CONTAINER BASED EMERGENCY SANITATION:

A FEASIBILITY REPORT FOR EUGENE, OREGON AFTER THE CASCADIA SUBDUCTION ZONE EARTHQUAKE

by

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A THESIS

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Kory Russel

The Pacific Northwest is sitting on a ticking time bomb. Within the next century, there is a high likelihood that the Cascadia Subduction Zone will cause a devastating earthquake to ripple throughout the region. As result of this event, sewerage systems will be devastated as wastewater treatment plants and transportation pipes are destroyed in the shaking. For this project, I investigate the feasibility of using container based-sanitation (CBS) toilets in place of standard toilet and sewer systems in the event of major earthquakes, specifically in Eugene, Oregon. Container based sanitation refers to a system where toilets collect human excreta, are sealed and then are transported to a treatment facility. The toilets I focus on are urine diversion toilets, meaning that urine and feces are collected in separate sealable containers to be treated separately. Though these toilets are commonly implemented in communities where running water is not available, my findings indicate that these toilets have direct application in post-earthquake disaster scenarios. I focus my research on Eugene, Oregon after the Cascadia Subduction Zone earthquake, where piped wastewater systems are projected to be unusable for upwards of a year. Looking at the use of container-based toilets in Japan, New Zealand and Haiti after large earthquakes, I will determine the feasibility of their application in Eugene. Understanding proper sanitation management techniques for use after natural disasters is crucial for successful public health, environmental protection and human dignity at a particularly vulnerable time. Container-based toilets have the potential to provide safe, easy and cost-effective sanitation management during disaster recovery periods after major earthquakes throughout the world.

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Finally, I would like to take a moment to acknowledge the privilege this experience has been. This year, a friend and classmate of mine, Nicole Panet-Raymond, passed away before being able to participate in this process for herself. I would like to dedicate this thesis to her, and her family and friends.

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Glossary

Bio-cycle: The processing of bio solids, or organic byproduct of the wastewater treatment process.

Bucket Toilet: Dry toilet where a bucket is used to collect human waste.

Cascadia Subduction Zone (CSZ): A convergent plate boundary located on the West coast of the United States stitching from British Columbia to Northern California.

Compost Toilet: A toilet that reclaims human waste by transforming the waste into compost material.

Container Based Sanitation: A form of sanitation in which waste is collected into sealable, removable containers and transported to separate facilities for treatment.

Disaster Mitigation Act (DMA): A piece of Federal legislation passed in 2002 requiring states to have hazard mitigation plans before qualifying for certain federal recovery funds. It also established the Pre-Disaster Mitigation program.

Ecological Sanitation (EcoSan): Approach to waste management that aims to safely reuse the nutrients found in human waste for agriculture.

Emergency Operations Plan (EOP): A plan with the intent to develop a course of action in order to mitigated against damage from potential emergency situations.

Federal Emergency Management Agency (FEMA): Responsible for coordinating the federal government's response to natural and manmade disasters.

Hazard Mitigation: Any sustained effort to reduce and eliminate risks to life and property associated with a hazard event.

Improved Sanitation: Access to a facility that safely and effectively separates waste from human contact.

Natural Hazards Mitigation Plan (NHMP): A NHMP demonstrates a community's effort and commitment to reduce risks to life and property from natural hazards.

Oregon Resilience Plan (ORP): A document created in 2013 in response to the threat of the Cascade Subduction Zone earthquake. It highlights the vulnerabilities the state has if the earthquake was to strike, and provides some recommendations for mitigation strategies.

Pre- Disaster Mitigation (PDM) Grant Program: Designed to assist communities in implementing natural hazard mitigation plans in their communities, before disasters strike.

Pit Latrines: A form of toilet that collects feces in a hole in the ground. More sophisticated pit latrines may include a slab floor and ventilation around the toilet. According to the World Health Organization, pit latrines are a form of unimproved sanitation.

SOIL: Sustainable Organic Integrated Livelihoods (SOIL) is a non-profit working in Haiti to bring improved sanitation and replenish depleted soils with a container based ecological sanitation toilet system

Twin-Bucket Toilet: A form of emergency toilet that separates feces and urine in different buckets.

Urine Diversion (UD) Toilet: The process of separating urine from feces so they do not mix in the chamber. This can be done through a specific urine diversion toilet bowl or utilizing two separate chambers (i.e. a twin-bucket toilet). Also called a dry toilet.

Vulnerability Assessment: The process of identifying, quantifying and prioritizing the vulnerabilities in a community, thereby assessing the threats to population and infrastructure from a potential hazard.

Waste Sterilization: The process of removing all levels of pathogenic contaminants from waste.

Chapter 1: Introduction

Need For Sanitation

There are 2.4 billion people throughout the world without access to proper sanitation on a daily basis (Remington et al, 2016). From this number, it is estimate that one billion practice open defecation – the act of relieving oneself without any treatment of waste. The consequences of poor sanitation management "range from public health to nutrition, loss of dignity, gender inequality, education, water quality and broader economic development" (Brossard et al, 2015). These consequences are what residents in Eugene might face without an effective emergency sanitation management plan.

According to Franklin Huang of Stanford University, the total amount of feces produced by an average person in a day totals about a third of a pound. As there are 166,575 people living in Eugene (US Census, 2016), it can be estimated that the city produces roughly 49,725 pounds of feces every single day. For scale, that weight is equivalent to about three and a half African bush elephants (Larramendi, 2015). This high volume of waste demonstrates the importance of sanitation management. Due to the current system's heavy reliance on piped water systems, a disruption of those systems could leave all that waste with no safe place to go, threatening drinking water, public health and the health of the environment.

Feces is full of bacteria and potential pathogenic material. When fecal matter enters water sources, fecal coliform bacteria and disease causing agents pose a high risk of infection to those ingesting and coming in contact with the water. According to the WHO, "In 1998, it was estimated that 2.2 million deaths were associated with diarrhea each year, a good percentage of them due to fecal pollution of the water" (Santo-Domingo et al, 2008). Potential health risks associated with fecal contamination include but are not limited to ear infections, viral and bacterial gastroenteritis, hepatitis A and dehydration from diarrhea and vomiting. After the Cascadia Subduction Zone (CSZ) earthquake, predictions indicate that sewage pipes will break, increasing the risk of raw human sewage entering the Willamette River which flows through Eugene. With nearly 50,000 pounds of feces being produced by the city of Eugene each day, missing the proper collection and sanitation methods in place due to broken pipes and systems poses a great threat of contamination to the city's water supply. In turn, threatening the public health of a community that will already be suffering from the devastation of a 9.0 magnitude earthquake.

Until 40-years ago, scientists did not know the Cascadia Subduction Zone even existed, let alone it's potential to devastate the region's wastewater systems at any moment. The purpose of this research project is to provide the city and people of Eugene with suggestions for a solution for sanitation management in the inevitable event of the Cascadia Subduction Zone earthquake (Cascadia Subduction Zone, n.d.). Though this may seem to many to be part of the distant future, the reality is that this catastrophic event could happen within our lifetimes.

Current studies list the probability that this event will happen in the next 50 years at roughly one in three (Williams, 2016). It is important to have disaster plans in place in order to create a mitigation strategy before events happen. This in turn reduces the risk to human health, environmental degradation and financial loss (FEMA, n.d.). Due to Federal grant programs and regulations, Eugene and many cities in Oregon do have natural disaster plans. However, they often lack specific strategies for emergency wastewater and sanitation management, creating vulnerabilities in the plan.

Disaster Management and Planning Policies

In the United States, disaster management planning changed dramatically in 2000 with the passing of the Disaster Mitigation Act (DMA). The DMA, the leading natural hazard mitigation legislation to date, built upon the existing Stafford Act in two fundamental ways. First it, "required states and localities to prepare multi-hazard mitigation plans as a precondition for receipt of Hazard Mitigation Grant Program (HMGP) and other federal mitigation grants" (Schwab, 2010). The Hazard Mitigation Grant Program is sponsored by FEMA. A state, federally recognized tribe or territory can apply for a grant through the HMGP after a state of emergency is declared by the President. The goal of the HMGP is to help communities after a disaster has occurred, and "enact mitigation measures that reduce the risk of loss of life and property from future disasters" (FEMA, 2018).

The second major provision in the act was that "it established a competitive Pre-Disaster Mitigation (PDM) program providing for mitigation planning and project grants before disasters strike" (Schwab, 2010). The PDM program aims to "reduce overall risk to the population and structures from future hazard events, while also reducing reliance on Federal funding in future disasters" (FEMA, 2018). This incentivized pre-disaster mitigation financially, so communities would plan for disasters and have the resources to implement the plans. This is a change from the recovery mentality that lead natural disaster planning historically. Ideally, mitigation comes before the disaster event (see figure 1), and helps better prepare a community for future disasters. As a result of this legislation local hazard mitigation plans are required for all FEMA grants for mitigation projects. FEMA reviews these plans and determines whether or not they meet all standards necessary. According to FEMA they look for substantive citizen participation, identification of hazards and consistency in prioritization of those hazards with the state perspective, the use of the best available data, and adoption of measures that reflect the jurisdictions hazard profiles.

Figure 1: Disaster management process

Source: The Crisis Management and Disaster Response Centre of Excellence

Through these provisions, the DMA is attempting to encourage resiliency in communities in order to prevent and minimize losses after a natural disaster through pre-disaster mitigation. Resiliency can be defined as, "the ability to adapt to changing conditions and withstand and rapidly recover from disruption due to emergencies" (Department of Homeland Security, 2018). Important factors of resilience include the redundancy and diversification of systems. This way, if one system fails, there are alternatives that need different resources to operate, increasing the chances that at least one will work. Resiliency also includes education and participation from citizens, local, state and federal governments as well as non-profit organizations to provide a holistic approach that ensures needs do not fall through the cracks.

In Oregon, statewide planning Goal Seven addresses the ideas of pre-disaster mitigation and resiliency for the state. This planning goal states that, “local governments shall adopt comprehensive plans to reduce risk to people and property from natural hazards” (Oregon State, 2001). Oregon also prepared the Oregon Resilience Plan (ORP) in 2013 that was specifically tailored to mitigation and planning for the next Cascadia earthquake and tsunami. Throughout this entire document, sanitation is hardly mentioned. It includes in its recommendations to simply “encourage public health and wastewater agencies to coordinate and establish agreements for the use of temporary sanitary services (portable toilets) immediately after a seismic event”. It goes on to say that though there are no clear regulations, rules or precedents for who is supposed to manage that and how they are supposed to do it, “temporary, emergency sanitation services such as portable toilets…should be pre-established by public health and wastewater service providers” (Yu et al, 2013). This lack of attention and regulation for sanitation services post-disaster is mirrored in the Eugene-Springfield Emergency Operations Plan (EOP), Natural Hazards Mitigation Plan (NHMP) and the Vulnerability Assessment for the area.

The area’s Vulnerability Assessment acknowledges that, “sanitary sewer systems are expected to fail and be inoperable for a period of months and up to a year, increasing the likelihood of the spread of infectious disease.” The Assessment goes on to highlight that, “damage to between seventy-five to one-hundred-percent of the wastewater system’s physical infrastructure is expected.” Regardless of these findings, the EOP does not take this warning into consideration. In the EOP, the only statement regarding sanitation management is the assumption that, "utility or infrastructure emergencies involving failure or disruption of electrical, telephone, computer, water, fuel, sewer, or sanitation systems may impact large populations within the area." There are no subsequent recommendations or proposals for how to deal with this issue that is continuously agreed upon to be a threat to human health that will impact a large population for a significant amount of time. For a complete, effective and thorough mitigation plan and strategy, sanitation must be considered more comprehensively.

Chapter 2: Background

Cascadia Subduction Zone Earthquake

According to the Pacific Northwest Seismic Institute, a ‘full rupture’ of the Cascadia Subduction Zone (CSZ) would create an earthquake predicted to register between 8.7-9.2 magnitude on the Richter scale, giving it the potential to be one of the strongest earthquakes ever recorded. An earthquake of this scale could shake the Pacific Northwest for between four to five minutes. In these minutes, the 700 miles of subduction zone underneath British Columbia, Washington, Oregon and part of Northern California will release the immense pressure that has been building for centuries, wreaking havoc on the region. Geologists and seismologists predict that the entire continental shelf could drop by as much as six vertical feet. After the initial drop, the shelf is predicted to leap 30-100 feet west, fully releasing the accumulated pressure (Schultz, 2017). As this dramatic shift occurs, a wall of water will be displaced upwards into a large mound that will send two enormous waves in either direction: one towards Japan and one back towards the recently shaken Northwest region. This wave is expected to hit the Northwest coast in as little as fifteen minutes after the initial shaking has occurred (Cascadia Subduction Zone, n.d.). These predictions are estimates, as an earthquake like this has not hit the Pacific Northwest in hundreds of years. As a result no one is certain about the specific impacts such an event will bring. This uncertainty influences the strategies used to plan for emergency mitigation, response and recovery as the exact specifications and threats are unknown. Another uncertainty among scientists is when exactly the earthquake will hit.

This Pacific Northwest region has experienced around forty-one major earthquakes along the CSZ in the last ten thousand years (Shultz, 2017). This means that Cascadia's recurrence interval for a subduction zone earthquake is around 250 years, with the last major earthquake dated to 1700 AD. Based on this data, some scientists have estimated that the chance of a magnitude 9.0 event happening in the next 50 years is around 15-20%. Other estimates put the chances of such an earthquake happening at about 40% in the next 50 years (Williams, 2016). While there are discrepancies in the predictions, it is clear that the Pacific Northwest is due, if not overdue, to repeat history and experience a large earthquake relatively soon. The subsequent shaking will cause significant impacts to infrastructure, often damaging or destroying it. Sanitations facilities will be included in this infrastructure, so it is imperative that planning err on the side of caution. Indeed over preparedness is preferable, as the opposite may be deadly.

What to Expect in Eugene, Oregon Post-Disaster

In Eugene, catastrophic impacts to the wastewater system are expected after the CSZ earthquake. The Eugene-Springfield Vulnerability Assessment details wastewater physical infrastructure to include, "over 1,100 miles of public collection system pipe, and thousands of privately-owned collection system pipes." A large portion of these pipes are a part of a large underground network, making them particularly susceptible to damage during the earthquake. The Vulnerability Assessment goes on to note that, "damage to between seventy-five to one-hundred-percent of the wastewater system's physical infrastructure is expected" and that "this infrastructure is expensive and very difficult to repair, relocate or re-engineer" making recovery and rebuilding a difficult, long and complicated process. Another concern is the cross contamination of drinking water as there is “minimal separation in many areas” between wastewater and fresh water pipes.

Due to the of the pressing and potentially catastrophic nature of an event like the Cascadia Subduction Zone earthquake, the state of Oregon has implemented the Oregon Resilience Plan (ORP), which was developed in 2013. This document outlines assessments for different essential parts of a community such as transportation, critical buildings (healthcare, education, emergency operations, etc), energy, communications, water systems and wastewater systems. The ORP section on wastewater describes that after the CSZ earthquake, facilities will be so severely damaged that there will be a total loss of water and wastewater services for several months after the event, and in some cases years. The plan specifies that in the Willamette Valley, current systems, including treatment facilities, reservoirs and pump stations, will likely fail due to liquefaction, a phenomenon where “ground failure or loss of strength that causes otherwise solid soil to behave temporarily as a viscous liquid” caused by seismic waves interacting with water saturated sands and silt deposits (Rafferty, 2016). This would cause the buildings and facilities built in these places to fail and slide into waterways, halting water movement into the city and homes as well as creating sewage overflow into rivers and streams, causing upwelling in streets.

Such a water shut off, predicted after the CSZ earthquake, would render the current piped sewage system utterly useless. Water is an essential part of collecting raw sewage. It aids in routing sewage away from population centers and treating it, while also aiding in hand washing to protect against the contaminants present in raw sewage.

Further, the anticipated damage to underground wastewater pipes and regional wastewater treatment plants would halt use of the system regardless of water transmission. Without this system, people will be confronted with dealing with their waste in a way that they never have before, or else face the health implications of raw sewage contaminating water sources.

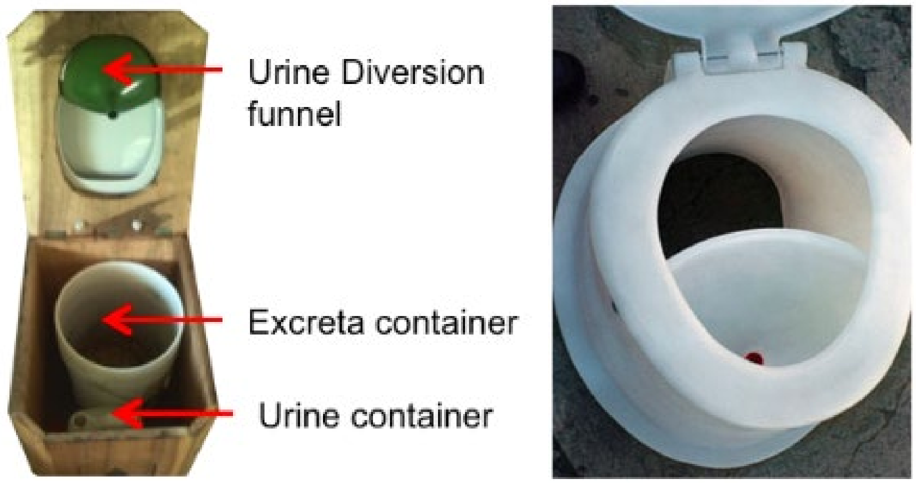
With this wide-scale damage to wastewater treatment pipes and facilities, flush toilets will be unusable, creating a lot of untreated waste build up within the city. Despite this prediction, there has been minimal effort and success in creating a citywide plan for what to do with this waste. The Metropolitan Vulnerability Assessment states that, "despite the high potential for major impacts, only limited discussion regarding earthquake is taking place. As a priority, planning for earthquake is low". Without working sewerage systems, the city and its citizens must look to alternatives to ensure that their waste will not pose a threat to the health of their community or the environment for the weeks, months or even years between the earthquake and restoration of widespread piped sewage systems.

Container-Based Sanitation

One alternative to standard sewer systems that has promise in emergency sanitation situations is container based sanitation. Container based sanitation (CBS) refers to a toilet system where human waste is collected in sealable, removable containers that can be transported to treatment centers. These toilets allow for waste to be stored and treated while using minimal water resources, making them suitable for places and situations without piped water systems. Over the past several years, "CBS has been gaining traction in urban centers of Kenya, Ghana, Haiti and Peru", because of its low cost, small footprint and versatility while using minimal water resources (Skylar, 2017) . Though widespread use of this system is not commonplace, people in communities where sanitation services are not provided are turning to CBS for its low impact, low cost and high success rates.

The basic CBS system has four components: 1) the containment of waste, 2) the collection of waste, 3) transport to secondary treatment centers and 4) the treatment of waste. Beginning with the containment of waste, there are two major varieties of CBS toilets. The first is a mixed-tank toilet. This design has feces and urine mixed into one container to await transport and treatment. The second design features a no mix or urine-diversion method. In this design the urine is separated through a urine diverting pedestal in the toilet bowl (see figure 2) or is deposited into an entirely different container.

Figure 2: Urine diversion toilet



View from inside the toilet with lid open, and view looking down into the toilet bowl.
Source: Remington et al, 2016

There are many benefits to the urine diversion system. Due to the fact that urine carries far less pathogens than feces, it does not need the same level of treatment. By diverting urine into a separate tank, there is a much lower volume of waste that needs to be treated and transported. Additionally, urine diversion toilets keep fecal matter dry, reducing odor and helping to reduce the breeding of disease vectors, such as flies, in the waste material (Kramer et al, 2011) both of which are major issues with mixed tank CBS toilets. Because of the benefits of the urine diversion systems, this paper will focus on this form of containment of waste, noting that there are limitations of urine diversion including difficulty of use for children.

The next component of the CBS toilet is the collection of waste. After one defecates into the chamber, it is imperative that a dry carbon source is added to the waste in an attempt to dry it. Carbon sources include but are not limited to ash, shredded leaves (dry), corn cobs, shredded cardboard or paper, and sawdust (Winblad, 2004). In places where lime is an abundant and an inexpensive resource, it can be used to sanitize and dry the waste before disposal. The aim is to find a material that is dry, quickly breaks down and is very fine, in an attempt to cover the surface of the feces completely. Due to the quantity that is needed to fully cover feces in the chamber, it is crucial that the carbon source be available locally and in large quantities. Urine collection takes place in a separate container that needs no primary treatment or cover material added.

Like feces, urine containes pathogens, though at a much lower rate. Unlike feces, urine contains "uncharged ammonia (NH_3), a volatile compound produced during biological urea hydrolysis, acts as an in situ sanitizer in stored urine" (Bischel et al, 2015). This means that if stored for a period of time, the urine will sterilize itself. The time needed varies and is dependent on temperature urine is stored at, if urine is diluted and if aeration is occurring. Ideal urine storage would take place in an airtight container, with little dilution and high temperatures, and with fluctuating temperatures "due to diurnal heating from the sun [which] may further enhance inactivation" of pathogens (Bischel et al, 2015). Once urine is stored, it is safe to be placed into a garden or in a soak way pit.

Transportation of waste is generally facilitated by an organization or utility that collects containers when they are full and ready to be taken for secondary treatment, leaving a clean empty container in its place. The people transporting the waste are educated and trained on the system in order to provide safe transport and take a large part of the responsibility needed to handle users waste.

Treatment of waste varies with different toilet designs and access to resources for treatment. Regardless of what treatment form is chosen, the focus is to kill pathogens in the feces so contamination of water supplies and other public health concernes can be avoided. For scenarios where water services are expected to be up and running in a timely manner, creating secondary treatment centers for waste is not essential as the waste can be stored in sealed containers until it can be disposed of in a landfill or until treatment is possible. However, in situations where water services are expected to be offline for multiple months and into years, as would be the case for Eugene after the CSZ earthquake, a longer term approach is necessary. For this reason many CBS systems are also part of an ecological sanitation (EcoSan) model.

Ecological Sanitation

EcoSan is a closed loop system that was developed in an attempt to "save water, prevent water pollution and recycle the nutrients in human excreta" (Winblad, 2004). This means incorporating composting of human waste into the treatment process. Importantly, this approach is foreign to many communities and is generally met with concern as handling human waste is often considered taboo. Composting human waste does require strict regulation and monitoring to ensure all levels of pathogen contamination are reduced to acceptable levels. However, when those regulatory standards are met, the product is safe to handle and introduce into the ecosystem. Due to the broad nature of ecological sanitation, there are countless adaptations and designs of these toilets around the world. Some toilets begin to compost in the vault that waste is dumped into, while others are taken from the toilet to offsite composting centers. Another option for treatment is to dehydrate waste long enough that all pathogenic material dies. This process takes multiple months and it can be difficult to determine when all pathogens are killed. The most effective way to "render [waste] hygienically safe is by thermophilic composting" (Jenkins, 2005). The World Health Organization states that pathogens in feces are "killed after one week at a sustained temperature of 122 degrees Fahrenheit" during thermophilic composting. Once these requirements are met, pathogens in the feces are killed and the waste is safe to handle, just like any other compost.

Figure 3: Compost made from human waste

Source: The Ringing Cedars EcoVillage, located in Italy

Though this system can be easily integrated into rural homes where land for composting is plentiful, communal urban-based centers can be equally as effective when properly handled. In the book *Ecological Sanitation*, Winblad states, "For urban areas we recommend dehydrating systems with primary and secondary treatment. Municipal authorities will collect all excreta products after primary treatment and take them to a special collection point for secondary treatment" (19). This system that Winblad describes allows for ecological sanitation to be successful in situations with higher population density where the attention, resources and management of waste cannot be provided by the users. The communal management that is being described above can carry out the secondary treatment needed in centers with trained personnel, proving to be “it is more convenient for the user and safer for public health” as their interaction with the waste is minimal (Winblad, 2004).

Container based EcoSan toilets have already begun playing a role in post-earthquake disaster scenarios. In Haiti, after the 7.0 magnitude earthquake hit in 2011, SOIL, a nonprofit that had been working with CBS toilet systems in communities in the north of the country, refocused their efforts to disaster relief toilets in Port-au-Prince. SOIL’s model was to provide families with CBS toilets and cover material; then after the containers were filled, trained personnel collected the containers and brought the waste to a secondary treatment site where the waste was turned into compost and sold to help subsidize the waste collection and treatment process. The success of SOIL’s model in a disaster application came from the pre-existing experience and education about the system before the earthquake hit. In Japan, researchers from the Graduate School of Global Environmental Studies in Kyoto took prototype container based toilets inspired by urine diversion composting toilets and camping toilets to evacuation centers throughout the Miyagi prefecture, the area hardest hit by the 9.0 magnitude earthquake and following tsunami in 2011. These toilets were shown to be an improvement over portable toilet options in evacuation centers, and researchers found that communities were interested in purchasing them to have for resiliency and emergency preparedness in the future. Similarly, in New Zealand after the Canterbury earthquake sequence, residents and local emergency management authorities have started implementing container based EcoSan toilets in the area. The Wellington Regional Emergency Management Office conducted a study with volunteers to use such a toilet over the course of four weeks and report on how well it was received. Participants overwhelmingly liked this alternative and reported favorably to continued long term use.

The diversity of population density, location, climate, existing sewer systems, cultural norms and available resources in these case studies shows the versatility of the container based toilet as an alternative to piped water sewer systems.

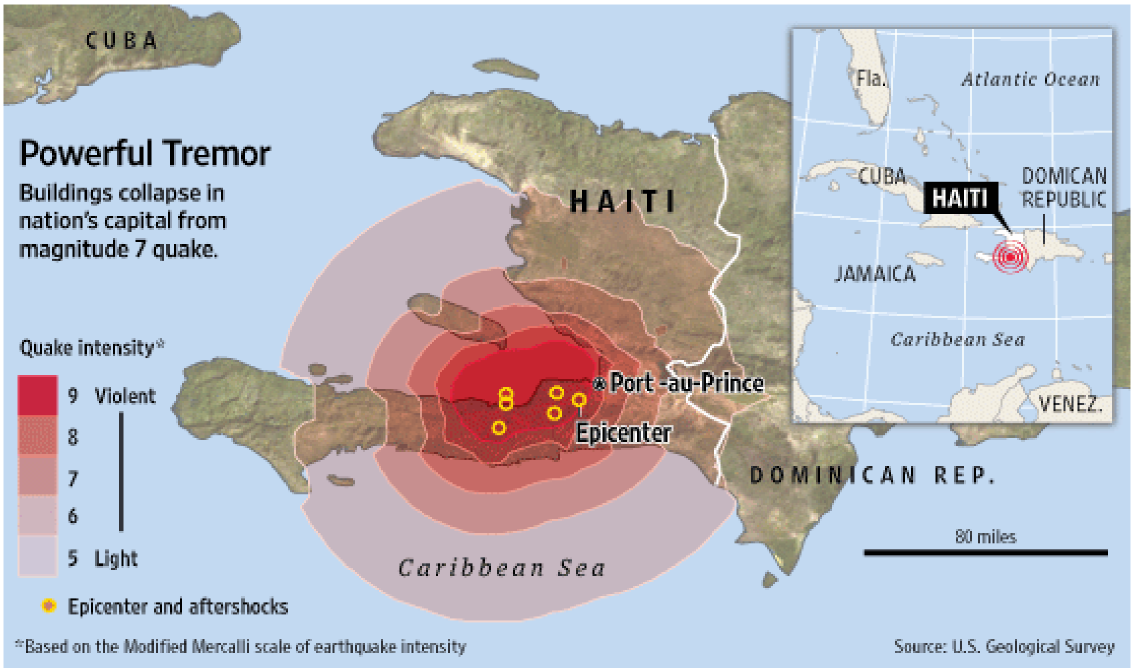
Chapter 3: Case Study – Haiti Earthquake, 2010

Earthquake and Aftermath

On January 12th, 2010 the largest earthquake to ever hit Haiti struck 15 miles Southwest of Port-au-Prince, Haiti's capital (Margesson, 2010). The 7.0 magnitude earthquake killed an estimated 200,000 individuals, and injured 300,000 more. Additionally, millions were forced into homelessness as structures were damaged and rendered uninhabitable (Margesson, 2010). The devastation of buildings and infrastructure damage was widespread and catastrophic (see figure 4). An estimated 250,000 dwellings were damaged in the earthquake with thousands more commercial, government and public structures impacted (Bilham, 2010). This is due in large part to buildings not being built to code and with insufficient building materials. Following the event, many experts stated that, "engineering could have averted much of the damage in the Port-au-Prince area" (Bilham, 2010).

Before the earthquake struck, Haiti was already the poorest country in the Western hemisphere. Over half the population, nearly 5.3 million people, lived in extreme poverty, defined as less than one dollar a day (WHO, n.d.). In this extreme poverty, improved sanitation was not an everyday reality for a large percentage of Haitians. Pre-event estimates put improved sanitation levels at 12% for rural Haitians and 29% for those living in urban centers (Kramer et al, 2011). Lack of improved sanitation can lead to a higher risk of contracting a wide array of diseases, negatively impacting the health of the community. According to the Pan American Health Organization, acute diarrheal disease was the number one health problem in Haitian children five years and younger (WHO, n.d.). After the earthquake, what improved sanitation infrastructure did exist was often damaged, destroyed or unusable.

Figure 4: Map of intensity, Haiti earthquake 2010



Source: The Wall Street Journal

With many people displaced following the earthquake, spontaneous shelters and settlements cropped up. Camps often provided sanitation in the form of open defecation and pit latrines. In a report to the United States Congress a month after the earthquake, the Congressional Research Service noted that, “Latrine usage and sanitation remain a problem at spontaneous settlements. The main priority is to increase sanitation support. This is seen as an important public health issue to avoid spread of disease” (Margesson , 2010). However, with limited resources and available infrastructure improvements, widespread improved sanitation was not achieved. By October 2010, the first cholera outbreak in over a century hit, creating a public health crisis in the already devastated country (Piarroux, 2010).

Cholera is caused by the ingestion of the Vibrio Cholera bacterium through contaminated food or water and is transmitted through oral contact with fecal matter. According to the World Health Organization cholera is, "closely linked to inadequate access to clean water and sanitation facilities" with at-risk areas including "peri-urban slums, and camps for internally displaced persons or refugees, where minimum requirements of clean water and sanitation are not met" (WHO, 2017) . After the earthquake in Port-au-Prince, many people were living in close quarters with minimal access to proper sanitation, making it the perfect breeding ground for such a disease.

According to a UN report released in 2011, researchers have found that there was a confluence of factors that lead to the cholera outbreak that devastated Haiti after the 2010 earthquake. Though the exact cause is disputed, many believe that the bacteria was imported to Haiti through Nepalese peacekeepers stationed in the mountains of central Haiti. Just a month before their deployment there was a confirmed outbreak of cholera in Kathmandu, Nepal making them prime candidates for suspicion (Piarroux, 2011). Others argue that the bacteria is naturally occurring in the environment bloomed due to the La Niña year, allowing it to spread into the water systems (Piarroux, 2011). However the bacteria was introduced, the lack of immunity in the population, the dispersion of people after the earthquake and the poor water and sanitation conditions along the Artibonite River delta spread the disease like wildfire throughout the country until every region was infected (United Nations, 2011). This outbreak serves as an example for the importance of emergency sanitation to fight against the vulnerabilities that arise in disaster situations. Sanitation management becomes an essential focus to maintain the health of the community, as a baseline to rebuild and recover.

Container Based Sanitation in Haiti - SOIL

Starting in 2006, a nonprofit called Sustainable Organic Integrated Livelihoods (SOIL) was formed by a group of expatriates and Haitian nationals hoping to address two of the country's biggest problems: (1) sanitation management and (2) depleted soils. Soon after SOIL arrived, the organization opened its first waste treatment facility servicing the select communities of Cap-Haitien, Milot and Borgne in Northern Haiti. Their idea was to bring container-based sanitation into these communities and use an EcoSan approach for treatment. The system was designed so that improved sanitation could be offered to communities and their byproducts used as a resource to enhance soils for agriculture, further giving back to the community. The original design was a double-vault communal toilet, which was quickly phased out due to water coming into the vaults from the high water table of the region (Kramer et al, 2010). At this point, experiments began with using 15-gallon drums to collect waste and remove it from the site for treatment. After the drums were filled, trained personnel collected them and transported them to waste treatment compost sites "where through a carefully monitored process… of thermophilic composting, the waste is transformed into nutrient rich compost" (Kramer et al, 2010). This soil is then sold as an alternative to harsh chemical fertilizers and the proceeds generate revenue to continue the sanitation services. It was during the early phases of the experiments with 15-gallon drum container toilets that the earthquake hit Haiti.

In 2010, SOIL refocused their efforts to provide container-based toilets for Port-au-Prince in the wake of the earthquake, specifically focusing on camps of displaced persons. SOIL implemented the 15-gallon drum design. The drum was placed beneath the toilet to collect feces and cover material. When the drum was full, it was taken out and replaced with another empty drum. The full drum could be sealed and stored until taken to the composting site to be properly treated and handled. SOIL reported “This system requires less handling of wastes but maintenance must happen on a regular basis as opposed to semi-annually, as with the double vault model”. Continuing on to explain that the 15-gallon drum “system works particularly well when there is extensive usage of the toilet”, the report notes that off-site composting is required for this toilet design (Kramer et al, 2011). To handle the waste, SOIL established “5 composting sites in Port-au-Prince and northern Haiti, the largest of which can treat the wastes of over 30,000 people” (Kramer et al, 2011). In addition to this style of toilet, 4,000 portable toilets were brought to Haiti as an emergency toilet by international aid organizations. Soon after their implementation though, these toilets had to be converted to urine diversion toilets, as the mixed waste was harder to store, transport and treat (Remington et al, 2016).

In a detailed report released by SOIL in February 2011, the organization outlined their findings for CBS toilet implementation in Haiti after the earthquake. Their experiences brought them to the conclusion that in order for a successful CBS toilet campaign it is essential to maintain relationships with the committees in charge of the toilets in order to streamline regulation and understanding of the systems. They also found that paying operators of the toilets, compared to having operators be community volunteers, increased the maintenance and proper usage of the toilets. This also created more regular supervision of the toilets, which allowed them to be serviced when needed. Lastly, providing a trash receptacle near the toilet helped prevent trash from being deposited into the drum, which would disrupt the treatment process. With all of these considerations in place, the expansion of CBS toilets in Haiti after the earthquake had been very successful. As of March 2016, SOIL provided CBS toilets for 721 households, or 4,000 users in Cap-Haitien and Port-au-Prince, and it has transformed over 20.6 metric tons of human waste into over 100 metric tons of compost to date, as "demand for the service continues to grow" (Remington et al, 2016).

Key Findings

The Haitian earthquake of 2010 demonstrates the importance of proper sanitation management, and how quickly mismanaged waste can impact a population. Due to SOIL's experience and knowledge of this system before the earthquake hit, implementation of the toilets as an emergency response method could be implemented quickly and efficiently. Additionally, it provides an example of how improved sanitation can be met without reliance on running water.

Before the earthquake, CBS systems in Haiti were being successfully utilized in Northern regions where piped water was not, and had never been, a reality. The double vaulted CBS system SOIL implemented allowed for safe and inexpensive sanitation management and treatment, though the high water table of the area inhibited its success, as waste was not able to dry out properly in the vaults. This CBS toilet design provides a solution for long-term use that allows for less frequent pick-ups of waste-filled containers by SOIL operators. During the emergency response after the earthquake, toilets changed design to more appropriately reflect the needs of the situation. This quick adaption of the CBS system shows the versatility of these systems to fit in under different circumstances for various communities as needed. The urine diversion portable toilet systems and 15-gallon drums implemented proved to be better for communal toilets when toilet operators were present and paid for their labor. This took the waste handling responsibility away from untrained users, ensuring proper management practices were being implemented. However, the 15-gallon drum system required consistent maintenance and removal of drums to ensure they did not overflow and become unusable. This demanded more personnel, money and resources to operate the system.

Significantly, in Haiti, SOIL had experience using this form of sanitation system in Northern communities before emergency sanitation measures were needed in Port-au-Prince, helping with the transition and success of the program post-disaster. SOIL was able to quickly and efficiently build the required infrastructure to move the operation's efforts South to Port-au-Prince, as well as safely manage waste within the community. Similar trainings and widespread understanding would need to be achieved before the Cascadia Subduction Zone earthquake struck in the Pacific Northwest to ensure that the system could be effectively and efficiently managed in a high stakes, emergency environment.

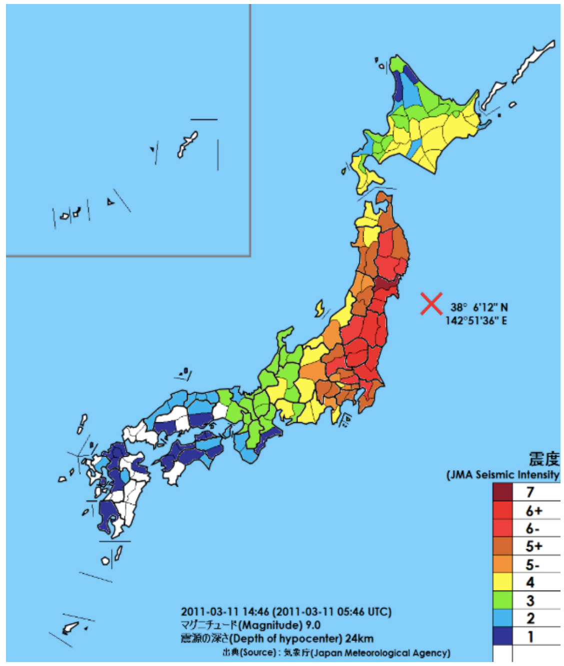
SOIL's container based urine diversion toilets provide a safe, inexpensive and easy-to-use option for emergency sanitation management that is not reliant on running water. It is easily adaptable to rural and urban spaces, and uses materials that can be found locally for cover material, making the model adaptable to any area, including Eugene. Limitations and concerns include initial investments in infrastructure for composting sites, the logistics of container pickup on a large scale, and community education on proper use.

Chapter 4: Case Study – Great East Japan Earthquake, 2011

Earthquake and Aftermath

On March 11th, 2011 at 2:46 PM a 9.0 magnitude earthquake shook the Sanriku coast of Japan. This event, referred to as the Tohoku event, created hundreds of aftershocks throughout the country and triggered a 10-meter high tsunami barreling towards the Northeastern coast in as little as 30-minutes after the initial shake. The Tohoku event was the fourth largest seismologic event to be recorded since the advent of modern semiology, and caused the damage to match this distinction (Ratnapradipa et al, 2011). One day after the event the death toll stood at 14,998 with nearly 10,000 more missing and hundreds-of-thousands homeless (Japan National Police Agency, 2011). Infrastructure was severely affected after the event. Immediately after the disaster, more than 2.2 million homes were disconnected from the piped water supply system, 946 km of sewer networks were destroyed, and 120 wastewater treatments plants were impacted, with 48 completely shut down (Ministry of Health, Labor and Welfare and Japan Water Works Association, 2011). People were in need of water, food and sanitation solutions. However, rolling electrical blackouts, railroad and road damage disrupted rapid response efforts, leaving some without these essential items for days (Ratnapradipa et al, 2011). The disaster left thousands in need and with infrastructure so badly damaged that relief and aid had difficulty reaching them in a timely manner.

Figure 5: Map of areas affected by Tohoku event



Red areas show areas impacted with 6- to 7 magnitude shaking. These areas include the Miyagi and Fukushima Prefectures. Source: Japan Meteorological Society

Figure 6 and 7: Devastation to infrastructure on Sanriku coast after the event

Source: National Geographic

Source: National Geographic

After the devastation, many people found that they were without a place to relieve themselves. Public water supply service was not available or consistent in many areas, rendering the toilets that survived the disaster useless. Reports were coming out of communities where “Toilets, flushed with buckets of water from school pools, soon became clogged and overflowed” (Parmar et al, 2013). Cities scrambled to solve the problem by providing conventional portable toilets, but found problems getting them to severely damaged areas as roads and bridges were unpassable. Additional problems arose in places where these toilets were successfully placed, as desludging of toilets after they were filled proved to be another hurdle (Harada et al, 2012). It has been estimated that in the weeks after the earthquake nearly 40% of evacuation centers had inadequate sanitation management of toilet systems (Sankei Shinbun, 2011), forcing some to fall into unsanitary waste management practices such as defecating on newspaper, in a hole in the ground, or in a bag and burying their waste (Harada et al, 2012). This disposal of waste increased the risk of drinking water contamination, in turn increasing the potential of public health problems and environmental degradation. Additionally, defecation in ways such as those listed above are often correlated with a reduced sense of personal dignity as people have lost privacy and comfort while using the toilet (Brossard et al, 2015).

Sanitation in Evacuation Centers

In the Miyagi Prefecture, the district located closest to the epicenter, total counts of evacuees reached more than 30,000 people (Tokuda et al, 2014) or nearly a quarter of its population. In an attempt to house these displaced people, evacuation centers were set up throughout the region. Unfortunately, many were suffering from lack of consistent food, water, electricity and sufficient numbers of toilets to accommodate demand. A team of researchers from the Tohoku University Graduate School of Medicine surveyed 324 evacuation centers two weeks after the Tohoku event to investigate the management of sanitation and the health of those in the centers. These researchers found that there were three main factors contributing to the successful or unsuccessful management of these systems: (1) size of the evacuation center, (2) water availability, and (3) designated sanitation management personnel.

In regards to the size of evacuation centers, researchers found that in smaller evacuation centers, defined as centers with 50 of fewer evacuees, most inhabitants were locals who knew each other and therefore brought a sense of community to the center. These centers were found to work more “cooperatively for the procurement of supplies as well as for feeding, cleaning, and health care management” (Tokuda et al, 2014).

Large centers, with 101-500 or more evacuees, lacked the familiarity and background that smaller centers did, and struggled to work together and manage the center as a group. This often led sanitation and health issues to slip through the cracks. It is important to note that the observations reported in the study are limited to the perceptions of the researchers on the day they visited each center as well as the accounts from the leadership in the evacuation centers.

The second factor that contributed to the sanitation management success of an evacuation center was the status of the water supply to the center. Due to damage of pipes as well as water treatment and purification plants, efforts to get water service restored to evacuation centers was delayed and remained unavailable in many areas. Conversely, the evacuation centers fortunate enough to get water back online in a timely manner showed increased successful sanitation efforts with cleaning and maintenance of toilets being cited as satisfactory. These centers had sanitation resources similar to those before the earthquake and were able to maintain higher levels of sanitation for that reason.

Lastly, evacuation centers that had a clearly designated person in charge of health matters were more successful in their sanitation management practices. Having a point person with a clear role in the management of the evacuation centers sanitation created accountability to that person to uphold their duties. Some of these managers of health matters were selected out of the evacuees at the center, while others were dispatched by the authorities. Their roles varied between the centers as well, but across the board, the main purpose was to monitor the health status of evacuees and isolate those with health problems and symptoms. These roles sometimes stretched further to include managing the sanitation of the center, including toilet monitoring and maintenance.

Container Based Sanitation in Evacuation Centers

In a separate study after the Great East Japan earthquake, researchers from the Graduate School of Global Environmental Studies in Kyoto, Japan tackled the question of how to improve sanitation in the evacuation centers. They developed a disaster response portable toilet unit inspired by urine diversion composting toilets and portable camping toilets. Just months after the Tohoku event, 54 toilets had been distributed to evacuation centers throughout Japan. In order for the toilet to be effective, it was essential that the toilet not need to use water or electricity to operate, as those resources were limited at the time. The finished model was a container-based system that diverted urine into a separate tank (see figure 8). Unlike the toilets used by SOIL in Haiti, no composting infrastructure, physical or experiential, was available before the earthquake making it much more difficult to use an EcoSan design. Though no composting was intended as a form of treatment, cover material was used to dry and limit odor from the waste. In their design, in order to dry and dehydrate the fecal matter, a combination of lime and carbonized rice husks or dry soil were added (Harada et al, 2012). These additives were readily available to the communities in Japan as lime was used for agriculture and the carbonized rice husks were locally produced. The researchers instructed users to place a cup of lime and dry material on top of their feces immediately after relieving themselves. This would dry the waste as well as discourage the foul odor, then the bucket would store the feces until solid waste collection services were running, at which point the waste would be collected by municipalities.

Alternatively, the user could retain the waste and wait 6-10 months until the waste was no longer a risk of contamination. In that time frame the understanding was that, if properly covered and stored, the pH of the container along with the lack of moisture would reduce pathogen contamination enough that users could bury the waste themselves. As events played out, water systems and infrastructure for waste collection were restored before the six-month time period was completed, allowing for alternative treatment and disposal to take place.

Figure 8 : Final model of toilet used by researchers

Made of plastic and cardboard. Foldable and ready to assemble, making it ideal for storage, transport and set up. Source: Harada et al, 2012

In the system used by these researchers, urine was diverted and collected into a separate container where primary treatment of the urine consisted of adding a small amount of lime.

Lime has been used historically to reduce odor from open pit latrines due to its highly alkaline nature (Greya et al, 2016). Researchers from the University of Malawi conducted a study to see how effective lime could be at treating human waste in eliminating pathogens for emergency sanitation procedures. Lime was chosen in part due to its low cost and availability as it is often used as a building material. In their study they found that lime stabilization of waste "was able to sanitize fecal sludge to below the detection limit" of the WHO standards, leading them to further conclude that "off-site lime stabilization can be adopted to treat fecal sludge during acute phase of an emergency situation" for immediate response (Greya et al, 2016). Though lime can sanitize waste effectively, it can impede the composting process when used as the main cover material for extended periods of time, so alternative solutions would be needed for disposing of lime-sanitized feces.

The researchers found that their toilets were "evaluated positively and acquired for future preparedness" (Harada et al, 2012) in many communities due to their compact and storable design. Though these numbers are less than those of SOIL's work in Haiti, it is important to note that these toilets were not in use before the earthquake, so trial and error was occurring in evacuation centers. Even so, they were found to provide improved sanitation over the alternative of open defecation or simply burying highly contaminated waste. The container based sanitation model allowed for sanitation to be managed safely until infrastructure could be repaired enough to continue prior services.

Key Findings

The Tohoku event in 2011 displayed the catastrophic damage to sewerage systems major earthquakes can bring. After the event, more than 2.2 million homes were disconnected from the piped water supply system, 946 km of sewer networks were destroyed and 120 wastewater treatments plants were impacted, with 48 completely shut down (Ministry of Health, Labor and Welfare and Japan Water Works Association, 2011). As a result of this and the structural damage to buildings, many people were displaced from their homes to evacuation centers. These centers varied greatly in size and population. Researchers found that for centers fortunate enough to have running water, to be of a small size, and having designated toilet management personnel, proper sanitation was achieved at a higher rate than in other evacuation centers. Additionally, the adoption of container toilets was a welcomed alternative to the portable toilets initially provided. The portable toilets proved to be ineffective, as distribution and desludging of toilets was challenging due to damaged roads.

Chapter 5: Case Study - Canterbury Earthquake Sequence, New Zealand, 2010-2011

Earthquake and Aftermath

On September 4th, 2010 the first of four major earthquakes to strike the Canterbury Region of New Zealand hit, ringing in at a magnitude 7.1 on the Richter scale. In the next year, three more significant earthquakes would rattle the region, wreaking havoc on the infrastructure and recovery efforts. Referred to as the Canterbury Earthquake Sequence, this series of earthquakes included the 7.1 magnitude (M) earthquake on September 4th, 2010, a 6.2 M earthquake on February 22nd, 2011, a 6 M earthquake on June 13th 2011 and lastly a 5.9 M earthquake on December 23 2011. The Canterbury sequence caused between $15-16 billion NZD in damage, making it the most costly natural disaster to hit New Zealand, and the third most costly earthquake to occur worldwide (Potangaroa et al, 2011).

These earthquakes damaged "528 kilometers of sewer pipes which accounts for approximately 31% of the total (1700 kilometers) sewerage system in Christchurch" along with approximately 100 sewer pump stations in the area (Liu et al, 2013). One day after the earthquake on February 22, "Christchurch Mayor Bob Parker said sanitation and access to clean water was still the biggest problem the city faced" (Rickard, 2011). Though some utilities, like electricity, were up and running within days of the disaster for most people, water and sewer systems took much longer to re-establish in Christchurch (The New Zealand Ministry of Culture and Heritage, 2017). Within one day of the February 22 event, 780 portable toilets were allocated throughout the city, with an additional 1,213 portable toilets in transit to Christchurch from other countries (Potangaroa et al, 2011). Furthermore, thousands of chemical toilets were being imported into the country to fill the holes in portable toilet allocation. These toilets went to residents in suburbs that had been initially overlooked, as recovery efforts focused on central Christchurch where damage was highest. Two-weeks after the event, forty percent of residents were still unable to use their in-home toilets. As a result, they were using one of the 40,131 portable and chemical toilets deployed to the city. Those who had water were still warned to check for blockages on their property and their surrounding neighborhood because though toilets may be flushing, disturbances down the line could cause sewage to leak out and flow into streets and water systems. Further problems arose as delivery and maintenance of portable and chemical toilets were delayed with heavy traffic and disrupted infrastructure (Potangaroa et al, 2011). After each earthquake, Christchurch found itself in a major crisis: in need of water, sanitation and infrastructure to replace the devastated sewer system. Recovery efforts focused on the short-term solutions of portable and chemical toilets to hold waste. These required massive efforts to acquire, and the city struggled to distribute them evenly throughout all affected areas.

Wellington Compost Toilet Trial

Having seen the chaos revolving around sanitation management after the Canterbury Earthquake Sequence, the Wellington Regional Emergency Management Office (WREMO) recognized the vulnerabilities in the sewer systems in place and what disruption of this system can do to the community. A trial was organized to see how user-friendly composting container-based toilets could be, and what the community's response would be to using them on a regular basis. WREMO used Facebook and local newspapers to reach potential volunteers throughout Wellington, finally finding eleven households to agree to participate in the trial. WREMO researchers then provided volunteers with no-mix container based toilets to use for the next four weeks. Cover materials, storage containers for waste, sanitizer, and an instruction booklet with paper to record thoughts, concerns and experiences with the toilet were provided as well. Participants were instructed to use exclusively the compost toilet, and dump the waste into 'wheelie bins' such as curbside trash bins when the toilets in the home began to smell or fill up. At the end of the trial, the waste in the wheelie bins was collected and brought to the local landfill where it was disposed of. Given that the landfill is sealed and waste will not seep out of it, this is a perfectly acceptable short-term solution when assembly of a composting system is too complicated.

Figure 9: Toilets used in Wellington project

The flexibility of the emergency compost toilet. Left: Part of 'split' toilet installed in narrow space in a bathroom. Middle: Compost toilet located in an outside laundry. Right: A lined unit located in spare room of the house. Source: WREMO, 2012.

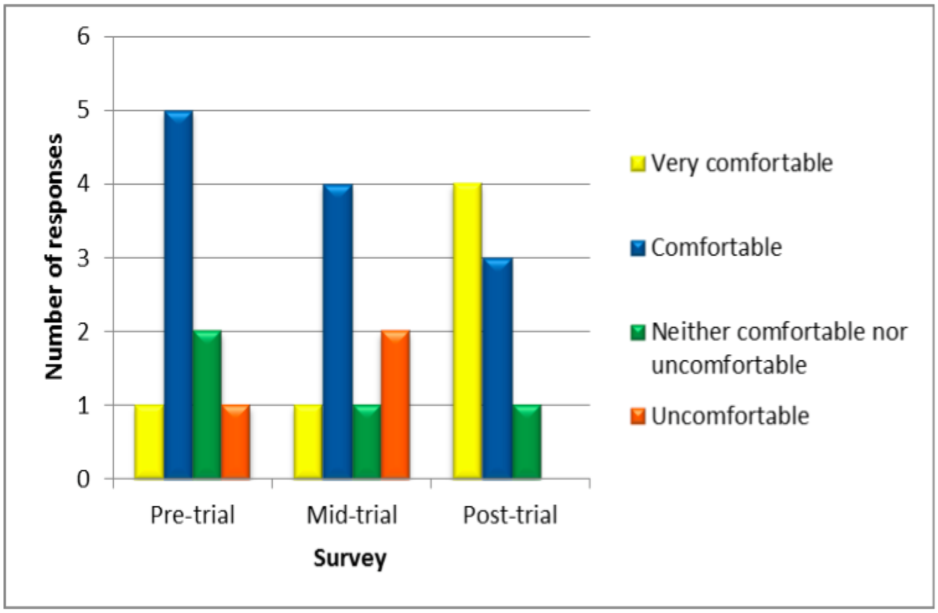
The results of the study were very promising. First, participants found the toilets easy to assemble. Researchers reported that "Several of the participants requested that the toilet unit was not assembled, wishing to assemble it themselves". Of these participants, "all were able to do this successfully in less than 5 minutes" (WREMO, 2012). The toilets also included the feature of splitting the feces and urine chambers if space did not allow for them to be together, making them very adaptable to different spaces. The ease to assemble these units speaks to the versatility and accessibility of the toilets, which is a very important characteristic for the toilets to have, especially when intended to be used in emergency situations. When it came to the use of the toilet, generally participants found it easy and enjoyable, with the exception of children. Many of the children in the study needed encouragement and engagement from the onset of the trial to keep interest. Some families addressed this by allowing the children to decorate the toilet. Some also added timber under the toilet chamber to "reduce the gap between seat and bucket and the potential for spills" that were more common among children (WREMO, 2012). In these homes, this process was found to be essential for reducing spills and contamination of the waste. Limitations of this study include the small sample size of only eleven participants and the use of flush toilets in some cases, in particular with children.

Figure 10: Children's art on the toilet

Image of children's drawings of urine and feces taped onto the appropriate side of the twin-bucket toilet. Researchers found that engaging children made them more likely to use the toilet. Source: WREMO, 2012.

Overall, the participant's comfort using compost toilets increased dramatically over the four-week trial period (See figure 11). Researchers found that participants were quickly able to adapt to the new sanitation method and took steps to make their toilets their own. Some people put essential oil diffusers on them or placed magazines nearby to create a familiar environment and integrate the toilet into their homes. People often reported that the white coloring of the units was appreciated as they made the units seem cleaner. This study shows that container based toilet systems are usable and liked by users in a urban and suburban setting.

Figure 11: Comfortability of participants to use a compost toilet for up to 3 months



Source: WREMO, 2012.

At the time of the disaster, before the research done in Wellington, similar toilets were developed by residents fed up with the chemical and portable toilets provided as a recovery sanitation method on the South Island of New Zealand in Christchurch (RELIEVE, n.d.). These EcoSan alternatives promoted were no-mix composting toilets. A citizen group, who call themselves RELIEVE, created informational guides, like their "Emergency Compost Toilet Booklet", that outline how to create the system, treat the waste, and properly manage the toilet with long and short-term solutions. Since the earthquake, they have expanded their outreach to actually creating toilet units for people to buy and use in their homes. Their intention is to help people "get started on [their] emergency or everyday composting toilet system" (RELIEVE, 2011). Their toilet kit includes a plywood box and two toilet seats on two separate buckets to separate urine from feces (see figure 12), one bag of cover material, a user guide and a do's and don'ts quick reference guide. The only thing they do not include is a large container, such as a wheelie-recycling bin, to compost the waste in. Alternatively, they provide instructions on their website for how one could collect the materials and build a composting toilet of their own.

Figure 12: Christchurch No-Mix composting toilet design

Source: RELIEVE

RELIEVE and the Wellington Regional Emergency Management Office have taken important steps to normalize and provide education for the public on container toilets. The work they are doing demonstrates the importance of alternative emergency toilets, as citizens and local authorities search to find solutions other than chemical and portable toilets, which proved to be unsatisfactory to many in the emergency recovery period after the Canterbury Earthquake Sequence.

Key Findings

The case study of the Canterbury Earthquake Sequence in New Zealand shows the devastation an earthquake can cause to sewers, pipes and treatment plants and the reliance of communities on those services. The people and Emergency Management Office of the region were unsatisfied with the emergency sanitation response from the disaster, and thus began experimentation with the container based EcoSan models. The Wellington Regional Emergency Management Office's study on residents using a compost toilet for four weeks highlighted the ease and acceptance of such a toilet in a relatively short time frame. Participants steadily became more accustomed to and accepting of using these toilets in their own homes. This was shown through survey data collected throughout the study as well as in the personal touches added to the toilets and their immediate surroundings such as magazines, candles and children's drawings. Participants also responded that smell of waste was not an issue, and that setup and maintenance was manageable by the families.

RELIEVE's work to continue to push education, outreach and availability of compost toilets for future disasters has also been quite successful. Their work stemmed from their personal need after the earthquake during response and recovery periods where piped sewerage systems were not running at full capacity. They have created a format where people can easily research maintenance tips and guidelines on their website, as well as offering a platform to order a Christchurch no-mix toilet to be delivered. The city of Portland, Oregon refers to their guides on their emergency management web page, demonstrating the international impacts of the organization.

This case study shows the application of a composting toilet in an urban and suburban setting where the use of proper sanitation through piped sewerage systems is considered the norm. Though the size of the study was on a small scale, its overwhelming success and the continuation of efforts through RELIEVE shows the application and versatility of such a system.

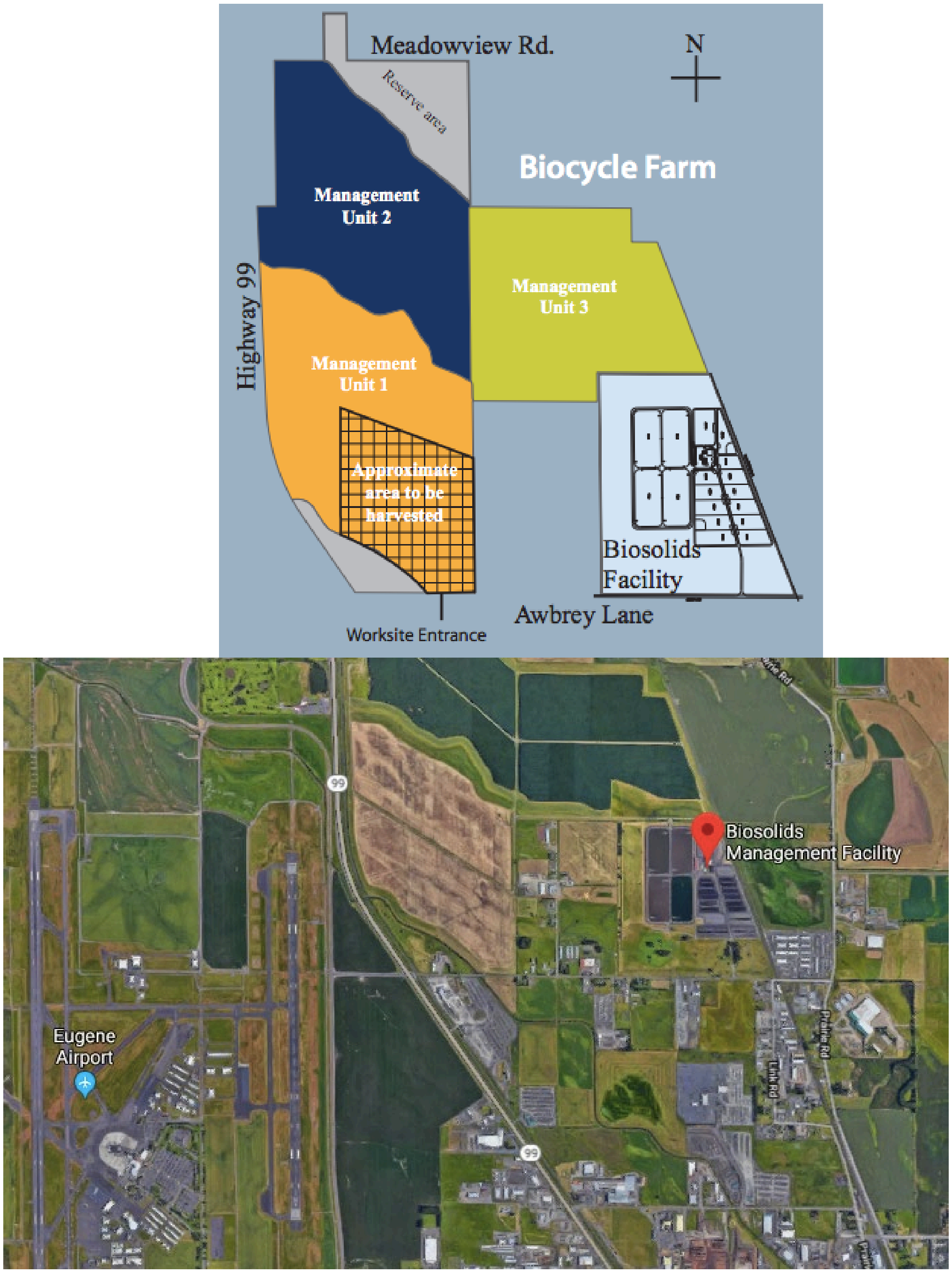
Chapter 6: Discussion and Recommendations for Container Based Sanitation in Eugene

Taking the knowledge gleaned from the case studies of Haiti, Japan and New Zealand after their respective earthquakes, I assessed the feasibility of implementing a urine diversion ecological sanitation system in Eugene. It is important to look at the specific strengths and weaknesses of a city and community to gather what would be needed and what is already in place to make a system like this be successful.

Using Existing Infrastructure: Metropolitan Wastewater Management Commission's Bio-cycle Farm

Located west of downtown Eugene, near the local airport, the Metropolitan Wastewater Management Commission (MWMC) currently operates a bio-cylce farm. On the farm, human biosolids, a byproduct of the wastewater treatment process, are turned into nutrient-rich, organic material. This material is then applied to 400 acres of poplar trees that are being managed as an agricultural crop. The first round of trees were planted in spring 2004, and are harvested every 12 years. The end-use products from the poplar trees go to craft paper, wood chips, charcoal, and cardboard. In addition to the poplar tree crop, "for the last 20 years, the MWMC has provided local grass seed growers with bio-cycle to fertilize their farms" (MWMC, 2017). The biosolids are fully treated at the Biosolids Management Facility, located just west of the farm, and are further "dried using mechanical dewatering and air-drying processes" (MWMC, 2017). All bio-solid product applied to the land is approved by the Department of Environmental Quality.

Figure 13: Metropolitan Wastewater Management Commission map



Top: Drawn map of the MWMC bio-cycle facility. Source: MWWC. Bottom: Location of the farm - across Hwy 99 from the Eugene Airport in West Eugene. Source: Google Maps.

At this facility, the MWMC is using human waste collected from the city of Eugene to create nutrient-rich soils for agriculture. This experience and existing land dedicated to the biocycle process provides essential knowledge and resources that could be utilized by the city and surrounding areas to process and treat the waste collected in containers after the CSZ earthquake. This successful program has continued for the last 14 years in Lane County, without major issues, proving the feasibility of an ecological sanitation model in Eugene.

In addition to the Bio-cycle farm, Eugene has a large-scale organic private composting facility for food waste and yard debris located in Coburg just North of the city. Facilities such as this could be re-designed to rapidly include a human waste composting department to aid in the composting of the city's waste in the event of the CSZ earthquake.

Picking the Right Toilet: Twin-Bucket Toilets vs. Urine Diversion Bowl Toilets

In Oregon, talk of container based sanitation solutions for emergency settings has already begun. Portland is home of the Twin Bucket Brigade, run through the nonprofit organization PHLUSH. PLUSH focuses on spreading education, awareness and supplies for citizens to use container toilets in case of emergency situations. The twin bucket system uses two separate buckets, one for feces and one for urine. Each bucket is equipped with a seat. Then cover material is added to dry the solid waste, similar to other CBS toilet systems. Materials to provide information and properly label each bucket are available on the projects website (pictured below).

Figure 14: Twin Bucket Brigade toilet labels

Labels for 'Pee' and 'Poo' buckets include instructions, supply checklists and resources to help users learn more about the system. Source: City of Portland, OR.

The city of Portland's Bureau of Emergency Management has endorsed the twin bucket system. This system is successful in large part due to its inexpensive cost of production and the availability of materials. Additionally, setup is streamlined, as there are fewer pieces to assemble, making it easy to construct quickly and successfully.

Issues with the twin bucket system include difficulty of use for children, people with disabilities and seniors who may not be able to defecate and then urinate in separate containers. This model is very similar to the Christchurch and Wellington no-mix toilets from New Zealand.

The alternative to the twin-bucket system is urine diversion in the bowl. This is the design chosen by SOIL in Haiti and researchers in Japan after the earthquakes there. Urine is diverted in the front of the bowl into a separate collection container as feces drops behind into the larger onto which cover material is applied. Urine diversion in the bowl is more compact, as there is only one toilet needed. Like the twin bucket system, some children find use of the urine diversion toilet to be difficult due to their size.

Education and Familiarity

In Eugene, like in many places in the United States, it is commonplace to use exclusively modern, piped water toilets with the occasional use of a portable toilet. Waste is washed away within a few seconds and personal sanitation management only requires flushing the toilet and washing one's hands. Beyond that, waste is out of sight and out of mind due to the convenient and complex system of underground pipes and the regional wastewater treatment facility. Defecation is also often considered a taboo topic, something private to be left in the bathroom. However, after the CSZ earthquake people will need to quickly adopt alternatives as the sewerage system is likely to be offline for a long period of time. A key component of adopting a CBS and EcoSan approach to emergency sanitation management will be ensuring that citizens are educated and comfortable using the system. Without these components, systems have a higher risk of mismanagement and failure.

The Wellington Regional Emergency Management Office's pilot program is a great way to start such a campaign. By giving citizens the opportunity to try this toilet system before an emergency scenario, they are provided with invaluable experience becoming accustomed to the system. This way, in the chaos of the emergency situation, they can rely on their previous experience to help guide them through use of the toilets and managing their own sanitation in their home.

In Eugene, similar pilot programs could be implemented to raise awareness for the toilet system. Additionally, Eugene could bring CBS toilets to community events like the Saturday Market, monthly art walks, or small festivals. It is important to take note of the Japan case study where researchers found that designated personnel to manage the use of toilets were essential to the toilets success. At these events, Eugene emergency management officials and sanitation personnel would need to monitor the toilet use. In addition, these events would provide an opportunity for city officials to promote the toilets by educating the public on their use as well as familiarizing the new concept. Future studies should consider other community outreach ideas for the city of Eugene and what forms of education would be most successful.

A Multi-Dimensional Approach

One way to integrate CBS and EcoSan toilet models into Eugene's emergency management operations would be to provide a tiered approach that can adapt to the severity and needs of recovery processes. The first essential component of a successful CBS toilet is the proper cover material. In Eugene, bark chips, dried leaves and sawdust would all be easily attainable local materials to use as a cover material. For the toilet itself, further research into what form of toilet (urine diversion or twin bucket) would work best for the city should be conducted. Once the toilet type is selected, ensuring the materials for toilet units are available for pilots and disaster response would be the next step. After this process, it is important to determine the scale of toilet distribution. Options include small scale CBS, such as toilets are in individual households, a slightly larger scale including a few families, or even larger to be neighborhood wide in scale. All options have strengths and difficulties and research should be done to conclude which scale would work in different sections of Eugene.

It is important to note that the population density of an area within Eugene's urban growth boundary has a significant impact on the scale of toilet distribution. In a rural area where households have large swaths of land between them having communal emergency toilet systems is less effective because they are not easy to access. Conversely, in a place like an apartment building having each person have their own emergency toilet may not be necessary, and a more effective approach may be some sort of group access to the toilet. Research into appropriate allocation of toilets for different densities of population could provide valuable insight into the most effective system.

One possibility could be a multi-dimensional system that would provide different options based on availability of infrastructure and population density after the earthquake. The most basic element of sanitation management is to ensure pathogens are eliminated thus preserving public and environmental health. The table below outlines different possibilities with the projected benefits and drawbacks of each system.

Table 1: Possible container based sanitation treatment options

	Description	Projected Benefits	Projected Drawbacks
***Minimal* Preparation and Processing** Tier 1	Keep waste in containers to be taken to the landfill	• Easy to implement • Little user contact with waste • Minimal resources need (only for collection and transport)	• Influx of feces to landfill • Containment and relocation of waste - not treatment • Not utilizing nutrients in waste • Need to organize transport to landfill • Infrastructure (roads and trucks) to transport waste to be treated.
***Minimal* Preparation and Processing** Tier 2	Apply lime to containers to sterilize waste -waste taken to a landfill	• Little user contact • Sterilization of waste does occur • Minimal resources need (only for collection and transport)	• Influx of feces to landfill • Not utilizing nutrients in waste • Pre-disaster collection and distribution of lime • Need to organize transport to landfill • Infrastructure (roads and trucks) to transport waste to be treated.
***Moderate* Preparation and Processing**	Citywide collection of waste in containers that are brought to composting centers (i.e. Rexius or MWMC Bio-cycle farm) for treatment	• Complete treatment of waste • Waste turns into product that can be sold to subsidize cost of system • Utilizing nutrients in waste • Infrastructure for human waste composting already in place	• Personnel needed to collect, transport and treat waste • Infrastructure (roads and trucks) needed to transport waste to be treated. • Land and center needed to treat waste • User education about cover material and toilet use • Need to organize transport to compost site

	Description	Projected Benefits	Projected Drawbacks
***Maximum* Preparation and Processing**	Small scale composting of waste (i.e. households or community gardens)	• If transportation infrastructure is limited and damaged, treatment can still be achieved • Utilizing nutrients in waste • Creation of compost for agriculture	• Increased need for thorough education of system • Difficult to regulate to ensure waste is being treated properly • Increased user contact and responsibility • Increased risk of user error and potential subsequent pathogenic contamination • Not all households have the space to conduct on-site composting

Source: Indigo Larson, 2018.

Transportation of waste to either a landfill or a treatment facility such as the MWMC Bio-Cycle Farm on a citywide scale is reliant on roads being navigable and trucks available to transport waste. If damage to roads was not an issue, garbage and solid waste disposal companies like Sani Pac and Lane Apex could allocate a portion of their dump trucks to this purpose. People driving the trucks would be trained in how to handle the waste and feces could be collected similarly, to how garbage and recycling is currently collected.

In the likely case that the roads are not navigable easily by car or truck, an alternative would need to be implemented. One option could be to have treatment centers at a neighborhood scale. These centers could be in school playgrounds or local parks where land is available and away from people's homes. This would allow for waste to be treated without needing to be transported a long way. People could walk their container buckets full of feces to the treatment center drop spot where community members trained in treatment practices could closely monitor the waste in a way that would be difficult for each person to do at their home. Further research into the scale of a system like this would be needed to ensure the ease of use for community members and the success of the treatment and processing of the waste.

Checklist for Implementation

Regardless of what option is chosen from the table above, certain steps will be essential in creating a successful container based toilet system. Below is a basic checklist that includes some of the important factors to consider when implementing this kind of system.

- Determine type or types of CBS toilets (Urine Diverting or twin bucket, or others) to be suggested to Eugene citizens.
- Provide community education and engagement to normalize concept of container based sanitation (and ecological sanitation if implemented).
- Participate in pilot programs and events to encourage Eugene citizens to gain experience using the CBS toilet.
- Provide opportunities for public to obtain toilets, or materials for toilets as part of emergency preparedness kits.
- If landfill option is chosen, create waste pickup sites for waste to be transported to landfill.
- If composting option is chosen, create pickup site for waste to be transported to compost site. Improve and expand compost sites to meet demand.
- Identify implementation strategies for most commonly anticipate disaster scenarios, not just earthquakes. Information that can help in this canoe found in the Vulnerability Assessment.

Insights that Lead to Better Performing Emergency Sanitation Systems

This list includes insights compiled from the case studies of Haiti, Japan and New Zealand after implementing emergency container toilets after earthquake scenarios.

- Build toilets out of materials that are inexpensive and easy to access. This will aid in the ease of adoption of the toilet.
- Find cover material that is local and in bulk to ensure it does not run out. Encourage homes to have a bag of cover material at all times.
- Separate feces from urine - separated waste reduces odors and risk of pathogen and disease vector growth. Additionally, this makes the waste easier to contain, transport and treat, as there is less material to handle.
- Size of community using a single toilet is important. The more people that are using a single toilet, the harder it is to manage.
- Having a designated sanitation management person for each toilet improves the sanitary conditions of a toilet.
- Children's engagement in toilet use is critical, as they might be less willing and comfortable using alternative toilets. This can include decorations done by the children as well as adding timber under the toilet chamber to reduce the gap between the seat and container reducing potential for spills.
- Education and experience can improve comfortability and understanding of the system, aiding in the success of system overall.

Chapter 7: Summary and Conclusion

With the impending damage to sewerage systems from the Cascadia Subduction Zone earthquake in Eugene, an alternative method of sanitation will be needed, potentially for an extended period of time. Container based sanitation has provided earthquake damaged regions around the world with a successful option for emergency sanitation management that can be applied to Eugene. By separating urine from feces, stored waste is drier, thus reducing odors and breeding of disease vectors like flies. Additionally, there is less liquid weight, allowing for easier containment, transport and treatment. This waste can be treated with lime in the containers and disposed of in landfills to provide an effective sanitation method that protects the public from pathogens commonly found in feces. Treatment can be taken further to include ecological sanitation and the composting of human waste. This system reclaims the nutrients found in waste and creates a product that can be safe enough to grow agricultural food crops in, among other things. The versatility in toilet design allows it to be easily adapted to many different implementation plans in a variety of regions.

With existing composting sites like the MWMC bio-cycle farm and Rexius composting in areas surrounding Eugene, taking treatment a step further to employ ecological sanitation is a feasible option that deserves serious further consideration. If properly implemented, container based toilets and EcoSan treatment of waste has the potential to fill the deficit in Eugene's Emergency Operations Plan and provide improved sanitation to the community after such an earth-shattering event.

List of Resources

These texts offer more comprehensive information about ecological sanitation and emergency sanitation methods, often including tips for more efficient systems.

The Humanure Handbook by Joseph Jenkins

Ecological Sanitation by Uno Winblad, Mayling Simpson-Hébert, and Paul Calvert

The SOIL Guide to Ecological Sanitation published by SOIL

A Sewer Catastrophe Companion published by PLUSH

*Emergency Compost Toilet Guid*e published by RELIEVE

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