier to quantify and predict. Therefore, the creators of USEPA has deemed resource depletion the most controversial (Bare et al., 2012).

3.4.7 Carcinogenics and Non-Carcinogenics

Carcinogenic and non-carcinogenic effects refer to the impact on human toxicity. The chronic toxicological effects on human health is determined by the impacts of a chemical based on the amount (kg) of chemical released into the environment. Similarly, to ecotoxicity, human toxicity due to carcinogenic and non-carcinogenic are based on the USEtox model in which it calculates carcinogenic and non-carcinogenic impacts for chemical emission to urban air, rural air, freshwater, saltwater, and soil (SimaPro Database Manual, 2016).

3.4.8 Particulate Matter and Respiratory Effects

Particulate matter (PM) is a collection of microscopic particles in the ambient air which can heave negative health effects (Bare et al., 2012). TRACI categorizes PM and precursors to PM as a human health impact category. The primary source of PM is particulates emitted into the atmosphere, the secondary PM may be a product of chemical reactions in the air such as sulfur dioxide and nitrogen oxides (Bare, Young, & Hopton, 2012). The largest PM contributors include fossil fuel combustions, wood combustion, and dust particles from roads and fields (Bare et al., 2012). Two major groups of PM is inhalable coarse particles (PM10) which range from 2.5 to 10 micrometres in diameter and fine particles (PM2.5), which have a diameter equal to or less than 2.5 micrometers. The latter poses a serious threat to sensitive groups such as the elderly, children, and people with respiratory issues as the microscopic particles can penetrate deep into the lungs and may even get into the bloodstream. TRACI and IMPACT 2002+ characterizes emitted substances as PM2.5 equivalent, and only considers the effect of PM as a factor of human health, i.e., what percent of emitted PM will be inhaled by a human being. This is a function of the type of substance (primary or secondary source), quantity, background concentrations, but also the geographical location in which the substance is releases.

3.4.9 Photochemical Smog Formation

Of the five LCIAs used in this study, only TRACI considers the formation of photochemical smog. TRACI characterizes smog as Ozone (O_3) which created in a series of reactions between NOx and volatile organic compounds (VOCs) in sunlight. Aside from increasing respiratory issues (bronchitis, asthma and emphysema) permanent lung damage can occur from prolonged exposure to ozone. Smog can also damage crops and ecosystems. Primary ozone precursors include motor vehicles, electric power utilities and industrial facilities (Bare et al., 2012).

3.4.10 Additional Impact Categories

Additional impact categories include land occupation and water use/depletion. TRACI does not presently consider water use and land occupation, however the European based LCIAs, ILCD and ReCiPe consider both impact categories. Land occupation is typically in square meters, while water use is in cubic meters. Mineral extraction as included in IMPACT refers to the damage for every mega joule (MJ) of energy used to extract 1 kg of mineral. The listed additional categories will not be a primary focus of this study, due to the focus of TRACI's impact categories, as it is a North America LCIA, and incorporates data from both the US and Canada.

3.5 Procedure

The use of SimaPro without critical understanding of how the features of the software can undermine or strengthen findings, and many unsubstantiated modelling assumptions. There are a large number of datasets that need to be carefully examined as they all contain different information. Figure 3-2 illustrates the ecoinvent dataset choices for HDPE.

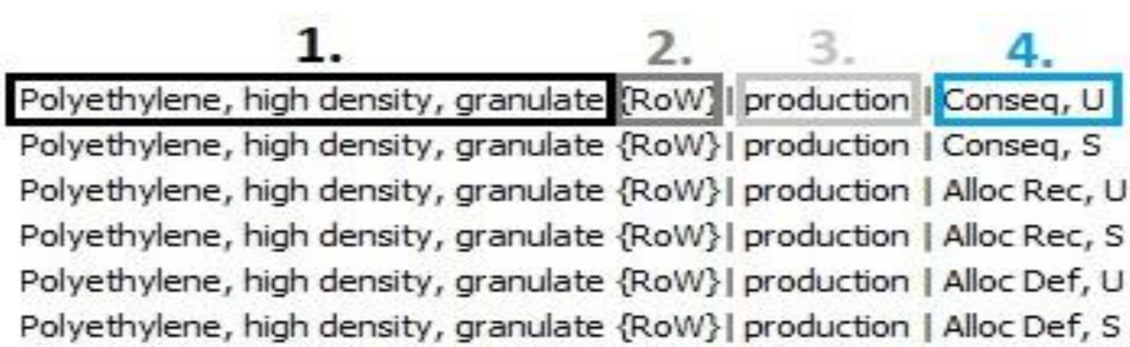

Figure 3-2: SimaPro Dataset

Figure 3-2 illustrates the ecoinvent dataset choices for HDPE, and the numbering refers to four various dataset information:

1. The product;
2. Location of where the data was collected from/for, RoW is the rest of the world;
3. The process, the production;
4. The system model.

There are three different model systems, with a unit (U) or system (S) process. The consequential system model (Conseq) has two methodological decisions: (1) based on market activity data and on information about the technology level, it uses a constrained supply of products, (2) It uses substitution/system expansion to convert multi-product datasets into single-product databases (Goedkoop et al. 2016). This database considers the constrained market, where a change in demand results in a change in consumption, not a corresponding change in supply. For example, the by-product market is constrained by the reference (main) product market, if the demand for the main product decreases, so will the production of the by-products, even if the demand for the by-product does not decrease. This model system reflects the consequences of small scale and long-term decisions (Goedkoop et al. 2016).

The allocation recycled content system model (Alloc Rec), uses two methodological decisions, different from the consequential system model, (1) it uses the average unconstrained supply of products (as described in their market activity datasets), (2) uses partitioning/allocation to convert multi-product datasets to single-product datasets (Goedkoop et al. 2016). The allocation default system model (Alloc, Def) is similar to the recycled model however the former does not consider the environmental benefit of recycling a material (Goedkoop et al. 2016).

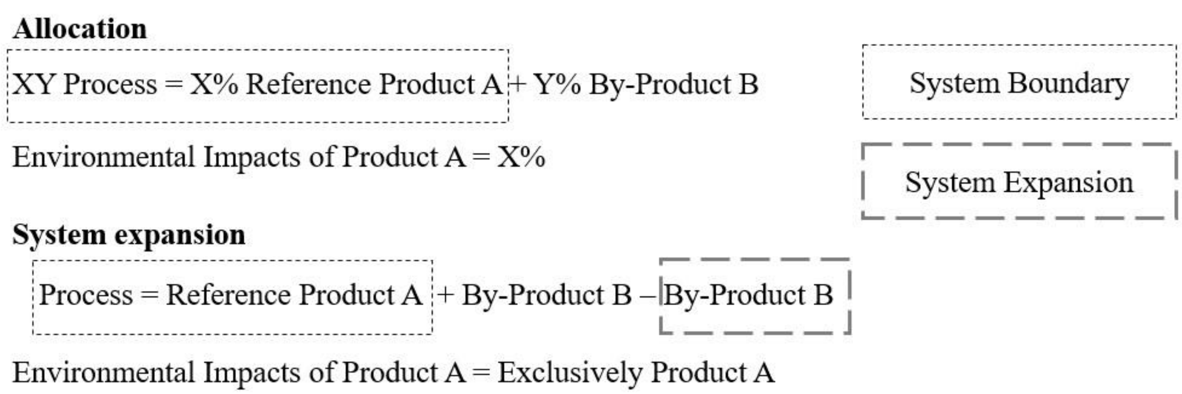

Figure 3-3: Allocation vs. System Expansion

The primary database used for this thesis is the ecoinvent database which as seen above has two processes, unit (U) and system (S). The ecoinvent v3 database contains over 10,000 processes which utilizes various Swiss institutions to create and update integrated LCI databases. Both processes offer the same results, with differences in the sixth decimal place. The unit process contains emissions and resource inputs for the reference process and its subsequent upstream processes, all of which can be investigated in the SimaPro's Network tree. For example, in Figure 3-4, the system process includes the inputs and outputs for 1 kg of HDPE, but these upstream processes can't be selected, just the final reference material. Therefore, the system process is considered a black box process which allowed for a simple process tree, fast calculation, but contains no uncertainty information. The HDPE unit process includes a total of 8,922 processes, of which only 13 are shown in Figure 3-4. Unit processes allow for a large transparent process tree that allows for the tracing of all individual unit processes. In addition, unit processes contain uncertainty information which allows for the user to conduct a statistical analysis. However, unit process can be a relatively slow calculation. In general, system processes are used in LCA screenings and unit processes in full LCAs (Goedkoop et al. 2016).

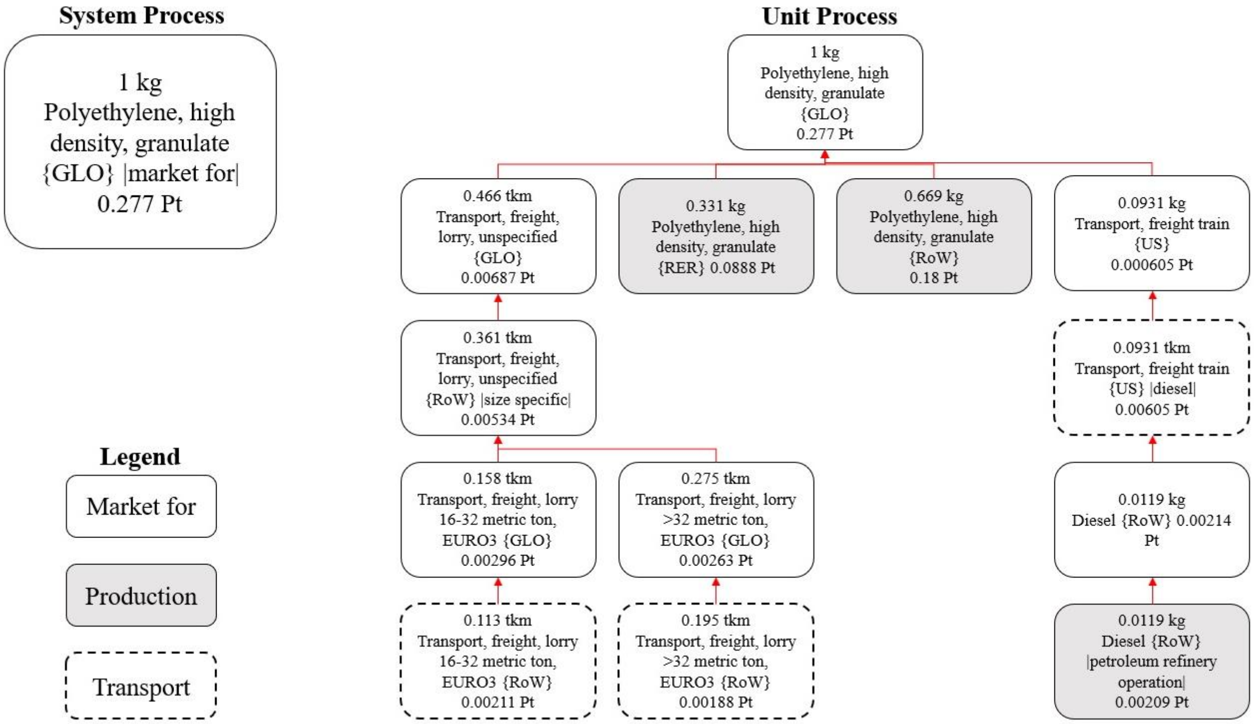

Figure 3-4: Unit Process Network Analysis

In addition to understanding the database names and what system they use; another helpful tool is the comment box as denoted by the red box in Figure 3-5.

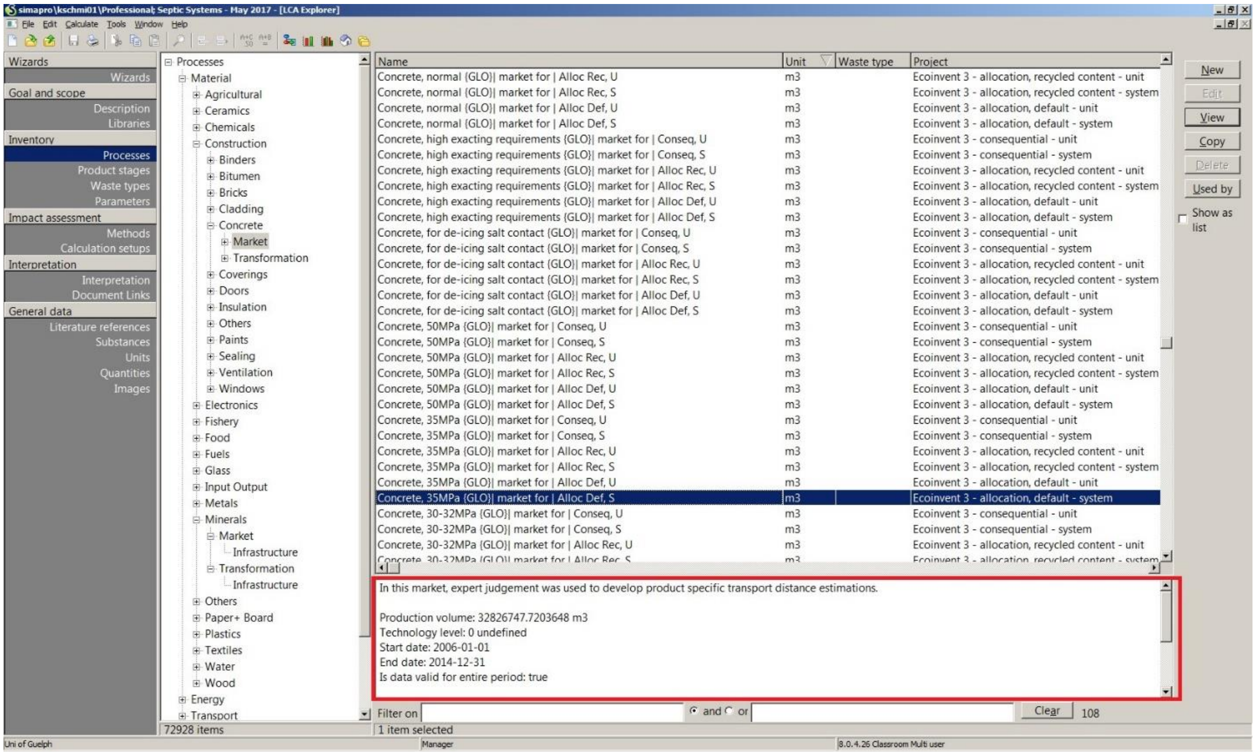

Figure 3-5: Additional Dataset Information in SimaPro

Using the tools listed above, alongside with engineering judgement, the datasets were thoroughly investigated to find the most appropriate and applicable datasets for this LCA study. Lastly, PRé's "Introduction to LCA with SimaPro" and "SimaPro Tutorial" were used to become familiar with the LCA software. The six lessons/tutorials are a great place to start for anyone new to LCA. However, Appendix D includes a brief procedure of how this LCA study was modelled in SimaPro.

4 RESULTS AND DISCUSSION

4.1 TRACI

4.1.1 Primary Model

The LCI data was used to form the various models, in which the models are ran though the selected LCIA. SimaPro presents the LCIA results as characterization factors, due to the 10 various impact categories and the magnitude of the values, in which the values are divided by the largest number and represented as a percent. Table 4-1 presents the values of impact categories and, Table 4-2 presents the characterization factors of the five septic systems for an easier comparison.

Table 4-1: TRACI Midpoint Results of the 5 Septic Systems

Impact category	Unit	CLB	SFB	SBT	Type A	Type B
Ozone depletion	kg CFC-11 eq	5.37E-04	3.96E-04	2.58E-04	3.30E-04	3.28E-04
Global warming	kg CO2 eq	10,914	3,447	4,371	4,857	5,280
Smog	kg O3 eq	616.4	387.7	227.4	313.8	302.9
Acidification	kg SO2 eq	42.3	17.1	14.4	17.7	18.0
Eutrophication	kg N eq	8.49	5.79	6.41	6.86	7.28
Carcinogenics	CTUh	1.22E-03	2.47E-04	5.94E-04	6.29E-04	6.34E-04
Non carcinogenics	CTUh	1.48E-03	7.08E-04	9.60E-04	1.02E-03	1.21E-03
Respiratory effects	kg PM2.5 eq	3.89	2.35	2.37	2.78	2.82
Ecotoxicity	CTUe	106,504	61,492	86,138	86,688	87,704
Fossil fuel depletion	MJ surplus	15,057	4,725	5,926	6,700	6,721

Table 4-2: TRACI Characterization Factors of the 5 Septic Systems

Impact category	Unit	CLB	SFB	SBT	Type A	Type B
Ozone depletion	kg CFC-11 eq	100	73.8	48.1	61.5	61.2
Global warming	kg CO2 eq	100	31.6	40.1	44.5	48.4
Smog	kg O3 eq	100	62.9	36.9	50.9	49.1
Acidification	kg SO2 eq	100	40.5	34.0	41.9	42.5
Eutrophication	kg N eq	100	68.2	75.5	80.7	85.7
Carcinogenics	CTUh	100	20.2	48.6	51.4	51.9
Non carcinogenics	CTUh	100	47.7	64.7	68.4	81.3
Respiratory effects	kg PM2.5 eq	100	60.4	60.9	71.4	72.6
Ecotoxicity	CTUe	100	57.7	80.9	81.4	82.3
Fossil fuel depletion	MJ surplus	100	31.4	39.4	44.5	44.6

It can be seen in Table 4-2 above; the conventional leaching bed has the largest environmental impacts in all 10 midpoint categories, making it the worst system to install in a soil with a percolation time of 40 min/cm from an environmental viewpoint. However, the sand filter bed has the lowest values in 70% (except in ozone depletion, smog, and acidification) of the categories, but it does not mean it is the most environmentally friendly system, as ISO 14040 encourages LCA practitioners to present the results, and not apply a biased weighting. The conventional leaching bed and sand filter bed are the two most common beds installed in Ontario, with the other three beds are seldomly installed. To better understand the environmental hotspots, the life cycle stages (i.e., raw materials extraction/manufacturing, transportation, installation, use, and waste disposal) of each septic system is presented in Table 4-3 through 4-7.

Table 4-3: Conventional Leaching Bed (CLB) Stage Results

Impact category	Unit	Manufacture	Install	Use	Maintenance	Transport	Waste Disposal	Stone Reuse	Total
Ozone depletion	kg CFC-11 eq	34.4	13.9	0.2	0.3	73.0	23.3	-45.1	100%
Global warming	kg CO2 eq	62.2	2.9	0.2	0.2	14.9	30.6	-11.1	100%
Smog	kg O3 eq	60.3	14.4	0.2	0.3	41.1	8.0	-24.4	100%
Acidification	kg SO2 eq	69.1	7.1	0.4	0.4	23.2	16.9	-17.1	100%
Eutrophication	kg N eq	74.7	5.1	1.3	13.8	26.3	10.5	-31.7	100%
Carcinogenics	CTUh	96.8	1.2	0.1	0.5	4.2	1.7	-4.5	100%
Non carcinogenics	CTUh	73.0	1.6	0.5	4.4	32.3	14.7	-26.6	100%
Respiratory effects	kg PM2.5 eq	67.2	10.6	0.3	0.6	32.9	13.7	-25.3	100%
Ecotoxicity	CTUe	13.5	0.6	0.6	0.6	15.4	80.4	-11.1	100%
Fossil fuel depletion	MJ surplus	79.8	4.4	0.1	0.1	23.3	6.8	-14.6	100%

The electricity used over the 25-year life span and the treatment of septic sludge at a local wastewater treatment plant contributes to less than 1% in all but two categories for maintenance (eutrophication (10.5%) and human health non-carcinogenic (3.5%)). Manufacturing causes 92.6% of the damage to human health due to carcinogenic emissions; more specifically due the manufacturing of PVC pipe (74%). Manufacturing contributes to more than 50% in 7 impact categories. Waste disposal contributes to 72.4% in ecotoxicity, primarily due to landfilling; landfilling 1 kg of concrete and/or steel has 225 times more impacts on ecotoxicity than incinerating 1 kg of mixed plastics. Moreover, about one fourth of the global warming impacts is due to waste disposal - specifically incineration, even though one of the primary GHG released from landfills is methane which is 25 more harmful than carbon dioxide on a by-weight basis.

Incinerating 1 kg of mixed plastics produced approximately 204 times more CO_2eq emissions than landfilling 1 kg of concrete and/or steel.

Installation has a relatively low impact, with 7/10 impact categories contributing to less than 10% of the overall impact. Similar to transportation, the three highest values of excavating the soil and installing the septic system is ozone depletion (13.9%), smog (14.4%) and respiratory effects (10.6%), primarily due to the production of petroleum and gas, and the production of stainless and reinforced steel. Transportation contributes to approximately half of the ozone depleting emissions and one third to the ozone formation (smog). Transportation also contributes to approximately 20% to 25% of the environmental impacts of acidification, eutrophication, non-carcinogenic, respiratory effects and fossil fuel depletion. Acidification due to transportation is primarily due to the electricity used in the production of petroleum and diesel, and the burning of diesel in machines for the construction of new roads. Eutrophication is influenced by the production of petroleum, and the following three waste treatments: sulfidic tailing, spoil from hard coal mining due to the production of HDPE, and spoil lignite from lignite mining. Non-carcinogenic and respiratory effects due to transportation is primarily due to the waste treatment from brake and tire wear emissions, zinc residue, and sulfidic tailings. Road wear emissions waste treatment and the construction of roads also contribute to respiratory effects. Fossil fuel depletion is solely due to the production of petroleum and gas.

In SimaPro reusing materials or a product gives the product an environmental score of zero, therefore to better understand the effects of quarrying, transporting and installing the stone, the reuse was included. The largest environmental gain from reusing the stone is 45.1% less ozone depletion contribution. This is primarily due to the transportation of the stone. The conventional leaching bed is a larger system and requires more materials than the sand filter bed.

Table 4-4: Sand Filter Bed (SFB) Stage Results

Impact category	Unit	Manufacture	Install	Maintenance	Transport	Waste Disposal	Sand & Stone Reuse	Total
Ozone depletion	kg CFC-11 eq	42.7	24.8	0.5	122.7	7.4	-98.1	100%
Global warming	kg CO2 eq	66.7	12.3	0.6	58.2	18.0	-55.9	100%
Smog	kg O3 eq	46.4	30.1	0.5	82.4	4.4	-63.9	100%
Acidification	kg SO2 eq	66.2	23.1	1.1	71.8	6.5	-68.6	100%
Eutrophication	kg N eq	88.4	9.9	20.2	47.2	7.8	-73.5	100%
Carcinogenics	CTUh	95.4	7.8	2.3	25.1	4.6	-35.2	100%
Non carcinogenics	CTUh	75.2	4.4	9.3	83.9	14.2	-87.1	100%
Respiratory effects	kg PM2.5 eq	65.8	23.3	1.0	68.0	10.0	-68.0	100%
Ecotoxicity	CTUe	17.7	1.3	1.1	31.6	78.3	-30.0	100%
Fossil fuel depletion	MJ surplus	58.1	18.6	0.4	92.3	5.0	-74.4	100%

The sand filter bed does not require a pump chamber and requires less PVC pipe than the conventional leaching bed. Majority of the environmental impacts are due to transportation and manufacturing. However, over half of the environmental impacts will be 'mitigated' in 80% of the categories if the sand and stone is reused. Ecotoxicity and carcinogenic effects are the two impact categories where approximately two thirds of the impacts are not related to the quarry and transportation of sand and stone. Carcinogenic effects on human health are primarily due to the manufacturing of the PVC pipe, and 78.3% of ecotoxicity effects are due to the landfilling of reinforced concrete. Installation contributes to less than 20% of environmental impacts in half of the categories. However, it does contribute to approximately one fourth in ozone depletion, smog, acidification, and respiratory effects due to the production of petroleum, gas, stainless steel and reinforcing steel. Similar to manufacturing, transportation contributes to over 50% in seven out of the 10 categories due to various waste treatments of sulfidic tailings, zinc residue, spoil coal and spoil lignite mining, and the production of petroleum. Maintenance contributes to less than 10% in nine out of 10 categories, and as found in the literature review wastewater treatment is a major contributor to eutrophication. The sand filter bed uses the least amount of concrete and plastic compared to the other four systems. However, the shallow buried trench system does not require imported sand or stone due to the hourly dosing.

Table 4-5: Shallow Buried Trench (SBT) Stage Results

Impact category	Unit	Manufacture	Install	Use	Maintenance	Transport	Waste Disposal	Total
Ozone depletion	kg CFC-11 eq	36.7	2.3	0.5	0.7	46.2	13.6	100%
Global warming	kg CO2 eq	60.5	0.6	0.8	0.5	11.5	26.1	100%
Smog	kg O3 eq	54.7	3.1	0.9	0.9	30.7	9.6	100%
Acidification	kg SO2 eq	66.6	1.7	2.0	1.3	19.7	8.8	100%
Eutrophication	kg N eq	57.6	0.5	2.8	18.3	11.6	9.2	100%
Carcinogenics	CTUh	92.9	0.2	0.4	1.0	3.0	2.5	100%
Non carcinogenics	CTUh	61.6	0.2	1.3	6.9	15.4	14.6	100%
Respiratory effects	kg PM2.5 eq	68.2	1.4	0.8	0.9	15.7	12.8	100%
Ecotoxicity	CTUe	16.8	0.1	1.2	0.8	7.5	73.6	100%
Fossil fuel depletion	MJ surplus	75.5	0.9	0.3	0.4	18.1	4.8	100%

Similar to the previous two systems, manufacturing and transportation make up most of the environmental impacts. As established the 93.9% carcinogenic effects are due to the manufacturing of PVC pipe. Global warming (26.1%) and Ecotoxicity (73.6%) are the only two impact categories that contribute over 15% for waste disposal due to incineration of mixed plastics and landfilling reinforced concrete. Similar trends can be found such as transportation is the largest percent contribution to ozone depletion.

Table 4-6: Type A Dispersal Bed Stage Results

Impact category	Unit	Manufacture	Install	Use	Maintenance	Transport	Waste Disposal	Sand & Stone Reuse	Total
Ozone depletion	kg CFC-11 eq	49.7	11.9	0.4	0.5	112.2	11.3	-86.0	100%
Global warming	kg CO2 eq	66.8	3.5	0.7	0.4	31.6	25.6	-28.6	100%
Smog	kg O3 eq	62.7	14.9	0.6	0.6	76.7	7.2	-62.8	100%
Acidification	kg SO2 eq	78.1	8.9	1.6	1.0	52.6	8.0	-50.1	100%
Eutrophication	kg N eq	80.9	3.3	2.6	17.1	30.7	8.6	-43.3	100%
Carcinogenics	CTUh	97.4	1.2	0.4	0.9	7.7	2.4	-10.0	100%
Non carcinogenics	CTUh	73.3	1.2	1.2	6.5	44.7	13.9	-40.8	100%
Respiratory effects	kg PM2.5 eq	79.5	7.9	0.7	0.8	43.6	11.1	-43.6	100%
Ecotoxicity	CTUe	21.1	0.4	1.2	0.7	17.7	73.1	-14.3	100%
Fossil fuel depletion	MJ surplus	78.3	5.2	0.3	0.3	49.6	4.6	-38.3	100%

Table 4-7: Type B Dispersal Bed Stage Results

Impact category	Unit	Manufacture	Install	Use	Maintenance	Transport	Waste Disposal	Stone Reuse	Total
Ozone depletion	kg CFC-11 eq	57.3	8.6	0.4	0.5	119.1	11.6	-97.6	100%
Global warming	kg CO2 eq	65.1	2.3	0.7	0.4	30.6	30.5	-29.6	100%
Smog	kg O3 eq	71.5	11.1	0.6	0.7	84.1	7.6	-75.6	100%
Acidification	kg SO2 eq	84.6	6.3	1.6	1.0	54.6	8.2	-56.4	100%
Eutrophication	kg N eq	85.7	2.3	2.5	16.1	30.4	8.2	-45.1	100%
Carcinogenics	CTUh	98.6	0.9	0.4	0.9	8.0	2.4	-11.1	100%
Non carcinogenics	CTUh	78.9	0.7	1.0	5.5	39.6	11.7	-37.4	100%
Respiratory effects	kg PM2.5 eq	85.6	5.6	0.7	0.8	45.3	11.0	-48.9	100%
Ecotoxicity	CTUe	22.5	0.3	1.2	0.7	18.3	72.3	-15.3	100%
Fossil fuel depletion	MJ surplus	81.8	3.8	0.3	0.3	52.2	4.7	-43.1	100%

Type A and Type B present similar trends to the other beds, specifically with the manufacturing of PVC contributing 95%$^+$ to carcinogenic effects on human health, transportation contributes the most to ozone depletion, and 40% to almost 98% of the environmental impacts can be mitigated for 7 out of 10 impact categories. Sand and/or stone reuse marginally effects the mitigation of carcinogenic and ecotoxicity due to the manufacturing of PVC and the landfilling of the reinforced concrete. Similarly, the installation, use and maintenance of the septic system has less than a combined 10% impact in 8 out of the 10 categories for both Type A and B. Eutrophication contributes to approximately 16.5% due to the treatment of the septic sludge that is pumped out and treated at a local wastewater treatment plant.

4.1.2 Sensitivity Analysis

4.1.2.1 50 Years

Due to various factors such as money, and property turn overs, a septic system may not be replaced every 25 years. Moreover, with newer technologies such as Level IV treatment units, homeowners may see an increase in their septic systems longevity. Therefore, a septic system lifespan analysis was completed. The conventional leaching bed and sand filter bed leaching beds were assumed to be installed at year 0 and replaced at year 25, while the septic tank and pumping chamber were assumed to be installed at year 0 and last for 50 years. The Level IV treatment unit decreases the loading on the shallow buried trench, Type A, and Type B leaching beds; therefore, it was assumed the leaching bed, septic tank, and pumping chambers had a lifespan of 50 years, while the Level IV treatment unit was installed and replaced at year 0 and year 25 respectively. The results can be seen in Table 4-8 and Table 4-9.

Table 4-8: 50 Year Lifespan Results

Impact category	Unit	CLB	SFB	SBT	Type A	Type B
Ozone depletion	kg CFC-11 eq	8.48E-04	6.50E-04	2.69E-04	3.41E-04	5.87E-04
Global warming	kg CO2 eq	19,584	5,465	5,902	6,388	10,638
Smog	kg O3 eq	1062.7	672.2	258.5	345.0	543.7
Acidification	kg SO2 eq	76.1	28.9	17.3	20.6	33.4
Eutrophication	kg N eq	13.61	9.25	7.21	7.65	14.21
Carcinogenics	CTUh	2.30E-03	3.75E-04	6.53E-04	6.88E-04	1.23E-03
Non carcinogenics	CTUh	2.45E-03	1.07E-03	1.01E-03	1.07E-03	2.18E-03
Respiratory effects	kg PM2.5 eq	6.37	3.77	2.65	3.06	5.38
Ecotoxicity	CTUe	121,702	66,182	88,350	88,900	175,056
Fossil fuel depletion	MJ surplus	27,740	7,843	8,547	9,320	14,466

Table 4-9: 50 Year Lifespan Characterization

Impact category	Unit	CLB	SFB	SBT	Type A	Type B
Ozone depletion	kg CFC-11 eq	100.0	76.7	31.7	40.2	69.3
Global warming	kg CO2 eq	100.0	27.9	30.1	32.6	54.3
Smog	kg O3 eq	100.0	63.3	24.3	32.5	51.2
Acidification	kg SO2 eq	100.0	37.9	22.7	27.1	43.9
Eutrophication	kg N eq	95.8	65.1	50.7	53.8	100.0
Carcinogenics	CTUh	100.0	16.3	28.4	29.9	53.5
Non carcinogenics	CTUh	100.0	43.5	41.3	43.6	89.1
Respiratory effects	kg PM2.5 eq	100.0	59.2	41.6	48.1	84.5
Ecotoxicity	CTUe	69.5	37.8	50.5	50.8	100.0
Fossil fuel depletion	MJ surplus	100.0	28.3	30.8	33.6	52.1

The conventional leaching bed has the highest values in 8 out of 10 impacts categories, as opposed to 10 out of 10 in the original model. Type B has the largest effect on eutrophication and ecotoxicity, in which 50% of the associated impacts are due to the life cycle of the leaching bed, with the landfilling of reinforced concrete making up approximately 36% of the ecotoxicity impacts but only 4% of the eutrophication impacts. While the life cycle of the septic tank contributes to 25% of Type B's eutrophication makeup, overall the eutrophication emissions are not primarily due to one material or life cycle stage. The five largest eutrophication impacts are due to the production of concrete (7.1%), landfilling of the reinforced concrete (4%), the manufacturing of the reinforcing steel (7.9%), and the manufacturing of the polyurethane foam (7.1%), and the wastewater treatment of septic sludge (8.2%). The sand filter bed only has the lowest impacts in 4 out of 10, instead of 7 out of 10 which is caused by the increase in building paper and PVC pipe. The shallow buried trench has the lowest environmental impact in the other 6 out of 10 categories, as it does not require building paper and extra PVC pipe.

4.1.2.2 Sand Filter Bed Pump Chamber

The sand filter bed does not require a pump chamber, however the Ontario Onsite Wastewater Association (OOWA) recommends a pump chamber to ensure even effluent flow distribution across the leaching bed (Ontario Onsite Wastewater Association, 2016). Therefore, to understand the effects of a pump chamber, the submersible pumps, and the electricity use, a pump chamber was included in the sand filter bed as the second sensitivity analysis which can be seen in Table 4-10 and Table 4-11.

Table 4-10: Sand Filter Bed Pumping Chamber Results

Impact category	Unit	Without Pumping Chamber	With 1,130 L Pumping Chamber	Percent Difference
Ozone depletion	kg CFC-11 eq	3.96E-04	4.45E-04	10.9
Global warming	kg CO2 eq	3,447	4,006	14.0
Smog	kg O3 eq	387.7	428.0	9.4
Acidification	kg SO2 eq	17.1	19.5	12.1
Eutrophication	kg N eq	5.79	6.96	16.8
Carcinogenics	CTUh	2.47E-04	4.41E-04	43.9
Non carcinogenics	CTUh	7.08E-04	9.61E-04	26.3
Respiratory effects	kg PM2.5 eq	2.35	2.95	20.4
Ecotoxicity	CTUe	61,492	81,996	25.0
Fossil fuel depletion	MJ surplus	4,725	5,182	8.8

Table 4-11: Sand Filter Bed Pumping Chamber Characterization

Impact category	Unit	CLB	SFB	SBT	Type A	Type B
Ozone depletion	kg CFC-11 eq	100	82.9	48.1	61.5	61.2
Global warming	kg CO2 eq	100	36.7	40.1	44.5	48.4
Smog	kg O3 eq	100	69.4	36.9	50.9	49.1
Acidification	kg SO2 eq	100	46.0	34.0	41.9	42.5
Eutrophication	kg N eq	100	81.9	75.5	80.7	85.7
Carcinogenics	CTUh	100	36.1	48.6	51.4	51.9
Non carcinogenics	CTUh	100	64.8	64.7	68.4	81.3
Respiratory effects	kg PM2.5 eq	100	75.9	60.9	71.4	72.6
Ecotoxicity	CTUe	100	77.0	80.9	81.4	82.3
Fossil fuel depletion	MJ surplus	100	34.4	39.4	44.5	44.6

By adding a pumping chamber, the carcinogenic impacts increase by 43.9% due to the manufacturing of cast iron and stainless steel for the submersible pumps. However, the sand filter bed still has the lowest carcinogenic impacts compared to the other four systems. Non-carcinogenic, and respiratory effects increase approximately by 20% to 25% due to the manufacturing of the pumps. Ecotoxicity also increases by 25% due to the increased landfilling of the reinforced concrete. Compared to the other four septic systems, the sand filter bed scores the lowest in only 4 out of 10 categories compared to having the lowest impact in 7 out of 10 impact categories with no pump chamber.

4.1.2.3 Transportation

Transportation has a linear relationship, the transportation distance was multiplied by ±25% and ±50%, however the lorry transportation unit in SimaPro is defined by transportation multiplied by the weight resulting in an input of tonnes-kilometers (tkm). For this sensitivity analysis only, the transportation distance was changed, and the weight of the products remained the same (Table 4-12).

Table 4-12: Transportation Sensitivity Analysis Results

		CLB		**SFB**		**SBT**		**Type A**		**Type B**	
Impact category	**Unit**	**± 25%**	**± 50%**	**± 25%**	**± 50%**	**± 25%**	**± 50%**	**± 25%**	**± 50%**	**± 25%**	**± 50%**
Ozone depletion	kg CFC-11 eq	± 18.2	±36.5	±30.7	±61.4	±11.6	±23.1	±28.1	±56.1	±29.8	±59.5
Global warming	kg CO2 eq	±3.7	±7.4	±14.6	±29.0	±2.9	±5.8	±7.9	±15.8	±7.7	±15.3
Smog	kg O3 eq	±10.3	±20.6	±20.6	±41.2	±7.7	±15.4	±19.2	±38.4	±21.0	±42.0
Acidification	kg SO2 eq	±5.8	±11.6	±18.0	±35.9	±4.9	±9.9	±13.1	±26.3	±13.7	±27.3
Eutrophication	kg N eq	±6.6	±13.2	±11.8	±23.6	±2.9	±5.8	±7.7	±15.4	±7.6	±15.2
Carcinogenics	CTUh	±1.0	±2.1	±6.3	±12.6	±0.8	±1.5	±1.9	±3.8	±2.0	±4.0
Non carcinogenics	CTUh	±8.1	±16.2	±21.0	±42.0	±3.9	±7.7	±11.2	±22.3	±9.9	±19.8
Respiratory effects	kg PM2.5 eq	±8.2	±16.4	±17.0	±34.0	±3.9	±7.9	±10.9	±21.8	±11.3	±22.7
Ecotoxicity	CTUe	±3.8	±7.7	±7.9	±15.8	±1.9	±3.8	±4.4	±8.8	±4.6	±9.1
Fossil fuel depletion	MJ surplus	±5.8	±11.7	±23.1	±46.2	±4.5	±9.1	±12.4	±24.8	±13.0	±26.1

Sand and Stone are the largest contributors to transported weight. The sand filter bed, Type A, and Type B had the largest amount of sand and stone; therefore, their environmental impacts will be higher than the shallow buried trench that requires no imported sand and stone. For most categories and systems adding plus or minus 25% or 50% does not produce a linear relationship. The sand filter bed has the largest weight of products, mostly due to the amount of sand required for the bed. The sand filter bed had the largest difference in all impact categories except for smog (Type B is slightly higher). Therefore, transporting sand filter bed components could have the largest transportation impacts or the least depending on the distance. The almost linear increase/decrease relationship between transportation and ozone depletion is primarily due to production and refinery of petroleum in order to produce diesel.

Varying the transportation distance has the least affect on carcinogenic and ecotoxicity. For the beds that require less sand and/or stone, such as conventional leaching bed and shallow buried trench, the GWP was less than ±7.5% when changing the transportation by ±50%. Overall the shallow buried trench, was the least effected by change in transportation, as it is the lightest system by weight, due to the lack of imported sand and stone for a T-time of 40 min/cm.

4.1.2.4 Sand and Stone

The weight of sand and stone was increased/decreased by 10% and 20%, increasing the amount of sand and stone impacts the quarrying and transportation. Similar to the transportation sensitivity analysis increasing the sand and stone by 10% and 20% produce a linear relationship (Table 4-13). Type B has a relatively low percent change, with at ±20% the highest change is ozone depletion (±8%). The impact categories with the largest change for sand filter bed, Type A and Type B are ozone depletion, smog, non-carcinogenic, respiratory effects and ecotoxicity. Across the four septic systems, the quarrying and transportation of sand and stone has the least change in carcinogenic effects on human health, which as seen above is caused by the manufacturing of PVC pipe.

Table 4-13: Sand and Stone Sensitivity Analysis Results

Impact category	Unit	CLB ± 10%	CLB ± 20%	SFB ± 10%	SFB ± 20%	Type A ± 10%	Type A ± 20%	Type B ± 10%	Type B ± 20%
Ozone depletion	kg CFC-11 eq	±4.0	±8.0	±8.0	±16.0	±8.7	±17.4	±8.6	±17.2
Global warming	kg CO2 eq	±1.2	±2.5	±6.2	±12.4	±6.4	±12.8	±5.5	±11.0
Smog	kg O3 eq	±3.0	±6.1	±7.1	±14.3	±8.0	±15.8	±8.0	±15.9
Acidification	kg SO2 eq	±2.0	±4.1	±7.0	±13.9	±7.4	±14.6	±7.1	±14.2
Eutrophication	kg N eq	±2.8	±5.5	±7.6	±15.2	±8.7	±17.3	±7.7	±15.4
Carcinogenics	CTUh	±0.5	±1.1	±5.2	±10.3	±4.6	±9.1	±4.5	±9.0
Non carcinogenics	CTUh	±2.2	±4.4	±7.5	±15.0	±8.5	±16.8	±6.2	±12.5
Respiratory effects	kg PM2.5 eq	±2.8	±5.6	±7.4	±14.8	±8.2	±16.4	±7.8	±15.6
Ecotoxicity	CTUe	±1.0	±2.1	±9.1	±18.1	±9.2	±18.2	±8.5	±17.0
Fossil fuel depletion	MJ surplus	±1.6	±3.3	±6.9	±13.9	±7.0	±13.9	±6.9	±13.8

The weight of sand and stone was increased/decreased by 10% and 20%, increasing the amount of sand and stone impacts the quarrying and transportation. Similar to the transportation sensitivity analysis increasing the sand and stone by 10% and 20% produce a linear relationship. Type B has a relatively low percent change, with at ±20% the highest change is ozone depletion (±8%). The impact categories with the largest change for sand filter bed, Type A and Type B are ozone depletion, smog, non-carcinogenic, respiratory effects and ecotoxicity. Across the four septic systems, the quarrying and transportation of sand and stone has the least change in carcinogenic effects on human health, which as seen above is caused by the manufacturing of PVC pipe.

For the quarrying of sand and gravel network analyses, the primary processes that contribute to the 10 impact categories include: the production of petroleum, the burning of diesel, and high voltage electricity. In addition, the waste treatment of: wastewater from medium density board production, spoil from hard coal mining, sulfidic tailings, basic oxygen furnace and slag, unalloyed electric arc furnace steel, and sludge from steel rolling also have a large contribution to eutrophication, carcinogenic, non-carcinogenic, and ecotoxicity effects.

4.1.2.5 T-Time of 10

A T-time of 10 min/cm is more indicative of Southwestern Ontario's native soil profile. The conventional leaching bed environmental impacts are reduced by over half in 9 out of 10 impact categories (Table 4-14 and Table 4-15), due to reduction of the leaching bed and omission of the 2,700 L pump chamber. The sand filter bed does not require a mantle and requires approximately 38% less sand, reducing the environmental impacts from 11.8% to up to 73.8%. The shallow buried trench does not change as the same system can be installed for both native soil T-times of 40 min/cm and 10 min/cm. Type A and Type B only see changes greater than 15% in four impact categories, of which all are under 20%, except for Type A smog formation.

Table 4-14: Characterization factors T-time of 10 cm/min

Impact category	Unit	Conventional	Filter Bed	Shallow Buried Trench	Type A	Type B
Ozone depletion	kg CFC-11 eq	81.1	37.8	94.3	98.8	100.0
Global warming	kg CO2 eq	83.8	50.3	96.7	96.4	100.0
Smog	kg O3 eq	86.5	42.5	93.5	98.2	100.0
Acidification	kg SO2 eq	91.2	48.4	95.5	97.0	100.0
Eutrophication	kg N eq	61.2	61.7	97.7	98.6	100.0
Carcinogenics	CTUh	61.4	34.0	99.0	97.9	100.0
Non carcinogenics	CTUh	59.2	51.6	94.4	96.9	100.0
Respiratory effects	kg PM2.5 eq	57.0	39.7	96.1	98.7	100.0
Ecotoxicity	CTUe	68.0	62.8	99.7	99.8	100.0
Fossil fuel depletion	MJ surplus	84.2	37.0	99.0	97.3	100.0

Table 4-15: Percent Difference between T-time of 40 versus T-time of 10

Impact category	Unit	Conventional	Filter Bed	Type A	Type B
Ozone depletion	kg CFC-11 eq	58.6	73.8	18.1	16.6
Global warming	kg CO2 eq	65.3	34.0	10.3	14.4
Smog	kg O3 eq	65.9	73.3	23.9	19.7
Acidification	kg SO2 eq	67.6	57.5	17.6	16.4
Eutrophication	kg N eq	52.7	30.1	5.6	9.8
Carcinogenics	CTUh	69.8	17.5	6.5	5.4
Non carcinogenics	CTUh	59.5	25.9	3.0	15.8
Respiratory effects	kg PM2.5 eq	63.9	58.4	12.5	12.8
Ecotoxicity	CTUe	44.9	11.8	0.6	1.5
Fossil fuel depletion	MJ surplus	66.5	53.1	13.0	10.9

The change in percolation time has a large effect on the environmental impacts. In the primary model, the conventional leaching bed was the most environmentally damaging system, whereas in native soil with a T-time of 10 min/cm, Type B is the most environmentally damaging system. When the native soil has a T-time of 10 min/cm, the conventional leaching bed does not require the system to be dosed and omits the need of a pump chamber as well as the amount of required PVC pipe is reduced by 75% from 400 m to 100. The sand filter bed has the least environmental impact in 9 out of 10 categories, with the conventional leaching bed scoring 0.5%

less in eutrophication. The shallow buried trench system does not change between the two percolation times, and the Type A and Type B still require a pump chamber, Level IV treatment unit and a slightly smaller bed (approximately 47% less adsorption material for Type A and 75% less stone for Type B). The three systems that require a Level IV treatment unit result in very similar scores, primarily due to the assumption that the sand and stone are reused and therefore have zero environmental effects. The OBC formulas vary for native soil with a T-time ≥ 15 min/cm, therefore installing a conventional leaching bed or sand filter bed for properties with a native soil percolation time of less than 15 min/cm is preferred as opposed to the other systems which are rarely installed.

4.1.3 Uncertainty Analysis

4.1.3.1 Pedigree Matrix Approach

This LCA used 22 datasets, of which, 18 datasets were ecoinvent. Most ecoinvent datasets contained 5 assigned pedigree values ranging from a score of 1-5 as described in Chapter 2.1.4.1. All ecoinvent datasets for materials, sludge treatment, and electricity contained the pedigree values, whereas the transportation, excavation, and most waste treatments (except for scrap and steel waste treatment) did not contain pedigree values. For each of the five pedigree matrix criteria, 884 values were used to determine the uncertainty of 18 of 22 datasets used; the average value and standard deviation can be seen in Table 4-16.

Table 4-16: Pedigree Matrix Results

Parameter	Average	SD	Pedigree Matrix Score & Description
Reliability	1.94	1.01	2: Verified data partly based on assumptions OR non-verified data based on measurements
Completeness	2.2	1.16	2: Representative data from >50% of the sites relevant for the market considered over an adequate period to even out normal fluctuations
Temporal Correlation	3.97	1.59	4: Less than 15 years of difference to the reference year
Geographical Correlation	4.03	1.56	4: Data from area with slightly similar production conditions
Further Technological Correlation	1.29	0.82	1: Data from enterprises, processes, and materials under study (i.e., identical technology)

As seen in Table 4-16, the further technological correlation scored 1.29 and confirms on average the processes used to create the datasets were identical technologies. Reliability and Completeness scored an average of approximately 2, therefore the ecoinvent datasets were mostly complete and reliable. Overall, the datasets are older than 15 years, but with the manufacturing of materials and older processes such as concrete production, the temporal correlation is not of a large concern for this study as the materials used in this study are common materials and have been manufactured the same way for decades. Due to the lack of Canadian and North American datasets, it was expected the geographical correlation criteria would be slightly higher as many global or multi-regional datasets are extrapolated from a single dataset (Treyer & Bauer, 2013). The further technological correlation has the lowest score and the least uncertainty, which is due to the common materials as it would not be a large challenge to find a concrete or plastic manufacturing process. The pedigree matrix is based on values assigned by the dataset authors; however, the pedigree matrix is useful for first, second, third, etc. processes connected with each dataset (Lewandowska et al., 2004).

4.1.3.2 Monte Carlo Simulation

This study contained several assumptions and estimations and therefore the LCIA results should be checked for uncertainty. Monte Carlo simulations were ran 1,000 times and each septic system was compared to the other septic systems, therefore 10 simulations were calculated. Table 4-17 illustrates the percentage that system 'A' has a larger environmental impact than system 'B' for each of the 10 TRACI impact categories in order to determine if system 'A' is always more environmentally preferred compared to system 'B' over the 1,000 different scenarios (i.e., runs).

Table 4-17: Monte Carlo Simulations Results

Impact category	CLB >= SFB	CLB >= SBT	CLB >= Type A	CLB >= Type B	SFB>= SBT	SFB>= Type A	SFB>= Type B	SBT>= Type A	SBT>= Type B	Type A>= Type B
Acidification	52.1	100	100	100	100	100	100	0	0	0
Carcinogenics	98.1	100	99.9	99.6	93.8	19.8	12.4	0	0	4.7
Ecotoxicity	0.7	100	62.3	21	100	99.9	99.9	0	0	0.6
Eutrophication	0	100	99.8	75.8	100	100	100	0	0	0
Fossil fuel depletion	80.9	100	100	100	100	100	100	0	0	0
Global warming	100	100	100	100	100	100	100	0	0	0
Non carcinogenics	13.6	84.3	49.5	47.3	92	84.1	71	2.8	7.3	39.3
Ozone depletion	0	100	100	10.7	100	100	100	0	0	0
Respiratory effects	0	100	100	94.9	100	100	100	0	0	0
Smog	0	100	100	100	100	100	100	0	0	0

Hung & Ma (2009) found that the impact categories with the highest uncertainties were ecotoxicity, human health, and photochemical smog formation. The impact categories with the lowest uncertainties was global warming followed by eutrophication (Hung & Ma, 2009). For this study the impact categories with the highest amount of uncertainty are non-carcinogenic, carcinogenic, ecotoxicity, and eutrophication impacts. In contrast, the lowest uncertainty impact categories are global warming, and smog, followed by acidification, fossil fuel depletion, ozone depletion and respiratory effects. Therefore, when interpreting and weighting the results presented in this study, caution should be taken with the higher uncertainty categories, carcinogenic and non-carcinogenic effects on human health and ecotoxicity. Figure 4-1 illustrates the 10 scenarios GWP average and standard deviation based on the inputted value. The bar graphs represent the difference between the two septic systems (i.e., system 'A' – system 'B').

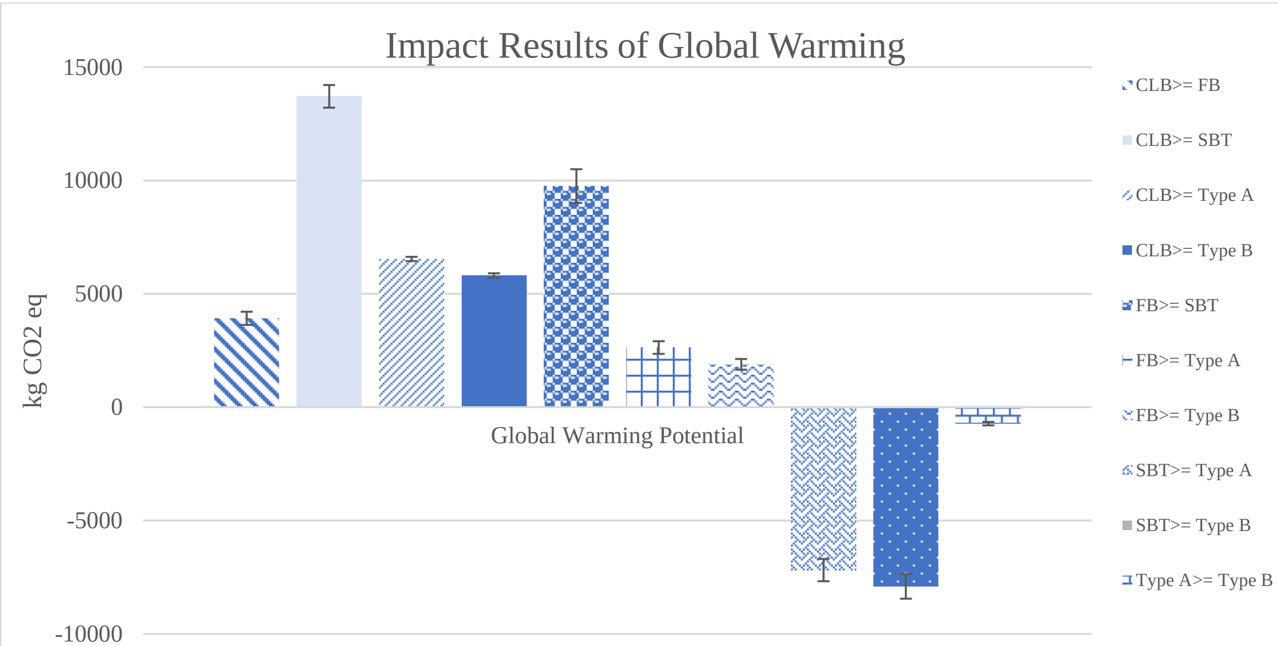

Figure 4-1: Global Warming Potential Monte Carlo

The standard deviations of CO_2 eq emissions is relatively small. The conventional leaching bed and sand filter produces more CO_2 eq when compared to the other septic systems. As seen in the results above the largest difference is between the conventional leaching which produces the most emissions and the sand filter bed which produces the least. Type A and Type B produce similar emissions and therefore have a difference of less than 1000 CO_2 eq. The other nine impact categories can be seen in Appendix D.

It should be noted that the Monte Carlo simulation uses the pedigree matrix values, which is unique to the ecoinvent database. As stated in the section above, not all datasets used in this LCA were ecoinvent, and therefore, some datasets do not contain the pedigree matrix values. The landfilling waste scenarios contained very few pedigree values, while the incineration waste scenarios are not ecoinvent datasets and do not contain any pedigree values. The PVC pipe contributed to a large amount of environmental effects associated with manufacturing. The PVC pipe dataset did not contain pedigree values and therefore was omitted from the PMA and Monte Carlo uncertainty analysis and is a short coming of this study. However, the LCI stage is typically the primary source for uncertainty under any LCIA method (Hung & Ma, 2009).

4.2 Life Cycle Impact Assessment Comparisons

There are similar impact categories between the five LCIAs, however many express the impact categories in different units. Assessing the septic systems through multiple LCIAs allows for LCA practitioners to evaluate model robustness. It should be noted that the methodology to calculate some impact assessment are the same or very similar. For example, the amount of CO_2eq and CFC-11eq are very similar across all five impact assessments.

The conventional leaching bed typically has the largest environmental effect in most of the impact categories, with the Type B scoring higher in abiotic depletion (CML-IA), marine aquatic ecotoxicity (CML-IA), freshwater eutrophication (ILCD 2011 and ReCiPe), and mineral/metal depletion (ILCD 2011, ReCiPe, and IMPACT 2002). The amount of PVC pipe required for a conventional leaching bed with a native soil T-time of 40 min/cm, is between 3 to 11 times than the other septic systems and proves to be an issue.

Decision makers can weight the impact categories, or chose which categories are more important to them or the problem they are facing. For example, with the growing concern of algal blooms in Lake Erie, the OBC may want to consider weighting the eutrophication impacts higher than other impact categories. In addition, the public may not be familiar with ecotoxicity and the associated unit CTU, however, most people will be familiar with terminology such as Global Warming or Climate Change and know that excess CO_2 is not environmentally beneficial.

TRACI only has 10 impact categories, giving it a more simplistic but holistic impact assessment method. CML puts more emphasis on the various types of ecotoxicity, as it includes three different ecotoxicity impact categories (freshwater aquatic, marine aquatic, and terrestrial). ILCD puts less emphasis on ecotoxicity as it only includes freshwater ecotoxicity, however it includes three eutrophication impact categories, two ionising radiation impact categories as well as land use, water resource depletion, and mineral, fossil and renewable resource depletion. IMPACT includes similar categories to the previous three LCIAs, however, it includes two respiratory effects categories, respiratory organics and respiratory inorganics. Similar to ILCD, IMPACT also includes land occupation, non-renewable energy (fossil resource depletion), and mineral extraction. ReCiPe includes 18 impact categories, with the main impact categories including: ecotoxicity (terrestrial, freshwater, marine), land occupation (agricultural, urban, and natural), and depletion (water, metal and fossil).

4.2.1 Climate Change and Global Warming Potential

Climate change or GWP is present in all five LCIAs as kg CO_2eq. ReCiPe and ILCD produced the same results for all five septic systems and CLM-IA either had the same results or differentiates by less than 2 kg of CO_2eq emissions produced. IMPACT resulted in the all five septic systems producing the lowest CO_2eq emissions ranging from 3 to 8% less CO_2eq than ReCiPe. The conventional leaching bed and sand filter bed produce the same emissions across TRACI, ILCD, and ReCiPe. However, shallow buried trench, Type A and Type B produces 7 to 9% more emissions under the TRACI impact assessment compared to ReCiPe.

The conventional leaching bed produces the most kg CO_2eq, while the sand filter bed produces the least amount of CO_2eq in all five LCIAs, with average emissions of 10,750 and 3,424 kg of CO_2eq respectively. The shallow buried trench has the second lowest emissions, with an average of 4,420 kg CO_2eq over it's lifetime. Type A emits on average 4,902, and Type B emits the second highest amount of CO_2eq with an average of 5,323 kg CO_2eq. However, Type B emits approximately 50% less emissions than the conventional leaching bed. Four LCIAs (all except TRACI) GWP are derived for European documentation, whereas TRACI derives its GWP formulas from USEPA documentation.

4.2.2 Ozone Depletion

Similar to climate change, ozone depletion is present in all five LCIAs as kg CFC-11eq. The conventional leaching bed emits the largest amount of CFC-11eq, on average 4.61E-04 in all five LCIAs, whereas the shallow buried trench emits the least. However, when compared to the other four LCIAs, TRACI produces slightly higher values in all five septic systems compared to it's European counterparts. CML, ILCD, and IMPACT produce either the same values, or within 1% of each other. ReCiPe produces slightly higher values than the other three European LCIAs, however it is within 5% of the other European LCIAs.

4.2.3 Acidification

Acidification is presented in all five LCIAs, mostly in kg SO_2eq, except for ILCD which presents in molecule H^+ eq. Even with the two units, the results are similar, with the lowest impacts ranging from 12.6 to 15.9 kg SO_2eq and the highest impacts ranging from 34.2 to 42.8 kg SO_2eq. However, in all five LCIA acidification results, the shallow buried trench has the lowest impact, the conventional leaching bed has the largest impact, and Type A and Type B have similar impacts with the quantity released differentiating by 0.2 to 0.4 kg SO_2eq. Unlike the other 4 LCIAs, IMPACT presents two acidification categories, aquatic acidification and terrestrial acidification/nutrients. The later included eutrophication and results in higher SO_2 eq values, ranging from 60.4 to 159.9 kg SO_2eq. The same results apply to the acidification/nutrients grouping where the shallow buried trench had the lowest impact (60.4 kg), the conventional leaching bed has the highest impact (159.9 kg) and the Type A and Type B have similar impacts, 80.4 and 78.8 kg respectively.

4.2.4 Ecotoxicity

Ecotoxicity is presented as freshwater ecotoxicity (i.e., TRACI and ILCD), or combination of aquatic, freshwater aquatic, marine aquatic, or terrestrial ecotoxicity (i.e., the European LCIAs). In addition to the various ecotoxicity designations, ecotoxicity is presented in different units, kg 1,4 DB eq, CTUe, or kg TEG). TRACI and ILCD solely present freshwater ecotoxicity as CTUe, the conventional leaching bed has the largest impact, and the sand filter bed has the lowest impact, with the values varying by less than 1% between the two LCIAs for the respective septic systems. However, when comparing the results of the shallow buried trench, Type A, and Type B between the two LCIAs, TRACI produces approximately 16% higher values than ILCD.

IMPACT presents aquatic and terrestrial ecotoxicity as kg TEG (tri-ethylene glycol) water and kg TEG soil respectively. Similar to the other four LCIAs, the conventional leaching bed produces the largest amount of emitted substances, 529,273 and 212,193 kg TEG water and soil respectively. However, the shallow buried trench has the least impact in both ecotoxicity impacts, 267,463 and 125,197 kg TEF water and soil respectively.

Lastly, CML and ReCiPe include the same three ecotoxicity impact categories (terrestrial, freshwater, and marine) with the same units, kg 1,4, DB eq. However, the values from the two LCIAs produce extremely different results with CML's freshwater and terrestrial ecotoxicity greater by a magnitude of 100, while CML's marine ecotoxicity is greater on a magnitude of 10,000 (2,517,527 vs 214 kg 1,4 DB eq). CML's ecotoxicity is a result of emissions to air, water, and soil, which applies to a global, continental, regional and local scale. The ecotoxicity potential is calculated with USES-LCA (United States Environmental Services – Life Cycle Assessment), describing fate, exposure and effects of toxic substances. In contrast, ReCiPe accounts for the fate, exposure and effect of a chemical, and does not calculate the effects using the USES-LCA method; hence the difference in values despite the same units. However, despite the variance in values the model robustness confirms conventional leaching bed has the largest effect on all three ecotoxicity categories, while the sand filter bed has the least for both European LCIAs.

4.2.5 Eutrophication

Eutrophication is largely due to phosphorus and nitrogen based molecules, therefore each of the five LCIAs, present eutrophication as kg Neq, molecule Neq, kg Peq, kg PO4 P-limited, or kg PO4eq, or mixture of the three. TRACI, ILCD and ReCiPe present eutrophication as kg N, additionally ILCD includes terrestrial eutrophication as molecule Neq. The three LCIAs concluded the conventional leaching bed produced the largest amount of kg N eq, however under TRACI the sand filter bed produced the lowest (5.8 kg N eq), while the other two European LCIAs resulted in the shallow buried trench producing the lowest kg Neq with 5.5 and 2.4 kg N eq for ILCD and ReCiPe respectively. ILCD produced the largest values (5.5 to 11.7 kg N eq), while ReCiPe produced the lowest (2.4 to 3.1 kg N eq). In addition to present eutrophication as kg N eq, ILCD has an additional terrestrial eutrophication as molecules of nitrogen. While the other LCIAs do not include this category or the units, the general trend of the conventional leaching bed having the largest impact and the shallow buried trench having the lowest impact remains the same.

In terms of eutrophic impacts caused by kg P eq, ILCD and ReCiPe produce the same values, with the conventional leaching bed emitting the largest amount (0.54 kg P eq) and the sand filter bed emitting the least (0.34 kg P eq). Lastly, CML and IMPACT present eutrophication as kg PO_4 eq, and kg PO_4 P-limited respectively. Due to the slight variation in total phosphorus versus limited PO_4, the two impact categories do not produce similar values, however the conventional leaching bed emits the highest total and limited P-PO_4, while the shallow buried trench produces the least.

4.2.6 Resource Depletion

Resource depletion is an umbrella term that can include one or multiple of the following impact categories: fossil fuels, renewable resources, water, and mineral depletion. No two LCIAs have the same number of resource depletion impact categories with the same units, therefore this is the most difficult impact category to compare in terms of units.

Dissimilar to the other impact categories, the conventional leaching bed is not the most environmentally damaging septic system under all resource depletion impact categories. However, despite the various resource depletion categories and units, the sand filter bed is the most environmentally friendly. While the conventional leaching bed does score the highest in 6 out of 10 the resource depletion categories, Type B has the largest impacts in 30% of the categories; ILCD's solely inclusive mineral, fossil and renewable resource depletion, CML's abiotic depletion and IMPACT's mineral extraction. Lastly, Type A has the highest metal depletion under ReCiPe.

4.2.7 Carcinogenic and Non-carcinogenic Effects

As seen in the midpoint category, ecotoxicity, TRACI and ILCD express the carcinogenic and non-carcinogenic impacts as CTUh; CML and ReCiPe express human toxicity as one impact category as kg 1,4-DBeq, and IMPACT expresses carcinogenic, and non-carcinogenic effects on human health in kg C_2H_3Cleq (vinyl chloride equivalent).

The TRACI and ILCD results of carcinogenic and non-carcinogenic effects mirrors the results of ecotoxicity where the conventional leaching bed results in the high impact, and the sand filter bed has the least impact with the values for the respective beds being identical. For the three systems that require a Level IV treatment unit, TRACI produces slightly higher values (6% to 9.5%).

IMPACT is the only impact assessment that expresses carcinogenic and non-carcinogenic effects as kg C_2H_3Cleq, but does not produce the same model robustness as the other four LCIAs. The conventional leaching bed has the largest impact, however for non-carcinogenic effects, the shallow buried trench is preferable system. For carcinogenic effects, the sand filter bed has the least carcinogenic impact on human health.

Again, mirroring the results of ecotoxicity, the both CML and ReCiPe agree the conventional leaching bed will have the highest impact on human toxicity, and the sand filter bed will have the least. Moreover, CML produces much higher values, with values differencing up to a factor of 10, which is due to the variations in calculation methods.

4.2.8 Particulate Matter and Respiratory Effects

Similar to the other impact categories the conventional leaching bed has the impact on respiratory effects to human health. TRACI, IMPACT, and ILCD present respiratory effects/particulate matter as kg $PM_{2.5}$eq, while ReCiPe presents it as kg PM_{10}eq. The sand filter bed and shallow buried trench have the lowest respiratory effects, with the shallow buried trench scoring the least in three LCIAs, and the sand filter bed scoring the lowest in TRACI. The five septic systems have higher $PM_{2.5}$eq emissions under IMPACT (3.4 to 7.8 kg $PM_{2.5}$eq). Since ReCiPe presents respiratory effects as PM_{10}eq, the quantity is emitted PM is higher, ranging from 6.9 (shallow buried trench) to 15.2 (conventional leaching bed) kg PM_{10}eq. Type A and Type B emit the same quantity of PM or within 0.2 kg across the four LCIAs.

4.2.9 Additional Impacts

The additional impact categories include ionising radiation, and land occupation/transformation, in which the latter is represented by various impact categories (i.e., land occupation, natural land transformation, agricultural land transformation, etc.). All five LCIAs produce similar results in terms of robustness, the conventional leaching bed is the most environmentally impactful septic system, and there is not superior system for land occupation/transformation categories. However, the sand filter bed has the least impact for the three LCIAs that include ionising radiation, ILCD, IMPACT, and ReCiPe.

4.3 Supplementary LCA studies

Until the date of this study, August 2018, no other septic systems LCAs were found. The peer-reviewed articles listed in Chapter 2.8. focused on LCAs and environmental impacts on larger wastewater treatment systems, many of which included the impacts of biosolids applications and advanced treatment such as aeration. This LCA does not include advanced treatment, aeration, or the effects of nutrients on the local environment and therefore cannot be compared with the studies previously mentioned. However, James et al., 2014; Sowah et al., 2014, and Philips et al., 2015 found there is a significant effect between septic system effluent and the faecal pollution levels in a local watersheds and waterbodies. Therefore, it is recommended that primary effluent data is collected from each of the five systems and compared to the results from this LCA study to model and identify the environmental impacts associated with the discharges treated effluent and how it compares to the impacts associated with the life cycle of each system.

4.4 Life Cycle Cost Analysis

The capital cost and installation were provided by a local installer. The average price to pump out the sludge from a residential septic tank is approximately $200 and will occur every 3 years for 25 years; 8 desludging visits in total. The electricity was calculated based on the kwh needed for each system and using a mid-peak electricity price of 9.5¢ per kwh (Ontario Energy Board, 2018). It was assumed three pumps would be required over a life-span of 25 years for each component that required a pump. Therefore, assuming an effluent submergible pump was included in the capital cost, the conventional leaching bed would require the owner to buy 2 more pumps. However, the shallow buried trench, Type A, and Type B require a pump in both the pump chamber and the Level IV treatment unit. An effluent pump cost approximately $813 per pump. The cost summary for each of the five systems for a T-time of 40 min/cm can be seen in Table 4-18.

Table 4-18: Life Cycle Cost Analysis Over 25 Years

	Capital and Installation	Septic Tank Maintenance	Electricity	Pumps	Total Life Time Cost
Conventional Leaching Bed	$17,620	$1,600	$213	$1,626	$21,059
Sand Filter Bed	$15,975	$1,600	$0	$0	$17,575
Shallow Buried Trench	$28,400	$1,600	$213	$3,252	$33,465
Type A Dispersal Bed	$27,400	$1,600	$213	$3,252	$32,465
Type B Dispersal Bed	$28,265	$1,600	$213	$3,252	$33,330

Majority of the cost comes from the capital and installation of the septic systems. The sand filter bed is the least expensive ($17,575) due to the installation of a septic tank and leaching bed, as the other systems require a pumping chamber and the shallow buried trench, Type A, and Type B require a Level IV treatment unit. However, maintenance especially for the leaching beds is another hidden cost that can be minimized by implementing a Level IV treatment unit or other advanced treatment systems. The two most commonly installed septic systems, the conventional leaching bed and sand filter bed are the least expensive and have a cost difference of approximately $3,500. Due to the massive size of the bed, and due to the cost, a homeowner would be more inclined to install a filter bed. The other three beds (shallow buried trench, Type A, and Type B) are rarely installed due to increased maintenance, cost, and their unfamiliarity to Ontarians. While the shallow buried trench has been approved since 1998, Type A and Type B were introduced to Ontario in 2012, and were designed for smaller lots, and/or difficult landscapes such as rocky terrain.

As seen in Section 4.1.2.5, for a T-time of 10 min/cm, the materials required for the conventional leaching bed and sand filter bed reduce significantly. The sand filter bed does not require a filter sand mantle for a soil with a T-time of 10 min/cm and the conventional leaching bed does not require a pump chamber and only 100 m of PVC pipe, reducing the size of the bed and the amount of stone required. The shallow buried trench, Type A and Type B require a pumping chamber and a Level IV treatment unit regardless of the T-time. Moreover, the shallow buried trench systems does not vary in size or materials required for a native soil with a T-time of 40 min/cm or 10 min/cm. The Type A and Type B sand and stone reduce by 47% and 75% respectively. Therefore, the conventional leaching bed and the sand filter bed would be less expensive than the other three beds for both native soil T-times of 10 min/cm and 40 min/cm.

5 ENGINEERING APPLICATIONS

Identifying environmental hotspots and assessing where improvements can be made throughout different life cycle stages allows for decision makers such as OBC regulators, law makers, politicians, and homeowners to assess the environmental impacts of septic systems. This study can be used as a part of a larger LCA that could compare different wastewater treatment options. For example, when building a new residential neighbourhood, the local government could compare the environmental impacts of installing a septic system on each lot or routing the sanitary sewage to the local WWTP, and impacts associated with the WWTP upgrades to accommodate more wastewater. In addition, LCA can be used for various aspects in the wastewater treatment industry:

- Compare full-size WWTP
- Compare individual processes
- A tool for cleaner production
- Assess carbon and water footprints

With a growing concern for a more sustainable future, LCA is a flexible tool that can be tailored to assess environmental impacts and help decision makers choose a greener future.

6 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

Wastewater decisions in developed countries such as Canada are often made based on an analysis of the core system for wastewater treatment (from the collection system to the wastewater treatment plant) and only considers the effects on the surface water quality. LCA is a technique to quantify impacts with all the stages of a product, service, or process. With an estimated 30% of septic systems failing or not meeting the required treatment, an LCA on the five OBC regulated septic system was conducted to identify environment hotspots. Moreover, the LCA and LCCA results can be used in decision making for both the homeowner and regulators alike.

Life cycle assessment is a new environmental management tool which can lead to more informed decision making by providing an alternative environmental impact assessment and indirect insight of socioeconomic impacts. While broader assessments consider the materials and energy used at the treatment facilities, significantly more information about the environmental effects of wastewater treatment may be gained by extending the analysis beyond the core system.

In the primary model, the conventional leaching bed contributed to the largest environmental effects in all and majority of the midpoint categories for TRACI, and the other four LCIA, respectively. The sand filter bed scored the lowest in 7 out of 10, however is not the most environmentally friendly. Each septic system was divided into life cycle stages (i.e., manufacturing, use, etc.). Transportation, specifically the production and refinery of petroleum for the manufacturing of diesel and manufacturing of the septic systems made up the majority of the environmental impacts. The reuse of sand and/or stone reduces up to 98.1% of most impact categories, except carcinogenic and ecotoxicity effects which are primarily due to landfilling and manufacturing of PVC pipe.

By increasing the lifespan of the septic system to 50 years, the conventional leaching bed only scored the highest values in 8 out of 10 impact categories, while the sand filter bed only scored the least in 40% as opposed to 70% from the original 25-year lifespan model. Adding a pump chamber to the sand filter bed assists in the even distribution of effluent, however carcinogenic, non-carcinogenic, and respiratory effects increase by 20 to 45% due to the manufacturing of the pumps. Ecotoxicity impacts also increased by 25% due to the landfilling of the reinforced concrete pump chamber. Altering the transportation distance by ±25% and ±50% did not result in a linear relationship with the impact categories. For most systems and impact categories, the impacts were less than the changed distances. For example, when increasing the transportation distance by ±50%, GWP only varied between ±5.8% and ±29%. Similar to the transportation sensitivity analysis, varying the amount of sand and/or stone required by ±10% and ±20%, did not produce a linear relationship, with all of the results being less than 10% and 20% and more than -10% and -20% for their respective categories. Lastly, the change in native soil percolation time had a large effect on the environmental emissions. The conventional leaching bed impacts are reduced by over 50% in 9 out of 10 impact categories due to the reduced leaching bed size and the omittance of the 2,700 L pump chamber. The sand filter bed scores the lowest in 9 out of 10 impact categories, except for eutrophication, and while the three septic systems that require a Level IV treatment unit have similar values, Type B is the worst septic system environmentally.

Two uncertainty analysis were completed on the model, the pedigree matrix approach, and the Monte Carlo simulation. Both uncertainty analyses use the pedigree matrix values, five categories relating to the reliability, completeness, temporal correlation, geographical correlation, and further technological correlation, with an evaluation from 1 to 5, with 1 being the most preferable, and 5 the least. However, only 18 of the 22 datasets used contained the pedigree matrix values, omitting datasets such as waste disposal and transportation. Out of the 18 datasets 884 pedigree values from each category was used to determine that the reliability, completeness, and further technological correlation and produced preferable results with average values of 1.94, 2.2 and 1.29 respectively. Temporal and geographical correlation scored approximately a 4 for both categories, due the global datasets and the age of the datasets (greater than 15 years). The Monte Carlo Simulation compared each septic system to each other (n=10) for 1000 runs. Overall there is higher uncertainty in the carcinogenic, non-carcinogenic, and ecotoxicity midpoint categories. In contrast, the midpoint categories with the lowest uncertainty include: global warming potential and smog.

The most commonly installed systems, the conventional leaching bed and the sand filter bed are the least expensive options compared to the other three septic systems. The conventional leaching bed and sand filter bed over a 25-year lifespan are more than $10,000 less than the other three septic systems, due to the shallow buried trench, Type A, and Type B requiring a Level IV treatment unit and pumping chambers. However, a Level IV treatment may increase the longevity of a leaching bed due to the decreased effluent and environmental loading on the leaching bed.

Life cycle assessment is a new environmental management tool which can lead to more informed decision making by providing an alternative environmental impact assessment and indirect insight of socioeconomic impacts. While broader assessments consider the materials and energy used at the treatment facilities, significantly more information about the environmental effects of wastewater treatment may be gained by extending the analysis beyond the core system.

6.2 Recommendations

Wastewater management is a case-by-case scenario with several economic, social, and environmental factors. Life Cycle Assessment is a comprehensive tool that can help with decision making. With the expected population growth of 30.3% from 14 million in 2016 to 18.2 million in 2041 (Ontario Population Projections Update, 2017), subdivisions and land development in Ontario is a must. This study allows for decision makers such as homeowner, builders, and OBC regulators, to assess the most favourable septic system based on their own criteria. However, next steps include assess septic systems with other decentralized wastewater treatments or centralized options. It is recommended the next steps is to conduct an LCA and assess the environmental hotspots of other wastewater treatment processes.

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APPENDIX A: ONTARIO BUILDING CODE AND SAMPLE CALCULATIONS

Note: CAD or Shop drawings from Unit Precast and Waterloo Biofilter was not included for privacy reasons.

Life Cycle Inventory Figures and Tables

Table A-1: Density of Materials

Septic System Inputs	Material	Density at 20°C (kg/m^3)	Source
Concrete Tank	35 MPa Concrete	2315	SimaPro Database
Inlet Baffle, Effluent Filter and Casing	Polypropylene	946	www.ineos.com
Effluent Filter Ball	Polyethylene	941	http://www.plastima.lt
Riser, Riser Adapter, Lids	HDPE	950	www.upcinc.com
Septic Tank Rubber Boots (2)	EPDM Rubber	1100	www.polyhedronlab.com
Anchor Bolts	Galvanized Steel	7850	www.machinemfg.com
Screws	Stainless Steel	7723	fusiontables.google.com
Riser Seal	Butyl Tape (Synthetic Rubber based)	1,600	Ego.de
Rubber Seals for Aeration	Ethylene vinyl acetate copolymer (EVA)	935	www.polymers-products.total.com
Stone	Gravel	2,400	Acton Group Uxbridge
Filter Sand	Sand	1,600	Lafarge Canada Inc.
4” Pipe	PVC	2.99 kg/m	www.petersenproducts.com
1” Pipe	PVC	0.48 kg/m	www.petersenproducts.com
Reinforcing steel (15M)	Reinforcing Steel (9-15M bars)	1.57 kg/m	www.engineeringtoolbox.com
Reinforcing steel (10M)	Reinforcing Steel (7-10M bars)	0.785 kg/m	www.engineeringtoolbox.com

Table A-2: 4,500 L Concrete Septic Tank Specifications

Concrete Parameter	Value	Unit	Concrete Parameter	Value	Unit
Height	1.78	m	Top Thickness	0.115	m
Length	2.59	m	Side Aerations Volume	0.0036	m^3
Width	1.68	m	Access Covers Volume	0.031	m^3
Inlet & Outlet Thickness	0.079	m	Inlet & Outlet Volume	0.35	m^3
Bottom Thickness	0.102	m	Side Walls Volumes	0.6	m^3
Inlet Height	1.485	m	Baffle Volume	0.35	m^3

Inlet Width	1.52	m	Bottom Volume	0.44	m^3
Side Wall Length	2.591	m	Top Volume	0.43	m^3
Side Wall Height	1.485	m	Total Volume of Concrete	2.04	m^3
Baffle Height	1.485	m	Total Weight of Concrete	4,745.80	kg
Rebar Parameter	**Value**	**Unit**	**Rebar Parameter**	**Value**	**Unit**
Reinforcing Steel Bar 10M Length	38.4	m	Reinforcing Steel Bar 10M Weight	30.2	kg
Reinforcing Steel Bar 15M Length	22	m	Reinforcing Steel Bar 15M Weight	34.4	kg

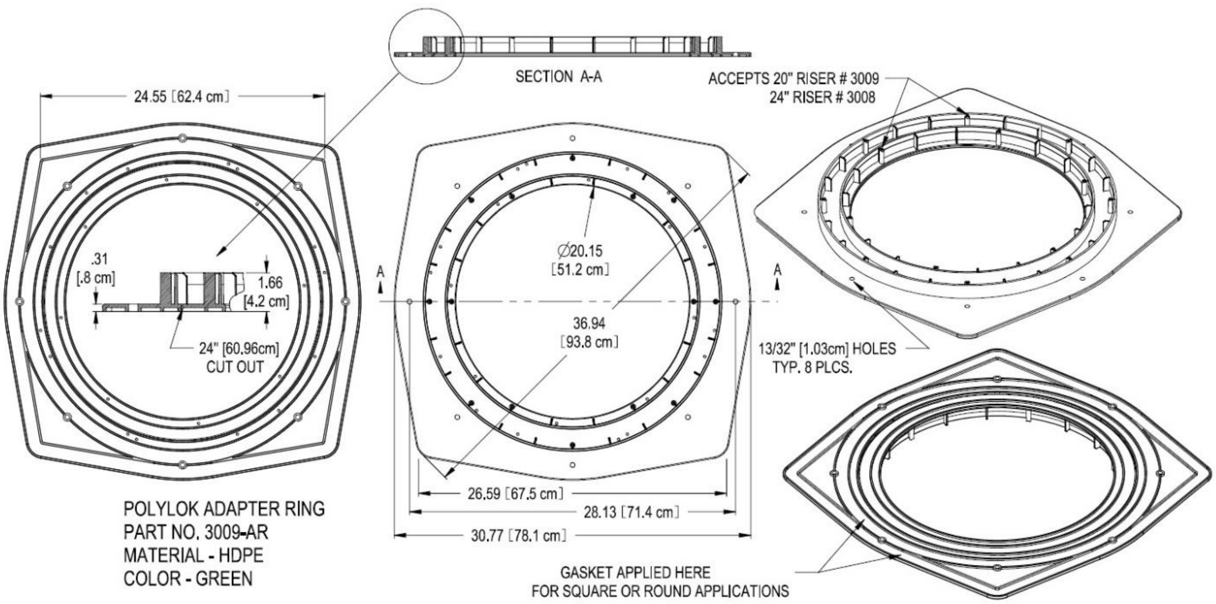


Figure A-1: Septic Tank Riser Adapters

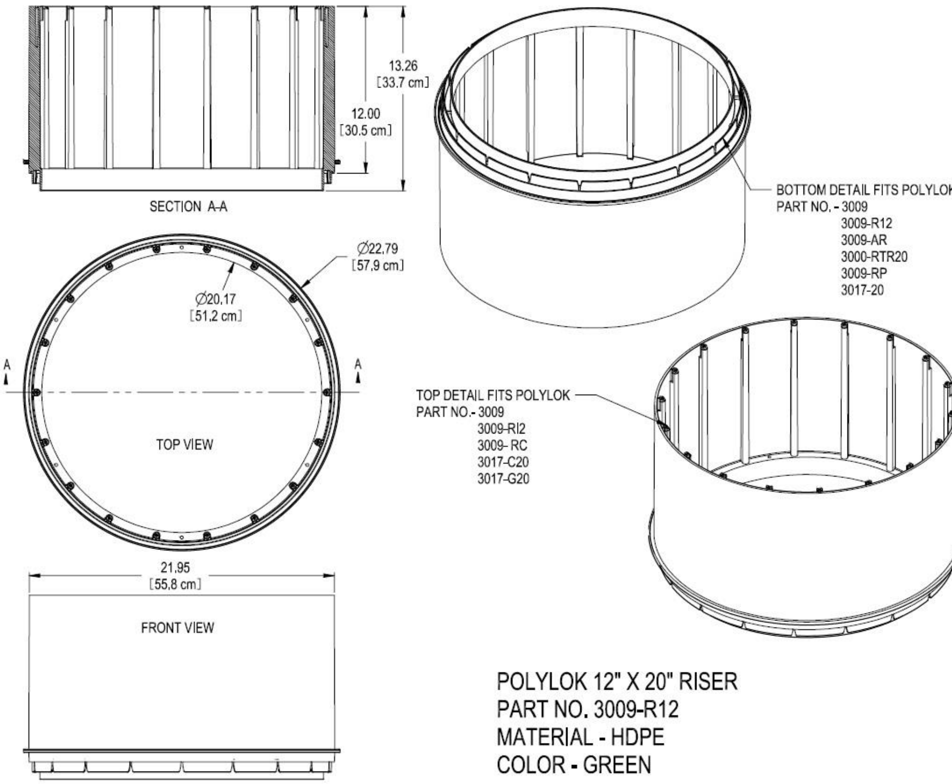


Figure A-2: Septic Tank Risers

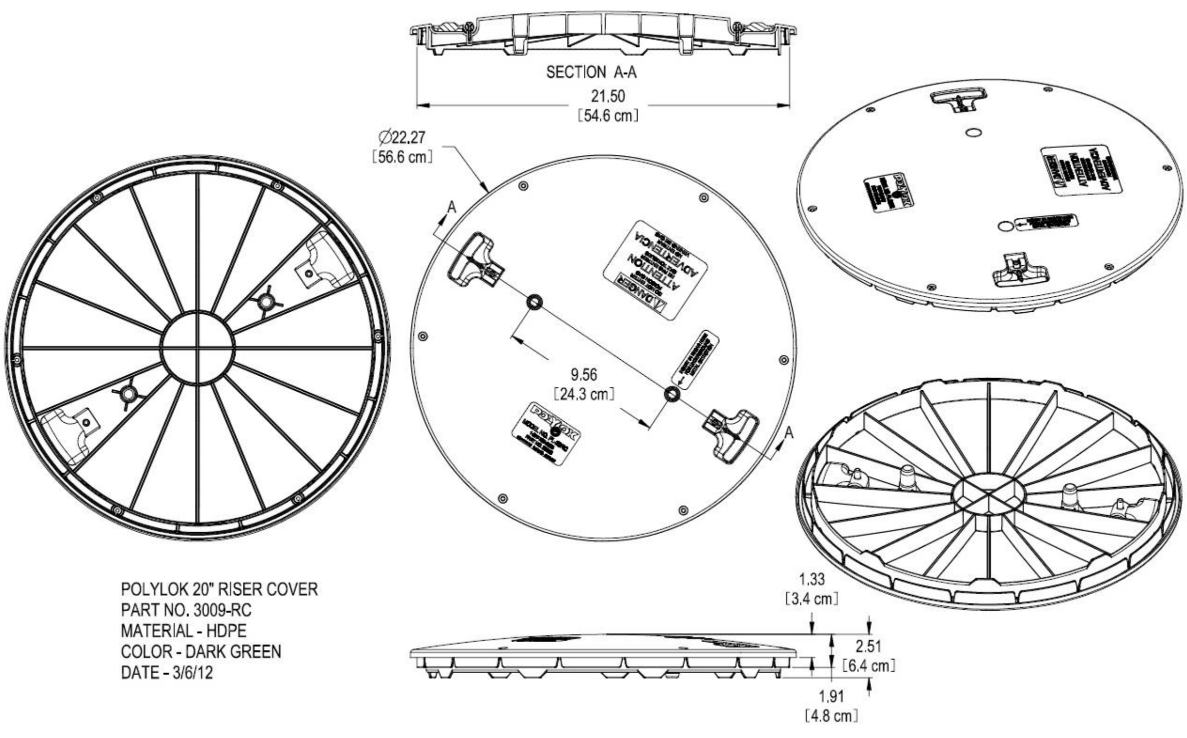


Figure A-3: Septic Tank Riser Lids

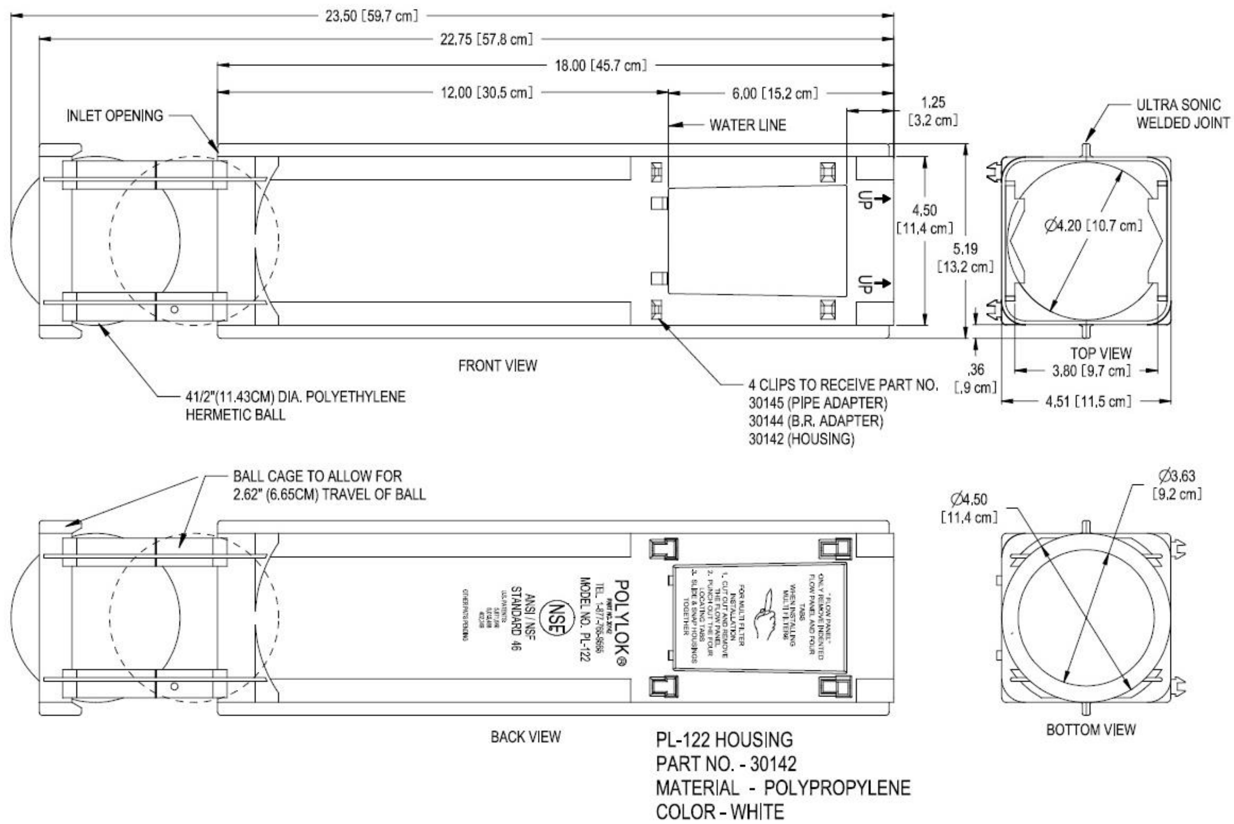


Figure A-4: Effluent Filter Housing

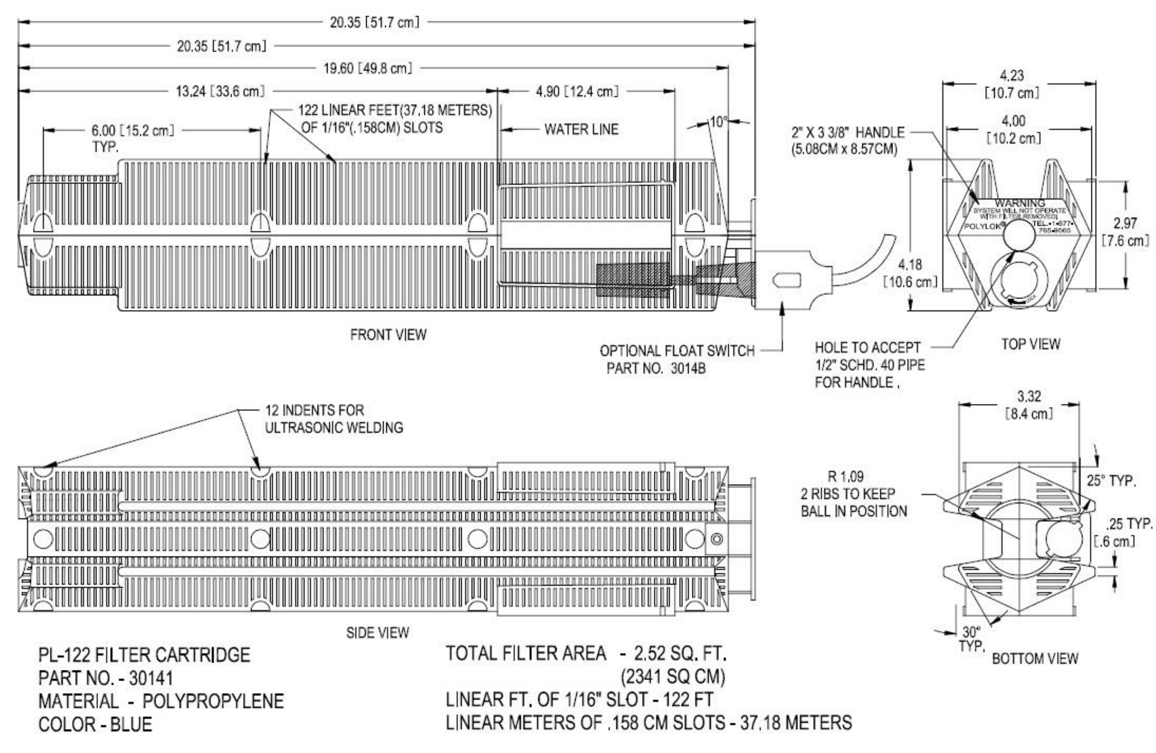


Figure A-5: Effluent Filter

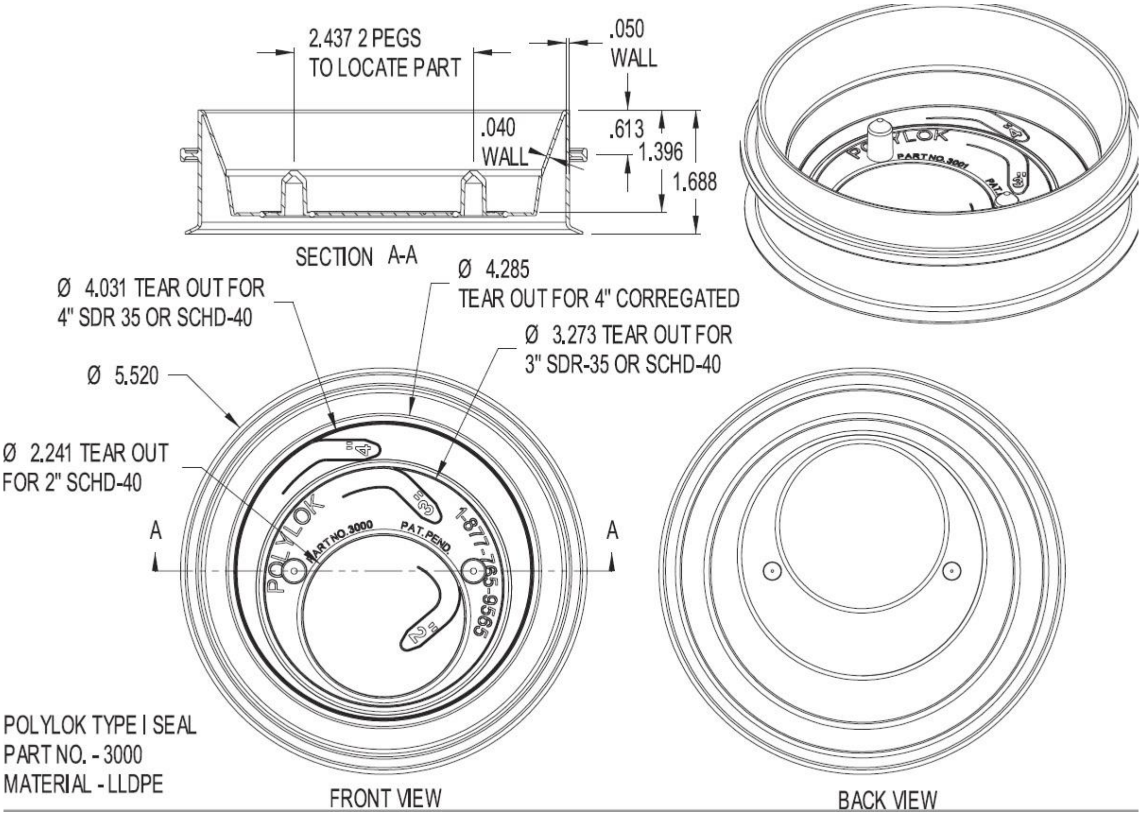


Figure A-6: Rubber Seals for Septic Tanks and Distribution Boxes

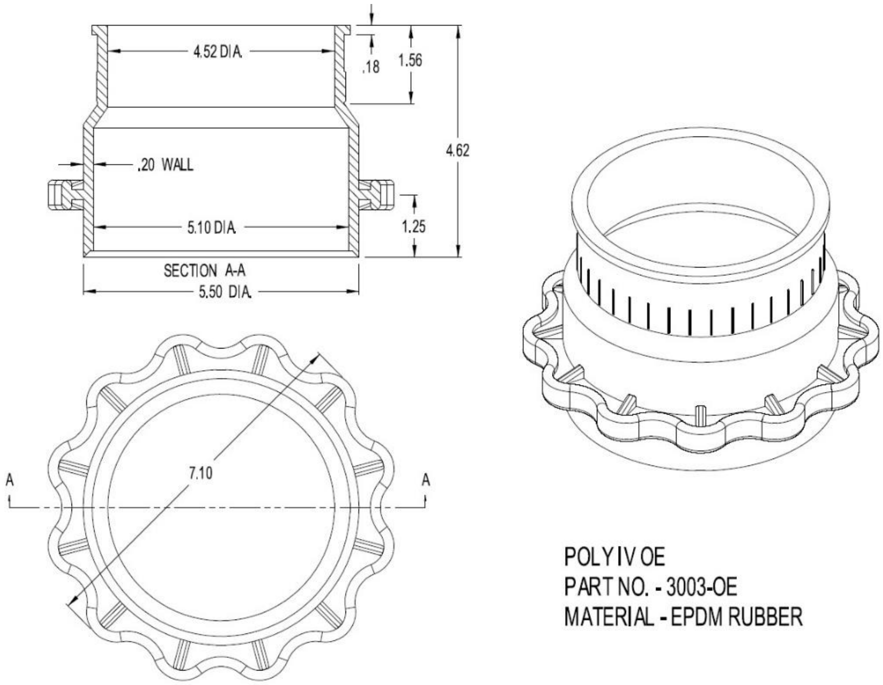


Figure A-7: Septic Tank Rubber Boots

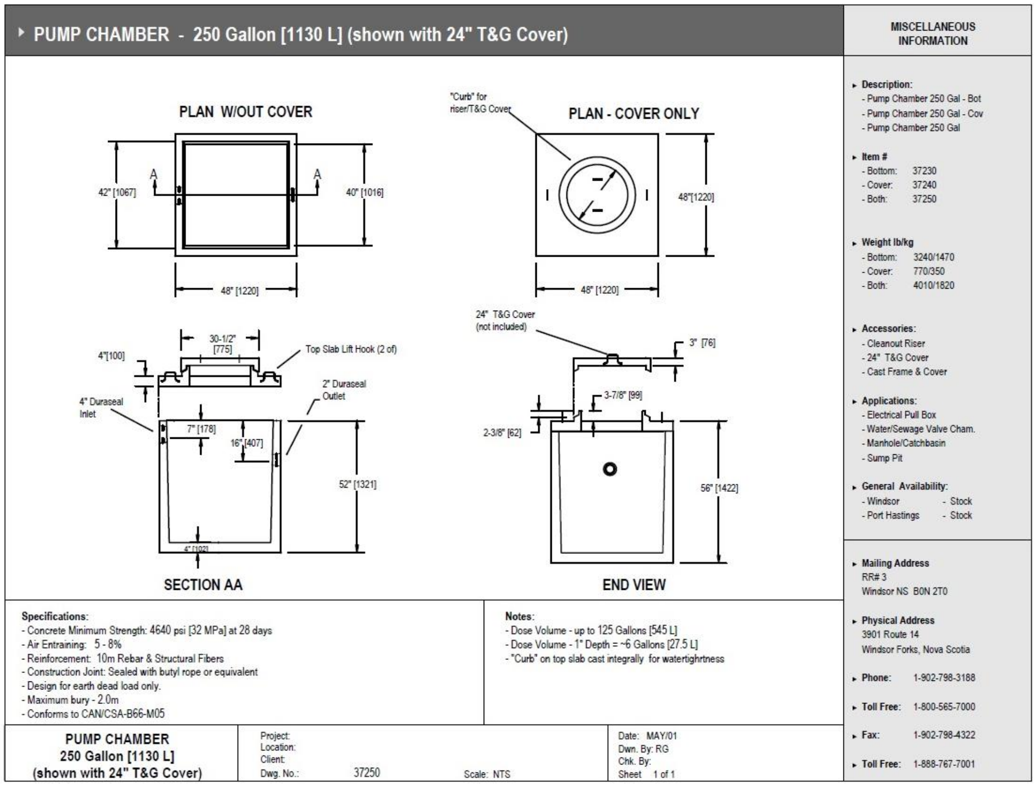


Figure A-8: 1,130 L Pump Chamber

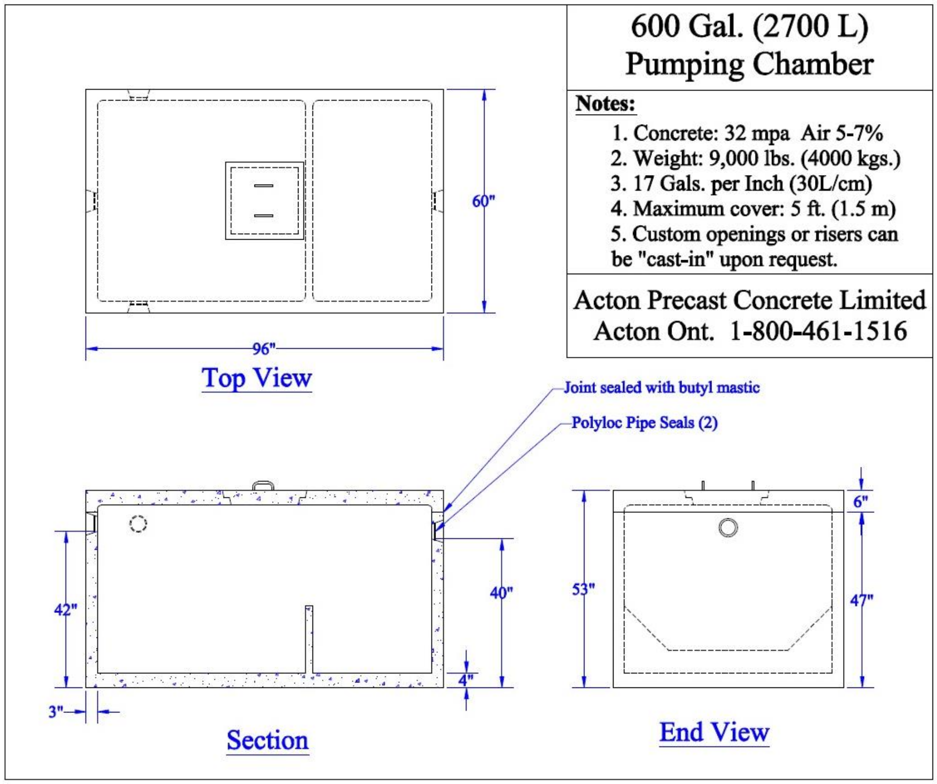


Figure A-9: 2,700 L Pump Chamber

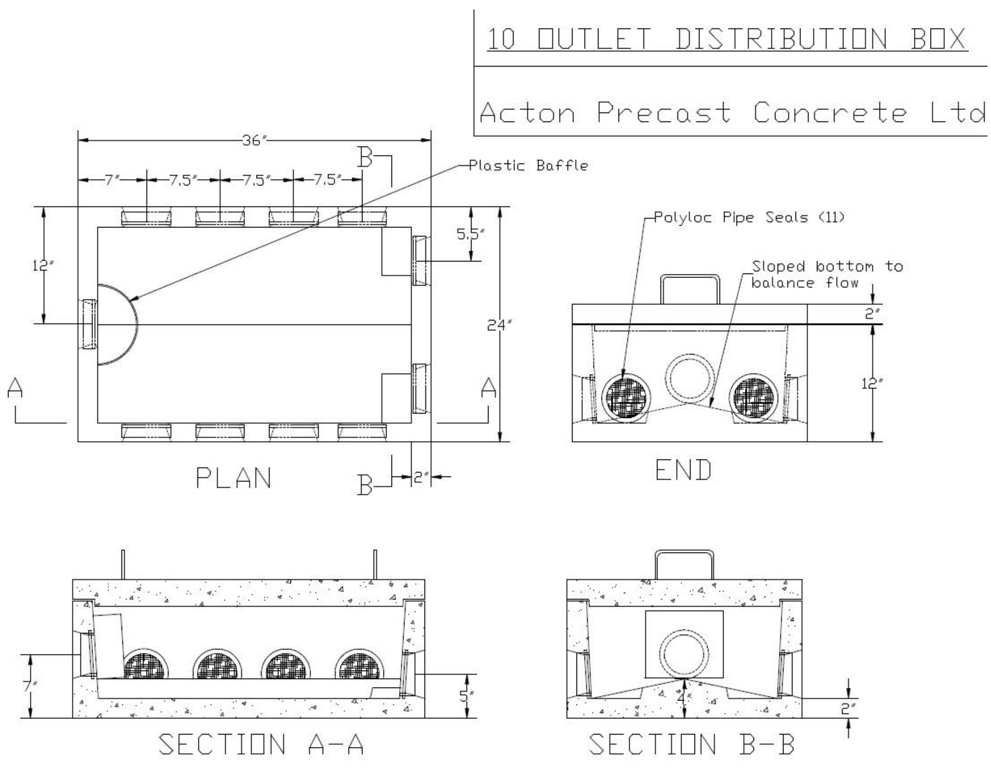


Figure A-10: Distribution Boxes

Figure A- 11: Submersible Pump

Ontario Building Code Calculations

Table A-3: Ontario Building Code Treatment, Holding Tanks, and General Leaching Bed Requirements

Component	Ontario Building Code Regulation	Stipulation
Treatment and Holding Tanks	8.2.2.3(1)	The minimum working capacity of a septic tank shall be the greater of 3,600 L
	8.2.2.3(1)(a)	in residential occupancies, twice the daily design sanitary sewage flow
	8.2.2.3(2)	Every septic tank shall be constructed in such a manner that any sanitary sewage flowing through the tank will pass through at least 2 compartments
	8.2.2.3(3)	The working capacity of the compartments required in Sentence (2) shall be sized such that,
	8.2.2.3(3)(a)	the first compartment is at least 1.3 times the daily design flow but in no case less than 2,400 L, and
	8.2.2.3(3)(b)	each subsequent compartment shall be at least 50% of the first compartment
General Leaching Bed Design and	8.7.2.1(1)	A leaching bed shall not be located,
	8.7.2.1(1)(a)	in an area that has an average slope that exceeds one unit vertically to four units horizontally

Construction Requirements	8.7.2.1(1)(b)	in soil or leaching bed fill having a percolation time of,
	8.7.2.1(1)(b)(i)	less than one minute, or greater than 125 mins if constructed as a shallow buried trench, or
	8.7.2.1(1)(b)(ii)	less than one minute, or greater than 50 minutes for all other leaching beds, or
	8.7.2.1(1)(c)	in or on an area that is subject to flooding that mat be expected to cause damage to the leaching bed or impair the operation of the leaching bed
	8.7.2.1(2)	A leaching bed shall not be covered with any material having a hydraulic conductivity less than 0.01 m/day
	8.7.2.1(3)	The surface of the leaching bed shall be shaped to shed water and together with the side slopes of any raised portion, shall be protected against erosion in such a manner as to not inhibit the evaporation and transpiration of waters from the soil or leaching bed fill, and not to cause plugging of the distribution pipe
	8.7.2.1(4)	No part of the leaching bed shall be sloped steeper than 1 unit vertically to 4 units horizontally

Table A-4: Ontario Building Code Absorption Trench Design and Construction

Component	Ontario Building Code Regulation	Stipulation
Absorption Trench Construction	8.7.3.1(1)	The total length of the distribution pipe shall,
	8.7.3.1(1)(a)	not be less than 30 m when constructed as a shallow buried trench
	8.7.3.1(1)(b)	not be less than 40 m for any other absorption trench
Absorption Trenches	8.7.3.2(1)	Except as provided in Sentence (2), absorption trenches shall be,
	8.7.3.2(1)(a)	approximately the same length and not more than 30 m in length,
	8.7.3.2(1)(b)	not less than 500 mm and not more than 1,000 mm in width,
	8.7.3.2(1)(c)	not less than 600 mm ad not more than 900 mm in depth
	8.7.3.2(1)(d)	centred not less than 1,600 mm apart
	8.7.3.2(1)(e)	located so that the bottom of the absorption trench is not less than 900 mm above the high ground water table, rock, or soil with a percolation time of more than 50 minutes and,

	8.7.3.2(1)(f)	backfilled, after the installation of the distribution pipe with leaching bed fill, so as to ensure that after the leaching bed fill settles, the surface of the leaching bed will not form any depressions.
	8.7.3.2(2)	Absorption trenches constructed as a shallow buried trench shall be,
	8.7.3.2(2)(a)	approximately the same length and not more than 30 m in length,
	8.7.3.2(2)(b)	not less than 300 mm and not more than 600 mm in width,
	8.7.3.2(2)(c)	not less than 300 mm and not more than 600 mm in depth,
	8.7.3.2(2)(d)	centred not less than 2,000 mm apart
	8.7.3.2(2)(e)	not less than 900 mm at all points on the bottom of the absorption trench above the high ground water table or rock, and
	8.7.3.2(2)(f)	backfilled, after the installation of the distribution pipe with leaching bed fill, so as to ensure that after the leaching bed fill settles, the surface of the leaching bed will not form any depressions.

Table A-5: Ontario Building Code Distribution Pipe

Component	Ontario Building Code Regulation	Stipulation
Distribution Pipe	8.7.3.3(1)	Except for a shallow buried trench, the distribution pipe used in the construction of a leaching bed shall be,
	8.7.3.3(1)(a)	not less than 3 in. trade size for gravity flow systems
	8.7.3.3(1)(b)	installed with a uniform downward slope from the inlet with a drop of not less than 30 mm and not more than 50 mm for each 10 m of distribution pipe for gravity flow systems, and
	8.7.3.3(1)(c)	installed with a layer of stone conforming to Sentence (5)

8.7.3.3(2)	Prior to backfilling, the stone layer required by Clause (1)(c) shall be protected in such a manner so as to prevent soil or leaching bed fill from entering the stone by completely covering it with,
8.7.3.3(2)(a)	untreated building paper, or
8.7.3.3(2)(b)	a permeable geo-textile fabric
8.7.3.3(3)	Every pressurized distribution pipe shall be self-draining so as to prevent freezing of its contents
8.7.3.3(4)	Every pressurized distribution pipe shall,
8.7.3.3(4)	not be less than 1 in. trade size, and
8.7.3.3(4)	have orifices of at least 3 mm in diameter, spaced equally along the length of the pipe
8.7.3.3(5)	The stone layer required by Clause (1)(c) shall,
8.7.3.3(5)(a)	be comprised of washed septic stone, free of fine material, with gradation conforming to Table 8.7.3.3.,
8.7.3.3(5)(b)	be not less than 500 mm in width
8.7.3.3(5)(c)	extend not less than 150 mm below the distribution pipe, and
8.7.3.3(5)(d)	extend not less than 50 mm above the distribution pipe.

Table A-6: Ontario Building Code Fill Based Absorption Trenches

Component	Ontario Building Code Regulation	Stipulation
Fill Based Absorption Trenches	8.7.4.1(1)	The area described in Sentence 8.7.4(1) shall be designed such that the loading rate does not exceed, for soil having a percolation time set out in Column 1 of Table 8.7.4.1., the maximum value set out opposite it in Column 2 of Table 8.7.4.1.
	8.7.4.2(1)	Except for a shallow buried trench, a leaching bed comprised of absorption trenches may be constructed in leaching bed fill, if unsaturated soil or leaching bed fill complying with Subclause 8.7.2.1(1)(b)(ii) extends,
	8.7.4.2(1)(a)	to a depth of at least 250 mm over the area covered by the leaching bed fill, and

8.7.4.2(1)(b)	for at least 15 m beyond the outer distribution pipes in any direction in which the effluent entering the soil or leaching bed fill will move horizontally
8.7.4.2(2)	If the unsaturated soil or leaching bed fill described in Sentence (1) has a percolation time of greater than 15 minutes, any additional leaching bed fill added to it to form the leaching bed shall have a percolation time not less than 75% of the percolation time of the unsaturated soil or leaching bed fill to which it is added
8.7.4.2(3)	Leaching bed fill that does not meet the requirements of Sentence (2) may be used to form the leaching bed if,
8.7.4.2(3)(a)	the distance from the bottom of the absorption trench to the underlying soil is not less than 900 mm, or
8.7.4.2(3)(b)	where the distance from the bottom of the absorption trench to the underlying soil is less than 900 mm, the percolation time of the least permeable soil or leaching bed fill within 900 mm from the bottom of the absorption trench is used to calculate the length of the distribution pipe under Article 8.7.3.1
8.7.4.2(4)	Sentence (2) does not apply to any leaching bed fill added as backfill above the stone layer in which the distribution pipe is located

Table A-7: Septic Systems Required and Optional Components

Leaching Bed	Septic Tank	Level IV Treatment	Pressurized or Dosed Distribution
Conventional	Required	Optional	Yes, if length of distribution pipe exceeds 150 m
Sand Filter Bed	Required	Optional	Optional
Shallow Buried Trench	Required	Required	Yes
Type A Dispersal Bed	Required	Required	Optional
Type B Dispersal Bed	Required	Required	Yes

Table A-8: Daily Design Flowrate Residential Occupancy and Volumes

Residential Occupancy		Volume (liters)
Apartments, condominiums, or other multi-family dwelling, per person		275
Boarding houses	Per person, with meals and laundry facilities	200
	Per person, without meals or laundry facilities	150

	Per non-resident staff per 8-hour shift	40
Boarding school, per person		300
Dwellings	1-bedroom dwelling	750
	2-bedroom dwelling	1,100
	3-bedroom dwelling	1,600
	4-bedroom dwelling	2,000
	5-bedroom dwelling	2,500
Additional flow for	Each bedroom over 5	500
	Each 10 m^2 (or part of it) over 200 m^2 up to 400 m^2	100
	Each 10 m^2 (or part of it) over 400 m^2 up to 600 m^2	75
	Each 10 m^2 (or part of it) over 600 m^2	50
	Each fixture unit over 20 fixture units	50

Table A-9: Percolation Time and Distribution Pipe Length

Column 1 Percolation Time, (T) of Soil, min	Column 2 Length of Distribution Pipe, m
$1 < T \leq 20$	Q/75
$20 < T \leq 50$	Q/50
$50 < T < 125$	Q/30

Table A-10: Required Soil Distribution of Septic Stone

Column 1 Particle Size	Column 2 Percent Passing
53 mm	100
19 mm	0-5
75 µm	0-1

Table A-11: Percolation Time and Leaching Bed Loading Rates

Column 1 Percolation Time (T) of Soil, min	Column 2 Loading Rates, $(L/m^2)/day$
$1 < T \leq 20$	10
$20 < T \leq 35$	8
$35 < T \leq 50$	6
$T > 50$	4

Table A-12: Required Effluent Quality of Treatment Units

Column 1 Classification of Treatment Unit	Column 2 Suspended Solids	Column 3 CBOD5
Level II	30	25
Level III	15	15
Level IV	10	10

Table A-13: Ontario Building Code Equations

Component	Ontario Building Code Regulation	Stipulation	Equation	Additional Information
Absorption Trench	8.7.3.1(2)	Except as provided in Sentences (1), (3), and (4) every leaching bed constructed by means of absorption trenches shall have a total length of distribution pipe not less than the value determined by the formula	$L = \frac{QT}{200}$	L = total length of distribution pipe in metres, Q = the total daily design sanitary sewage flow in liters, T = the design percolation time
	8.7.3.1(3)	Except as provided in Sentence (1), where a leaching bed recieves effluent from a Level II, Level III or Level IV treatment unit as described in Table 8.6.2.2., the leaching bed may have a total length of distribution pipe not less than the value determined by the formula	$L = \frac{QT}{300}$	L = total length of distribution pipe in metres, Q = the total daily design sanitary sewage flow in liters, T = the design percolation time

Filter Beds	8.7.5.3(6)	The base of the filter medium shall extend to a thickness of at least 250 mm over an area meeting the requirements of the following formula	$A = \frac{QT}{850}$	A = the area of contact in square meters between the base of the filter medium and the underlying soil Q = the total daily design sanitary sewage flow in litres, and T= the lesser of 50 and the percolation time of the underlying soil
Type A Dispersal Bed	8.7.7.1(4)(c)(ii)	the value (sand area) determined by the formula	$A = \frac{QT}{850}$	A = the area of contact in square meters between the base of the filter medium and the underlying soil Q = the total daily design sanitary sewage flow in litres, and T= the lesser of 50 and the percolation time of the underlying soil
	8.7.7.1(5)(b)	have an area (sand mantle) that is not less than the value determined by this formula	$A = \frac{QT}{400}$	A = the area of contact in square metres between the base of the sand and the underlying soil, or leaching bed fill if utilized, Q = the total daily design sanitary sewage flow in litres, and T = the lesser of 50 and the percolation time of the underlying soil
	8.7.7.1(6)(e)	have a minimum area (stone) not less than the value determined by the formula	$A = \frac{Q}{B}$	A = the area of the stone layer in square metres, B = the following amount, (i) 50, if the total daily design sanitary sewage flow exceeds 3,000 L or (ii) 75, of the total daily design sanitary sewage flow does not exceed 3,000L and Q = the total daily design sanitary sewage flow in litres.

Type B Dispersal Bed	8.7.8.3(2)(b)	the value (the area of the stone layer) determined by the formula	$A = \frac{QT}{400}$	A = the area of contact in square metres between the stone layer and the underlying soil, or leaching bed fill if utilized, Q = the total daily design sanitary sewage flow in litres, and T = the percolation time of the underlying soil

Sample Calculations for Time of 40 min/cm

The following design conditions were assumed:

Number of Bedrooms: 3
Area of the house: 240 m^2
Percolation time of the native soil (T-Time): 40 min/cm

Tank Design and Components

Table 8.2.1.3.A from the OBC, total daily deign sanitary sewage flow:

$$Q = 1{,}600\ L + (100\ L \times 4) = 2{,}000\ L$$

$$Minimum\ Septic\ Tank\ Volume = Q \times 2 = 2{,}000\ L \times 2 = 4{,}000\ L$$

The minimum required septic tank volume is 4,000 L, the closet prefabricated size is 4,500 L. Therefore the 4,500 L tank manufactured by Unit Precast was chosen, the amount of excavated soil was calculated using the outer most length (2.56 m), width (1.68 m), and height (1.78 m) of the septic tank. In addition, the maximum burial depth is 1 m, therefore it was assumed the septic tank would be installed 1 m below ground. An additional factor of 15% was applied to all components as backhoes due to the irregular digging. The total required excavated volume for the septic tank is:

$$Vexcavated = [2.56\ m \times 1.68\ m \times (1.78\ m + 1\ m)] \times 1.15 = 13.7m^3$$

CAD drawings, which included measurements and material composition were supplied for: the septic tank, pumping chambers, and polylok's products. The volume was found for each product and converted to a mass by multiplying the volume by the density of the material.

Transportation distances were assumed, due to local installers, and manufacturers around Guelph. The transport truck/larger vehicle input in SimaPro is in tonnes-km, which is the mass transported multiplied by the distance.

$$Septic\ Tank\ Transport\ Input = Septic\ tank\ weight\ \times distance$$
$$= 4.8429\ tonnes\ \times 50\ km$$

$$Septic\ Tank\ Transport\ Input = 242.1\ tkm$$

Concrete Pumping Chamber: 2,700 L

The 2,700 L pumping chamber consists of a length, width, and height of 2.44 m, 1.52 m, and 1.35 m respectively. The maximum burial depth is 1.5 m, therefore:

$$Vexcavated = [2.44\ m \times 1.52 \times (1.35\ m + 1.5\ m)] \times 1.15 = 12.2\ m^3$$

Concrete Pumping Chamber: 1,130 L

The 1,130 L pumping chamber consists of a length, width, and height of 1.22 m, 1.22 m, and 1.422 m respectively. The maximum burial depth is 2 m, therefore:

$$Vexcavated = [1.22\ m \times 1.22\ m \times (1.422\ m + 2\ m)] \times 1.15 = 5.9\ m^3$$

Level IV Treatment Unit

For the assumed lot and daily sewage flow conditions, Waterloo Biofilter would use a Roth ST-750 Tank with a capacity of 2,840 L and with a length of 2.62 m, a width of 1.57 m and a height of 1.30 m. The maximum burial depth is 0.91 m. therefore the total amount of excavated soil to install a Roth ST-750 Tank is:

$$Vexcavated = [2.62\ m\ \times 1.52\ m\ \times (1.30\ m + 0.91\ m)] \times 1.15 = 10.1\ m^3$$

Conventional Leaching Bed

$$Pipe\ Length = \frac{Q \times T}{200} = \frac{2{,}000 \times 40}{200} = 400\ m$$

For a conventional leaching bed, if the pipe length is equal to or greater than 150 m, the effluent must be dosed by either a pump or siphon. Since 400 m of distribution pipe is required, it was assumed there would be 14 runs with a length of 30 m for each run, with an additional of 15 m of extra piping for the distribution from the septic tank to the pumping chambers to the leaching bed. The minimum required width is 0.5 m, and the thickness/height of the stone layer for the absorption trench was assumed to be 275 mm, as a minimum height of 50 mm and 150 mm is required for above and below the pipe respectively. The remaining 75 mm was assumed to be the soil in line with the pipe.

$$Vstone = l \times w \times h = 30\ m \times 0.5\ m\ \times 0.275\ m \times 14\ runs = 54.3\ m^3$$

Building paper is required for all leaching beds except shallow buried trench, therefore the area of the building paper required is:

$$Abuilding\ paper = l \times w = 30\ m\ \times 0.5\ m\ \times 14\ runs = 210\ m^2$$

Assuming a slope of 1 unit vertically to 20 units horizontally (a 5% slope), and assuming an approximate length of 10 m between the outlet of the septic tank and the distribution pipes in the leaching bed. It was assumed the excavated depth of backfill and topsoil was approximately 1.5 m, therefore the total amount of excavated soil is:

$$Vexcavated = (Vstone + Vbackfill) \times 1.15$$

$$Vexcavated = [54.3\ m^3 + (210\ m^2 \times 2\ m)] \times 1.15 = 545.4\ m^3$$

Filter Sand Bed

$$Astone = \frac{Q}{75} = \frac{2{,}000}{75} = 26.7\ m^2 \cong 27 m^2$$

It was assumed the length and width of the stone layer is 5.5 m and 5 m respectively. It was assumed 4 runs of 5.5 m would be installed, which would equal 22 m of PVC pipe. In addition, 15 m of extra PVC pipe was assumed for each scenario as pipes are required between the leaching bed and septic tank. The total PVC required is for both the leaching bed and distribution is 37 m. The minimum required thickness for the stone layer is 0.3 m, therefore:

$$Vstone = Astone\ \times h = 27\ m^2 \times 0.3\ m = 8.1\ m^3$$

if Q<3000 L/d

$$Amantle = \frac{Q}{LR} = \frac{2{,}000}{6} = 333.4\ m^2$$

The minimum required height of the mantle is 0.2 m, therefore:

$$Vmantle = Amantle \times h = 333.4\ m^2 \times 0.2\ m = 66.7 m^3$$

$$Afilterbed = Agravel = 27\ m^2$$

The minimum required height of a filter bed is 0.75 m, therefore:

$$Vfilter\ bed = Afilterbed\ \times h = 27\ m^2 \times 0.75\ m = 20.25\ m^3$$

Where LR = 6 if 35<T≤50 (Table 8.7.4.1)

$$Abottom = \frac{Q \times T}{850} = \frac{2{,}000 \times 40}{850} = 94.1\ m^2 \cong 95\ m^2$$

The minimum required height of the filter bed is 0.25 m, therefore:

$$Vbottom = (Abottom - Afilterbed) \times h = (95 - 27) \times 0.25 = 17\ m^3$$

The total volume of sand required for the filter bed, the extended base and the mantle is:

$$Vtotal = Vmantle + Vfilterbed + Vbottom = 66.7\ m^3 + 20.25\ m^3 + 17\ m^3 \cong 104\ m^3$$

$$Abuilding\ paper = Astone = 27\ m^2$$

Due to the small footprint of the filter bed, the depth of backfill excavation was assumed to be 1.5 m, as the top of the septic tank is located 1 m below surface. The filter bed has a calculated surface area of 27 m^2, therefore the total amount of excavated soil for the filter bed is:

$$Vexcavated = (Vstone + Vsand + Vbackfill) \times 1.15$$
$$= [8.1\ m^3 + 104\ m^3 + ((27\ m^2 + 333.4\ m^2) \times 1.5\ m)] \times 1.15$$

$$Vexcavated = 750.6\ m^3$$

Shallow Buried Trench

$$Pipe\ Length = \frac{Q}{50} = \frac{2,000}{50} = 40\ m$$

Therefore 4 runs of 10 m for both 1 inch diameter perforated PVC pipe and 12 inch (0.3048 m) diameter Big-O (half domes) was assumed, , with an additional 20 m of 4 inch diameter piping, 15 m as specified above, and 5 m to support the 1 inch dosing pipe.

Since a shallow buried trench is installed on site with high ground water tables, it was assumed the shallow buried trench was 0.5 m below the ground's surface. Therefore the total amount of excavated soil is:

$$Vexcavated = (Vbig - O + Vbackfill) \times 1.15$$
$$= [(0.3048\ m\ \times 0.1524\ m\ \times 40\ m) + (0.3048\ m \times 40\ m \times 0.5\ m)] \times 1.15$$
$$Vexcavated = \ 9.1\ m^3$$

Type A Dispersal Bed

$$Astone = \frac{Q}{B} = \frac{2,000}{75} = 26.7m^2$$

Therefore, the minimum required area is 26.7 m2, a length and width of 7.5 m and 3.6 m was assumed respectively. The minimum required thickness for the stone layer is 0.2 m, therefore:

$$Vstone = l \times w \times h = 7.5\ m\ \times 3.6\ m\ \times 0.2\ m = 5.2\ m^3$$

$$Asand = \frac{Q \times T}{850} = \frac{2,000 \times 40}{850} = 94.1\ m^2$$

The minimum required area is 94.1 m^2, and the code specifies the sand area must extended at least 600 mm from each side of the stone layer. Therefore, the length and width assumed was 11.8 m and 8 m respectively. In addition, the PVC distribution pipe must not be within 600 mm of the stone layer from every side. Therefore 3 runs of 6.3 m of 4 inch diameter was assumed for the leaching bed and an extra 15 m for distribution. In total approximately 37 m of PVC pipe will be used. The minimum required thickness of the sand layer is 0.3 m, therefore:

$$Vsand = l \times w \times h = 11.8\ m \times 8\ m \times 0.3\ m = 28.2\ m^3$$

$$Amantle = \frac{Q \times T}{400} = \frac{2,000 \times 40}{400} = 200\ m^2$$

The minimum required area is 200 m2, a length and width of 17 m and 11.8 m was assumed. The minimum required thickness for the mantle is 0.2 m, therefore:

$$Vmantle = l \times w \times h = 17\ m\ \times 11.8\ m\ \times 0.2\ m = 40.2\ m^3$$

The total volume of sand required is the sum of the sand layer and the mantle

$$Vtotal = Vsand + Vmantle = 28.4\ m^3 + 40.2\ m^3 = 68.6\ m^3$$

$$Abuilding\ paper = Astone = 27\ m^2$$

Similarly, to shallow buried trench leaching beds, Type A and B dispersal beds are typically installed in lots with high ground water tables. Therefore, the depth from the ground surface to the top of the trenches was assumed to be 0.5 m.

$$Vexcavated = Vsand\ and\ stone + Vmantle$$
$$= \{[94.1\ m^2 \times (0.5\ m + 0.5m\ )] + [200\ m^2 \times (0.2 + 0.5)]\} \times 1.15$$
$$Vexcavated = 269.2\ m^3$$

Type B Dispersal Bed

$$Astone = \frac{Q \times T}{400} = \frac{2{,}000 \times 40}{400} = 200\ m^2$$

The maximum width of the stone layer is 4 m, therefore assuming a width of 4 m, a length of 50 m was assumed. Similarly, to the Type A dispersal bed, the dosing pipe must not be within 600 mm from the edge of the stone layer. It was assumed 3 runs of 48.8 m of 1 inch diameter and 15 m of 4 inch diameter PVC piping will be installed. The minimum required thickness of the stone layer is 0.3 m, therefore:

$$Vstone = Astone \times h = 200\ m^2 \times 0.3\ m = 60\ m^3$$
$$Abuilding\ paper = Astone = 200\ m^2$$
$$Vexcavated = [200\ m^2 \times (0.3\ m + 0.5\ m)] \times 1.15 = 184\ m^3$$

The same depths, but different surface areas were used to calculate the required excavated soil for a T-time of 10 minutes/cm.

Septic System Maintenance

$$\rho_{slurry} = \%\rho_{sludge} + \%\rho_{water} = \left(\frac{1}{3}\right) \times 1400 \frac{kg}{m^3} + \left(\frac{2}{3}\right) 1000 \frac{kg}{m^3} = 1136.7\ \frac{kg}{m^3}$$

$$mass\ of\ slurry = m_{slurry} = 4.5\ m^3 \times 1136.7\ \frac{kg}{m^3} \times \frac{25\ years}{once\ every\ 3\ years} = 42{,}626.3\ kg$$

APPENDIX B: LIFE CYCLE INVENTORY TABLES

Table B-1: Septic Tank LCI Inputs

Septic Tank Inputs	Quantity	Material	SimaPro Dataset	Value	Units
Concrete Tank	1	35 MPa Concrete	Construction/Concrete/Transformation/Concrete, 35MPa {CA-QC} |concrete production 35MPa, RNA only | Alloc Def, S	4745.8	kg
Inlet Baffle	1	PVC	Plastics/Thermoplastics/PVC Pipe E	0.9	kg
Effluent Filter Ball	1	Plastics/Thermoplasts/Market	Plastics/Thermoplasts/Market/Polyethylene, low density, granulate {GLO}| market for | Alloc Def, S	3.15E-08	kg
Effluent Filter and Casing	1	Polypropylene	Plastics/Thermoplasts/Market/Polypropylene granulate {GLO}| market for | Alloc Def, S	3.1	kg
Riser Adapter and Riser	2	HDPE	Plastics/Thermoplasts/Market/Polyethylene, high density, granulate {GLO}|market for|Alloc Def, S	11.5	kg
Lids	2	HDPE	Plastics/Thermoplasts/Market/Polyethylene, high density, granulate {GLO}|market for|Alloc Def, S	10.1	kg
Septic Tank Rubber Boots	2	EPDM Rubber	Plastics/Rubbers/Market/Synthetic rubber {GLO} |market for| Alloc Def, S	0.60	kg
Rubber Seals for Aeration	1	Ethylene vinyl acetate copolymer (EVA)	Plastics/Thermoplastics/Market/Ethylene vinyl acetate copolymer {GLO}|market for|Alloc Def, S	0.22	kg
Riser Seal	4 m	Butyl Tape (Synthetic Rubber based)	Plastics /Rubbers/Market/Synthetic rubber {GLO} |market for| Alloc Def, S	0.13	kg
Anchor Bolts	16	Galvanized Steel	Metals/Ferro/Steel hot rolled coil (ILCD), blast furnace route, production mix, at plant, 1kg, typical thickness between 2 - 7 mm. typical width between 600 - 2100 mm GLO S	2.3	kg
Screws	40	Stainless Steel	Metals/Ferro/Market/Steel, low-alloyed {GLO}| market for | Alloc Def, S	0.93	kg
Pipe	1.25 m	PVC	Plastics/Thermoplastics/PVC Pipe E	3.74	kg

Reinforcing Steel for Tank (15M)	22 m	Steel	Metals/Ferro/Market/Reinforcing steel {GLO}| market for | Alloc Def, S	34.4	kg
Reinforcing Steel for Tank and Frame (10M)	38.5 m	Steel	Metals/Ferro/Market/Reinforcing steel {GLO}| market for | Alloc Def, S	30.2	kg
Transportation by a Transport Truck	50 km	-	Transport/Road/Market/Transport, freight, lorry 16-32 metric ton, EURO 3 {GLO} | market for | Alloc Def, S	242.2	tkm
Excavation by a Hydraulic Digger	2.36 m^3	-	Transport/Building Equipment/Market/Excavation, Hydraulic Digger {GLO} |market for|Alloc Def, S	13.7	m^3
Transportation of Installers	250 km over 5 days	-	Transport, passenger car, medium size, petrol, EURO 3 {GLO}|market for| Alloc Def, S	250	km
Treatment of Sludge	12500 L	-	Waste treatment/Wastewater Treatment/Transformation/Wastewater, from residence {RoW}|treatment of, capacity 1.1E10L/yr|Alloc Def, S	42,626	kg
Transportation of Sludge	30 km	-	Transport/Road/Market/Transport, freight, lorry 16-32 metric ton, EURO 3 {GLO} | market for | Alloc Def, S	1278.8	tkm

Table B-2: Conventional Leaching Bed LCI Inputs

Phase	Conventional Adsorption Trench Inputs	Quantity	Material	SimaPro Dataset	Value	Units
Manufacturing	Concrete Distribution Box	2 Boxes (0.21 m3)	35 MPa Concrete	Construction/Concrete/Transformation/Concrete, 35MPa {CA-QC} |concrete production 35MPa, RNA only | Alloc Def, S	476.1	kg
	PVC	435 m	PVC	Plastics/Thermoplastics/PVC Pipe E	1,301	kg
	Building Paper	210 m^2	Kraft Paper	Paper + Board/Packaging paper/Market/Kraft Paper, unbleached {GLO} |market for| Alloc Def, S	133.4	kg

	Handles	4	Galvanized Steel	Metals/Ferro/Steel hot dip galvanized (ILCD), blast furnace route, production mix, at plant, 1 kg, typical thickness 0.3-3mm. Typical width 600-1200 mm. GLO S	8	kg
	Seals	16	EDPM Rubber	Plastics/Thermoplastics/Market/Ethylene vinyl acetate copolymer {GLO}|market for|Alloc Def, S	1.7	kg
	Water Tight Seal Tape	13 m	Butyl Tape	Plastics/Rubbers/Transformation/Synthetic Rubber {GLO}|production| Alloc Def, S	0.63	kg
	Stone	54.3 m3	Gravel	Minerals/Transformation/Gravel, round {RoW} |gravel and sand quarry operation| Alloc Def, S	118,472	kg
Installation	Transportation by a Transport Truck	50 km	-	Transport/Road/Market/Transport, freight, lorry 16-32 metric ton, EURO 3 {GLO} | market for | Alloc Def, S	5,948	tkm
	Transportation by Car	20 km	-	Transport/Road/Market/Transport, passenger car, medium size, petrol, EURO 3 {GLO}|market for| Alloc Def, S	60	km
	Excavation by Hydraulic Digger	545.4 m^3	-	Transport/Building Equipment/Market/Excavation, Hydraulic Digger {GLO} |market for|Alloc Def, S	545.4	m^3
Use	Electricity	65.5 kwh	-	Energy/Electricity by country mix/Low Voltage/Market/Electricity, low voltage {CA-ON}|market for| Alloc Def, S	65.5	kwh

Table B-3: 2,700 L and 1,130 L Pump Chamber LCI Inputs

Pumping Chamber Inputs	Quantity	Material	SimaPro Dataset	Value	Units
Pumping Chamber	1.35 m^3	32 MPa Concrete	Construction/Concrete/Market/Concrete, 35MPa {GLO} |market for| Alloc Def, S	3,123.3	kg
Handles	2	Galvanized Steel	Metals/Ferro/Steel hot dip galvanized (ILCD), blast furnace route, production mix, at plant, 1 kg, typical thickness 0.3-3mm. Typical width 600-1200 mm. GLO S	4	kg
Screws and fasteners for the handles	16	Stainless Steel	Metals/Ferro/Market/Steel, low-alloyed {GLO}| market for | Alloc Def, S	0.37	kg

Transportation by a Transport Truck	50 km	-	Transport/Road/Market/Transport, freight, lorry 16-32 metric ton, EURO 3 {GLO} | market for | Alloc Def, S	156.4	tkm
Excavation by a Hydraulic Digger	12.2 m^3	-	Transport/Building Equipment/Market/Excavation, Hydraulic Digger {GLO} |market for|Alloc Def, S	18.6	m^3
Pump Chamber	0.611 m3	32 MPa Concrete	Construction/Concrete/Market/Concrete, 35MPa {GLO} |market for| Alloc Def, U	1,414.5	kg
Handles	2	Galvanized Steel	Metals/Ferro/Steel hot dip galvanized (ILCD), blast furnace route, production mix, at plant, 1 kg, typical thickness 0.3-3mm. Typical width 600-1200 mm. GLO S	4	kg
Screws and fasteners for the handles	16	Stainless Steel	Metals/Ferro/Market/Steel, low-alloyed {GLO}| market for | Alloc Def, S	0.37	kg
Reinforcing Steel for Tank and Frame (10M)	30.1 m	Steel	Metals/Ferro/Market/Reinforcing steel {GLO}| market for | Alloc Def, S	23.6	kg
Transportation by a Transport Truck	50 km	-	Transport/Road/Market/Transport, freight, lorry 16-32 metric ton, EURO 3 {GLO} | market for | Alloc Def, S	72.1	tkm
Excavation by a Hydraulic Digger	5.9 m^3		Transport/Building Equipment/Market/Excavation, Hydraulic Digger {GLO} |market for|Alloc Def, S	9.3	m^3
Casing	3	Cast Iron	Metals/Ferro/Market/Cast iron {GLO} |market for| Alloc Def, S	31.8	kg
Pump	3	Stainless Steel	Metals/Ferro/Market/Steel, chromium steel 18/8 {GLO}| market for| alloc Def, S	17.2	kg

Table B-4: Sand Filter Bed LCI Inputs

Sand Filter Bed Inputs	Quantity	Material	SimaPro Dataset	Value	Units
Pipe	37 m	PVC	Plastics/Thermoplastics/PVC Pipe E	110.6	kg
Building Paper	27 m^2	Kraft Paper	Paper + Board/Packaging paper/Market/Kraft Paper, unbleached {GLO} |market for| Alloc Def, S	85.7	kg

Filter Sand	104 m^3	Filter Sand	Chemicals/Inorganic/Market/Silica sand {GLO}|market for|Alloc Def, S	166,320	kg
Stone	8.1 m^3	Gravel	Minerals/Transformation/Gravel, round {RoW} |gravel and sand quarry operation| Alloc Def, S	17,658	kg
Transportation by a Transport Truck	50 km	-	Transport/Road/Market/Transport, freight, lorry 16-32 metric ton, EURO 3 {GLO} | market for | Alloc Def, S	9,198.9	tkm
Transportation by Car	20 km	-	Transport/Road/Market/Transport, passenger car, medium size, petrol, EURO 3 {GLO}|market for| Alloc Def, S	20	km
Excavation By Hydraulic Digger	750.6 m^3	-	Transport/Building Equipment/Market/Excavation, Hydraulic Digger {GLO} |market for|Alloc Def, S	750.6	m^3

Table B-5: Shallow Buried Trench LCI Inputs

Phase	Shallow Buried Trench Inputs	Quantity	Material	SimaPro Dataset	Value	Units
Manufacturing	Pipe	20 m of the 4-inch diameter pipe and 40 m of the 1 inch diameter pipe	PVC	Plastics/Thermoplastics/PVC Pipe E	78.8	kg
	Half Dome (Big-O)	40 m	HDPE	Construction/Ventilation/Transformation/Polyethylene Pipe, Corrugated, DN 75 {RoW}|Production|Alloc Def, S	10.2	kg

Installation	Transportation by Car	20 km	-	Transport/Road/Market/Transport, passenger car, medium size, petrol, EURO 3 {GLO}|market for| Alloc Def, S	20	km
	Excavation By Hydraulic Digger	9.1 m^3	-	Transport/Building Equipment/Market/Excavation, Hydraulic Digger {GLO} |market for|Alloc Def, S	9.1	m^3
Use	Electricity	52.5 kwh	-	Energy/Electricity by country mix/Low Voltage/Market/Electricity, low voltage {CA-ON}|market for| Alloc Def, S	52.5	kwh

Table B-6 Type A Dispersal Bed LCI Inputs

Type A Dispersal Bed Inputs	Quantity	Material	SimaPro Dataset	Value	Units
Pipe	37 m	PVC	Plastics/Thermoplastics/PVC Pipe E	110.6	kg
Building Paper	26.7 m^2	Kraft Paper	Paper + Board/Packaging paper/Market/Kraft Paper, unbleached {GLO} |market for| Alloc Def, S	17	kg
Sand	68.6 m^3	Sand	Minerals/Transformation/Sand {RoW}|gravel and sand quarry operation|Alloc Def, S	109,760	kg
Stone	5.2 m^3	Gravel	Minerals/Transformation/Gravel, round {RoW} |gravel and sand quarry operation| Alloc Def, S	11,393	kg
Transportation by a Transport Truck	50 km	-	Transport/Road/Market/Transport, freight, lorry 16-32 metric ton, EURO 3 {GLO} | market for | Alloc Def, S	6,057.7	tkm
Transportation by Car	20 km	-	Transport/Road/Market/Transport, passenger car, medium size, petrol, EURO 3 {GLO}|market for| Alloc Def, S	20	km
Excavation By Hydraulic Digger	269.2 m^3	-	Transport/Building Equipment/Market/Excavation, Hydraulic Digger {GLO} |market for|Alloc Def, S	269.2	m^3

Electricity	52.5 kwh	-	Energy/Electricity by country mix/Low Voltage/Market/Electricity, low voltage {CA-ON}|market for| Alloc Def, S	52.5	kwh

Table B-7: Type B Dispersal Bed LCI Inputs

Phase	Type B Dispersal Bed Inputs	Quantity	Material	SimaPro Dataset	Value	Units
Manufacturing	Pipe	15 m of the 4 inch diameter pipe and 146.4 m of the 1 inch diameter pipe	PVC	Plastics/Thermoplastics/PVC Pipe E	114.5	kg
	Building Paper	200 m^2	Kraft Paper	Paper + Board/Packaging paper/Market/Kraft Paper, unbleached {GLO} |market for| Alloc Def, S	127	kg
	Stone	60 m3	Gravel	Minerals/Transformation/Gravel, round {RoW} |gravel and sand quarry operation| Alloc Def, S	130,648	kg
Installation	Transportation by a Transport Truck	50 km	-	Transport/Road/Market/Transport, freight, lorry 16-32 metric ton, EURO 3 {GLO} | market for | Alloc Def, S	6,532.4	tkm
	Transportation by Car	20 km	-	Transport/Road/Market/Transport, passenger car, medium size, petrol, EURO 3 {GLO}|market for| Alloc Def, S	20	km
	Excavation By Hydraulic Digger	184 m3		Transport/Building Equipment/Market/Excavation, Hydraulic Digger {GLO} |market for|Alloc Def, S	184	m3
Use	Electricity	52.5 kwh	-	Energy/Electiricty by country mix/Low Voltage/Market/Electricity, low voltage {CA-ON}|market for| Alloc Def, S	52.5	kwh

Table B-8: Level IV Treatment LCI Inputs

Phase	Level IV Inputs	Quantity	Material	SimaPro Dataset	Value	Units
Manufacturing	Pipe	10 m of 25 mm diameter and 3 m of 10 mm diameter	PVC	Plastics/Thermoplastics/PVC Pipe E	13.8	kg
	Tank	149.7 kg	HDPE	Plastics/Thermoplasts/Polyethylene high density granulate (PE-HD), production mix, at plant RER	149.7	kg
	Riser and Lids	2	HDPE	Plastics/Thermoplasts/Polyethylene high density granulate (PE-HD), production mix, at plant RER	51.4	kg
	Reinforcing Steel for Tank and Frame (10M)	38.5 m	Steel	Metals/Ferro/Market/Reinforcing steel {GLO}| market for | Alloc Def, S	13.6	kg
	Filter Medium	2.7 m^3	Polyurethane	Plastics/Thermosets/Market/Polyurethane, flexible foam {GLO}|market for|Alloc Def, S	43.2	kg
Installation	Transportation by a Transport Truck	50 km	-	Transport/Road/Market/Transport, freight, lorry 16-32 metric ton, EURO 3 {GLO} | market for | Alloc Def, S	13.6	tkm
	Excavation by a Hydraulic Digger	10.1 m^3	-	Transport/Building Equipment/Market/Excavation, Hydraulic Digger {GLO} |market for|Alloc Def, S	10.1	m^3

Table B-9: Number of Installed Components Over 25 Years

	Septic Tank	Pump Tank	Pump	Level IV Treatment Unit	Leaching Bed
Conventional	1	1	3	-	1
Filter Bed	1	-	-	-	1
Shallow Buried Trench	1	2	3	1	1
Type A Dispersal	1	2	3	1	1
Type B Dispersal	1	2	3	1	1

Table B-10: Number of Installed Components Over 50 Years

	Septic Tank	Pump Tank	Pump	Level IV Treatment Unit	Leaching Bed
Conventional	1	1	6	-	2
Filter Bed	1	-	-	-	2
Shallow Buried Trench	1	2	6	2	1
Type A Dispersal	1	2	6	2	1
Type B Dispersal	1	2	6	2	1

Table B-11: Transportation Sensitivity Analysis LCI Inputs

Septic System	Components	Weight (kg)	Original Distance (km)	Transportation Inputs (tkm)			
				-50%	-25%	25%	50%
Conventional Leaching Bed	Gravel	118,472	50	2,961.8	4,442.7	7,404.5	8,885.4
	PVC pipe, building paper, pumps	1,581.4	60	30	45	75	90
	Pumping chamber and distribution boxes	3,611.8	50	90.3	135.4	225.7	270.9
	Incinerator	1,301	75	48.8	73.2	122.0	146.4
	Landfill	3663.1	180	329.7	509.6	824.3	989.1
Sand Filter Bed	Sand and gravel	183,978	50	4,600	6,899	11,499	13,798
	PVC pipe and building paper	196.3	20	10	15	25	30
	Incinerator	110.6	75	4.1	6.2	10.4	12.4
Shallow Buried Trench	PVC Pipe, Big-O, pumps	294	20	10	15	25	30
	Pump chambers	2,884.8	50	72.1	108.2	180.3	216.4
	Incinerator	89	75	3.3	5.0	8.3	10.0
	Landfill	2,884.8	180	259.6	389.4	649.1	778.9
Type A Dispersal Bed	Sand and gravel	120,873	50	3,022	4,533	7,555	9,066

	PVC pipe, building paper and pumps	421.6	20	10	15	25	30
	Pump Chambers	2,884.8	50	72.1	108.2	180.3	216.4
	Incinerator	110.6	75	4.1	6.2	10.4	12.4
	Landfill	2,884.8	180	259.6	389.4	649.1	778.9
Type B Dispersal Bed	Gravel	130,648	50	3,266	4,899	8,166	9,799
	PVC pipe, building paper and pumps	193.6	20	10	15	25	30
	Pumping Chambers	2,884.8	50	72.1	108.2	180.3	216.4
	Incinerator	114.5	75	4.3	6.4	10.7	12.9
	Landfill	2,884.80	180	259.6	389.4	649.1	778.9
Septic Tank and Accessories	Concrete Tank and Accessories	4,842.9	50	121.1	181.6	302.7	363.3
	Landfill	4,842.9	180	435.9	653.9	1,089.9	1,307.8
	Maintenance	42,626.3	30	639.4	959.1	1,598.5	1,918.2
Level IV Treatment	Tank and Accessories	271.7	50	6.8	10.2	17.0	20.4
	Incinerator	258.1	75	9.7	14.5	24.2	29.0
	Landfill	13.6	180	1.2	1.8	3.1	3.7

Table B-12: Sand and Stone Sensitivity Analysis LCI Inputs

		Weight (kg)					**Transportation (tkm)**				
		-20%	**-10%**	**Original**	**10%**	**20%**	**-20%**	**-10%**	**Original**	**10%**	**20%**
Conventional Leaching Bed	Stone	94,778	106,625	118,472	130,319	142,166	4,739	5,331	5,924	6,516	7,108
Filter Bed	Sand	133,056	149,688	166,320	182,952	199,584	7,359	8,279	9,199	10,119	11,039
	Stone	14,126	15,892	17,658	19,424	21,190					
Type A Dispersal Bed	Sand	87,808	98,784	109,760	120,736	131,712	4,835	5,439	6,044	6,648	7,252
	Stone	8,890	10,002	11,113	12,224	13,336					
Type B Dispersal Bed	Stone	104,518	117,583	130,648	143,713	156,778	5,226	5,879	6,532	7,186	7,839

Table B-13: Waste Allocation Summary

Component	Final Disposal	Waste	Amount (kg)	Transportation (tkm)
Conventional Leaching Bed	Incinerator	PVC Pipe	1,301	97.6
	Landfill	Septic Tank, Distribution Boxes, 2700 L Pumping Chamber, Pumps	8,604.0	1,548.7
Sand Filter Bed	Incinerator	PVC Pipe	125.6	9.4
	Landfill	Septic Tank	4,842.9	871.7
Shallow Buried Trench	Incinerator	PVC Pipe, HDPE Big-O	89.0	6.7
	Landfill	Septic Tank, 1130 L Pumping Chambers, Teritary Treatment Unit, Pump s	8,293.4	1,493
Type A Dispersal Bed	Incinerator	PVC Pipe	65.8	4.9
	Landfill	Septic Tank, 1130 L Pumping Chambers, Teritary Treatment Unit, Pumps	8,293.4	1,493
Type B Dispersal Bed	Incinerator	PVC Pipe	66.6	5.0
	Landfill	Septic Tank, 1130 L Pumping Chambers, Teritary Treatment Unit, Pumps	8,293.4	1,492.8

Table B-14: Conventional Leaching Bed LCI Inputs for T-Time of 10 min/cm

Phase	Conventional Adsorption Trench Inputs	Quantity	Material	SimaPro Dataset	Value	Units
Manufacturing	PVC	120 m	PVC	Plastics/Thermoplastics/PVC Pipe E	358.8	kg
	Building Paper	50 m^2	Kraft Paper	Paper + Board/Packaging paper/Market/Kraft Paper, unbleached {GLO} |market for| Alloc Def, S	31.8	kg
	Stone	54.3 m^3	Gravel	Minerals/Transformation/Gravel, round {RoW} |gravel and sand quarry operation| Alloc Def, S	28,208	kg

	Transportation by a Transport Truck	50 km	-	Transport/Road/Market/Transport, freight, lorry 16-32 metric ton, EURO 3 {GLO} | market for | Alloc Def, S	1,410	tkm
Installation	Transportation by Car	20 km	-	Transport/Road/Market/Transport, passenger car, medium size, petrol, EURO 3 {GLO}|market for| Alloc Def, S	20	km
	Excavation by Hydraulic Digger	102.1 m^3	-	Transport/Building Equipment/Market/Excavation, Hydraulic Digger {GLO} |market for|Alloc Def, S	102.1	m^3

Table B-15: Sand Filter Bed LCI Inputs for a T-Time of 10 min/cm

Phase	Sand Filter Bed Inputs	Quantity	Material	SimaPro Dataset	Value	Units
Manufacturing	Pipe	42 m	PVC	Plastics/Thermoplastics/PVC Pipe E	125.6	kg
	Building Paper	27 m2	Kraft Paper	Paper + Board/Packaging paper/Market/Kraft Paper, unbleached {GLO} |market for| Alloc Def, S	85.7	kg
	Filter Sand	61.6 m3	Filter Sand	Chemicals/Inorganic/Market/Silica sand {GLO}|market for|Alloc Def, S	98,600	kg
	Stone	8.1 m3	Gravel	Minerals/Transformation/Gravel, round {RoW} |gravel and sand quarry operation| Alloc Def, S	17,658	kg
Installation	Transportation by a Transport Truck	50 km	-	Transport/Road/Market/Transport, freight, lorry 16-32 metric ton, EURO 3 {GLO} | market for | Alloc Def, S	5,813	tkm
	Transportation by Car	20 km	-	Transport/Road/Market/Transport, passenger car, medium size, petrol, EURO 3 {GLO}|market for| Alloc Def, S	20	km
	Excavation by Hydraulic Digger	471.7 m^3	-	Transport/Building Equipment/Market/Excavation, Hydraulic Digger {GLO} |market for|Alloc Def, S	471.7	m3

Table B-16: Shallow Buried Trench LCI Inputs for T-Time of 10 min/cm

Phase	Shallow Buried Trench Inputs	Quantity	Material	SimaPro Dataset	Value	Units
Manufacturing	Pipe	20 m of the 4 inch diameter pipe and 30 m of the 1 inch diameter pipe	PVC	Plastics/Thermoplastics/PVC Pipe E	78.8	kg
	Half Dome (Big-O)	30 m	HDPE	Construction/Ventilation/Transformation/Polyethylene Pipe, Corrugated, DN 75 {RoW}|Production|Alloc Def, S	10.2	kg
Installation	Transportation by Car	20 km	-	Transport/Road/Market/Transport, passenger car, medium size, petrol, EURO 3 {GLO}|market for| Alloc Def, S	20	km
	Excavation by Hydraulic Digger	9.1 m^3	-	Transport/Building Equipment/Market/Excavation, Hydraulic Digger {GLO} |market for|Alloc Def, S	9.1	m^3
Use	Electricity	52.5 kwh	-	Energy/Electiricty by country mix/Low Voltage/Market/Electricity, low voltage {CA-ON}|market for| Alloc Def, S	52.5	kwh

Table B-17: Type A Dispersal Bed LCI Inputs for a T-Time of 10 min/cm

Phase	Type A Dispersal Bed Inputs	Quantity	Material	SimaPro Dataset	Value	Units
Manufacturing	Pipe	22 m	PVC	Plastics/Thermoplastics/PVC Pipe E	65.8	kg
	Building Paper	26.7 m^2	Kraft Paper	Paper + Board/Packaging paper/Market/Kraft Paper, unbleached {GLO} |market for| Alloc Def, S	17	kg

	Sand	12.6 m^3	Sand	Minerals/Transformation/Sand {RoW}|gravel and sand quarry operation|Alloc Def, S	20,160	kg
	Stone	5.2 m^3	Gravel	Minerals/Transformation/Gravel, round {RoW} |gravel and sand quarry operation| Alloc Def, S	11,393	kg
Installation	Transportation by a Transport Truck	50 km	-	Transport/Road/Market/Transport, freight, lorry 16-32 metric ton, EURO 3 {GLO} | market for | Alloc Def, S	1,578	tkm
	Transportation by Car	20 km	-	Transport/Road/Market/Transport, passenger car, medium size, petrol, EURO 3 {GLO}|market for| Alloc Def, S	20	km
	Excavation By Hydraulic Digger	48 m^3	-	Transport/Building Equipment/Market/Excavation, Hydraulic Digger {GLO} |market for|Alloc Def, S	48	m^3
Use	Electricity	52.5 kwh	-	Energy/Electiricty by country mix/Low Voltage/Market/Electricity, low voltage {CA-ON}|market for| Alloc Def, S	52.5	kwh

Table B-18: Type B Dispersal Bed LCI Inputs for a T-Time of 10 min/cm

Phase	Type B Dispersal Bed Inputs	Quantity	Material	SimaPro Dataset	Value	Units
Manufacturing	Pipe	15 m of the 4 inch diameter pipe and 77.6 m of the 1 inch diameter pipe	PVC	Plastics/Thermoplastics/PVC Pipe E	83.1	kg
	Building Paper	50 m^2	Kraft Paper	Paper + Board/Packaging paper/Market/Kraft Paper, unbleached {GLO} |market for| Alloc Def, S	31.8	kg
	Stone	15 m^3	Gravel	Minerals/Transformation/Gravel, round {RoW} |gravel and sand quarry operation| Alloc Def, S	32,611	kg
Installation	Transportation by a Transport Truck	50 km	-	Transport/Road/Market/Transport, freight, lorry 16-32 metric ton, EURO 3 {GLO} | market for | Alloc Def, S	1,631	tkm

	Transportation by Car	20 km	-	Transport/Road/Market/Transport, passenger car, medium size, petrol, EURO 3 {GLO}|market for| Alloc Def, S	20	km
	Excavation By Hydraulic Digger	46 m^3		Transport/Building Equipment/Market/Excavation, Hydraulic Digger {GLO} |market for|Alloc Def, S	46	m^3
Use	Electricity	52.5 kwh	-	Energy/Electiricty by country mix/Low Voltage/Market/Electricity, low voltage {CA-ON}|market for| Alloc Def, S	52.5	kwh

APPENDIX C: LIFE CYCLE IMPACT ASSESSMENT TABLES

Table C-1: TRACI Septic Tank Manufacturing

Impact category	Unit	Concrete Septic Tank	Polyethylene high density granulate (PE-HD), production mix, at plant RER	Polypropylene granulate {GLO}| market for | Alloc Def, S	Ethylene vinyl acetate copolymer {GLO}| market for | Alloc Def, S	Synthetic rubber {GLO}| market for | Alloc Def, S	PVC pipe E	Steel hot dip galvanized (ILCD), blast furnace route, production mix, at plant, 1kg, typical thickness between 0.3 - 3 mm. typical width between 600 - 2100 mm. GLO S	Steel, low-alloyed {GLO}| market for | Alloc Def, S	Reinforcing steel {GLO}| market for | Alloc Def, S
Ozone depletion	kg CFC-11 eq	4.13E-05	0	6.03635E-08	3.05E-08	6.338E-07	0	7.61565E-08	1.1E-07	9.957E-06
Global warming	kg CO2 eq	834.851	41.5105939	6.373930263	0.480039	2.2263221	15	5.732174553	1.70888	154.23165
Smog	kg O3 eq	39.84924	1.20651136	0.298895104	0.023578	0.1181237	0.702	0.131539494	0.10356	8.3917297
Acidification	kg SO2 eq	2.272511	0.13812634	0.021082626	0.001918	0.0114566	0.065	0.016796703	0.00838	0.6649017
Eutrophication	kg N eq	0.769512	0.00352035	0.002846098	0.001162	0.0081459	0.005	0.000721421	0.01131	0.6307942
Carcinogenics	CTUh	1.17E-05	2.1192E-06	1.7122E-07	1.55E-08	8.452E-08	3E-06	3.90263E-09	1.8E-06	7.681E-05
Non carcinogenics	CTUh	7.45E-05	4.7515E-08	1.47847E-07	7.42E-08	4.266E-07	1E-06	3.87104E-07	2.6E-06	8.816E-05
Respiratory effects	kg PM2.5 eq	0.264929	0.00597981	0.00166506	0.000214	0.0015874	0.003	0.001772008	0.00295	0.2119034
Ecotoxicity	CTUe	1575.519	0.6225992	11.60837914	2.729001	14.355082	0.724	0.306008049	67.0012	2516.747

Fossil fuel depletion	MJ surplus	439.6605	207.95731	31.69479787	2.247292	8.2917954	35.34	1.663629463	1.06552	90.980846

Table C-2: TRACI Septic Tank Installation, Transportation, and Maintenance

Impact category	Unit	Excavation, hydraulic digger {GLO}| market for | Alloc Def, S	Transport, passenger car, medium size, petrol, EURO 3 {GLO}| market for | Alloc Def, S	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S	Waste Scenario Concrete Septic Tank	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S	Wastewater, from residence {RoW}| treatment of, capacity 1.1E10l/year | Alloc Rec, S
Ozone depletion	kg CFC-11 eq	2.38E-06	2.0027E-05	1.00725E-05	5.75E-05	3.55E-05	1.7972E-06
Global warming	kg CO2 eq	10.245161	95.5819296	41.27182938	219.0172	145.3545	21.7990066
Smog	kg O3 eq	2.825876	3.21657955	6.847335968	39.48269	24.11551	1.9789172
Acidification	kg SO2 eq	0.0956067	0.29485289	0.259193523	1.495041	0.912849	0.18241862
Eutrophication	kg N eq	0.0138829	0.19563355	0.054635144	0.63411	0.192419	1.17040544
Carcinogenics	CTUh	4.658E-07	5.7941E-06	1.21068E-06	1.57E-05	4.26E-06	5.7892E-06
Non carcinogenics	CTUh	7.57E-07	2.694E-05	1.225E-05	0.000143	4.31E-05	6.5916E-05
Respiratory effects	kg PM2.5 eq	0.0132071	0.04269387	0.033602475	0.341915	0.118344	0.02238969
Ecotoxicity	CTUe	19.779675	2797.24308	355.0692517	49440.7	1250.512	647.596756
Fossil fuel depletion	MJ surplus	21.250288	182.772607	90.19233159	492.7845	317.6468	20.8603948

Table C-3: TRACI 2,700 L Pump Chamber

Impact category	Unit	Concrete, 30-32MPa {CA-QC}| concrete production 30-32MPa, RNA only | Alloc Def, S	Steel hot dip galvanized (ILCD), blast furnace route, production mix, at plant, 1kg, typical thickness between 0.3 - 3 mm. typical width between 600 - 2100 mm. GLO S	Steel, low-alloyed {GLO}| market for | Alloc Def, S	Steel, chromium steel 18/8 {GLO}| market for | Alloc Def, S	Cast iron {GLO}| market for | Alloc Def, S	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S	Excavation, hydraulic digger {GLO}| market for | Alloc Def, S	Waste Scenario - 2700 L Pumping Chamber
Ozone depletion	kg CFC-11 eq	2.86818E-05	1.32446E-07	4.4596E-08	5.7063E-06	4.061E-06	6.5043E-06	2.3772E-06	3.72189E-05
Global warming	kg CO2 eq	590.3918263	9.968999223	0.67987658	75.4897101	64.553369	26.65117306	10.2451611	141.8125365
Smog	kg O3 eq	27.91398714	0.228764337	0.04119953	5.22712543	3.5122324	4.421648825	2.825876	25.57851366
Acidification	kg SO2 eq	1.585908289	0.029211657	0.00333504	0.48186685	0.2900828	0.167373522	0.0956067	0.968323534
Eutrophication	kg N eq	0.530311238	0.001254644	0.00449879	0.28796687	0.1847408	0.035280498	0.0138829	0.412959398
Carcinogenics	CTUh	8.00178E-06	6.78717E-09	7.3573E-07	6.7266E-05	8.856E-05	7.81795E-07	4.6578E-07	1.0203E-05
Non carcinogenics	CTUh	5.15995E-05	6.73225E-07	1.0381E-06	5.9489E-05	8.798E-05	7.9104E-06	7.5698E-07	9.32114E-05
Respiratory effects	kg PM2.5 eq	0.184545381	0.003081753	0.00117461	0.22838442	0.0869917	0.021698708	0.01320712	0.222533806
Ecotoxicity	CTUe	1068.916068	0.532187911	26.6564097	1988.81527	1535.3045	229.2850163	19.7796753	32365.0083
Fossil fuel depletion	MJ surplus	288.4097225	2.893268631	0.42391548	63.0999202	37.23632	58.24145607	21.250288	318.716328

Table C-4: TRACI 1,130 L Pump Chamber

Impact category	Unit	Concrete, 30-32MPa {CA-QC}| concrete production 30-32MPa, RNA only | Alloc Def, S	Steel hot dip galvanized (ILCD), blast furnace route, production mix, at plant, 1kg, typical thickness between 0.3 - 3 mm. typical width between 600 - 2100 mm. GLO S	Steel, low-alloyed {GLO}| market for | Alloc Def, S	Reinforcing steel {GLO}| market for | Alloc Def, S	Cast iron {GLO}| market for | Alloc Def, S	Steel, chromium steel 18/8 {GLO}| market for | Alloc Def, S	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S	Excavation, hydraulic digger {GLO}| market for | Alloc Def, S	1130 L Pumping Chamber
Ozone depletion	kg CFC-11 eq	1.299E-05	1.3245E-07	4.46E-08	3.6374E-06	4E-06	5.71E-06	2.9985E-06	1.1886E-06	1.78E-05
Global warming	kg CO2 eq	267.40505	9.96899922	0.679877	56.34468983	64.553	75.48971	12.2861226	5.12258053	67.63475
Smog	kg O3 eq	12.643029	0.22876434	0.0412	3.065709312	3.5122	5.227125	2.0383688	1.412938	12.19904
Acidification	kg SO2 eq	0.7183024	0.02921166	0.003335	0.24290526	0.2901	0.481867	0.07715877	0.04780335	0.461818
Eutrophication	kg N eq	0.2401929	0.00125464	0.004499	0.230444952	0.1847	0.287967	0.01626422	0.00694145	0.196938

Carcinogenics	CTUh	3.624E-06	6.7872E-09	7.36E-07	2.80612E-05	9E-05	6.73E-05	3.6041E-07	2.3289E-07	4.87E-06
Non carcinogenics	CTUh	2.337E-05	6.7322E-07	1.04E-06	3.22081E-05	9E-05	5.95E-05	3.6467E-06	3.7849E-07	4.45E-05
Respiratory effects	kg PM2.5 eq	0.0835858	0.00308175	0.001175	0.077413611	0.087	0.228384	0.01000305	0.00660356	0.106126
Ecotoxicity	CTUe	484.14212	0.53218791	26.65641	919.4308056	1535.3	1988.815	105.699806	9.88983767	15433.76
Fossil fuel depletion	MJ surplus	130.62887	2.89326863	0.423915	33.23758451	37.236	63.09992	26.8491623	10.625144	152.005

Table C-5: TRACI Level IV Treatment Unit

Impact category	Unit	Polyethylene high density granulate (PE-HD), production mix, at plant RER	PVC pipe E	Polyurethane, flexible foam {GLO}| market for | Alloc Def, S	Reinforcing steel {GLO}| market for | Alloc Def, S	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S	Excavation, hydraulic digger {GLO}| market for | Alloc Def, S	Electricity, low voltage {CA-ON}| market for | Alloc Def, S	Waste Scenario Waterloo Biofilter
Ozone depletion	kg CFC-11 eq	0	0	3.26904E-06	2.09613E-06	5.65592E-07	1.2908E-06	7.0275E-07	2.599E-06
Global warming	kg CO2 eq	386.4713165	44.623	216.6609912	32.46982126	2.317493309	5.56323262	17.4923801	825.7335
Smog	kg O3 eq	11.2328442	2.0882	11.62030951	1.766679943	0.384491202	1.53448105	0.96758784	1.5601098
Acidification	kg SO2 eq	1.285981838	0.1944	0.948959229	0.139979302	0.014554219	0.05191547	0.14170002	0.166355
Eutrophication	kg N eq	0.032775085	0.0146	0.504766097	0.132798786	0.003067869	0.00753856	0.08977619	0.0108316
Carcinogenics	CTUh	1.97302E-05	9E-06	1.24366E-05	1.61708E-05	6.79822E-08	2.5292E-07	1.1922E-06	1.251E-07
Non carcinogenics	CTUh	4.42375E-07	4E-06	2.26717E-05	1.85606E-05	6.8786E-07	4.1105E-07	6.0952E-06	1.389E-06

Respiratory effects	kg PM2.5 eq	0.055673133	0.0088	0.149823151	0.044611233	0.001886844	0.00717161	0.00997083	0.0075265
Ecotoxicity	CTUe	5.79651381	2.1536	1076.688694	529.8414812	19.93782751	10.7405764	534.345876	32.874061
Fossil fuel depletion	MJ surplus	1936.121071	105.09	504.601388	19.15386226	5.064474441	11.5391349	10.3233341	28.955904

Table C-6: TRACI Conventional Leaching Bed Manufacturing and Use

Impact category	Unit	Distribution Box (2)	PVC pipe E	Kraft paper, unbleached {GLO}| market for | Alloc Rec, S	Steel hot dip galvanized (ILCD), blast furnace route, production mix, at plant	Ethylene vinyl acetate copolymer {GLO}| market for | Alloc Def, S	Synthetic rubber {RoW}| production | Alloc Def, S	Electricity, low voltage {CA-ON}| market for | Alloc Def, S
Ozone depletion	kg CFC-11 eq	4.37349E-06	0	2.30081E-05	2.64892E-07	2.3603E-07	5.34339E-07	8.76769E-07
Global warming	kg CO2 eq	90.02490635	4206.871166	167.6555586	19.93799845	3.70939274	1.914078475	21.82382657
Smog	kg O3 eq	4.256417461	196.8629137	16.67377823	0.457528675	0.18219407	0.097135518	1.207181021
Acidification	kg SO2 eq	0.241824563	18.32270994	1.258319336	0.058423313	0.01482108	0.009983846	0.17678764
Eutrophication	kg N eq	0.080863619	1.378418033	0.659996866	0.002509289	0.00897909	0.006122762	0.112006486
Carcinogenics	CTUh	1.22014E-06	0.000872579	9.05168E-06	1.35743E-08	1.198E-07	7.01207E-08	1.48741E-06
Non carcinogenics	CTUh	7.86806E-06	0.000348693	0.000238711	1.34645E-06	5.733E-07	3.52887E-07	7.60449E-06
Respiratory effects	kg PM2.5 eq	0.028140093	0.830506715	0.196795453	0.006163505	0.00165461	0.001423384	0.012439798
Ecotoxicity	CTUe	162.9918719	203.0338005	1435.745605	1.064375823	21.0877369	11.91544753	666.6600932
Fossil fuel depletion	MJ surplus	43.97767229	9907.533545	212.3411036	5.786537263	17.3654396	7.077449966	12.87958821

Table C-7: TRACI Conventional Leaching Bed Transportation, Stone, Waste Disposal, and Reuse

Impact category	Unit	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S	Excavation, hydraulic digger {GLO}| market for | Alloc Def, S	Transport, passenger car, medium size, petrol, EURO 3 {GLO}| market for | Alloc Def, S	Gravel, round {RoW}| gravel and sand quarry operation | Alloc Def, S	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S	Waste Scenario Conventional Leaching Bed	Conventional Leaching Bed - Gravel Disposal
Ozone depletion	kg CFC-11 eq	1.01058E-06	6.9705E-05	4.80656E-06	6.57226E-05	0.000246348	9.3527E-05	-0.000242366
Global warming	kg CO2 eq	4.140815251	300.414562	22.93966311	497.6305942	1009.404659	3239.97243	-1206.620692
Smog	kg O3 eq	0.68699531	82.8619769	0.771979091	65.54131886	167.4685357	27.2690197	-150.1478777
Acidification	kg SO2 eq	0.026004965	2.80343528	0.070764694	3.70779879	6.339218641	6.29905406	-7.243582146
Eutrophication	kg N eq	0.005481561	0.40708236	0.046952052	1.765945754	1.336237575	0.1848588	-2.695100968
Carcinogenics	CTUh	1.21468E-07	1.3658E-05	1.39059E-06	3.8593E-05	2.96102E-05	2.6266E-06	-5.45454E-05
Non carcinogenics	CTUh	1.22904E-06	2.2197E-05	6.46555E-06	0.000117045	0.000299604	5.8421E-05	-0.000394452
Respiratory effects	kg PM2.5 eq	0.003371347	0.3872668	0.01024653	0.549130407	0.821831633	0.17509846	-0.98369524
Ecotoxicity	CTUe	35.6242065	579.991125	671.3383384	3697.20481	8684.096693	5549.43354	-11801.31038
Fossil fuel depletion	MJ surplus	9.049024185	623.113285	43.86542557	609.7892217	2205.876529	774.585401	-2192.552466

Table C-8: TRACI Sand Filter Bed

Impact category	Unit	PVC pipe E	Kraft paper, unbleached {GLO}| market for | Alloc Def, S	Transport, passenger car, medium size, petrol, EURO 3 {GLO}| market for | Alloc Def, S	Gravel, round {RoW}| gravel and sand quarry operation | Alloc Def, S	Sand {RoW}| gravel and quarry operation | Alloc Def, S	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S	Excavation, hydraulic digger {GLO}| market for | Alloc Def, S	Waste Scenario Filter Bed	Filter Bed - Sand and Gravel Disposal

Ozone depletion	kg CFC-11 eq	0	1.51516E-05	1.60219E-06	9.7958E-06	9.227E-05	0.000382565	9.593E-05	8.26E-06	-0.000389
Global warming	kg CO2 eq	357.6326	107.2895153	7.646554369	74.1707832	698.61166	1567.545658	413.44182	551.746	-1926.886
Smog	kg O3 eq	16.73562	10.71974855	0.257326364	9.76879439	92.011886	260.0687183	114.03777	2.593722	-247.8116
Acidification	kg SO2 eq	1.557642	0.808188511	0.023588231	0.55263954	5.2052898	9.844431136	3.8581931	0.563752	-11.74417
Eutrophication	kg N eq	0.117181	0.828414376	0.015650684	0.26321046	2.4791689	2.075097822	0.5602421	0.014618	-4.257235
Carcinogenics	CTUh	7.42E-05	5.8199E-06	4.63532E-07	5.7522E-06	5.418E-05	4.59829E-05	1.88E-05	1.21E-07	-8.71E-05
Non carcinogenics	CTUh	2.96E-05	0.00015324	2.15518E-06	1.7445E-05	0.0001643	0.000465267	3.055E-05	2.26E-06	-0.000616
Respiratory effects	kg PM2.5 eq	0.070603	0.12643239	0.00341551	0.08184672	0.770911	1.276255856	0.5329711	0.014816	-1.596042
Ecotoxicity	CTUe	17.26021	929.3182696	223.7794461	551.060525	5190.4172	13485.88789	798.20561	24.69523	-18429.16
Fossil fuel depletion	MJ surplus	842.2546	137.1749904	14.62180852	90.8877885	856.06847	3425.595616	857.55195	70.95912	-3515

Table C-9: Shallow Buried Trench

Impact category	Unit	PVC pipe E	Polyethylene pipe, corrugated, DN 75 {RoW}| production | Alloc Def, S	Excavation, hydraulic digger {GLO}| market for | Alloc Def, S	Transport, passenger car, medium size, petrol, EURO 3 {GLO}| market for | Alloc Def, S	Electricity, low voltage {CA-ON}| market for | Alloc Def, S	Waste Scenario Shallow Buried Trench
Ozone depletion	kg CFC-11 eq	0	9.99414E-07	1.163E-06	1.60219E-06	7.02754E-07	5.57171E-06

Global warming	kg CO2 eq	254.8051098	30.81379595	5.01241751	7.646554369	17.49238008	228.4313903
Smog	kg O3 eq	11.92374912	1.546724619	1.38255224	0.257326364	0.967587841	1.597632588
Acidification	kg SO2 eq	1.10978443	0.137878708	0.04677532	0.023588231	0.141700017	0.381486056
Eutrophication	kg N eq	0.083489117	0.071343499	0.00679217	0.015650684	0.089776191	0.008610387
Carcinogenics	CTUh	5.28511E-05	1.28253E-06	2.2788E-07	4.63532E-07	1.1922E-06	6.52411E-08
Non carcinogenics	CTUh	2.11199E-05	5.12116E-06	3.7035E-07	2.15518E-06	6.0952E-06	1.39565E-06
Respiratory effects	kg PM2.5 eq	0.050302789	0.014534167	0.00646155	0.00341551	0.00997083	0.009413602
Ecotoxicity	CTUe	12.29751228	205.7710658	9.67715299	223.7794461	534.3458762	11.9680675
Fossil fuel depletion	MJ surplus	600.0873507	119.4820832	10.3966463	14.62180852	10.32333406	46.4511435

Table C-10: TRACI Type A Dispersal Bed

Impact category	Unit	Kraft paper, unbleached {GLO}| market for | Alloc Rec, S	PVC pipe E	Transport, passenger car, medium size, petrol, EURO 3 {GLO}| market for | Alloc Def, S	Electricity, low voltage {CA-ON}| market for | Alloc Def, S	Waste Scenario Type A	Gravel, round {RoW}| gravel and sand quarry operation | Alloc Def, S	Sand {RoW}| gravel and quarry operation | Alloc Def, S	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S	Excavation, hydraulic digger {GLO}| market for | Alloc Def, S	Type A - Sand and Gravel Disposal
Ozone depletion	kg CFC-11 eq	2.9321E-06	0	1.60219E-06	7.028E-07	7.8E-06	6.32E-06	6.089E-05	0.0002513	3.4405E-05	-0.0003
Global warming	kg CO2 eq	21.36540	357.63	7.64655436	17.49238	329.3	47.85523	461.03665	1029.9212	148.27942	-1390.5
Smog	kg O3 eq	2.124844	16.735	0.25732636	0.967587	2.2547	6.302858	60.721648	170.87241	40.899237	-196.99

Acidification	kg SO2 eq	0.160355	1.5576	0.02358823	0.1417	0.5364	0.356564	3.4351407	6.4680662	1.3837271	-8.8757
Eutrophication	kg N eq	0.084107	0.1171	0.01565068	0.089776	0.0121	0.169824	1.6360845	1.3633972	0.2009288	-2.9683
Carcinogenics	CTUh	1.1535E-06	7.4E-05	4.63532E-07	1.192E-06	9.3E-08	3.711E-06	3.5755E-05	3.0212E-05	6.7413E-06	-6.3E-05
Non carcinogenics	CTUh	3.042E-05	3E-05	2.15518E-06	6.095E-06	2E-06	1.126E-05	0.0001084	0.0003056	1.0956E-05	-0.0004
Respiratory effects	kg PM2.5 eq	0.025078	0.0706	0.00341551	0.009970	0.0132	0.052807	0.5087493	0.8385357	0.1911481	-1.2089
Ecotoxicity	CTUe	182.9660	17.260	223.779446	534.3458	17.053	355.5460	3425.3258	8860.6051	286.27358	-12355
Fossil fuel depletion	MJ surplus	27.05996	842.25	14.6218085	10.32333	65.402	58.64110	564.94754	2250.7120	307.55793	-2566.6

Table C-11: TRACI Type B Dispersal Bed

Impact category	Unit	Kraft paper, unbleached {GLO}| market for | Alloc Rec, S	PVC pipe E	Excavation hydraulic digger {GLO}| market for | Alloc Def, S	Transport, passenger car, medium size, petrol, EURO 3 {GLO}| market for | Alloc Def, S	Electricity low voltage {CA-ON}| market for | Alloc Def, S	Waste Scenario for Type B	Gravel, round {RoW}| gravel and sand quarry operation | Alloc Def, S	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S	Type B - Gravel Disposal
Ozone depletion	kg CFC-11 eq	2.1904E-05	0	2.3516E-05	1.60219E-06	7.028E-07	8.78E-06	7.24773E-05	0.0002716	-0.00032
Global warming	kg CO2 eq	159.61211	370.243	101.34998	7.6465543	17.49238	695.145	548.774747	1113.0784	-1560.50

Smog	kg O3 eq	15.873836	17.3257	27.954902	0.2573263	0.9675878	2.87447	72.2773501	184.66886	-228.991
Acidification	kg SO2 eq	1.1979501	1.61256	0.9457867	0.0235882	0.1417	0.59884	4.08886906	6.9903059	-10.1333
Eutrophication	kg N eq	0.6283328	0.12131	0.1373361	0.01565068	0.0897762	0.01649	1.94744142	1.4734796	-3.28358
Carcinogenics	CTUh	8.6174E-06	7.68E-05	4.6077E-06	4.63532E-07	1.192E-06	1.41E-07	4.25594E-05	3.2651E-05	-7.06E-05
Non carcinogenics	CTUh	0.0002272	3.07E-05	7.4884E-06	2.15518E-06	6.095E-06	2.5E-06	0.00012907	0.0003303	-0.00045
Respiratory effects	kg PM2.5 eq	0.1873539	0.07309	0.1306510	0.0034155	0.0099708	0.01620	0.60556747	0.9062401	-1.38115
Ecotoxicity	CTUe	1366.8642	17.8688	195.66990	223.77944	534.34588	29.8466	4077.18628	9576.0212	-13457.5
Fossil fuel depletion	MJ surplus	202.15382	871.954	210.21790	14.621808	10.323334	76.5629	672.460515	2432.4372	-2894.67

Table C-12: TRACI Conventional Leaching Bed T-Time of 10 min/cm

Impact category	Unit	PVC pipe E	Kraft paper, unbleached {GLO}| market for | Alloc Rec, S	Excavation, hydraulic digger {GLO}| market for | Alloc Def, S	Transport, passenger car, medium size, petrol, EURO 3 {GLO}| market for | Alloc Def, S	T-Time of 10 - Conventional Leaching Bed	Gravel, round {RoW}| gravel and sand quarry operation | Alloc Def, S	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S	T-Time of 10 - Conventional Leaching Bed - Gravel	Excavation, hydraulic digger {GLO}| market for | Alloc Def, S
Ozone depletion	kg CFC-11 eq	0	5.4847E-06	1.305E-05	1.6022E-06	2.5275E-05	1.565E-05	5.87E-05	-7.4304E-05	1.3049E-05

Global warming	kg CO2 eq	1160.20398	39.9658678	56.238223	7.64655437	992.680318	118.48507	240.3377	-358.822763	56.2382228
Smog	kg O3 eq	54.2924008	3.97470875	15.511932	0.25732636	7.19874384	15.605287	39.874	-55.4792861	15.5119322
Acidification	kg SO2 eq	5.05318088	0.29995918	0.5248088	0.02358823	1.73107238	0.8828212	1.509358	-2.39217931	0.52480884
Eutrophication	kg N eq	0.38015095	0.15733059	0.0762067	0.01565068	0.03865673	0.420469	0.318156	-0.73862505	0.07620665
Carcinogenics	CTUh	0.00024065	2.1577E-06	2.557E-06	4.6353E-07	2.9047E-07	9.189E-06	7.05E-06	-1.6239E-05	2.5568E-06
Non carcinogenics	CTUh	9.6165E-05	5.6904E-05	4.155E-06	2.1552E-06	6.2874E-06	2.787E-05	7.13E-05	-9.9203E-05	4.1553E-06
Respiratory effects	kg PM2.5 eq	0.22904367	0.04691226	0.0724971	0.00341551	0.04251597	0.1307471	0.195677	-0.32642394	0.07249714
Ecotoxicity	CTUe	55.9942564	342.2542	108.57553	223.779446	52.6833995	880.29875	2067.67	-2947.96874	108.57553
Fossil fuel depletion	MJ surplus	2732.37743	50.6180442	116.64809	14.6218085	210.275411	145.18987	525.2158	-670.405661	116.648087

Table C-13: TRACI Sand Filter Bed T-Time of 10 min/cm

Impact category	Unit	PVC pipe E	Kraft paper, unbleached {GLO}| market for | Alloc Def, S	Transport, passenger car, medium size, petrol, EURO 3 {GLO}| market for | Alloc Def, S	Gravel, round {RoW}| gravel and sand quarry operation | Alloc Def, S	Sand {RoW}| gravel and quarry operation | Alloc Def, S	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S	Excavation, hydraulic digger {GLO}| market for | Alloc Def, S	T-Time of 10 - Filter Bed	T-Time of 10 - Filter Bed - Sand and Gravel
Ozone depletion	kg CFC-11 eq	0	1.5152E-05	1.6022E-06	9.796E-06	5.47E-05	0.000241749	6.0286E-05	9.3E-06	-0.0004
Global warming	kg CO2 eq	406.13606	107.289515	7.64655437	74.170783	414.16011	990.5579859	259.819488	588.934	-1738.7

Smog	kg O3 eq	19.005367	10.7197486	0.25732636	9.7687944	54.547691	164.3417175	71.664823	2.88693	-300.32
Acidification	kg SO2 eq	1.768895	0.80818851	0.02358823	0.5526395	3.0858681	6.220858592	2.42460657	0.63555	-12.284
Eutrophication	kg N eq	0.133074	0.82841438	0.01565068	0.2632105	1.4697334	1.311288579	0.35207325	0.01618	-3.3963
Carcinogenics	CTUh	8.424E-05	5.8199E-06	4.6353E-07	5.752E-06	3.212E-05	2.90574E-05	1.1812E-05	1.3E-07	-7.87E-05
Non carcinogenics	CTUh	3.366E-05	0.00015324	2.1552E-06	1.745E-05	9.741E-05	0.00029401	1.9197E-05	2.5E-06	-0.0004
Respiratory effects	kg PM2.5 eq	0.0801781	0.12643239	0.00341551	0.0818467	0.4570216	0.80648715	0.33493537	0.01656	-1.6803
Ecotoxicity	CTUe	19.601111	929.31827	223.779446	551.06053	3077.0511	8521.955243	501.61682	26.6882	-12651.6
Fossil fuel depletion	MJ surplus	956.48441	137.17499	14.6218085	90.887788	507.50572	2164.690436	538.911875	79.6267	-3302

Table C-14: TRACI Type A Dispersal Bed T-Time of 10 min/cm

Impact category	Unit	Kraft paper, unbleached {GLO}| market for | Alloc Rec, S	PVC pipe E	Transport, passenger car, medium size, petrol, EURO 3 {GLO}| market for | Alloc Def, S	Electricity, low voltage {CA-ON}| market for | Alloc Def, S	T-Time of 10 - Type A	Gravel, round {RoW}| gravel and sand quarry operation | Alloc Def, S	Sand {RoW}| gravel and quarry operation | Alloc Def, S	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S	Excavation, hydraulic digger {GLO}| market for | Alloc Def, S	Reuse

Ozone depletion	kg CFC-11 eq	2.9321E-06	0	1.6E-06	7.03E-07	4.7E-06	6.32E-06	1.12E-05	6.56E-05	6.135E-06	-7.7E-05
Global warming	kg CO2 eq	21.365401	212.76	7.646554	17.49238	218.201	47.8552	84.6802	268.8974	26.439125	-374.99
Smog	kg O3 eq	2.1248443	9.9566	0.257326	0.967588	1.37407	6.30285	11.1529	44.61229	7.2925832	-54.775
Acidification	kg SO2 eq	0.1603555	0.9266	0.023588	0.1417	0.32184	0.35656	0.63094	1.688718	0.246727	-2.4295
Eutrophication	kg N eq	0.0841075	0.0697	0.015651	0.089776	0.00747	0.16982	0.30050	0.355963	0.0358268	-0.7904
Carcinogenics	CTUh	1.1535E-06	4.41E-05	4.64E-07	1.19E-06	5.76E-08	3.71E-06	6.57E-06	7.89E-06	1.202E-06	-1.7E-05
Non carcinogenics	CTUh	3.042E-05	1.76E-05	2.16E-06	6.1E-06	1.2E-06	1.13E-05	1.99E-05	7.98E-05	1.954E-06	-0.0001
Respiratory effects	kg PM2.5 eq	0.0250788	0.0420	0.003416	0.009971	0.008043	0.052808	0.093444	0.218929	0.0340829	-0.3310
Ecotoxicity	CTUe	182.96608	10.268	223.7794	534.3459	10.84151	355.5461	629.1415	2313.374	51.044323	-3247.0
Fossil fuel depletion	MJ surplus	27.059960	501.08	14.62181	10.32333	39.44964	58.6411	103.7659	587.628	54.839453	-695.19

Table C-15: TRACI Type B Dispersal Bed T-Time of 10 min/cm

Impact category	Unit	Gravel, round {RoW}| gravel and sand quarry operation | Alloc Def, S	Transport, freight, lorry 16-32 metric ton, EURO3 {GLO}| market for | Alloc Def, S	Kraft paper, unbleached {GLO}| market for | Alloc Rec, S	PVC pipe E	Excavation, hydraulic digger {GLO}| market for | Alloc Def, S	Transport, passenger car, medium size, petrol, EURO 3 {GLO}| market for | Alloc Def, S	Electricity, low voltage {CA-ON}| market for | Alloc Def, S	T-Time of 10 - Type B	Reuse

Ozone depletion	kg CFC-11 eq	1.809E-05	6.7829E-05	5.48E-06	0	5.879E-06	1.6022E-06	7.028E-07	6.002E-06	-8.004E-05
Global warming	kg CO2 eq	136.9794	277.92879	39.96587	268.70	25.337495	7.6465543	17.49238	309.02122	-389.57
Smog	kg O3 eq	18.04112	46.110672	3.974709	12.574	6.9887255	0.2573263	0.9675878	1.7865938	-57.163
Acidification	kg SO2 eq	1.020621	1.7454361	0.299959	1.1703	0.2364466	0.0235882	0.1417	0.4105823	-2.5296
Eutrophication	kg N eq	0.486100	0.3679187	0.157331	0.0880	0.0343340	0.0156506	0.0897762	0.0098125	-0.8196
Carcinogenics	CTUh	1.062E-05	8.1529E-06	2.16E-06	5.6E-05	1.1519E-06	4.6353E-07	1.192E-06	7.7028E-08	-1.762E-05
Non carcinogenics	CTUh	3.222E-05	8.2493E-05	5.69E-05	2.2E-05	1.8721E-06	2.1552E-06	6.095E-06	1.556E-06	-0.0001
Respiratory effects	kg PM2.5 eq	0.151155	0.2262825	0.046912	0.0530	0.0326627	0.0034155	0.0099708	0.0103911	-0.3447
Ecotoxicity	CTUe	1017.705	2391.0732	342.2542	12.968	48.917476	223.77944	534.34588	14.856044	-3359.9
Fossil fuel depletion	MJ surplus	167.85263	607.364545	50.61804	632.833	52.5544758	14.6218085	10.323334	50.6609708	-722.66

Table C-16: CML-IA Baseline Summary and Characterization

		Total					Characterization				
Impact category	Unit	Conventional	Filter Bed	Shallow Buried Trench	Type A	Type B	Conventional	Filter Bed	Shallow Buried Trench	Type A	Type B

Abiotic depletion	kg Sb eq	9.95E-03	4.73E-03	1.02E-02	1.05E-02	1.14E-02	87.3	41.5	89.9	92.0	100.0
Abiotic depletion (fossil fuels)	MJ	122,808	37,371	47,975	53,845	54,531	100	30.4	39.1	43.8	44.4
Global warming (GWP100a)	kg CO2 eq	10,912	3,447	4,369	4,855	5,278	100	31.6	40.0	44.5	48.4
Ozone layer depletion (ODP)	kg CFC-11 eq	4.19E-04	3.02E-04	1.99E-04	2.54E-04	2.53E-04	100	72.1	47.5	60.5	60.3
Human toxicity	kg 1,4-DB eq	10,639	1,603	4,399	4,653	4,720	100	15.1	41.3	43.7	44.4
Fresh water aquatic ecotox.	kg 1,4-DB eq	4,408	1,729	2,731	2,788	2,827	100	39.2	62.0	63.3	64.1
Marine aquatic ecotoxicity	kg 1,4-DB eq	2,519,527	1,297,094	2,214,554	2,275,429	2,394,221	100	51.5	87.9	90.3	95.0
Terrestrial ecotoxicity	kg 1,4-DB eq	22.9	5.8	13.8	14.5	15.2	100	25.5	60.4	63.3	66.3
Photochemical oxidation	kg C2H4 eq	1.8	0.6	0.8	0.9	1.0	100	34.6	46.1	50.9	52.8
Acidification	kg SO2 eq	36.5	14.6	13.4	16.1	16.5	100	40.0	36.6	44.0	45.2
Eutrophication	kg PO4--- eq	6.5	4.2	3.7	4.3	4.5	100	64.4	57.3	66.1	69.2

Table C-17: ILCD 2011+ Baseline Summary and Characterization

		Total					Characterization				
Impact category	Unit	Conventional	Filter Bed	Shallow Buried Trench	Type A	Type B	Conventional	Filter Bed	Shallow Buried Trench	Type A	Type B
Climate change	kg CO2 eq	10,914	3,447	4,371	4,857	5,280	100	31.6	40.1	44.5	48.4
Ozone depletion	kg CFC-11 eq	4.20E-04	3.02E-04	2.00E-04	2.54E-04	2.53E-04	100	72.0	47.6	60.5	60.4
Human toxicity, cancer effects	CTUh	1.22E-03	2.47E-04	5.94E-04	6.29E-04	6.34E-04	100	20.2	48.6	51.4	51.9
Human toxicity, non-cancer effects	CTUh	1.48E-03	7.08E-04	9.60E-04	1.02E-03	1.21E-03	100	47.7	64.7	68.4	81.3
Particulate matter	kg PM2.5 eq	4.3	2.4	2.3	2.7	2.9	100	57.2	53.6	63.5	67.0
Ionizing radiation HH	kBq U235 eq	340.0	170.4	221.5	247.4	267.9	100	50.1	65.1	72.8	78.8
Ionizing radiation E (interim)	CTUe	0.0020	0.0009	0.0011	0.0013	0.0013	100	42.9	54.7	62.2	64.0
Photochemical ozone formation	kg NMVOC eq	30.5	18.8	12.9	17.0	16.5	100	61.6	42.5	55.7	54.2
Acidification	molc H+ eq	45.0	19.1	16.6	20.2	20.6	100	42.4	36.9	45.0	45.9
Terrestrial eutrophication	molc N eq	109.12	67.86	41.62	56.57	54.94	100	62.2	38.1	51.8	50.3
Freshwater eutrophication	kg P eq	0.54	0.34	0.45	0.47	0.54	98.5	63.3	82.5	87.1	100.0
Marine eutrophication	kg N eq	11.7	7.9	5.5	6.9	6.7	100	67.9	47.0	58.9	57.7
Freshwater ecotoxicity	CTUe	106,626	61,540	86,314	86,868	87,887	100	57.7	81.0	81.5	82.4
Land use	kg C deficit	9,290	6,798	4,823	5,757	7,505	100	73.2	51.9	62.0	80.8

Water resource depletion	m3 water eq	25.2	-0.7	3.5	4.0	4.7	100	-2.8	13.8	15.9	18.6
Mineral, fossil & ren resource depletion	kg Sb eq	1.85E-01	9.19E-02	1.65E-01	1.71E-01	2.01E-01	92.1	45.8	82.4	85.4	100.0

Table C-18: IMPACT 2002+ Summary and Characterization

		Total (With Reuse)					**Characterization**				
Impact category	Unit	Conventional	Filter Bed	Shallow Buried Trench	Type A	Type B	Conventional	Filter Bed	Shallow Buried Trench	Type A	Type B
Carcinogens	kg C2H3Cl eq	1,602.5	175.7	201.0	238.7	246.3	100.0	11.0	12.5	14.9	15.4
Non-carcinogens	kg C2H3Cl eq	7,383.8	700.0	606.3	788.6	831.3	100.0	9.5	8.2	10.7	11.3
Respiratory inorganics	kg PM2.5 eq	7.8	4.2	3.4	4.2	4.2	100.0	53.9	43.5	54.6	54.6
Ionizing radiation	Bq C-14 eq	34,240	17,144	22,788	25,385	27,474	100.0	50.1	66.6	74.1	80.2
Ozone layer depletion	kg CFC-11 eq	4.23E-04	3.02E-04	2.00E-04	2.54E-04	2.54E-04	100.0	71.4	47.2	60.1	59.9
Respiratory organics	kg C2H4 eq	2.2	1.6	1.7	2.0	2.0	100.0	71.7	77.4	90.4	88.5
Aquatic ecotoxicity	kg TEG water	529,273	358,463	267,463	304,278	463,026	100.0	67.7	50.5	57.5	87.5
Terrestrial ecotoxicity	kg TEG soil	212,193	138,453	125,197	136,979	193,695	100.0	65.2	59.0	64.6	91.3
Terrestrial acid/nutri	kg SO2 eq	159.9	92.7	60.4	80.4	78.8	100.0	58.0	37.8	50.3	49.3
Land occupation	m2org.arable	153.8	98.8	44.5	57.8	142.4	100.0	64.2	28.9	37.6	92.6
Aquatic acidification	kg SO2 eq	42.8	17.4	14.7	18.1	18.3	100.0	40.6	34.4	42.2	42.9

Aquatic eutrophication	kg PO4 P-lim	1.08	0.48	0.48	0.53	0.62	100.0	44.8	44.1	48.9	57.1
Global warming	kg CO2 eq	10,094	3,335	4,198	4,663	5,078	100.0	33.0	41.6	46.2	50.3
Non-renewable energy	MJ primary	135,696	39,271	51,734	57,900	58,884	100.0	28.9	38.1	42.7	43.4
Mineral extraction	MJ surplus	504	146	835	846	849	59.4	17.1	98.3	99.6	100.0

Table C-19: ReCiPe Summary and Characterization

		Total (With Reuse)					Characterization				
Impact category	Unit	Conventional	Filter Bed	Shallow Buried Trench	Type A	Type B	Conventional	Filter Bed	Shallow Buried Trench	Type A	Type B
Climate change	kg CO2 eq	10,914	3,447	4,371	4,857	5,280	100.0	31.6	40.1	44.5	48.4
Ozone depletion	kg CFC-11 eq	5.04E-04	3.10E-04	2.10E-04	2.66E-04	2.66E-04	100.0	61.6	41.7	52.9	52.8
Terrestrial acidification	kg SO2 eq	34.2	14.5	12.6	15.4	15.7	100.0	42.4	36.9	45.0	45.9
Freshwater eutrophication	kg P eq	0.54	0.34	0.45	0.47	0.54	98.5	63.3	82.6	87.1	100.0
Marine eutrophication	kg N eq	3.1	2.6	2.4	2.6	2.6	100.0	83.7	79.0	84.4	85.8
Human toxicity	kg 1,4-DB eq	1,731	743	1,068	1,109	1,170	100.0	42.9	61.7	64.0	67.6
Photochemical oxidant formation	kg NMVOC	30.8	19.1	13.3	17.4	16.9	100.0	62.0	43.3	56.5	55.0
Particulate matter formation	kg PM10 eq	15.2	7.4	6.9	8.3	8.3	100.0	48.6	45.6	54.4	54.7
Terrestrial ecotoxicity	kg 1,4-DB eq	0.79	0.45	0.51	0.54	0.60	100.0	57.2	64.5	67.5	75.8

Freshwater ecotoxicity	kg 1,4-DB eq	214.7	121.5	171.8	172.7	174.2	100.0	56.6	80.0	80.4	81.1
Marine ecotoxicity	kg 1,4-DB eq	191.5	107.9	154.2	155.1	156.6	100.0	56.3	80.5	81.0	81.7
Ionising radiation	kBq U235 eq	340.2	170.6	221.7	247.6	268.2	100.0	50.1	65.2	72.8	78.8
Agricultural land occupation	m2a	989.4	632.7	51.2	169.9	946.5	100.0	63.9	5.2	17.2	95.7
Urban land occupation	m2a	61.7	39.7	47.6	48.9	53.3	100.0	64.3	77.2	79.2	86.5
Natural land transformation	m2	0.58	0.53	0.30	0.40	0.41	100.0	91.8	52.2	70.2	71.6
Water depletion	m3	3.4	-20.0	-8.0	-7.1	-4.6	100.0	-586.1	-233.2	-208.3	-133.5
Metal depletion	kg Fe eq	537	239	796	815	815	65.8	29.3	97.7	100.0	99.9
Fossil depletion	kg oil eq	2,736	840	1,073	1,205	1,220	100.0	30.7	39.2	44.1	44.6

APPENDIX D: MONTE CARLO SIMULATION

Table D-1: Monte Carlo Raw Data for CLB vs. SFB and CLB vs. SBT

	CLB>=S FB			CLB>= SBT		
	Mean	Median	SD	Mean	Median	SD
Acidification	-0.2461551	0.18604142	2.94260143	69.7956359	69.1332335	5.4773376
Carcinogenics	0.00063973	0.00073545	0.00090687	0.0012017	0.00107898	0.00062064
Ecotoxicity	-224621.84	-163027.79	210106.146	545475.277	428741.706	455550.506
Eutrophication	-3.5989805	-3.1265205	2.85197784	14.491099	13.541219	5.93082566
Fossil fuel depletion	1431.59042	1719.36752	1650.91467	23895.3716	23579.6805	3018.96621
Global warming	3919.41363	3934.28213	292.140119	13709.2652	13670.7137	500.098394
Non carcinogenics	-0.0109838	-0.008944	0.01475406	0.02566158	0.0211655	0.03282613
Ozone depletion	-0.0008278	-0.0007347	0.00045123	0.00188758	0.00167954	0.00094767
Respiratory effects	-1.7689317	-1.6785873	0.48298671	7.10552674	6.98116577	0.78812407
Smog	-398.85138	-389.48356	65.454272	1400.68358	1382.11256	122.980278

Table D-2: Monte Carlo Raw Data for CLB vs. Type A and CLB vs. Type B

	CLB>= Type A			CLB>= Type B		
	Mean	Median	SD	Mean	Median	SD
Acidification	21.673351	21.6088918	0.69000232	16.8970216	16.9210578	0.6407196
Carcinogenics	0.00058718	0.00059291	0.00026807	0.00052594	0.00054688	0.00052837
Ecotoxicity	8078.34682	8101.10704	27520.0821	-33140.288	-26101.26	54176.566
Eutrophication	1.69941056	1.60209732	0.75257792	0.13216547	0.2705931	1.96561332
Fossil fuel depletion	7422.19478	7408.94252	178.377228	5900.93474	5938.87233	285.47676
Global warming	6536.24741	6532.23257	94.9126995	5807.42098	5803.49905	97.5638816
Non carcinogenics	3.6394E-06	-0.0001277	0.01592847	-0.0014841	-0.0011497	0.01923785
Ozone depletion	0.00010412	9.5453E-05	4.3404E-05	-6.497E-05	-5.223E-05	6.8747E-05
Respiratory effects	0.84990406	0.83360583	0.14774585	0.20597461	0.20010785	0.13227577
Smog	215.382211	211.950866	20.4100955	111.585393	111.041353	17.1555247

Table D-3: Monte Carlo Raw Data for SFB vs. SBT and SFB vs. Type A

	SFB>= SBT			SFB>= Type A		
	Mean	Median	SD	Mean	Median	SD
Acidification	69.8217833	68.6817096	9.22278927	21.84641307	21.4028509	3.15173069
Carcinogenics	0.00059004	0.00033591	0.00159553	-8.59784E-05	-0.0001335	0.00025483
Ecotoxicity	744342.278	587492.336	563952.373	251900.8443	185289.321	250754.529
Eutrophication	18.5144263	16.7992373	12.1740649	5.647541179	4.84550667	12.2438555
Fossil fuel depletion	22243.4691	21905.5235	4530.65131	5965.555106	5737.60639	1587.70826
Global warming	9751.26499	9677.13217	743.736691	2630.193875	2614.44874	278.707474

Non carcinogenics	0.03837406	0.03009276	0.04692038	0.012554396	0.01035722	0.01659215
Ozone depletion	0.00266414	0.00236597	0.00130374	0.000911311	0.00077246	0.00050624
Respiratory effects	8.85505031	8.62528129	1.2811634	2.603705257	2.53931334	0.50179898
Smog	1793.30445	1771.55504	178.245414	609.8613349	598.599528	72.031372

Table D- 4: Monte Carlo Raw Data for SFB vs. Type B and SBT vs. Type A

	SFB>= Type B			**SBT>= Type A**		
	Mean	**Median**	**SD**	**Mean**	**Median**	**SD**
Acidification	17.0954221	16.8565306	2.34469713	-48.157198	-47.370177	5.12370648
Carcinogenics	-0.0001282	-0.0001795	0.00034991	-0.000608	-0.0004636	0.00117445
Ecotoxicity	212502.79	151003.087	234339.484	-498033.96	-399222.21	398678.587
Eutrophication	4.12585248	3.50521691	7.06423803	-13.838235	-12.200304	11.7484436
Fossil fuel depletion	4444.81149	4252.99613	1392.07331	-16519.305	-16134.072	2966.56634
Global warming	1890.17602	1875.75418	235.760598	-7183.9298	-7130.0298	492.906095
Non carcinogenics	0.00976485	0.00831484	0.01731101	-0.0230126	-0.0177023	0.02294003
Ozone depletion	0.00076251	0.00066372	0.00041434	-0.0017783	-0.0015631	0.0008908
Respiratory effects	1.97684936	1.92223755	0.39442337	-6.2771014	-6.1700218	0.76735429
Smog	507.151714	500.950128	55.7421488	-1187.9411	-1175.9723	108.339456

Table D- 5: Monte Carlo Raw Data for SBT vs. Type B and Type A vs. Type B

	SBT>= Type B			**Type A>= Type B**		
	Mean	**Median**	**SD**	**Mean**	**Median**	**SD**
Acidification	-52.764828	-51.9482	5.91707852	-4.714429527	-4.625133172	0.83292511
Carcinogenics	-0.0007157	-0.0005017	0.0023705	-5.87843E-05	-4.31162E-05	0.0001169
Ecotoxicity	-568386.11	-417662.01	488215.284	-41811.64753	-34025.26811	31991.9071
Eutrophication	-14.119173	-13.190396	7.00154557	-1.493541508	-1.340064156	0.83548357
Fossil fuel depletion	-18021.247	-17865.617	3189.26794	-1507.426727	-1468.710913	322.460803
Global warming	-7905.2117	-7854.4346	540.609635	-725.3111826	-718.7076419	75.5518056
Non carcinogenics	-0.0271391	-0.021079	0.02948771	-0.00185268	-0.001826986	0.00891736
Ozone depletion	-0.0019343	-0.0017194	0.00094882	-0.000162217	-0.000139226	9.391E-05
Respiratory effects	-6.9278017	-6.7803846	0.86120287	-0.636928245	-0.603636871	0.17175753

Smog	-1288.3072	-1271.7884	132.799022	-102.0273376	-98.86734013	23.5030611

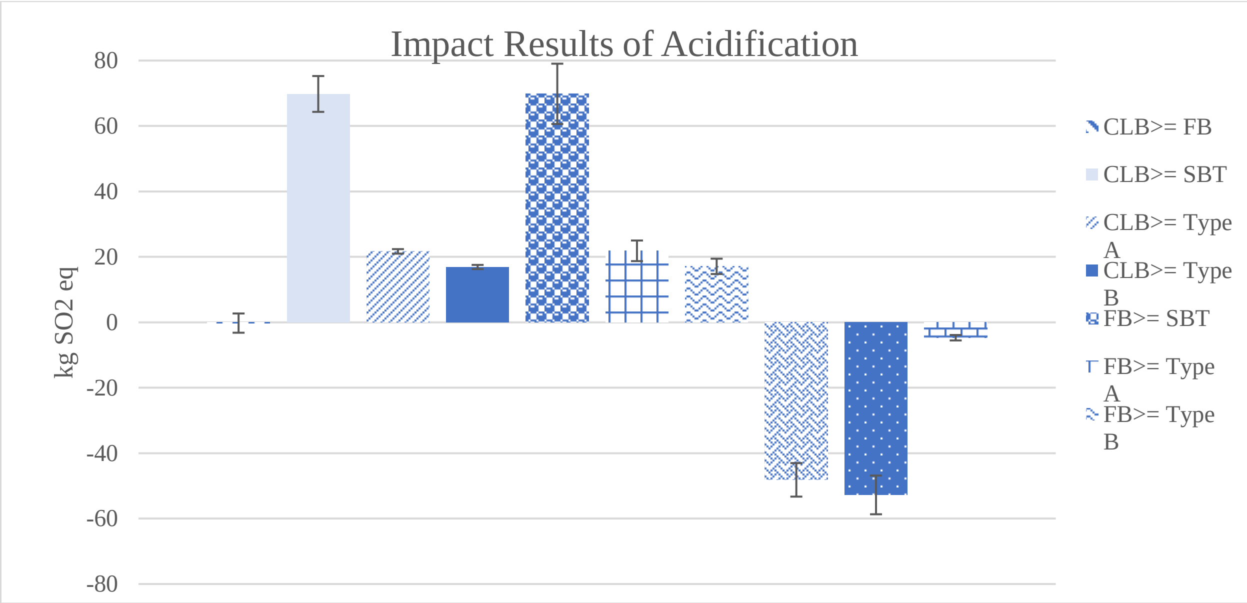


Figure D-1: Acidification Monte Carlo Mean and Standard Deviation

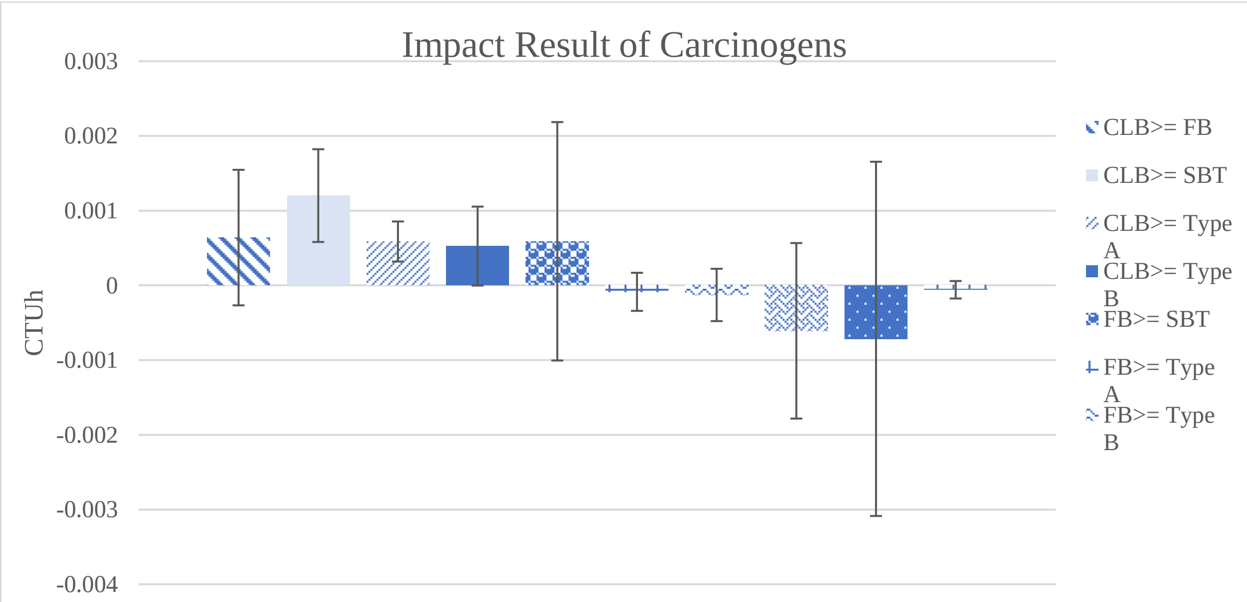


Figure D-2: Carcinogens Monte Carlo Mean and Standard Deviation

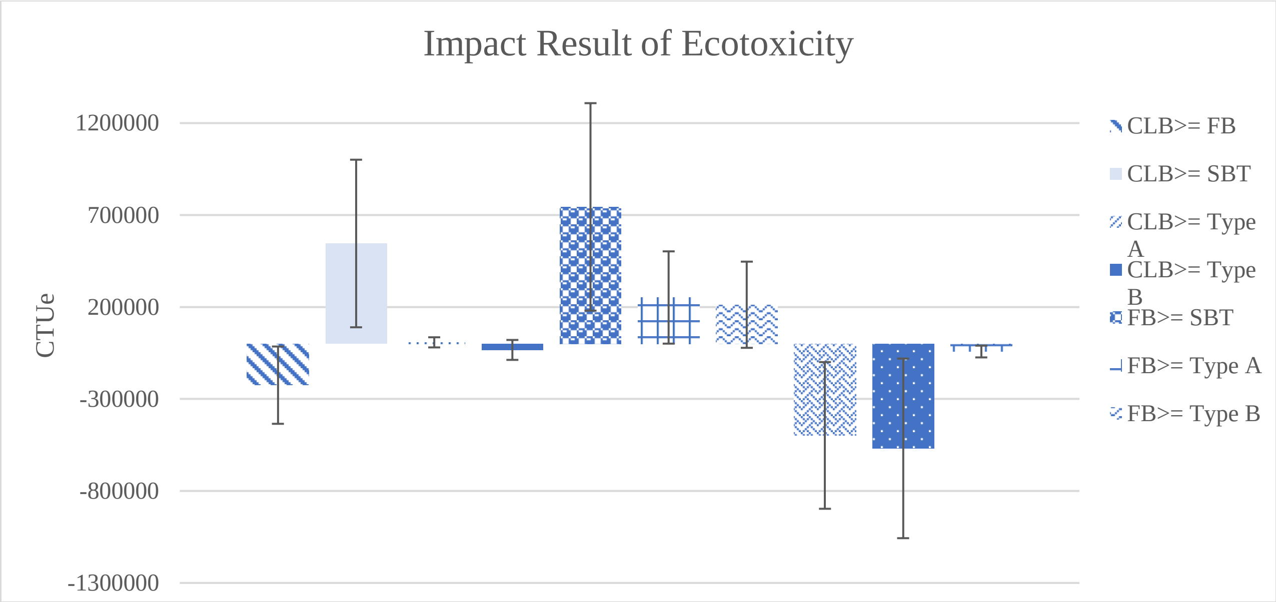


Figure D-3: Ecotoxicity Monte Carlo Mean and Standard Deviation

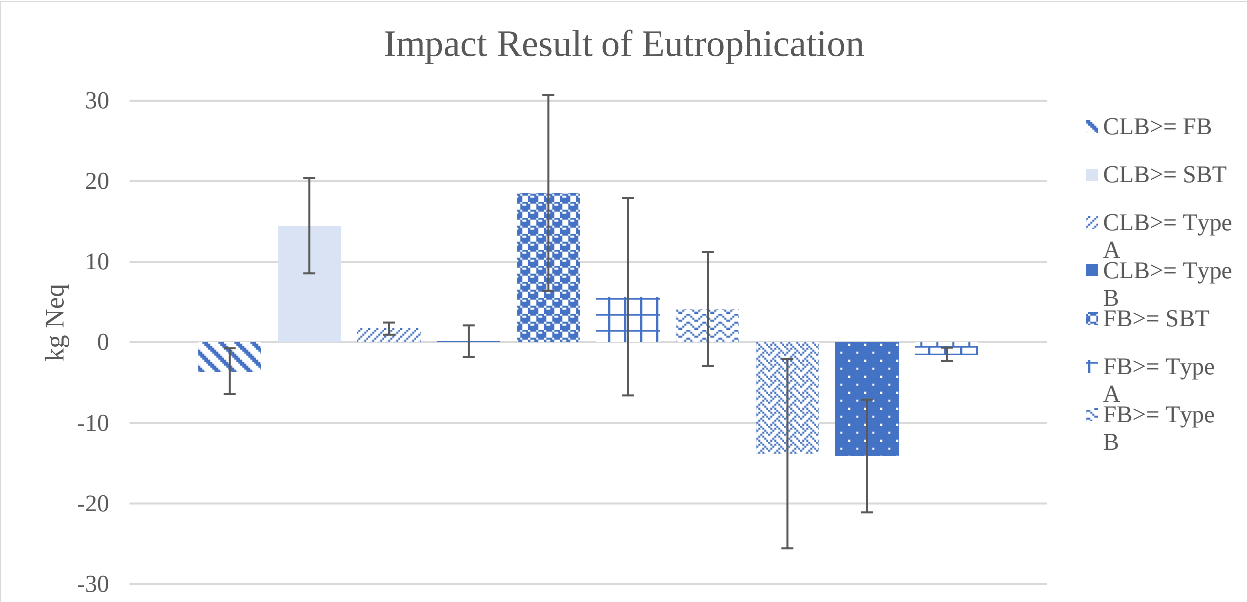


Figure D-4: Eutrophication Monte Carlo Mean and Standard Deviation

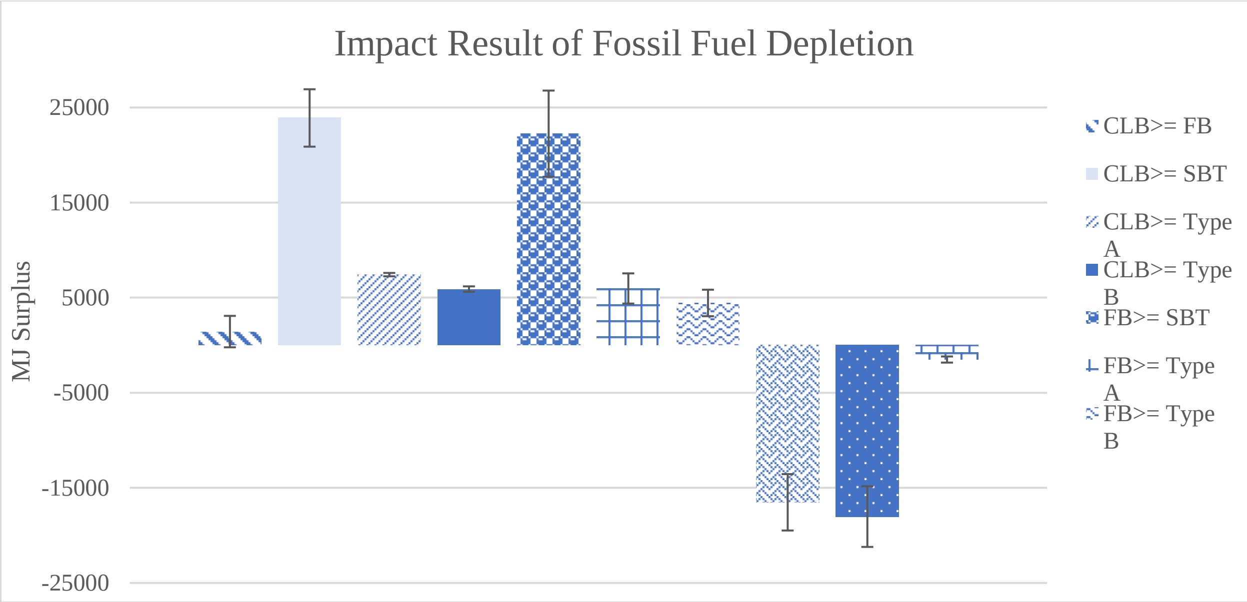


Figure D-5: Fossil Fuel Depletion Monte Carlo Mean and Standard Deviation

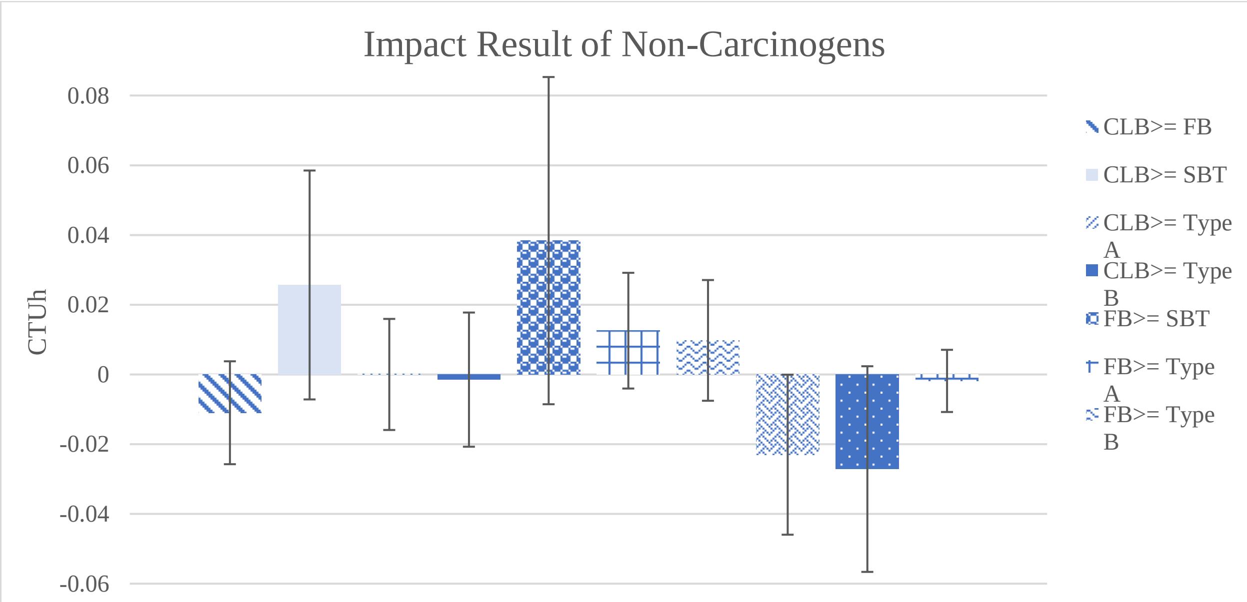


Figure D-6: Non-Carcinogens Monte Carlo Mean and Standard Deviation

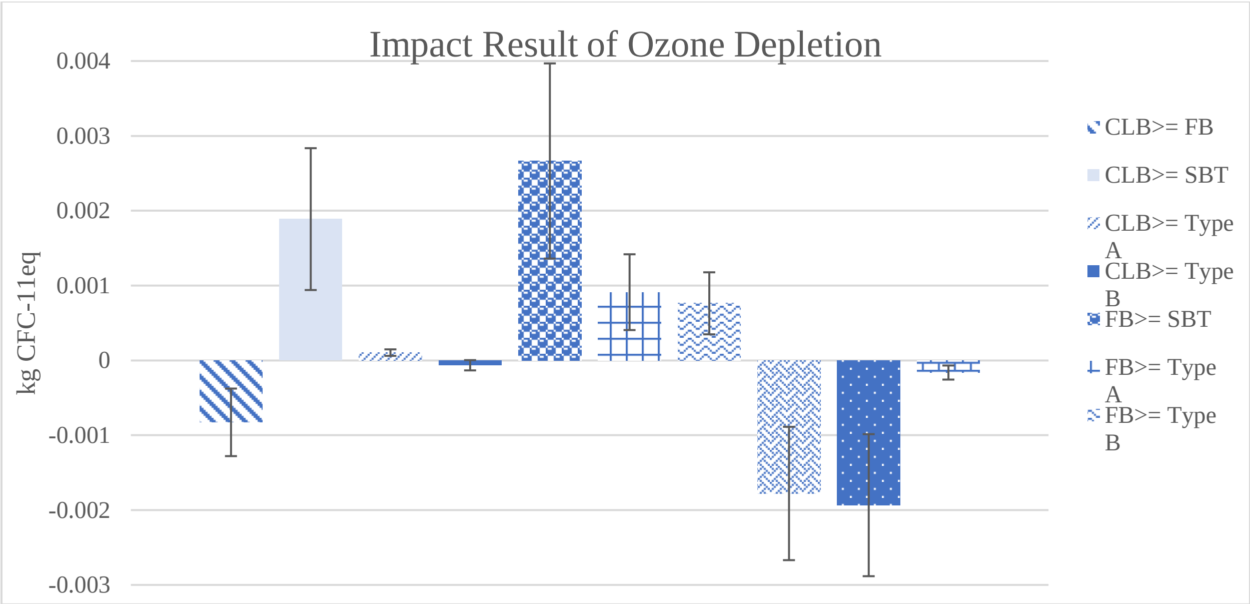


Figure D-7: Ozone Depletion Monte Carlo Mean and Standard Deviation

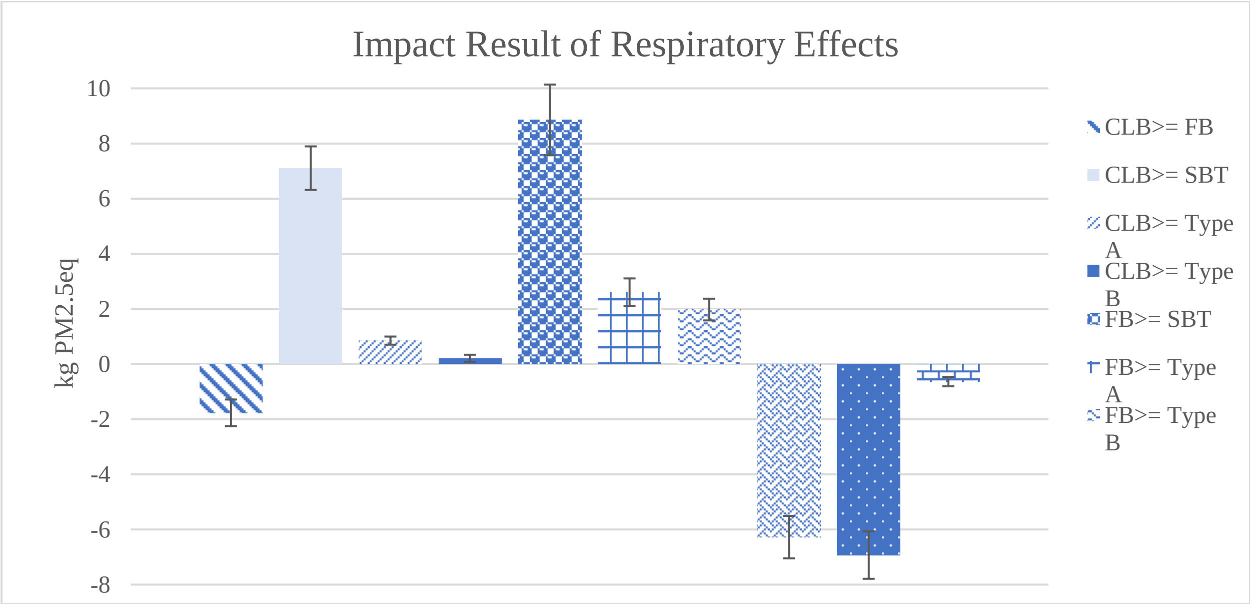


Figure D-8: Respiratory Effects Monte Carlo Mean and Standard Deviation

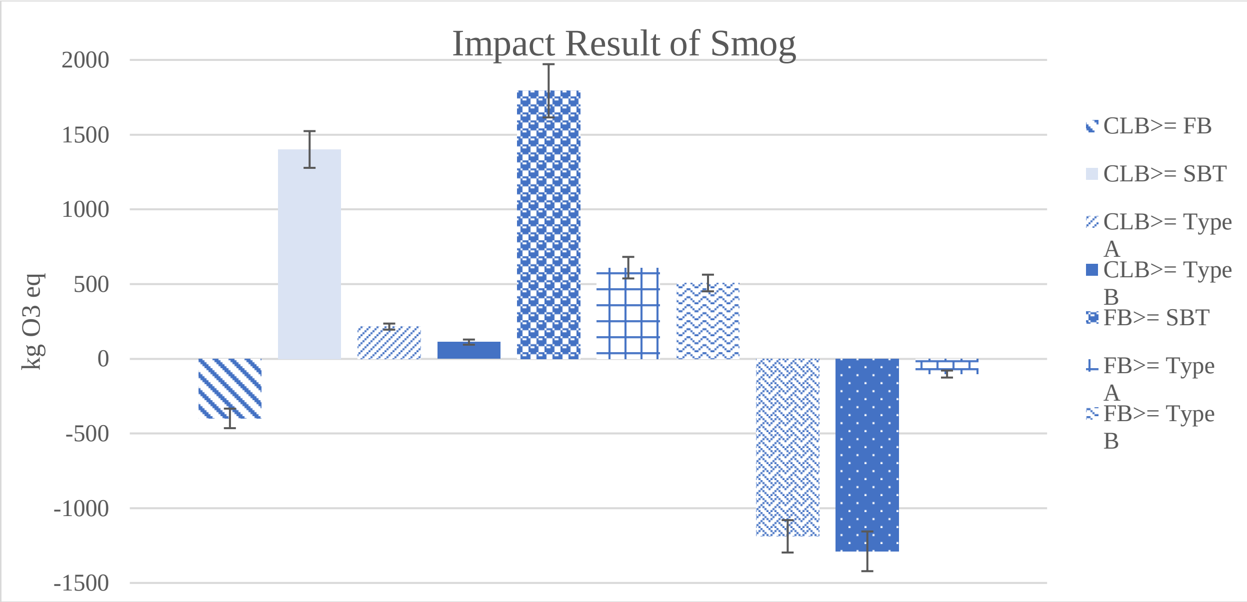


Figure D- 9: Smog Monte Carlo Mean and Standard Deviation

APPENDIX E: SIMAPRO PROCEDURE

Once logged into SimaPro and you've created a new project, this is one of the first screens that you'll find yourself on. Figure E-1 below illustrates the general screen and a brief list of key functions which will be elaborated on in later figures.

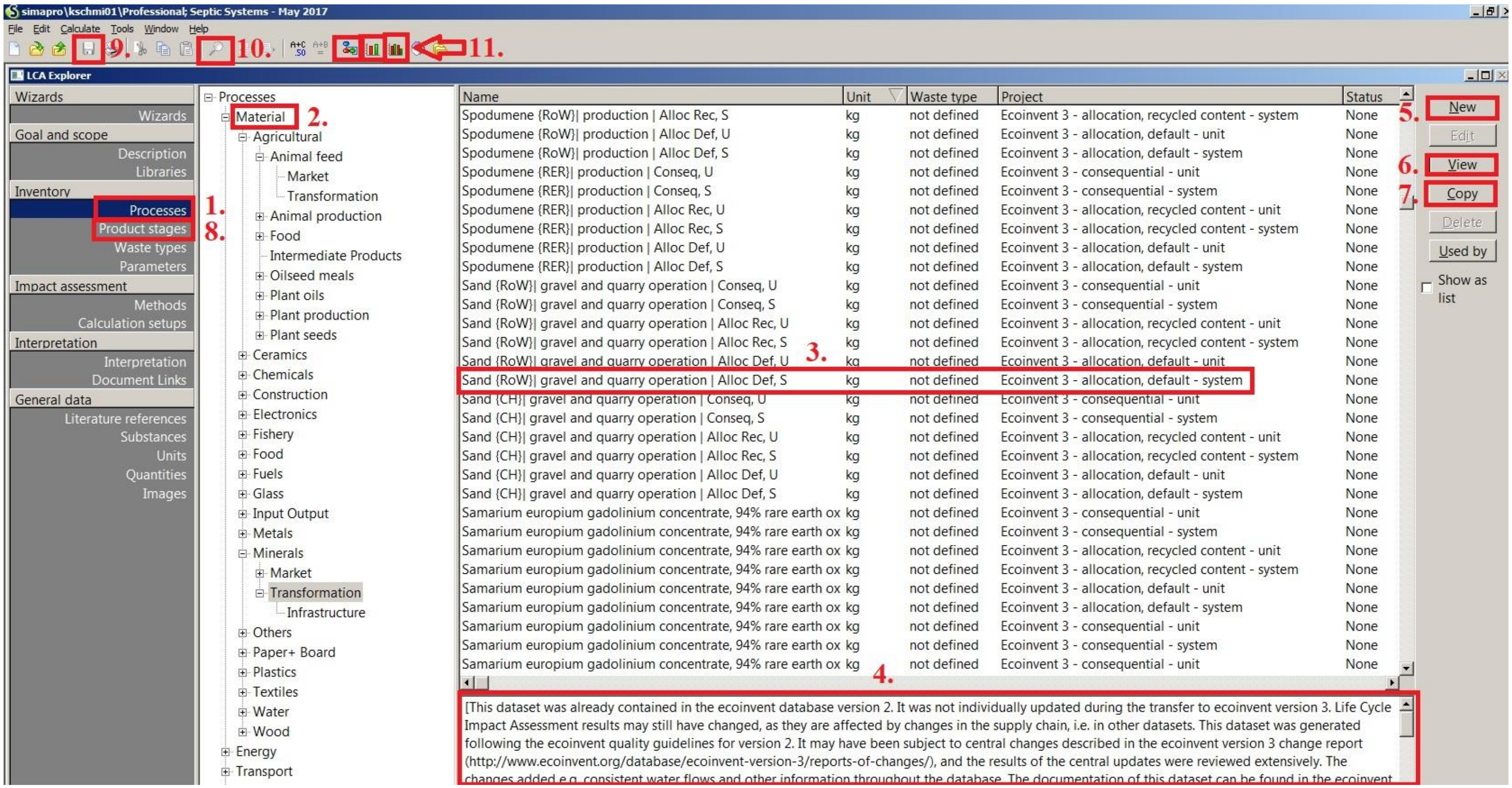


Figure E-1: SimaPro Main Screen

The numbers in the Figure E-1 are as follows:

1. Processes – once your goal and scope has been defined, the first thing you'll want to do is under 'Inventory' click on 'Processes'. Processes contain all the pre-made datasets which are contained under the following sub-headings:
    a. Material
    b. Energy
    c. Transport
    d. Processing
    e. Use
    f. Waste Scenario
    g. Waste Treatment

Each sub-heading then contains more sub-headings where the datasets can be found and/or created.

2. The main sub-heading under 'Processes' that was primarily used for this thesis is 'Material'. As described in Section 3.5 this is where the different datasets and their respective allocations are.
3. Pre-made Dataset: this is an example of a pre-made ecoinvent version 3 dataset for a gravel and quarry operation to produce sand, which was taken from the Rest of the World (RoW) and uses the default allocation system method with kg as it's unit.
4. The comment box: the comment box can be useful in determining which dataset is best for your study, for example I calculated the volume of concrete required for the septic tank and the concrete dataset comment box specified the density allowing for a more accurate weight to be calculated.
5. New: to create a new dataset.
6. View: to view a dataset.
7. Copy: you can't revise a pre-made dataset, however you can copy it, save it under a different name and revise the copied dataset.
8. Product stages: once you've assessed the datasets and know which ones you'll be using, you will click 'Product Stages' and create your assembly and eventually your life cycle, but this will be explained in more depth later.
9. Save: to save a dataset, assembly, life cycle, or anything you create or edit.
10. Find: this is one the most useful tools as it allows you to search datasets, libraries, etc. This was extremely useful when I didn't know where to start, i.e., I would use the search button as a starting point and to help create a shortlist of potential datasets for certain materials (i.e., PVC)
11. The analyses buttons, from left to right their functions are as follows:
    a. Network Analysis: can look at the network of *unit processes* to help identify environmental hotspots,

b. Analyze: by clicking analyze, you can select your impact assessment of choice and it will output the environmental impacts in both a bar graph and a chart,
c. Compare: compare two or more assemblies, life cycles, or datasets.

Now onto a more step-by-step procedure of how to do a standard LCA:

Step 1: After defining the goal and scope, under the 'Inventory' heading, click 'Processes', this is where all of the pre-made datasets are and where you will find the datasets that are best suited for your study, or where you will revise existing datasets, or create new ones, or use a mixture of all three options (Figure E-2). The five sub-headings used in this study were: Material, Energy, Transport, Waste Scenario, and Waste Treatment.

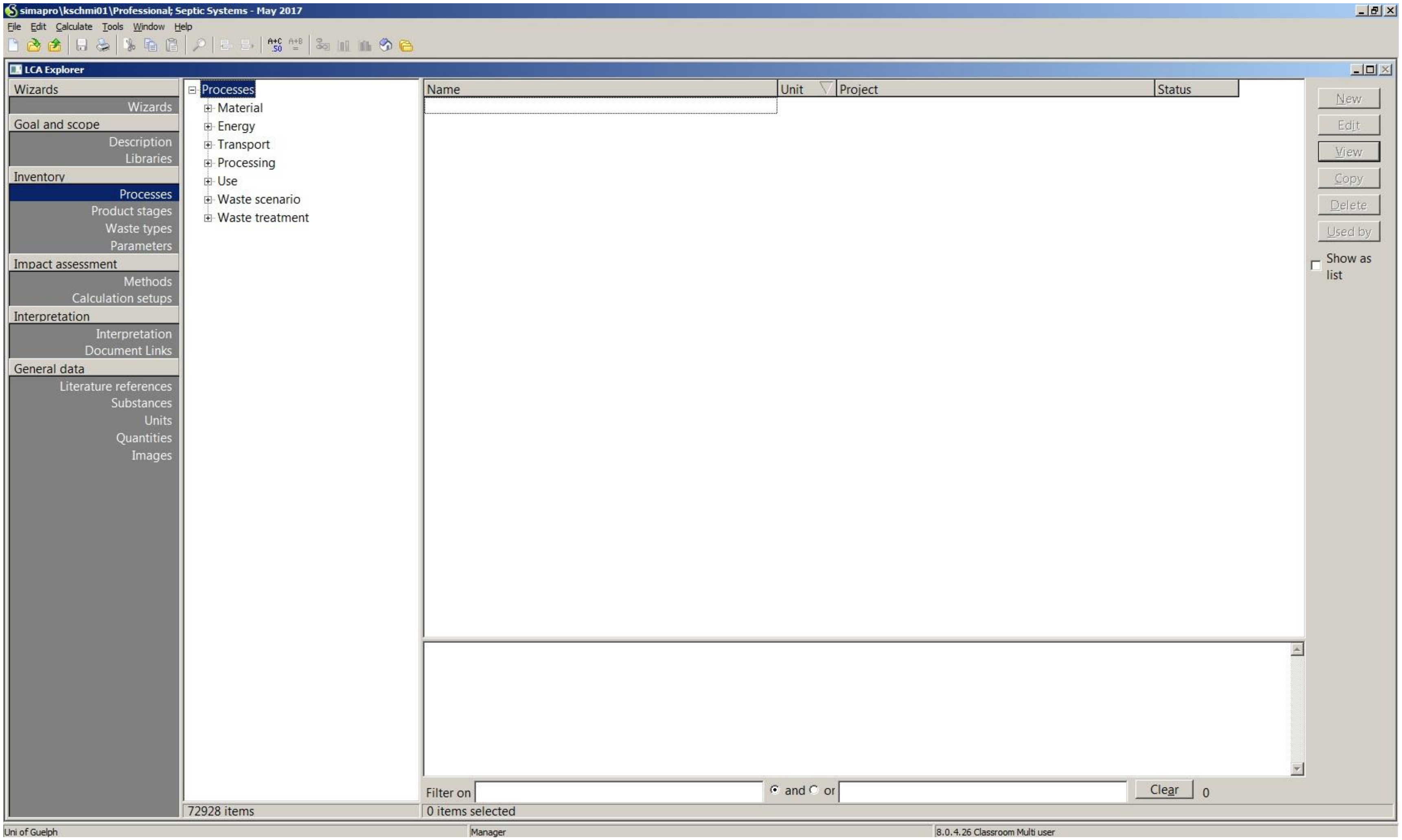


Figure E-2: Processes

Step 2: Get familiar with the pre-made datasets, the ecoinvent database is the most widely used and makes up majority of the pre-made datasets. In Figure E-3, if you were looking for gravel you would go under 'Processes' → 'Material' → 'Minerals' → 'Market' → then you could click on the different gravel datasets, look at the comment box on the bottom of the screen and click the 'View' button on the right-hand side to get a better idea of the inputs and outputs of the dataset.

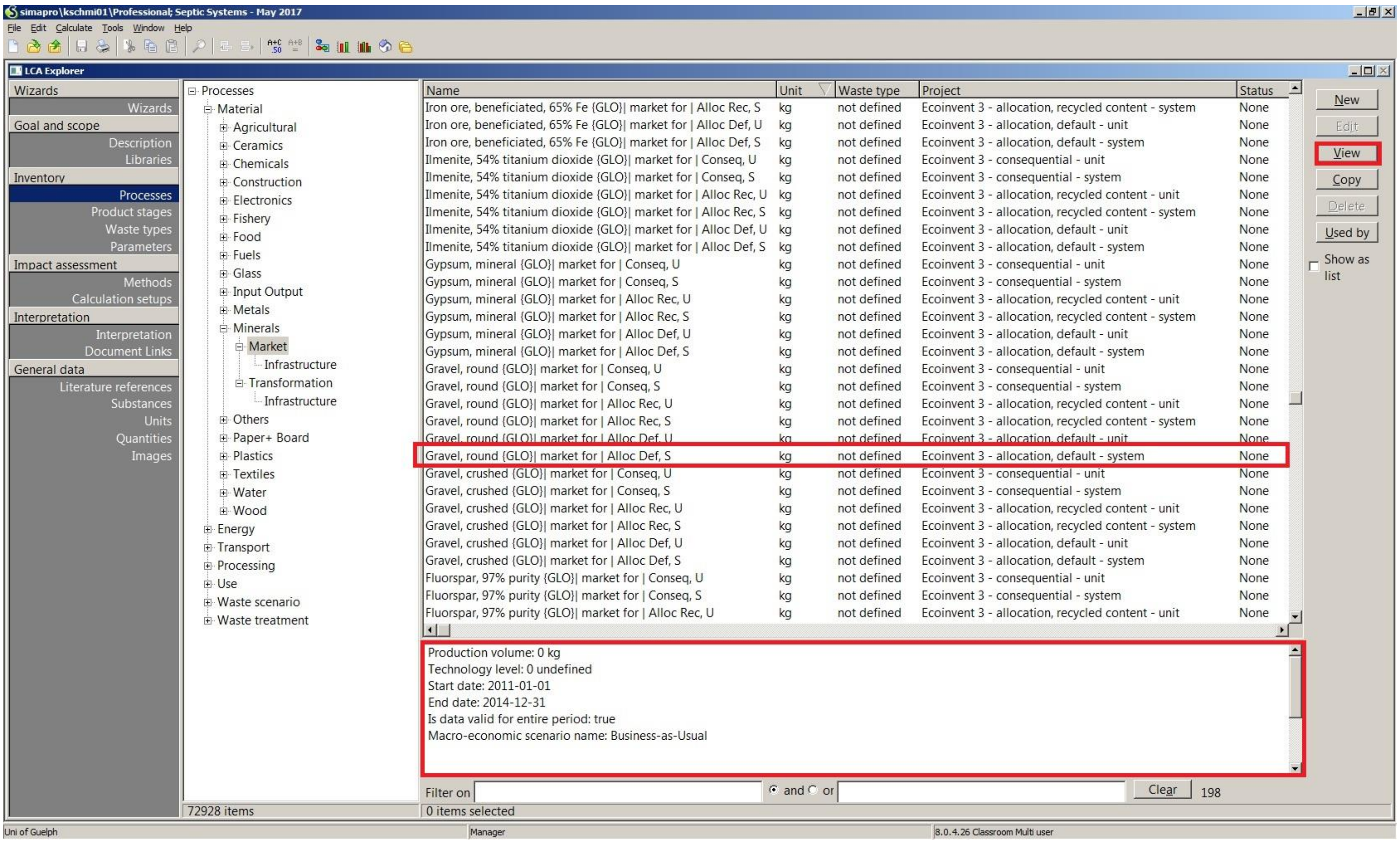


Figure E-3: Gravel Dataset Example

Step 3: If you click on the 'Gravel, round {GLO}|market for|Alloc Def, S' dataset (Figure E-4), and select the 'View' button on the right side, you can view the dataset. Make sure the 'Input/Output' tab is selected to view the inputs/outputs of the dataset. The name of the dataset and the produced product and co-products will appear in the first line, along with the amount produced given the inputs and outputs (i.e., 1 kg) the Quantity (i.e., Mass) and the Allocation, which is 100% in this case (you could produce more than 1 product and split their allocations based on whatever quality is specified such as mass or economic). However, for this study only a mass allocation was used. Next you see the known outputs from the technosphere, and the known inputs from nature. There are thousands of inputs and outputs, as the scroll bar is extremely small. Lastly, you cannot make changes to this dataset since you just clicked 'View' and therefore you cannot save it as the 'Save' button is faded.

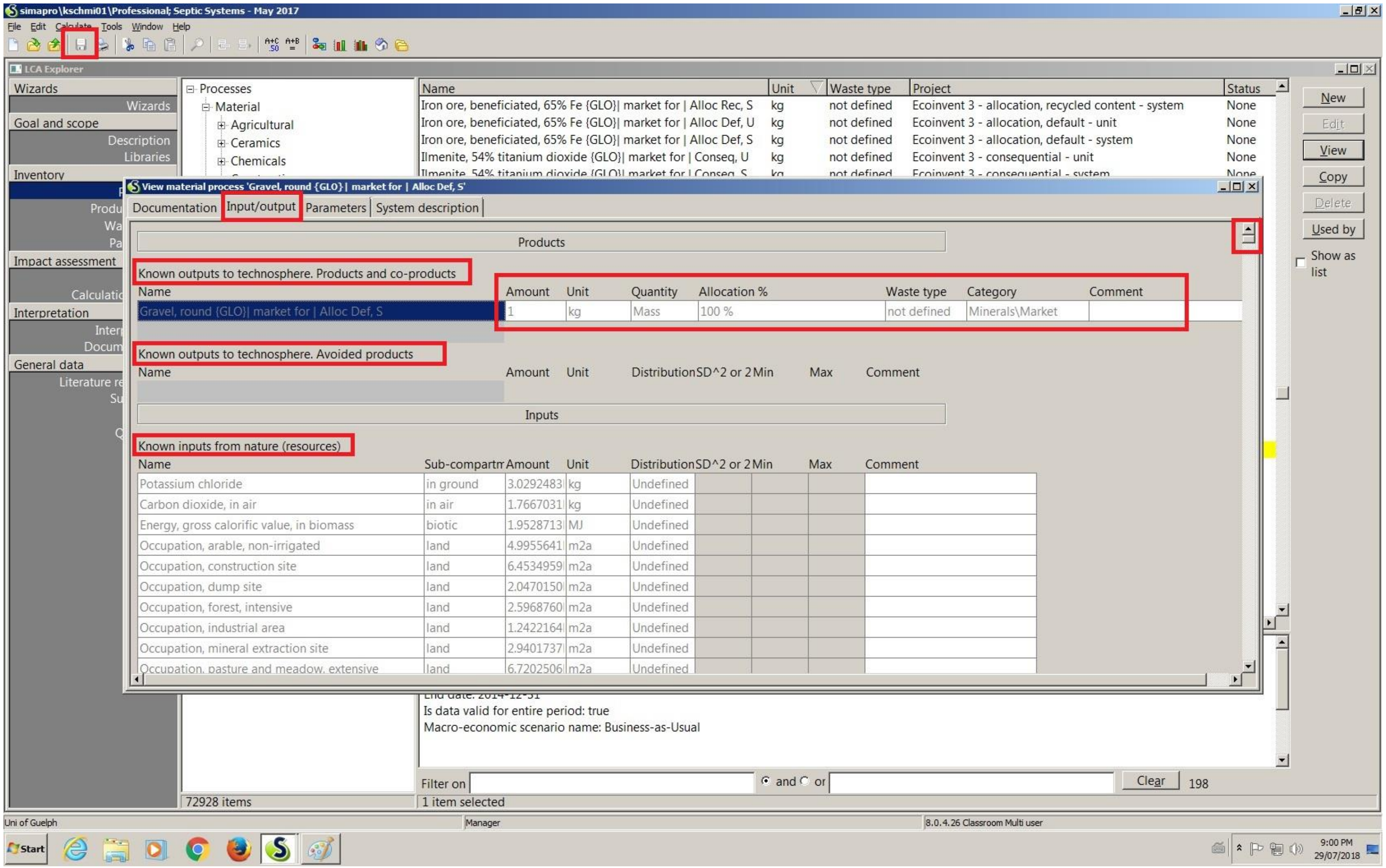


Figure E-4: Gravel Dataset

Step 4: Once you've looked at the different material datasets, if applicable, the next dataset you'll want to familiarize yourself with is the Transport Datasets. The transport datasets are under 'Processes' → 'Transport', and as you can see in Figure E-5, contains various methods of transportation, but also building equipment. It is important to note that the units between transportation methods vary. For example, a lorry or transport truck's input is in tkm (ton-kilometers, which is the weight of whatever is transported multiplied by the distance), however a personal vehicle such as a small car's input is only in distance (i.e., km).

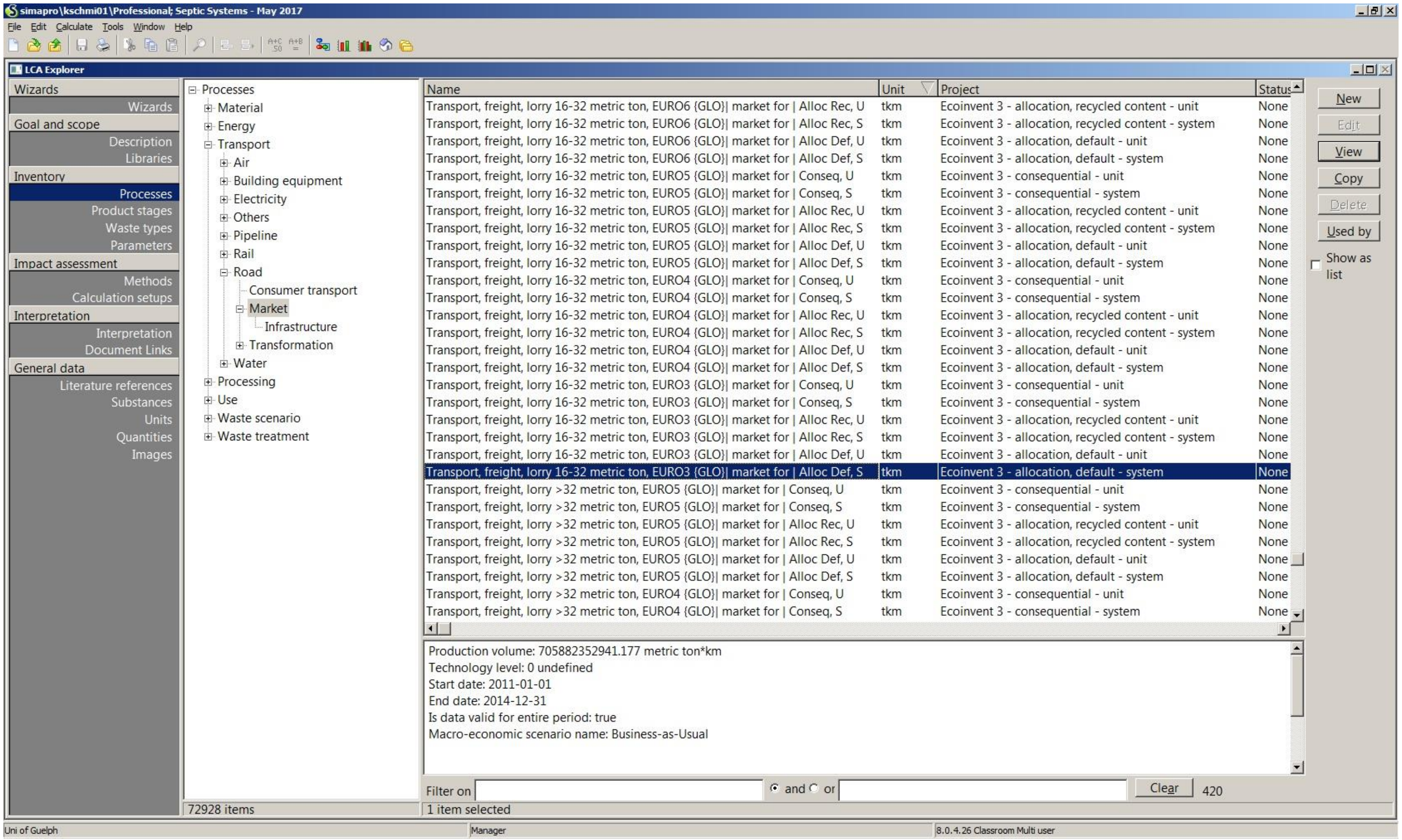


Figure E-5: Transport Dataset

Step 5: Next, after the 'Material' datasets, but before the transport datasets are the energy datasets. In Figure E-6, under 'Energy' → 'Electricity Country Mix' → 'Low Voltage' → 'Market' → the low voltage Ontario electricity was selected for this study, but as you can see there are various sources of electricity and the energy dataset you choose should be best suited for your study.

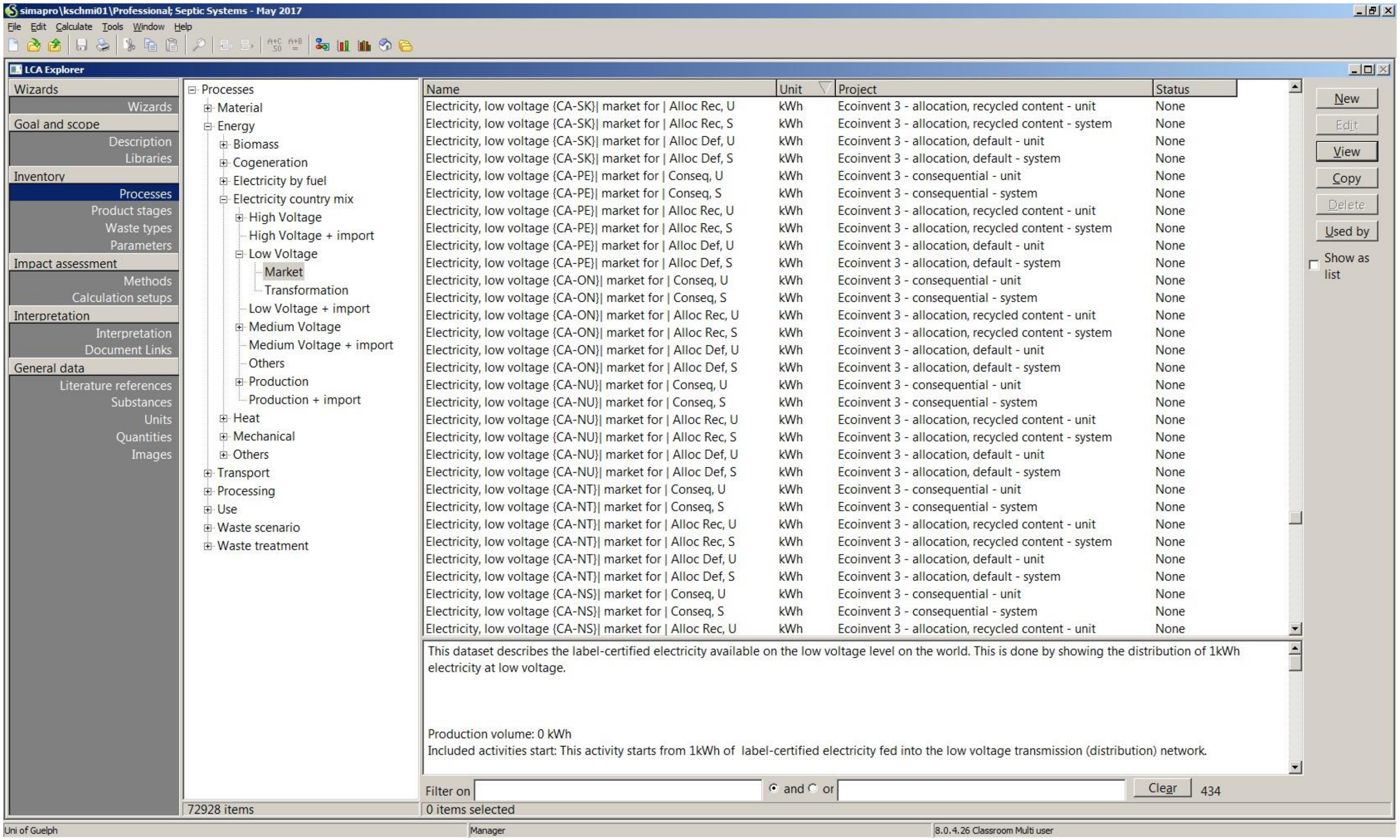


Figure E-6: Low Voltage Electricity

Step 6: Next you should familiarize yourself with the 'Waste Treatment' datasets, as these will be used in the next step to create your waste scenarios. There are a few pre-made Waste Scenario datasets, however it is likely you'll have to make your own. The waste scenario datasets are specific to how a product will be disposed of and will be linked to an assembly when creating a LCA of a product. As you can see from Figure E-7, I created multiple waste scenarios for my different models. Since the septic tank goes to landfill I created my waste scenario under the 'Landfill' sub-heading. Next, I clicked the 'New' button on the right side.

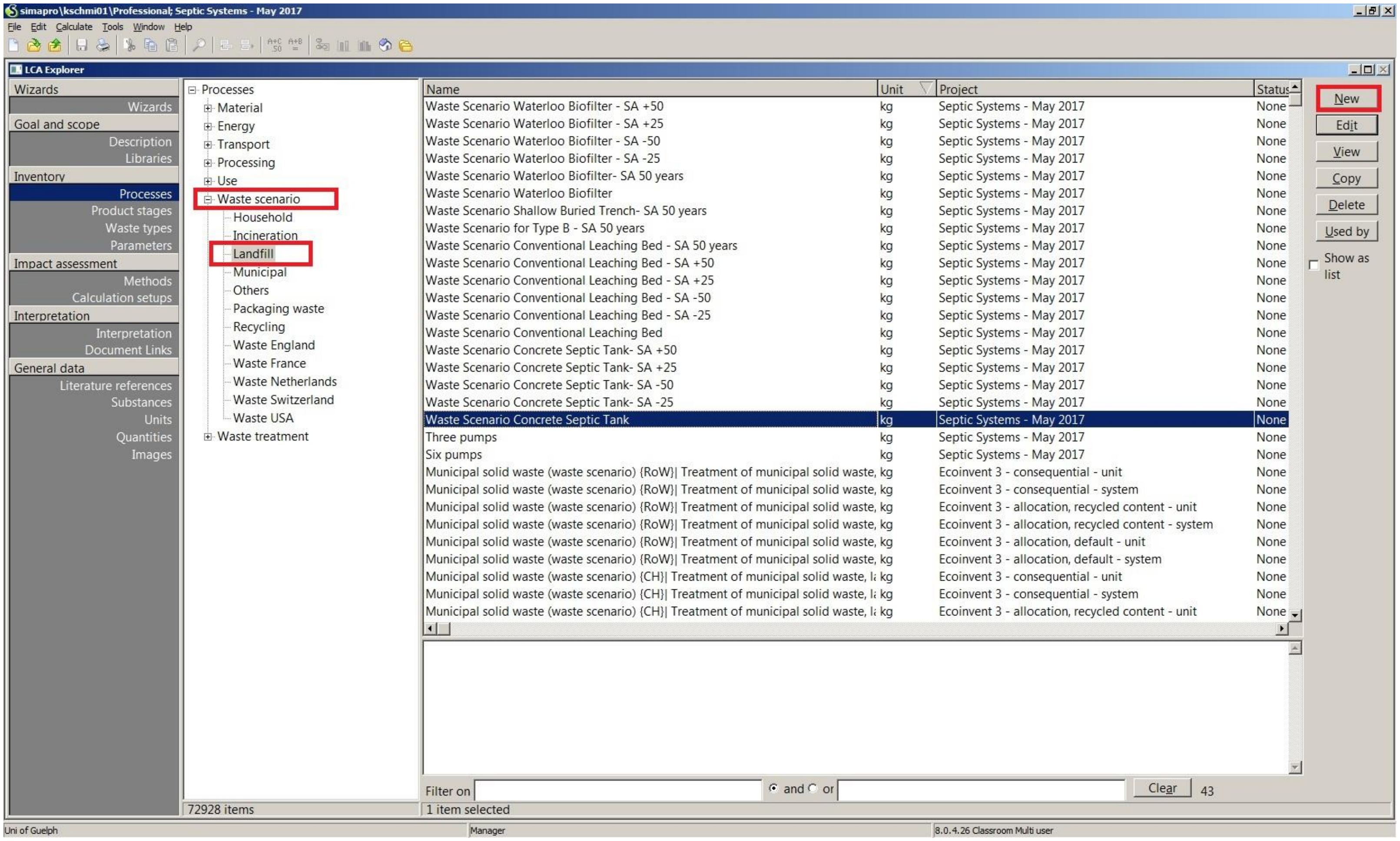


Figure E-7: Waste Scenario

From the ascending from the top to the bottom red box in Figure E-8:

1. Create a name for the waste scenario and enter the amount of which will be going to waste, as you can see the septic tank and its accessories were approximately 4843.8 kg,
2. Enter any inputs from the technosphere, I assumed the waste will travel 180 km to the Twin Creeks Landfill in Watford Ontario, therefore the input for the lorry transportation = (4,843.8 kg/1,000)*180 km = 871.9 tkm,
3. The third box represents the waste separation allocation. Your product or system may be made up of various materials and each of them will have their own waste stream (e.g., inert materials to landfill, plastics to recycling, etc.). If you click on the box, a screen will pop up (see Figure E-9). From there you can go through the waste treatments and choose the most appropriate datasets. Once you've chosen the waste treatment, select the material/waste type that the waste treatment applies to. As seen in Figure E-8 I have broken up the septic tank into three waste scenarios and have allocated to only three materials: steel, cement, and plastics, with 100% allocation (i.e., all steel, cement, and plastics are disposed of to their respective waste treatment).
4. The last box is similar to the third box; however it is for the leftover or remaining waste scenarios. There may be a few materials that do not fit into the assigned waste streams, and therefore the user must specify a waste treatment in which the remaining materials are assigned to.

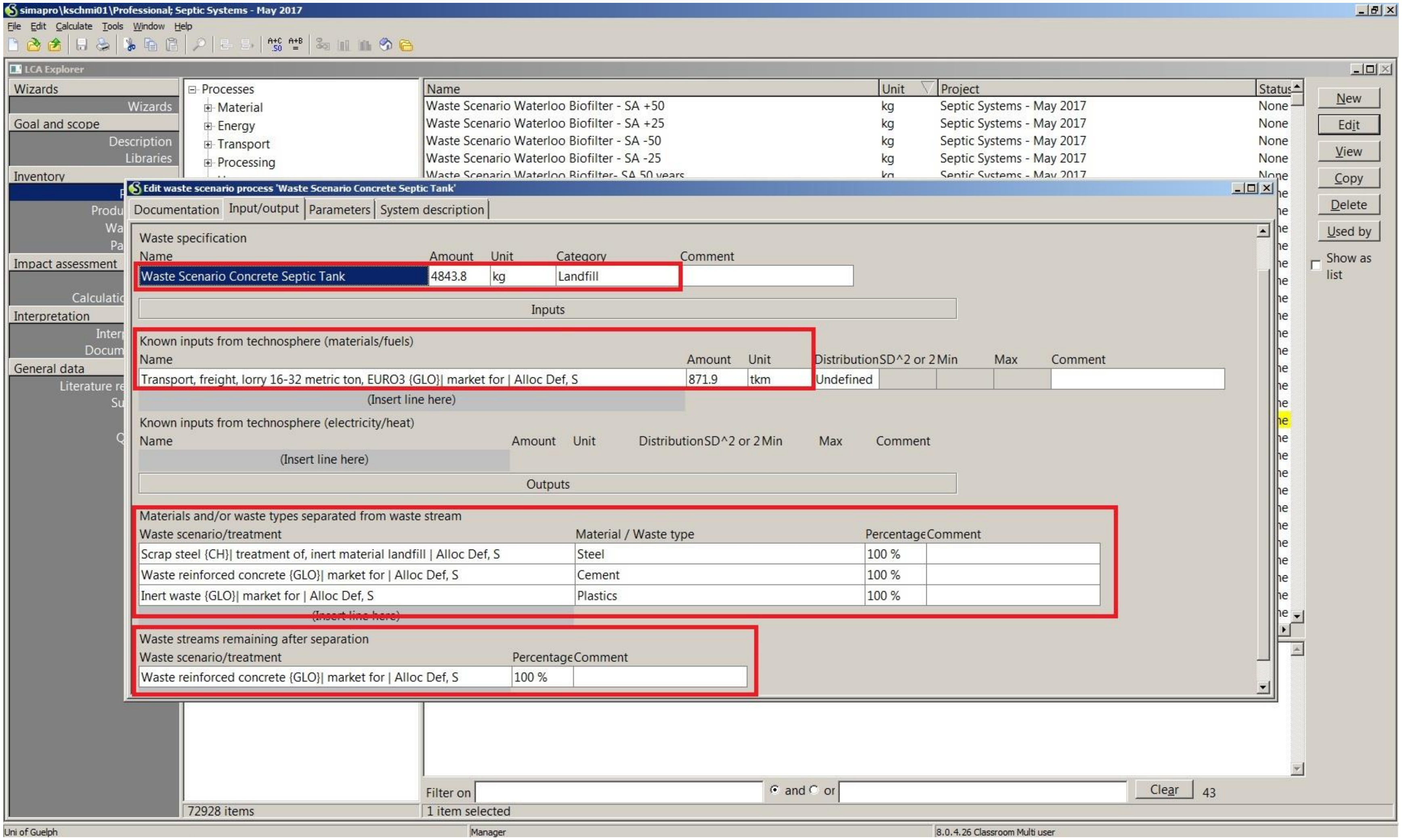


Figure E-8: Waste Scenario Breakdown

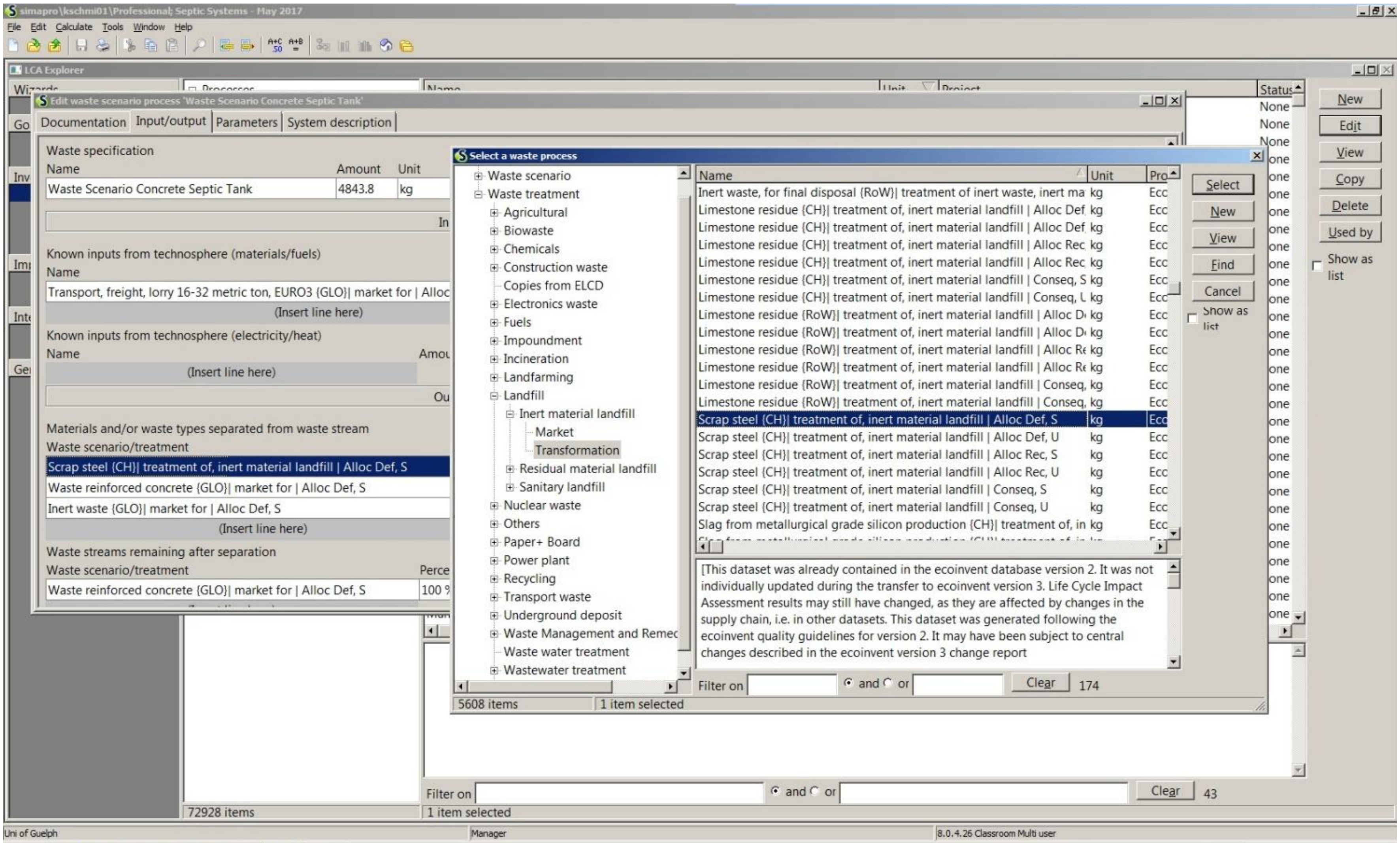


Figure E-9: Waste Scenario and Choosing Waste Treatments

Step 7: Once you have an idea of the database you would like to use, it's time to build an assembly. Click 'Product Stages' on the left side, then 'Assembly' and 'Others'. Here you will create a 'New' assembly. As per Figure E-10, I have already created multiple assemblies for my study. Let's investigate how to create an assembly, specifically how I created the Concrete Septic Tank Assembly. Figure E-11 illustrates the main screen of the assembly.

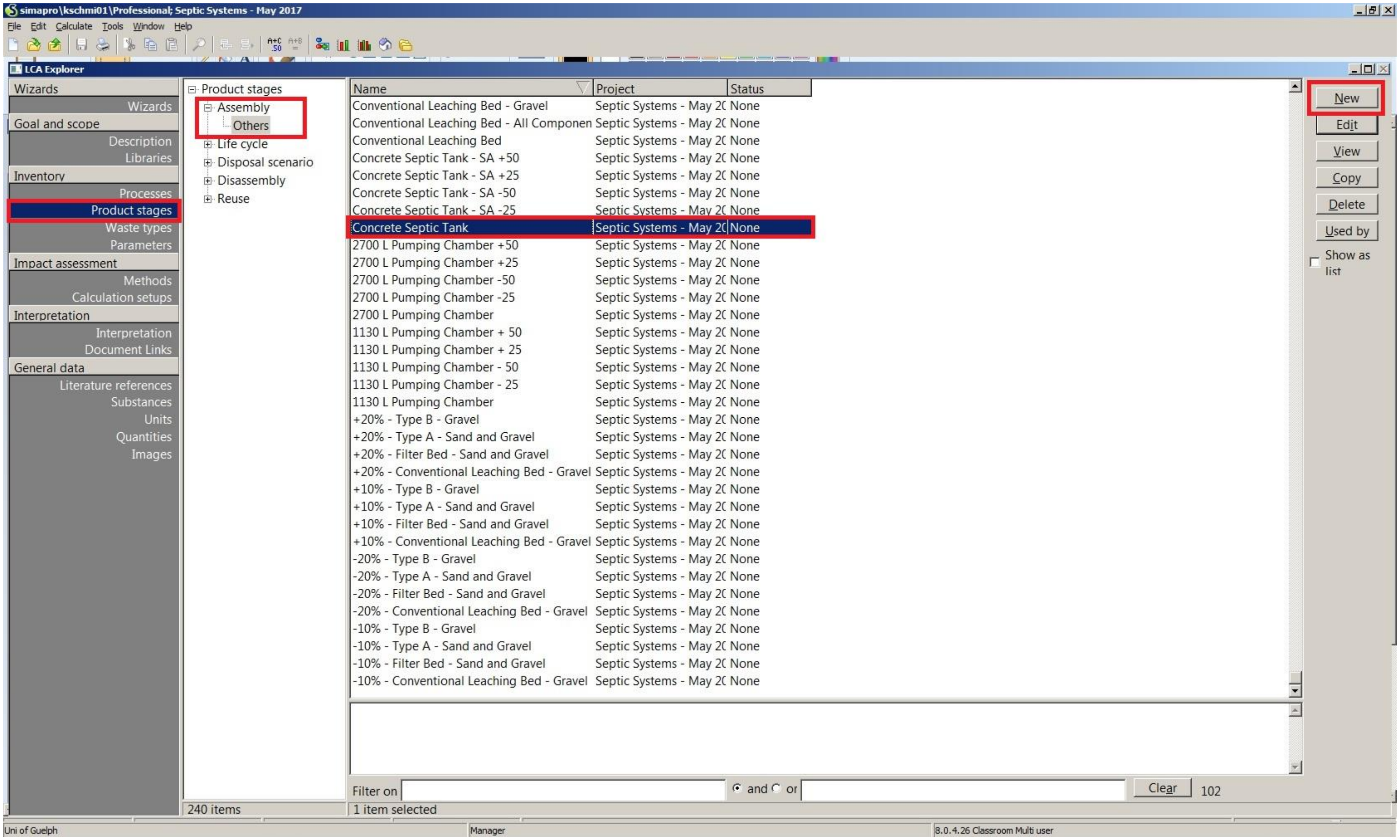


Figure E-10: Assembly

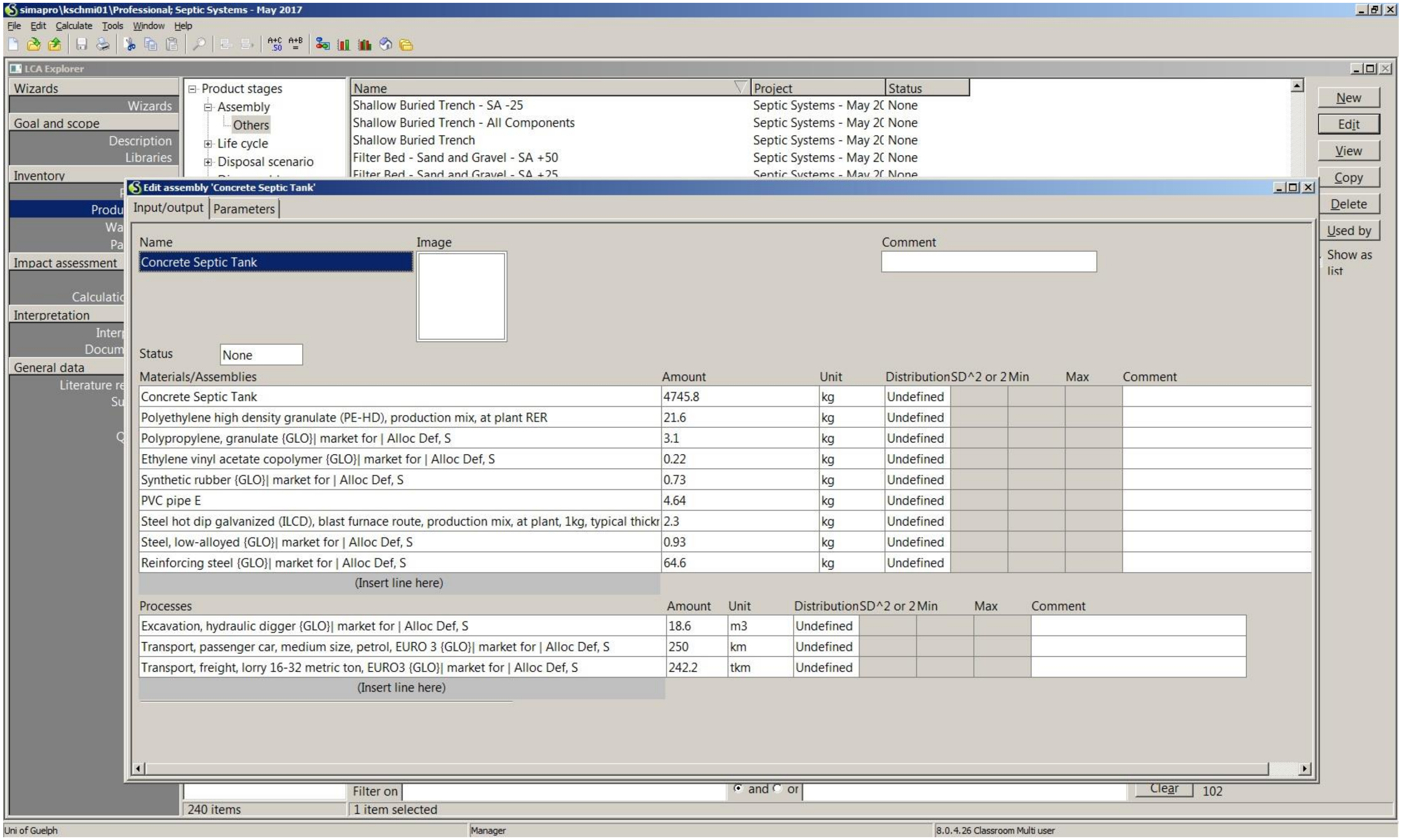


Figure E-11: Concrete Septic Tank Assembly

Step 8: If you click on a white box, you can select the databases as seen in the previous steps. Figure E-12 illustrates that under ‘Material’ → ‘Metals’ → ‘Ferro’ → ‘Market’, I selected the global dataset for low-alloyed steel. Once you have created and saved your assembly, you will create a ‘Life Cycle’, the next option under ‘Assembly’.

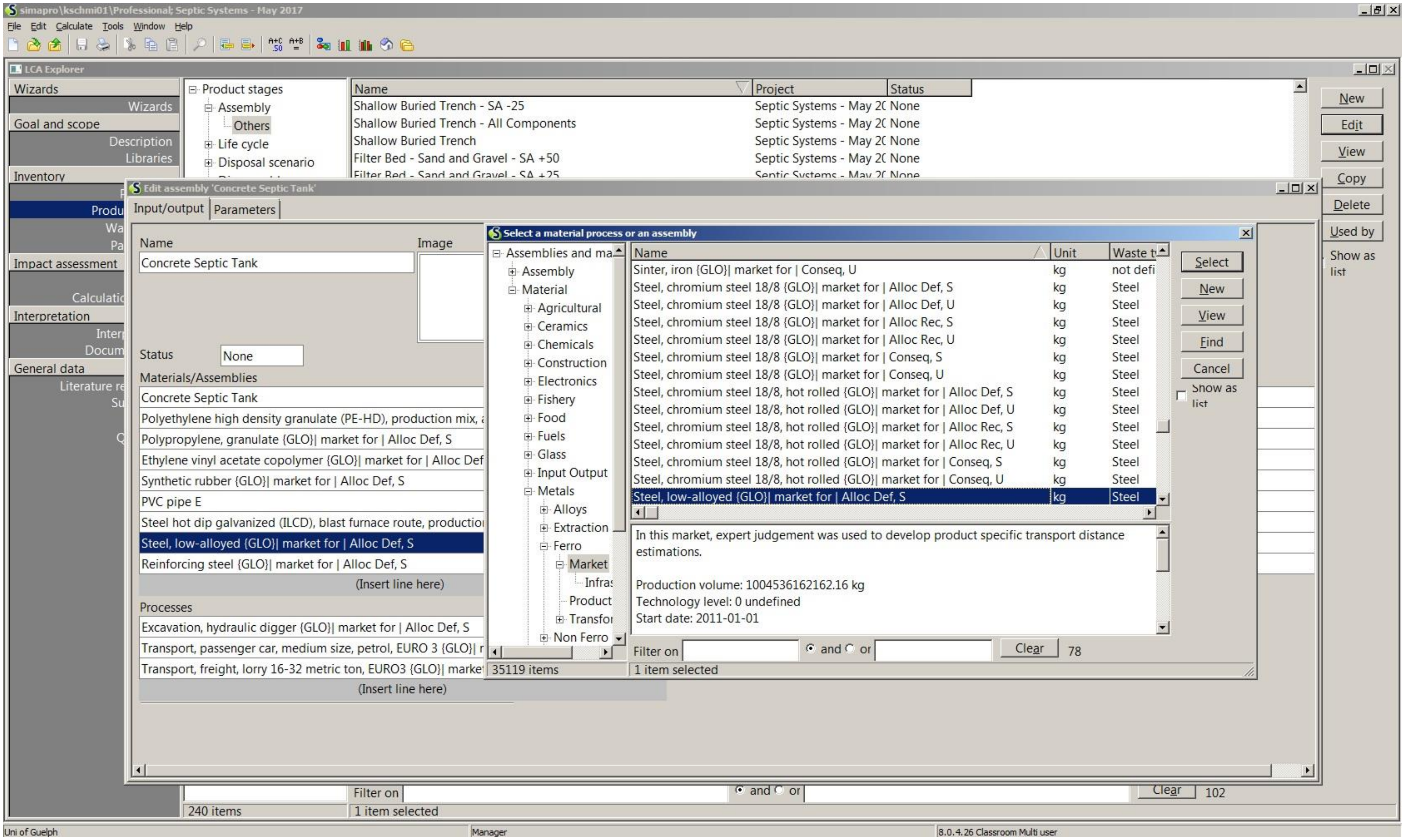


Figure E-12: Selecting Datasets for an Assembly

Step 9: Similar to the assembly stage, under 'Life Cycle' click 'Others' and create a 'New' life cycle. As per Figure E-13, you'll create a name, and then select the assembly which will be linked to a waste scenario to create a life cycle. Once you have selected an assembly, you will specify the amount of assemblies or products you want to analyze in the life cycle. For my project I only looked at 1 septic tank (i.e., 1 p).

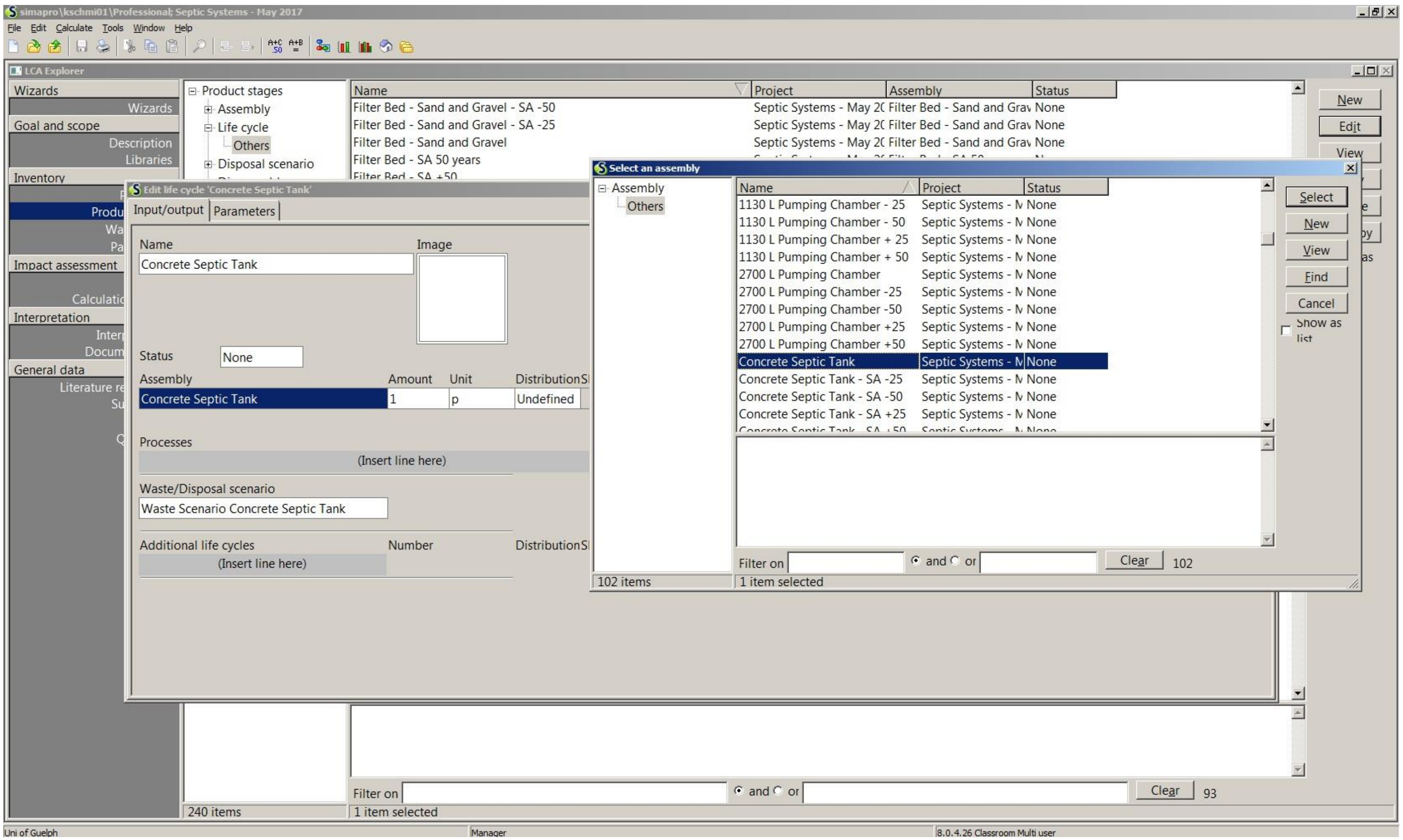


Figure E-13: Selecting an Assembly for a Life Cycle

Step 10: After choosing the assembly, you will select the waste scenario which you created earlier. Once you have chosen the waste scenario save the life cycle and now we can move on to analyzing the life cycle.

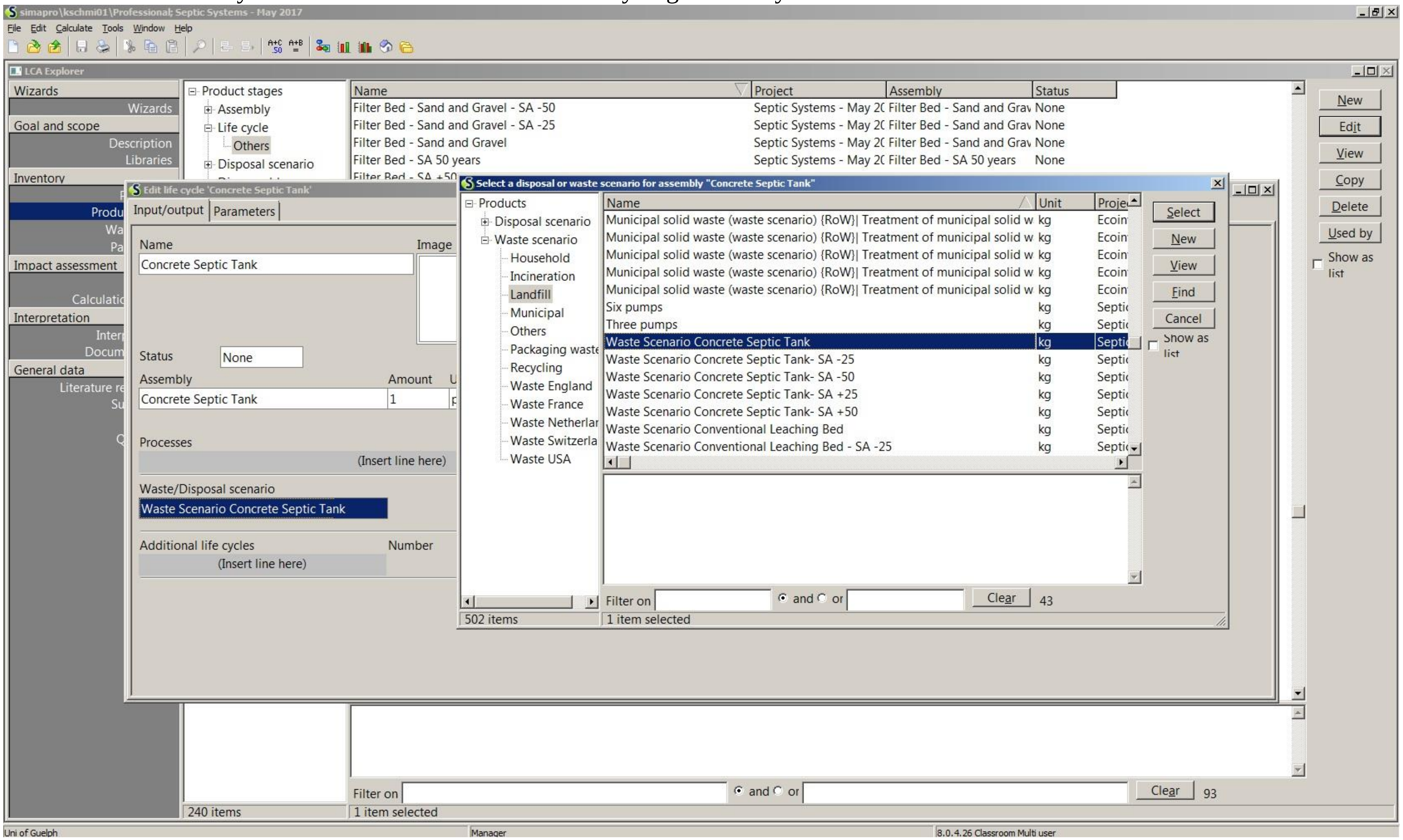


Figure E-14: Selecting a Waste Scenario for a Life Cycle

Step 11: Select the life cycle (or assembly, or dataset) you want to analyze and click the analyze button (the button highlighted by the top red box in Figure E-15)

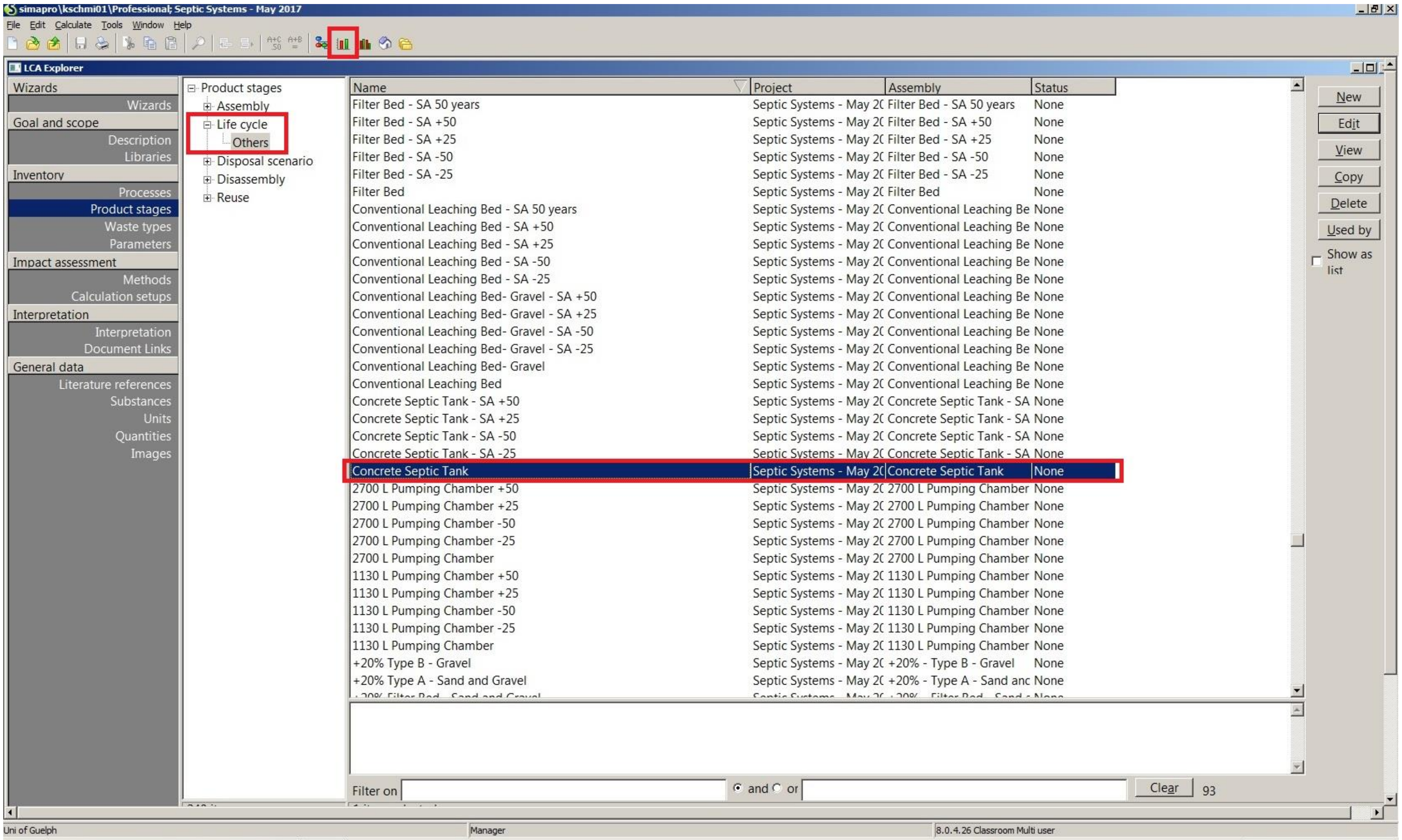


Figure E-15: Analyzing a Product

Step 12: Once you've inputted how many of the life cycles you would like to analyze, as per Figure E-16, I only analyzed once septic tank. You will click the box under 'Method' to select your LCIA of choice. I used the North American method TRACI 2.1, and selected the US-Canadian 2008 Normalization/Weighting (note: I did not use normalization or weighting in this study). Once you've selected the LCIA, click the calculate button in the bottom right corner.

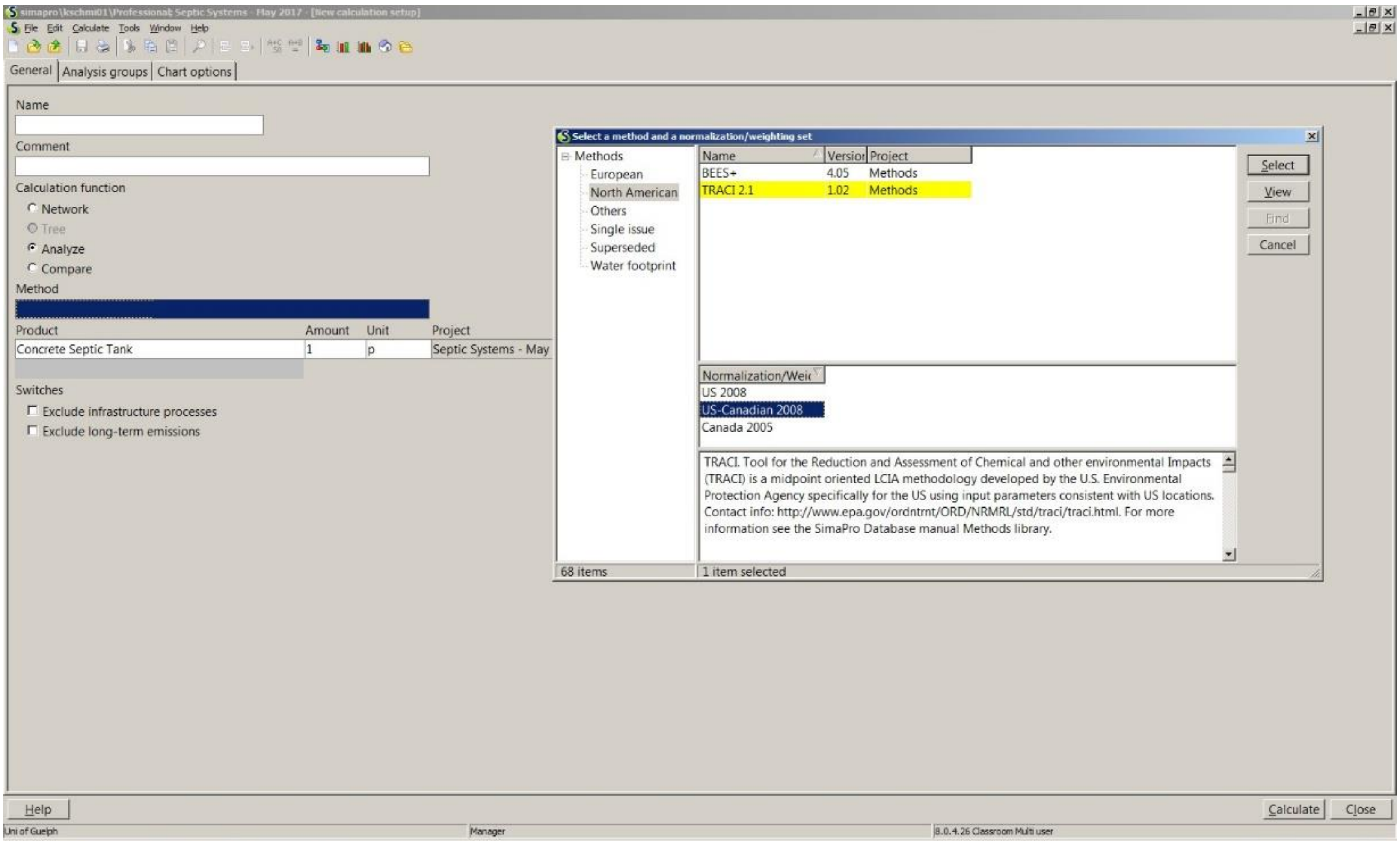
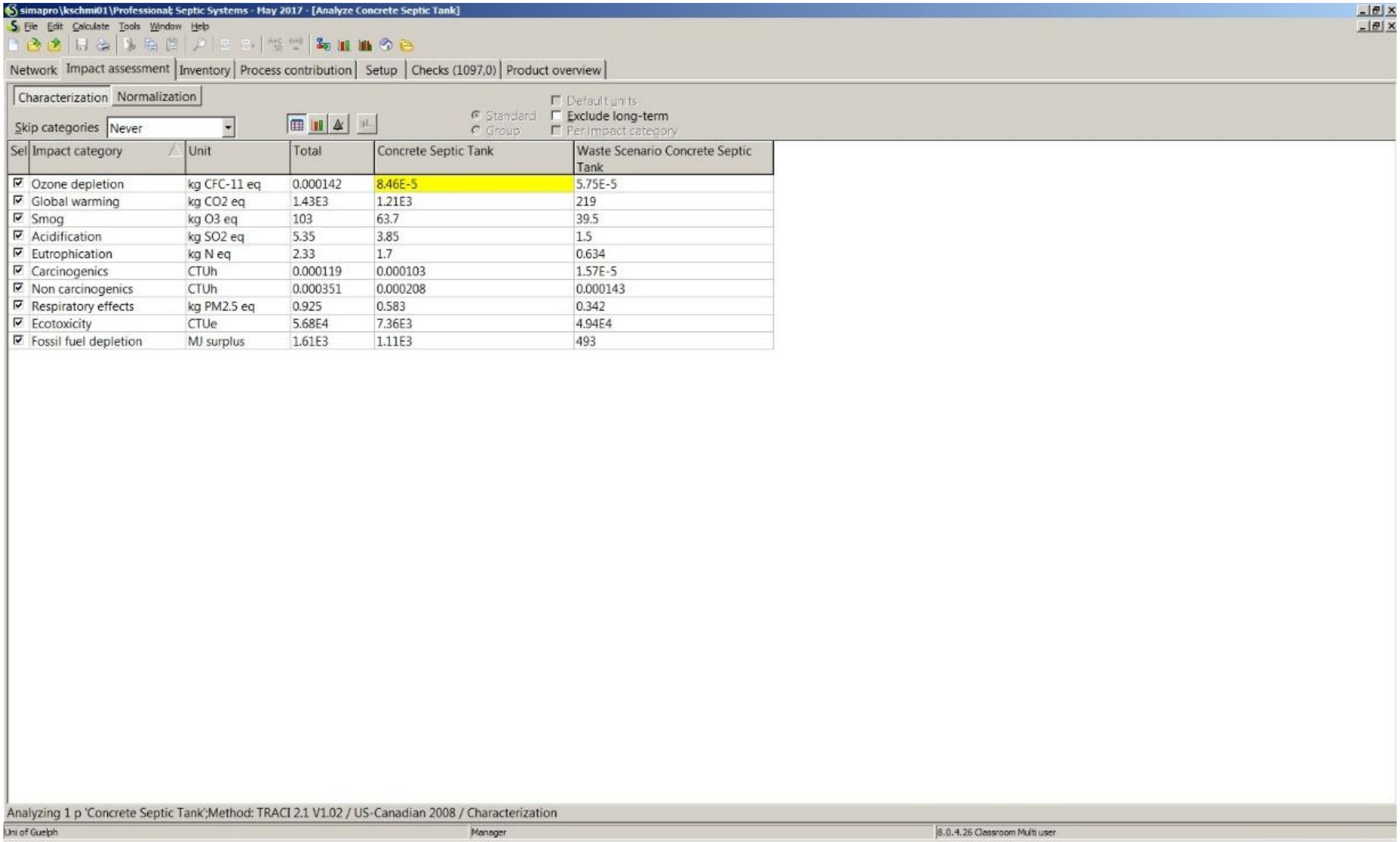


Figure E-16: Selecting a LCIA

Step 13: Once it is done analyzing, the characterization chart is the default output, you can click on the chart button (as seen in Figure E-17 below) to see the values, as characterization only illustrates the results as a percent makeup. The other red box that highlights 'Network' which allows users to look at the processes networks. Figure E-18 below illustrates the results as a chart.

Figure E-17: Results presented in a Graph



Sel	Impact category	Unit	Total	Concrete Septic Tank	Waste Scenario Concrete Septic Tank
☑	Ozone depletion	kg CFC-11 eq	0.000142	8.46E-5	5.75E-5
☑	Global warming	kg CO2 eq	1.43E3	1.21E3	219
☑	Smog	kg O3 eq	103	63.7	39.5
☑	Acidification	kg SO2 eq	5.35	3.85	1.5
☑	Eutrophication	kg N eq	2.33	1.7	0.634
☑	Carcinogenics	CTUh	0.000119	0.000103	1.57E-5
☑	Non carcinogenics	CTUh	0.000351	0.000208	0.000143
☑	Respiratory effects	kg PM2.5 eq	0.925	0.583	0.342
☑	Ecotoxicity	CTUe	5.68E4	7.36E3	4.94E4
☑	Fossil fuel depletion	MJ surplus	1.61E3	1.11E3	493

Figure E-18: Results presented as a Chart

Step 14: To export, click 'File' then 'Export' (Figure E-19).

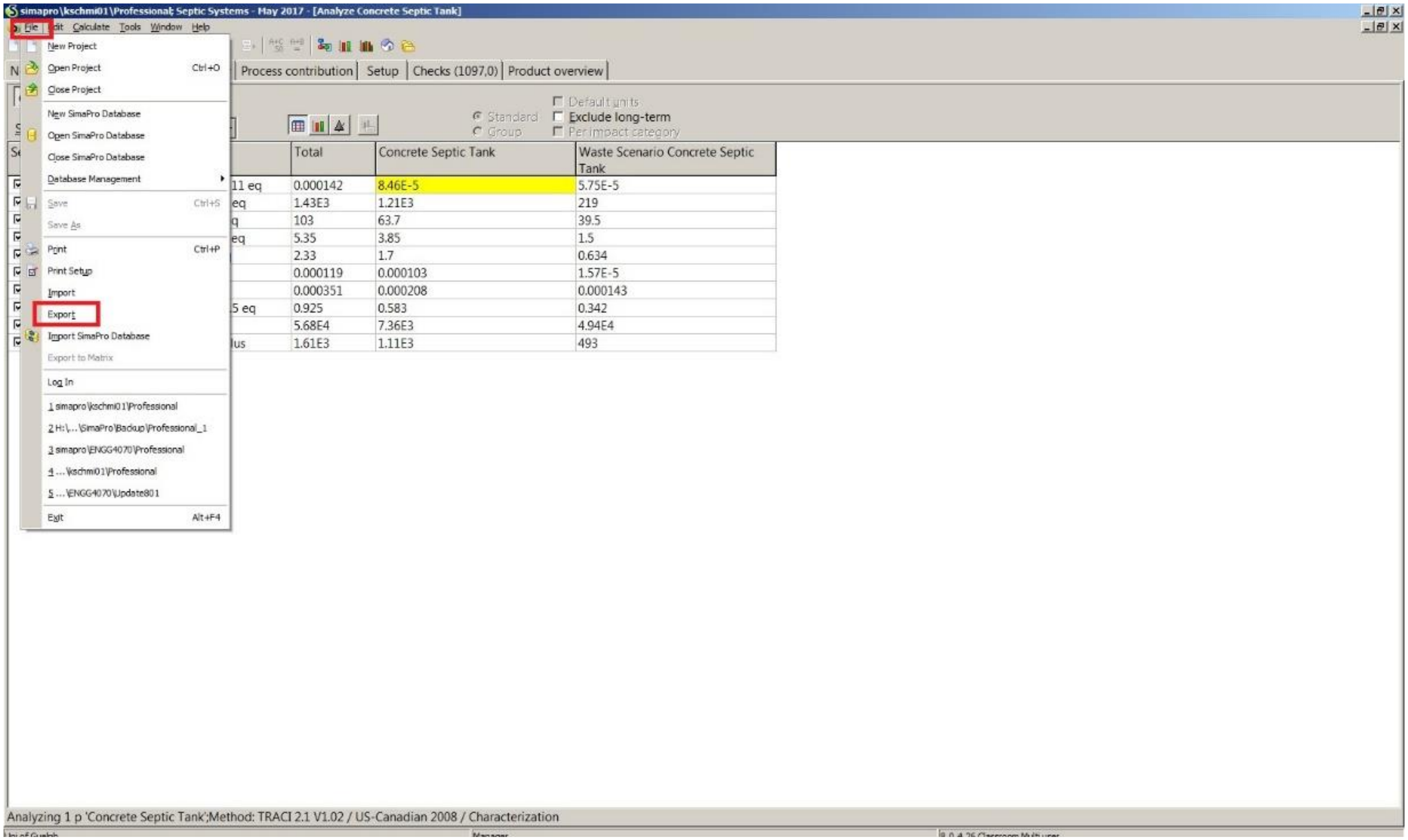


Figure E-19: Exporting Results

Step 15: Finally, save the chart or graph to the folder of your choice. The chart will export as an excel file and the graph will export as a jpeg (Figure E-20).

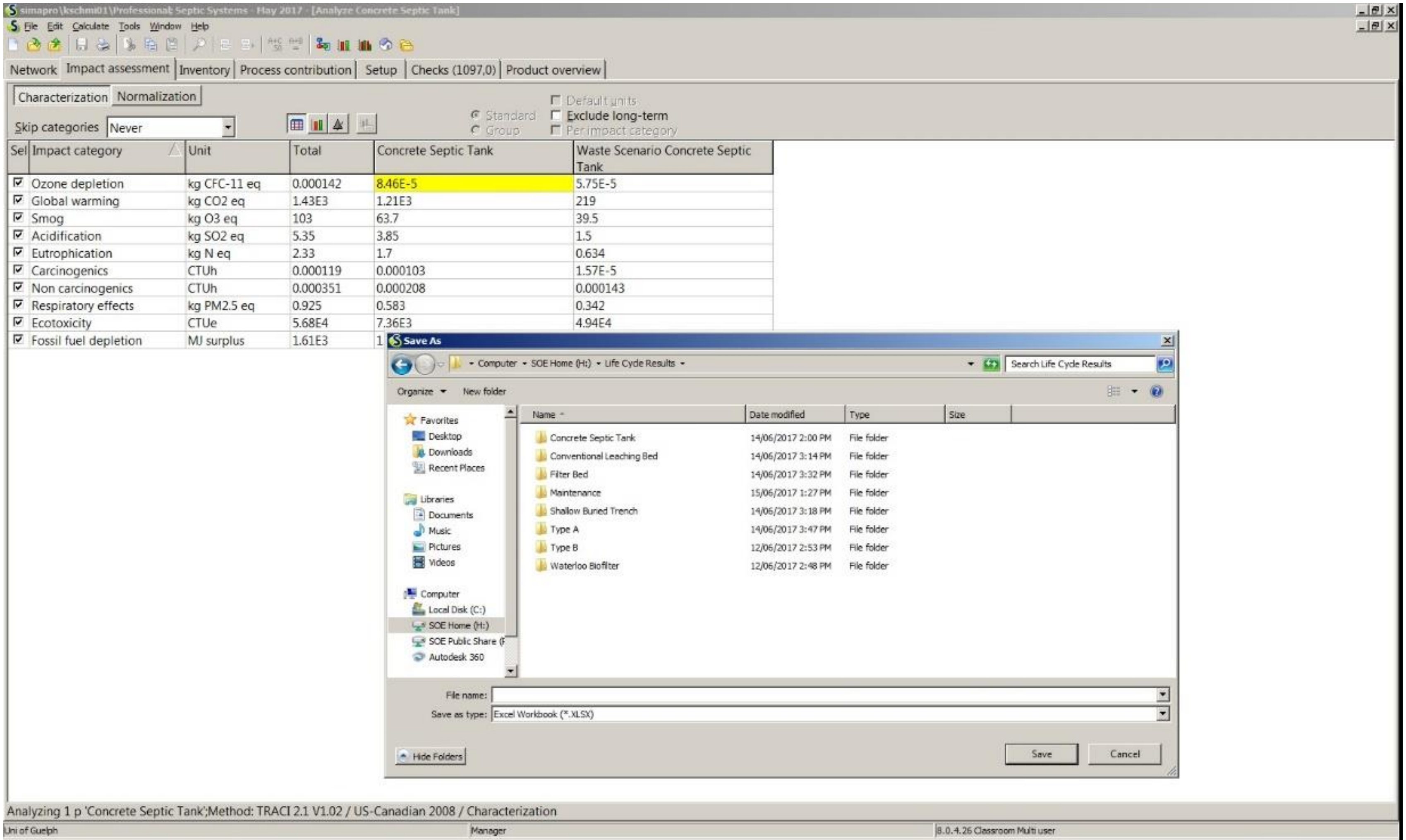


Figure E-20: Saving the Exported Results