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Design, Testing, and Deployment of a Mobile Emergency Water Treatment System

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Design, Testing, and Deployment of a Mobile Emergency Water Treatment System

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Disclaimer

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The contractor role did not include establishing Agency policy.

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Abbreviations

BG	*Bacillus globigii*
BSL	Biosafety Level
BWS	bulk water sample
ºC	degrees Celsius
cfu	colony forming units
CRADA	Cooperative Research and Development Agreement
E. coli	*Escherichia coli*
EPA	U.S. Environmental Protection Agency
FTTA	Federal Technology Transfer Act of 1986
ft	foot
GAC	granular activated carbon
gpm	gallons per minute
hr	hour
INL	Idaho National Laboratory
L	Liter
m	meter
mg/L	milligram per liter
ml	milliliter
min	minute
MPN	most probable number
NPDES	National Pollutant Discharge Elimination System
NTU	Nephelometric Turbidity Units
PEX	cross-linked polyethylene
MOP	Miscellaneous Operating Procedure
T&E	Test and Evaluation
TPH	total petroleum hydrocarbons
WOW	Water On Wheels
WSTB	Water Security Test Bed

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Executive Summary

The U.S. Environmental Protection Agency's (EPA) Homeland Security Research Program partnered with Edge Outreach Technologies, LLC (DBA WaterStep) to develop and deploy a mobile emergency water treatment system utilizing the Federal Technology Transfer Act (FTTA) of 1986, that enabled the Government to enter into a Cooperative Research and Development Agreement (CRADA) and to negotiate licenses for patented inventions. The purpose of this study was to design, build, evaluate, and deploy a mobile emergency water treatment system capable of treating a wide variety of contaminated water following a natural or man-made disaster. Most emergency water treatment systems are very large and expensive tractor-trailer mounted systems. They can be complicated to operate and maintain (very high pressures and concentrated wastes) given their use of reverse osmosis water treatment technology. Water may be contaminated with chemical, biological or radionuclide contaminants. Therefore, an emergency water treatment system must be designed and built so the treatment train can be configured on-site to treat a broad spectrum of contaminants without utilizing other unnecessary and costly unit processes and without producing large amounts of contaminated wastes. Bottled water is typically the first responder's choice when responding to an incident. However, excessive dependence on bottled water creates a large solid waste disposal problem and, often times, large vehicles transporting bottled water are unable to get to affected locations because of road debris and damage. Bottled water in large or extended recovery situations cannot be used for cooking, bathing and sanitation purposes. However, it could be used in conjunction with an inexpensive and versatile mobile emergency water treatment system providing water for other non-drinking water applications. Not all the water being treated needs to be drinking water quality. In some cases, contaminated stormwater or wash water from building decontamination activities need only to be treated to levels safe for disposal to the wastewater treatment plants or to the environment. For longer-term mitigation efforts, large volumes of contaminated wash water can be produced and needs to be safely transported and disposed of in a hazardous waste facility. Mobile treatment of the contaminated water can significantly reduce the volume of water to be transported and reduce the liability and cost of transporting and disposing of a hazardous waste.

The mobile treatment technology system in this study is referred to as the Water-On-Wheels (WOW) Cart. The mobile system originally consisted of a pre-filter, an on-site chlorine generator, and a pump attached to a dolly or frame with wheels. The frame also provided space to store accessory equipment and to transport two empty 1,250-gallon bladder tanks used to store treated water. Building upon the original device, this study designed, built, challenged and deployed an inexpensive mobile water treatment system with expanded water treatment and power supply capabilities. The system integrated the pre-filtration step with additional media filtration (e.g., granular activated carbon) and on-site chlorine gas generation with options for UV LED and/or ultrafiltration membranes, which were all stored and transported on a wheeled, powder-coated steel frame This study also added multiple power supply options that can be operated from the electrical grid (110v AC), a duel-fuel generator, and peripherals with a 12v DC deep cell marine battery (with solar recharge). There are also additional electrical outlets and USB ports for phones, computers, etc. The WOW Cart can now also produce liquid bleach for sanitation purposes.

A prototype mobile system (Version 2.0) was challenged with *Bacillus globigii* spores (a non-pathogenic surrogate for anthrax spores) from a dirty lagoon at the EPA Water Security Test Bed located near Idaho Falls, Idaho. The mobile system was easily deployed and able to produce a large amount of chlorine, but it could not overcome the large chlorine demand from the lagoon. Thus, it was determined that the WOW Cart should be operated in batch mode utilizing a bladder tank to overcome chlorine demand of the dirty water by providing controlled contact time. This setup then demonstrated greater than 7 log reduction of the anthrax surrogate. Shortly after this successful testing, Hurricane Maria slammed Puerto Rico. The non-profit organization WaterStep was able to deploy over 100 disaster kits (pre-filter and chlorine generator) to municipal governments and to other non-profit organizations providing access to safe drinking water to approximately 225,000 people daily.

Learning from both the field challenge and Hurricane Maria experience, the final version of the WOW Cart was fabricated. It was challenged with secondary wastewater at the EPA Test and Evaluation Facility located in Cincinnati, Ohio and subsequently successfully tested again at the Water Security Test Bed against lagoon water contaminated with diesel fuel and *Escherichia coli.* The WOW Cart successfully removed 4 to 6 Logs of *E. coli* and Total Coliforms respectively to non-detection levels from the contaminated lagoon simultaneously with diesel fuel components. Diesel fuel components were removed to below detection levels as well, thus making the water safe to drink. Given that in most cases, microbial water quality is of the utmost importance given the shorter duration of use, disinfection by-products and long-term health effects were not a focus of this research. Nor was an extensive evaluation of a number of chemical contaminants, particulates, viruses, metals, or pathogens undertaken given their widely known removal characteristics in the commercial and research literature, especially since GAC is the likely first choice for most emergency responders dealing with an unknown quantity and type of chemical contamination. In the event, the WOW Cart would be used for long-term community drinking water supply, regulatory considerations for that particular community and nation would need to be considered. The primary purpose of this report to document and evaluate the ease of deployment, operation, and general efficacy of a mobile water treatment system for emergency use, both for drinking and non-drinking water purposes. This report describes the results of those evaluations and provides details on the WOW Cart design.

1.0 Introduction

1.1 Background

The U.S. Environmental Protection Agency's (EPA) Homeland Security Research Program partnered with Edge Outreach Technologies, LLC (DBA WaterStep) to develop and deploy a mobile emergency water treatment system utilizing a Federal Technology Transfer Act (FTTA) Cooperative Research and Development Agreement (CRADA). The CRADA was originally signed in August 2015 with a subsequent modification in January 2017. The goal of this CRADA was to provide potable water in areas without a safe traditional water supply and in emergency response situations such as after a man-made or natural disaster. This mobile water treatment system incorporated innovative on-site chlorine generation for disinfection, multiple filtration steps, media adsorption, multiple alternative power supply options, and distribution technologies. This mobile treatment technology system is referred to as the Water-On-Wheels (WOW) Cart.

There are a variety of scenarios that can result in compromised or untreated water entering a drinking water distribution system, wastewater, and/or stormwater collection systems, such as:

- Large or multiple pipe breaks
- Loss of power and pressure for days, weeks, months due to floods, hurricanes, tornadoes, earthquakes
- Terrorist or disgruntled employees directly introducing contaminants into a system

In a drinking water distribution system where a boil water advisory has been issued, a mobile emergency water treatment system can be quickly deployed. The system can provide an interim potable water supply to critical institutions such as hospitals, nursing homes, and prisons where populations cannot be easily relocated. The mobile system can even be stored on-site at such institutions as part of their emergency preparedness plan. Under natural disaster scenarios, the mobile emergency system can be an interim solution for days, weeks, or months. Developing countries lacking a reliable water supply or intermittent power could also utilize such a low-cost, easy to operate water treatment system as a permanent solution. For example, in Puerto Rico the WOW Cart has become a permanent solution in some locations following Hurricane Maria. Following a large-scale natural disaster, untreated wastewater and stormwater can be discharged directly into the environment where they will mix with chemical contamination from road and building surfaces. These waters and wastes require treatment to prevent excess contamination from spreading further into the environment. The mobile emergency water treatment system can provide localized mitigation at overflow points in the wastewater and stormwater infrastructure. In some cases, contaminated stormwater or wash water from building decontamination activities need only to be treated to levels safe for disposal to the wastewater treatment plants or to the environment. For longer-term mitigation efforts, large volumes of contaminated wash water can be produced and needs to be safely transported and disposed of in a hazardous waste facility. Mobile treatment of the contaminated water can significantly reduce the volume of water to be transported and reduce the liability and cost of transporting and disposing of a hazardous waste.

In 2012, the downtown area of Louisville, Kentucky had six water main breaks in a short amount of time, which put a burden on The Louisville Water Company and the city's Emergency Management Agency. After those issues were resolved, WaterStep was contacted by Louisville's Emergency Management Agency about a problem they faced during the event that affected the downtown jail (2000 people) and juvenile detention center (600 people). The Emergency Management Agency was only hours away from being forced to move the residents out of the jail to a hotel because of the lack of water during the emergency. Obviously, moving the population of the jail to another facility posed a large logistical issue. The Louisville Office of Emergency Director wanted to discuss ideas WaterStep had as a result of its history working in the developing world and in disaster relief. Over the years, WaterStep had designed simple, affordable, efficient and sustainable equipment for people in developing countries to provide their own safe water. The City of Louisville was provided three carts that consisted of a pre-filter, on-site chlorine generator, and pump attached to a dolly or frame with wheels. These units could serve approximately 2,000 people per day. The frame also provided space to store accessory equipment and to transport two empty 1,250-gallon bladder tanks that could be used to store treated water. Those carts began the concept of the current WOW cart.

1.2 Project Objectives

The objective of this CRADA was to design, develop, and deploy a turnkey robust water treatment system, capable of being transported, set-up and operated for the treatment, storage, and discharge of water contaminated by intentional acts, industrial accidents, natural disasters, by alternative untreated drinking water sources, or when traditional water supplies are unavailable. Any untreated runoff that enters the surrounding environment could spread the contaminant outside the containment field, risking further public health and environmental consequences. In situations where runoff water is contaminated from precipitation or by wash water from cleaning contaminated roads, parking lots, or buildings, the untreated water is typically collected and shipped offsite. For extremely large volumes of contaminated water, this is very expensive. Onsite treatment of this water would reduce costs and waste volumes to be shipped. The water treatment system is intended to address these emergencies and meet these needs locally.

A robust system would most likely employ multiple treatment unit processes capable of treating a broad suite, and broad concentrations, of contaminants ranging from volatile and non-volatile organics, hydrophobic/hydrophilic (particulates) contaminants, pathogens, viruses, parasites, and metals representative of untreated source water, wastewater, stormwater, or contaminated wash water. In addition to the mobile system being easy to set up and inexpensive, it must also be easily configured (plug and play) to most effectively treat contaminants for any given contamination event. The ideal system would also include real-time monitoring and communication capabilities.

Special considerations to be evaluated were:

- Energy minimization and use of alternative renewable energy sources
- Packaging for rapid deployment, set-up and take-down
- Economies of scale for manufacture and operation

- Real-time optimization for water quality vs. costs
- Easy set-up and operation for laymen
- Inline and batch operation
- Self-contained such that supplies, and materials needed to operate for an extended period are included

1.3 Water Quantity and Quality Scenarios

The mobile system must be able to treat a variety of water treatment scenarios. Design requirements were quite varied, depending on the quality of the untreated water and the ultimate end use of the treated water. The mobile system must be able to acquire and use water from the following sources:

- Open sources:
    - Rivers
    - Creeks
    - Springs and Seeps
    - Streams
    - Lakes
    - Rain water catchment
- Well water
- Contaminated wash water from wide-area decontamination events
- Municipal water that has been compromised
    - Hydrants
    - Distribution network pipes
- Tanker trucks
- Barges

The treatment goal will also be varied depending on the water's ultimate end use. The mobile system must be able to treat water of sufficient quantity and quality for the following end uses:

- ❖ Quantity
    - Point of Use – Individuals (approximately 5 gallons per person per day)
    - Small Batch – Families (25 gallons/day/family of five)
    - Large Quantity – Community Size (Assume up to 50,000 gallons per day)

- ❖ Quality
    - Human Consumption
    - Discharge to receiving wastewater treatment plant
    - Discharge to stormwater drain or combined sewer system such that discharge criteria is met
    - Discharge to permitted National Pollutant Discharge Elimination System (NPDES) outfalls or other non-permitted outfalls as the situation requires.

- Discharge to receiving water bodies

1.3.1 Other Design Considerations

The ability to use multiple energy sources as well as ease of operation and maintenance are also critical. The system must be able to be stored for long periods without sacrificing performance and without requiring long start-up procedures.

Energy Consumption design considerations are:

- Worst-case scenario utilizing a hand pump and 12-volt DC battery operated system
- Best-case scenario is generator provided service or utility provided AC
- Need to design the system for the worst-case scenario (total blackout situation)
- For long-term disasters such as those following a hurricane, tornadoes, or tsunamis, the mobile system should be capable of being operated off the electrical grid

Operation and Maintenance design considerations:

- Little to minimal assembly
- Little to minimal maintenance
- Portable
- Easily transportable to developing and rural areas
    - Meet airline size and weight requirements
- Low purchase and operational costs amenable to small and/or rural communities lacking technical, managerial, and financial resources
- No hazardous materials (i.e., adhere to airline restrictions)
- Can be easily modified to whatever water systems are currently being used locally
- Minimal electronics (harsh environmental conditions, no maintenance available locally)
- Ability to add components as needed in the field (i.e., each system can be customized based on what is needed, such as adding different types of filters)
- Long-term operation (several months)
- Minimal, if any reliance on reagents, consumables, and calibration standards, which might be inaccessible
- Allow for recirculation of water through the chlorination unit in case multiple passes are needed to reach the desired level of disinfection.

2.0 *Evaluation of the Baseline Water Treatment System*

2.1 2nd Generation WOW Cart Description

Version 1.0 proved effective for providing disinfection, but it became apparent that the system could be improved to make it more user-friendly. Version 2.0 of the WOW Cart included the WaterStep M-100 Chlorine Generator and pre-filters, plus pre-piped PVC manifolds and valves, a frame-mounted jet pump, media adsorptive filtration, alternative power supplies including a 12v DC deep cell marine battery, solar panel, two 500-gallon bladder tanks, quick connect hoses, salt, and extra parts and supplies. Figure 1 conceptually describes the WOW Cart treatment train. The solid arrow describes the full treatment train with the dotted arrow showing alternative paths when less treatment is required.

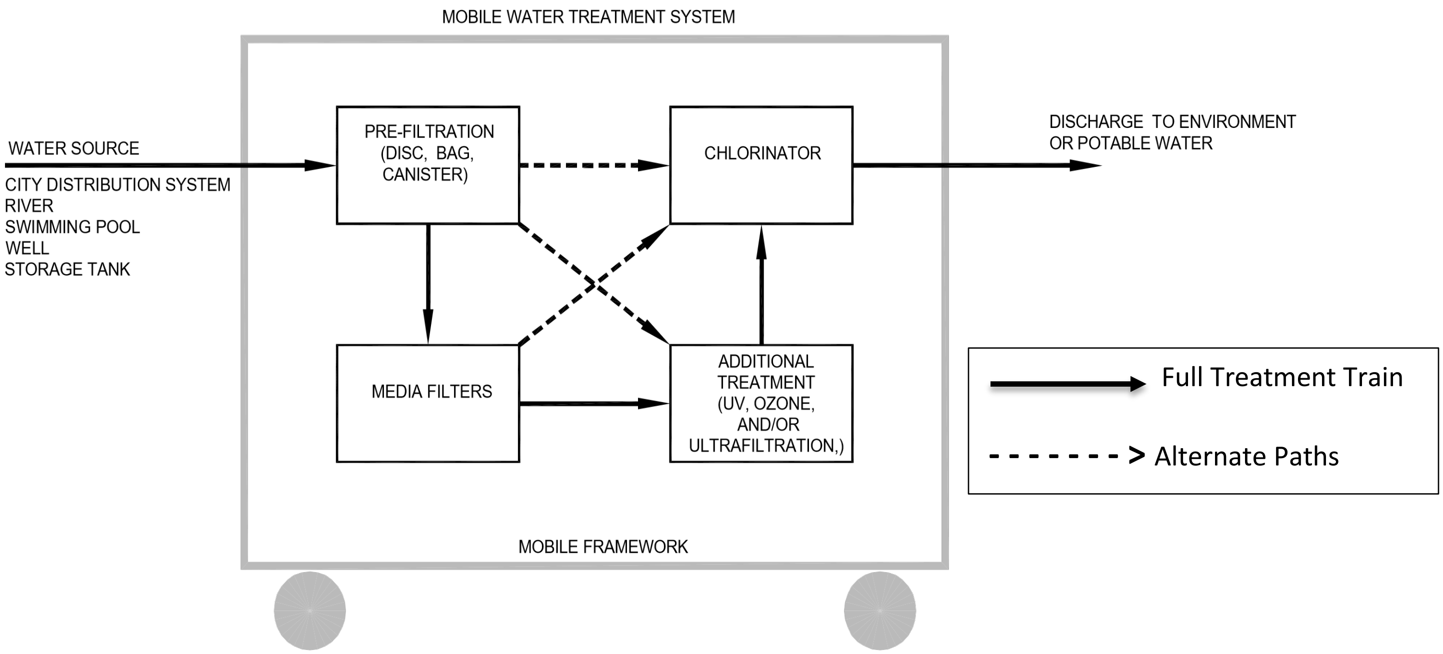

Figure 1. WOW Cart Proposed Schematic.

The built Version 2.0 of the WOW Cart (Figures 2 and 3) was assembled into a steel frame with wheels to make deployment and use much easier.

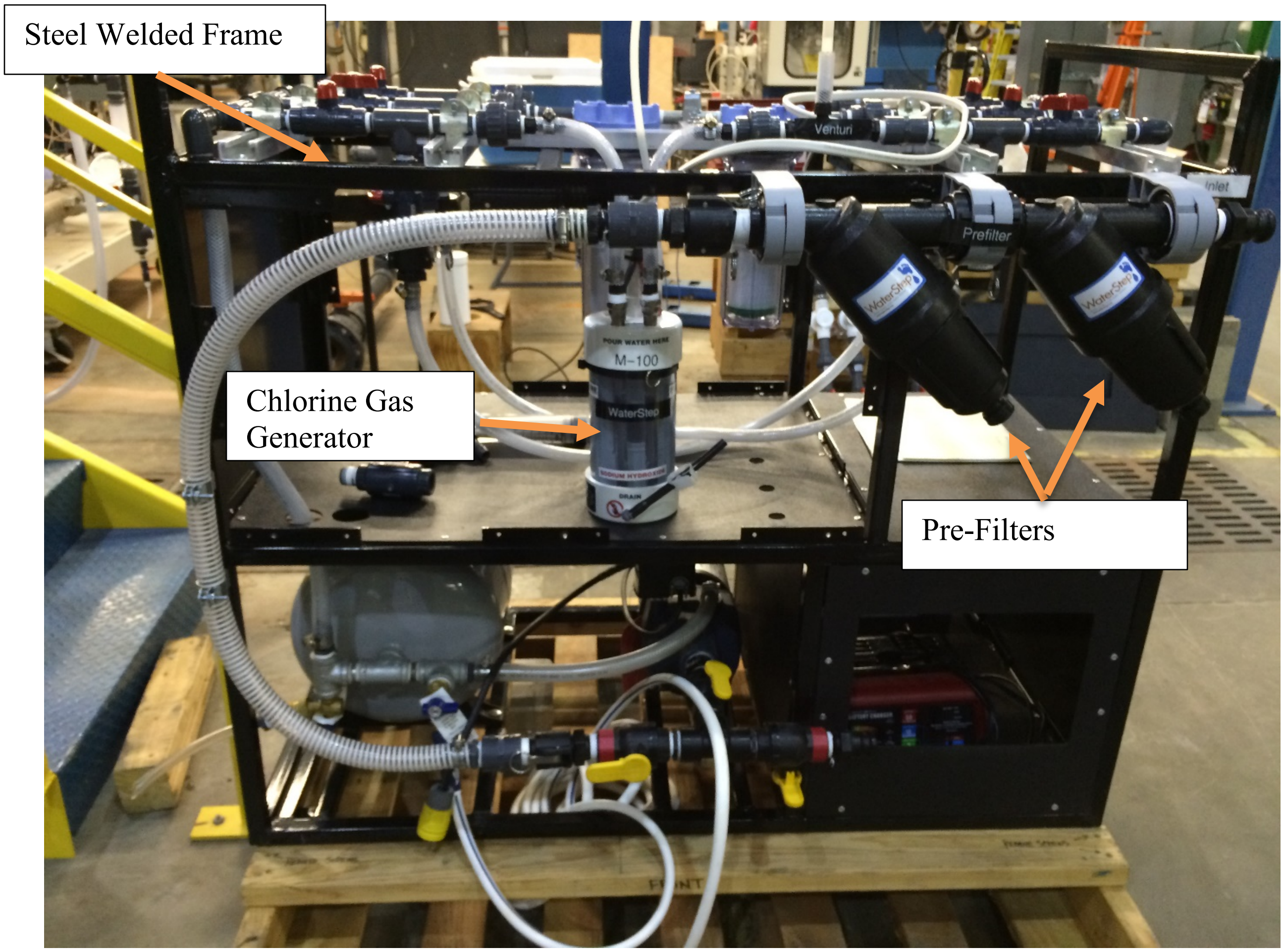

Figure 2. 2nd generation WOW cart prototype (front).

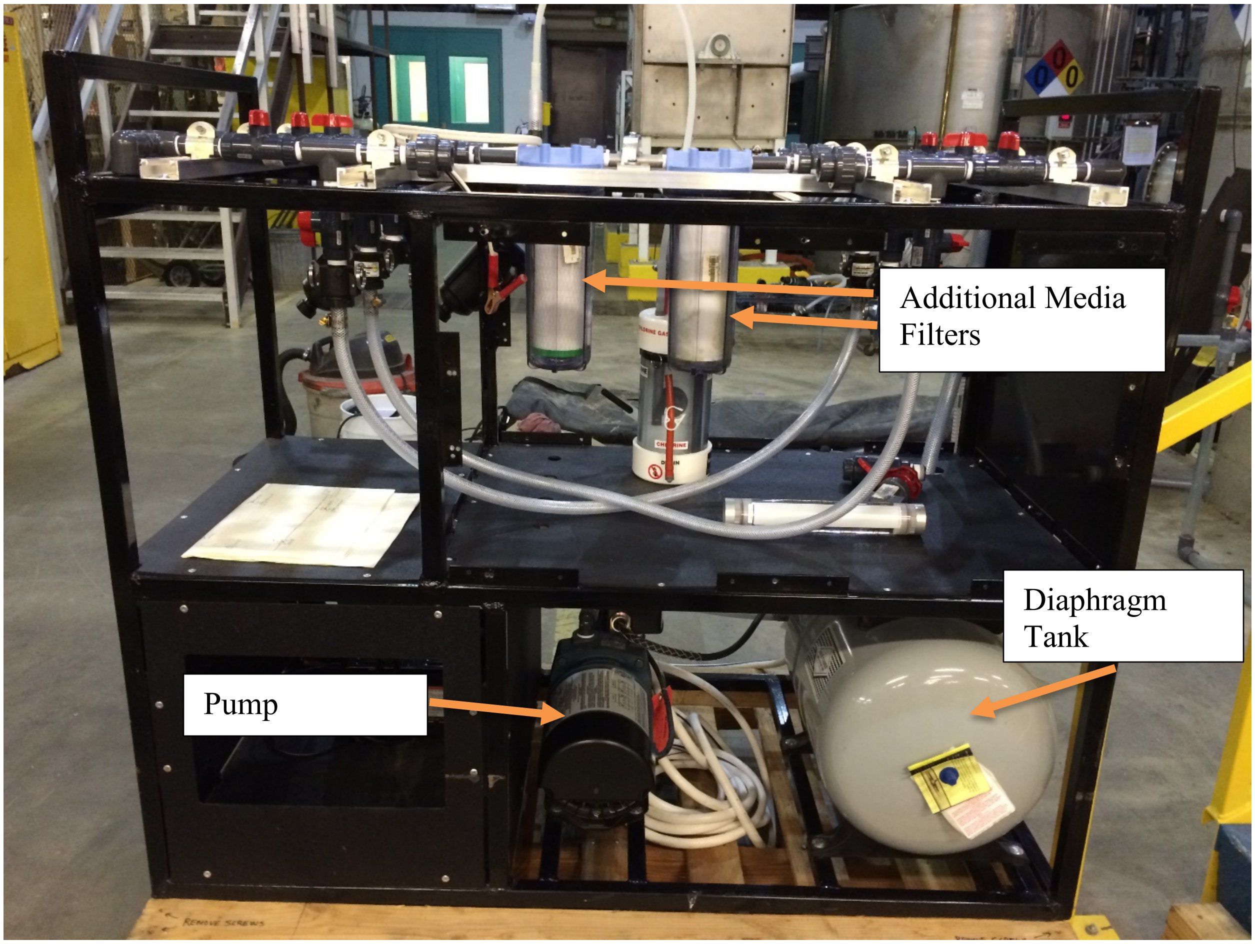

Figure 3. 2nd generation WOW cart prototype with media filters installed (back).

2.2 Preliminary Testing at the Water Security Test Bed

Preliminary testing was conducted to determine the operability and performance of the new WOW Cart. This experiment was designed to assess the ability of the portable disinfection unit within this treatment train to treat a large volume of water containing *Bacillus globigii* spores, a surrogate for anthrax contamination, as well evaluate the ease of operation and setup. This was conducted at the National Homeland Security Research Center's Water Security Test Bed (WSTB) located near Idaho Falls, Idaho at the Department of Energy's Idaho National Laboratory (INL).

The WSTB consists primarily of an 8-inch (20 cm) diameter drinking water pipe oriented in the shape of a small drinking water distribution system (US EPA, 2016b). The WSTB contains ports for simulating water demand from service connections and a 15-foot (5 m) removable coupon section designed to sample the pipe interior. Figure 4 schematically depicts the main features of the WSTB.

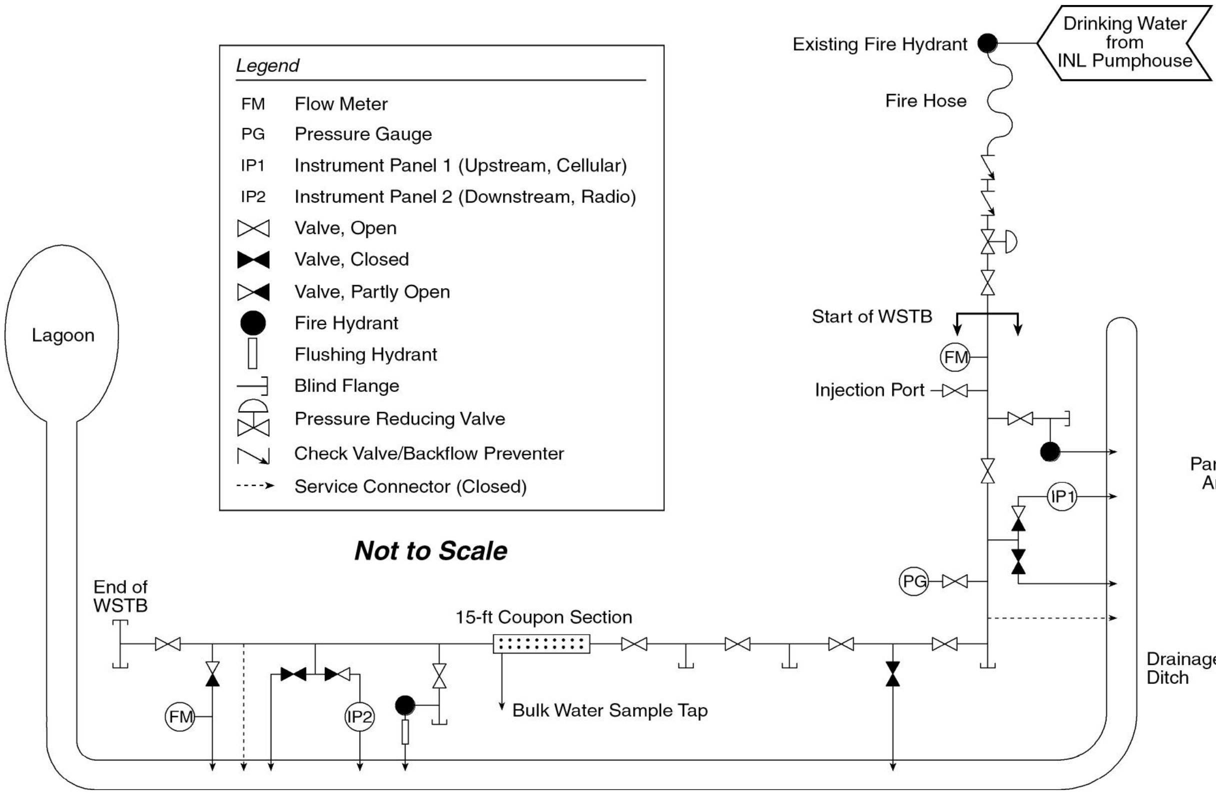

Figure 4. Schematic overview of Water Security Test Bed.

Figure 5 shows the aerial view of the WSTB. The lower right corner shows the upstream and system inlet; the upper left corner shows the lagoon.

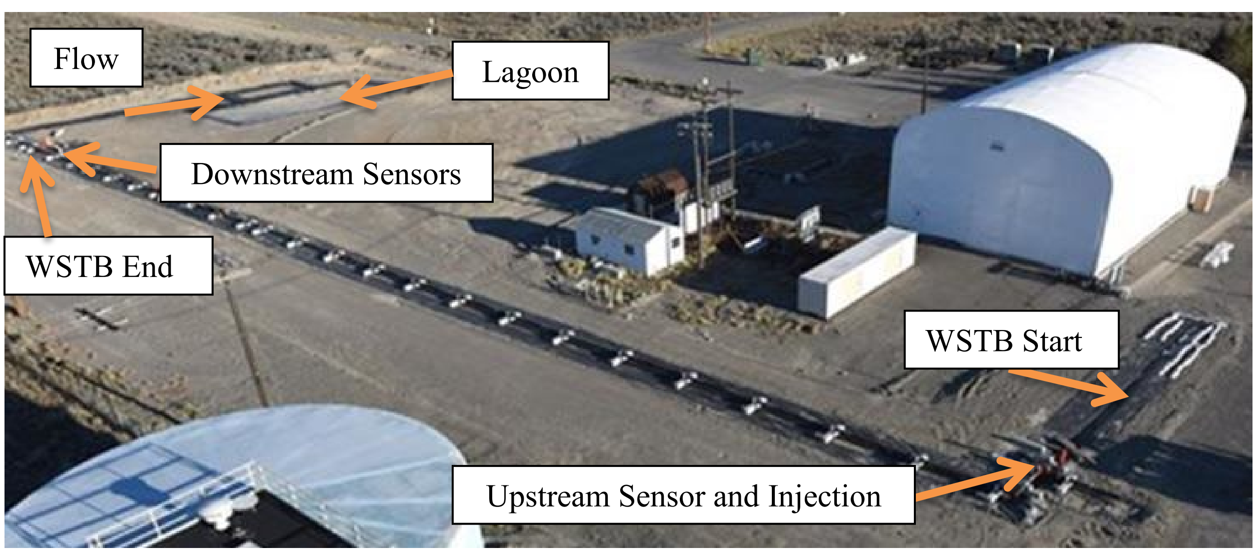

Figure 5. Aerial view of the Water Security Test Bed.

The water from the WSTB system is discharged to a lagoon (Figure 6) which has a water storage capacity of 28,000 gallons (105,980 L).

Figure 6. Water Security Test Bed lagoon.

Water from this lagoon was used for studies on disinfection technologies to determine their ability to treat large volumes of biologically contaminated water. Water in the lagoon contained dirt and sediment from the surrounding area, as well as algae. The dirt and algal growth created disinfectant demand in the water and rendered the water "dirty." *Bacillus globigii* (BG) spores were dumped into the lagoon in order to simulate contaminated wash water resulting from the decontamination of a drinking water pipeline or building with a contamination goal of 10^5 to 10^7 cfu/100 ml.

The effectiveness of the treatment technology was evaluated by sampling the lagoon water containing BG spores before it entered the WOW Cart. The concentration of BG spores in the influent (or before treatment began) was then compared to the concentration in the effluent (after treatment).

2.2.1 On-site Chlorinator Lagoon Water Testing

The WOW Cart was challenged to assess its disinfection capability. The self-contained device was shipped in a pallet/skid for easy deployment. It was mounted on one locking, rolling storage cart with the following components:

1. The WaterStep M-100 chlorinator (an onsite chlorine generator)
2. Pumps: circulating pump (12V DC), distribution pump (120V AC) and a hand pump
3. Electrical Components: connectors and cords for equipment needing a power supply including a ground fault interrupter, one 12V DC, a deep cycle battery, a storage case, a solar panel, and one 10/2/50 ampere automatic battery charger
4. Plumbing Components: tubing and quick-connect cam-lock fittings for all water connections

The system setup is depicted in Figure 7.

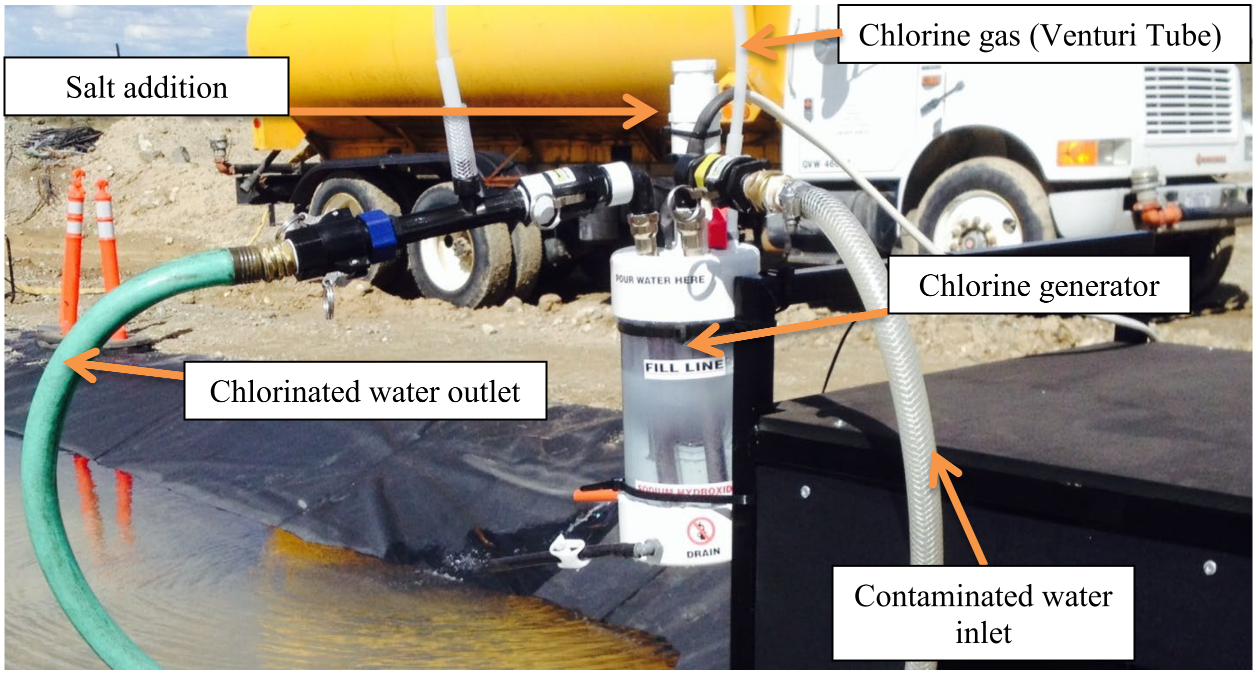

Figure 7. WaterStep chlorine generator components.

The chlorinator uses salt (sodium chloride) and the process of electrolysis using direct current from a 12-volt battery to produce chlorine gas and sodium hydroxide. Table salt purchased from a grocery store was used in this experiment. The system runs an electrical current between the two electrodes, separated by a membrane, in a solution of sodium chloride. Electrolysis breaks up the salt molecules and frees chlorine gas from the brine. The chlorine gas is used as the disinfectant. A small amount of sodium hydroxide is generated, which can be reused for other purposes at the response site as needed.

The chlorine gas is introduced into the water stream using a venturi tube connected to the chlorine generator. A pressure pump (a shallow well pump with bladder tank and a pressure switch) is used to draw water from the lagoon and to circulate it through the venturi using a garden hose. As the water passes through the venturi, it creates a vacuum which draws the chlorine gas out of the chlorine generator. As the water is mixed with the chlorine gas, it flows through and returns to the source or a bladder tank for storage and disinfection contact time. This process is typically continued until the free chlorine concentration in the finished water reaches the desired level.

The WOW Cart has the capability to pump water into 10,000 gallon (37,850 L) portable bladders, where the contaminated water is temporarily stored to provide contact time for disinfection before treated water is disposed of. These bladders were not used during tests at the Idaho National Laboratory. Instead, the WOW Cart was set-up to pump contaminated water directly from the lagoon through the chlorinator and then recirculated back into the lagoon for storage and contact time allowing for disinfection to occur. During planning of the water treatment experiments, the research team felt that pumping water from the lagoon directly into the WaterStep unit (and bypassing the bladders) would be a more accurate representation of how the unit might be deployed during an emergency water treatment scenario. They expected the enclosed lagoon would provide the necessary contact time and storage.

Operationally, water was drawn from near the lagoon inlet (the presumed point of highest contamination in the lagoon) into the WOW Cart. The chlorinated effluent from the WOW Cart was pumped back into the far end of the lagoon while a portion of the untreated effluent water was re-directed to another portion of the lagoon, away from the inlet near the WSTB piping, to increase or promote mixing within the lagoon that was not mechanically mixed. Figure 8 shows the operational setup of the experiment.

Figure 8. WOW cart setup at the lagoon.

The unit operated for 4 hours and 40 minutes. Throughout this period, samples from the chlorinated water outlet were collected and analyzed for free chlorine using a swimming pool kit. The numbers reported were consistently above 5 ppm (the kit can only report values up to 5 ppm). Field dilution was not performed because this was simply a check to determine if chlorine was being generated by the system. Grab samples were collected from the lagoon to evaluate the chlorine levels and were submitted offsite for analysis of BG to determine if disinfection was being accomplished.

After the chlorine treatment, the lagoon sampling results indicated that each of the BG values reported were greater than 10^5 cfu/100 ml. Although the reported chlorine values produced by the on-site chlorinator were consistently above 5 mg/L, the field methodology of delivering the chlorine disinfectant to the lagoon without the bladder tanks was ineffective for disinfection of such a dirty water source. The highest *free* chlorine residual detected in the lagoon was 0.03 mg/L, but the highest *total* chlorine residual detected was 1.71 mg/L. This indicated that the free chlorine being generated by the WOW Cart was being transformed into total (or combined) chlorine once it entered the lagoon. The large exposed surface area of the lagoon, in combination with shallow depth, and intense sunlight, may all have contributed to the rapid degradation of the chlorine delivered to the lagoon. Another confounding factor was the high organic load from the dusty lined lagoon. Thus, the research team concluded that temporary storage bladders would need to be used in emergency situations to provide sufficient contact time, reduce surface area, remove the adverse effects of sunlight on the disinfection process, and reduce the impact of the organic load that could be found in the environment.

2.2.2 Bladder Tank Chlorinator Testing

Next, the experiment was designed to assess the ability of the WOW Cart to disinfect a large volume of water containing BG spores utilizing a bladder tank rather than the lagoon (US EPA, 2016a).

As in the previous experiment, the lagoon contained dirt and sediment from the surrounding area. Disinfection experiments with the WOW Cart chlorine generator were conducted by spiking a vendor supplied 1,250-gallon (4,732 L) tank with BG spores (10^6 spores/100 ml), filled with lagoon water, and then chlorinated. The system set-up only included the chlorine generator and power supply and is depicted in Figure 9. The free chlorine flows into a bladder tank where it could disinfect the contained water. The system was operated using a 12-volt DC battery on the cart (as shown in the middle of Figure 9). The battery was placed on a trickle charger to maintain full charge for operational stability during the testing. There is one contained volume of contaminated water that is exposed to free chlorine, which can facilitate disinfection of the BG spores over time. The bladder tank was manually agitated by pushing on its side to mix the spores. Manual agitation took place approximately every 15 minutes throughout the experiments. Before disinfection, the bladder tank was sampled to determine the initial spore density, and then the chlorination started. Subsequent samples were considered as treated, or disinfected water samples.

The bulk water samples (BWSs) for BG concentrations were collected from the same sampling port that served as both inlet/outlet of the system using the grab sampling technique in 100-ml sterile sample bottles with a 10 mg sodium thiosulfate tablet. The BWS sampling port was opened and the water was drained for 15 seconds prior to collection of the sample.

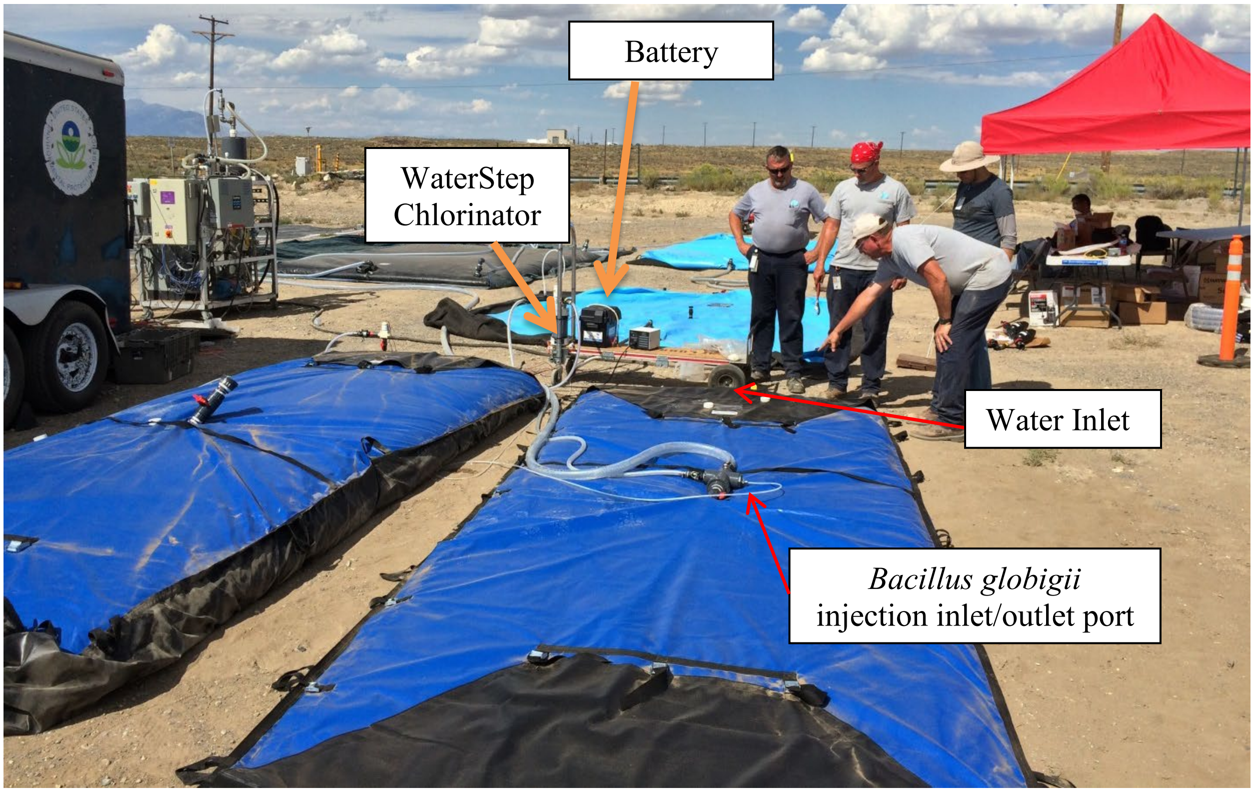

Figure 9. WaterStep chlorinator system with bladder tanks (dark blue).

2.2.2.1 Analysis of Test Results

Data analyses and results from the disinfection experiments are presented in the following sections.

Figure 10 shows the increase in free chlorine concentration inside the bladder tank over the course of the experiment, and the subsequent decrease in BG spores. No free chlorine was detected in the water at the time the experiment began. During the first 60 minutes after the chlorinator was turned on, the free chlorine concentration in the bladder tank increased slowly due to the organic demand in the water (turbidity was measured as 11 to 13 Nephelometric Turbidity Units (NTU). However, after the first hour, the demand was overcome and free chlorine in the bladder tank increased at a faster rate. The chlorinator was turned off after 210 minutes. The free chlorine was around 12 mg/L free chlorine at that time. The subsequent free chlorine samples reflect the decay due to demand and temperature in the bladder tank.

At the start of the experiment, BG spores were mixed in the bladder tank volume by pushing on the outside of the bladder tank to slosh the water around and promote mixing. The first three samples taken from the bladder tank show that the volume was well mixed. BG spore density averaged 2.4×10^7 cfu/100 ml over the first three samples. Figure 10 shows that even as the free chlorine concentration rose from 0.14 to 3.30 mg/L from 60 to 120 minutes, spore density remained the same. This is due to a well-known phenomenon in the field of disinfection knowns as a “lag phase” or “shoulder”. *Bacillus* spores are well known to be resistant to inactivation via oxidative disinfectants, and their concentration will remain stable for a period time in the presence of disinfectants before decreasing (AWWA, 1999; Rice et al., 2005). Once free chlorine did inactivate the BG spores, approximately 7-log reduction was achieved after 300 minutes of contact time.

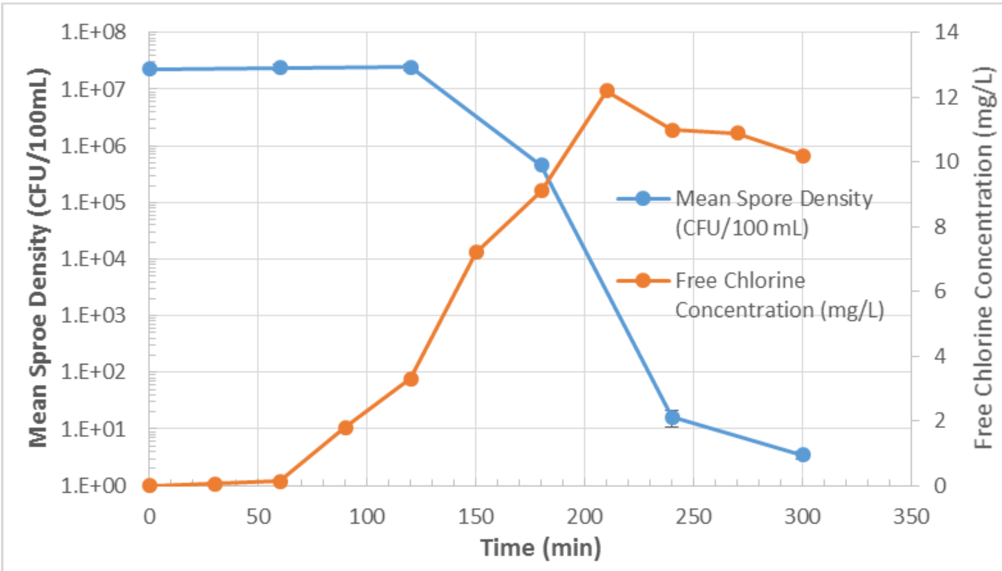

Figure 10. Free chlorine concentration (orange) and *Bacillus globigii* spores (blue line) density over time in the WaterStep bladder tank.

Figure 11 displays the log reduction of BG spores plotted against disinfectant (free chlorine) concentration multiplied by the contact time with the disinfectant (Ct). The Ct concept is often used in the disinfection field to determine the combination of disinfectant concentration and contact time needed to achieve a log reduction for a microorganism at fixed pH and temperature conditions. If the disinfection kinetics are linear, different combinations of disinfectant concentration and contact time can yield the same Ct (AWWA, 1999). Often, disinfection kinetic curves for *Bacillus* spores developed using empirical data are not linear due to the "lag phase" or shouldering phenomenon mentioned earlier in this section. The disinfection kinetics displayed in Figure 10 and 11 are not linear, and this non-linearity is exacerbated by the presence of disinfectant demand (dirty water) in the lagoon water as well as varying temperature over the course of the experiment.

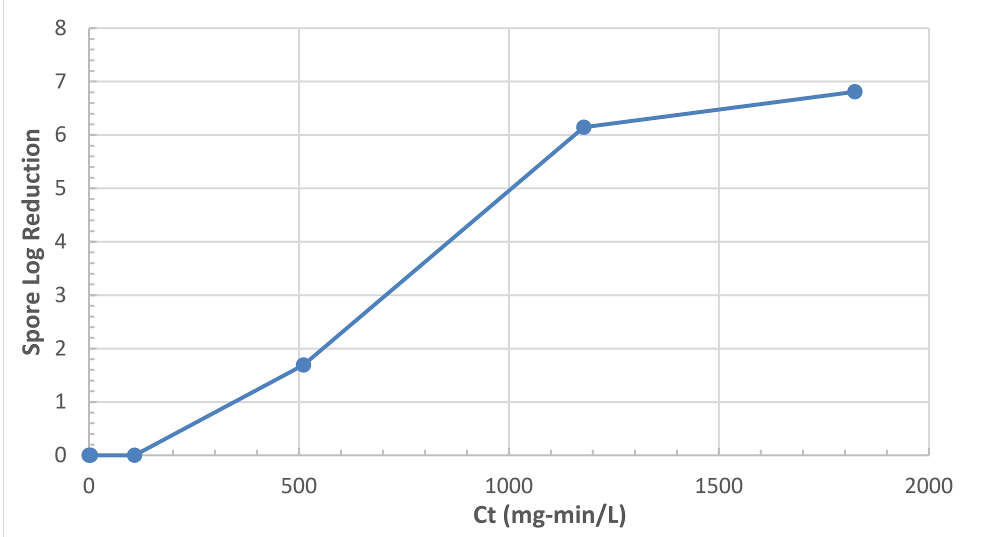

Figure 11. The log reduction in spores during the WaterStep experiment plotted against the Ct value (disinfectant concentration multiplied by time).

Ct values have been compiled in the literature for disinfection of pathogenic and non-pathogenic *Bacillus* spores. These Ct values were often collected in experiments focused on disinfection of drinking water, which generally has less disinfectant demand than the lagoon water used in these experiments. For example, a Ct of 106 mg-min/L was needed for a 3-log reduction of *B. anthracis* Ames at pH 7 and 25° C in the presence of 1 mg/L free chlorine. The 3-log reduction Ct value for BG spores at similar conditions was 136 mg-min/L (US EPA, 2012). In the WaterStep experiments with lagoon water, the 3-log reduction Ct was 707 mg-min/L at pH 7 and temperature ranging from 20 to 25°C.

Some of the increase in the Ct values found in lagoon water comes from the fact that temperature started lower than in the drinking water Ct experiments (15°C to 25°C), where temperature was constant (25°C). Disinfectant concentration is generally fixed in lab Ct studies, where in this experiment it had to increase from zero once the chlorinator was started. Furthermore, disinfectant demand is much less of a factor in lab studies, unlike this field study where disinfectant concentration had to build over time in the presence of an organic load. These factors resulted in a Ct value that is approximately 5 to 6 times higher than those found for the same or similar spores observed under drinking water treatment conditions.

In summary, the WOW Cart achieved 6.8 log removal in a 1,250-gallon (4,732 L) bladder tank within 5 hours of the start of the experiment while achieving 12.2 mg/L free chlorine. This was a small volume and appropriate under certain scenarios, but evaluation of larger volumes of water under flow-through conditions also needed to be challenged and will discussed later in this report.

Table 1 contains a summary of the WOW Cart technology-specific equipment observations recorded during the treatment experiments and considerations for similar field deployments. The terms Low, Medium and High are the opinions of the authors of this study and are based on their experience operating the equipment in the field. The text in the table is meant to support these opinions, and they are specific to this piece of equipment. Other equipment operators may come to different conclusions under different conditions.

Table 1. WaterStep Technology-specific Consideration and Observations*

Technology Considerations	Rating and Comments
Market Availability	High. Commercially available off-the-shelf product from a non-profit organization for producing drinking water in communities in developing countries. Self-contained kit could be used in disaster zone to purify water if there was no power available from the electrical grid. Available from http://waterstep.org/
Capital Cost	Medium (estimate $15,000). Includes storage bladders, pump, battery, charger, solar cell, mounting/transportation rack, and salt-based chlorine generator (chlorinator).
Shipment to Site	Medium. Needs to go on a truck or commercial transportation. Could be transported in a smaller vehicle, if mounting and transportation rack are not used. The unit weighs approximately 460 pounds and is built to meet airline size and weight requirements.
Setup Considerations	Medium. Need flat surface to spread out the bladder tanks. Need to recirculate chlorinated water to provide contact time for disinfection. Not a flow through system. Test kit (strips or colorimetric) required to periodically check chlorine generation. After disinfection, if chlorine is not consumed, the excess chlorine may need to be neutralized before being discharged to the environment.
Operational Considerations	Low. Simple to operate on a short-term basis. If extended contact period is required greater than 3 hours, the salt solution needs to be replenished, electrolytic cell must be drained, and, if not on 110-volt AC power, the battery needs to be charged. Each unit can treat up to 10 GPM providing drinking water to approximately 500 people daily. Consumables depend on the useage, primarily consisting of only salt, filtration media, and power source.
Maintenance and Consumables	Low. Table salt is the only consumable. For optimal chlorine generation, the electrolytic cell needs to be cleaned periodically. Gasoline or propane for generator. Pumps, hoses and O-rings need to be checked periodically for wear and cracking.
Result Summary	Under the tested conditions, a 7-log removal of *Bacillus globigii* was observed in a batch type operation with 300-minutes of contact time.

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use of a specific product

3.0 *Puerto Rico Deployment*

3.1 Background

Just three weeks after Hurricane Maria made landfall in Puerto Rico Wednesday, September 20, 2017, WaterStep's team was on the ground training emergency workers and distributing kits with components of the 2nd generation WOW Cart. The impact continues after over 100 kits were deployed and hundreds of people trained in the proper use of the equipment. Though some kits are still being used, many are now positioned and poised to be used during the next disaster. Below is a summary of the work WaterStep accomplished in its disaster response.

3.2 Achievements

WaterStep received a generous donation from General Electric Appliance Park, a Louisville, Kentucky foundation, as well as funding from many donors to respond in Puerto Rico. In addition, WaterStep received a donation of the use of a DC-3 for the cost of fuel, the staff time of the response team, and the initial shipment of disaster kits. These kits consisted of:

- Hand pump
- Pre-filters
- On-site chlorine gas generator
- BleachMaker*
- Pump
- Power supply
- Solar charger
- Single hole recirculation manifold
- Bladder tank
- Quick connect fittings and hoses
- Salt

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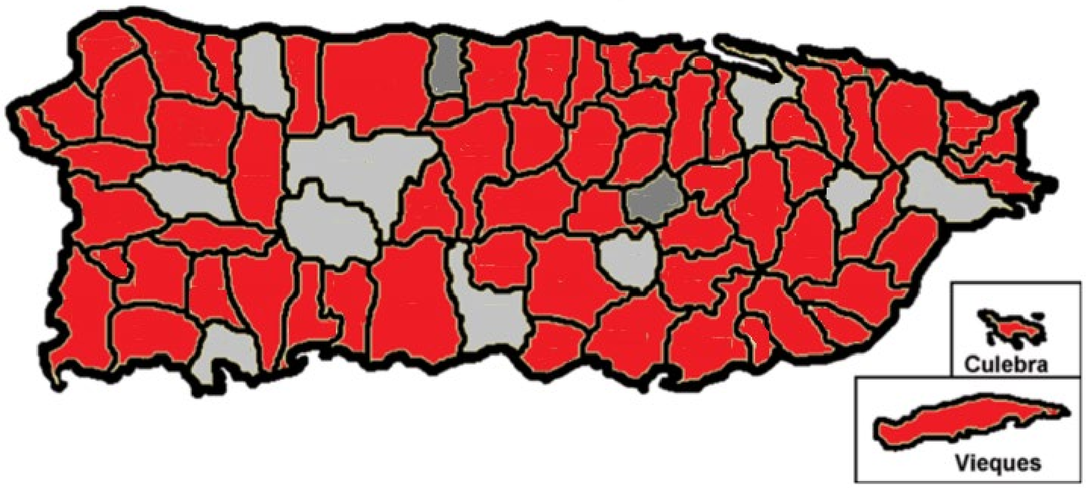
* 1-litre containers of a 1% solution of liquid bleach produced concurrently with the water treatment to be used for general cleaning and support of medical triage by emergency personnel.

Deployment onto the island occurred within three weeks after the hurricane. Coordination for training and distribution of equipment was coordinated in conjunction with the National Puerto Rican Leadership Council Education Fund. Training and equipment were first given to the most affected municipalities. After receiving a grant from Unidos por Puerto Rico, WaterStep was charged to make sure each municipality (78) had one disaster kit to be used by their emergency management office. The municipalities identified in red in Figure 12 denotes those who had received disaster kits by Spring, 2018. Thanks to the commitment of Doctoras Boricuas and the Unidos por Puerto Rico grant, more than 100 bleach makers and chlorine generators were delivered in total around the island including more than 20 to non-profit and medical organizations. Hundreds of people from the government, private sector, doctors, non-profit volunteers, and students have been trained on how to properly use each disaster kit. Each unit is in the responsible hands of trained people in a government or non-profit organization who will keep the equipment safe and operational until another emergency occurs. If all equipment is working at one time, the WaterStep equipment placed in Puerto Rico has the potential to generate 1 million gallons of safe water per day serving approximately 50,000 people.



' RESPONSE IN PUERTO RICO 2017-18

Figure 12. Municipalities that received a disaster kit within weeks of Hurricane Maria (red).

3.3 Strong Communication

In Puerto Rico, WaterStep was careful to ensure that the government was involved in deployment and training in the proper use of the equipment. This created better communication and a higher sense of confidence. It was noticed that emergency management teams shared their experiences with each other and also shared best practices on the equipment's various uses during the emergency.

There was some hesitation about drinking the water after just treating it with the chlorine gas generator. There was some concern among the communities as to whether or not the Puerto Rico Department of Health and the EPA had approved the use of the WaterStep system. The successful testing of the WOW Cart at the EPA Water Security Test Bed was important to the local governments' acceptance of the system. It is recommended that there should be additional education and a water-safety educational campaign, so everyone knows about safe ways to treat water. Everyone from government officials, business people, volunteers, citizens, elderly, to even children must be educated in order to better respond to another emergency. Also, coordinating work with other non-profit organizations is key.

3.4 Success Highlights

Figure 13 is an example deployment. A training event was conducted near San Juan for many of the municipalities and emergency responders. One of the first disaster kits was given to the municipality of Orocovis. The Orocovis emergency management team was trained and returned with a logistics plan to disinfect and distribute water throughout the most affected areas in

Orocovis. This included most of the municipality's population of 24,000 people. A few months later, the Director of Emergency Response in charge of the Orocovis equipment reported how effective the system had been in terms of being simple to use and providing drinking water. An additional system was soon installed permanently at a baseball complex to treat water from a nearby spring. Piping was installed to bring the water to the treatment system and then to be stored in new tanks. The primary lesson learned was to be as inclusive and active as possible communicating with government officials, emergency responders, and community leaders on the use and operation of the technology.

In the municipality of Isabela, a unique approach was to use a flatbed truck to house the bladder tank and fill it from local rivers and streams; the disinfection process was started in transit. Safe water was transported and easily distributed to the community.

The disaster kit was shown to be a powerful tool to provide safe water during the initial weeks of response after Hurricane Maria in Puerto Rico. However, due to the sustainable housing and structure of the equipment, it is designed to be used again and again. With over 100 disaster units on the Island of Puerto Rico, emergency workers and medical personnel are now prepared for storms in the future. The link below provides information on the Puerto Rico deployment and the FTTA utilization.

https://www.youtube.com/watch?v=Db9M1Si0Jkk&feature=youtu.be

Figure 13. Disaster kit installation.

4.0 *Full-Scale Deployment*

4.1 Description of the Final Version of the WOW Cart

The WaterStep saltwater chlorine gas generator is at the heart of the Version 3.0 WOW Cart treatment system. The unit is customizable with flow rates ranging up to 10 gallons per minute (gpm) (37.85 L/min). In addition to chlorine-based disinfection, the WOW Cart first utilizes 100 micron and 25-micron disc pre-filters to remove particulates. The small media cartridges were replaced with larger media tanks to prolong filter life. In many situations, media such as granular activated carbon (GAC) is a likely choice given its ability to remove a broad spectrum of chemical contaminants (Figure 14). Other types of media could be used for their ability to remove radioactive or other types of inorganic contamination.

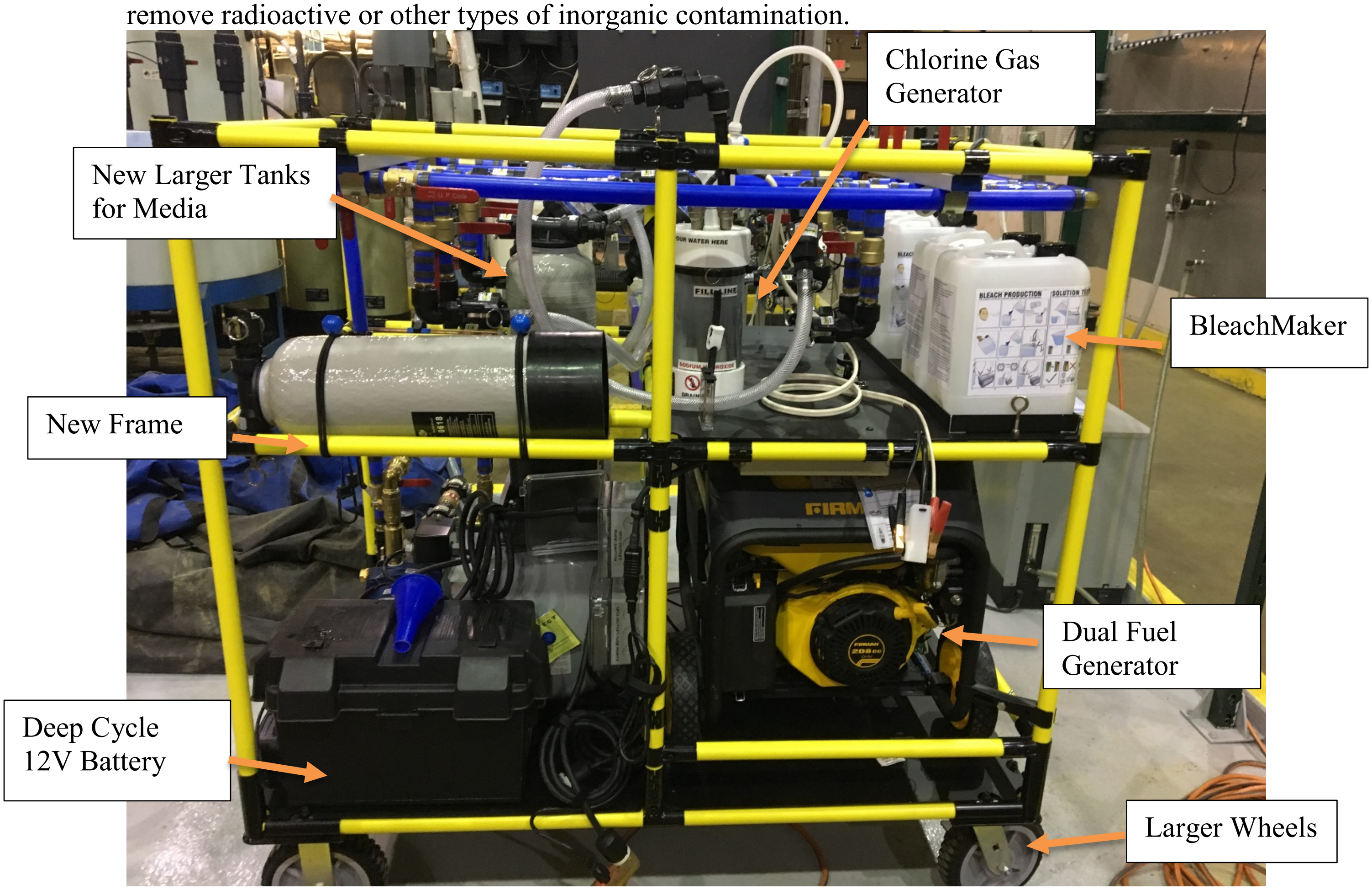


Figure 14. 3rd generation of the WOW cart following Puerto Rico deployment.

The WOW Cart is self-contained and self-supported; therefore, it does not require any additional installation beyond connections to the raw water source and electric power. If necessary, the

WOW Cart can also be powered by a generator that comes with the cart. Version 3.0 of the WOW Cart utilizes a user-friendly duel-fuel gasoline/propane 3,500-watt generator. The chlorine generator and a small recirculation pump can be powered by a deep cycle marine battery and charged by a solar panel.

During the redesign, a few other issues were addressed. The frame of the cart was slightly increased to accommodate the generator, the larger media tanks, and other possible treatment devices such as UV LED and/or ultrafiltration membranes if required by the particular emergency response incident. The new frame material is poly coated steel. The cart frame can now be pre-cut and assembled without welding enabling size adjustments according to the situational needs without waiting on frame design, welding, and powder coating. Larger wheels were added to insure better mobility on different terrains and with the larger frame.

The use of schedule 80 solvent piping and valves was changed to PEX (cross-linked polyethylene) piping and brass for durability. An additional section of PEX piping was inserted into the frame to accommodate extra filters or other accessories such as UV disinfection or additional filtration.

The extra room of the larger cart allowed for the installation of five 1-liter containers of the new WaterStep BleachMakers. This enables the production of a 1% solution of liquid bleach concurrently with the water treatment. The bleach solution can then be used for general cleaning and support of medical triage by emergency personnel.

This newest version still fits on a standard skid and weighs less than 700 pounds (weight will vary depending on tank bladder size.) A new SingleHole Manifold (Figure 15) for connections from the WOW cart to the bladder tanks was developed. This manifold allowed for the reduction in the amount of plumbing (hoses) and has proven to be much more user friendly to re-circulate the stored water. Auxiliary 120v electrical outlets, and USB ports have also been added into the system for on-site access to recharge phones, tablets, and lap-tops (Figure 16).

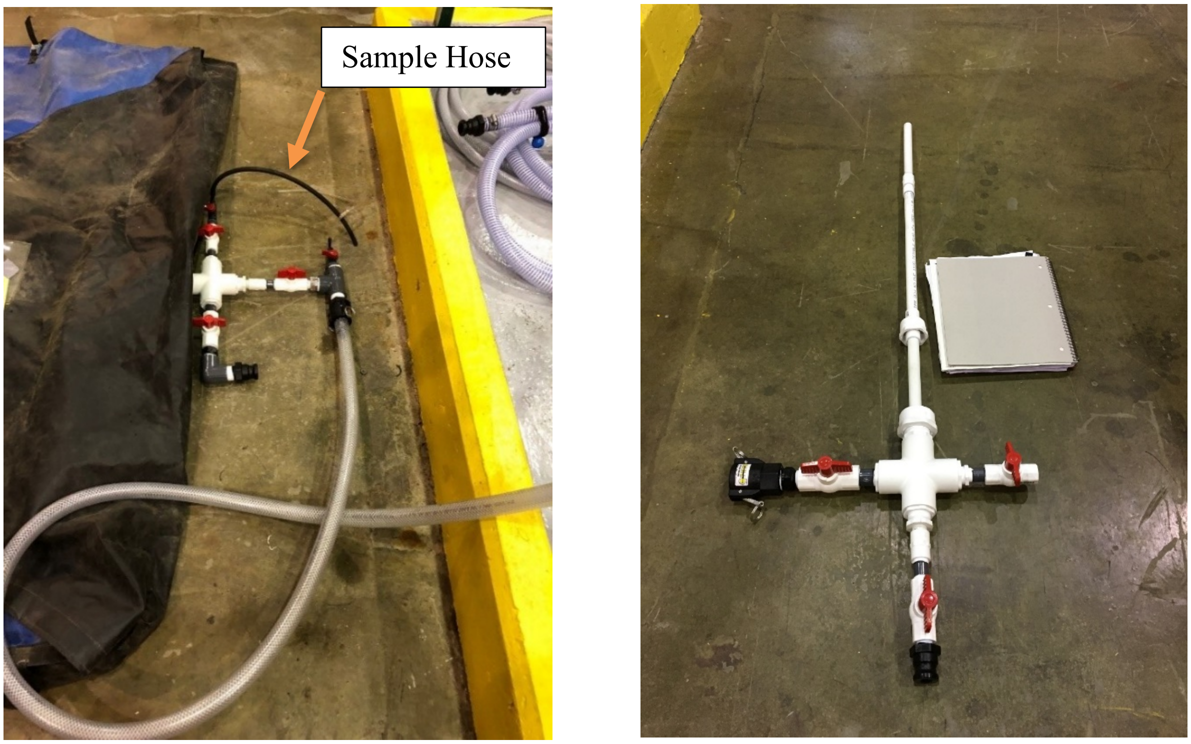


Figure 15. SingleHole Recirculation Manifold.

Figure 16. Electrical outlets and phone charging station.

4.2 Secondary Wastewater Challenge

The Secondary Wastewater challenge evaluated the ability of 3rd generation WOW Cart to disinfect a turbid non-chlorinated secondary effluent discharged from the Greater Cincinnati Metropolitan Sewer District's Gest St. Wastewater Treatment Plant. Secondary wastewater was selected to simulate a contaminated surface drinking water source or a combined stormwater and sanitary sewer effluent. The challenge was based on free chlorine residual produced by the chlorine gas generator and the subsequent inactivation of *Escherichia coli* and total coliforms in the secondary effluent. (Total coliforms are a group of related bacteria that are common in the environment [soil and vegetation] and are used as a general indicator of drinking water quality.) This unit was evaluated at the EPA Test and Evaluation (T&E) Facility, located in Cincinnati, Ohio. The unit and its associated bladder tank used in this evaluation is shown in Figure 17.

Figure 17. WOW cart secondary wastewater challenge set-up with empty 1,250-gallon bladder tank at T&E Facility.

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Non-chlorinated secondary effluent enters the T&E Facility directly from the Greater Cincinnati Metropolitan Sewer District through an 8-inch PVC pipe. For this experiment, a portion of the secondary effluent flow was directed into a 1,000-gallon stainless steel tank located on the floor of the T&E high bay (Figure 18). The WOW Cart was connected to the tank through a manifold. The WOW Cart's optional onboard jet pump pulled the secondary effluent from the tank through the disc pre-filters and then through the chlorine generator. The treated water was then pumped into the 1,250-gallon bladder tank.

Figure 18. Secondary wastewater effluent holding tank and WOW cart at T&E Facility.

The test was performed on June 27, 2018. The secondary effluent made a single pass through the WOW Cart's disc pre-filters and then through the chlorinator and was discharged into the bladder tank. The water flow through the WOW Cart was approximately 6 gpm (22.71 liters per minute) as shown on the rotameter in Figure 19.

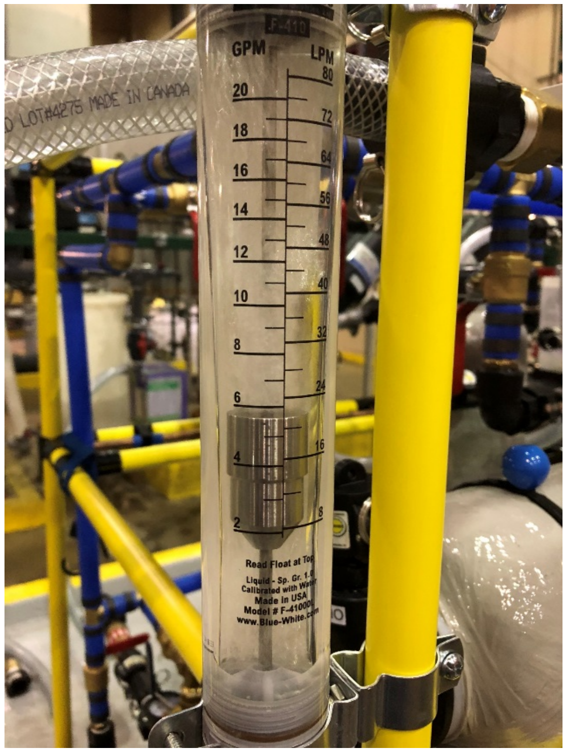

Figure 19. Rotameter showing flow through the WOW cart.

When the bladder tank was approximately half full (~660 gallons), as shown in Figure 20, the secondary effluent flow from the tank was shut off to the WOW Cart and the pump lines were reconfigured to allow the bladder contents to continuously recirculate through the WOW Cart's disinfection system and back into the bladder tank. The manifold "mixer" bar inside the bladder tank was used to mix and recirculate the water within the bladder tank. The recirculation and chlorination of the secondary effluent continued for one hour. The water passed through the chlorinator throughout the entire test period.

Figure 20. Bladder tank (660 gallons - 1/2 full).

4.2.1 Analysis of Test Results

During the test, inlet and outlet samples from the WOW Cart were collected and analyzed for *E. coli* and total coliforms. The secondary effluent was the source of the bacteria microorganisms: *E. coli* and total coliforms. The inlet samples were collected from the WOW Cart's lower sample port located just before the water enters the cart's disinfection device, while the outlet samples were collected from the port on the short side of the mixer manifold located at the bladder inlet. Samples were collected as the bladder was being filled and during the recirculation of the water through the bladder tank. Throughout the test, the inlet and outlet water were analyzed for free and total chlorine. Results of these analyses are presented in Table 2. Figure 21 shows the oxidizing capabilities of the WOW Cart. The blue-green color of the inlet secondary effluent sample (left) was stripped from the water and the resulting outlet sample (right) was clear.

Table 2. Chlorine Concentrations at the WOW Cart Outlet (single pass)

Sample Time	Free chlorine, mg/L	Total chlorine, mg/L
Startup – single pass through cart	0.06	0.12
20 minutes of single pass water	12	14.2
2 hours of single pass water	13.6	15.4
2.5 hours of single pass water	12.9	14.1
Start recirculation in bladder tank		
30 minutes of recirculating water	23	27
45 minutes of recirculating water	25	31
1 hour of recirculating water	27	33

Note: It was not necessary to achieve these high chlorine levels to completely disinfect the *E. coli*. It was just done to demonstrate the capability of the system

Figure 21. WOW cart inlet (left) and outlet (right) samples.

The *E. coli* samples were analyzed at the T&E Facility Biosafety Level (BSL) 2 Laboratory following the APTIM T&E MOP [Miscellaneous Operating Procedure] 310, Revision 2: “Total Coliform and *E. coli* Analysis Using IDEXX Colilert-18.” The 100 ml samples and/or diluted samples were mixed with Colilert®-18 media powder (IDEXX Laboratories, Inc., Westbrook, Maine). When the media powder dissolved, the sample-media mixture was poured into an IDEXX Quanti-tray®/2000. After incubating at 35°C for 24 hours, the trays are examined under UV light to count the number of fluorescent wells. The number of fluorescent wells is cross-referenced with a most probable number (MPN) table to obtain the MPN of *E. coli* in the original sample.

The results from the *E. coli* and total coliform analyses of water samples collected from the WOW Cart are summarized in Table 3. Individual inlet concentrations were compared to the corresponding outlet concentrations to compute the log reduction values shown in Table 3. Log reduction values for *E. coli* and total coliforms from the initial outlet samples were not presented since the chlorination had not started. The data show that *E.coli* and total coliforms were removed to below the level of detection by the WOW Cart during the first 15 minutes of the recirculation of the water through the bladder tank. Comparing inlet and outlet *E. coli* concentrations, the WOW Cart produced log reductions up to 2.8 while operating in the single pass mode. Log reductions of 4 or greater (complete removal of *E. coli* and total coliforms) were achieved while recirculating the contents of the bladder tank. As shown in Table 2, this is most likely due to the higher chlorine concentrations present in the recirculated bladder tank water. Utilizing the recirculating manifold from the initial start-up would have most likely reduced the time to complete inactivation of the *E. coli* and total coliforms.

Table 3. WOW Cart Summary of *E. coli* and Total Coliforms Disinfection Results

Sample Condition	**Total Elapsed Time (min)**	**Inlet *E. coli* (MPN/100 ml)**	**Inlet Total Coliforms (MPN/100 ml)**	**Outlet *E. coli* (MPN/100 ml)**	**Outlet Total Coliforms (MPN/100 ml)**	***E. coli* Log Reduction**	**Total Coliforms Log Reductions**
Single Pass through the WOW Cart							
Started filling bladder with secondary wastewater and turned on chlorinator							
Initial	2	1.07E+04	2.40E+05	1.50E+04	2.40E+05	NA	NA
330 gal in bladder	42	2.00E+04	1.60E+05	6.40E+01	6.10E+02	2.4	2.6
660 gal in bladder	143	1.40E+04	2.04E+05	2.70E+01	3.00E+02	2.8	2.9
Average inlet concentration		1.70E+04	2.13E+05				
***E. coli* and Total Coliforms were removed below detection level within 15 minutes of recirculation** **NA – Log reduction cannot be calculated at start-up of the test**							

4.3 WSTB Microbial and Diesel Fuel Challenge

The objective of the test was to next evaluate the efficacy of the WOW Cart treatment train to decontaminate a mixed water supply contaminated with bacteria and petroleum-based chemicals. The scenario is reflective of a surface water contaminated by a barge spill or flood waters contaminated with untreated sewage.

Figure 22 shows the WOW Cart being deployed on-site at the WSTB. The WOW Cart was unpacked and wheeled to its location adjacent to the lagoon (Figure 23). For this experiment, the lagoon was to be filled to ~7,000 gallons of potable water from the Water Security Test Bed pipeline. Prior to the WOW Cart being deployed, the main WSTB pipeline experienced a severe joint failure flooding the area causing the lagoon to overflow, thus creating a much more realistic emergency response scenario. Power was available on-site, so the duel fuel generator was not necessary.

Non-pathogenic *E. coli* K-12 bacteria and diesel fuel were added to the lagoon. The contaminants were allowed to mix and disperse overnight. The next day, the water was pumped through the WOW Cart. The desired contaminant concentrations in the lagoon were ~20 mg/L diesel fuel and 10^5 MPN/100 ml *E. coli*. To achieve those concentrations throughout the lagoon the contaminants were physically mixed by walking through the lagoon. Benzene, toluene, ethylbenzene, and xylene (BTEX) make up 0.5–1.2% of typical diesel fuel. The effluent from the WOW Cart was collected in a 2,000-gallon bladder. Water samples from the lagoon were compared to water samples taken from the bladder.

Figure 22. WOW cart delivered on-site at the Water Security Test Bed.


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4.3.1 Analysis of Test Results

Table 4 describes the *E. coli* and total coliform reduction and/or inactivation of microbial contaminants by the WOW Cart being operated in flow through mode. In order to provide increasing Ct for disinfection, bladder tank outlet samples were collected at set intervals to show an increasing disinfection rate. Effluent samples were taken from the bladder tank over time providing Contact Time. After about 45 minutes of operation, the WOW Cart effluent showed a reduction of around 1 log of both microbial contaminants. Following another 45 minutes of treatment and contact time (90 minutes total) both the WOW Cart effluent and bladder tank contents showed reductions of *E. coli* and total coliforms of 6 log and 4 logs respectively.

Table 4. Microbial Results from the Lagoon

WOW Cart Inlet (Lagoon Source Water)			**Treated WOW Cart Outlet to Bladder Tank**		**Recirculated Treated Bladder Tank**	
Sample Time	Total Coliforms (MPN/100 ml)	*E. coli* (MPN/100 ml)	Total Coliforms (MPN/100 ml)	*E. coli* (*MPN*/100 ml)	Total Coliforms (MPN/100 ml)	*E. coli* (MPN/100 ml)
15:15	>2.4E+06	1.5E+04	2.1E+05	8.4E+03	1.7E+01	2.0E+00
16:00	>2.4E+06	3.5E+03	1.0E+00	1.0E+00	1.0E+00	ND
16:45	>2.4E+06	5.6E+04	1.0E+00	ND	1.0E+00	ND
17:30	2.4E+06	1.5E+05	1.2E+05	1.5E+04	2.0E+01	5.1E+01
18:15	1.3E+06	1.1E+04	ND	ND	2.0E+01	ND
19:00	1.4E+06	1.3E+03	ND	ND	ND	ND
E. coli and Diesel fuel added to the lagoon at 14:25 and 14:27 respectively ND – non-detect (<1 MPN/100mL)						

Table 5 describes the influent and effluent levels of the diesel fuel components. Because of the extremely high turbidity in the lagoon (> 100 NTU), the GAC filter media tanks became clogged and were removed from the WOW Cart after 3 hours of operation prior to sampling at 17:30 hours. Results indicate that diesel range organics (DRO) C10 – C20, oil range organics (ORO) C20 – C34, gasoline range organics (GRO) C6 – C12, and Total Petroleum Hydrocarbons (TPH) were removed through the first two hours of operation prior to the GAC being removed as shown by the BWS-4-1 sample. One sample taken at 14:00 hours indicates that DRO and TPH may have started to breakthrough given the GAC clogging prior to the removal of the GAC media.

Table 5. Diesel Fuel Removal Rates

WOW Cart Inlet (Lagoon Source Water)					Treated WOW Cart Outlet to Bladder Tank			
Sample Time	DRO (mg/L)	ORO (mg/L)	GRO (mg/L)	TPH (mg/L)	DRO (mg/L)	ORO (mg/L)	GRO (mg/L)	TPH (mg/L)
15:15	6.500	1.300	0.110[J]	7.910	U	U	U	U
16:00	U	0.120	U	0.120	0.110	U	U	0.110
16:45	U	0.120	0.200[J]	0.320	U	U	U	U
17:30	0.150	0.140	0.170[J]	0.460	0.140	0.120	0.120[J]	0.380
18:15	0.170	0.170	0.140[J]	0.480	0.250	0.120	U	0.370
19:00	0.190	0.140	0.120[J]	0.450	0.140	0.110[J]	0.120[J]	0.370
WOW Cart Inlet (Lagoon Source Water)					Treated WOW Cart Outlet to Bladder Tank			
Sample Time	Benzene (ug/L)	Ethylbenzene (ug/L)	Toluene (ug/L)	Total Xylene (ug/L)	Benzene (ug/L)	Ethylbenzene (ug/L)	Toluene (ug/L)	TPH (ug/L)
15:15	U	U	U	U	U	U	U	U
16:00	U	U	U	U	U	U	U	U
16:45	U	U	U	1.200[J]	U	U	U	U
17:30	U	U	U	1.200[J]	U	U	U	U
18:15	U	U	U	U	U	U	U	U
19:00	U	U	U	U	U	U	U	U
E. coli and diesel added to the lagoon at 14:25 and 14:27 respectively U = Non-detect value [J] = Estimated value								

5.0 *Conclusions*

The WOW Cart has shown that it is able to treat natural waters highly contaminated with *Bacillus globigii* (an anthrax surrogate), *E. coli*, and total coliforms. Simultaneously, it was also able to treat diesel-fuel contaminated water. Based upon the field evaluations and Hurricane Maria response, the deployment, training, and operation of the WOW Cart was determined to be easy and cost-effective. Capital cost of the WOW Cart has been estimated to range between $15,000 and $25,000 depending on quantity fabricated.

- *Bacillus globigii* showed a 7-log reduction with a free chlorine residual around 10 mg/L when operated in a batch mode over a few hours in a 1,250-gallon bladder tank.

- Following Hurricane Maria in Puerto Rico, over 100 disaster kits (pre-filtration and chlorination) were deployed, providing microbially safe drinking water to tens of thousands of people.

- The 3rd generation WOW Cart disinfected 4 and 5-log levels of *E.coli* and total coliforms respectively, found in secondary wastewater while exhibiting high levels of free and total chlorine.

- The WOW Cart successfully removed similar levels as above of *E. coli* and total coliforms from a contaminated lagoon while simultaneously removing diesel fuel components to below detection levels. Because of the extreme high turbidity (> 100 NTU), the granular activated carbon media treating the diesel fuel clogged after approximately two hours of operation. This suggest that if a better source water cannot be utilized during an actual emergency response, an additional pre-filtration step may be necessary to reduce excess media replacement.

- Additional research is ongoing to evaluate the integration of additional pre-filtration technologies (e.g. electro-coagulation), multi-media filtration, UV-C LED, ozone, and ultrafiltration membranes to increase the WOW Cart's ability to treat an even broader suite of contaminants and increase unit process longevity (e.g. GAC) and decrease O&M replacement costs.

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7.0 *Appendices -USEPA T&E Facility Contract Technical Standard Operating Procedure*

Appendix A: Total Coliform and *E. coli* Analysis Using IDEXX Colilert® 18 Method	MOP 310 Total Coliform and E coli
Appendix B: Free Chlorine Analysis by HACH® Method 8021 and Total Chlorine Analysis by HACH® Method 8167 N.N-diethyl-p-phenylene-diamine (DPD) Colorimetric Method (0.02 to 2.00 mg/L Cl2)	504 Free Chlorine and Total Chlorine An

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