Life Cycle Analysis of Drinking Water Systems at the University of Pittsburgh

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Executive Summary

As a basic human need, access to clean drinking water is an integral part of a thriving campus community. This report examines the environmental impacts of two alternative systems by which drinking water is distributed in the context of the University of Pittsburgh's main campus. Bottled water was examined and compared with reusable water bottles and their filling stations using Life Cycle Assessment (LCA) techniques. The results are intended to inform implementation of future water delivery infrastructure by providing information on the relative environmental impacts of each system.

The scope of the LCA included appropriate manufacturing, transportation, use, and end-of-life processes for each system. Data was obtained from primary sources, peer-reviewed articles, and estimation when necessary. A base case was established for each system, and a sensitivity analysis was performed to examine how each life cycle phase affects the net environmental impact.

It was determined that the net environmental impacts of the bottle fountain system were about **one-third** those of a single use water bottle, for an equivalent amount of water delivered.

The net environmental impacts of the bottle fountain system was determined to be most sensitive to system lifetime, use rate, and energy use. It was found that below a certain usage rate, estimated to be roughly 50 eight oz servings per day assuming a 5 year system lifetime, the relative environmental impacts of the bottle fountain system are similar to those of the single use water bottles. Future implementation efforts should focus on placing hydration stations in high-traffic areas.

The net environmental impacts of each system were found to depend very little on the end of life scenario. Specifically for single use bottled water, recycling the bottles reduced net environmental impacts by **only 0.5%** relative to landfilling. Based on this analysis it is recommended that future efforts focus on reducing consumption of single use water bottles, rather than increasing recycling efforts.

This report offers an analysis of the environmental impacts of bottled water, and should be considered as part of a broader study that includes economic, social, and human health impacts of alternative systems.

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1. Introduction

1.1 Problem Background

Proper hydration is essential for personal health and well-being [1]. As one of our most basic resources, access to drinking water is a necessity for a healthy and vibrant community. Therefore it is important to understand and improve our water delivery systems, with the goal of providing efficient access to this essential resource.

Until recently, drinking water in the United States was primarily delivered almost exclusively through municipal distribution networks. However, over the past two decades the bottled water industry has exploded into a $12 billion industry in the United States, providing more than 30 gallons of bottled water per person per year [2], the equivalent of more than 240 standard bottles of water consumed by every person in the United States each year[1]. Given the significant and growing impact that this industry has on our essential infrastructure, it is important to objectively evaluate the social, economic, and environmental impacts in order to make informed decisions about where water should be sourced from. This report considers the environmental impacts associated with water delivery systems, in order to provide consumers and policy-makers with the data necessary to make an informed decision.

1.2 Stakeholders

The success of our project depended upon communication with a number of key stakeholders, including students, university facilities management, representatives from bottle fountain companies, and university dining contractors.

2. Methods

2.1 Alternatives Considered

Two main subsystems: reusable water bottle filling stations and single use water bottles, were examined and compared at the University of Pittsburgh Oakland Campus, using an eight oz serving as the functional unit of comparison. Reusable water bottle filling stations or 'bottle fountains' as they will be referred to are designed to fill reusable water bottles with water. Bottle fountains have been recently introduced on campus and there are now more than 30 in various campus buildings[2]. By

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[1] 30 gallons per person per year x 128 oz. per gallon / 16 oz per bottle = 240 bottles per person per year

[2] Appendix A - Bottle fountain List and Data

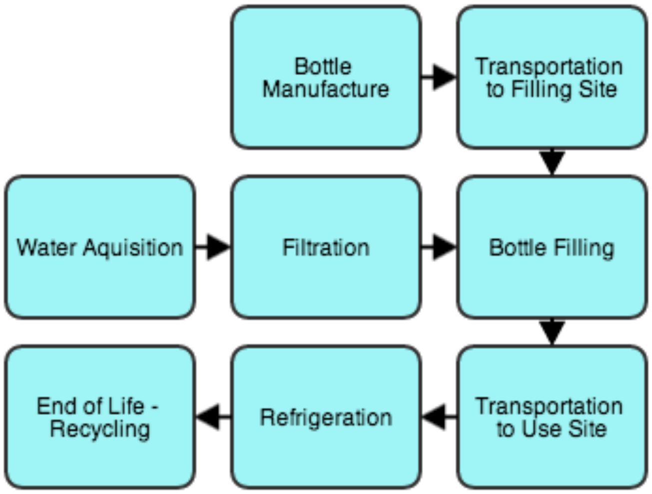

Figure 1: Bottled Water Process Diagram

collecting usage data, as well as energy consumption, and material impacts, the environmental impacts of bottle fountains relative to another campus hydration option were evaluated, single use plastic water bottles. Plastic water bottles are a widely available and commonly used source of drinking water which were evaluated based on available usage data as well as material and energy costs associated with their production, transportation, and refrigeration. Per unit environmental impacts of this subsystem were used as a basis of comparison for bottle fountains existing drinking water delivery systems (e.g. bottle fountains and water fountains) and hypothetical alternatives.

Single use plastic water bottles were examined as a base case. They are a commonly available form of water on campus, and reliable data is available on their life cycle processes. A complete system flow chart is shown in Figure 1.

Bottle manufacture typically consists of stretch blowing of PET [3], and injection molding of PP caps [4]. Bottles must then be transported to the filling site. Water, acquired from either public or natural sources must be filtered, before being put into individual bottles. Filled bottles must then be transported to their point of sale, where they will be refrigerated and ultimately either reused, recycled, or thrown away. There are a number of variations for each of these steps in the system, so it is necessary to make assumptions to simplify the system.

Table 1 shows embodied energy in terms of MJ per liter of water delivered for various process stages in the life cycle of bottled water [4]. It can be seen that treatment at the bottling plant, and bottle filling make up far less than 1% of the total life cycle impacts, regardless of scenario. While embodied energy is not a true measure of all of the potential environmental impacts that a given process may entail, it does give a good sense of the order of magnitude of the impacts of each process. Based on this analysis, impacts associated with water treatment at the bottling plant, filling, labeling, and sealing the bottle were omitted from the life cycle assessment.

Table 1: Bottled Water Embodied Energy

Process	Energy Intensity (MJ/ liter of water)	Percent of Total Impacts (%)
Manufacture plastic bottle	4.0	39.0 - 71.4
Treatment at bottling plant	0.0001-0.02	0.001 - 0.357
Fill, label and seal bottle	0.01	0.098 - 0.180
Transportation	1.4-5.8	13.7 - 100
Refrigeration	0.2-0.4	1.96 - 7.14
Total	5.6-10.2	100

Transportation of plastic water bottles prior to filling was considered negligible and excluded from process list. The average weight of PET used in a water bottle is around 20 grams, or 4% of the weight of filled water bottles, and PET is usually blown into the water bottle shape on site, allowing for efficient transport of bulk PET to the bottling site [4]. Impacts associated with shipping are directly related to shipping weight and volume, so the impacts of shipping PET to the bottling facility were excluded.

Water in bottled water can come from a public source, or a natural spring source, before being filtered and bottled. There are no reliable data available on the distribution of sources for bottled water, but by law water must be labeled ‘purified’ if it originates at a public source and is then purified and sold, or ‘spring’ if it originates at a natural spring source before being purified [4]. All observed samples of bottled water available on Pitt’s campus were labeled ‘purified’ indicating that they originated at a public source. Because both bottled water and water distributed through on campus bottle fountains originate in public sources, impacts originating from treatment of public water appear in the same way in both systems and therefore were excluded from the analysis. A simplified process diagram, showing only the aspects of the water bottle life cycle which were examined, is shown in Figure 2.

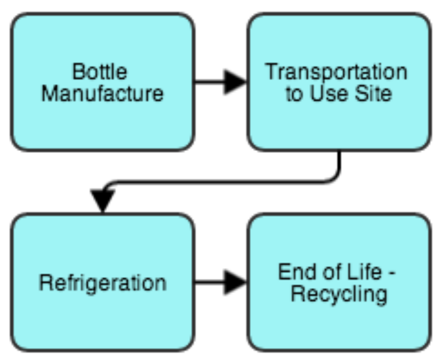

Figure 2: Simplified Bottled Water Process Diagram

Figure 3: 16.9 oz Aquafina water bottle and Elkay LZS8WSS bottle fountain with 32 oz reusable bottle

The Elkay model LZS8WSSK bottle fountain shown in Figure 3 is the most common type on campus, and was considered in the analysis. Life cycle for the bottle fountain and reusable water bottle were similar to those for the single water bottle system. Bottle fountains are manufactured, transported to the use site, consume electricity in cooling water, and are assumed to be discarded in a landfill. Reusable water bottles are assumed to be manufactured, transported, and recycled. This system is discussed further in the Data Sources section.

2.2 Data Sources

Data were taken from a number of sources. Measured values were used when possible and were supplemented with literature values where available. Estimates were also frequently used where measured and/or literature values were unavailable. The assumptions listed below are for base cases. A sensitivity analysis was performed to assess the system sensitivity to individual individual processes, and to justify assumptions.

For the single use water bottle system data was obtained for the four main life cycle processes: manufacturing, transportation, refrigeration, and end-of-life. Information on manufacturing was sourced from established literature. 16.9 oz water bottles are made of PET which is formed by a stretch blow molding process [5][6]. Transportation data was estimated based on information disclosed on the water bottles for sale on campus. Labeling information indicated that Aquafina bottles are bottled in Wytheville, VA, which is approximately 300 miles from Pittsburgh, PA[3].

[3] https://www.google.com/maps/dir/Wytheville,+VA+24382/Pittsburgh,+PA/@38.6781875,-82.9915572,7z/data=!3m1!4b1!4m13!4m12!1m5!1m1!1s0x8851e036ed078515:0xa66a3b265ddc58d!2m2!1d-81.084811!2d36.9484528!1m5!1m1!1s0x8834f16f48068503:0x8df915a15aa21b34!2m2!1d-79.9958864!2d40.4406248

Transportation was assumed to be via truck and trailer based on information from sources within university dining service. Refrigeration energy use was broken into two parts. Energy required to cool the water bottles was estimated from fundamental thermodynamic principles[7], and a refrigerator efficiency of 20%. Energy required to maintain the water bottles at a cooled temperature was estimated based on literature values for refrigerator energy use, and water bottle purchasing data obtained from dining services personnel. Exact recycling rates were not obtained, however Pitt has an extensive recycling program so it was assumed that the dominant end of life stream was recycling [8].

For the bottle fountain system, data was again obtained for the four main processes. Data was more frequently estimated because of a lack of availability. Manufacturing, transportation, use, and end-of-life were considered for both aspects of the system.

The shipping weight of the bottle filling station is 69 lb. according to Elkay employees. Stations were assumed to last for 5 years. This is a very conservative estimate based on information from Elkay employees and facilities managers at the University of Pittsburgh. The stations were assumed to be made of stainless steel sheet metal and injection molded HDPE parts, the main material components according to an Elkay representative. These were assumed to be the only two material components, and their weights were estimated to be 80% and 20% of the total shipping weight, respectively. Reusable water bottles were assumed to be 32 oz HDPE containers weighing 150 grams, manufactured by injection molding[4] [9].

Both the water bottles and bottle fountains were assumed to be transported by truck from 500 miles away. Elkay bottle fountains are manufactured in Broadview, IL, approximately 500 miles from Pittsburgh[5]. No data was available on water bottle manufacturing distance, so 500 miles was selected as a conservative estimate.

The use phase for bottle fountains consists of electricity usage in cooling the water. This was estimated based on thermodynamic considerations, similar to the calculations for cooling water bottles. Based on this analysis, it was estimated that a bottle fountain takes about 0.022 kWh per 8 oz serving of water to cool the water, which translates to about 1700 kWh per year of use. For comparison, a refrigerator uses about 1000 kWh per year of standard use [10], indicating that the calculation is on the right order of magnitude.

Reusable bottles were assumed to have no impacts during the use phase. Energy impacts associated with washing bottles were ignored. Reusable bottles were assumed to last for an average of 6 months before being replaced. This was based on a conservative best estimate, which was tested for sensitivity.

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[4] I weighed my water bottle :)

[5] https://www.google.com/maps/dir/Pittsburgh,+PA/Broadview,+IL/@41.1416657,-86.1212821,7z/data=!3m1!4b1!4m14!4m13!1m5!1m1!1s0x8834f16f48068503:0x8df915a15aa21b34!2m2!1d-79.9958864!2d40.4406248!1m5!1m1!1s0x880e360642cde391:0xafca3e0560b805c4!2m2!1d-87.8533931!2d41.8639201!3e0

Bottle fountains were assumed to provide 200, eight-oz servings per day, based on data collected at the University of Pittsburgh during the Fall of 2013 [11].

End of life for bottle fountains was assumed to be disposal in a landfill. While theoretically recyclable, large items rarely are. Reusable bottles were assumed to be recycled.

2.3 Assessment Criteria

The weighted total of all impact categories was considered as the main comparative metric between different systems. The weighting system will be discussed in the Software Usage section below. A weighted total was considered sufficient for our analysis because the focus was to give an overview of relative environmental impacts rather than a detailed hotspot analysis of each system.

Economic and social metrics were also considered in evaluating alternatives. The dollar per unit cost to the consumer, as well as effects of water privatization on public access to potable drinking water are important metrics to consider.

2.4 Software Usage

Sustainable Minds was used to evaluate the relative environmental impacts of our concepts. The software was found to be flexible, easy to use, and simple enough to allow for quick evaluation of possible alternatives and sensitivity analysis.

A base case utilizing best available data and estimates was established for each concept. This base case was then tested for sensitivity by changing each variable and observing the overall impact change. A best and worst case were also established, allowing for a basic understanding of how uncertainty in the data effected the final relative environmental impacts. The software allows the user to see what percentage of the total impacts originate from each process, which simplifies a 'hotspot' analysis.

Impacts for each scenario were exported from the Sustainable Minds interface and input into a Microsoft Excel spreadsheet, to allow for more flexible comparisons between concepts. A spreadsheet containing impact data for each concept as well as all assumptions is available for download [12].

Sustainable Minds software uses the TRACI methodology to assess the life cycle impacts of a concept in each impact category [13]. These impact categories are then normalized to the impact produced by an average US person in 1 year, in order to give them common units and allow for comparison. These normalized results are given the units of milliPoints (mPts) by Sustainable Minds [13]. Normalized results are then weighted to reflect the relative importance of each impact category. Weighting is a socially defined step, and is performed according to standards developed by NIST [14]. Weighted impacts are combined into a single number for easy comparison between concepts.

3. Results and Discussion

3.1 Comparison of Results

Net environmental impacts normalized to the impacts of the single use water bottle system and the bottle fountain system are shown in figure 4. According to this analysis the bottle fountain system has about 1/3 of the net environmental impacts of the single use water bottle system.

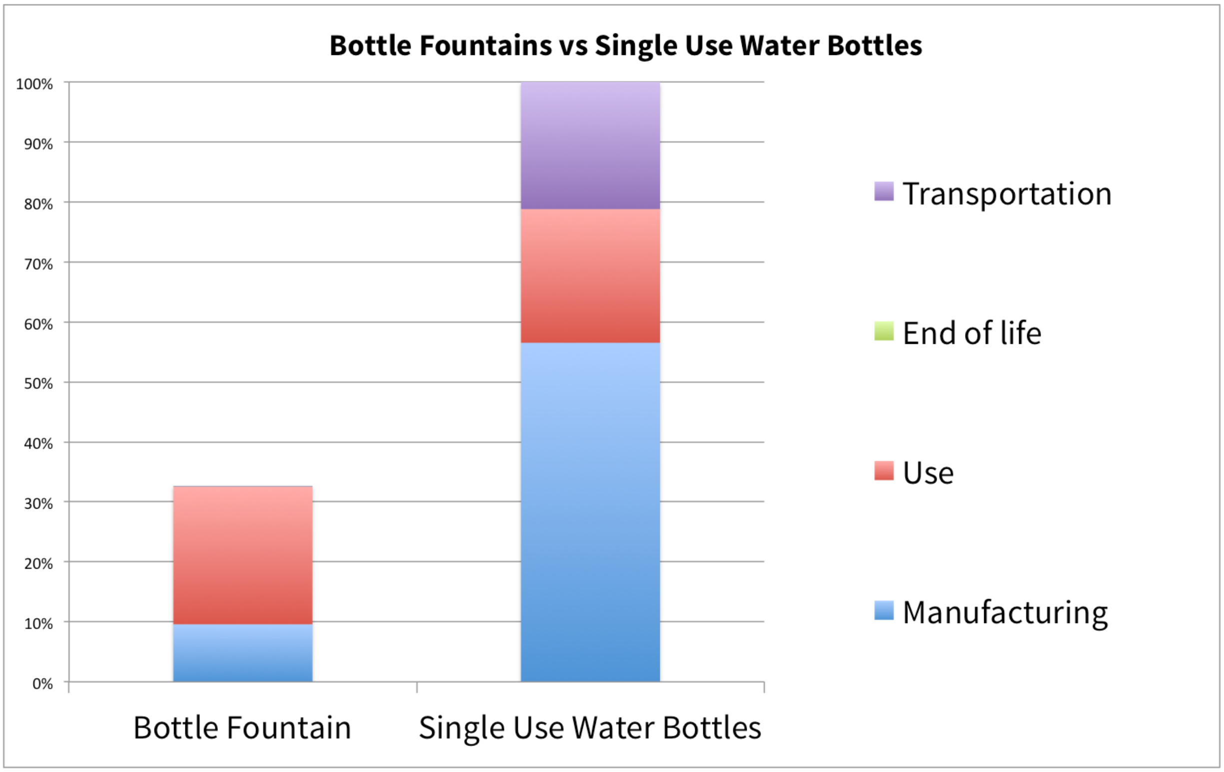

Figure 4: Environmental impacts of bottle fountain system vs. single use water bottle system according to life cycle

Use rate was found to have the most largest impact on the net environmental impacts of the bottle fountain system. The net environmental impacts of bottle fountains in a high use case, a base case, and a low use case, as compared to the impacts of the single use water bottle system are shown in Figure 5. High use case assumes to 500 eight oz servings per day, base case assumes 200, and low use assumes 50. All three cases assume a 5 year life span. It can be seen that there is a break even point where in usage, where the environmental impacts of a bottle fountain do not outweigh the environmental costs of the system, relative to the single use water bottle system.

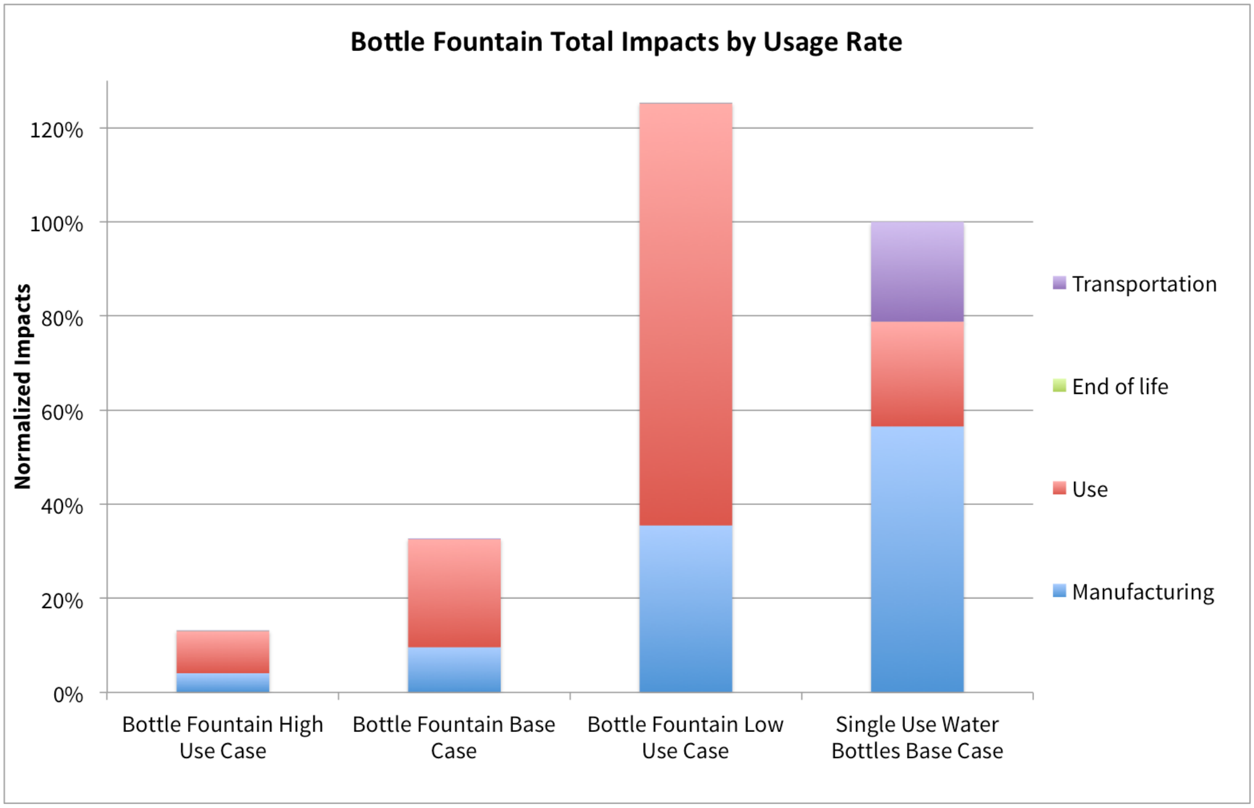

Figure 5: Net environmental impacts by life cycle phase for high, base, and low use cases for bottle fountain as compared to single use water bottles.

Economic costs to the consumer were not considered in depth, but a quick examination of the system indicates that bottle fountains are much more cost effective than single use water bottles.

3.2 Challenges

Facilities management was quite receptive to the project, and furthered the project by providing useful data and support wherever possible. Due to proprietary concerns, it was not possible to obtain specific information about the amount or type of materials used in bottle fountains. Energy usage data for bottle fountains was not available and due to access constraints it wasn't feasible to take apart and weigh a bottle fountain, or monitor individual bottle fountain energy usage. Material and energy consumption were estimated as accurately as possible, but the lack of data limits the reliability of our results.

3.3 Points of Caution

Water delivery systems are complex systems, with social, economic, environmental, and human health concerns that cannot be completely separated. This report offers a limited analysis of the environmental impacts of bottled water, and should be considered as part of a larger analysis.

There was a clear lack of available data on the bottle fountains units. Only the final weight of the units were known, so material inputs had to be roughly estimated based on judgement. However, according to a sensitivity analysis, the total impacts were not highly dependent on the relative amount of material inputs to this system so this may not be a major concern. A major weakness of the analysis is the lack of data on energy use of the bottle fountains. The bottle fountain system was found to be very sensitive to energy use, so the rough estimate that was used is not sufficient, and decreases the reliability of our relative environmental impact results.

It should be noted that the assumptions made in the LCA were conservative, and bottle fountain impacts were likely overestimated.

4. Conclusions

Bottle fountains were found to be have an overall environmental impact of about one third that of single use water bottles. At minimal capital cost to the student and the university, bottle fountains are an economical way to provide clean water, in a way that provides equal access to all.

According to the results of the LCA, the environmental impacts of the bottle fountain systems are most sensitive to use rate, system lifetime, and energy usage. Therefore, bottle fountains should be installed in high use areas, and the most efficient and longest lasting available systems should be used.

An interesting conclusion of this analysis is that recycling had almost no effect on the net environmental impacts of any system considered. For example, single use plastic water bottle discarded in a landfill produced only 0.5% greater total environmental impacts than recycled bottled. Based on this analysis, it is more important to take steps to reduce consumption of plastic water bottles than to increase recycling efforts.

More data should be collected on use rates of bottle fountains, in order to understand the factors which affect how often they are used, and guide future implementation efforts.

References

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Appendix

Bottle fountain Usage Data

Average Bottles Filled Per Day for Sample Period (October 2012)	
Hillman Library	299
	221
	172
	142
	204
Salk	67
Parran	61
Crabtree	35
Mervis	57
	30
Peterson Events Center	1,684
Nordenberg Hall	92
	132
	121
	132
	123
	141
	134
	129
Average	209