UBC Social Ecological Economic Development Studies (SEEDS) Student Report

Emergency Potable Water Planning at UBC: Planning for the storage, transportation, and distribution of locally filtered water on campus

Arielle Dalley

University of British Columbia

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Executive Summary

This project is the result of a partnership between the Social Ecological Economic Development Studies (SEEDS) Program and Risk Management Services, and comprises of two reports which begin to answer the question, “What are the best solutions for getting clean water into the hands of the UBC community after a significant seismic event?” This report specifically addresses alternatives for storing, transporting, and distributing water which will be locally filtered by a water filtration trailer in the event of an emergency. A complimentary report prepared by the co-investigator on this project, Sarah Marshall, addresses strategies to enhance the resilience of the emergency water supply system.

It is necessary to outline the various alternatives for storing, transporting, and distributing water as there are few documents which comprehensively describe emergency water supply systems. The key considerations against which the alternatives were evaluated include the following:

- Minimal storage space required
- Minimal maintenance required
- Ability to integrate equipment into day-to-day operations, or use existing equipment
- Simplicity, or ease of use
- Flexibility of options
- Minimal cost

The storage alternatives considered include two alternatives for static storage containers which would be set up next to the water filtration trailer, and two alternatives for transporting the water between the site of the water filtration trailer and the water distribution sites. As a static water storage solution, water bladders have a slight advantage to onion tanks, although they are very similar. Similarly, cage totes might be a slightly better solution than water buffalo for storing water during transportation, but both have their advantages and disadvantages. The decisions would likely also depend on which transportation method is preferred. Out of the three transportation alternatives considered, both the alternatives of using a flatbed truck with an auto-levelling attachment and using pickup trucks to tow trailers are appropriate solutions. Again, they have their advantages and disadvantages, and the preferred alternative would likely depend on which alternative for storage during transportation is considered appropriate. Clearly, the decisions about which storage and transportation alternatives to implement are intertwined and are dependent in some ways on one another. Finally, it became clear that simple tapstands would be the most appropriate method of distributing the water from bulk storage containers at the distribution sites to people.

Given the results of the evaluation of the various alternatives, and considering how these pieces work together as a system, in addition to considering the equipment which has already been acquired or tested, I recommended using water bladders as the static storage alternative, with cage totes as the intermediate storage container between the water filtration trailer and the distribution sites, flatbed trucks as the method of transportation, and simple tapstands as the method of distribution. This report concludes with some recommendations for next steps.

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1.0 Introduction

Because of the University of British Columbia's (UBC) geographic location, it is vulnerable to earthquakes and must plan to respond to the impacts which an earthquake would have on the campus. One of the main, life-sustaining concerns after an earthquake is the need for potable water (Urban Systems, 2002). However, given UBC's geographically isolated position with respect to the City of Vancouver, if the municipal supply of potable water to campus is interrupted, there will be many challenges to providing potable water for many of the university's needs. As a result of these concerns, many departments throughout UBC have taken steps towards preparing for a potable water outage. One of these steps was to purchase a mobile water filtration trailer to produce potable water by filtering water from two creeks on campus. However, many questions remain regarding the process for getting this water to the people who will need it.

This report is the result of a project initiated by the Risk Management Services department at the UBC, in partnership with the Social Ecological Economic Development Studies (SEEDS) Program, to answer this question:

What are the best solutions for getting clean water into the hands of the UBC community after a significant seismic event?

The two primary objectives of this project as follows:

1. **Complete the planning process for a water filtration trailer which has been purchased**
2. **Consider additional ways to increase resilience**

This report addresses the first of these objectives, by examining options for storing, transporting, and distributing the water from the water filtration trailer. It also integrates resilience concerns into the planning process for the water filtration trailer. However, the second objective is addressed more comprehensively through a complimentary report prepared by the co-investigator on this project, Sarah Marshall.

2.0 Background

2.1 Water Filtration Trailer

The mobile emergency water treatment plant, hereafter known as the water filtration trailer, was commissioned from BI Pure Water Inc. (BIPW) by UBC in 2016 **(Figure 1)**. The purpose of this water filtration trailer is to increase UBC's resilience in a sustainable way by filtering water from two creeks on the university's campus for drinking water purposes in the event of an emergency where municipal water supply is interrupted. Under optimal conditions, the water filtration trailer can filter approximately 120,000L of water per day. These conditions include adequate water supply in the creeks and no issues with turbidity of the water in the creeks. This supply of filtered water is intended primarily to address drinking water needs on campus in the event of an emergency, in which case it could supply approximately 2L of water per day for 60,000 people. However, this is on the low end of the recommended guidelines outlined in a complimentary report prepared by the co-investigator on this project.

Figure 1 The water filtration trailer. Source: Personal photo.

2.2 Planning for Emergency Drinking Water Supply

There are four major elements for supplying water, both in normal conditions and emergency conditions, which include the source of the water, its treatment, storage, and distribution (U.S. EPA, 2011). However, when the existing water distribution system is damaged to the point that it is not practical to use it for distribution, coordinating the transportation of water to distribution sites is another critical step (U.S. EPA, 2011). Since this project considers how UBC can supply water when the normal distribution systems will not be operational, the additional step of transportation has been added. For UBC, this step specifically refers to the transportation of water from the location of the water filtration trailer to the distribution sites. Additionally, since the source and treatment elements have already been determined and are closely related for UBC, they have been combined into one step **(Figure 2, following page)**.

For each stage of providing water, there are key considerations identified by the literature associated with the procurement, implementation, and operation of the solutions chosen. When procuring equipment, agencies should coordinate between themselves, and any financial terms and legal and regulatory constraints, should be considered (U.S. EPA, 2011). When considering how the solutions will be implemented, it is also important to coordinate between agencies and consider siting and permitting requirements (U.S. EPA, 2011). Finally, with regard to operationalizing solutions, it is again important to coordinate between agencies, and consider staffing requirements, maintenance, and the demobilization of equipment (U.S. EPA, 2011).

Clearly, coordination between agencies is critical for providing emergency drinking water. At UBC, this can be translated into coordination between the many departments at UBC who have been involved in emergency drinking water planning and who have yet to be involved, but who need to be involved. Although many of the considerations outlined by the literature are integrated into this report, not all of them have been addressed and should be considered in future studies.

2.3 Operationalizing the Water System

Some of the key departments who will need to coordinate include Energy and Water Services (EWS), Building Operations (BO), and Student Housing and Hospitality Services (SHHS) **(Figure 2)**, although many other departments should also be involved in the decision-making process. These departments need to coordinate because EWS is the operational lead for the source and treatment of the water, including drawing the water from the creeks and filtering it through the water filtration trailer, BO is the operational lead for the storage and transportation of the water to the distribution sites, and SHHS has been identified as the likely operational lead for distributing the water to people. Although there have been efforts to address the storage, transportation, and distribution stages of water supply, there are still many questions which remain. To ensure that the methods of storage, transportation, and distribution which will be used in an emergency work together as a cohesive system, these departments need to coordinate their decision-making.

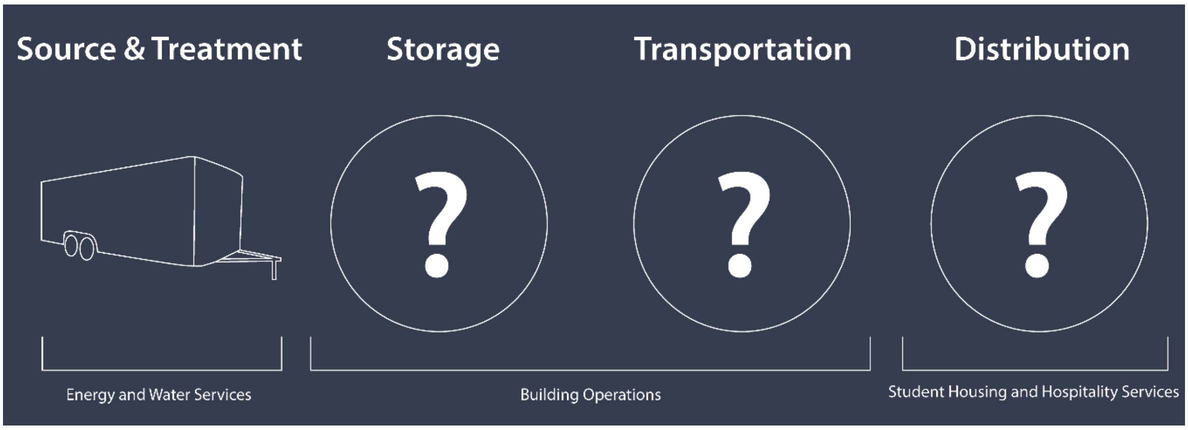

Figure 2 Four elements of supplying water, modified to suit the elements of this project, with the associated departments at UBC responsible for each stage outlined underneath.

3.0 Methodology

In order to frame this project, key documents related to planning for emergency water supply were examined. These documents included guidelines and frameworks published by organizations involved in planning for emergencies, as well as planning documents from universities and cities which were publicly available. This project also heavily relied on informal discussions with key stakeholders at UBC, which informed the context of the project, the alternatives considered, and the considerations against which the alternatives were evaluated. Details about the alternatives were gathered from industry websites, internal UBC documents, planning literature, and conversations with key stakeholders. The alternatives were then evaluated subjectively based on this information. An informal scan of other universities was also conducted to understand what plans universities have in place for how to supply emergency water, as well as what some of the alternatives are for providing this water. The results of this scan are mainly integrated into the complimentary report prepared by the co-investigator for this project.

4.0 Significance of Research

This research is significant because there are only a few academic and industry documents which describe how water should be stored, transported, and distributed in an emergency. Many documents cover the specifications of mobile water filtration trailers, but they do not identify the following steps of storage, transportation, and distribution of the water. Some companies outline services they offer, and there are guidelines published by some organizations, but since contexts and circumstances vary so widely, there was no description about how systems work together as a whole.

Additionally, many universities and cities do not explicitly outline how they will respond to a loss of municipal water supply. For example, the Regional District of Fraser-Fort George's Emergency Response Plan simply says they will arrange for alternative water sources if necessary (Regional District of Fraser-Fort George, n.d.). As well, the University of Connecticut (UCONN) also outlined that they would determine how to address a lack of water supply once an event had already occurred (UCONN, 2007). Although using mobile water treatment together with water packaging or water tap distribution was identified as an option for supplying potable water in an emergency (U.S. EPA, 2011), many universities have not prepared to implement this strategy for addressing drinking water needs in an emergency.

The results of the informal scan of other universities only yielded one other university which plans to use a mobile water filtration trailer to provide emergency drinking water. They plan to filter water from the pools and water features on campus, and store the water in 55 gallon drums, which hold approximately 200L, and 5 gallon carboys, which hold nearly 20L. Their student population is less than 10,000, and given the scale of their solutions, it appears that they are not planning to provide water to everyone. This scale of solution does not seem to be appropriate or transferable to UBC.

5.0 Alternatives

The following section outlines the various alternatives which were considered with regard to the storage, transportation, and distribution of water from the water filtration trailer. These alternatives were evaluated on how well they met the priorities and considerations outlined by key stakeholders throughout the project, and which would help increase the resiliency of the emergency water supply system.

5.1 Considerations

There are many considerations which were outlined by the various departments who were engaged throughout this process. These considerations will be briefly outlined below to establish a broad understanding of the factors at play in the decision-making process, and they will be discussed in further detail throughout the discussion of the various storage, transportation, and distribution alternatives.

One of the major priorities, particularly for BO, is that they are able to incorporate pre-existing equipment as much as possible. They indicated that they would be looking at different options for transporting the water based on the capacity of their existing vehicles to haul the water. BO also does not have a lot of storage space, so ideally the storage space needed for equipment should be minimal. However, there may be an opportunity to store some equipment outside the South Campus Warehouse, given that it was identified that many of the items that are currently being stored there will soon be cleared out. SHHS did identify that they have a shipping container which could be used to store some supplies, but there is a limit to space to which they have access. The desire for minimal maintenance requirements was also a concern which was identified, as well as ensuring that the maintenance needs and schedules are clearly communicated. Ideally, the chosen alternative would also be able to be integrated into the departments' regular operational activities, or would involve existing equipment as much as possible. By integrating the equipment into the operations, or using existing equipment, more personnel would be trained on the equipment and this training would not be lost as a result of not using the equipment. As well, this means the equipment would likely be more regularly maintained. Simplicity of systems, or the ease with which they can be used, is another important consideration, both for departments and with regards to increasing resiliency. Ideally, the solutions would be simple enough for anyone to easily learn how to setup or operate, in case people with the right skill sets are not on campus at the time of the emergency. BO identified that, at any given point, only 23% of their staff are on campus, and only approximately 10% live in close proximity to campus. Complexity of systems also results in a higher likelihood that something will go wrong. Similarly, the flexibility of options is important. A flexible system is more resilient and can better adapt to changing needs or requirements. Finally, it was important to also consider the cost of the options. Unfortunately, exact costs were unable to be determined within the timeframe of this project, and so the next steps should include gathering more detailed cost estimates.

In sum, the storage, transportation, and distribution options will be generally evaluated based on the following criteria:

- **Minimal storage space required**
- **Minimal maintenance required**
- **Ability to integrate equipment into day-to-day operations, or use existing equipment**
- **Simplicity, or ease of use**
- **Flexibility of options**
- **Minimal cost**

The evaluation of the alternatives was a subjective process, which was based in part on a combination of discussions with key stakeholders, and information available online about the different options.

5.2 Storage

The water filtration trailer can filter approximately 120,000L of water every 24 hours. However, in order to achieve this volume of water, the water filtration trailer cannot be stopped. In order to prevent the filtration process from having to stop, dedicated storage next to the water filtration trailer is important. There is the possibility of pre-packaging water at either the source area, which would be next to the water filtration trailer, or at a staging area (U.S. EPA, 2011). However, many issues limit the practicality and effectiveness of on-site water bottling. This includes the availability of containers, selecting materials and receiving certification for these materials, certification to operate these facilities, and testing-monitoring requirements (U.S. EPA, 2011). Therefore, pre-packaging water was not considered as a method of storing water.

Collapsible tanks, such as water bladders and onion tanks, are well suited for emergency response, as their main use is for when very quick action is required, such as within hours or days of an event (de Veer, 2002) **(Figure 3)**. However, they are not very easy to transport. Therefore, other solutions need to be considered for storing water while it is being transported to the distribution sites, including water buffalo and cage totes **(Figure 3)**. The first two options considered for this section are intended to be used for storage next to the water filtration trailer, and the last two options are to be considered for transporting the water between the collapsible tanks by the water filtration trailer and the distribution sites.

Figure 3: Storage alternatives considered. **Top, left to right**: water bladder (BI Pure Water Inc., 2016), onion tank (SEI Industries, 2015). **Bottom, left to right**: water buffalo (Snodgress Equipment, n.d.), cage tote (personal photo).

5.2.1 Water Bladders

Water bladders, also known as bladder tanks or pillow tanks, are collapsible tanks which are typically made of UV-resistant EVA or PVC coated polyester (de Veer, 2002) **(Figure 3)**. Water bladders come in a variety of sizes, with some suppliers offering water bladders which could hold nearly 800,000L of water (GEI Works, n.d.). These water bladders should also be NSF 61 rated and any hoses used to connect the water filtration trailer to the water bladder should also be NSF 61. These water bladders were identified by the company who built the water filtration trailer to be used for drinking water storage (BIPW, 2016). Two 10,000L water bladders have already been purchased and are located in a warehouse at UBC. It is important to note that before filling with water, the bladder would need to be disinfected with a strong bleach solution (25ppm for 2 hours, or a lower concentration for a longer time) once unrolled (BIPW, 2016). More details regarding the specifications of pressure requirements and other important processes can be found in the BIPW manual for the water filtration trailer.

When not in use, water bladders take up minimal storage space in comparison to their size when filled, and would require minimal maintenance, although they should be stored inside buildings when temperatures are close to 0℃ (de Veer, 2002). It is unlikely that they would be integrated into day-to-day activities, but they would utilize existing equipment. Although it is important to note that since the water bladders have not yet been used, it is possible that they might be able to be returned should another option be considered more desirable. Water bladders are simple and easy to set up and use. Additionally, the inside of the bladder tank would be pressured when filled with water, which means that a pump might not be required to transfer the water from the water bladder into a secondary storage tank for transportation, although this should be tested to confirm. However, the water bladders lack some flexibility, particularly with regard to their siting needs. Water bladders need to be setup on a nearly level location where they would not be ripped or punctured, and it is advised that a tarp be placed underneath (BIPW, 2016; de Veer, 2002). The area where the water filtration trailer sits appears to have been levelled, but the rest of the area near the trailer appears to be at an angle of approximately 3.8 degrees. This is a rough estimate calculated from contour lines and distances taken from the City of Vancouver’s VanMap program for the parking lot. This angle of the area should be measured in person to determine if there are spots where the angle of the parking lot is less steep, or if the ground would need to be made more level to use this option, since this angle slightly exceeds the recommended limit of using water bladders on slopes no steeper than 3 degrees, as identified by SEI Industries Terra Tank manual (SEI Industries, 2015). Lastly, as the cost investment has already been made, there would be minimal costs involved with this option. However, as mentioned previously, the water bladders which have been purchased have not been used yet, and could possibly be returned should it be decided that another option is more appropriate.

5.2.2 Onion Tanks

Similarly, onion tanks, which are also called flotation collar tanks, could be used to store recently treated water near the water filtration trailer, and are typically made of synthetic rubber (de Veer, 2002) **(Figure 3)**. They have a self-supporting buoyant foam-filled or inflatable rim, and either have a loose cover or a zippered top (de Veer, 2002; SEI Industries, 2014). They are found in a similar range of sizes to water bladders.

Onion tanks also have minimal storage requirements in comparison to their size when full, and would require minimal maintenance. Like water bladders, it is unlikely that they would be integrated into regular operations. They are also easy to set up, however, it is assumed that due to the nature of the top of the tank, with either a loose cover or a zipper close, that these tanks would be unable to be pressurized. This means that a pump would be required to transfer the filtered water from the onion tank to a smaller container for transportation. Additionally, they are more flexible than water bladders, because they can be used on slopes up to 12.5 degrees (SEI Industries, 2014). However, it is important to note that setting up an onion tank on a slope would likely reduce its storage capacity because the tank would slump (Oxfam, 2014).

5.2.3 Water Buffalo

Water Buffalo, otherwise known as water trailers or water wagons, can also be found in many sizes, with some as large as 5,000 gallons, which is slightly less than 20,000L (Wastecorp, n.d.) **(Figure 3)**. Water buffalos are a possible intermediary storage and transportation option. Water could be pumped into them from the static storage near the water filtration trailer, and then the water could be pumped out of the tank again at the distribution sites. The water buffalos could be unloaded to additional stationary storage containers at the distribution sites, or could be directly connected to a method of distributing water to people. However, it may not be the best method to simply unhitch trailer-mounted water buffalo, connect it directly to a distribution method, and leave the water buffalo at the distribution site to be emptied as the water is used, because more water buffalo would be required to ensure that water is continually being transported to distribution sites.

The hard-shelled nature of water buffalo means that there would be a lot of storage space required when this equipment is not in use. There would likely be some maintenance required, although this would mostly be minimal. The water buffalo might be able to be integrated into day-to-day activities such as events on campus or for irrigation purposes, if their size is appropriate for the BO Soft Landscape Crew. However, they would need to be thoroughly cleaned and disinfected prior to use if it carries anything other than potable water day-to-day. They are relatively easy and simple to use, and are flexible because they could be hauled by a variety of different vehicles. However, they would need to be emptied from ground level, so it is unlikely that gravity could be relied on to empty the tank, and therefore, a pump would be required. Finally, there is some costs associated with purchasing the water buffalo.

5.2.4 Cage Totes

Cage totes, which are also known as intermediate bulk containers and have been colloquially referred to as ‘blibbets’ by project stakeholders, and typically consist of a high-density polyethylene container inside of a galvanized steel cage (The Cary Company, n.d.; ULINE, n.d.) **(Figure 3)**. Most hold approximately 1,000L of water, although there are some which can care 1,250L (The Cary Company, n.d.). At present, UBC has purchased one of these cage totes to use for testing. If the cage totes could be filled at the same rate which water will be filtered by the water filtration trailer (2 L/s), then the cage totes could be filled in just over 8 minutes. Cage totes are relatively light when empty, and could be carried by one to two people. However, they weigh approximately 1,000 kg when full.

When not in use, the number of cage totes which would be required (it is estimated that between 20 and 40 might be appropriate) would require a significant amount of storage space. However, unlike water buffalo, cage totes are able to be stacked two or three high when empty (ULINE, n.d.). It has also been identified that approximately 20-30 may be able to fit in the space next to the South Campus Warehouse. However, this would be outside, so it is important to determine how UV resistant cage totes are or plan to cover them to reduce degradation of the materials. They would likely require some maintenance, although this would mostly be minimal. Similar to the water buffalo, there are some possibilities that the cage totes could be integrated into regular operations, however, they may not be appropriate for departments to use regularly. Although they are a relatively simple concept, in practice there may be some challenges with using the cage totes. These cage totes are only designed to be lifted by forklift or pallet jack, so they cannot be lifted from above (The Cary Company, n.d.). This is confirmed by tests which were conducted by UBC staff. This means that either an auto-levelling attachment would need to be used with a flatbed trailer and crane, or forklifts would need to be placed at the source and distribution sites. This also means they are less flexible. However, in some respects they are also more flexible than water buffalo, as they are small enough and could be lifted to elevated locations such loading docks, which means that there might be enough pressure head to allow for gravity-fed distribution. Although the cage totes would not be expensive individually, the number required would mean that the costs would not be minimal.

5.2.5 Overall Evaluation

Although both water bladders and onion tanks are good options for static storage near the water filtration trailer, there are some key differences **(Figure 4)**. As mentioned, the water bladders require a more level surface, whereas the onion tanks could be located on slightly steeper slopes. However, the water bladders are able to be pressurized, which may negate the need for a pump to transfer the water to a more portable storage option, whereas the onion tank would require a pump.

With regard to the storage options for transportation between the water filtration trailer and the distribution sites, both water buffalo and cage totes are good options **(Figure 4)**. The main differences are that the cage totes could be stacked to take up less storage space than the water buffalo, and that water buffalo would likely require pumps, whereas the cage totes might allow for gravity-fed distribution. Additionally, the preferred transportation option should be considered when deciding which portable water storage alternative is appropriate.

	Minimal Storage Space	Minimal Maintenance	Ability to Integrate/ Uses existing equipment	Simplicity/ Ease of Use	Flexibility	Minimal Cost
Water Bladder	●	◐	◐	●	◐	◐
Onion Tanks	●	◐	○	◐	●	◐
Water Buffalo	○	◐	◐	◐	◐	◐
Cage Totes	◐	◐	◐	◐	◐	◐

● = Meets consideration ◐ = Partially meets consideration ○ = Does not meet consideration

Figure 4 Evaluation of storage alternatives.

5.3 Transportation

Transporting the water between the staging area by the water filtration trailer, where storage may be set up, to the distribution sites **(Figure 5)** can also be accomplished via a few different methods **(Figure 6)**. Methods considered in this section include using a flatbed truck to transport the cage totes and using pick-up trucks to haul water buffalo trailers. Piping was also briefly considered as an option to reduce some of the many intermediate steps between the water filtration trailer and the distribution sites. It was identified by stakeholders that the Kubota Utility Vehicles which BO already owns could be a possibility for towing water. However, upon further inspection, it was determined that the vehicles which BO owns are Kubota RTV-X1100C's, which only have a towing capacity of 560 kg, approximately half of what a full 1,000L cage tote would weigh on its own, without any trailer attachment (Kubota Tractor Corporation, n.d.). Transporting quantities of water less than 1,000L likely does not make logistical sense, so this option was not evaluated further.

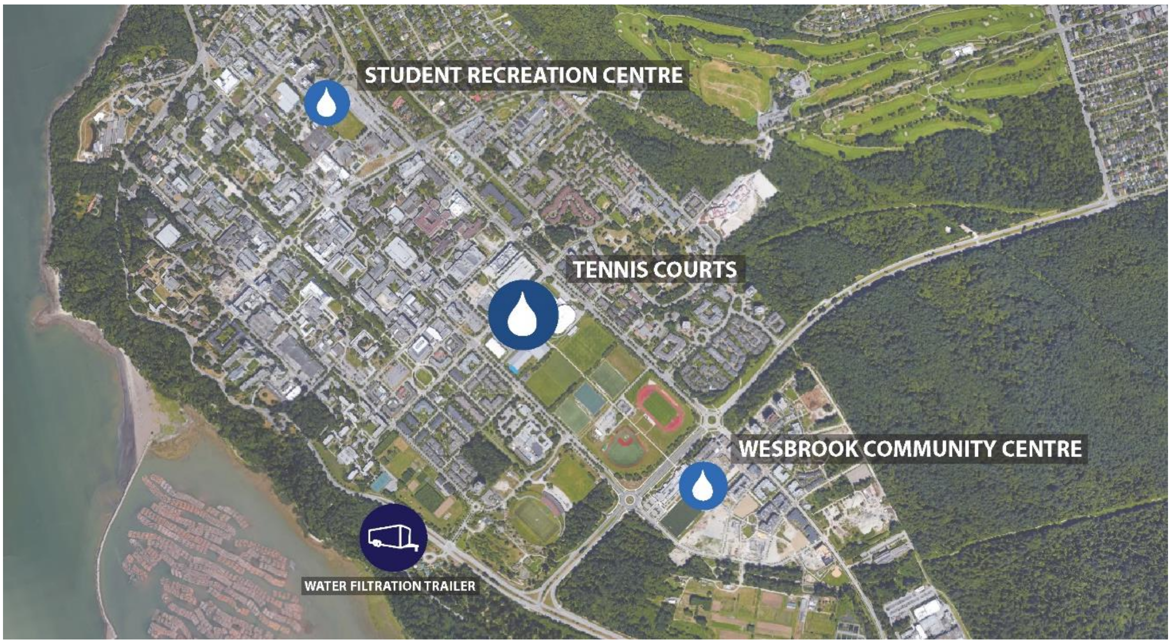

Figure 5 Location of the water filtration trailer and three sites which have been identified by SHHS as possible mass care locations; these mass care locations are likely to also be used for water distribution.

Figure 6 Transportation alternatives considered. **From left to right**: flatbed truck with crane to which an auto-levelling attachment could be attached (Francois Desmarais), pickup truck which would tow trailers with water buffalo (Carleton University, n.d.), piping (with road crossing pictured) (TanMar Companies, n.d.).

5.3.1 Flatbed with Auto-Levelling Attachment

In order to transport water, a flatbed truck with an auto-levelling attachment could be used **(Figure 6)**. Both of these pieces of equipment are already owned by UBC. These trucks would likely be used in tandem with cage totes, should that be the preferred intermediate storage method, as the auto-levelling attachment could be used to lift the cage totes onto and off of the truck from below. The two flatbed trucks with cranes on the back which UBC owns can lift upwards of 1,000 kg, and should have no problem lifting the cage totes, except when they are close to fully extended, because the carry capacity is reduced the further the crane has to reach. The larger of the two trucks would be able to fit 6 cage totes on its flatbed, and would be able to carry the associated weight. It is also important to note that these trucks would be in high-demand after an earthquake for other response-related tasks.

The storage space and maintenance required for this alternative would be no more than under normal conditions, since this equipment is already owned and used by UBC. This is why the costs involved are also minimal. If this truck is operated by someone with the proper training, it would be relatively easy to use. However, this alternative would not be as easy to use, and would likely to be dangerous to operate, if it were to be operated by someone with no training. Requiring specialized knowledge about how to operate the crane could be problematic in an emergency situation if the personnel with that knowledge are not on campus. Since there are only two of these trucks, this means that this alternative is not as flexible as it could be. However, it does provide a lot of flexibility with regard to where the cage totes could be placed because of the crane.

5.3.2 Pickup Trucks Towing Trailers

Another option is to have a water buffalo loaded onto a trailer which is hitched to a pickup truck. In total, there are 12 trucks with a towing capacity above 10,000 kg, which is equivalent to 10,000L **(Figure 6)**. Given the weight of a trailer plus water, this should not be a problem for trucks hauling water buffalos, as the water buffalos would likely be smaller than 10,000L. It may also be possible to use pickup trucks to haul the cage totes if there is room in the back of the truck, but this would require forklifts to be located at the source and distribution sites. These trucks would also be in high-demand after an earthquake for other response-related tasks. It is important to note that the evaluation of this alternative is based solely on the use of the pickup trucks, as the storage, maintenance, and other considerations of the trailer itself are accounted for in the discussion of the water buffalos in section 5.2.3.

This alternative is similar to the flatbed alternative in many regards. No more storage or maintenance than normal would be required for the trucks, as they are already owned by UBC. This option would be easier to use for a wider variety of people, and would not require some of the specialized knowledge that would be needed to operate the crane on the flatbed truck. However, some knowledge would be required for maneuvering the truck with the trailer attached. It is also flexible with regard to the ability to use a variety of trucks to tow the trailers, however, it is not flexible with regard to where they can place the trailers themselves.

5.3.3 Piping

It might also be possible to pipe the water from the water filtration trailer to the distribution sites **(Figure 6)**. One university which plans to pipe water from its emergency storage container to a distribution site plans to use virgin fire hoses to transport the water. However, fire hoses are typically 15 m in length, so many would be required to bridge the distances between the water filtration trailer and the distribution sites at UBC.

A lot of equipment would be required for this alternative, including piping, pumps, and road crossings for the pipes, which would require a lot of storage, and some of this equipment would need to be maintained. Much of this equipment would also need to be purchased. This system would not be very easy to set up, and would not be very flexible. It would also take a long time to set-up, which might be suitable if the water supply was expected to be interrupted for several weeks or months. However, the co-investigator for this project determined that the length of a potential water outage is assumed to be between 3 and 7 days, so it would likely not be an appropriate solution. Finally, there would be some costs associated with purchasing the equipment needed for this alternative.

5.3.4 Overall Evaluation

Using either a flatbed truck with an auto-levelling attachment, or pickup trucks to tow trailers, are viable alternatives for transporting **(Figure 7)**. Both have benefits and drawbacks. The flatbed truck would likely require more specialized knowledge to operate the crane and auto-levelling attachment, but it does provide more flexibility with regard to placing the storage containers. Using pickup trucks to tow trailers would require less specialized knowledge, although it would still require some knowledge, and since there are more pickup trucks than flatbed trucks, it is also a more flexible alternative in some regards. The most appropriate method of distribution would also depend on the preferred storage alternative, so these decisions are intertwined.

	Minimal Storage Space	Minimal Maintenance	Uses Existing Equipment	Simplicity/ Ease of Use	Flexibility	Minimal Cost
Flatbed with Auto-Levelling Attachment	●	●	●	◐	◐	●
Pickup Trucks Towing Trailers	●	●	●	◐	◐	●
Piping	○	◐	○	○	○	◐

● = Meets consideration ◐ = Partially meets consideration ○ = Does not meet consideration

Figure 7 Evaluation of transportation alternatives.

5.4 Distribution

Since the pre-packaging of water was not considered in this report, the distribution of pre-packaged water was also not considered. In this report, only alternatives related to the distribution of water from bulk potable water sources to people were considered **(Figure 8)**. Recommendations vary for the ratio of water taps to people, but range from 80 people per tap to 500 people per tap (de Buck, Borra, de Weerdt, vande Veegaete, & Vandekerckhove, 2015; de Veer, 2002). Considering an assumption of anywhere between 30,000 and 70,000 people who will be in need of assistance, that could mean anywhere between 60 and 875 taps are recommended, depending on which guidelines are followed.

More research should be conducted examining the methods by which people should collect this water, such as using their own personal water bottles or having bottles provided by UBC. As well, ideal siting, particularly for water distribution, includes open space, near emergency shelters, with easy road access and good lighting (U.S. EPA, 2011). In future research, specific locations near the sites identified as possible mass-care settings should be considered for their ability to meet some of these considerations.

Figure 8 Distribution alternatives considered. **Top, left to right**: simple tapstand (BI Pure Water Inc., 2016), DIVVY POD (Aquamira, n.d.). **Bottom, left to right**: WaterFillz station (WaterFillz, n.d.), QuenchBuggy (Quench Buggy, n.d.).

5.4.1 Simple Tapstands

A simple tapstand setup is typically made of galvanized or stainless steel, and can have anywhere from 3 to 8 taps (Evenproducts, n.d.) **(Figure 8)**. In the BIPW manual for the water filtration trailer, there is also a picture of how a simple tapstand for water dispensing could look. It has 6 taps, with one water connection. The setup, and the picture, are not referred to at all in the text of the manual, so the details of this particular setup are unable to be determined. Many of the waters connections to these simple tapstands are 2” connections, which match with the size of the outflow valves of typical cage totes. It is advised that these setups have push taps, or self-closing taps, to reduce water waste from taps being left open (de Veer, 2002; World Health Organization, 2002). It is important that the self-closing taps be designed for use at low water pressures, since self-closing taps which rely on water pressure to keep them closed can drip at low pressures, wasting more water and causing a slip hazard in the area (de Veer, 2002; Evenproducts, n.d.).

Simple tapstand setups require minimal storage space, as they can easily be collapsed into a carrying case. They would also not require a lot of maintenance. They could be used to provide water for events or other large gatherings, however, in reality this is unlikely as other more visually attractive setups are already being used on campus. Again, these tapstands would be very easy, both to set up and to take down. They are also flexible options because they do not require electricity, and may not need pumps if the tapstand is located adjacent to the bulk water container to which it is attached. Avoiding being dependent on pumps and power supplies means the system would be more resilient (World Health Organization, 2002). Evenproducts, a company based in the UK, advertise that their tapstands would only need to be elevated by 1.5 m to provide enough water pressure to deliver the water through the taps with gravity. Because they can fill a variety of container sizes, they are also a flexible option. These tapstands would be relatively easy and cheap to build.

5.4.2 DIVVY Point of Distribution Pump Station

The DIVVY Point of Distribution (POD) Pump Station would be an intermediate solution to the problem of distributing water to people **(Figure 8)**. It is sold by the Aquamira Technologies company, based out of Utah, and is designed to be part of the DIVVY 250 Emergency Water System. Although the pump station is designed to be part of their DIVVY system, it can be used separately with simple conversion fittings and connected to anything from tanker trucks, to fire hydrants, to swimming pools (Aquamira, n.d.). It can dispense up to 4 gallons (or approximately 15 L) per minute and has a filtration system which filters Cryptosporidium and Giardia to NSF standards (Aquamira, n.d.).

The DIVVY PODs are also able to be collapsed, and so take up less storage space, although it would take up slightly more space than simple tapstands. However, they might require some maintenance for the filtration system which is attached. It is simple to set up by untrained personnel and because it is operated by hand-pump, it would be relatively easy to use and is a flexible option since it does not require electricity or a pump which would need fuel. However, this means that personnel would be needed to expend manpower in order to run the system, which might otherwise be unnecessary with a simpler distribution system. Like the simple tapstands, the distribution taps are hoses which can fill a variety of sized containers. Unfortunately, there is more of a cost involved because of the added filtration system. In most instances, this filtration system is redundant, because the water will have already been filtered by the water filtration trailer. Although it is possible that this could be used to draw water from other sources, in which case the filtration system could be worth the investment.

5.4.3 WaterFillz

WaterFillz supplies portable outdoor event water refill stations which can be wheeled around **(Figure 8)**. It has four ports to fill water bottles, with one of those ports being located lower down and on the side so as to be handicap accessible (WaterFillz, n.d.). According to WaterFillz, UBC AMS has already purchased two of these stations. UVIC also has an event station, but they have not planned to use it for an emergency, as they stockpile bottled water (University of Victoria - Campus Planning and Sustainability, n.d.).

WaterFillz stations would require a large amount of storage space, due to the number of taps which are recommended for water distribution, and there would be some maintenance required for the filtration system inside the station. Since UBC AMS already owns a couple of these stations, it is clear that at least some of the stations could be integrated into day-to-day use, although it is unlikely that all of them would be. They are relatively easy to set up, but they do require 110V plug-in and only a ⅜" water source, which is a different size than the 2" valve on the cage totes, so various pipes and fittings would be required to connect the two if cage totes are used to store water, making this option less flexible (WaterFillz, n.d.). It is also less flexible because the openings for the taps are a particular size, so only your average water bottle would be able to be filled easily by this system. Although two are already owned by UBC AMS, many more would need to be purchased, and they would be very expensive, in part because of the redundant filtration system.

5.4.4 QuenchBuggy

The QuenchBuggy is a similar unit to WaterFillz, although it was eight tap stations instead of four and two of them are accessible (Quench Buggy, n.d.) **(Figure 8)**. The QuenchBuggy also has a filtration system within it (Quench Buggy, n.d.) .

It would require less storage space than WaterFillz, because they have either tap stations, and so less units would be required. However, they would require similar maintenance. They have the same likelihood of being used for purposes other than in an emergency on campus, but UBC does not own any units. They are similarly easy to easy, and slightly more flexible than WaterFillz stations because the taps are positioned in a manner that a larger variety of container sized could be filled. Lastly, purchasing these units would involve similar costs to WaterFillz stations, and again, the filtration system would add a lot to the cost, while providing little additional benefits.

5.4.5 Overall Evaluation

Overall, it is clear that the simple tapstand set up would address many of the considerations the best, and would be the most appropriate option for the distribution of water from bulk storage containers to people **(Figure 9)**.

	Minimal Storage Space	Minimal Maintenance	Ability to Integrate/ Uses Existing Equipment	Simplicity/ Ease of Use	Flexibility	Minimal Cost
Simple Tapstands	●	●	◐	●	●	●
DIVVY POD	●	◐	◐	◐	●	◐
WaterFillz	○	◐	●	◐	○	○
QuenchBuggy	◐	◐	◐	◐	◐	○

● = Meets consideration ◐ = Partially meets consideration ○ = Does not meet consideration

Figure 9 Evaluation of distribution alternatives.

6.0 Recommendations

Given the results of the evaluation of the various alternatives, and considering how these pieces work together as a system, in addition to considering the equipment which has already been acquired or tested, I recommended the following course of action **(Figure 10)**: water from the water filtration trailer should be pumped into water bladders, from which cage totes would be filled. These cage totes would then be lifted onto the flatbed truck using an auto-levelling attachment. The cage totes would be transported to the potential mass-care locations and unloaded to an appropriate location, with preference given to locations elevated with respect to the distribution points. The cage totes would then be connected to simple tapstands, from which people could collect drinking water.

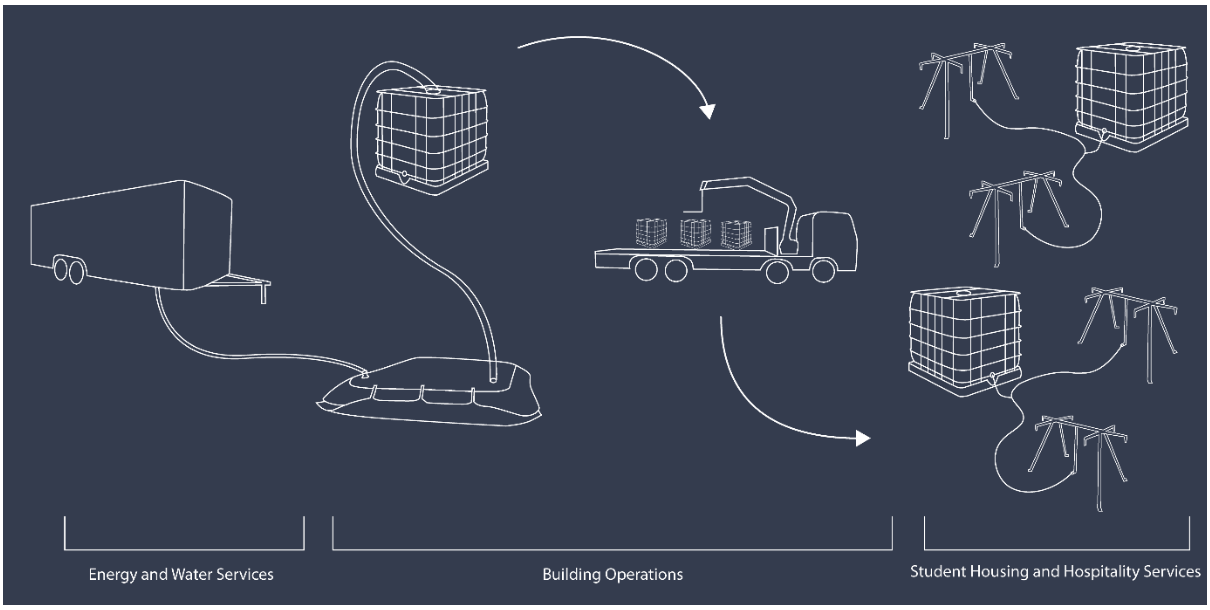

Figure 10 Recommended system for storing, transporting, and distributing water in an emergency.

The alternatives presented in this report represent the initial development and evaluation of alternatives. However, there should be further discussion to ensure that the recommended course of action is the most appropriate strategy for supplying emergency water, and cost estimates from companies should be gathered, since exact costs were not presented in this report. Additionally, a suite of options could be bundled into a portfolio which accounts for different scales and durations of possible outages and responses. The solutions need to be coordinated between the operational leads for each of the stages of supplying emergency water, and other key departments on campus should also be involved in these discussions.

With regard to training, many people should be trained on the water filtration trailer, and how to use the equipment needed to store, transport, and distribute the potable water. Particularly with regard to the water filtration trailer, it was suggested that since there are always at least two operating engineers on shift at all times, all the engineers should be trained in the water filtration trailer so that if an emergency occurs, there will be at least one or two people who are trained on that piece of technology.

7.0 Next Steps

Moving forward, the alternatives for water storage, transportation and distribution should be considered, and decisions should be coordinated between departments. However, there are other important steps which should be taken. These include:

- **Testing the system and having regularly scheduled drills** to ensure that the system works together as a whole and that people are aware of how to use the equipment;
- **Cross-train staff on equipment,** as well as **consider prioritizing campus housing for people with critical specialty training**, which will help to ensure that there are staff on or near campus who will be able to operate the water filtration trailer, and the water storage, transportation, and distribution methods;
- **Evaluate how people should be collecting water at distribution sites**, as well as **create a distribution plan**, including protocols for different situations, and determining locations for distribution, staffing requirements, and security requirements;
- and **create a plan for communicating water distribution information**, including pre-disaster communication regarding personal preparedness, as well as post-disaster communication about protocols for different situations and locations for obtaining water.

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