



DEPARTMENT OF THE ARMY  
US ARMY PUBLIC HEALTH COMMAND (PROVISIONAL)  
5158 BLACKHAWK ROAD  
ABERDEEN PROVING GROUND MD 21010-5403

MCHB-TS-EWS

05 OCT 2010

MEMORANDUM FOR Deputy Assistant Secretary of the Army, Environment, Safety, and Occupational Health (DASA-ESOH), 110 Army Pentagon, Washington, DC 20310-0100

SUBJECT: Water Supply Management Program, Project No. 31-EC-0AE9-09, Technical Evaluation and Operational Needs Assessment of Commercial-off-the-Shelf Small Unit Water Purifiers

1. The subject report, which was sponsored by your office and funded by the Army Studies Program, is enclosed in fulfillment of our commitment to study, evaluate and make recommendations concerning the use of Commercial-off-the-Shelf small unit water purifiers to fill the gap in functionality between individual water purifiers and reverse osmosis water purification units currently in the Army inventory.

2. The point of contact for your questions is Mr. Todd Richards, Water Supply Management Program, US Army Public Health Command (Provisional) [USAPHC (Prov)] [formerly the US Army Center for Health Promotion and Preventive Medicine (USACHPPM)], at commercial (410) 436-7747, DSN 584-7747, or e-mail at [todd.richards@us.army.mil](mailto:todd.richards@us.army.mil).

FOR THE COMMANDER:

Encl

A handwritten signature in cursive script that reads "William J. Bettin".

WILLIAM J. BETTIN

LTC, MS

Director, Environmental Health Engineering

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U.S. Army Public Health Command  
(Provisional)

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**WATER SUPPLY MANAGEMENT PROGRAM  
PROJECT NO. 31-EC-0AE9-09  
TECHNICAL EVALUATION AND OPERATIONAL NEEDS  
ASSESSMENT OF COMMERCIAL-OFF-THE-SHELF  
SMALL UNIT WATER PURIFIERS**

Distribution authorized to U.S. Government agencies only; protection of privileged information: May 2010. Requests for this document must be referred to Deputy Assistant Secretary of the Army, Environment, Safety, and Occupational Health (DASA-ESOH), 110 Army Pentagon, Washington, DC 20310-0100.

Preventive Medicine Survey: 40-5f1

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EXECUTIVE SUMMARY  
WATER SUPPLY MANAGEMENT PROGRAM  
PROJECT NO. 31-EC-0AE9-09  
TECHNICAL EVALUATION AND OPERATIONAL NEEDS ASSESSMENT OF  
COMMERCIAL-OFF-THE-SHELF SMALL UNIT WATER PURIFIERS

**1. PURPOSE.** The US Army Public Health Command (Provisional) [USAPHC (Prov)] [formerly the US Army Center for Health Promotion and Preventive Medicine (USACHPPM)] designed and executed this study to address (b) (5)

(b) (5) Specifically, the objectives were to assess commercial-off-the-shelf (COTS) water treatment systems for small units, to produce a detailed catalogue of COTS technologies, and to generate recommendations to facilitate informed decisions on their use.

**2. CONCLUSIONS.** We concluded through our research, testing, and detailed assessment, that a single COTS Small Unit Water Purifier (SUWP) is not currently available that can autonomously and completely fill the (b) (5) (b) (5) nor will any single system we evaluated likely be the perfect solution for all deployment needs. The lack of available performance verification data limited our capability to identify clear leaders, echoed in the narrow band of score totals produced using the evaluation model. Ultimately, it was the Integrated Project Team's (IPT) observations as experienced engineers and scientists that separated one SUWP from another in terms of anticipated functionality. The information products produced during this study will assist potential users with weighing and comparing the benefits and shortcomings of each COTS SUWP and help them choose appropriate systems by matching SUWP capabilities with mission requirements; mindful that it may be necessary to combine systems or enhance systems with additional technologies to produce a complete solution. The experience gained by the IPT positions USAPHC (Prov) to provide relevant and ready consultation to potential military users, as well as to members of the public health community who may be called upon to provide medical oversight for SUWP employments.

a. Multiple Barriers. SUWPs with more than one treatment barrier and real-time performance monitors which arrest operation are superior to those which may contain only a single treatment barrier as well as those that lack performance feedback. Non-water treatment characteristics such as external design and packaging may impact the overall resilience necessary to meet the demands of the mission.

b. Performance Verification. Protocol-driven independent performance verification provides the highest level of confidence that a SUWP will produce microbiologically safe water. The use of certified components in the construction of SUWPs provides the next level of confidence; however, the use of a single certified component in the system does not equate to performance verification of the entire system.

c. Raw Water Assemblies. Inadequate raw water assemblies require COTS SUWPs to be located very close, as close as 4 feet, to the raw water source, or be augmented with raw water collection and storage systems. This may negatively impact the practicality, convenience, and security of producing water with an SUWP.

d. Filter Longevity. Filter clogging can severely reduce water production rates. The need to stock many filter spares increases the capital and logistical burden associated with many COTS SUWPs. However, some of the evaluated units have the ability to automatically backwash filters in place, and can thus reduce this burden.

e. Disinfectant/Disinfectant Residual. SUWPs lacking a disinfection step or using technologies, such as ultraviolet radiation that do not provide disinfectant residuals, require additional treatment steps (such as chlorination) by the user unless the water is to be directly consumed. This may impact the complexity and required man-hours dedicated to water production.

f. Additional Gaps in the COTS SUWP Platform. COTS SUWPs are generally an incomplete water production platform. In addition to materiel add-ons, the military planner will encounter gaps across the Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities (DOTMLPF) spectrum associated with SUWP operation and quality oversight.

**3. RECOMMENDATIONS.** Decision makers should define the water requirements for each mission before approaching the COTS SUWP market, and consider the following:

- Why is a military reverse osmosis water purification unit an untenable solution?
- Is the raw water source-fresh or salt or brackish, and is it surface or ground or municipal?
- Number of personnel supported
- Duration of mission
- Other available water resources (i.e., bottled water, delivered bulk water)
- Quantity of water required-consult US Army Combined Arms Support Command *Water Planning Guide* (reference 6)
- Required portability and available transportation assets
- Budget

With these considerations made, the information products in Appendix F can help narrow the search for an SUWP that will be best suited for the defined mission. USAPHC (Prov) can assist with further consultation. Extending from the study findings and conclusions, we offer the following recommendations.

- a. Multiple Barriers. Select SUWPs which offer multiple barriers to microbiological and chemical contaminants and provide performance monitoring.
- b. Performance Verification. Evaluate the quality of manufacturer-provided performance verifications or certifications when reviewing candidate SUWPs. Recognize that many certifications are for material properties only, and are not performance-based. Further recognize that standards may be very narrowly focused and not accurately reflect complete system performance. They should only be used as tools to support comprehensive assessments. Consult official product listings such as [http://www.nsf.org/certified/consumer/listings\\_main.asp](http://www.nsf.org/certified/consumer/listings_main.asp).
- c. Raw Water Assemblies. Consider accessibility and security of the source water site in the mission planning and SUWP procurement process. If it is not practical to operate on or very near the water source, additional materiel solutions must be planned as well as transportation of product water. USAPHC (Prov) can provide examples of add-on enhancements to raw water assemblies.
- d. Filter Longevity. Choose SUWPs that provide prefilters that can be cleaned or backwashed without removing the filters. Otherwise, if simplicity of design and operation outweigh other measures, plan for frequent filter changes and the associated logistical impact.
- e. Disinfectants/Disinfectant Residuals. Ensure that the product water is disinfected if it will be stored prior to distribution to individual consumers. Consider SUWPs or add-on assemblies which provide a means to meter or dose disinfectants and provide a residual (chlorine is the recommended disinfectant). If the water will be consumed directly or dispensed into individual user containers, e.g., canteens, a residual is less critical, yet remains desirable. See Appendix C, *Disinfectant Systems*, for a list of disinfectant systems and contact USAPHC (Prov) for assistance in making a selection.
- f. Additional Gaps in the COTS SUWP Platform. Consider all aspects of the water mission when entering the SUWP market. Develop a concept of operations that addresses the multiple barrier approach including quality oversight. Recognize the need to procure multiple equipment sets, perhaps from more than one source, in order to assemble a complete platform. Contact USAPHC (Prov) for assistance in choosing

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from available sources to build a more complete mission-oriented platform around the treatment train of a selected COTS SUWP.

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performance and potential health risks of COTS water purifiers to expand our knowledge base, enhance our capability to provide consultative support to units desiring to use COTS solutions, and to make the information readily available to military leaders and unit commanders.

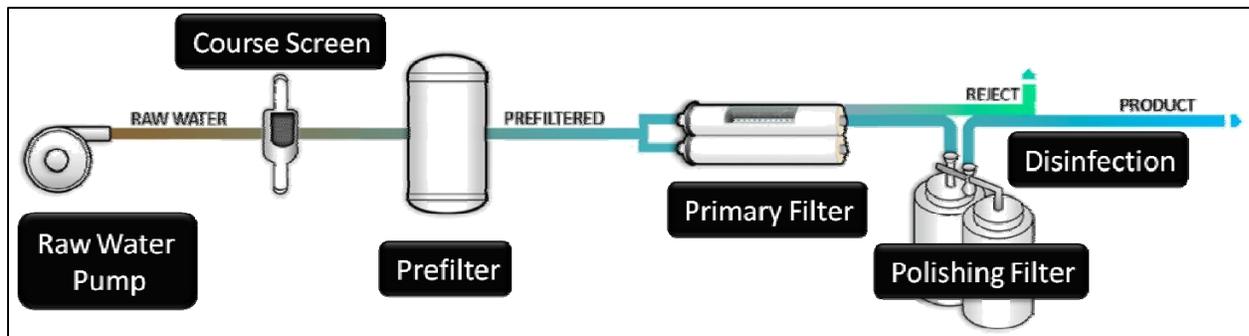
b. Concept of Operation (CONOP). USAPHC (Prov) identified three distinct operational scenarios in which a COTS water treatment system might offer a solution for a small military unit. The scenarios were driven by technology and system design and fit to likely operational uses. The first scenario was the case of disinfection only. Second was a plumbed-in device, commonly known as point-of-entry (POE) or point-of-use (POU) devices, operated from an existing pressurized water system such as, a municipal distribution system or a pressurized well service. Third was a self-contained water treatment system with an electric, fuel, or environmental energy (solar, wind, human) driven pump to draw water from an undeveloped natural water source and a complete water supply platform. We chose to concentrate this study on the third scenario, and designated such systems Small Unit Water Purifiers (SUWPs).

(1) Disinfection Only. This scenario assumed that through raw water characterization, planned water exposure, or lack of resources, only a chemical or physical disinfection process would be needed. Disinfection materiel research was limited to “systems,” which at a minimum, provided a means to supply a measured dose of disinfectant to the water supply regularly without operator interaction. The addition of chemicals to a storage container, for instance, in a batch method was not considered a system. The systems identified are presented in Appendix C, *Disinfectant Systems*, but were not further evaluated.

(2) POU/POE Devices. POU/POE devices include a broad spectrum of water treatment systems, and contaminant-specific media such as screw-on carbon filters, under-sink reverse osmosis (RO) cartridges, and stand-alone water softeners. Some POU/POE devices could be augmented with a pumping system to nearly equal the self-contained category. Many POU/POE devices have been assessed by manufacturer and independent laboratories in accordance with (IAW) NSF International (NSF) and American National Standards Institute (ANSI) Standards 53, 55, 58, 62, and NSF Protocol P231. To that end we did not further evaluate POU/POE devices. Potential users of POU/POE devices should refer to completed testing under the identified protocols and find a system that has been shown to offer microbiological and chemical reduction IAW these standards (references 3, 4 and 5). USAHPC (Prov) can provide consultation on specific devices as needed.

(3) Self-Contained SUWPs. As illustrated in the Figure below, the project team defined a theoretical desirable SUWP as a device or system that provides a complete water treatment platform; including:

- Raw water assembly – Mechanism(s) to pull or push raw water from the source
- One or more water treatment stages targeting microbiological and, ideally, chemical contaminants
- Disinfection to achieve microbiological performance
- A mechanism to dispense the product water (valve, tap, pump, etc.)



**Figure. Theoretical SUWP.**

As shown in the figure, the raw water assembly typically includes a pump and course screen. Treatment may include a prefilter(s), primary filter, and polishing filter. A reject stream is illustrated, and would be present with technologies such as RO. Disinfection, commonly an ultraviolet (UV) reactor in SUWPs, is the final stage illustrated. Additional qualifiers and assumptions we made for the SUWP CONOP include the following:

(a) An SUWP should provide safe drinking water from an identified freshwater, brackish, or salt water source as required by the mission. Such a system might be employed at any sustained, isolated bivouac or operation where there are limited or no military or contract assets to produce water. An SUWP may be desirable where it is impractical to carry or transport sufficient water for the duration of the mission, and water resupply is constrained by location, resources, security, or mission. For humanitarian assistance missions, SUWPs might be less vulnerable, more easily maintained, and encourage ownership and protection by local nationals, compared to building a large infrastructure.

(b) An SUWP is likely to be operated in a stationary mode, transported from location to location by vehicle or trailer, and is man-portable (could be modular) to the extent that mounting/dismounting and local moves should not require material handling equipment.

(c) Small units likely to use SUWPs were estimated to be from 5-50 personnel in size requiring approximately 30 to 425 gallons per day for a period of 10 days to 6 months.

## 5. APPROACH.

a. Integrated Project Team (IPT). The Water Supply Management Program at USAPHC (Prov) acted as the core team. We matrixed with multiple internal and external organizations to complete the study. We retained the ECBC DAT for their expertise in structured decision-making methodology (see Appendix B). We invited representatives from key agencies in research and development; testing; combat development; and conventional and special operations forces of the Army, Air Force, and Marine Corps to participate in a multi-disciplinary technical panel. The technical panel contributed to the development of the concept of operations, technical review procedures, prioritization of performance criteria used to score all the systems, and the ultimate ranking of the scored COTS SUWPs. Appendix D, *Multi-Disciplinary Team*, contains a list of participants.

b. Project Plan. We developed and followed a systematic, multi-faceted plan, which included the following, in chronological order:

- COTS SUWP Market Survey
- Evaluation Model Development
- Assessment
  - Paper studies and test data review
  - Operational analysis—handling, manipulating, and laboratory testing
  - Technical panel meetings – presentations, limited hands-on, and discussions
  - Scoring each COTS SUWP according to the established criteria and performance scales (applying the model)
  - Prioritizing (weighting) the model criteria, generating results
- Information Products—product development and web-enabled application

(1) The core team conducted a market survey to identify commercially available systems obtainable by deployed forces. The objective of the market survey was to identify systems that were designed and marketed for treatment of natural water sources with the goal of producing potable water. At a minimum, this meant they should provide microbiological pathogen removal and/or inactivation. Most SUWPs also provided limited chemical contaminant reduction, but systems that were designed solely for the reduction of a single contaminant, such as chlorine or lead, were not included in this study.

(a) We used internet outlets, customer references, and cross referrals from the first two. The SUWP vendors we identified were primarily small businesses with little presence in retail stores. Manufacturer, distributor, retailer, and technical support were

often one in the same. Selection for our study was not restricted by country of origin, but our sources were heavily weighted to North American and western European vendors, as these were more broadly marketed.

(b) USAPHC (Prov) continues to engage in market research as new equipment and technologies emerge; however, for this report, new systems were not included beyond the 20 July 2009 technical panel meeting. USAPHC (Prov) will capture new systems, as well as new data on existing systems, in order to advise customers and expand our database, as resources allow.

(2) The evaluation model defined a hierarchy of criteria, organized into goals and measures, that guided the assessment and decision making process. The DAT facilitated the identification of evaluation criteria that were discriminating, independent, and directly affected the production of potable water under the defined conditions. We hand-selected a working group of users and subject matter experts to review each criteria and the list as a whole.

(a) COTS materiel is generally purchased by a unit to fulfill an identified gap in fielded equipment, but one that has not (yet) been formally processed through the Military's Joint Capabilities Integration and Development System (JCIDS) process, and the unit cannot wait for a materiel solution to be developed through the normal Combat Development and JCIDS processes. For this study, the IPT constructed the model including goals and measures to integrate several diverse priorities, accepting that the lack of defined requirements would blur or result in overlap of certain operational objectives. The hierarchy of goals and measures began with resiliency; resiliency against waterborne pathogens and against the rigors of the military environment. Resiliency was supported by four goals of performance: robustness, redundancy, resourcefulness, and rapidity, which are defined below. Within each goal, we established detailed measures that were used to score each SUWP. The detailed measure definitions and performance scales are described in the DAT Report in Appendix B.

- Robustness – strength of system and its individual process elements or its key component to meet the demand and overcome environmental and operational extremes it may be subjected to.
- Redundancy – substitutable or backup functionality capable of achieving minimum performance requirements at less than full operational capability; compensation for vulnerability.
- Resourcefulness – extent to which the system provides discriminate (functional or operational) feedback, the vendor provides initial and ongoing

support, and the system design/employment compensates for failure and remediation.

- Rapidity – efficiency to set up, start up, maintain production, recover, warn, and repair; ease of use

(b) SUWPs were subdivided for evaluation according to size into the Briefcase, Footlocker, and Pallet bins shown in the Table. Briefcase-size SUWPs were only assessed and compared against other briefcase-sized systems. Footlocker and pallet-sized systems were assessed and compared together because of the anticipated overlap in their assumed mission scenarios. The cube, weight, and capacity values shown in Table 1 are the targets based on the study-developed CONOP, the US Army Combined Arms Support Command (CASCOM) *Water Planning Guide* (reference 6), and actual system specifications.

**Table. SUWP Size Bins.**

| <b>Metric</b>                | <b>Briefcase</b> | <b>Footlocker</b> | <b>Pallet</b> |
|------------------------------|------------------|-------------------|---------------|
| <b>Cube (ft<sup>3</sup>)</b> | 2                | 20                | 65            |
| <b>Weight (lbs)</b>          | 30               | 300               | 1000          |
| <b>Capacity (gal/day)</b>    | 30-130           | 100-300           | 200-650       |

(3) The assessment process was guided by the study objectives and the evaluation model. Beginning with the market survey results, we carried out a paper study of the data available from vendors and industry professionals to verify performance claims as objectively and completely as possible. In the absence of data, we conducted a limited theoretical assessment based on the technology employed. In order to generate more practical information, we made every effort to handle and test each SUWP. We attended trade shows and individual vendor demonstrations, and constructed our own laboratory test stand. We tested 13 of the candidate SUWPs, challenging each system with multiple water qualities. The protocol and findings of this effort are detailed in Appendix E. Finally, we convened the technical panel for an intensive 2-day panel meeting. The technical panel scored each SUWP against the model, prioritized the model criteria, and generated initial results for future analysis and interpretation by the DAT, presented in Appendix B.

(4) The core team was particularly interested in producing thorough and accurate information products to communicate actionable information to deployed forces. We sought to provide the right level of detail in a format that was convenient, and encouraged dialogue between the user, acquisitions personnel, and subject matter experts. Two-page specification sheets were developed for each SUWP, which provide objective summaries of the information gathered and assessments made (see Appendix

F). Mission-specific priorities will generate unique requirements that we can address with potential users on a case-by-case basis.

c. Assumptions and Limitations.

(1) The SUWPs evaluated were considered for use by a deployed military population. Characteristics of a military population relevant to this project and associated health risks from waterborne contaminants include:

- Fit and healthy
- 18-55 years of age
- No immuno-compromised members
- No pregnant members

(2) Only commercially-available systems were considered in this project. SUWPs were evaluated as commercially packaged and operated according to the manufacturers' instructions for use. No developmental or prototype systems were considered.

(3) SUWP cost was not considered in the analysis. Since each potential user would likely have different cost constraints, cost-benefit trade-offs would be unique to each user. Cost information was collected and included for reference in the study's informational products.

(4) Most analyses were constrained by data limitations. Few SUWP manufacturers had complete, third-party test data to verify their products' performance. As a result, the technical panel relied heavily on their professional experience and judgment to assess performance.

**6. FINDINGS AND DISCUSSION.** The project team compiled a set of weighted criteria considered critical to the acceptable performance of an SUWP and its capacity to provide safe drinking water in an austere military theater. The IPT findings relative to these criteria address both system hardware and its employment per manufacturer's operating instructions, but are general in nature, and not tied to a single system. By documenting the findings in this manner, we focused on the recurring gaps, which impacted the evaluation model scoring, found in Appendix B, *Data Analysis Team Report*. Finally, whereas some model criteria required subjective delineation, these findings are objective in nature. These findings used in conjunction with the model scoring will provide the decision maker insight to facilitate the selection process.

a. Multiple Barriers. The multiple barrier approach to safe drinking water as it applies to military field water supplies includes: 1) source water characterization, 2) treatment, 3) disinfection, 4) distribution system operation and maintenance, and 5) monitoring. The best SUWPs in terms of a multiple barrier approach employ two or more technologies, each capable of removing or inactivating microorganisms. They also provide real-time monitoring of performance and alert the operator or arrest production when error thresholds—identifying potentially unsafe water—are reached. The bulk of the SUWPs we assessed employed only a single treatment technology with the intended capability to remove or inactivate microorganisms. Likewise, the bulk of systems employed a single technology for limited chemical reduction. This reduced our confidence that a COTS SUWP could provide sustained potable drinking water without additional barriers. The risk of producing unsafe water was elevated if the single treatment barrier was particularly vulnerable to failure.

b. Performance Verification. The technical panel placed the greatest weight on verifiable microbiological treatment performance, considering its failure the greatest potential to cause mission degrading illness. Scales in the evaluation model reflected IPT levels of confidence that an SUWP could provide the necessary treatment. The greatest confidence, represented by a score of 100 on the evaluation model, was garnered by SUWPs that had protocol-driven, independent testing of the system as a whole. The technical panel gave a score of 85 to SUWPs whose primary treatment barrier was certified to an established standard. The majority of SUWPs fell below this level of confidence, with little or no verification of performance IAW established test protocols or standards.

c. Raw Water Assemblies. SUWP raw water assemblies include anchors, floats, screens, tubing, and pumps. The pumps serve to pull water from a raw water source, push it through the treatment train, and deliver the water to the consumer. Multiple burdens on these small pumps demand that the units be located very close to the water source. Some larger SUWPs employ separate, dedicated raw water pumps and lengthy water lines, which provide a superior solution from an operational perspective, but increases size, weight, and energy costs.

d. Filter Longevity. The majority of COTS SUWPs rely on one or more disposable cartridge filters for mechanical filtration. These are, with very few exceptions, configured with a single flow direction and no capacity for cleaning or regeneration while installed. The best SUWPs provide automatic cleaning and/or backwashing of non-fiber based filters. Though identified as cleanable—remove the filter, wash and replace—experience among the technical panel identified a severe decline in the operational time between cleanings after initial clogging of fiber-based filters. We also observed average filter lifecycles much shorter than advertised. Initial clogging typically occurred after a day's worth of production treating average quality surface water, and several times per

day when the source water was highly turbid. SUWPs trigger filter changes by means of an integrated alarm, decreased production rate, or pressure differential.

e. Disinfectants/Disinfectant Residuals. Very few SUWPs use a disinfectant that provides a residual. A pillar of the multi-barrier approach and particularly military field water is the use of a disinfectant that provides sustained, measurable residual. This means some of the disinfecting agent is carried through into and remains in the product water. It provides protection against bacterial re-growth, recontamination, and is measurable. If it is absent in stored water, the presumption is that something has contaminated the water. In military field water, chlorine is used for this purpose (reference 7). The predominant disinfection procedure employed by SUWPs is ultraviolet (UV) radiation (reference 8). While UV radiation is an effective method for the inactivation of microbes, UV does not provide a residual. A select few SUWPs offer a standard or optional chlorinator by way of solution injection or tablets for batch dosing.

f. Additional Gaps in the COTS SUWP Platform. Water production on any scale requires a source water, a means to collect or transport water to the treatment site, a treatment train, a second transport assembly likely with storage capacity, and finally a distribution network to deliver the water to the consumer. Unlike an individual water purifier where the end-to-end platform may quite literally fit into one's pocket, the SUWP CONOP, described above in paragraph 4b, calls for a mobile yet considerably more robust platform. Current commercial systems leave a number of gaps in that process. Some materiel limitations were identified above, including weaknesses in raw water assemblies, disinfectants, and disinfectants residual. Looking across the Doctrine, Organization, Training, Materiel, Leadership and Education, Personnel, and Facilities (DOTMLPF) spectrum, there are additional gaps not normally addressed by COTS solutions. They include establishing or developing of water sources, training of operators, public health oversight of water quality, sanitary storage and distribution of product water, and the ancillary equipment or procedures necessary to fill each gap.

g. SUWP Test Protocol. USAPHC (Prov) submitted the SUWP CONOP to NSF along with a list of recommended changes for incorporation into NSF Protocol P248, "Emergency Military Operations Microbiological Water Purifiers" (reference 9). NSF Protocol P248 was developed by USAPHC (Prov) for individual water purifiers in conjunction with a previous Army Study. Three commercial systems have to-date undergone testing using some or all of the modified P248 procedures. We will continue to work in close cooperation with NSF to publish an updated protocol for performance testing of SUWPs.

**7. CONCLUSIONS.** We concluded through our research, testing, and detailed assessment, that a single COTS SUWP is not currently available that can autonomously and completely fill the gap in military materiel for expeditionary forces to produce drinking water at the small unit level; nor will any single system we evaluated likely be the perfect solution for all deployment needs. The lack of available performance verification data limited our capability to identify clear leaders, echoed in the narrow band of score totals produced using the evaluation model. Ultimately, it was the IPT's observations as experienced engineers and scientists that separated one SUWP from another in terms of anticipated functionality. The information products produced during this study will assist potential users with weighing and comparing the benefits and shortcomings of each COTS SUWP and help them choose appropriate systems by matching SUWP capabilities with mission requirements; mindful that it may be necessary to combine systems or enhance systems with additional technologies to produce a complete solution. The experience gained by the IPT positions USAPHC (Prov) to provide relevant and ready consultation to potential military users, as well as to members of the public health community who may be called upon to provide medical oversight for SUWP employments.

a. Multiple Barriers. SUWPs with more than one treatment barrier and real-time performance monitors which arrest operation are superior to those which may contain only a single treatment barrier as well as those that lack performance feedback. Non-water treatment characteristics such as external design and packaging may impact the overall resilience necessary to meet the demands of the mission.

b. Performance Verification. Protocol-driven independent performance verification provides the highest level of confidence that a SUWP will provide microbiologically safe water. Certified components provide the next level of confidence. The presence of a single component certification does not equate to performance verification of the entire system.

c. Raw Water Assemblies. Inadequate raw water assemblies require COTS SUWPs to be located very close, as close as 4 feet, to the raw water source, or be augmented with raw water collection and storage systems. This may negatively impact the practicality, convenience, and security of producing water with an SUWP.

d. Filter Longevity. Filter clogging can severely reduce water production rates. The need to stock many filter spares increases the capital and logistical burden associated with many COTS SUWPs. However, some of the evaluated units have the ability to automatically backwash filters in place, and can thus reduce this burden.

e. Disinfectants/Disinfectant Residuals. SUWPs employing no disinfectant technologies, or only one such as UV radiation that does not provide a measurable

residual, require supplemental disinfection by the user unless the water is to be directly consumed. This may impact the complexity and required man-hours dedicated to water production.

f. Additional Gaps in the COTS SUWP Platform. COTS SUWPs are an incomplete water production platform. In addition to materiel add-ons, the military planner will encounter gaps across the DOTMLPF spectrum associated with SUWP operation and also quality oversight.

**8. RECOMMENDATIONS.** Decision makers should define the water requirements for each mission before approaching the COTS SUWP market, and consider the following:

- Why is a military reverse osmosis water purification unit an untenable solution?
- Is the raw water source-fresh or salt or brackish, and is it surface or ground or municipal?
- Number of personnel supported
- Duration of mission
- Other available water resources (i.e., bottled water, delivered bulk water)
- Quantity of water required-consult CASCOM *Water Planning Guide* (reference 6)
- Required portability and available transportation assets
- Budget

With these considerations made, the information products in Appendix F can help narrow the search for an SUWP that will be best suited for the defined mission. USAPHC (Prov) can assist with further consultation. Extending from the study findings and conclusions, we offer the following recommendations.

a. Multiple Barriers. Select SUWPs which offer multiple barriers to microbiological and chemical contaminants and provide performance monitoring.

b. Performance Verification. Evaluate the quality of manufacturer-provided performance verifications or certifications when reviewing candidate SUWPs. Recognize that many certifications are for material properties only, and are not performance-based. Further recognize that standards may be very narrowly focused and not accurately reflect complete system performance. They should only be used as tools to support comprehensive assessments. Consult official product listings such as [http://www.nsf.org/certified/consumer/listings\\_main.asp](http://www.nsf.org/certified/consumer/listings_main.asp).

c. Raw Water Assemblies. Consider accessibility and security of the source water site in the mission planning and SUWP procurement process. If it is not practical to operate on or very near the water source, additional materiel solutions must be planned

as well as transportation of product water. USAPHC (Prov) can provide examples of add-on enhancements to raw water assemblies.

d. Filter Longevity. Choose SUWPs that provide prefilters that can be cleaned or backwashed without removing the filters. Otherwise, if simplicity of design and operation outweigh other measures, plan for frequent filter changes and the associated logistical impact.

e. Disinfectants/Disinfectant Residuals. Ensure that the product water is disinfected if it will be stored prior to distribution to individual consumers. Consider SUWPs or add-on assemblies which provide a means to meter or dose disinfectants and provide a residual (chlorine is the recommended disinfectant). If the water will be consumed directly or dispensed into individual user containers, e.g., canteens, a residual is less critical, yet remains desirable. See Appendix C, *Disinfectant Systems*, for a list of disinfectant systems and contact USAPHC (Prov) for assistance in making a selection.

f. Additional Gaps in the COTS SUWP Platform. Consider all aspects of the water mission when entering the SUWP market. Develop a concept of operations that addresses the multiple barrier approach including quality oversight. Recognize the need to procure multiple equipment sets, perhaps from more than one source, in order to assemble a complete platform. Contact USAPHC (Prov) for assistance in choosing from available sources to build a more complete mission-oriented platform around the treatment train of a selected COTS SUWP.



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## APPENDIX A

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**APPENDIX B  
DATA ANALYSIS TEAM REPORT**

Prepared by:  
Edgewood Chemical Biological Center Decision Analysis Team

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# EDGEWOOD

## CHEMICAL BIOLOGICAL CENTER

U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND

ECBC-TR-796

### SMALL UNIT WATER PURIFIER STUDY

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U.S. ARMY CENTER FOR HEALTH PROMOTION  
AND PREVENTIVE MEDICINE

August 2010

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## EXECUTIVE SUMMARY

Water supply is a critical requirement for Warfighter sustainment on the battlefield. A (b) (3) (A), whereby small, isolated Military units may need to supplement traditional water supplies. A Small Unit Water Purification (SUWP) system should provide microbiologically safe water to keep soldiers mission ready in cases where they do not have access to an Army-provided water supply. Small units are procuring and using Commercial off the Shelf (COTS) SUWP systems that are not designed as military equipment and as such, may vary greatly in their capabilities, treatment methods, water production (capacity), and field worthiness. (b) (3) (A)

To address this problem, the U.S. Army Center for Health Promotion and Preventive Medicine (CHPPM) conducted a study to evaluate COTS SUWP systems and recommend the best available systems for procurement and use. SUWPs were assessed based on ability to provide adequate volumes of microbiologically safe drinking water in environments throughout the world where Warfighters are deployed. User and market surveys were conducted to identify available SUWP needs and systems, and a database was developed to organize information collected from various sources to help assess the SUWP systems.

CHPPM tasked the U.S. Army Edgewood Chemical Biological Center Decision Analysis Team (DAT) to support the assessment of SUWP systems. DAT developed a Multi-Criteria Decision Making approach for this evaluation. In this methodology, each SUWP system was evaluated against criteria developed to address the robustness, redundancy, rapidity, and resourcefulness of the system. Each criterion was defined, a performance scale was developed, and the factors were weighted based on their importance to and impact on the evaluation. Each system was scored against the evaluation criteria, and results were analyzed to develop recommendations for COTS SUWP systems for use by small units.

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## PREFACE

The work described in this report was started in September 2008 and completed in September 2009.

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This report has not been approved for public release.

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Warfighters are deployed. As part of the study, CHPPM conducted user and market surveys to identify available SUWP needs and systems. CHPPM also developed a database to organize information that was collected from various sources to help assess the SUWP systems. However, none of the systems under consideration have been tested, evaluated, or approved by any of the Services' Surgeons General.

The ECBC Decision Analysis Team (DAT) supported CHPPM by developing and implementing an approach to evaluate the SUWP systems, which is described in the next section.

### 3. EVALUATION PROCESS

The approach to assess the SUWP systems used a logical, structured decision analysis process, which included thorough documentation of the results and rationale so that final recommendations could be readily explained and defended. This process was comprised of the following five phases:

1. Form study team and identify participants
2. Perform operational and requirements analysis
3. Identify and describe SUWP systems
4. Develop evaluation model
5. Assess SUWP systems

The five phases are described in detail in this section, followed by the analysis of results, and then the study's conclusions and recommendations.

#### 3.1 Study Team and Participants

A study team was formed as the first step of the evaluation process. The core study team consisted of CHPPM personnel and decision analysts from the DAT. The decision analysts were responsible for developing and implementing the evaluation approach, facilitating the study team through the process, and analyzing the results. The core team identified user representatives and technical experts to participate in subsequent study steps.

The user representatives' primary role was to articulate the water use and consumption needs of the service member (user). The technical experts were selected for their knowledge and expertise in water purification technologies, which they used to assess the various SUWP systems.

The study was performed in a collaborative fashion, using facilitated decision conferences to accomplish most of the required work. The study participants are listed in Appendix A.

## 3.2 Operational and Requirements Analysis - User Profile Development

### 3.2.1 Water Treatment Scenarios

Three distinct water treatment scenarios were identified in which a commercialized water treatment system might offer an off-the-shelf solution to small military unit water demands. However, only self-contained systems, referred to as SUWPs, were considered to be applicable for this study. These autonomous, self contained water treatment systems, with a power, fuel, or environmental energy (e.g., solar, wind) source, would provide a complete water supply platform that would meet the needs of the user.

The distinctions between the three treatment scenarios are highly driven by technology and system design and likely operational use. These scenarios are described in detail below:

#### 3.2.1.1 Disinfection Only

Through raw water characterization, planned water exposure, or lack of resources, it is determined that only a chemical or physical disinfection process is needed. Only disinfection “systems” were considered. The device must include a method for supplying a calculated or measured dose of disinfectant to the water supply regularly without operator interaction. For instance, the addition of chemicals to a storage container in a batch method would not be considered a system. This study did not evaluate disinfection only systems because they do not provide the user with a complete water treatment solution.

#### 3.2.1.2 Point of Entry Devices

Plumbed-in or point of entry (POE) devices operate from existing pressurized water systems, whether municipal or established well service. POE devices include complete water treatment systems, lacking only a means to draw and distribute water, and devices targeted at a single contaminant (such as water softeners). POEs supplemented with a pump system would be relatively equivalent to the self contained category and may be sufficient to meet the user’s needs.

This study did not evaluate POE systems because information is readily available for the user to identify an appropriate system that will meet their needs. Additionally, POE systems may be well characterized by NSF/ANSI Standards 53, 58, 62, and Protocol P231 that verify the system’s ability to reduce microbiological and chemical contaminants that may be present in water. Users should refer to certification testing under the identified protocols to find a system that offers microbiological and chemical reduction in accordance with these standards and their needs.

#### 3.2.1.3 Self-Contained

The project team defined a SUWP as a self-contained device or system providing a complete water supply platform; including:

- Raw water assembly- mechanism(s) to pull or push raw water from the source

- One or more water treatment stages targeting microbiological and also, ideally, chemical contaminants
- Disinfection, although not expressly required, likely necessary to achieve microbiological performance
- Mechanism to dispense the product water

### 3.2.2 SUWP Operational Scenario

This section further describes the conditions and constraints of the likely SUWP operational concept.

#### 3.2.2.1 Mounted, Dismounted, or Stationary

A SUWP is likely to be operated in a stationary camp, but portability is an objective due to the potential need to frequently move the system. A SUWP is likely to be transported by vehicle or trailer and must be man portable only in so much as mounting/dismounting and local moves should not require material handling equipment.

#### 3.2.2.2 Water Sustainment

A SUWP would be primarily employed under a planned use or to augment a planned use scenario. The length of use ranges widely from (b) (3) (A).

#### 3.2.2.3 Daily Water Requirement

Based on the 2008 U.S. Army Combined Arms Support Command (CASCOM) water planning guide, Appendix B, for a conventional theater of operations, the arid and temperate minimum potable water requirements are 8.5 and 6 gal (32 and 23 L), per person per day, respectively. Small units likely to use a SUWP consist of 5 to 50 personnel. The resulting water demand ranges from 30 to 425 gal/day and a required flow rate of less than 1 gallon per minute (gpm) up to around 2 gpm.

#### 3.2.2.4 Example Locations

An outpost in an urban area situated among local forces with intermittent municipal water supply of uncharacterized quality. Resupply is sporadic.

An outpost in remote rural location with well water supply. Technical terrain prohibits vehicle traffic. Air resupply is available, but weight and cube are limited.

A base camp with surface water supply and local national water delivery/waste recovery where the water quality is unknown and assumed contaminated. Security and weather along supply routes make frequent logistics support difficult.

A short duration mission that does not warrant or allow logistics train.

### 3.2.2.5 Size Bins

SUWPs were subdivided according to size. Recognizing that a user enters the market looking for a specific size or water capacity, three size bins were defined. The characteristics for each bin are shown in Table 1 below. Larger systems have an inherent advantage over briefcase sized SUWPs as they can produce much larger quantities of water. For this reason, briefcase sized SUWPs will be evaluated separately from the footlocker and pallet sized systems. Footlocker and pallet sized systems were assessed together based on the assumption that both sizes would be used in similar stationary scenarios with greater water requirement.

Table 1. SUWP Size Bins

|  | <b>Briefcase</b> | <b>Footlocker</b> | <b>Pallet</b> |
|--|------------------|-------------------|---------------|
| Cube (ft <sup>3</sup> ) <sup>1</sup>               | 3                | 16                | 53            |
| Weight (lbs)                                       | 55               | 330               | 650           |
| Dist <sup>2</sup> Capacity (gal/day <sup>3</sup> ) | 75-750           | 180-5520          | 900-2220      |
| Dist Cube (ft <sup>3</sup> )                       | 0.3-6.5          | 5.8-24.6          | 25.6-53.8     |
| Dist Weight (lbs)                                  | 27-70            | 100-450           | 550-900       |
| Dist flow rate (gal/min)                           | 0.1-4.5          | 0.6-22            | 0.7-8.3       |
| Number of COTS <sup>4</sup>                        | 12               | 8                 | 3             |

<sup>1</sup> Cube and weight are averaged values intended to define each bin.

<sup>2</sup> Distribution or "dist" capacity, cube, weight, and flow rate are the distribution of actual system characteristics within each bin.

<sup>3</sup> A day was considered to be 10 h as this is the amount of time that the Warfighter is expected to be able to dedicate to water production.

<sup>4</sup> Number of COTS is the total of number of systems that were evaluated in this bin.

### 3.3 System Identification and Screening

CHPPM attempted to evaluate any commercially available system obtainable by the deployed Warfighter. SUWPs were primarily identified from internet sources (e.g., vendor and government websites), customer references, and cross referrals from the two. Selection was not restricted by country of origin as long as the system could be purchased but was heavily weighted to North American and western European vendors as these were more broadly marketed. The objective of the survey was to identify all systems that were designed and marketed for treatment of natural water sources with the goal of producing potable water. At a minimum this meant they should provide microbiological pathogen removal and/or inactivation. Most SUWPs also provided limited chemical contaminant reduction capacity, but systems that were designed solely for the reduction of a single contaminant such as chlorine or lead were not included in this evaluation.

To evaluate the pathogen reduction ability of the systems, laboratory testing results were critical. Every effort was made to locate and review all available laboratory results showing system efficacy. Sources of data included, but were not limited to, web searches, direct manufacturer contact (through correspondence or in person), previous market surveys, and contact with other DoD organizations. In the absence of data, the treatment technology used by the system became the primary basis for determining efficacy. When possible, systems evaluated were obtained and personally inspected, and limited system testing was

conducted in some cases by CHPPM. The information gathered from CHPPM testing was not considered protocol driven testing but was used to advise user and technical experts during their evaluation of the SUWPs.

The survey of available COTS SUWP systems revealed 54 systems produced by 16 manufacturers. Initial review of the systems indicated that many of them were not feasible candidates for meeting the needs of the Warfighter as defined in this study. To reduce the number of systems that would be evaluated against the detailed evaluation model (Section 3.4), CHPPM experts, conducted a screening phase. In this phase, systems were eliminated for consideration in the detailed evaluation based upon the following four primary reasons:

1. The system is from the same manufacturer and is very similar to another system that was included in the detailed evaluation.
2. The system was intended for use as an individual water purification (IWP) device, not to supply sustained water to a small unit.
3. The system was determined to be too large to fit in the footlocker and pallet size bin.
4. The system was an incomplete platform. For example, the system was disinfectant only or did not include a raw water pump.

Using these requirements, 31 systems were eliminated with rationale documenting why they were not considered further. This left 23 systems from 13 manufacturers to be included in the detailed evaluation (12 briefcase and 11 footlocker/pallet). A complete list of the screened SUWPS, including the rationale for removal, is shown in Appendix C.

Information was collected on each of the remaining systems and recorded in a database developed for this study. The database includes test results and physical properties of the SUWPs. System information papers were developed based on this information; the information papers were used by the technical experts during their evaluation of the SUWPs.

Table 2 lists the systems that were considered for the detailed evaluation, their manufacturer, the system name abbreviation, and the size bin of the system. For the remainder of this report, the systems will be referred to by the name abbreviations in Table 2.

Table 2. SUWP System Description

| Manufacturer                                  | System Name                                  | System Abbreviation   | Size Bin   |
|---|--|-----------------------|------------|
| Aspen Water, Inc.                             | Aspen 1000DM                                 | Aspen 1000DM          | Footlocker |
| Aspen Water, Inc.                             | Aspen 1800 Water Purification System         | Aspen 1800            | Briefcase  |
| Aspen Water, Inc.                             | Aspen 5500M                                  | Aspen 5500M           | Footlocker |
| Blue Spring Corporation, USA                  | WP-35  | Blue Spring WP-35     | Briefcase  |
| Blue Spring Corporation, USA                  | WP-60S                                       | Blue Spring WP-60S    | Briefcase  |
| First Water Systems                           | Outpost-4                                    | First Water Outpost-4 | Footlocker |
| First Water Systems                           | Responder                                    | First Water Responder | Briefcase  |
| Global Hydration Water Treatment System, Inc. | Can Pure LT22c                               | Can Pure LT22c        | Footlocker |
| Global Hydration Water Treatment System, Inc. | Can Pure P3-2008A                            | Can Pure P3-2008A     | Footlocker |
| Global Hydration Water Treatment System, Inc. | Can Pure P3-2008B                            | Can Pure P3-2008B     | Pallet     |
| Global Water Group, Inc.                      | LS3 M5000                                    | Global LS3 M5000      | Footlocker |
| Global Water Group, Inc.                      | LS3 SP BP UV                                 | Global LS3 SP BP UV   | Briefcase  |
| Karcher Futuretech                            | WTC 500                                      | Karcher WTC 500       | Footlocker |
| Noah Water Systems, Inc.                      | Trekker Portable Series                      | Noah Trekker          | Briefcase  |
| Pre-Mac International, Ltd.                   | JWP Range4                                   | Pre-Mac JWP-4         | Briefcase  |
| Safe DWP, LLC.                                | V-2 Purification Unit                        | Safe DWP V2           | Briefcase  |
| Seldon Technologies                           | Seldon Waterbox                              | Seldon Waterbox       | Briefcase  |
| SLMCO Pure Water Systems, LLC.                | Portable Series 5.0                          | SLMCO Ser. 5.0        | Briefcase  |
| Spectra Watermakers                           | Aquifer Portable System                      | Spectra Aquifer       | Briefcase  |
| Spectra Watermakers                           | Fresh Water Module Model FWM 22000           | Spectra FWM 22000     | Pallet     |
| Spectra Watermakers                           | Salt Water Module Model SWM 1500             | Spectra SWM 1500      | Footlocker |
| Spectra Watermakers                           | Solar Ultra Filtration Unit Model SSUF 20000 | Spectra SSUF 20000    | Pallet     |
| Village Marine Tec                            | Aquapack 400                                 | Village Aquapack 400  | Briefcase  |

The SUWPs can be further classified into two groups based on the technologies used for disinfection and filtration: 1) multi-stage cartridge and carbon filtration and 2) ultra-filtration and/or reverse osmosis, as shown in Tables 3 and 4. This information was not used for screening the systems; however, it was used during the detailed evaluations.

Table 3. Briefcase SUWP Technology Classification

| Multi-Stage Cartridge and Carbon Filtration | Ultra-Filtration and/or Reverse Osmosis |
|---|---|
| Aspen 1800                                  | Blue Spring WP-35                       |
| First Water Responder                       | Blue Spring WP-60S                      |
| Global LS3 SP BP UV                         | SLMCO Ser. 5.0                          |
| Noah Trekker                                | Spectra Aquifer                         |
| Pre-Mac JWP-4                               | Village Aquapack 400                    |
| Safe DWP V2                                 |   |
| Seldon Waterbox                             |   |

Table 4. Footlocker and Pallet SUWP Technology Classification

| Multi-Stage Cartridge and Carbon Filtration | Ultra-Filtration and/or Reverse Osmosis |
|---|---|
| Aspen 5500M                                 | Aspen 1000DM                            |
| First Water Outpost-4                       | Can Pure P3-2008B                       |
| Can Pure LT22c                              | Karcher WTC 500                         |
| Can Pure P3-2008A                           | Spectra SSUF 20000                      |
| Global LS3 M5000                            | Spectra FWM 22000                       |
|   | Spectra SWM 1500                        |

### 3.4 Evaluation Model

#### 3.4.1 Model Overview

A structured decision analysis process was used for the SUWP assessment. This process has been used by the ECBC DAT for numerous similar studies over the past several years. Decision analysis is a structured process for decision making based on established principles of operations research. The decision analysis process is composed of systematic development and examination of alternative courses of action to define and clarify available choices and associated advantages and disadvantages. It also includes thorough documentation of results and associated rationale so that final recommendations can be readily explained and defended.

This section describes how the evaluation model was developed and presents the primary elements of the model: the evaluation criteria, definitions, performance scales, and weights.

#### 3.4.2 Evaluation Criteria

The decision analysis methodology used for this study is referred to as Multi-Criteria Decision Making (MCDM). At its core is the identification of evaluation criteria, against which options are assessed. Several factors were considered during development of the evaluation criteria. First, evaluation criteria should differentiate the systems, so the criteria had

to be discriminating. Criteria also had to be independent so that aspects measured in one criterion were not repeated in another criterion. Finally, it was important to focus on the criteria that were most relevant and important to the decision.

For this study, an initial set of criteria was developed by the core study team. The initial criteria were based primarily upon those developed for a previous CHPPM study of IWPs, but were modified to apply to SUWPs. On 12 May 2009, a panel of user and technical experts (Appendix A) met with the CHPPM study team and the DAT to review and modify the criteria. These criteria were further modified and finalized during the assessment process, as described in Section 3.5.

The criteria were structured as a hierarchy, which is referred to as the evaluation model. The highest level of the model consisted of four criteria categories or goals: Robust, Redundant, Rapid, and Resourceful (defined in Section 3.4.3). The lowest level of the model was formed when each goal was further broken down into evaluation measures (e.g., *Bacteria Removal*). The SUWP systems were evaluated against each measure.

A decision support software tool, [REDACTED] (b) (5) was used to develop and document the evaluation model. Figure 1 depicts the evaluation model with goals (represented by rectangles) and measures (represented by ovals). Note that the basic structure of the model (goals and measures) is identical for briefcase and footlocker/pallet sized systems.

The study team decided to exclude cost from the potential evaluation criteria because each potential SUWP user would have different cost constraints, resulting in cost-benefit trade-offs that would be unique to each user. A cost-benefit analysis was conducted later and included in Section 4.4 of this report.

### 3.4.3 Definitions and Performance Scales

Definitions and performance scales were developed for each measure. Measure definitions are narrative descriptions that must be adequately and appropriately stated and clearly understood by the study participants and evaluation panel.

The performance scales serve as the “rating scheme” used to evaluate the systems, and represent the different levels of performance that could be expected among all the systems for each measure.

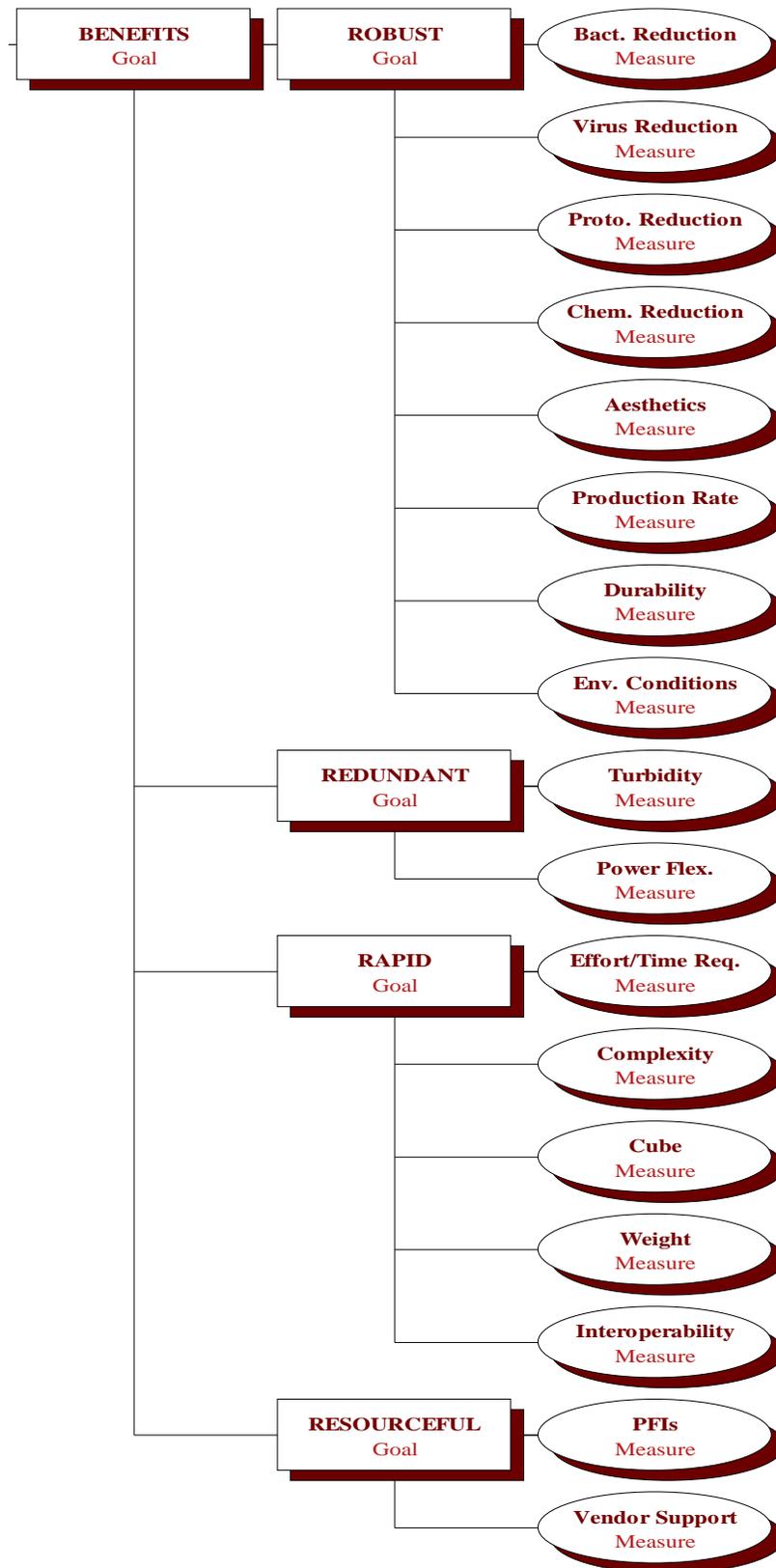
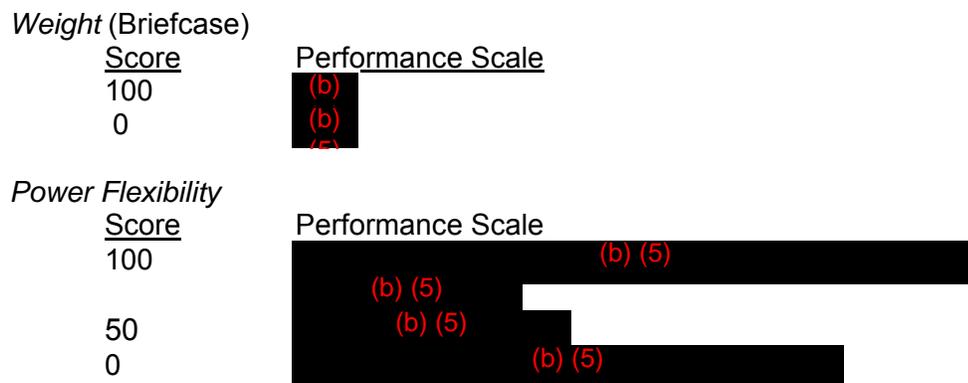


Figure 1. SUWP Evaluation Hierarchy

Some performance scales are continuous (e.g., numeric range of *Weight*), whereas others are discontinuous, or discrete levels referred to as labels (e.g., *Power Flexibility*). An example of each is shown below.



Performance scales are expressed as utility functions, which convert the different units for all the performance scales to a common scale. To set relevant endpoints and to establish appropriate intermediate utility values, the SUWP system characteristics had to be defined. Utility values of 100 and 0 were assigned to the high and low end of each performance scale. Intermediate level utilities were derived through various elicitation techniques focused on the relative importance of moving to-and-from various points on the utility function. In several cases the intermediate points were simply reference points, and the process allowed for scores anywhere along the scale. Each SUWP is assigned a score for each measure based on the performance scale for that measure.

The evaluation model can be comprised of quantitative and qualitative measures. For example, the *Weight* measure is a quantitative criterion, measured in numerical units (pounds). The *Durability* measure is an example of a qualitative measure, better assessed in more subjective terms (adjectival descriptors, e.g., high/medium/low). Additionally, some qualitative measures (identified in Appendix E) use relative scales where the systems are scored mostly relative to each other (e.g., *Complexity*).

The goals, measures, definitions, and defined performance scales are shown in Table 5. These apply to the briefcase and footlocker/pallet sized systems except where noted otherwise (e.g., *Weight*).

The three Pathogen Reduction criteria (*Bacteria*, *Virus*, and *Protozoa Reduction*), as well as *Chemical Reduction*, were each given separate scores for clean and worst case waters. Clean water was defined as water that is comparable in physical characteristics to the 'General' test water of NSF protocol P248 and worst case comparable to the P248 'Challenge' water. The overall score for each of those four measures was an average of the two scores for clean and worst case waters.

The measures in this assessment were grouped into four main goals: Robust, Redundant, Rapid, and Resourceful. The Robust goal addresses the strength or the ability of the system to perform through a given level of stress or demand without suffering degradation or loss of function. The Redundant goal addresses the extent to which a system has substitutable functionality capable of achieving minimum performance requirements; to compensate for vulnerability. Rapidity is the capacity of the system to meet priorities and

achieve goals in a timely manner to contain losses and avoid or minimize disruption to the operator. Resourcefulness is the capacity of the system to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some element, system, or other unit of analysis.

Table 5. Measure Definitions and Scales

| Robust |                           | Scales   |
|--------|---------------------------|--|
| #      | Measure                   | Definition   |
| 1      | Micro Reduction: Bacteria | <p>Ability to reduce bacterial pathogens from worst case source water (surface water, high turbidity, contaminated with pathogens).</p> <p>Measures 1-4 were scored twice for "clean" and "worst case" water</p> |
| 2      | Micro Reduction: Virus    | <p>Ability to reduce viral pathogens from worst case source water.</p> <p>Measures 1-4 were scored twice for "clean" and "worst case" water</p>  |

Table 5. Measure Definitions and Scales (Continued)

|   |                           | Robust   |  | Scales<br>(b) (5) |  |
|---|---------------------------|--|--|-------------------|--|
| # | Measure                   | Definition   |  |                   |  |
| 3 | Micro Reduction: Protozoa | <p>Ability to reduce protozoic pathogens from worst case source water.</p> <p>Measures 1-4 were scored twice for "clean" and "worst case" water</p>  |  |                   |  |
| 4 | Chemical Reduction        | <p>Ability to reduce chemicals in worst case source water, to include the range of chemicals removed (those causing acute and chronic health effects), removal rates, and capacity.</p> <p>Measures 1-4 were scored twice for "clean" and "worst case" water</p> |  |                   |  |

**(b) (5)** 5. Measure Definitions and Scales (Continued)

| Robust |                 | Scales  |
|--------|-----------------|---|
| #      | Measure         | Definition  |
| 5      | Aesthetics      | Reduces objectionable taste and odor considering extreme water temperatures. It is ideal for the SUWP to reduce taste and odor in source water and not impart any objectionable taste or odor to product water. |
| 6      | Production Rate | Gallons produced in a 10 h day.   |
| 7      | Durability      | Perceived ability of SUWP (including system and all accessories) to withstand drops, rough handling, etc. during transport and use. Includes published quality of design, construction, and materials.          |

(b) (5)

[Redacted content]

Briefcase:

(b) (5)

Footlocker/Pallet:

(b) (5)

[Redacted content]

Table 5. Measure Definitions and Scales (Continued)

| Robust    |                          |  |                   |
|-----------|--------------------------|--|-------------------|
| #         | Measure                  | Definition   | Scales<br>(b) (5) |
| 8         | Environmental Conditions | Impact of extreme environmental conditions on operations, stagnation, and storage of the system. Conditions required for maximum life of SUWP and consumable to include storage after the system has been used and may contain water (to account for freezing concerns).       | [REDACTED]        |
| Redundant |                          |  |                   |
| #         | Criterion                | Definition   | Scales<br>(b) (5) |
| 9         | Turbidity                | Impact of turbidity on the ability of the SUWP to maintain production rate. Based on the filtration process design to treat turbid water. (The impact of turbidity on pathogen reduction is included in the pathogen reduction ratings and is not included in this criterion). | [REDACTED]        |
| 10        | Power Flexibility        | The type of power required to operate the system and the flexibility of the system to use multiple power sources.  | [REDACTED]        |

Table 5. Measure Definitions and Scales (Continued)

|    |            | Rapid   |  |
|----|------------|---|--|
| #  | Criterion  | Definition  | Scales   |
| 11 | Effort     | Amount of dedicated effort by a single person required to operate SUWP (includes time and manpower). Includes set up and tear down, effort to reach minimum required volume, hazardous material use and disposal, cleaning, and scheduled maintenance requirements (e.g., scheduled filter replacement) during daily use. | (b) (5)  |
| 12 | Complexity | Complexity of the system – includes required technical knowledge and training to operate, trouble shoot, and repair in the field. (b) (5)   | (b) (5)  |
| 13 | Cube       | Cubic size of SUWP (including system and all consumables required to complete a 30-day mission).  | Briefcase: (b) (5)<br>Footlocker/Pallet: (b) (5) |
| 14 | Weight     | Weight of SUWP (including system and all consumables required to complete a 30-day mission).  | Briefcase: (b) (5)<br>Footlocker/Pallet: (b) (5) |

Table 5. Measure Definitions and Scales (Continued)

| Rapid       |                            |   |                   |
|-------------|----------------------------|---|-------------------|
| #           | Criterion                  | Definition  | Scales<br>(b) (5) |
| 15          | Inter-operability          | The use of commercially available (non-proprietary) consumables and common failure items.   | [Redacted]        |
| Resourceful |                            |   |                   |
| #           | Criterion                  | Definition  | Scales<br>(b) (5) |
| 16          | Process Failure Indicators | Indication of failure (e.g., alarm) of SUWP to produce safe water due to: unexpected failure, maintenance required, and/or capacities exceeded/end-of-life.<br>(b) (5)                          | [Redacted]        |
| 17          | Vendor Support             | Vendor provided reach-back, supply availability, technical and maintenance support and available training package. The likelihood of continued availability of support will also be considered. | [Redacted]        |

### 3.4.4 Measure Weights

The final model development step was to assign weights for the goals and measures, based on the importance of each goal/measure relative to the others. One hundred points were distributed among the measures. The weighting process considers relative priority and the concept of swing weighting. Swing weighting compares the effects of moving from the lowest point on the performance scale to the highest for any measure in relation to a similar move for any other measure. An example of this in the briefcase model was determining whether it was more important to move from (b) (5) for the *Environmental Conditions* measure or to move from (b) (5) for the *Weight* measure.

Various techniques are available for eliciting weights, including the Analytic Hierarchy Process (AHP), the Smart and Smarter algorithms, and direct entry. The Smarter Method was the primary weighting technique used to establish weights in this study. In this process, the user and technical representatives rank-ordered the measures, and an algorithm generated an initial weight for each measure that is dependent on its rank and the number of measures. After generating initial weights via Smarter algorithms, the user representatives adjusted the weights using direct entry.

The weights that were developed were different for the two SUWP size bins. The user representatives generated the weights for briefcase SUWPs first and then adjusted those weights to account for the different requirements of the footlocker/pallet sized SUWPs. The following discussion summarizes the structure of the weights and the differences between the two size bins. A complete list of weights can be found in Table 6 for briefcase and footlocker/pallet SUWPs.

Briefcase SUWPs: These systems are better suited for short duration missions that do not warrant/allow a large logistics trail.

- Most important to the user and technical experts were the *Bacteria* and *Virus Reduction* measures, followed by *Durability*, *Protozoa* and *Chemical Reduction*. These (b) (5).
- *Environmental Conditions* and *Power Flexibility* were more important for briefcase SUWPs (b) (5) than footlocker/pallet (b) (5) because they will probably be used in scenarios that require greater mobility and flexibility.
- *Weight* and *Effect of Turbidity* were low weighted (b) (5) because there was a relatively small range of performance with respect to these two measures for the briefcase systems.

Footlocker/Pallet SUWPs: These systems are probably used at relatively fixed locations.

- The Pathogen Reduction (*Bacteria*, *Virus*, and *Protozoa*) and *Chemical Reduction* weights did not change from the briefcase model, but *Durability* was ranked slightly lower for footlocker/pallet sized systems (b) (5) than for briefcase (b) (5).
- *Weight* and *Effect of Turbidity* were higher weighted (b) (5) due to a wider range in scores between footlocker/pallet sized systems.

The remaining measures not discussed were given the same or almost the same weight between the two models (+/-1%).

Table 6. Briefcase and Footlocker/Pallet SUWP Measure Weights

| Measure | Briefcase Weights (%) | Footlocker/Pallet Weights (%) |
|---------|-----------------------|-------------------------------|
| (b) (5) |                       |                               |

### 3.5 Assessment Process

On 21-22 July 2009, a panel of technical and user experts met with the CHPPM study team and the DAT to evaluate the remaining systems that passed the screening phase (Table 2) against the detailed evaluation model. Starting with briefcase SUWPs, the experts evaluated each system against each measure in the evaluation model. The panel discussed measure scores for each system, using the data presented in the system information papers as well as their own expertise, knowledge, and judgment. Discussion continued until a consensus was reached, at which point a score was assigned, based on the performance scale in the evaluation model. Scoring rationale was documented when required. This process was repeated until each system had been assessed against each measure for the briefcase SUWPs. This process was then repeated for the systems in the footlocker/pallet size bin.

A consistency check of the scores was performed to ensure that all systems were scored accurately relative to the performance scales and relative to each other. A few corrections were made and approved by the technical experts. The study team also modified the evaluation model in some cases to improve the ability of the model to discriminate between the different systems. (b) (5)

(b) (5) . A few scores were further modified after the detailed evaluation meeting based on results of on-going system testing performed by CHPPM. (b) (5)

The scores assigned to each briefcase and footlocker/pallet system are shown in Table 7.<sup>1</sup> The scoring rationale is shown in Appendix D. Once the scores were finalized, results were generated and analysis was performed. For scales based in natural units (*Production Rate, Cube, and Weight* measures) (b) (5) to a converted score on a scale from 0-100 based on the utility curve. These converted scores for briefcase and footlocker/pallet systems are shown in Table 8.

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<sup>1</sup> (b) (4)

Table 7. Assigned System Scores for Briefcase and Footlocker/Pallet SUWPs

| SUWP  | Robust             |       |                 |       |                    |       |                    |       |                                     |            | Redundant                |                     |                   |                 |            | Rapid           |              |                  |                            | Resourceful    |            |
|---|--------------------|-------|-----------------|-------|--------------------|-------|--------------------|-------|-------------------------------------|------------|--------------------------|---------------------|-------------------|-----------------|------------|-----------------|--------------|------------------|----------------------------|----------------|------------|
|   | Bacteria Reduction |       | Virus Reduction |       | Protozoa Reduction |       | Chemical Reduction |       | Production Rate (gal per 10 hr day) | Durability | Environmental Conditions | Effect of Turbidity | Power Flexibility | Effort Required | Complexity | Cube (cubic ft) | Weight (lbs) | Interoperability | Process Failure Indicators | Vendor Support |            |
|   | Worst Case         | Clean | Worst Case      | Clean | Worst Case         | Clean | Worst Case         | Clean |                                     |            |                          |                     |                   |                 |            |                 |              |                  |                            |                | Aesthetics |
| (b) (5)s  | 100                | 100   | 100             | 100   | 100                | 100   | 100                | 100   | 6000.0                              | 50         | 70                       | 67                  | 50                | 60              | 50         | 1.9             | 47.0         | 60               | 100                        | 50             |            |
| (b) (5)   | 67                 | 33    | 67              | 33    | 33                 | 33    | 40                 | 100   | 360.0                               | 85         | 80                       | 33                  | 100               | 75              | 90         | 4.0             | 65.0         | 25               | 60                         | 60             |            |
| (b) (5)   | 33                 | 33    | 33              | 33    | 33                 | 33    | 85                 | 70    | 150.0                               | 80         | 70                       | 50                  | 50                | 65              | 75         | 3.3             | 53.0         | 60               | 60                         | 85             |            |
| (b) (5)   | 33                 | 33    | 20              | 0     | 33                 | 33    | 60                 | 70    | 750.0                               | 80         | 80                       | 33                  | 100               | 50              | 70         | 3.9             | 68.0         | 50               | 90                         | 60             |            |
| (b) (5)   | 33                 | 33    | 33              | 33    | 33                 | 33    | 40                 | 50    | 540.0                               | 40         | 60                       | 33                  | 60                | 50              | 90         | 1.8             | 45.0         | 60               | 80                         | 50             |            |
| (b) (5)   | 33                 | 33    | 33              | 33    | 33                 | 33    | 85                 | 70    | 96.0                                | 80         | 70                       | 50                  | 100               | 60              | 40         | 6.5             | 70.0         | 50               | 60                         | 75             |            |
| (b) (5)   | 100                | 0     | 0               | 0     | 100                | 0     | 40                 | 70    | 600.0                               | 40         | 60                       | 33                  | 50                | 50              | 90         | 1.9             | 27.0         | 100              | 35                         | 50             |            |
| (b) (5)   | 33                 | 33    | 33              | 33    | 33                 | 33    | 70                 | 70    | 300.0                               | 25         | 25                       | 50                  | 50                | 50              | 50         | 1.0             | 45.0         | 60               | 60                         | 50             |            |
| (b) (5)   | 33                 | 0     | 0               | 0     | 0                  | 0     | 40                 | 25    | 600.0                               | 60         | 60                       | 33                  | 100               | 50              | 100        | 2.4             | 35.0         | 75               | 35                         | 40             |            |
| (b) (5)   | 33                 | 33    | 33              | 33    | 33                 | 33    | 70                 | 70    | 75.0                                | 25         | 25                       | 50                  | 75                | 50              | 50         | 0.3             | 60.0         | 60               | 60                         | 50             |            |
| (b) (5)   | 33                 | 33    | 20              | 0     | 33                 | 33    | 60                 | 70    | 540.0                               | 10         | 10                       | 33                  | 90                | 50              | 60         | 1.5             | 50.0         | 50               | 80                         | 40             |            |
| (b) (5)   | 33                 | 33    | 20              | 0     | 33                 | 33    | 40                 | 70    | 540.0                               | 0          | 0                        | 33                  | 60                | 30              | 60         | 1.9             | 30.0         | 100              | 35                         | 25             |            |
| The following SUWPs were categorized in the briefcase size bin              |                    |       |                 |       |                    |       |                    |       |                                     |            |                          |                     |                   |                 |            |                 |              |                  |                            |                |            |
| (b) (5)   | 85                 | 33    | 85              | 20    | 85                 | 20    | 85                 | 20    | 5520.0                              | 70         | 60                       | 67                  | 0                 | 60              | 65         | 16.1            | 448.0        | 65               | 100                        | 70             |            |
| (b) (5)   | 85                 | 85    | 85              | 85    | 85                 | 85    | 85                 | 70    | 1020.0                              | 70         | 60                       | 33                  | 0                 | 50              | 40         | 53.8            | 629.0        | 65               | 100                        | 70             |            |
| (b) (5)   | 33                 | 33    | 33              | 33    | 85                 | 20    | 20                 | 25    | 2700.0                              | 70         | 100                      | 67                  | 50                | 75              | 90         | 5.8             | 100.0        | 75               | 60                         | 70             |            |
| (b) (5)   | 85                 | 85    | 45              | 45    | 85                 | 85    | 85                 | 50    | 1560.0                              | 25         | 50                       | 50                  | 50                | 30              | 25         | 19.4            | 450.0        | 35               | 75                         | 60             |            |
| (b) (5)   | 33                 | 33    | 33              | 33    | 33                 | 100   | 100                | 100   | 180.0                               | 85         | 85                       | 75                  | 100               | 60              | 40         | 13.0            | 350.0        | 25               | 60                         | 75             |            |
| (b) (5)   | 45                 | 45    | 45              | 45    | 45                 | 100   | 100                | 100   | 780.0                               | 70         | 85                       | 50                  | 100               | 60              | 25         | 24.3            | 450.0        | 50               | 60                         | 60             |            |
| (b) (5)   | 45                 | 45    | 45              | 45    | 33                 | 60    | 60                 | 50    | 2040.0                              | 60         | 80                       | 33                  | 100               | 30              | 50         | 16.0            | 290.0        | 50               | 85                         | 40             |            |
| (b) (5)   | 33                 | 33    | 20              | 0     | 33                 | 60    | 60                 | 70    | 2100.0                              | 70         | 80                       | 33                  | 100               | 50              | 70         | 14.6            | 330.0        | 50               | 90                         | 60             |            |
| (b) (5)   | 33                 | 33    | 33              | 33    | 33                 | 40    | 40                 | 70    | 2220.0                              | 70         | 70                       | 100                 | 50                | 80              | 20         | 32.8            | 560.0        | 45               | 35                         | 75             |            |
| (b) (5)   | 33                 | 33    | 20              | 0     | 33                 | 40    | 40                 | 70    | 500.0                               | 0          | 40                       | 33                  | 60                | 75              | 80         | 24.6            | 200.0        | 100              | 80                         | 50             |            |
| (b) (5)   | 33                 | 33    | 33              | 33    | 33                 | 40    | 40                 | 70    | 900.0                               | 40         | 65                       | 100                 | 50                | 75              | 15         | 25.6            | 900.0        | 45               | 35                         | 75             |            |
| The following SUWPs were categorized in the footlocker and pallet size bins |                    |       |                 |       |                    |       |                    |       |                                     |            |                          |                     |                   |                 |            |                 |              |                  |                            |                |            |

Table 8. Converted System Scores for Briefcase and Footlocker/Pallet SUWPs

| SUWP  | Robust          |                 |                  |                 |            |                 | Redundant  |                          |           |             | Rapid |                 |            |      | Resourceful |                   |                            |                |
|---|-----------------|-----------------|------------------|-----------------|------------|-----------------|------------|--------------------------|-----------|-------------|-------|-----------------|------------|------|-------------|-------------------|----------------------------|----------------|
|   | Bact. Reduction | Virus Reduction | Proto. Reduction | Chem. Reduction | Aesthetics | Production Rate | Durability | Environmental Conditions | Turbidity | Flexibility | Power | Effort/Time Req | Complexity | Cube | Weight      | Inter-operability | Process Failure Indicators | Vendor Support |
| (b) (5)   | 100             | 100             | 50               | 85              | 100        | 78              | 50         | 70                       | 67        | 50          | 60    | 50              | 74         | 53   | 60          | 100               | 50                         |                |
| (b) (5)   | 50              | 50              | 33               | 40              | 100        | 42              | 85         | 80                       | 33        | 100         | 75    | 90              | 40         | 12   | 25          | 60                | 60                         |                |
| (b) (5)   | 33              | 33              | 33               | 85              | 70         | 11              | 80         | 70                       | 50        | 50          | 65    | 75              | 52         | 40   | 60          | 60                | 85                         |                |
| (b) (5)   | 33              | 10              | 33               | 60              | 70         | 100             | 80         | 80                       | 33        | 100         | 50    | 70              | 42         | 5    | 50          | 90                | 60                         |                |
| (b) (5)   | 33              | 33              | 33               | 40              | 50         | 69              | 40         | 60                       | 33        | 60          | 50    | 90              | 76         | 58   | 60          | 80                | 50                         |                |
| (b) (5)   | 33              | 33              | 33               | 85              | 70         | 3               | 80         | 70                       | 50        | 100         | 60    | 40              | 0          | 0    | 50          | 60                | 75                         |                |
| (b) (5)   | 50              | 0               | 50               | 40              | 70         | 78              | 40         | 60                       | 33        | 50          | 50    | 90              | 74         | 100  | 100         | 35                | 50                         |                |
| (b) (5)   | 33              | 33              | 33               | 70              | 70         | 33              | 25         | 25                       | 50        | 50          | 50    | 50              | 89         | 58   | 60          | 60                | 50                         |                |
| (b) (5)   | 17              | 0               | 0                | 40              | 25         | 78              | 60         | 60                       | 33        | 100         | 50    | 100             | 66         | 81   | 75          | 35                | 40                         |                |
| (b) (5)   | 33              | 33              | 33               | 70              | 70         | 0               | 25         | 25                       | 50        | 75          | 50    | 50              | 100        | 23   | 60          | 60                | 50                         |                |
| (b) (5)   | 33              | 10              | 33               | 60              | 70         | 69              | 10         | 10                       | 33        | 90          | 50    | 60              | 81         | 47   | 50          | 80                | 40                         |                |
| (b) (5)   | 33              | 10              | 33               | 40              | 70         | 69              | 0          | 0                        | 33        | 60          | 30    | 60              | 74         | 93   | 100         | 35                | 25                         |                |
| The following SUWPs were categorized in the briefcase size bin              |                 |                 |                  |                 |            |                 |            |                          |           |             |       |                 |            |      |             |                   |                            |                |
| (b) (5)   | 59              | 53              | 85               | 20              | 50         | 100             | 70         | 60                       | 67        | 0           | 60    | 65              | 79         | 56   | 65          | 100               | 70                         |                |
| (b) (5)   | 85              | 85              | 85               | 85              | 70         | 16              | 70         | 60                       | 33        | 0           | 50    | 40              | 0          | 34   | 65          | 100               | 70                         |                |
| (b) (5)   | 33              | 33              | 85               | 20              | 25         | 47              | 70         | 100                      | 67        | 50          | 75    | 90              | 100        | 100  | 75          | 60                | 70                         |                |
| (b) (5)   | 85              | 45              | 85               | 85              | 50         | 26              | 25         | 50                       | 50        | 50          | 30    | 25              | 72         | 56   | 35          | 75                | 60                         |                |
| (b) (5)   | 33              | 33              | 33               | 100             | 100        | 0               | 85         | 85                       | 75        | 100         | 60    | 40              | 85         | 69   | 25          | 60                | 75                         |                |
| (b) (5)   | 45              | 45              | 45               | 100             | 100        | 11              | 70         | 85                       | 50        | 100         | 60    | 25              | 61         | 56   | 50          | 60                | 60                         |                |
| (b) (5)   | 45              | 45              | 33               | 60              | 50         | 35              | 60         | 80                       | 33        | 100         | 30    | 50              | 79         | 76   | 50          | 85                | 40                         |                |
| (b) (5)   | 33              | 10              | 33               | 60              | 70         | 36              | 70         | 80                       | 33        | 100         | 50    | 70              | 82         | 71   | 50          | 90                | 60                         |                |
| (b) (5)   | 33              | 33              | 33               | 40              | 70         | 38              | 70         | 70                       | 100       | 50          | 80    | 20              | 44         | 44   | 45          | 35                | 75                         |                |
| (b) (5)   | 33              | 10              | 33               | 40              | 70         | 6               | 0          | 40                       | 33        | 60          | 75    | 80              | 61         | 88   | 100         | 80                | 50                         |                |
| (b) (5)   | 33              | 33              | 33               | 40              | 70         | 13              | 40         | 65                       | 100       | 50          | 75    | 15              | 59         | 0    | 45          | 35                | 75                         |                |
| The following SUWPs were categorized in the footlocker and pallet size bins |                 |                 |                  |                 |            |                 |            |                          |           |             |       |                 |            |      |             |                   |                            |                |

#### 4. RESULTS ANALYSIS

The analyses described here were conducted by the DAT (b) (5). The results analysis was performed from several perspectives:

- Overall scores and ranking relative to goals and measures (Section 4.1)
- Performance of individual systems, to identify strengths and weaknesses (Section 4.2)
- Sensitivity graphs, to identify the impact of variation in measure weights (Section 4.3)
- Cost Benefit graphs, to identify which systems received the highest benefit for the lowest cost (Section 4.4)

##### 4.1 Rankings Assessment

##### 4.1.1 Overall Results for Briefcase SUWPs

Twelve briefcase systems were evaluated. An overall score and ranking was generated for each system using a linear additive approach in which the converted score for each measure was multiplied by the measure weight and then summed across all measures. This resulted in an overall score and a ranking for each system.

Figure 2 shows a stacked bar chart which displays overall scores and rankings for the briefcase systems relative to the (b) (5) evaluation measures. The colored bars to the right of each system illustrate the proportion each measure contributed to the overall score for each system. The length of each sub-bar reflects the weight of the measure and the score a system received. The measures are listed in order of decreasing weight.

As seen in Figure 2, no system scored high on all attributes. Overall scores for most systems are in the moderate to low range:

- The top score was 72 (out of (b) (5)).
- The spread from the worst to best systems was 36 points (36 to 72).

(b) (5)  
(b) (5) scores fall into a "cascading" pattern, with no apparent tiers. The spread of scores among the systems ranked in the top half, other than (b) (5), is fairly narrow, indicating individual tradeoffs will be required to select preferred systems. Although systems that scored in the top half of the ranking are considered to have a higher benefit, any system may have a strength that makes it a viable option for a particular mission or application, provided the system is capable of producing sufficient quantities of safe drinking water. It should be noted that only two systems, the (b) (5), have had third party, protocol-driven testing. It is possible that other systems would score at least as well as these systems if this testing were conducted.

To determine the individual tradeoffs between systems, an in-depth analysis of the briefcase SUWP results for each measure under the Robust, Redundant, Rapid, and Resourceful goals is provided in Appendix E.

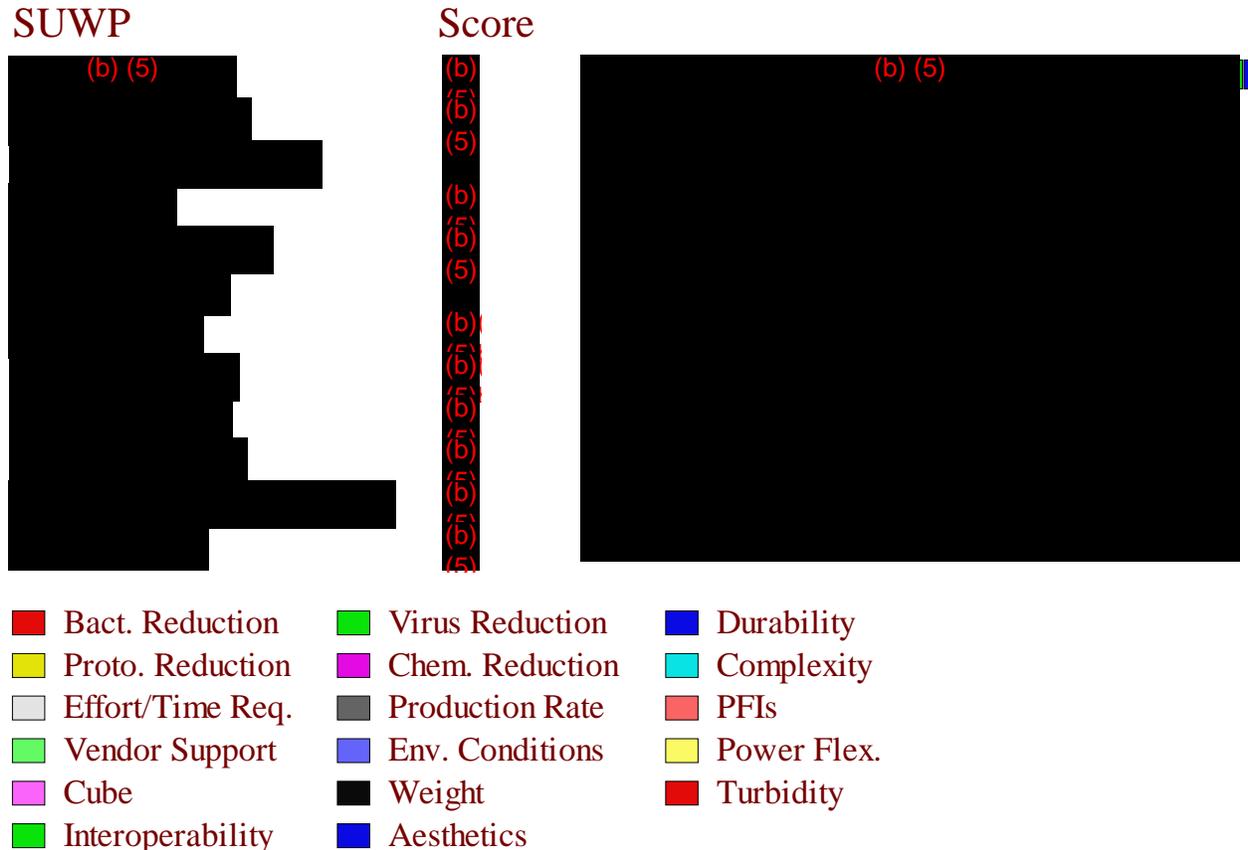


Figure 2. Stacked Bar Ranking for Briefcase SUWPs

#### 4.1.2 Overall Results for Footlocker and Pallet SUWPs

Footlocker and pallet sized systems were evaluated together because they will be used in similar mission scenarios. Eleven total systems were evaluated (eight footlocker and three pallet). Figure 3 shows the stacked bar charts for these systems. As with the briefcase SUWPs, no system scored high on all attributes. Overall scores for most systems are in the moderate range.

- The top score was 63 (out of (b) (5)).
- The spread from worst to best was only 23 points (b) (5).

As with the briefcase SUWPs, the system scores fall into a “cascading” pattern, with no apparent tiers. The spread of scores between the systems ranked in the top half is fairly

narrow, indicating individual tradeoffs will be required to select preferred systems. An in-depth analysis of the footlocker and pallet SUWP results for each measure can also be found in Appendix E.

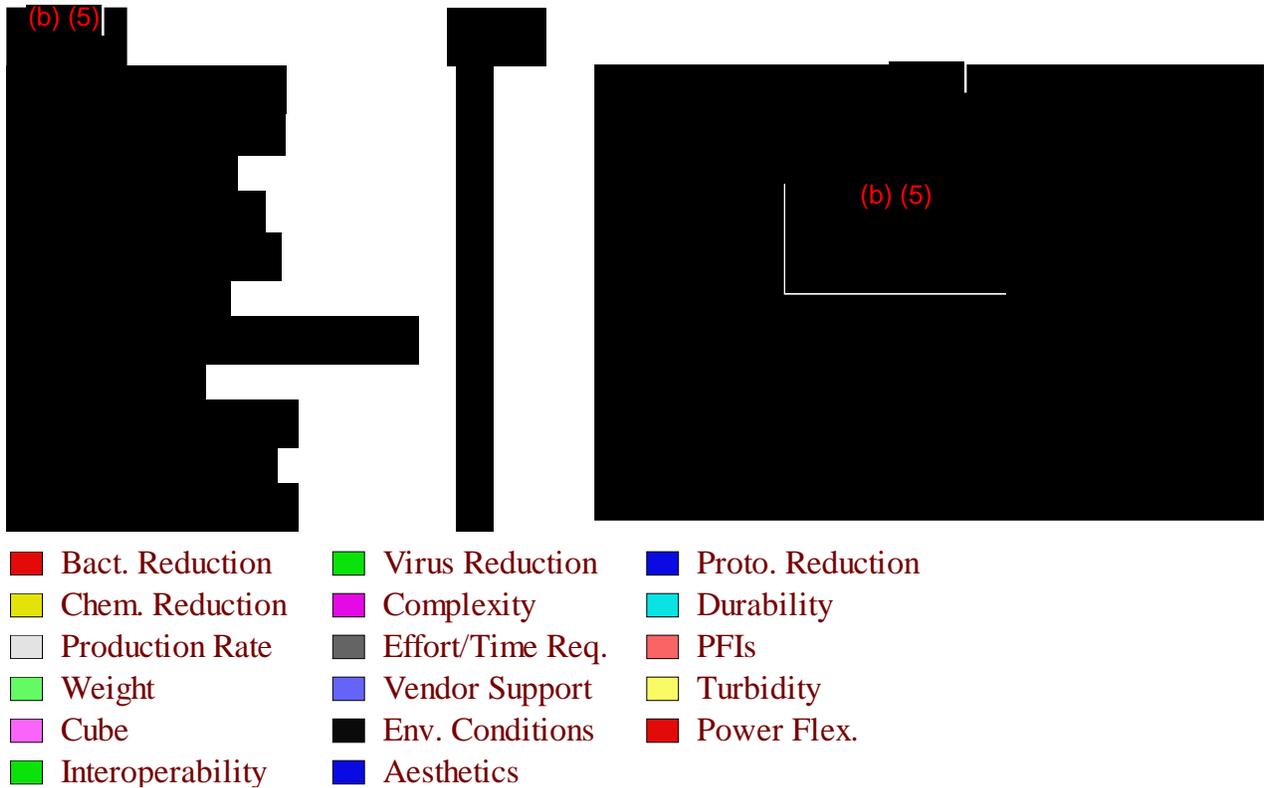
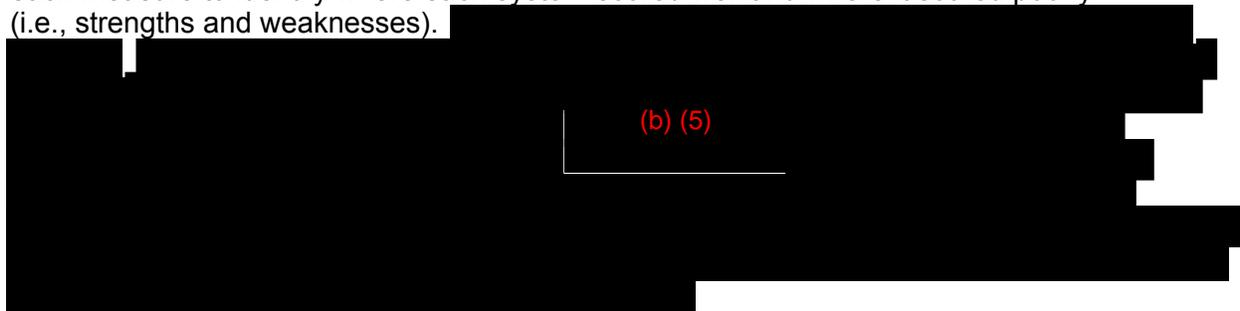
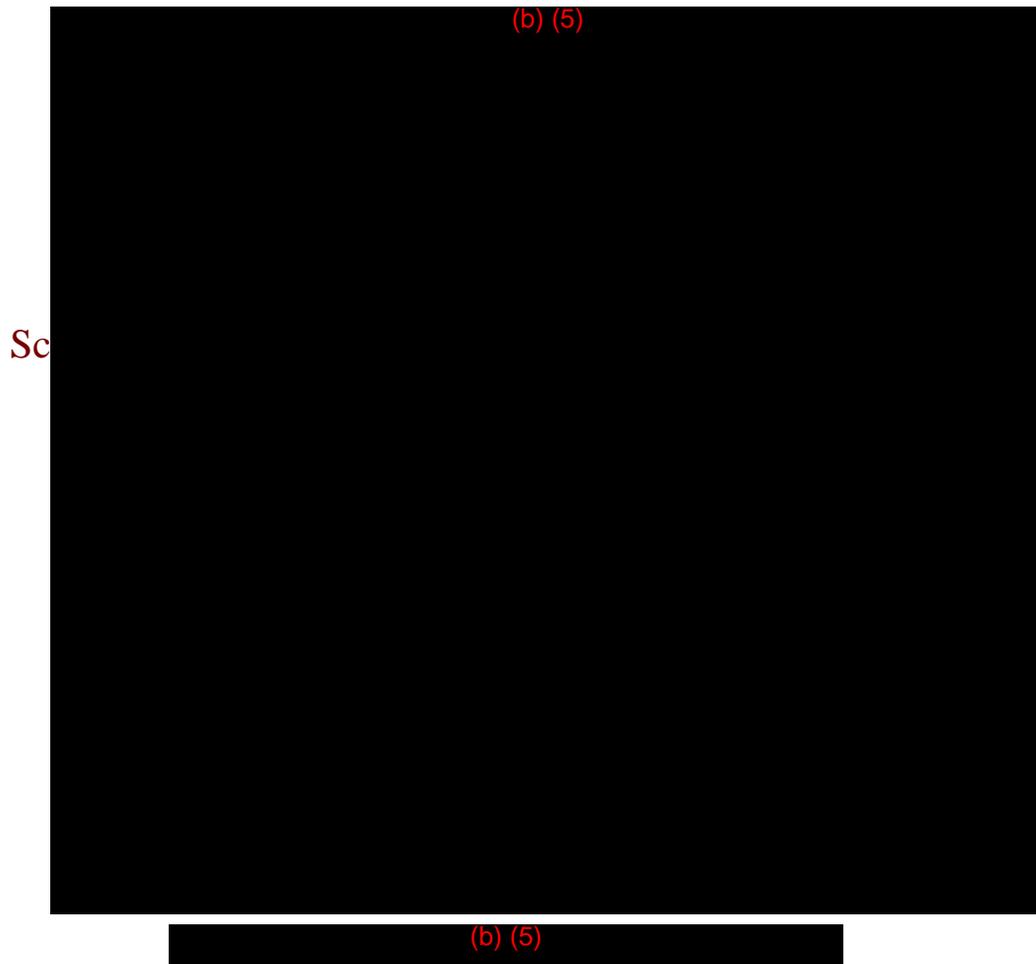


Figure 3. Stacked Bar Ranking for Footlocker and Pallet SUWPs<sup>2</sup>

#### 4.2 Performance of Individual Systems

In this part of the analysis, the scores for each system were reviewed relative to each measure to identify where each system scored well and where it scored poorly (i.e., strengths and weaknesses).





Tables 9 and 10 summarize the strengths and weaknesses for the briefcase and footlocker/pallet systems, respectively. The tables were generated by comparing the score for each evaluated system to the scores of the other evaluated systems, relative to each measure, and noting attributes that stand out, either positively or negatively, for each system (i.e., scores at the high or low end of the performance scale). The performance of every system (b) (5) is summarized relative to the three pathogen removal measures and *Chemical Reduction* as (b) (5) and are direct indicators of an SUWP's potential to produce quality water.

Table 9. Strengths and Weaknesses of Briefcase Systems

| System         | Strengths  | Weaknesses  |
|----------------|--|---|
| <p>(b) (5)</p> | <ul style="list-style-type: none"> <li>• Demonstrated to be effective against bacteria and viruses in clean and worst case waters</li> <li>• Demonstrated to be effective against protozoa in clean water</li> <li>• Multiple technologies known to reduce chemicals</li> <li>• Significantly reduces objectionable taste/odor</li> <li>• Includes capability to clean/flush filters</li> <li>• Engineered to automatically stop water flow and provide rationale upon failure</li> </ul>                            | <ul style="list-style-type: none"> <li>• Demonstrated to be ineffective against protozoa in worst case water</li> <li>• Minimal power flexibility</li> <li>• Concern that durability of construction will withstand rigors of military use</li> <li>• Complex construction may require trained operator to maintain and repair</li> </ul> |
| <p>(b) (5)</p> | <ul style="list-style-type: none"> <li>• Proven effective against bacteria and viruses in clean water by third party testing (anticipated effective in worst case water)</li> <li>• Anticipated to be effective against protozoa</li> <li>• Significantly reduces objectionable taste/odor</li> <li>• Most durable and least susceptibility to environmental conditions</li> <li>• Minimal effort (only 1 filter to replace) and low complexity</li> <li>• Multiple power sources (including manual pump)</li> </ul> | <ul style="list-style-type: none"> <li>• Only one technology to reduce chemicals (carbon adsorption)</li> <li>• One of the larger briefcase systems (4 ft<sup>3</sup>, 65 lb)</li> <li>• High percentage of proprietary consumables and common failure items</li> <li>• Pre-filters likely to be effected by turbidity</li> </ul>         |
| <p>(b) (5)</p> | <ul style="list-style-type: none"> <li>• Anticipated to be effective against all three pathogens</li> <li>• High pressure RO known to reduce chemicals</li> <li>• Durable</li> <li>• Confidence that vendor training/support will meet Warfighter needs</li> </ul>   | <ul style="list-style-type: none"> <li>• Minimal power flexibility</li> <li>• Low flow rate compared to others in class</li> </ul>  |

Table 9. Strengths and Weaknesses of Briefcase Systems (Continued)

| System  | Strengths   | Weaknesses  |
|---------|---|---|
| (b) (5) | <ul style="list-style-type: none"> <li>Anticipated to be effective against bacteria and protozoa</li> <li>Multiple technologies known to reduce chemicals</li> <li>Durable and least susceptible to environmental conditions</li> <li>Multiple power sources (solar optional)</li> </ul>                    | <ul style="list-style-type: none"> <li>Inadequate UV design information to determine effectiveness against viruses in clean water</li> <li>Not anticipated to be effective against viruses in worst case water</li> <li>Heavy (68 lb)</li> <li>Pre-filters likely to be effected by turbidity</li> </ul>  |
| (b) (5) | <ul style="list-style-type: none"> <li>Anticipated to be effective against all three pathogens</li> <li>Low complexity</li> <li>Engineered to automatically stop water flow upon UV failure</li> </ul>  | <ul style="list-style-type: none"> <li>Only one technology to reduce chemicals (nanoceram filter media with PAC)</li> <li>Pre-filters likely to be effected by turbidity</li> </ul>   |
| (b) (5) | <ul style="list-style-type: none"> <li>Anticipated to be effective against all three pathogens</li> <li>High pressure RO known to reduce chemicals</li> <li>Durable</li> <li>Multiple power sources (solar optional)</li> <li>Confidence that vendor training/support will meet Warfighter needs</li> </ul> | <ul style="list-style-type: none"> <li>Produces &lt;150 gal in a 10 h day</li> <li>Heaviest and largest briefcase system (70 lb, 6.5 ft<sup>3</sup>)</li> <li>Most complex briefcase system</li> </ul>  |
| (b) (5) | <ul style="list-style-type: none"> <li>Demonstrated to be effective against bacteria and protozoa in clean water</li> <li>Low Complexity</li> <li>Lightest weight (27 lb)</li> <li>Many non-proprietary consumables and common failure items</li> </ul>   | <ul style="list-style-type: none"> <li>Demonstrated to be ineffective pathogen barrier in worst case water and against viruses in clean water.</li> <li>Only one technology to reduce chemicals (carbon block)</li> <li>Scheduled service by volume or time (no engineered PFIs)</li> <li>Pre-filters likely to be effected by turbidity</li> </ul> |
| (b) (5) | <ul style="list-style-type: none"> <li>Anticipated to be effective against all three pathogens</li> <li>Low pressure RO known to reduce chemicals</li> <li>Small</li> </ul>   | <ul style="list-style-type: none"> <li>Appears more appropriate for a laboratory setting</li> <li>Susceptible to environmental conditions</li> <li>Complex construction may require trained operator to maintain and repair</li> </ul>  |

Table 9. Strengths and Weaknesses of Briefcase Systems (Continued)

|                           | Strengths   | Weaknesses   |
|---------------------------|---|--|
| <p>System<br/>(b) (5)</p> | <ul style="list-style-type: none"> <li>• Anticipated to be effective against bacteria in clean water</li> <li>• Multiple power sources</li> <li>• Least complex of evaluated systems</li> </ul>   | <ul style="list-style-type: none"> <li>• Iodine resin is primary method of pathogen reduction, but published wait time is not provided. This reduces confidence in unit's ability to reduce viruses, protozoa or bacteria, particularly in worst case waters.</li> <li>• Only one technology to reduce chemicals (carbon block)</li> <li>• Iodine imparts objectionable taste/odor</li> <li>• Scheduled service by volume or time (no engineered PFIs)</li> <li>• Pre-filters likely to be effected by turbidity</li> <li>• Lack of confidence in vendor training/support</li> </ul> |
| <p>(b) (5)</p>            | <ul style="list-style-type: none"> <li>• Anticipated to be effective against all three pathogens</li> <li>• Low pressure RO known to reduce chemicals</li> <li>• Smallest briefcase system</li> </ul>   | <ul style="list-style-type: none"> <li>• Produces &lt;150 gal in a 10 h day and can only operate for 8 h a day on solar power</li> <li>• Low Durability: Appears more appropriate for a laboratory setting</li> <li>• Susceptible to environmental conditions</li> <li>• Complex construction may require trained operator to maintain and repair</li> </ul>   |
| <p>(b) (5)</p>            | <ul style="list-style-type: none"> <li>• Anticipated to be effective against bacteria and protozoa</li> <li>• Multiple technologies known to reduce chemicals</li> <li>• Multiple power sources (including optional solar and foot pump)</li> <li>• Engineered to automatically stop water flow upon failure</li> </ul> | <ul style="list-style-type: none"> <li>• Vendor claims &lt;3 log reduction of viruses, versus 4 log required</li> <li>• Low durability</li> <li>• Not encased during operation (susceptible to environment)</li> <li>• No indication that UV is not powered (reducing effectiveness against pathogens) when using foot pump</li> <li>• Pre-filters likely to be effected by turbidity</li> <li>• Low confidence that vendor training/support will meet Warfighter needs</li> </ul>   |

Table 9. Strengths and Weaknesses of Briefcase Systems (Continued)

| System         | Strengths  | Weaknesses  |
|----------------|--|---|
| <p>(b) (5)</p> | <ul style="list-style-type: none"> <li>• Anticipated to be effective against bacteria and protozoa</li> <li>• Many non-proprietary consumables and common failure items</li> <li>• Lightweight (30 lbs)</li> </ul> | <ul style="list-style-type: none"> <li>• Technology potentially capable of reducing viruses in clean water, but inadequate design information available</li> <li>• Not anticipated to be effective against viruses in worst case water</li> <li>• Only one technology to reduce chemicals (carbon block)</li> <li>• Least durable and most susceptible to environmental conditions</li> <li>• Scheduled service by volume or time (no engineered PFIs)</li> <li>• Lack of confidence in vendor training/support</li> <li>• Pre-filters likely to be effected by turbidity</li> <li>• Highest level of effort required due to expected need for maintenance</li> </ul> |

Table 10. Strengths and Weaknesses of Footlocker and Pallet Systems

| System         | Strengths  | Weaknesses  |
|----------------|--|---|
| <p>(b) (5)</p> | <ul style="list-style-type: none"> <li>• Certified components effective against bacteria and viruses in clean water only</li> <li>• Certified components effective against protozoa.</li> <li>• Anticipated effectiveness against bacteria in worst case water</li> <li>• Process failure indicator employs UV intensity monitor and UV failure; shutdown of water flow upon trigger.</li> </ul> | <ul style="list-style-type: none"> <li>• Technology potentially capable of reducing viruses in worst case water, but not verified by protocol for certification.</li> <li>• May only remove some chemicals</li> <li>• Proprietary power source</li> </ul> |

Table 10. Strengths and Weaknesses of Footlocker and Pallet Systems (Continued)

|                           | Strengths  | Weaknesses   |
|---------------------------|--|--|
| <p>System<br/>(b) (5)</p> | <ul style="list-style-type: none"> <li>• Certified components effective against all three pathogens</li> <li>• Durable</li> <li>• Process failure indicator employs UV intensity monitor and UV failure; shutdown of water flow upon trigger (TDS monitor and pressure gauges also included)</li> </ul>  | <ul style="list-style-type: none"> <li>• Pre-filters likely to be effected by turbidity</li> <li>• Proprietary power source</li> <li>• Largest system (53.8 ft<sup>3</sup>)</li> </ul>   |
| <p>(b) (5)</p>            | <ul style="list-style-type: none"> <li>• Certified component for protozoa removal</li> <li>• Anticipated to be effective against bacteria and viruses</li> <li>• Durable and least susceptible to environmental conditions</li> <li>• Minimal effort required and least complex</li> <li>• Small and light (5.8 ft<sup>3</sup>, 100 lb)</li> </ul>   | <ul style="list-style-type: none"> <li>• May only remove some chemicals</li> <li>• Chlorine imparts taste/odor</li> </ul>  |
| <p>(b) (5)</p>            | <ul style="list-style-type: none"> <li>• Tested and proven components for bacteria and protozoa removal (German test data for entire system)</li> <li>• Anticipated to be effective against viruses based on multiple technologies</li> <li>• High pressure RO known to reduce chemicals</li> </ul>  | <ul style="list-style-type: none"> <li>• Components may not be well secured within the system</li> <li>• Exposed wires/gauges susceptible to environmental conditions</li> <li>• Significant effort and complex setup</li> <li>• All non-U.S. acquired parts/fittings, which may be less readily available to the Warfighter compared to other evaluated systems.</li> </ul> |
| <p>(b) (5)</p>            | <ul style="list-style-type: none"> <li>• Anticipated to be effective against all three pathogens</li> <li>• Technologies present are known to significantly reduce a broad spectrum of chemicals</li> <li>• Significantly reduces objectionable taste/odor</li> <li>• Most durable and resistant to environmental conditions</li> <li>• Automatic backflushing and self-scrubbing pre-filtration for some filters</li> <li>• Confidence that vendor training/support will meet Warfighter needs</li> </ul> | <ul style="list-style-type: none"> <li>• Production rate &lt;300 gal/10 h day</li> <li>• Low interoperability: proprietary energy recovery pump and pre-filter system.</li> </ul>  |

Table 10. Strengths and Weaknesses of Footlocker and Pallet Systems (Continued)

| System                        | Strengths   | Weaknesses  |
|-------------------------------|---|---|
| <p>(b) (5)</p>                | <ul style="list-style-type: none"> <li>• Anticipated to be effective against all three pathogens based on multiple technologies</li> <li>• Technologies present are known to significantly reduce a broad spectrum of chemicals</li> <li>• Significantly reduces objectionable taste/odor</li> <li>• Multiple power sources</li> </ul>                  | <ul style="list-style-type: none"> <li>• Complex maintenance</li> </ul>   |
| <p>(b) (5)</p> <p>(b) (5)</p> | <ul style="list-style-type: none"> <li>• Anticipated to be effective against bacteria viruses, and protozoa based on multiple technologies</li> <li>• Multiple technologies known to reduce chemicals</li> <li>• Multiple power sources (solar optional)</li> <li>• Engineered to automatically stop water flow for UV failure and low flow.</li> </ul> | <ul style="list-style-type: none"> <li>• Pre-filters likely to be effected by turbidity</li> <li>• Effort required to maintain chlorine residual</li> <li>• Low confidence that vendor training/support will meet Warfighter needs</li> </ul>   |
| <p>(b) (5)</p>                | <ul style="list-style-type: none"> <li>• Anticipated to be effective against bacteria and protozoa</li> <li>• Multiple technologies known to reduce chemicals</li> <li>• Multiple power sources</li> <li>• Low complexity</li> <li>• Automatic shutoff for low flow and UV failure</li> </ul>   | <ul style="list-style-type: none"> <li>• Inadequate UV design information to determine effectiveness against viruses in clean water</li> <li>• Not anticipated to be effective against viruses in worst case water</li> <li>• Pre-filters likely to be effected by turbidity</li> </ul>   |
| <p>(b) (5)</p> <p>(b) (5)</p> | <ul style="list-style-type: none"> <li>• Anticipated to be effective against all three pathogens</li> <li>• Automated backflushing of filters</li> <li>• Minimal effort</li> <li>• Confidence that vendor training/support will meet Warfighter needs</li> </ul>  | <ul style="list-style-type: none"> <li>• Only a single technology known to have some chemical reduction capacity</li> <li>• High complexity</li> <li>• Low interoperability: proprietary pre-filter system</li> <li>• Scheduled service by volume or time (no engineered PFIs)</li> </ul> |

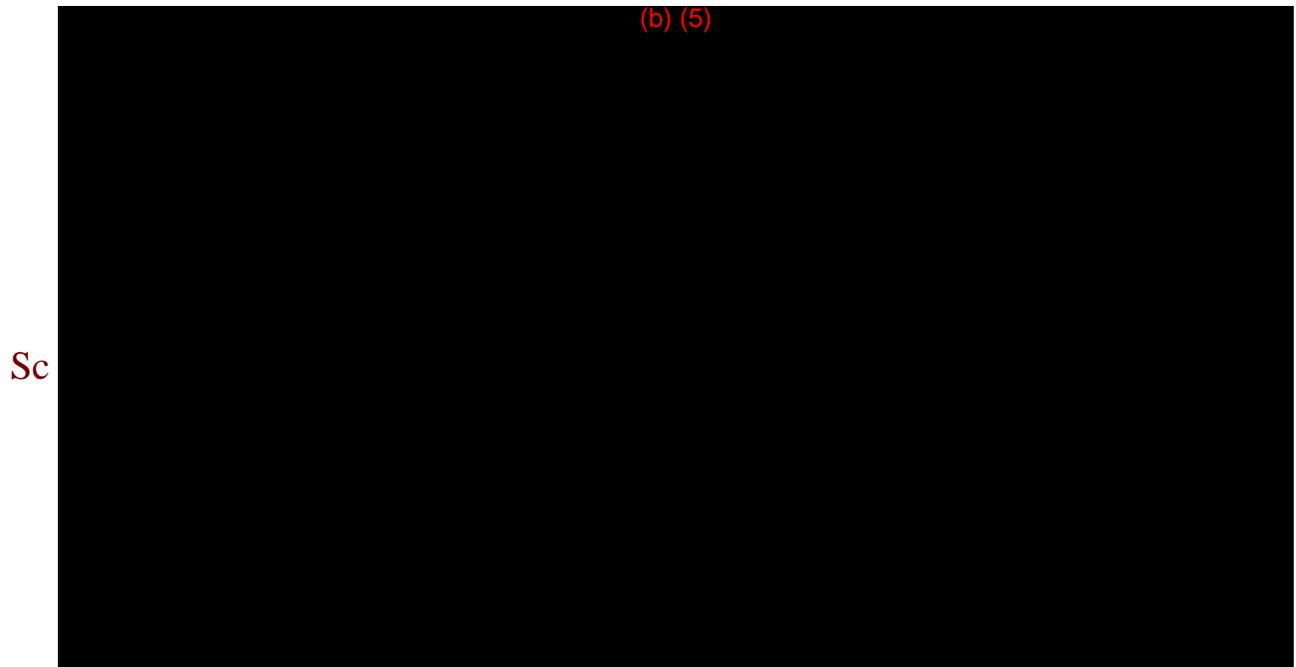
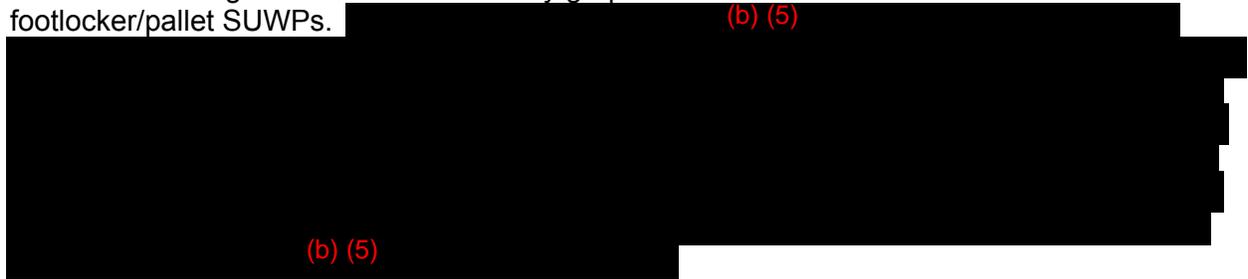
Table 10. Strengths and Weaknesses of Footlocker and Pallet Systems (Continued)

| <b>System</b>              | <b>Strengths</b>  | <b>Weaknesses</b>   |
|----------------------------|---|---|
| <p>(b) (5)<br/>(b) (5)</p> | <ul style="list-style-type: none"> <li>• Anticipated to be effective against bacteria and protozoa</li> <li>• Minimal effort and low complexity</li> <li>• Most consumables and common failure items are non-proprietary</li> </ul>                                       | <ul style="list-style-type: none"> <li>• Inadequate design information to determine effectiveness against viruses in clean water</li> <li>• Not anticipated to be effective against viruses in worst case water</li> <li>• Only a single technology known to have some chemical reduction capacity</li> <li>• Least durable and most susceptible to environmental conditions</li> <li>• Pre-filters likely to be effected by turbidity</li> </ul> |
| <p>(b) (5)<br/>(b) (5)</p> | <ul style="list-style-type: none"> <li>• Anticipated to be effective against all three pathogens</li> <li>• Automated backflushing of filters</li> <li>• Minimal effort required</li> <li>• Confidence that vendor training/support will meet Warfighter needs</li> </ul> | <ul style="list-style-type: none"> <li>• Only a single technology known to have some chemical reduction capacity</li> <li>• Most complex of evaluated systems</li> <li>• Heavy (900 lb)</li> <li>• Low interoperability: proprietary pre-filter system</li> <li>• Scheduled service by volume or time (no engineered PFIs)</li> <li>• Lower durability due to mounting of solar panel</li> </ul>  |

### 4.3 Sensitivity Analysis

Sensitivity analysis allows the analyst or decision maker to assess how the results produced by an evaluation model would be affected by varying the weights of the measures or goals. A typical approach is to vary the weights of individual measures by a reasonable amount to see if the overall ranking of the evaluated SUWPs is affected. A reasonable change in weight is defined here as doubling or halving the weight; if no or few rankings changed among the systems, particularly among the top ranked systems, the measure would not be considered sensitive.

Figure 5 shows a sensitivity graph for the *Chemical Reduction* measure for footlocker/pallet SUWPs.



Sc

Percent of Weight on Chem. Reduction Measure

Figure 5. Sensitivity of *Chemical Reduction* for Footlocker/Pallet SUWPs

A sensitivity analysis for each measure was performed and assessed to have either low, moderate, or high sensitivity to a change in weight. A low, moderate, or high sensitivity was characterized by no/few, some, or significant changes in the order of the systems (with extra consideration given to the top ranking systems), respectively.

Most measures had a low sensitivity to changes in weight for the briefcase and footlocker/pallet evaluation models. (b) (5)

(b) (5)

#### 4.3.1 Briefcase Sensitivity

(b) (5)

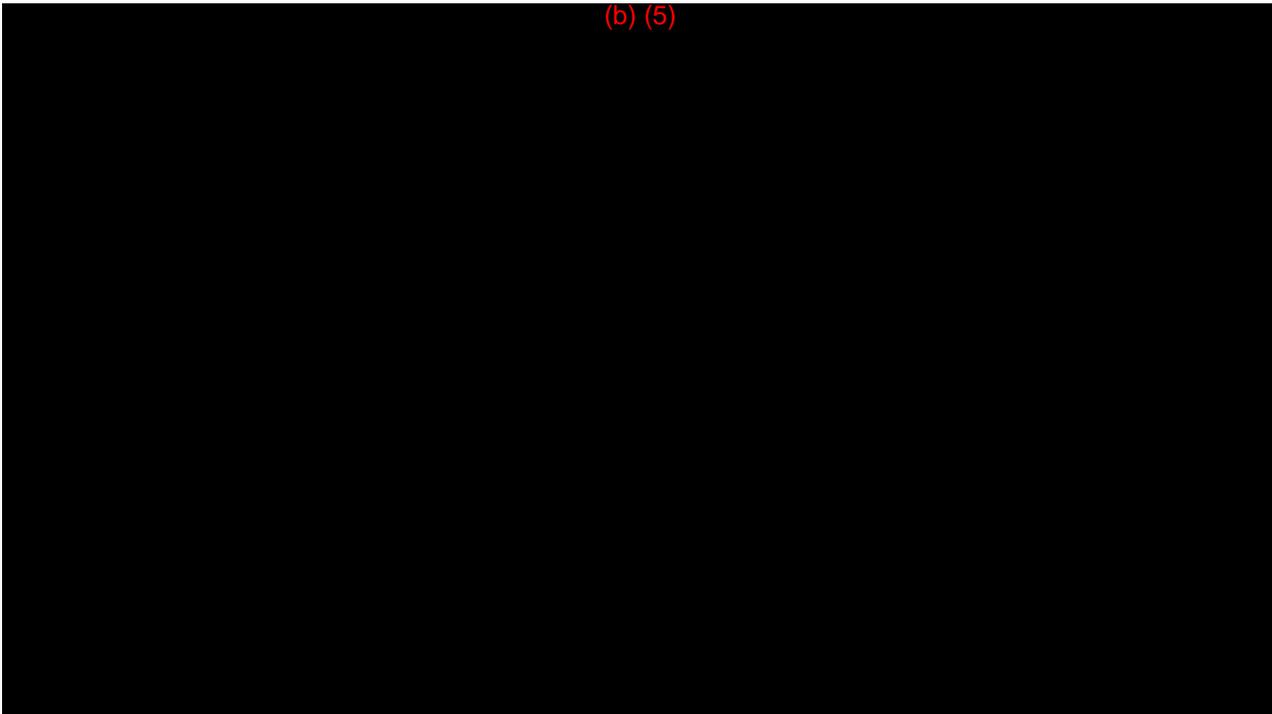
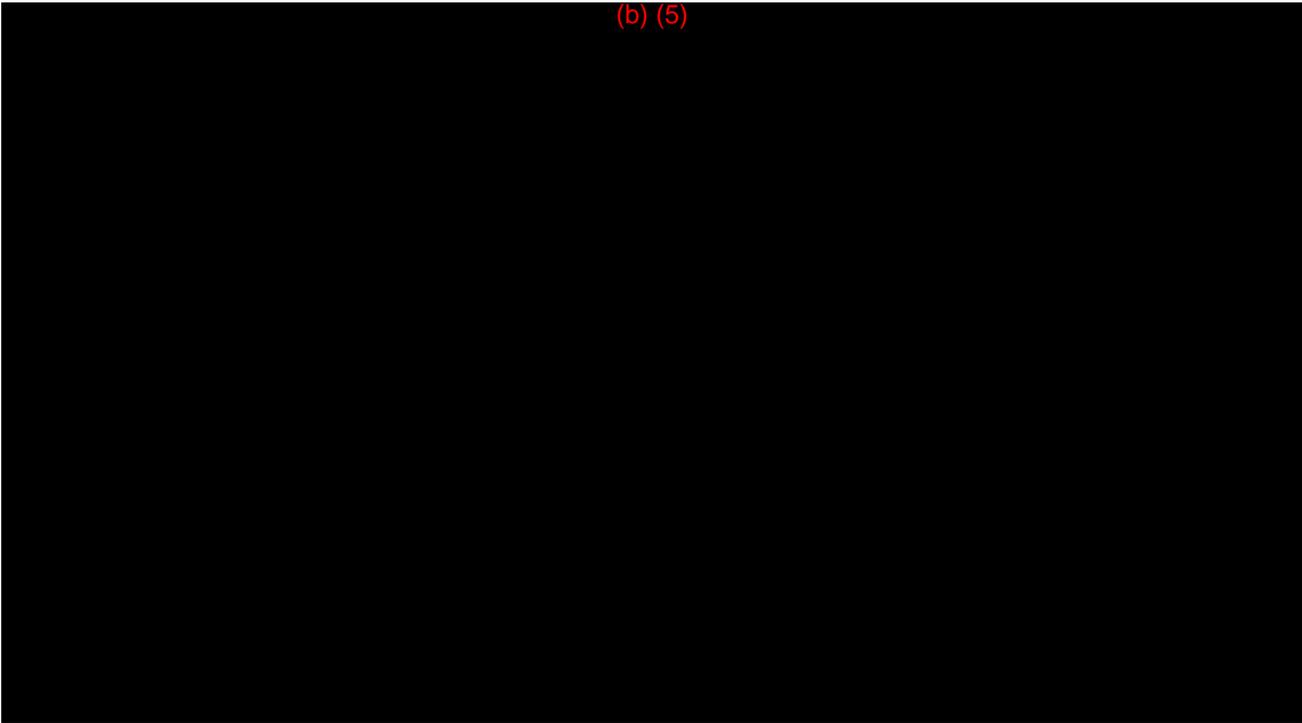


Figure 6. Sensitivity of *Complexity* for Briefcase SUWPs

(b) (5)



Percent of Weight on Production Rate Measure

Figure 7. Sensitivity of *Production Rate* for Briefcase SUWPs

(b) (5)



Percent of Weight on Power Flex. Measure

Figure 8. Sensitivity of *Power Flexibility* for Briefcase SUWPs



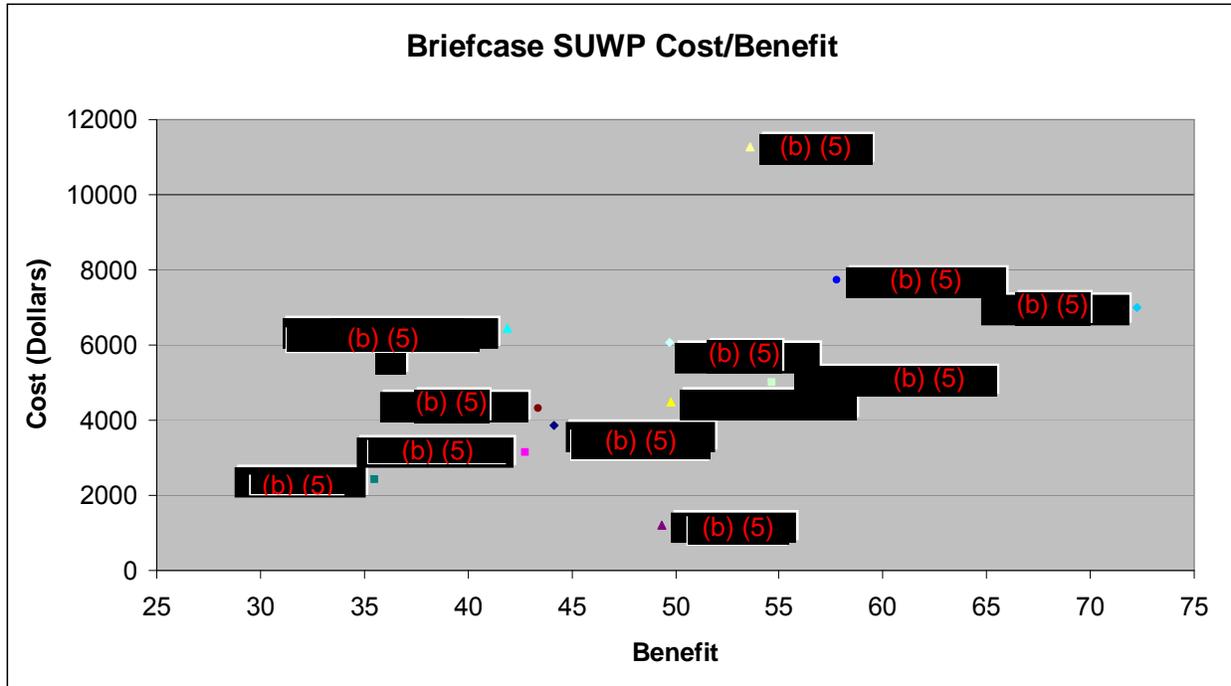


Figure 10. Briefcase SUWP Cost/Benefit

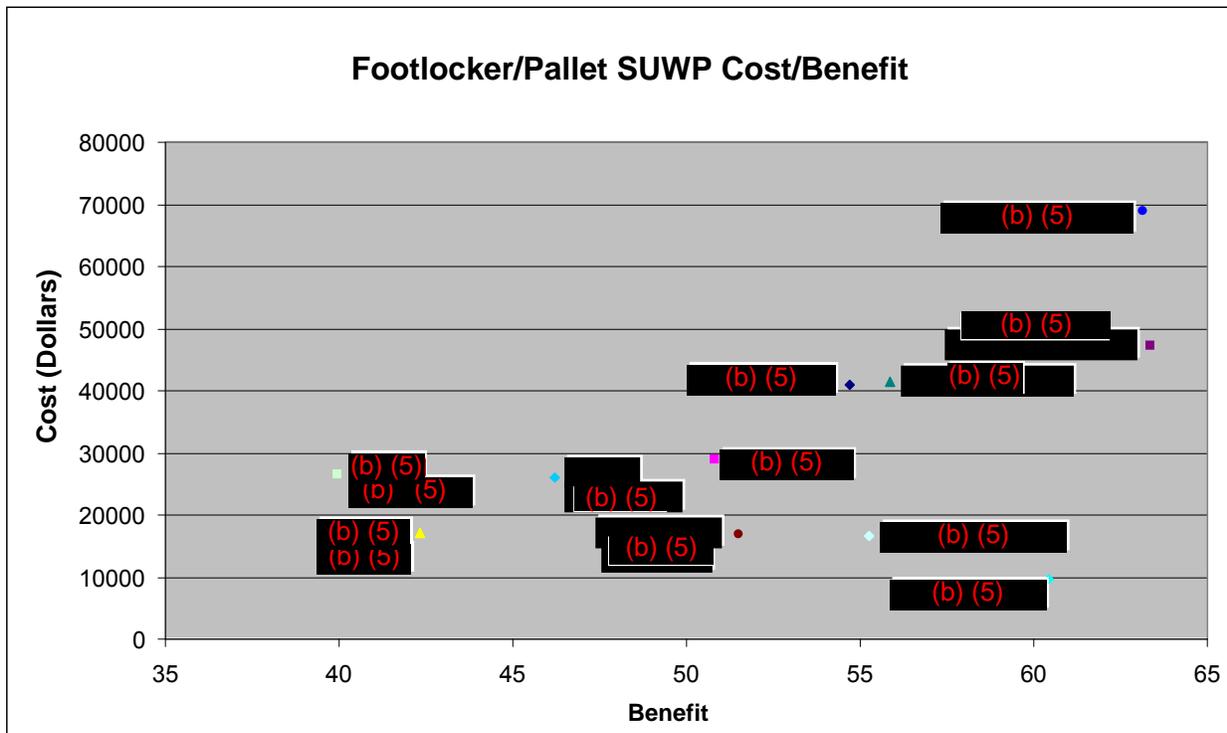


Figure 11. Footlocker/Pallet SUWP Cost/Benefit

## 5. CONCLUSIONS AND RECOMMENDATIONS

Following the manufacturer's instructions, all small unit water purifiers (SUWPs) were evaluated as packaged. It is possible individual users could make modifications/adjustments that might result in increased capabilities. For example, (b) (5)

(b) (5)  
(b) (5)  
(b) (5)

Primarily due to testing limitations, the expert panel relied heavily on vendor-supplied information and their own expertise/knowledge of the technologies. If testing or additional data becomes available, these assessments could be updated and new scores and recommendations generated. There is a need to perform independent testing to obtain additional performance data on the majority of the systems evaluated.

Due to the close range of scores for the systems in the briefcase and footlocker/pallet models, it was difficult to make recommendations based solely on the overall results generated by the evaluation model. However, there are several systems that can be distinguished from the other systems due to specific weaknesses or strengths as described below.

### 5.1 SUWPs Not Recommended

(b) (5) was determined to be unreliable and not ruggedized for military applications. There is also a lack of faith in customer service support from the manufacturer.

(b) (5) received the fourth highest overall benefit score, but it is significantly more expensive than other systems with similar and higher benefit scores. Therefore, procurement of this system would not be justified because a comparable or better system could be procured at a lower cost.

### 5.2 Recommended Briefcase SUWPs

(b) (5) is the only system to have passed independent, protocol driven testing for all three pathogens (bacteria, viruses, and protozoa). This system also received the highest score of any evaluated system for *Chemical Reduction* (85), as well as some of the highest scores for many other measures, to include, *Aesthetics*, *Production Rate*, *Effect of Turbidity*, and *Process Failure Indicators*.

(b) (5) has third party testing showing its effectiveness against bacteria and viruses. Therefore, this system may have greater potential for an increased score in Pathogen Reduction pending independent, protocol driven testing. This system also received high scores for *Aesthetics*, *Durability*, *Environmental Conditions*, *Power Flexibility*, *Effort Required*, and *Complexity*.

(b) (5) received the third highest overall benefit score and was the highest scoring system that can desalinate water. This system received the highest score for *Vendor Support* (85) and tied the highest score for *Chemical Reduction* (85). This system also scored well for *Durability*, *Environmental Conditions*, *Complexity* and *Aesthetics*.

### 5.3 Recommended Footlocker/Pallet SUWPs

(b) (5) (b) (5) for the highest overall benefit score for (b) (5) that are certified to be effective against all three pathogens, (b) (5) is not expected to perform as well in worst case waters. Trade-offs between the two systems will need to be assessed against the user's requirements to determine which system is better suited for a particular user.

(b) (5) received one of the highest overall benefit scores and has the lowest cost of all the evaluated footlocker/pallet SUWPs. It also contains technology that is certified for protozoa reduction. This system is also desirable because of its modular design and the incorporation of certified and reusable filters that can be easily removed and cleaned.

(b) (5) has multiple highly effective technologies (b) (5) (b) (5) for reduction of all three pathogens. Further, the system was perceived to be well packaged with the potential to be highly effective against pathogens in a Military environment. Although test data was not available, this system may have the potential to receive a higher score pending independent, protocol driven testing. This system also received the highest score possible for *Chemical Reduction* (100) and high scores in *Aesthetics* and *Power Flexibility*.

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## APPENDIX A

## STUDY PARTICIPANTS

The table below contains the name, service, organization, and role of each participant in this SUWP study.

Table. Study Participants

| Name                    | Service   | Organization                 | Role             |
|-------------------------|-----------|------------------------------|------------------|
| Ginn White              | Army      | USACHPPM                     | Study Team Lead  |
| Christopher Childs      | Army      | USACHPPM                     | Study Team       |
| Todd E. Richards        | Army      | USACHPPM                     | Study Team       |
| Art Lundquist           | Army      | USACHPPM                     | Study Team       |
| Steve Clarke            | Army      | USACHPPM                     | Study Team       |
| Steve Richards          | Army      | USACHPPM                     | Study Team       |
| Dick Burrows            | Army      | USACHPPM                     | Study Team       |
| CPT Alex Bonilla        | Army      | USACHPPM                     | Study Team       |
| Lindsey Wurster         | Army      | ECBC                         | Decision Analyst |
| Matthew Beebe           | Army      | ECBC                         | Decision Analyst |
| John Walther            | Army      | ECBC                         | Decision Analyst |
| Danielle Smith          | Army      | ECBC                         | Decision Analyst |
| HMI William White       | Navy      | MARSOC                       | User Rep         |
| Thomas Buck             | Marines   | MARSYSCOM                    | User Rep         |
| Mark Miller             | Army      | NAVFAC                       | Tech Exp         |
| Anna Royer              | Army      | NEPO ERL                     | Tech Exp         |
| Jeff Pacuska            | Army      | PM-CIE                       | Tech Exp         |
| MAJ Hugh Bailey         | Army      | USASOC                       | User Rep         |
| SFC Mike Brown          | Army      | USASOC                       | User Rep         |
| MAJ Eric Kelly          | Army      | USASOC                       | User Rep         |
| SSG Hank Holmes         | Army      | USASOC                       | User Rep         |
| CPT Ryan Holak          | Army      | CASCOM                       | User Rep         |
| Marella Akridge         | Army      | CASCOM                       | User Rep         |
| Thomas Yenkevich        | Army      | CASCOM                       | User Rep         |
| LCDR Eugene Garland     | Marines   | MARSOC                       | User Rep         |
| Ian Peek                | Navy      | NSWC                         | Tech Exp         |
| Bill Varnava            | Navy      | NSWC                         | Tech Exp         |
| Robert Ryczak           | Army      | OTSG                         | Tech Exp         |
| SFC Armando Arteagaharo | Army      | Quartermaster School         | User Rep         |
| CPT Brian Clarke        | Air Force | School of Aerospace Medicine | Tech Exp         |
| Jay Dusenbury           | Army      | TARDEC                       | Tech Exp         |
| Kevin Oehus             | Army      | TARDEC                       | Tech Exp         |
| Bob Shalewitz           | Army      | TARDEC                       | Tech Exp         |

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APPENDIX B

2008 CASCOM WATER PLANNING GUIDE

Table B-1. Standard Planning Factors Related To Personnel in Force (Gal/Person/Day), Conventional Theater  
 Note: Shaded Area Represents Potable Water

| Function                                      | Tropical   |         | Arid       |         | Temperate  |         | Cold       |         |
|---|------------|---------|------------|---------|------------|---------|------------|---------|
|   | Sustaining | Minimum | Sustaining | Minimum | Sustaining | Minimum | Sustaining | Minimum |
| Universal Unit Level <sup>a</sup>             | 6.91       | 4.87    | 7.27       | 5.23    | 5.26       | 3.22    | 5.81       | 3.77    |
| Role I and II Medical Treatment               | 0.03       | 0.03    | 0.03       | 0.03    | 0.03       | 0.03    | 0.03       | 0.03    |
| Role III and IV Medical Treatment             | 0.88       | 0.88    | 0.88       | 0.88    | 0.88       | 0.88    | 0.88       | 0.88    |
| Central Hygiene - Showers <sup>b</sup>        | 2.07       | 1.87    | 2.07       | 1.87    | 2.07       | 1.87    | 2.07       | 1.87    |
| Mortuary Affairs Operations                   | 0.03       | 0.03    | 0.22       | 0.22    | 0.03       | 0.03    | 0.03       | 0.03    |
| Potable Total                                 | 9.92       | 7.68    | 10.47      | 8.23    | 8.27       | 6.03    | 8.82       | 6.58    |
| Centralized Hygiene - Laundry <sup>b</sup>    | 0.26       | 0.12    | 0.26       | 0.12    | 0.26       | 0.12    | 0.26       | 0.12    |
| Mortuary Affairs Operations                   | 0.19       | 0.19    | NA         | NA      | 0.14       | 0.14    | 0.14       | 0.14    |
| Engineer Construction                         | 1.98       | 0.00    | 1.98       | 0.00    | 1.98       | 0.00    | 1.98       | 0.00    |
| Aircraft Maintenance                          | 0.14       | 0.14    | 0.14       | 0.14    | 0.14       | 0.14    | 0.14       | 0.14    |
| Vehicle Maintenance (non-potable part of UUL) | 0.36       | 0.36    |            |         | 0.19       | 0.19    | 0.19       | 0.19    |
| Non-potable Total <sup>c</sup>                | 2.93       | 0.81    | NA         | NA      | 2.72       | 0.60    | 2.72       | 0.60    |
| Theater Total                                 | 12.86      | 8.49    | 12.86      | 8.49    | 10.99      | 6.63    | 11.54      | 7.18    |

<sup>a</sup> Includes gal/person/day and/or per capita requirements for drinking, personal hygiene, field feeding, heat injury treatment and vehicle maintenance.

<sup>b</sup> Based on a central hygiene goal of two showers and 15 pounds of laundry per soldier per week.

<sup>c</sup> All potable in arid environment.

Table B-2. Details of Universal Unit Level Requirements (Gal/Person/Day)

| Function                           | Tropical                               |             | Arid        |             | Temperate   |             | Cold        |             |
|------------------------------------|--|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                                    | Sustaining                             | Minimum     | Sustaining  | Minimum     | Sustaining  | Minimum     | Sustaining  | Minimum     |
| Drinking <sup>f</sup>              | 3.30                                   | 3.30        | 3.30        | 3.30        | 1.65        | 1.65        | 2.20        | 2.20        |
| Personal Hygiene <sup>b</sup>      | Brushing Teeth 3 Times/Day             | 0.22        | NA          | 0.22        | NA          | 0.22        | 0.22        | NA          |
|                                    | Brushing Teeth 1 Time/Day              | NA          | 0.08        | NA          | 0.08        | NA          | NA          | 0.08        |
|                                    | Shaving                                | 0.23        | 0.23        | 0.23        | 0.23        | 0.23        | 0.23        | 0.23        |
|                                    | Washing Hands 6 Times/Day              | 0.83        | NA          | 0.83        | NA          | 0.83        | 0.83        | NA          |
|                                    | Washing Hands 3 Times/Day              | NA          | 0.42        | NA          | 0.42        | NA          | NA          | 0.42        |
|                                    | Sponge Bath 5 Times/Week               | 0.40        | 0.40        | 0.40        | 0.40        | 0.40        | 0.40        | 0.40        |
| Food Preparation <sup>c</sup>      | Individual Meal (MRE)                  | 0.14        | 0.43        | 0.14        | 0.43        | 0.14        | 0.14        | 0.43        |
|                                    | Unitized Group Ration (UGR) - A or H&S | 1.78        | NA          | 1.78        | NA          | 1.78        | 1.78        | NA          |
| Heat Injury Treatment <sup>d</sup> | 0.01                                   | 0.01        | 0.01        | 0.01        | 0.01        | 0.01        | 0.01        | 0.01        |
| Vehicle Maintenance <sup>e</sup>   | 0.36                                   | 0.36        | 0.36        | 0.36        | 0.19        | 0.19        | 0.19        | 0.19        |
| Non-potable Total                  | 0.36                                   | 0.36        | NA          | NA          | 0.19        | 0.19        | 0.19        | 0.19        |
| Potable Total                      | 6.91                                   | 4.87        | 7.27        | 5.23        | 5.26        | 3.22        | 5.81        | 3.77        |
| Theater Total                      | <b>7.27</b>                            | <b>5.23</b> | <b>7.27</b> | <b>5.23</b> | <b>5.45</b> | <b>3.41</b> | <b>6.00</b> | <b>3.96</b> |

APPENDIX C

SYSTEM SCREENING

The table below shows the rationale for any system that was eliminated from the evaluation during the screening phase of the assessment (reference section 3.3). If the rationale states that the system is “comparable to” that means it is similar to a system from the same manufacturer that was included in the detailed evaluation.

Table. Screened Systems

| Manufacturer | Model      | Screening Rationale |
|--------------|------------|---------------------|
| (b) (5)      | [REDACTED] | [REDACTED]          |
| [REDACTED]   | (b) (5)    | [REDACTED]          |
| [REDACTED]   | [REDACTED] | [REDACTED]          |

Table. Screened Systems (Continued)

| Manufacturer | Model   | Screening Rationale |
|--------------|---------|---------------------|
| (b) (5)      | (b) (5) |                     |
|              |         |                     |
|              | (b) (5) |                     |
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APPENDIX D

ASSIGNED SYSTEM SCORES WITH RATIONALE

Tables D-1 through D-4 below show the scores that each evaluated system received and the accompanying rationale. The tables are divided by goal (i.e., Robust, Redundant, Rapid, Resourceful) and SUWP size bin (i.e., briefcase or footlocker/pallet). Rationale was not provided if the score corresponded with the definitions provided in the performance scale (Table 5) for that measure.

Table D-1. Assigned Robust Scores with Rationale for Briefcase SUWPs

|         |         |         |
|---------|---------|---------|
| (b) (5) | (b) (5) | (b) (5) |
|---------|---------|---------|

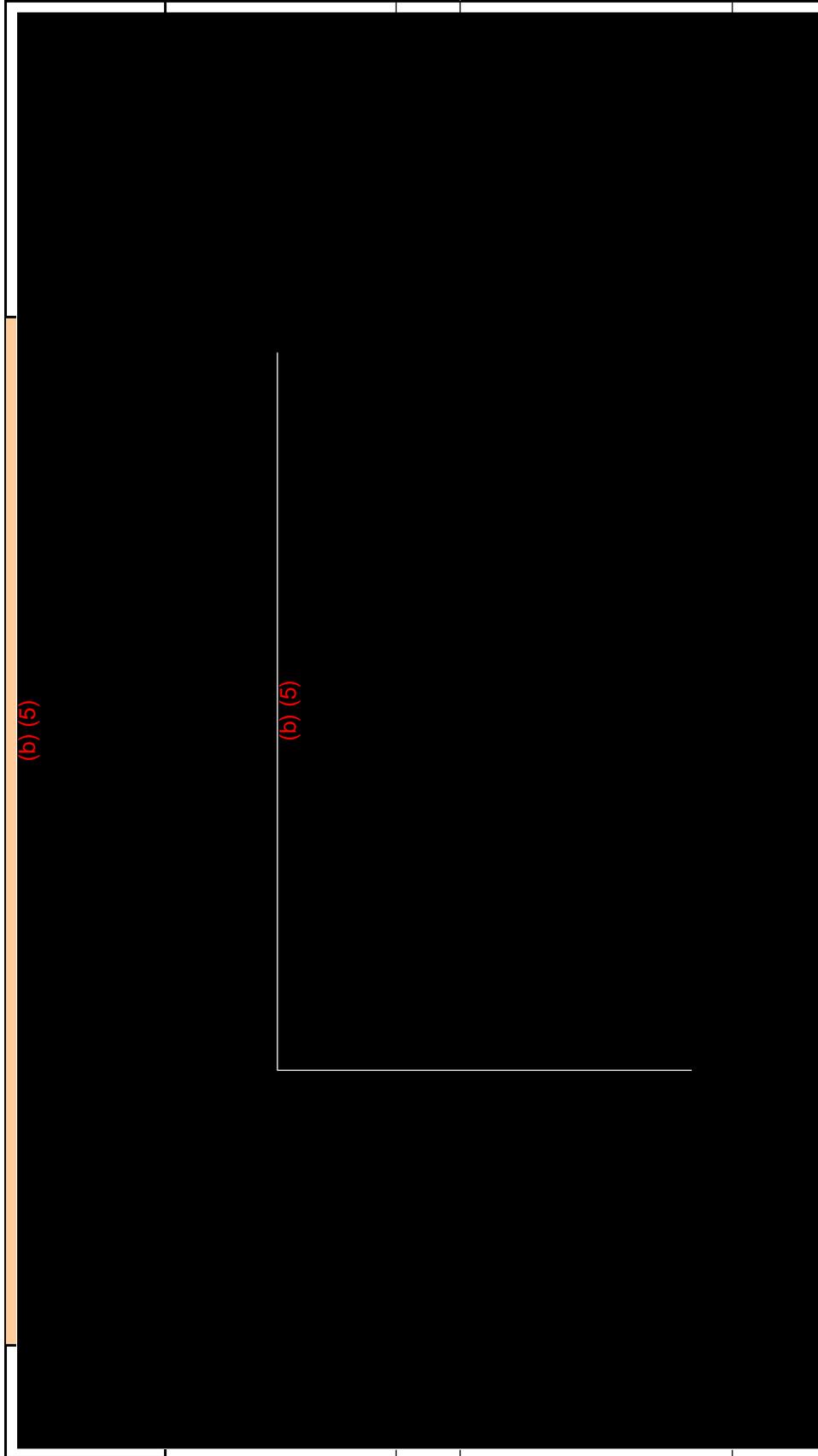


Table D-1. Assigned Robust Scores with Rationale for Briefcase SUWPs (Continued)

(b) (5)

(b) (5)

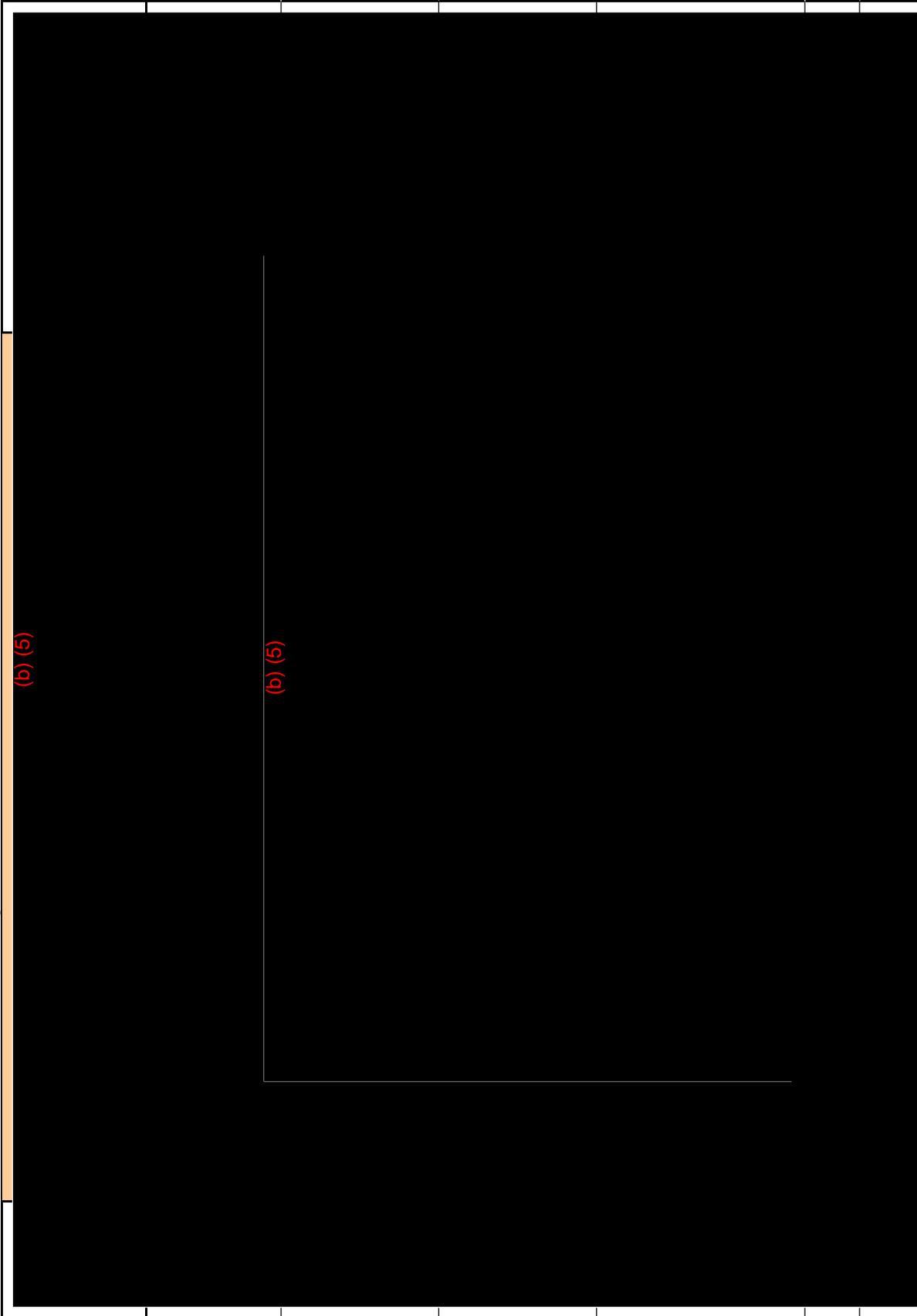
Table D-1. Assigned Robust Scores with Rationale for Briefcase SUWPs (Continued)



(b) (5)

(b) (5)

Table D-2. Assigned Robust Scores with Rationale for Footlocker and Pallet SUWPs



(b) (5)

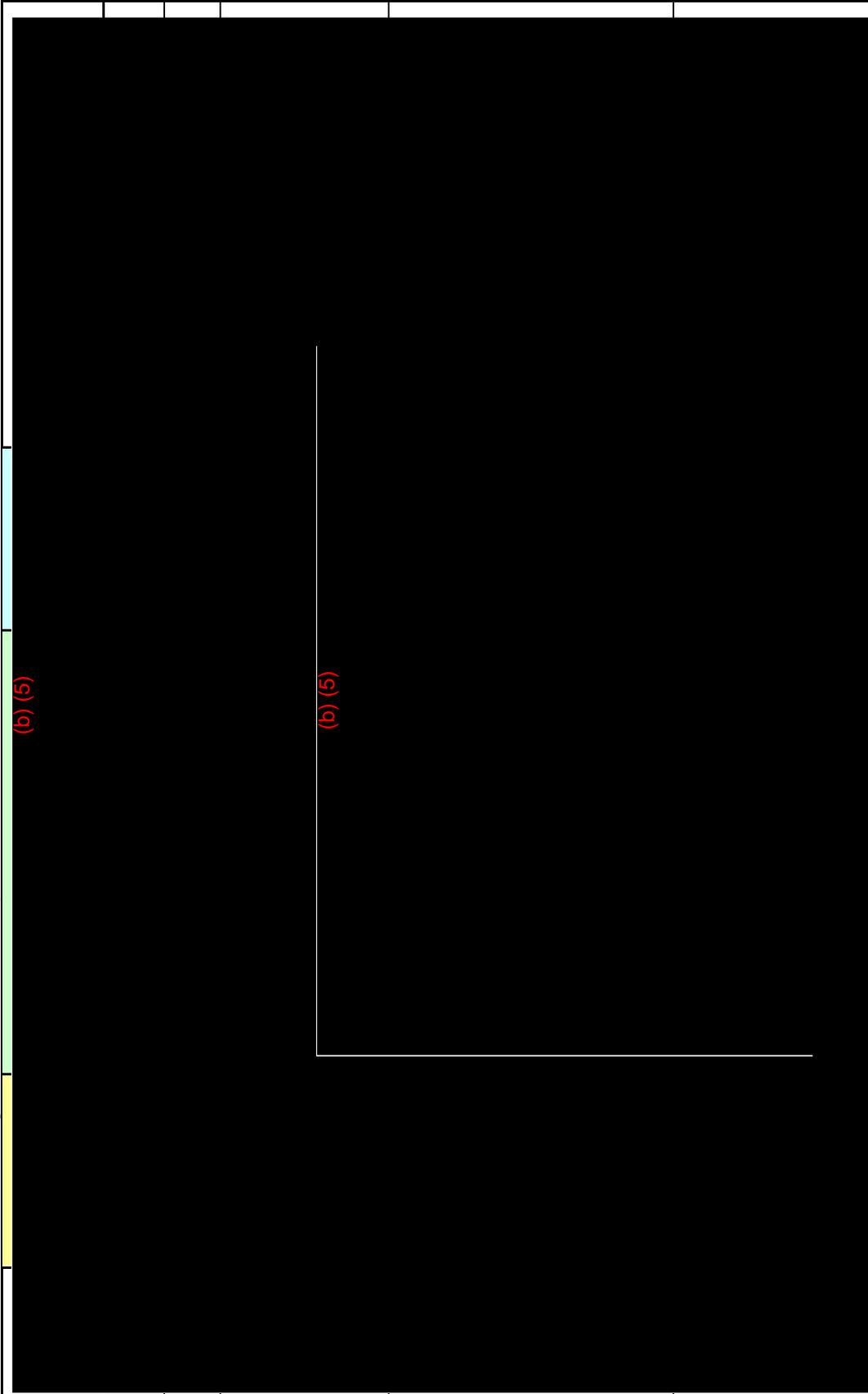
(b) (5)

Table D-2. Assigned Robust Scores with Rationale for Footlocker and Pallet SUWPs (Continued)

(b) (5)

(b) (5)

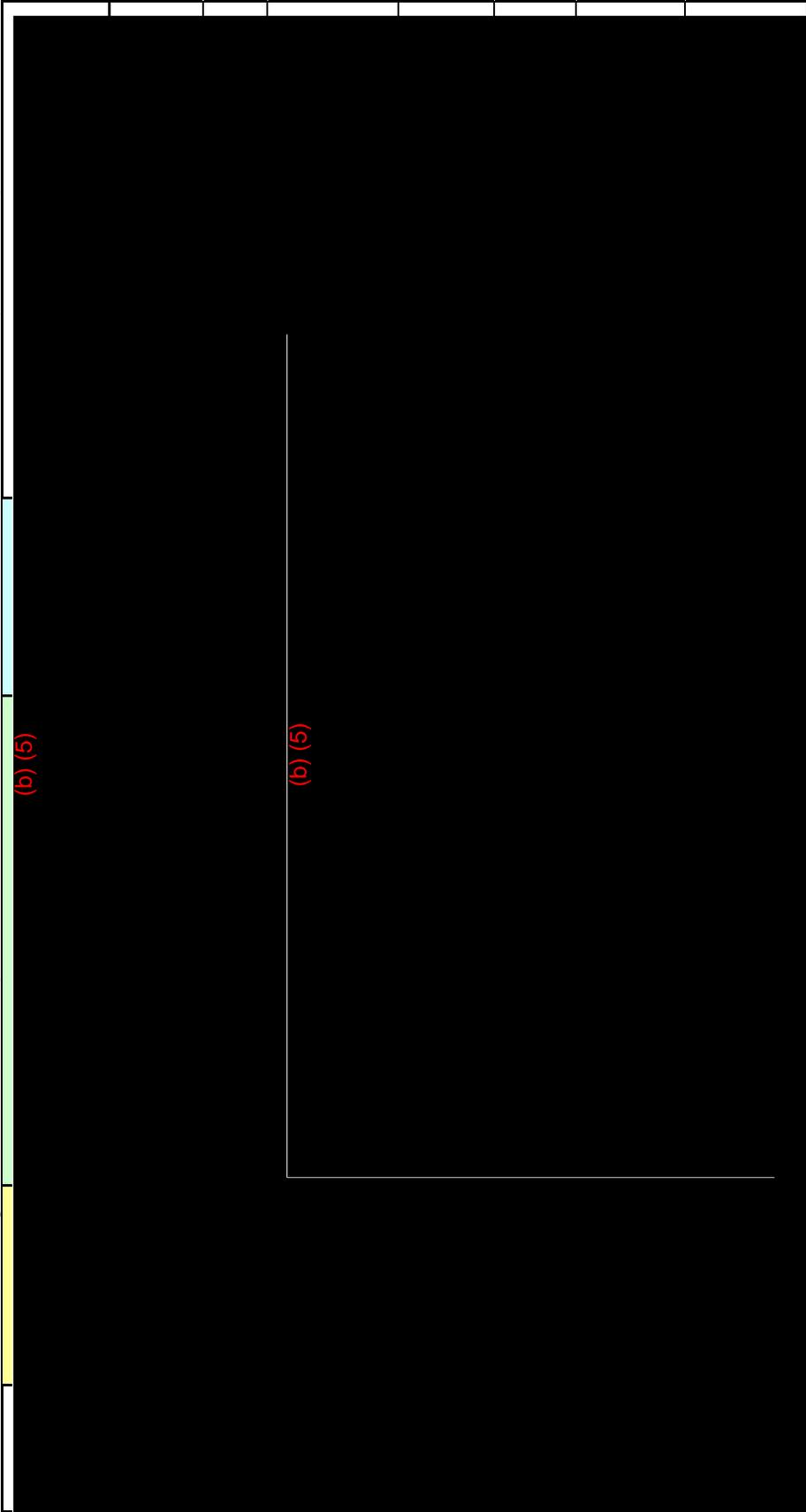
Table D-3. Assigned Redundant, Rapid, and Resourceful Scores with Rationale for Briefcase SUWPs



(b) (5)

(b) (5)

Table D-3. Assigned Redundant, Rapid, and Resourceful with Rationale for Briefcase SUWPs (Continued)

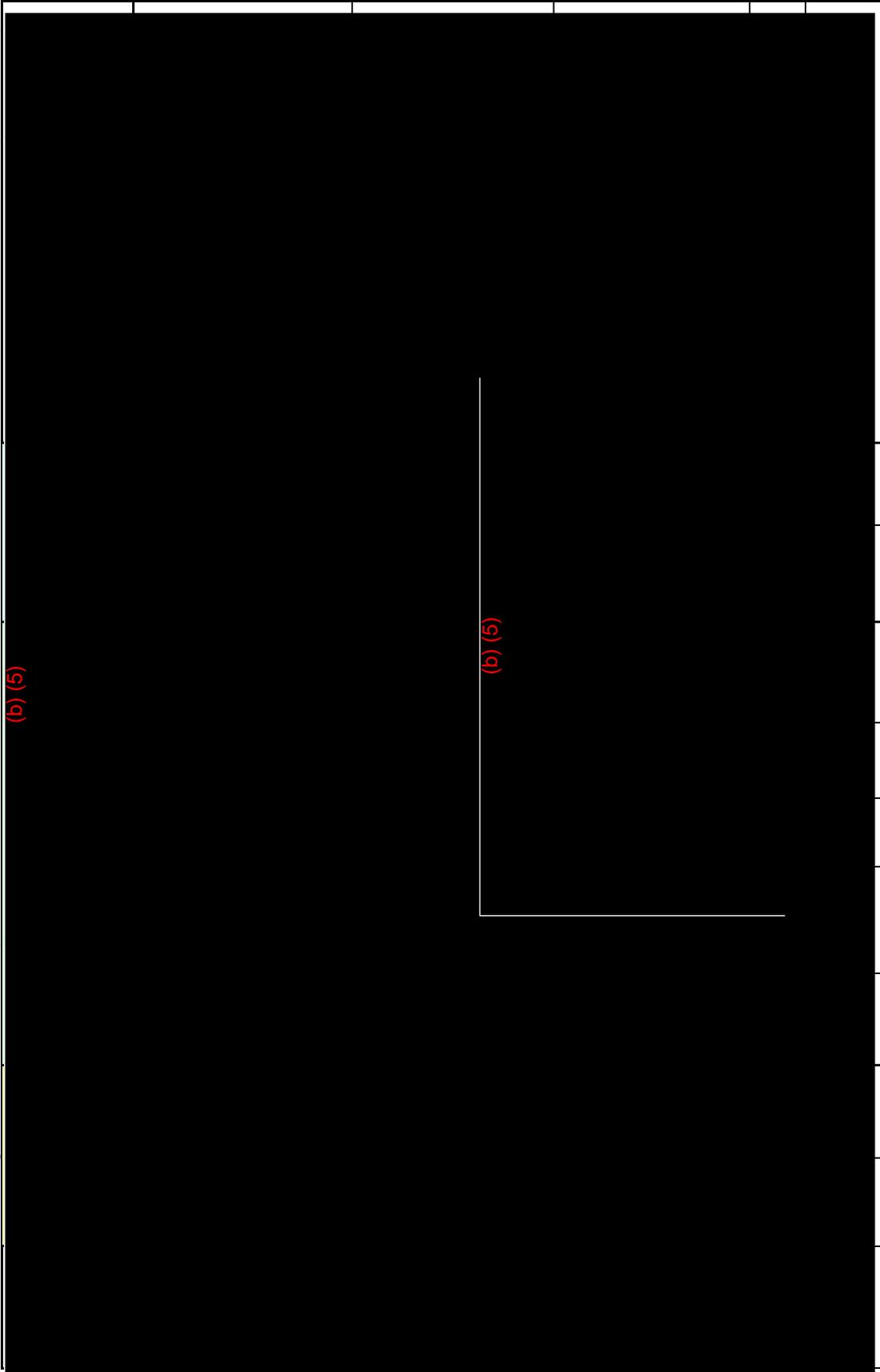


(b) (5)

(b) (5)



Table D-4. Assigned Redundant, Rapid, and Resourceful Scores with Rationale for Footlocker and Pallet SUWPs (Continued)



(b) (5)

(b) (5)



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## APPENDIX E

### DETAILED MEASURE RESULTS ANALYSIS

The following is an in-depth analysis of the briefcase and footlocker/pallet SUWP evaluation results for each measure, separated by goal (Robust, Redundant, Rapid, Resourceful).

#### E.1 Briefcase Results

##### E.1.1 Robust Results for Briefcase SUWPs

The Robust goal addresses the strength or the ability of the system to perform through a given level of stress or demand without suffering degradation or loss of function, which encompasses removal of three pathogen groups (*Bacteria*, *Virus*, and *Protozoa*), *Chemical Reduction*, *Aesthetics* (taste/odor), *Production Rate*, *Durability*, and *Environmental Conditions*.

There was a wide range of results in this area, as described below.

For *Bacteria*, *Virus*, and *Protozoa Reduction*, only two of the systems have undergone independent, protocol-driven testing for pathogen removal; therefore, all other systems scored <100 for these measures. Most scored a 33 or a 20 in clean and worst case waters for the three pathogen reduction measures with the following exceptions:

- [REDACTED] (b) (5)

Of the systems that were evaluated, those that include Reverse Osmosis (RO) are expected to perform well for *Chemical Reduction* (b) (5). Those that included other technologies, as well as RO, received higher scores. (b) (5)

(b) (5) :

- (b) (5) (b) (5) (b) (5)

For *Aesthetics*, few systems are likely to impart objectionable taste/odor and most may indeed improve the aesthetic quality of the water due to the incorporation of granular activated carbon and similar adsorption materials, as well as the lack of chemical disinfectants. (b) (5) :

- (b) (5) (b) (5) (b) (5)

*Production Rate* for most briefcase sized SUWPs met or exceeded the anticipated (b) (5). Exceptions (b) (5) (b) (5) respectively. (b) (5) (b) (5)

A relative scale was used to score systems on *Durability* and *Environmental Conditions*. Scores for the systems ranged from 0 to 85 and varied widely within that range based on numerous features of individual systems. Scores for *Durability* were typically lower if fragile UV lamps were included. All systems had at least one feature that was determined to be a weakness with respect to *Durability*; therefore, no system scored 100 for this measure. Due to the wide variation in results, these two measures should be helpful in differentiating between the systems.

### E.1.2 Redundant Results for Briefcase SUWPs

The Redundant goal addresses the extent to which a system has substitutable functionality capable of achieving minimum performance requirements; to compensate for vulnerability. This encompasses the *Effect of Turbidity* and *Power Flexibility* measures.

The *Effect of Turbidity* is more of an issue for the non-RO systems because they use disposable pre-filters that will be affected by turbidity, and thus, (b) (5) (b) (5) :

- (b) (5) (b) (5) (b) (5) (b) (5) (b) (5)

For *Power Flexibility*, all systems scored well (50 or higher) because no systems use proprietary power sources and many have multiple power sources. However, if a system can use only one power source, this lack of flexibility could impact the ability to produce water under some circumstances.

### E.1.3 Rapid Results for Briefcase SUWPs

Rapidity is the capacity of the system to meet priorities and achieve goals in a timely manner to contain losses and avoid or minimize disruption to the operator. Rapidity encompasses *Effort Required*, *Complexity*, *Cube*, *Weight*, and *Interoperability*. *Effort Required*, *Complexity*, and *Interoperability* were evaluated on relative scales.

The majority of systems scored 50 or higher for the *Effort Required*, *Complexity*, and *Interoperability* measures with the following exceptions:

- [REDACTED] (b) (5)  
[REDACTED] (D) (C)
- [REDACTED] (b) (5)  
[REDACTED] (D) (C)  
[REDACTED] (D) (C)
- [REDACTED] (b) (5)  
[REDACTED] (D) (C)

Additionally, the range of the raw scores for *Cube* and *Weight* was relatively small, primarily because the systems were already separated into different size bins. The briefcase SUWPs ranged in size from 27-70 lbs and 0.3-6.5 ft<sup>3</sup>.

### E.1.4 Resourceful Results for Briefcase SUWPs

The final two measures, *Process Failure Indicators (PFIs)* and *Vendor Support*, are under the Resourceful goal. Resourcefulness is the capacity of the system to identify problems, establish priorities, and mobilize resources when conditions exist that threaten to disrupt some element, system, or other unit of analysis. *Vendor Support* was evaluated on a relative scale.

The majority of the systems scored 60 or higher for *PFIs* with the following exceptions:

- [REDACTED] (b) (5)  
[REDACTED] (D) (C)

Scores for *Vendor Support* were all 50 or higher with three exceptions:

- [REDACTED] (b) (5)  
[REDACTED] (D) (C)  
[REDACTED] (D) (C)

E.2 Footlocker/Pallet Results

E.2.1 Robust Results for Footlocker and Pallet SUWPs

Robustness, as defined in E.1.1, encompasses the removal of three pathogens (*Bacteria*, *Virus*, and *Protozoa Reduction*), *Chemical Reduction*, *Aesthetics* (taste/odor), *Production Rate*, *Durability*, and *Environmental Conditions*. There was a wide range of results in this area, as described below.

For *Bacteria*, *Virus*, and *Protozoa Reduction*, none of the systems has undergone independent, protocol-driven testing for pathogen removal; therefore, no system scored 100 for these measures. (b) (5)

(b) (5)

- (b) (5)

(b) (5)

(b) (5)

(b) (5)

- (b) (5)

(b) (5)

- (b) (5) were not anticipated to be effective against viruses in worst case water and thus, received scores of zero for that measure.

For *Chemical Reduction*, the majority of footlocker and pallet sized SUWPs use multiple technologies known to be effective against some chemicals and thus scored either a 60 or higher in clean and worst case waters with the following exceptions:

- (b) (5)

(b) (5)

- (b) (5)

(b) (5)

Similar to the briefcase sized systems, few systems are likely to impart objectionable taste/odor and most may indeed improve the aesthetic quality of the water due to the incorporation of granular activated carbon and similar adsorption materials, as well as the lack of chemical disinfectants. As a result, most systems scored a 50 or higher for *Aesthetics* with one exception:

- (b) (5)

(b) (5)

For *Production Rate*, all of the systems produce at least 425 gal in a 10 h day, which [REDACTED] (b) (5), with one exception:

- [REDACTED] (b) (5)  
[REDACTED] (b) (5)

A relative scale was used to score systems on *Durability* and *Environmental Conditions*. Most systems scored well (50 or higher) for both measures with three exceptions:

- [REDACTED] (b) (5)  
[REDACTED] (b) (5)

- [REDACTED] (b) (5)  
[REDACTED] (b) (5)  
[REDACTED] (b) (5)

- [REDACTED] (b) (5)  
[REDACTED] (b) (5)

#### E.2.2 Redundant Results for Footlocker and Pallet SUWPs

Redundancy, as defined in E.1.2, encompasses the *Effect of Turbidity* and *Power Flexibility* measures.

*Effect of Turbidity* is less differentiating for the footlocker/pallet sized systems than the briefcase sized systems as most scored 50 or higher with the following exceptions:

- [REDACTED] (b) (5)  
[REDACTED] (b) (5)  
[REDACTED] (b) (5)

*Power Flexibility* is less differentiating because most systems do not use proprietary power sources and many have multiple power sources, with two exceptions:

- [REDACTED] (b) (5)  
[REDACTED] (b) (5)

#### E.2.3 Rapid Results for Footlocker and Pallet SUWPs

Rapidity, as defined in E.1.3, encompasses the *Effort Required*, *Complexity*, *Cube*, *Weight*, and *Interoperability* measures. *Effort Required*, *Complexity*, and *Interoperability* were evaluated on relative scales.

Most systems scored a 50 or higher for *Effort Required* with the following exceptions:

- [REDACTED] (b) (5)  
[REDACTED] (b) (5)

*Complexity* is a potential issue for the footlocker/pallet systems as there were six systems (55% of the systems) that scored below 50 (the remaining systems scored 50 or higher):

- [REDACTED] (b) (5)  
[REDACTED] (D) (C)

*Interoperability* is not significantly differentiating as most systems scored a 50 or higher with the following exceptions:

- [REDACTED] (b) (5)  
[REDACTED] (D) (C)
- [REDACTED] (b) (5)  
[REDACTED] (D) (C)
- [REDACTED] (b) (5)  
[REDACTED] (D) (C)

The range of scores for *Cube* and *Weight* was fairly wide (100-900 lb, 5.8-53.8 ft<sup>3</sup>), but most systems fell within the upper half of the converted score range (score of 50 or higher) as shown in Figure 4 in main text. The (b) (5) systems that scored below 50 were the [REDACTED] (b) (5)

[REDACTED] (b) (5) These systems were evaluated together with the footlocker sized systems because it was decided that they would be used for the same mission scenarios, so whether *Cube* and *Weight* discriminate depends on the user's intended mission. However, it should be noted that [REDACTED] (b) (5) is not compatible with standard military generators, so an additional generator would be needed to operate this system. The additional generator was not accounted for in the cube and weight of the [REDACTED] (b) (5)

#### E.2.4 Resourceful Results for Footlocker and Pallet SUWPs

Resourcefulness, as defined in E.1.4, encompasses the *Process Failure Indicators (PFIs)* and *Vendor Support* measures. *Vendor Support* was evaluated on a relative scale.

The majority of the systems scored 60 or higher for PFIs with the following exceptions:

- [REDACTED] (b) (5)  
[REDACTED] (D) (5)  
[REDACTED] (D) (5)

Scores for *Vendor Support* were all 50 or higher with one exception:

- [REDACTED] (b) (5)



**APPENDIX C**

**DISINFECTANT SYSTEMS**

**Table C-1. Disinfectant Systems for Small Unit Water Treatment.**

| <b>Manufacturer</b>   | <b>Model</b>        | <b>Technology</b>                  | <b>Max Capacity (gpm)<sup>1</sup></b> |
|-----------------------|---------------------|------------------------------------|---------------------------------------|
| MIOX                  | BPS                 | Electrolytic Oxidant Generator     | 20                                    |
| Karcher Futuretech    | E-chlorinator       | Electrolytic Oxidant Generator     | 25                                    |
| Vorigen, Inc          | Vorigen             | Silver Ion Generator               | 3                                     |
| Chemilizer            | HN55                | Water Diaphragm Injector, Chlorine | 13                                    |
| Dosatron              | DI1500              | Water Diaphragm Injector, Chlorine | 0.05-11                               |
| Dosmatic              | Micro-Dos           | Water Diaphragm Injector, Chlorine | 0.1-3.5                               |
| Arch Chemicals        | Constant Chlor Plus | Chlorine                           | Variable                              |
| Multiple <sup>2</sup> | Metering Pump       | Chlorine                           | Variable                              |
| Multiple <sup>2</sup> | Erosion Feeder      | Chlorine                           | Variable                              |

<sup>1</sup> Capacity is volume of water treated per unit time, gallons per minute.

<sup>2</sup> Metering pumps and erosion feeders are less turn-key solutions compared to other systems listed. Numerous manufactures offer each with included or third party chemicals available.

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## APPENDIX D

### MULTI-DISCIPLINARY TEAM

**Table D-1. Small Unit Water Purifier Study Multi-Disciplinary Team.**

| Name                     | Service   | Organization |
|--------------------------|-----------|--------------|
| Akridge, Marella         | Army      | CASCOM       |
| Arteagaharo, Armando SFC | Army      | CASCOM       |
| Bailey, Hugh B MAJ       | Army      | USASOC       |
| Beebe, Matthew D         | Army      | DAT, ECBC    |
| Bonilla, Alex CPT        | Army      | USAPHC       |
| Brown, Mike SFC          | Army      | USASOC       |
| Burrows, Dick Dr         | Army      | USAPHC       |
| Childs, Christopher M    | Army      | USAPHC       |
| Childs, Christopher M    | Army      | USAPHC       |
| Clarke, Brian CPT        | Air Force | USAFSAM      |
| Clarke, Steve            | Army      | USAPHC       |
| Dusenbury, Jay S Dr      | Army      | TARDEC       |
| Garland, Eugene          | Marines   | MARSOC       |
| Holak, Ryan L CPT        | Army      | CASCOM       |
| Holmes, Hank SSG         | Army      | USASOC       |
| Kelly Eric J. MAJ        | Army      | USASOC       |
| Lundquist, Arthur H      | Army      | USAPHC       |
| Miller, Mark C           | Navy      | TARDEC       |
| Oehus, Kevin M           | Army      | TARDEC       |
| Pacuska, Jeff            | Army      | PM-CIE       |
| Peek, Ian                | Navy      | NSWC         |
| Richards, Steven C Dr    | Army      | USAPHC       |
| Richards, Todd E         | Army      | USAPHC       |
| Royer, Anna M            | Navy      | NEPO ERL     |
| Ryczak, Robert S Dr      | Army      | OTSG         |
| Shalewitz, Bob           | Army      | TARDEC       |
| Thomas, Buck             | Marines   | MARSYSCOM    |
| Varnarva, William        | Navy      | NAVFAC       |
| White, Ginn              | Army      | USAPHC       |
| White, William HMI       | Navy      | MARSOC       |
| Wurster, Lindsey R       | Army      | DAT, ECBC    |
| Yenkevich, Thomas        | Army      | CASCOM       |

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**APPENDIX E**  
**SUWP TEST STAND**

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## 1. REFERENCES.

a. *Guide Standard and Protocol for Testing Microbiological Water Purifiers*. USEPA, Registration Division, Office of Pesticide Program, Criteria and Standards Division, Office of Drinking Water. April 1987.

b. NSF Protocol P248. *Emergency Military Operations, Microbiological Water Purifiers*. NSF International. December 2008.

**2. PURPOSE.** The US Army Public Health Command (Provisional) [USAPHC (Prov)], formerly US Army Center for Health Promotion and Preventive Medicine, Water Supply Management Program (WSMP) Small Unit Water Purifier (SUWP) Test Stand facilitated the operational and technical assessment of commercially available SUWPs for Military application with critical observational and performance data.

**3. METHOD.** Each SUWP was subject to a 10-hour test, replicating an operational day as defined by the concept of operations (CONOP). The test was divided into three phases, targeting three distinct water qualities. The first phase was tap water, intended as background assessment under non-challenging conditions. The second and third phases challenged the filtration and disinfection capabilities of the SUWP versus simulated worst-case water and microbiologically contaminated water, respectively. In all phases, assessors annotated pertinent operational information such as filter changes and corresponding system downtime as well as technical data, flowrates, turbidity, and bacteria concentration. In addition to this structured test in the laboratory, illustrated in Figure E-1, SUWPs were operated on natural water sources as time and resources allowed to expand our assessment.

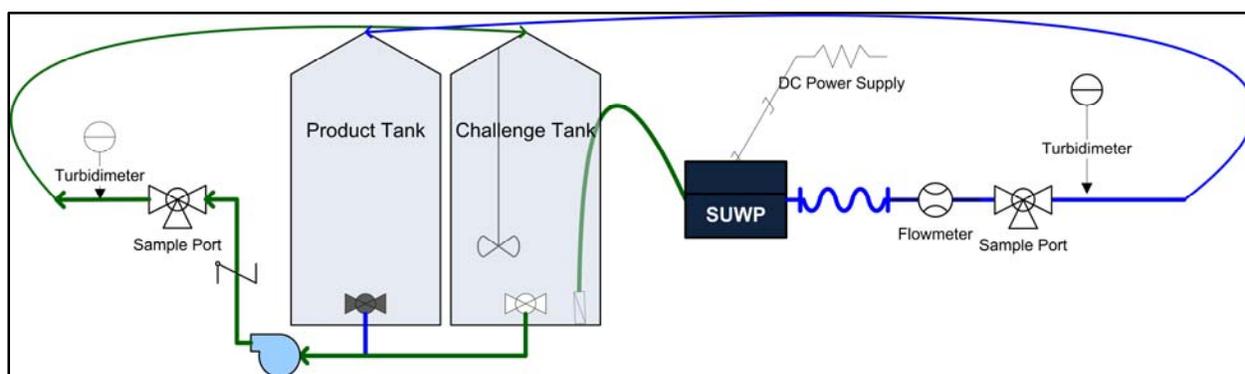


Figure E-1. Laboratory Test Stand Schematic.

a. For each phase of testing, the challenge tank was prepared with sufficient volume for an approximate 3 hour run. The left side of figure E-1 represents the recirculation loop and sample access for characterizing the challenge solution. SUWPs

were integrated into the right-hand portion of figure E-1. The DC Power supply shown was only used for units requiring 12 or 24V DC rather than alternating current (AC) power. Product water from the SUWP was collected in the product tank. The gray valve shown on this tank was normally closed.

b. Phase 2 water was derived from NSF Protocol P248 (reference b) “Filter Challenge Water” and is summarized in Table E-1. For the purposes of this study, Phase 2 water did not include background bacteria as described in Protocol P248. Phase 2 focused on the SUWP’s ability to reduce turbidity, total dissolved solids (TDS), and total organic carbon (TOC), and maintain water production.

**Table E-1. Phase 2 Challenge Water Constituents.**

| Constituent                             | Challenge Concentration | Additive              |
|---|-------------------------|-----------------------|
| Chlorine (mg/L)                         | < 0.1                   | Sodium thiosulfate    |
| pH                                      | 9.0                     | Sodium hydroxide      |
| TOC (mg/L)                              | 10-15                   | Tannic and humic acid |
| Turbidity (NTU)                         | 30-50                   | AC fine test dust     |
| TDS (mg/L)                              | 1500                    | Sodium chloride       |
| Alkalinity (mg/L as CaCO <sub>3</sub> ) | 100                     | Calcium bicarbonate   |

c. Phase 3 water consisted of secondary effluent from a local waste water treatment plant. Phase 3 targeted an SUWP’s ability to remove or inactivate bacteria.

d. Each SUWP was run at the manufacturer-specified flow rate, processing as much water as possible within each phase. Downtime for maintenance was added to the run time, meaning elapsed time was as much as double, or 6 hours for 3 hours of operation. Testing was extended over 3 days, 1 day for each phase to allow for this. In addition, 1 day was allotted for system setup and another for potential make-up operational time, system breakdown, and cleanup. In total, each system was allotted 1 week for testing.

e. Qualitative observations included ease of operation, availability of power source, security, and stability. The assessors also collected quantifiable specifications to include cube and weight, flowrate, pressure, turbidity, TDS, and color, see Table E-2. Both the qualitative and quantitative objectives were driven by the Evaluation Model developed for the SUWP study.

**Table E-2. Test Stand Measurements.**

| Measure                                 | Notes  |
|---|--|
| Cube (LxWxH)                            |  |
| Weight                                  |  |
| Packaging                               | Transportability by commercial parcel service                        |
| Sound Pressure Level                    | Stand-off distance for 85 decibels, if applicable                    |
| Flowrates                               | Product and reject where applicable                                  |
| Pressure                                | Primarily for pressure driven membranes, e.g. RO                     |
| Chlorine (mg/L)                         |  |
| pH                                      |  |
| TOC (mg/L)                              | Sample for external lab analysis <sup>1</sup>                        |
| Turbidity (NTU)                         |  |
| TDS (mg/L)                              |  |
| Alkalinity (mg/L as CaCO <sub>3</sub> ) |  |
| Hardness (mg/L CaCO <sub>3</sub> )      |  |
| Color (Color units)                     |  |
| Bacteria Concentration                  | Total Coliforms, <i>Escherichia coli</i> ( <i>E. coli</i> ), and HPC |

Notes:

LxWxH-length by width by height

mg/L-milligrams per liter

NTU-nephelometric turbidity units

CaCO<sub>3</sub>-calcium carbonate

<sup>1</sup>All other water quality parameters were direct read or in-house method

#### 4. RESULTS.

a. Table E-3 contains a list of systems tested. Systems tested during September 2009, with the exception (b) (5), were too large for the laboratory test stand. We executed an abbreviated test plan at the local waste water facility using Phase 3 water for all testing. (b) (5) was determined to be insufficient to support military operations and testing was terminated after no measureable flowrate was achieved on Phase 1 water.

**Table E-3. SUWP Systems Tested.**

| Manufacturer        | Model         | Technology               | Dates Tested (2009)       |
|---------------------|---------------|--------------------------|---------------------------|
| Seldon Technologies | Waterbox      | Carbon nanomesh          | 26-29 May                 |
| Noah Water Systems  | Trekker       | Carbon Block, (b) (5)    | 1-4 June                  |
| Global Water Group  | LS3 Backback  | Multimedia, (b) (5)      | 15-16, 23 June            |
| First Water         | Responder     | Nano-alumina, (b) (5)    | 3, 7-8 July, 26-28 August |
| Aspen Water         | 1800BC        | Multi-media, (b) (5)     | 8, 14-15 July             |
| SLMCO Pure Water    | 5.0 UF        | Ultrafilter              | 28-30 July, 11 August     |
| Village Marine Tec  | Little Wonder | Reverse Osmosis          | 4, 10-11 August           |
| Spectra Watermakers | Aquifer 150   | Reverse Osmosis          | 6, 10-11 August           |
| Aspen Water         | 5500          | Multimedia, (b) (5), Cl  | 29-30 Sept                |
| Aspen Water         | 1000DM        | Reverse Osmosis          | 1-2 September             |
| Global Water Group  | LS3-8000      | Multimedia, (b) (5), Cl  | 3 September               |
| Global Hydration    | LT22          | 1um Absolute, Cl         | 2 September               |
| Safe DWP            | V-2           | Reverse Osmosis, (b) (5) | 22 September              |

Notes:

(b) (5)

[Redacted text block]

b. Table E-4 presents the raw water quality, averages and ranges, for each phase of testing. Phase 1 water was dechlorinated to less than 0.1mg/L with sodium thiosulfate. Phase 1 and 3 waters were not otherwise altered; there was some seasonal variation in the water quality.

**Table E-4. Raw Water Quality, Averages and Ranges.**

| Constituent                             | Phase 1<br>Baseline |             |      | Phase 2<br>Lab Generated |                  |          | Phase 3<br>Wastewater<br>Effluent |             |          |
|---|---------------------|-------------|------|--------------------------|------------------|----------|-----------------------------------|-------------|----------|
|   | Min                 | Avg         | Max  | Min                      | Avg              | Max      | Min                               | Avg         | Max      |
| pH (pH units)                           | 7.4                 | <b>7.8</b>  | 8.3  | 6.5                      | <b>8.2</b>       | 8.8      | 5.9                               | <b>7.8</b>  | 9.9      |
| Temperature (°C)                        | 20.5                | <b>21.9</b> | 24.5 | 22.1                     | <b>23.9</b>      | 25.0     | 21.0                              | <b>25.0</b> | 28.8     |
| TOC (mg/L)                              | NA                  | <b>NA</b>   | NA   | 5.3                      | <b>7.6</b>       | 8.9      | 3.8                               | <b>4.0</b>  | 4.4      |
| Turbidity (NTU)                         | 0.9                 | <b>2.4</b>  | 6.8  | 19.7                     | <b>37.8</b>      | 73.0     | 1.8                               | <b>3.9</b>  | 9.6      |
| TDS (mg/L)                              | 128                 | <b>239</b>  | 898  | 155<br>0                 | <b>161<br/>2</b> | 169<br>6 | 530                               | <b>772</b>  | 109<br>7 |
| Total Coliforms (log <sub>10</sub> MPN) | NA                  | NA          | NA   | NA                       | NA               | NA       | 4.4                               | <b>5.3</b>  | 6.3      |
| <i>E. coli</i> (log <sub>10</sub> MPN)  | NA                  | NA          | NA   | NA                       | NA               | NA       | 3.0                               | <b>4.0</b>  | 4.9      |

Notes: mg/L-milligrams per liter

NTU-nephelometric turbidity units

MPN-most probable number, a semi-quantitative determination of bacterial concentration using the Quanti-Tray<sup>®</sup> method by Idexx



Figure E-2. *E. coli* positive wells fluoresce under UV light



Figure E-3. Test units at a natural water source

<sup>®</sup> Quanti-Tray is a registered trademarks of Idexx Laboratories, Westbrook, Maine

c. Table E-5 summarizes technical performance data for each of the SUWPs tested.

**Table E-5. WSMP SUWP Test Stand Summary.**

| Constituent                                      | (b) (5) |
|--|---------|---------|---------|---------|---------|---------|
| Total Hours Operation (all phases)               | 10.5    | 10      | 15      | 7       | 9.5     | 8       |
| Total Product Volume (gals)                      | 328     | 593     | 800     | 305     | 110     | 74      |
| Flowrate Phase 1 (gpm)                           | 0.67    | 1.1     | 1.1     | 0.8     | 0.2     | 0.16    |
| Phase 2  |         |         |         |         |         |         |
| Flowrate Phase 2 (gpm)                           | 0.5     | 0.9     | 0.6     | 0.8     | 0.2     | 0.1     |
| Effluent Turbidity (NTU)                         | 0.9     | 1.7     | 0.3     | 1.0     | 0.4     | 1.0     |
| Filter Longevity (gals)                          | 30      | 55      | 30      | 100     | 40      | 10      |
| Phase 3  |         |         |         |         |         |         |
| Flowrate Phase 3 (gpm)                           | 0.5     | 0.7     | 0.8     | 0.6     | 0.2     | 0.16    |
| Effluent Total Coliforms (log <sub>10</sub> MPN) | <1      | <1      | <1      | 1.9     | <1      | 1.9     |
| Effluent <i>E. coli</i> (log <sub>10</sub> MPN)  | <1      | <1      | <1      | <1      | <1      | <1      |

Notes:

Gals-gallons

GPM-gallons per minute

NTU-nephelometric turbidity units

MPN-most probable number

(b) (5)

**Table E-5. WSMP SUWP Test Stand Summary (cont).**

| Constituent                                      | (b) (5)          | (b) (5)          | (b) (5)          | (b) (5)         | (b) (5)          | (b) (5)            |
|--|------------------|------------------|------------------|-----------------|------------------|--------------------|
| Total Hours Operation (all phases)               | 11               | 5.5              | 6                | 8               | 2.2              | 3                  |
| Total Product Volume (gallons)                   | 544              | 905              | 542              | 266             | 210              | 380                |
| Flowrate Phase 1 (gpm)                           | 1.2              | NC <sup>5</sup>  | NC <sup>5</sup>  | 0.8             | NC <sup>5</sup>  | NC <sup>5</sup>    |
| Phase 2  |                  |                  |                  |                 |                  |                    |
| Flowrate Phase 2 (gpm)                           | 0.6              | NC <sup>5</sup>  | NC <sup>5</sup>  | NC <sup>7</sup> | NC <sup>5</sup>  | NC <sup>5</sup>    |
| Effluent Turbidity (NTU)                         | 1.9 <sup>4</sup> | NC <sup>5</sup>  | NC <sup>5</sup>  | NC <sup>7</sup> | NC <sup>5</sup>  | NC <sup>5</sup>    |
| Filter Longevity (gallons) <sup>2</sup>          | 26               | 140 <sup>6</sup> | 200 <sup>6</sup> | NC <sup>7</sup> | 150 <sup>6</sup> | 330 <sup>6,9</sup> |
| Phase 3  |                  |                  |                  |                 |                  |                    |
| Flowrate Phase 3 (gpm)                           | 0.7              | 2.75             | 1.5              | 0.7             | 1.6              | 2.1                |
| Effluent Total Coliforms (log <sub>10</sub> MPN) | <1               | <1               | <1               | 2.8             | 1.6 <sup>8</sup> | <1 <sup>10</sup>   |
| Effluent <i>E. coli</i> (log <sub>10</sub> MPN)  | <1               | <1               | <1               | 1.8             | 0 <sup>8</sup>   | <1                 |

Notes:

<sup>4</sup> Turbidity after the addition of nano-alumina post-filter. Turbidity without post-filter >10NTU.

<sup>5</sup> Not completed, system tested on Phase III water only, see discussion paragraph 4a reference system size and scheduling.

<sup>6</sup> Filter longevity based on Phase 3 water.

<sup>7</sup> Not completed due to system failure.

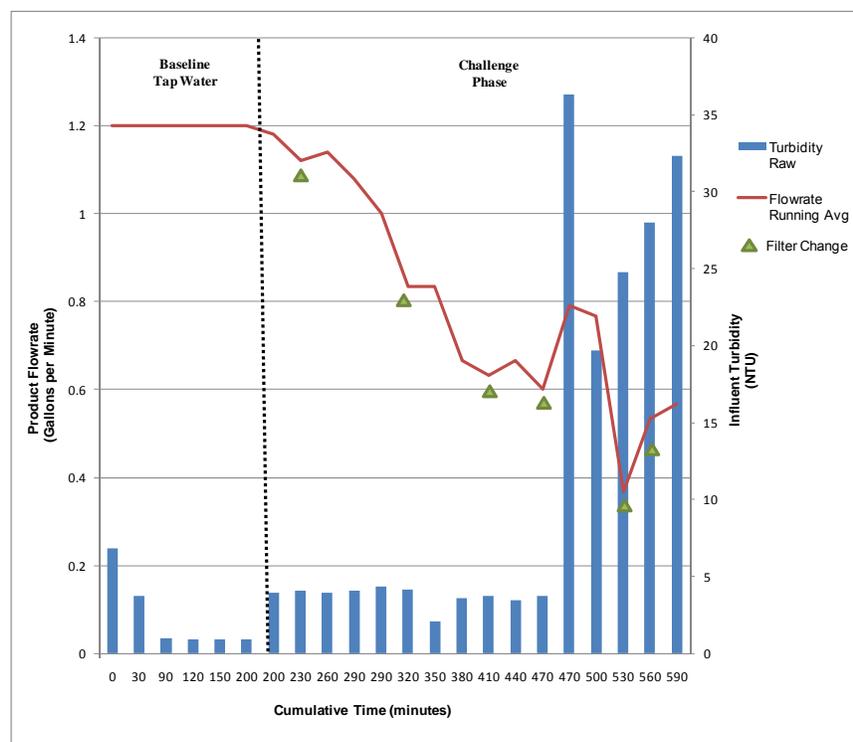
<sup>8</sup> Sample collected after 10 minute chlorine contact time per operating instructions. Free available chlorine (FAC) concentration average 2.6 mg/L.

<sup>9</sup> Cleaning only required.

<sup>10</sup> Samples collected after 30 minute and 60 minute contact times. FAC concentration average 0.4 mg/L at 30 minutes. Re-dosed according to vendor instruction. FAC at 60 minutes was >2mg/L, the target dose. Coliform and *E.coli* results were non-detect in all cases.

## 5. CONCLUSIONS.

a. SUWPs evaluated on the Test Stand met their respective design criteria, but only under non-challenging water conditions. SUWPs consist of a variety of technologies from basic mechanical filters and UV to reverse osmosis. The majority depend on simple cartridge filters which showed a dramatic propensity to clog. Figure E-4 depicts a typical performance curve for an SUWP under increasingly challenging water conditions, defined by water turbidity, blue bars. The flowrate, shown as a red line, falls initially with only stepped recovery following filter changes, indicated by green triangles. Filter longevity was as short as 30 minutes in the most turbid waters.



**Figure E-4. SUWP Performance Curve.**

b. The SUWPs tested demonstrated potential to reduce bacterial pathogens, with marked exceptions in Table E-5. Despite this performance, nearly all systems showed the presence of bacteria after a 24-hour stagnation period. This was attributable to the lack of a secondary disinfectant, allowing re-growth in filter media and system plumbing.

c. SUWPs as a group are insufficiently designed for practical field applications. Resource shortfalls include intake and product tubing length, consumables such as replacement filters, intake assembly (e.g., float and strainer), and general fit and finish.

The WSMP Test Stand was executed for the most part under controlled laboratory conditions with very little environmental strain on the test-systems, yet one unit experienced an electrical short. Systems were operated within 6 feet of the raw water tank with less than 2 feet vertical lift required; nevertheless, multiple systems could not reach the water source or were unable to prime.

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**APPENDIX F**  
**OPERATIONAL TECHNICAL SUMMARIES**

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**APPENDIX F**

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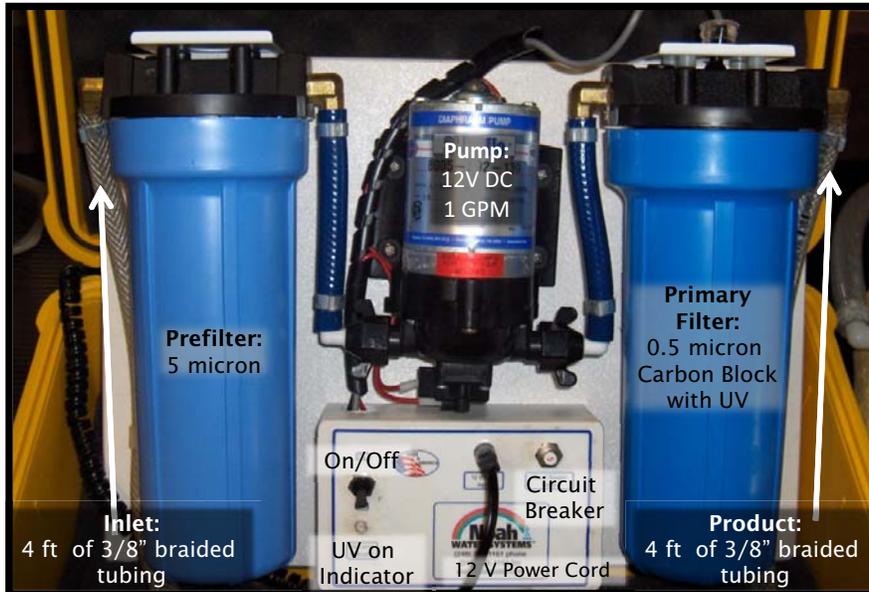
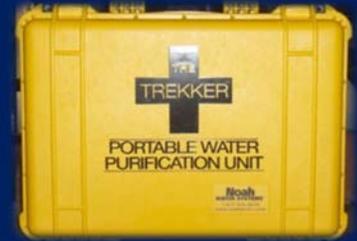
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# Noah Trekker™

## Operational and Technical Evaluation Summary

The Trekker™ (b) (5)  
 (b) (5)  
 (b) (5)  
 (b) (5)



**Technical Specs:**  
 1 gallon per minute  
 Carbon Block with UV  
 Treats Freshwater Only  
 12 V DC, 3 Amps

**Features:**  
 Packaged in a Poly Case  
 4 ft inlet and product hose  
 1GPM electric pump  
 Single 5 micron prefilter

**Dimensions:**  
 17 x 21 x 9 in.  
 27 lbs.



PALLET



FOOTLOCKER



BRIEFCASE

System Cost: \$1195

Filter Set : \$43

Noah Water Systems, Inc  
 877-356-6624  
 www.noahwater.com

This briefcase-sized system weighs about 27 pounds and produces one gallon per minute (gpm) from a freshwater source. This system is the lightest of the 12 briefcase sized systems evaluated. Treatment consists of filtration for sediment and some microbial pathogen reduction; carbon adsorption for some taste and odor reduction; and UV light for disinfection of microbial pathogens. Filtration is provided by a replaceable 5-micron nominal cartridge filter followed by a replaceable 0.5-micron nominal carbon block filter. The system requires a 12-volt Direct Current (DC) power source that is not included.

### Advantages

- Provides adequate treatment of cysts and bacteria.
- Simple to operate.
- Reduces objectionable taste and odor and chemical contaminants.

### Disadvantages

- Provides inadequate virus treatment. Additional treatment required.
- Concern of UV quartz sleeve breakage during transport.
- No fail-safe mechanism to prevent system from continuing to operate if UV lamp is broken or not performing adequately.
- No disinfectant residual

For more information contact:

**Water Supply Management Program  
 U.S. Army Public Health Command (Provisional)**

410.436.3919  
 water.supply@amedd.army.mil

™ Trekker is a trademark of Noah Water Systems, Inc, Novi, MI. Use of trademarked name does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

This system was tested against NSF Protocol P248, Emergency Military Operations Microbiological Water Purifiers. The Protocol requires the following minimum microbiological reductions under strict water quality conditions: 6 log (99.9999%) bacteria, 4 log (99.99%) viruses, and 3 log (99.9%) protozoa. Testing results for the Noah Trekker show the system is capable of providing **adequate treatment of cysts and bacteria in ‘General’<sup>1</sup> water only**. The system does not provide adequate treatment of viruses in any waters. Other third-party testing that did not follow NSF protocol P248 showed the system achieved 6-log reduction of bacteria. The 0.5-micron carbon block filter has received NSF certification for materials requirements only, internal manufacturer testing advertises 3.3 log removal of cysts. General research indicates the carbon block filter will reduce cysts, provide some reduction of bacteria, and provide little or no reduction of viruses based on size exclusion. The UV light is expected to provide significant reduction of bacteria, some reduction of cysts, and the least amount of virus reduction. Based on this information, the Trekker Portable Water Purification Unit is expected to sufficiently reduce cysts and bacteria in unchallenging waters, when used as directed. This system is not expected to consistently reduce viruses. **Additional treatment such as chlorine disinfection is necessary** to provide consistent virus reduction. Because disinfection is provided by UV, this system **does not provide a disinfectant residual**.

## SYSTEM OPERATION

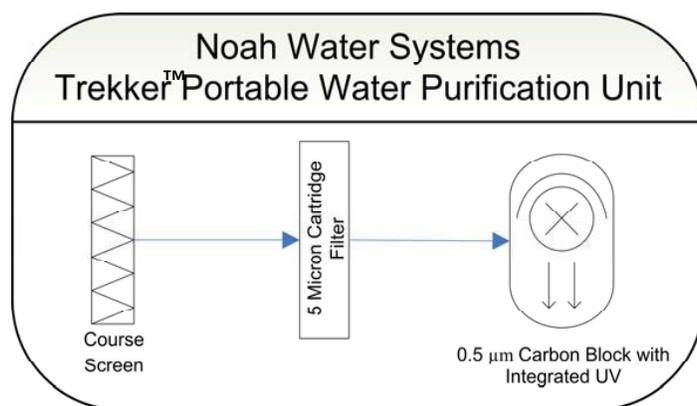


Figure. Flow Diagram.

*Setup & Operation.* Setup and operation involves locating the system near the fresh-water source, connecting a 12V DC power source, not provided, to the system, and turning the system on and allowing the UV light to warmup for 3 minutes before placing the 4-foot inlet hose in the water source. The system contains a self-priming pump that cannot be located greater than 4 feet from the water source. The vendor recommends the inlet and outlet hoses are not be extended. This **requires the system to be placed very close to the water source**, within 4 feet.

*Cleaning & Maintenance.* Maintenance involves filter replacement, cleaning of the quartz sleeve that protects the UV lamp, and UV lamp replacement. Both the 5-micron cartridge filter and the 0.5-micron carbon filter will require

**frequent replacement** in turbid, cloudy, waters. These filters are not cleanable. Reduced flow through the system indicates clogging and the need for filter replacement. The system manufacturer states the filters normally last about 3-6 months but will vary depending on water source conditions. Tests at USACHPPM showed filters needed replacement after treating 55 gallons of turbid (cloudy) water. Cleaning the UV quartz sleeve as well as the filter housings is recommended each time filters are changed. The operating manual recommends replacing the UV lamp every year or every 9,200 hours of use. There is no timer/counter identifying UV hours of use.

*Storage.* Long term storage involves flushing the entire system with a bleach solution for 8-10 minutes with the carbon filter removed. The system must be drained and allowed to dry for 48 hours before re-use or storage.

## Operational Evaluation

Compared to other SUWPs of its size, The Trekker Portable Water Purification Unit is simple to operate. Consider these attributes:

- Time, effort and expense in the purchase of additional filters: likely doubles necessary cube
- Carbon block filter should improve the taste of the treated water and should provide some reduction of chemicals
- Durability of the quartz sleeve surrounding the UV lamp, anecdotal evidence of frequent breakage during shipment
- The system contains a UV indicator light; it does not prevent the system from continuing to operate if the UV fails

<sup>1</sup> NSF Protocol P248 defines ‘General’ and ‘Challenge’ water qualities. Challenge water includes elevated water constituents likely to interfere with treatment processes, such as turbidity, TOC, and pH.

<sup>TM</sup> Trekker is a trademark of Noah Water Systems, Inc, Novi, MI. Use of trademarked name does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.



# Seldon Waterbox™

## Operational and Technical Evaluation Summary

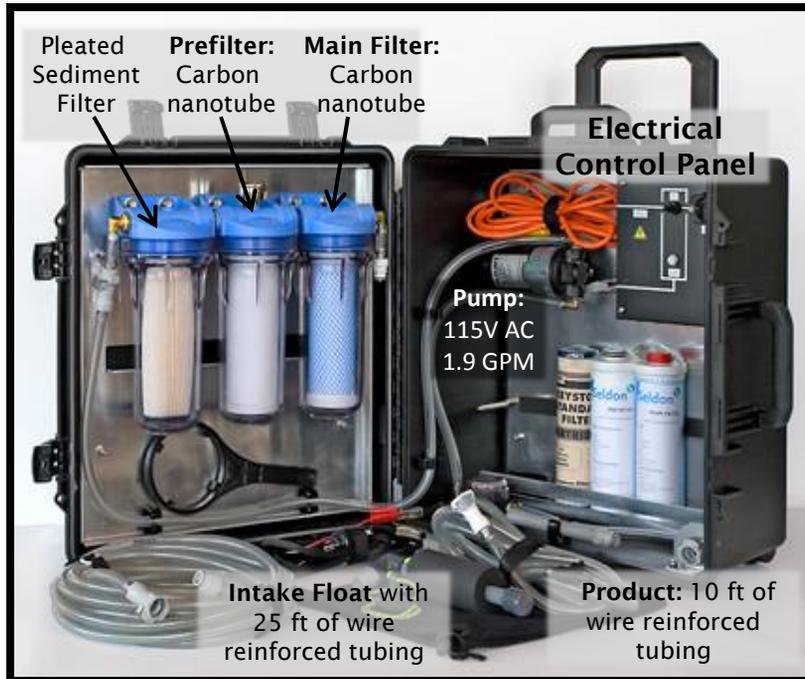
The Seldon Waterbox™

(b) (5)

(b) (5)

(b) (5)

(b) (5)



This briefcase-sized unit weighs about 70 pounds and is capable of producing 0.6 gallon per minute (gpm) from a freshwater source. This system is one of the heaviest of the twelve briefcase sized systems evaluated. Treatment consists of filtration for sediment, fine particle, and some microbial pathogen reduction; and carbon adsorption for chemical contaminant and taste and odor reduction. Prefiltration is provided by a pleated sediment filter. Filtration is provided by replaceable cartridge style carbon nanotube filters (trade-named Nanomesh™ filters), which also provides adsorption. The system is equipped with an electrical control box capable of operating 115-230 volt AC or 12-24 volt DC. An optional manual pump can be purchased separately.

### Advantages

- Expected to provide adequate treatment of microbial pathogens (bacteria, viruses, and cysts).
- Simple to operate with minimal maintenance and troubleshooting.

### Disadvantages

- Nanomesh filters are proprietary requiring purchase from a single provider.
- Prefilter likely requires frequent cleaning/replacement in turbid waters

For more information contact:

**Water Supply Management Program  
U.S. Army Public Health Command (Provisional)**

410.436.3919  
water.supply@amedd.army.mil



### Technical Specs:

0.6 gallons per minute  
Carbon Nanomesh™  
Treats Freshwater Only  
AC, DC, or manual pump

### Features:

Packaged in a Poly Case  
25 ft inlet hose  
10 ft product hose  
Quick connect fittings  
Nanomesh™ prefilter

### Dimensions:

25 x 20 x 14 in.  
70 lbs.



PALLET



FOOTLOCKER



BRIEFCASE

System Cost: \$7995

Filter Set: \$148

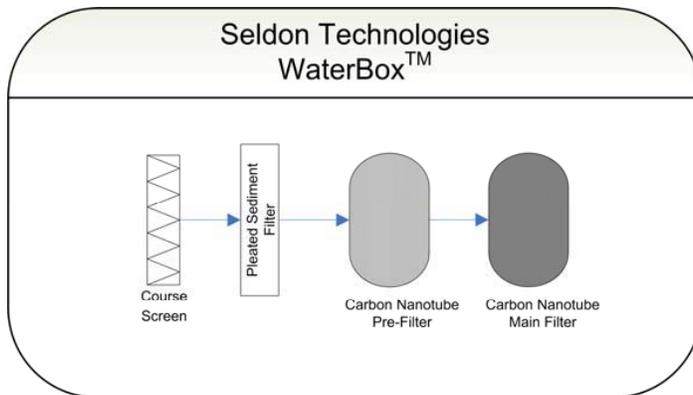
Seldon Technologies, Inc  
802-674-2444  
www.seldontech.com

™ Waterbox and Nanomesh are trademarks of Seldon Technologies Inc, Windsor, VT. Use of vendor and product names does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

There is manufacturer provided **third-party testing showing the system achieved 6-log reduction of bacteria and 4-log reduction of viruses** in ‘General’<sup>1</sup> test waters. The testing used NSF Protocol P231 quality water, but did not follow the complete requirements of the protocol. No data showing the effectiveness of this system in reducing cysts was available. The treatment components of the system –called Nanomesh™ cartridges– do not have independent individual third-party treatment certifications. Both the pre-filter and primary filter cartridges are constructed of a carbon nanotube mesh wound around a carbon block core. Based on available information, the system should be capable of consistently reducing bacteria, viruses, and cysts to the required minimum reductions in NSF Protocol P248 when used as directed. Additional treatment such as chlorine disinfection is **necessary to provide a disinfectant residual**.

## SYSTEM OPERATION



**Figure. Flow Diagram.**

*Setup & Operation.* Setup and operation requires the user to locate the system near the fresh-water source, connect the inlet and outlet hoses, connect to a power source, and turn on the unit and allow it to run and treat at least 1 gallon of water before consumption. The system contains a self-priming pump that cannot be located higher than 14 vertical feet from the water source. The system is supplied with 25 feet of inlet tubing. If necessary, air in the system can be bled out using a pressure relieve valve on the filter housing.

*Cleaning & Maintenance.* Cleaning and maintenance involves cleaning the pump intake strainer and filter cartridge replacement. The system contains a pressure gage that is used to determine when the pre-filter must be

replaced. When the pressure decreases by 10 psi, the pre-filter must be changed. If the pressure is still low after pre-filter replacement, the primary filter must be changed. Additionally, the primary filter should be changed after the pre-filter has been changed six times. Tests at USACHPPM showed the filter required frequent replacement, treating only 31 gallons of turbid (cloudy) water. The vendor has subsequently added an additional pleated sediment filter. The nanotube filters are proprietary preventing purchase of similar replacements from multiple vendors.

*Storage.* After operation the unit must be drained if stored in freezing conditions. If freezing conditions are not expected and the system will be operated again within 72 hours, draining is not necessary. For long-term storage the system should be drained and the filters should be discarded.

## OPERATIONAL EVALUATION

Consider these attributes for the Seldon Waterbox™:

- One of the easiest to operate, it will require the purchase of additional pre-filter and primary filter cartridges.
- Manual provides good maintenance information for all major system components.
- Will improve the aesthetics of the treated water and may reduce various chemical contaminants.
- Most durable SUWP evaluated of its size, completely contained in a poly-resin carrying case and free of identified fragile components such as a UV assembly.
- Decrease in system pressure is a fair indicator for filter replacement but not an absolute measure of process failure.
- Manual identifies unusually high pressures as a potential indication of filter failure (e.g., holes or cracks). Unknown if this will sufficiently illustrate loss of adequate treatment.

<sup>1</sup> NSF Protocol P231, Microbiological Water Purifiers, was written primarily for the testing of point-of-entry and point-of-use water purifiers, treating water with unknown microbiological water quality. While similar in concept to NSF Protocol P248, it does not encompass military mission-specific requirements and is not designed to evaluate the purification of natural water sources as is the latter protocol. NSF Protocol P231 defines ‘General’ and ‘Challenge’ water qualities. Challenge water includes elevated water constituents likely to interfere with treatment processes, such as turbidity, TOC, and pH.

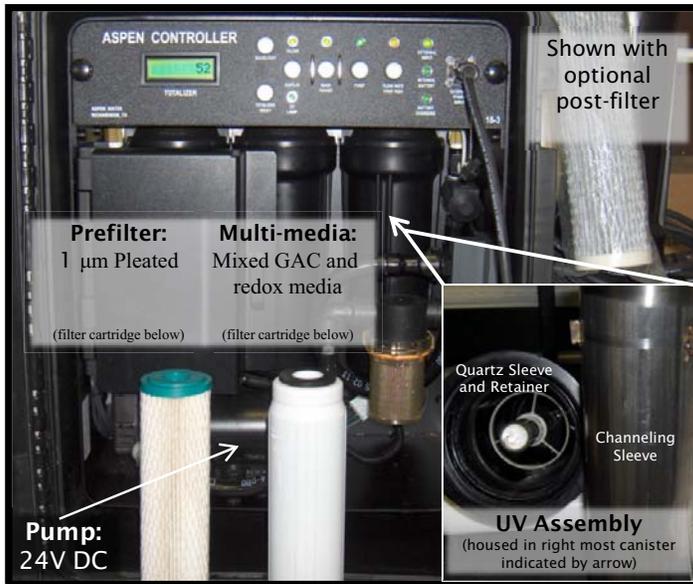
™ Nanomesh and Waterbox are trademarks of Seldon Technologies Inc, Windsor, VT. Use of vendor and product names does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.



# Aspen 1800BC

## Operational and Technical Evaluation Summary

The Aspen 1800BC (b) (5)  
 (b) (5)  
 (b) (5)



**Technical Specs:**  
 1.25 gallons per minute  
 Multimedia with UV  
 Treats Freshwater Only  
 AC or DC

**Features:**  
 Packaged in a Poly Case  
 10ft inlet and product hose  
 Camlock fittings  
 Extended use case  
 Single 1 micron prefilter

**Dimensions:**  
 25 x 20 x 14 in.  
 68 lbs.



PALLET



FOOTLOCKER



BRIEFCASE

**System Cost: \$11,000**

**Filter Set: \$91**

Aspen Water, Inc  
 972-889-9500

[www.aspenwater.com](http://www.aspenwater.com)

This briefcase-sized unit weighs about 68 pounds and is capable of producing 1.25 gallons per minute (gpm) from a freshwater source. This system is one of the heaviest of the briefcase sized systems evaluated. Treatment consists of filtration for sediment, fine particle, and some microbial pathogen reduction; oxidation-reduction (redox) provided by a copper-zinc granular media, and carbon adsorption, both for chemical contaminant and taste and odor reduction; and ultraviolet (UV) light for disinfection of microbial pathogens. Filtration is provided by a replaceable 1-micron sediment cartridge filter. Redox and carbon adsorption is provided by a replaceable multimedia filter containing copper-zinc granular media and granular activated carbon (GAC). The system can be powered by 90-260 V single phase alternating or 24 V direct current (AC/DC) and includes batteries with an advertised run capacity of 60 minutes. An optional solar battery charging system can be purchased separately.

**Advantages**

- Expected to provide adequate treatment of cysts and bacteria.
- Capable of using multiple power sources.
- Automatic shutdown if UV lamp burnout/breakage occurs.

**Disadvantages**

- Not expected to provide adequate treatment of viral pathogens.
- Additional treatment will be required.
- Concern of UV quartz sleeve breakage during transport.
- Batteries must be charged prior to initiating operations to achieve full production rate

For more information contact:  
**Water Supply Management Program**  
**U.S. Army Public Health Command (Provisional)**  
 410.436.3919  
[water.supply@amedd.army.mil](mailto:water.supply@amedd.army.mil)

Use of vendor and product names does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

Insufficient data to verify the effectiveness of this system in reducing microbial pathogens was available. The treatment components of the system – 1micron ( $\mu\text{m}$ ) sediment filter cartridge, multimedia filter canister (copper-zinc media and granular activated carbon (GAC)), and UV – do not have independent third-party treatment certifications. Based on general knowledge of the treatment technologies used, the system should be capable of consistently reducing cysts and bacteria to the respective 3-log and 6-log minimum reductions when used as directed. However, the system is not expected to consistently reduce viruses the required 4-log. Highly turbid waters may interfere with the UV efficacy to inactivate bacterial and protozoan (cyst) pathogens as well. **Additional treatment such as chlorine disinfection is necessary** to achieve adequate microbiological treatment and provide a **residual disinfectant** in the product water.

## SYSTEM OPERATION

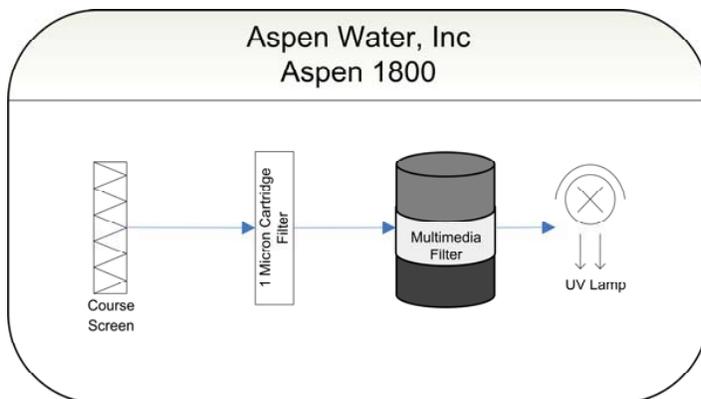


Figure. Flow Diagram.

*Setup & Operation.* Setup and operation requires the user to locate the system near the fresh-water source, connect the inlet and outlet hoses, connect to a power source or use the included batteries, and turn on the unit and allow it to run and treat at least 5 gallons of water before consumption. The system contains a self-priming pump and cannot be located greater than 10 feet from the water source with the provided tubing.

*Cleaning & Maintenance.* Cleaning and maintenance involves filter cartridge cleaning and replacement, multimedia filter canister replacement, cleaning of the quartz sleeve protecting the UV lamp, UV lamp replacement, and cleaning the pump. The 1 $\mu\text{m}$  filter may

be cleaned and reused three to four times by washing/flushing with clean water. When the system display indicates “LOW FLOW” (less than 1.25 gpm), the 1 $\mu\text{m}$  filter must be cleaned or replaced. Tests at USACHPPM showed the filter required frequent replacement, treating only 26 gallons of turbid (cloudy) water. The multimedia filter canister should be replaced based on total gallons of water treated, which can be tracked by the system’s digital totalizer, or if replacing the 1 $\mu\text{m}$  prefilter does not restore flowrate to 1.25 gpm. The vendor recommends canister replacement after 5,000 – 9,000 gallons of water have been treated. Cleaning the UV quartz sleeve is recommended after any extended use. UV lamps should be changed after 500,000 gallons. However, repeated on/off operation will degrade the UV lamp more quickly. Directions are included to clean the pump if it’s determined that the pump has become fouled. A “NO FLOW” condition may indicate the pump requires cleaning. All system components, including consumables are proprietary, but are of common dimensions which could be procured on the commercial market.

*Storage.* After operation the unit must be drained prior to moving. For long-term storage the system should be drained, the 1 $\mu\text{m}$  filter should be replaced, the multimedia filter canister and hoses should be cleaned and disinfected.

## OPERATIONAL EVALUATION

Compared to other SUWPs of its size, the Aspen 1800 BC water purification system is fairly easy to operate. Operating and maintaining the system does require time and effort and will require the purchase of additional 1 $\mu\text{m}$  and multimedia filter cartridges. The operator manual provides good maintenance information for all major system components. The multimedia (copper-zinc and GAC) will improve the aesthetics of the treated water by reducing objectionable tastes and odors, and various chemical contaminants. Being completely contained in a Storm Case<sup>®</sup> the system appears more durable compared to other SUWPs of its size. There is concern about the durability of the quartz sleeve surrounding the UV lamps as there is anecdotal evidence of frequent breakage in other SUWPs during shipment. The Aspen 1800 incorporate a quartz sleeve retainer not included in other SUWPs and may mitigate this hazard. The systems multiple power options provide some of the best flexibility for power sources among the SUWPs evaluated. The automatic shutdown in the event the UV lamp is broken/burned out is a good process failure indicator. However, there is no indicator to show if the UV lamp is working properly and providing adequate UV dose to the treated water. The system has a control panel with LCD display to show total gallons treated and error codes. The 1800 BC is 60% more expensive than comparable SUWPs of its size.

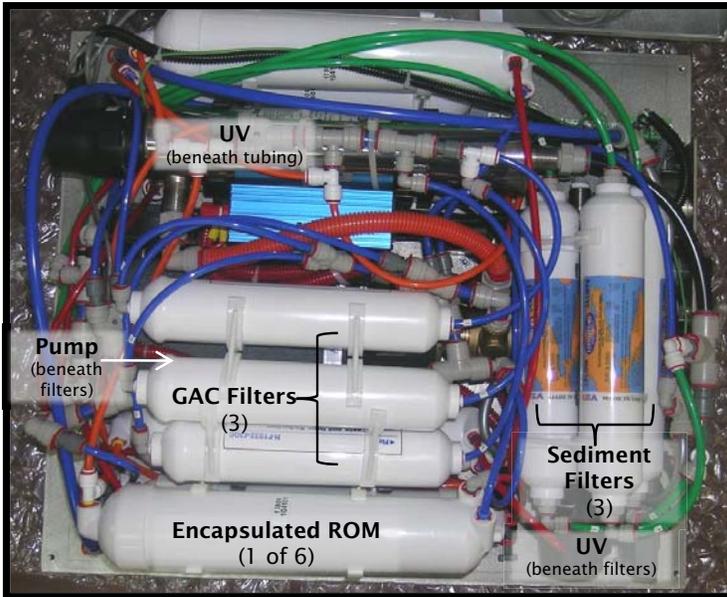
<sup>®</sup> Storm Case is a registered trademark of Hardigg Industries, South Deerfield, MA. Use of trademarked name does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.



# SLMCO Portable Series 5.0

## Operational and Technical Evaluation Summary

The SLMCO P [REDACTED] (b) (5)  
 [REDACTED] (b) (5)  
 [REDACTED] (b) (5)  
 [REDACTED] (b) (5)



This briefcase-sized unit weighs about 70 pounds, the average weight of all the briefcase sized systems evaluated. The system is capable of producing one gallon per minute (gpm) from a fresh or brackish water source (max 10,000 mg/L total dissolved solids). Treatment consists of prefiltration for sediment, fine particle, and some microbial pathogen reduction; carbon adsorption for chemical contaminant reduction; reverse osmosis membrane filtration for reduction of microbial pathogens, chemicals, and fine particles; and ultraviolet (UV) light for disinfection of microbial pathogens. Filtration is provided by replaceable 5 micron sediment filters and granular activated carbon (GAC) filters (3 each), and six cleanable reverse osmosis membranes (ROM) operated in parallel. Two UV lamps provide disinfection pre- and post-reverse osmosis. The system requires a 24-volt Direct Current (DC) power source, not included, or may be configured for 12 V DC or 120/240 V AC 60Hz.

### Advantages

- Provides adequate treatment of microbial pathogens (cysts, bacteria, and viruses)
- Highly effective at removing off-tastes and odors

### Disadvantages

- Operators manual is incomplete
- No UV failure indicator
- Concern of UV breakage during transport

For more information contact:

**Water Supply Management Program  
 U.S. Army Public Health Command (Provisional)**

410.436.3919  
 water.supply@amedd.army.mil



### Technical Specs:

1 gallon per minute  
 Reverse Osmosis with UV  
 Treats Fresh or brackish water Only  
 24 V DC

### Features:

Powder-coated aluminum  
 10 ft inlet and product hoses  
 Quick connect fittings  
 6 prefilters

### Dimensions:

24 x 7 x 20 in.  
 70 lbs.



PALLET



FOOTLOCKER



BRIEFCASE

System Cost: \$8000

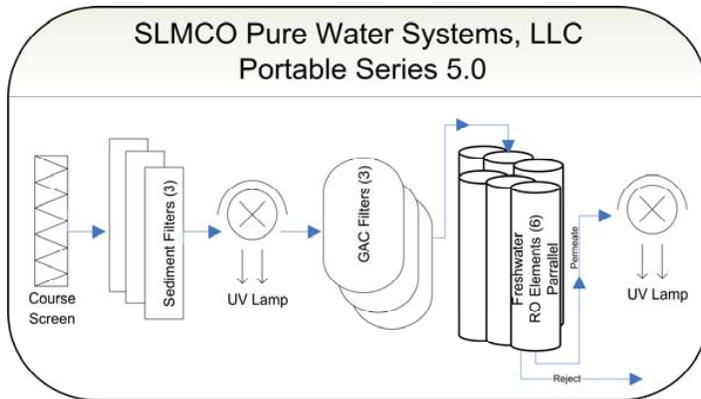
Pre-Filter Set : \$60

SLMCO  
 Pure Water Systems , LLC  
 850-980-1265  
 www.slmcopurewatersystems.com

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

This system was tested against NSF Protocol P248, Emergency Military Operations Microbiological Water Purifiers. The Protocol requires the following minimum microbiological reductions under strict water quality conditions: 6 log (99.9999%) bacteria, 4 log (99.99%) viruses, and 3 log (99.9%) protozoa. **Testing results for the SLMCO Series 5.0 verify adequate treatment** for bacteria, viruses, and cysts, except for cysts in ‘Challenge’<sup>1</sup> water conditions. Based on existing research of the treatment technologies used, the system should be capable of consistently reducing cysts, bacteria, and viruses to the required minimum log reductions when used as directed. The pre-RO and post-RO UV lamps are expected to provide significant reduction of bacteria, some reduction of cysts, and the least amount of virus reduction. The RO membranes are expected to provide significant reduction of cysts, bacteria, and viruses. Because disinfection is provided by UV, additional treatment such as chlorine disinfection is **necessary to provide a disinfectant residual**.

## SYSTEM OPERATION



**Setup & Operation.** Setup and operation involves locating the system near the water source, connecting the inlet, outlet (permeate), and concentrate (reject) hoses, and connecting the power cord to the power source. During startup the membrane pressure and permeate flow rate are set by the user to about 125 psi and 1 gallon per minute. An LCD readout provides feed and permeate total dissolved solids (TDS), run time, water temperature, and alarm status.

**Cleaning & Maintenance.** Cleaning and maintenance involves automatic flushing of the RO membranes, sediment and carbon cartridge filter replacement, and troubleshooting as necessary based on operational fault indicators. The system is preset to provide automatic forward flushing of the RO membranes every 30 minutes,

this frequency can be adjusted or augmented with manual flush cycles. If the permeate flow decreases to an extremely low level then

**Figure. Flow Diagram. All filter sets in parallel.**

the sediment and carbon filters must be replaced. The replacement carbon filter must be flushed to remove carbon “fines” prior to installation. The operational fault indicators use pressure and conductivity monitoring to identify potential treatment problems. There are no cleaning and maintenance instructions for the UV lamps.

**Storage.** There are no special storage requirements identified in the operating manual. General knowledge of reverse osmosis membranes and discussions with the vendor indicate the use of two cleaning chemicals and a third preservative are necessary for long term storage. The cleaning chemicals may also be used after extended use to improve membrane production. Chemicals are provided in premeasured packets of granules, diluted in one gallon of permeate, and processed through the system for ten minutes each.

## OPERATIONAL EVALUATION

Compared to other SUWPs of its size, The SLMCO Series 5.0 portable water purification unit is fairly complex to operate primarily due to the reverse osmosis treatment technology and intricate internal composition. Operating and maintaining the system does require time and effort and will require the purchase of additional sediment and carbon filters for operation. The operator manual does not contain maintenance information specifically for the UV lamps and the reverse osmosis membranes. Based on USACHPPM testing the sediment and carbon block filters needed replacement well before their estimated life cycle identified in the manual. The carbon filters and reverse osmosis membranes will improve the taste of the treated water by reducing objectionable tastes and odors, and chemical contaminants. There is concern about the durability of the quartz sleeve surrounding the UV lamps as there is anecdotal evidence of frequent breakage in other SUWPs during shipment. The quartz sleeve is necessary for operation of the UV lamp. The system uses conductivity, pressure, and flow for treatment failure indicators and will display the fault conditions on the control panel. However, there is no indicator to show if the UV lamp is broken or working properly and providing an adequate UV dose to the water.

<sup>1</sup> NSF Protocol P248 defines ‘General’ and ‘Challenge’ water qualities. Challenge water includes elevated water constituents likely to interfere with treatment processes, such as turbidity, TOC, and pH.



# First Water™ Responder-S™

## Operational and Technical Evaluation Summary

The Responder

(b) (5)  
 (b) (5)  
 (b) (5)  
 (b) (5)



This briefcase-sized system weighs about 45 pounds and produces one gallon per minute (gpm) from a freshwater source. Treatment consists of filtration for sediment and some microbial pathogen reduction; adsorption by activated carbon and alumina for taste and odor and some chemical reduction; and UV light for disinfection of microbial pathogens. Filtration is provided by a sediment filter on the inlet hose, followed by a 10 micron (µm) spun-wound cartridge filter, a 5 µm carbon block filter, and a nano-alumina and powder activated carbon (PAC) filter. The system has an integrated solar panel for power or will operate on a 12-volt direct current (DC) power source that is not included.

### Advantages

- Anticipated to provide adequate treatment of bacteria and cysts.
- Simple to operate.

### Disadvantages

- System may be susceptible to damage by severe environmental conditions and rigors of Military mission, particularly UV and solar components.
- No disinfectant residual.

For more information contact:

**Water Supply Management Program  
 U.S. Army Public Health Command (Provisional)**

410.436.3919  
 water.supply@amedd.army.mil



### Technical Specs:

1 gallon per minute  
 Nano-Alumina with UV  
 Treats Freshwater Only  
 12V DC or Solar

### Features:

Packaged in a Poly Case  
 10ft inlet, 4ft product hose  
 1GPM electric pump  
 Multiple Prefilters

### Dimensions:

17 x 20 x 9 in.  
 45 lbs.



PALLET



FOOTLOCKER



BRIEFCASE

System Cost: \$4500

Filter Set: \$84

First Water, Inc  
 770-235-5277  
 www.firstwaterinc.com

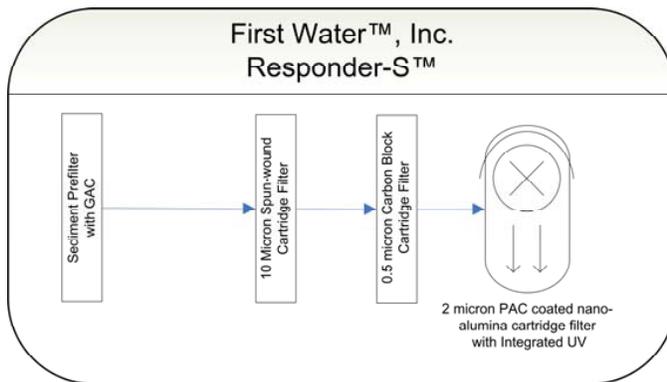
™ First Water and Responder-S are trademarks of First Water, Inc, Suwanee, GA. Use of trademarked names does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

No data was available to confirm the effectiveness of this system in reducing microbial pathogens. The treatment components of the system – 0.5-micron carbon block filter, nano-alumina / PAC filter, and ultraviolet (UV) reactor – do not have independent third-party treatment certifications. General research indicates nano-alumina filters will remove or reduce bacteria, cysts, and viruses through adsorption on the submicron scale and mechanical filtration on the micron scale. The UV light is expected to provide significant reduction of bacteria, some reduction of cysts, and some viral reduction. The carbon block filter should also provide some cyst reduction. Based on this information, the First™ Water Responder-S™ is expected to consistently reduce cysts and bacteria to the required 3-log and 6-log minimum reductions, respectively, when used as directed.

**Additional treatment such as chlorine disinfection is recommended** to ensure consistent virus reduction. Because disinfection is provided by UV, this system **does not provide a disinfectant residual**.

## SYSTEM OPERATION



*Setup & Operation.* Setup and operation involves locating the system within 10 feet of the fresh-water source, using the integrated solar panel or connecting to a 12V DC power source, not provided, to the system, and turning the system on and allowing the UV light to warm-up for 3 minutes before placing the 4-foot outlet hose in the product water container. The system contains a self-priming pump that should not be located greater than 8 feet vertically from the water source.

*Cleaning & Maintenance.* Maintenance involves filter replacement, cleaning of the quartz sleeve that protects the UV lamp, and UV lamp replacement. The sediment prefilter and 10-micron cartridge filter will likely require **frequent replacement** in turbid, cloudy, waters. The 0.5 micron carbon block and nano-alumina cartridge may be similarly effected if the prefilters do not capture the bulk of the suspended particulate in the water. The filters are not cleanable. Reduced flow through the system indicates clogging and the need for filter replacement. The vendor recommends cleaning the UV quartz sleeve as well as the filter housings each time filters are changed.

*Storage.* Long term storage involves draining the filter housings, running the system dry for 1 minute, and allowing the unit to dry prior to storage.

## OPERATIONAL EVALUATION

Compared to other SUWPs of its size, The Responder-S™ is simple to operate. The following were noted through the course of evaluation and should be considered when comparing this and other briefcase-sized SUWPs:

- Time, effort and expense in the purchase of additional filters: likely doubles necessary cube
- Durability of UV and solar panel components
- Unit must be located very near water source or water transported to unit for treatment
- Operating unit must provide product water storage and distribution equipment

™ First Water and Responder are trademarks of First Water, Inc, Suwanee, GA.

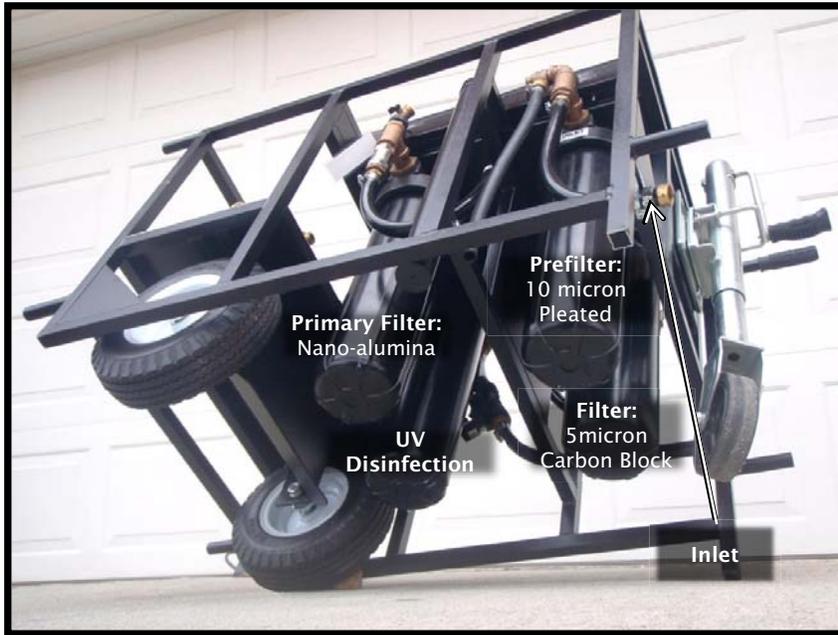
Use of trademarked names does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.



# First Water™ Outpost™

## Operational and Technical Evaluation Summary

### The Outpost



This footlocker-sized system weighs approximately 200 pounds and produces four gallons per minute (gpm) from a freshwater source with solar power. Treatment consists of filtration for sediment and some microbial pathogen reduction; carbon adsorption for some taste and odor reduction; and UV light for disinfection of microbial pathogens. Filtration is provided by replaceable 10-micron and 5-micron nominal cartridge filters, followed by a 0.5-micron carbon block filter. The system has an integrated solar panel for power or the 12-volt direct current (DC) batteries may be charged by another source that is not included.

#### Advantages

- Anticipated to provide adequate treatment of bacteria and cysts.
- Simple to operate.
- Reduces objectionable taste and odor and some chemical contaminants.

#### Disadvantages

- Concern of UV quartz sleeve breakage during transport.
- No disinfectant residual.
- Production severely impacted by highly turbid waters.

For more information contact:

**Water Supply Management Program  
U.S. Army Public Health Command (Provisional)**

410.436.3919  
water.supply@amedd.army.mil



#### Technical Specs:

4 gallons per minute  
Carbon block with UV  
Treats Freshwater Only  
12V DC or Solar

#### Features:

Wheeled metal frame  
75ft inlet hose  
10ft product hose  
Multiple Prefilters

#### Dimensions:

26 x 48 x 34 in.  
200 lbs.



PALLET



FOOTLOCKER



BRIEFCASE

System Cost: \$17, 000

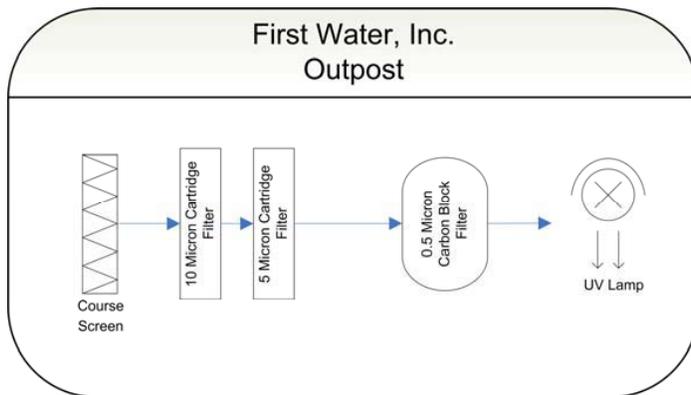
Filter Set: \$46

First Water, Inc  
770-235-5277  
www.firstwaterinc.com

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

No data was available to confirm the effectiveness of this system in reducing microbial pathogens. The treatment components of the system – 0.5-micron carbon block and ultraviolet (UV) reactor – do not have independent third-party treatment certifications. General research indicates the carbon block filter will reduce cysts, provide some reduction of bacteria, and provide little or no reduction of viruses based on size exclusion. The UV light is expected to provide significant reduction of bacteria, some reduction of cysts, and the least amount of virus reduction. Based on this information, the Outpost™ is expected to reduce cysts and bacteria the required 3-log and 6-log minimum reductions, respectively, in unchallenging water, when used as directed. This system is not expected to consistently reduce viruses. **Additional treatment such as chlorine disinfection is necessary** to provide consistent virus reduction. Because disinfection is provided by UV, this system **does not provide a disinfectant residual**.

## SYSTEM OPERATION



*Setup & Operation.* Setup and operation involves locating the system within 50 feet of the fresh-water source (max 15 feet vertical), using the integrated solar panel and on board battery or connecting to an AC power supply, turning the system on, and allowing the UV light to warm-up for 3 minutes before consuming the product water.

*Cleaning & Maintenance.* Maintenance involves filter replacement, cleaning of the quartz sleeve that protects the UV lamp, and UV lamp replacement. The 10-micron cartridge filter, 5-micron cartridge filter, and the 0.5-micron carbon

filter will require **frequent replacement** in turbid waters. These filters are not cleanable. Reduced flow through the system indicates clogging and the need for filter replacement. The system manufacturer states the filters may last 3-6 months but will vary with water conditions. Filters will likely require daily to weekly replacement in turbid waters. The vendor recommends cleaning the UV quartz sleeve as well as the filter housings each time filters are changed. The operating manual recommends replacing the UV lamp every year or every 9,200 hours of use. There is no timer/counter identifying UV hours of use.

*Storage.* Long term storage involves draining the filter housings, running the system dry for 1 minute, and allowing the unit to dry prior to storage.

## OPERATIONAL EVALUATION

Compared to other SUWPs of its size, The First Water™ Outpost™ is simple to operate. Consider these attributes when comparing other footlocker-sized SUWPs:

- Time, effort and expense in the purchase of additional filters: likely doubles necessary cube
- Carbon block filter should improve the taste of the treated water and should provide some reduction of chemicals
- Durability of UV and solar panel components
- Operating unit must provide product water storage and distribution equipment



# Kärcher WTC 500

## Operational and Technical Evaluation Summary

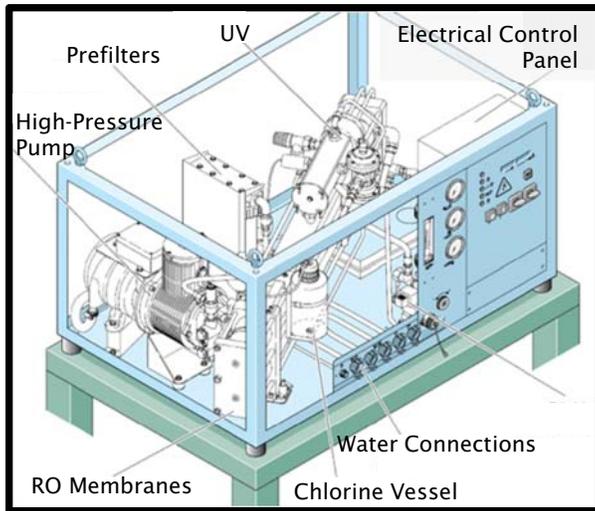
The Kärcher

(b) (5)

(b) (5)

(b) (5)

(b) (5)



This pallet-sized system, weighing about 450 pounds, is capable of producing 2.4 or 1.9 gallons per minute (gpm) from a fresh or salt water source respectively. Treatment consists of pre-filtration for sediment reduction; reverse osmosis membrane filtration for reduction of pathogens, salts and chemicals; and ultraviolet (UV) light and chlorine for disinfection of microbial pathogens. Pre-filtration is provided by replaceable 5 and 10-micron cartridge filters. The complete system with supplemental raw water pump, requires a 9 kilowatt alternating current (AC) power source which is not included. The vendor offers an optional diesel or JP8- fueled generator as well as more robust pre-filtration hardware and a trailer for carriage of the complete assembly.

### Advantages

- Tested and proven performance for bacteria and protozoa removal.
- Anticipated to be effective against viruses based on multiple technologies.
- High pressure RO known to reduce chemicals.
- Multiple water quality monitors and feedback mechanisms.

### Disadvantages

- System may be susceptible to damage by severe environmental conditions and rigors of Military mission.
- Effort to operate and maintain is estimated to be among the highest of systems evaluated; greater than 1 hour per 10 hours of operation.
- Resupply may be restricted by single vendor source.

For more information contact:

**Water Supply Management Program  
U.S. Army Public Health Command (Provisional)**

410.436.3919  
water.supply@amedd.army.mil



### Technical Specs:

2.6 gallons per minute  
Reverse Osmosis  
Treats most waters,  
including Saltwater  
400V AC

### Features:

Modular design  
Provides a chlorine residual

### Dimensions:

23 x 47 x 31 in.  
450 lbs.



PALLET



FOOTLOCKER



BRIEFCASE

System Cost: \$41,500

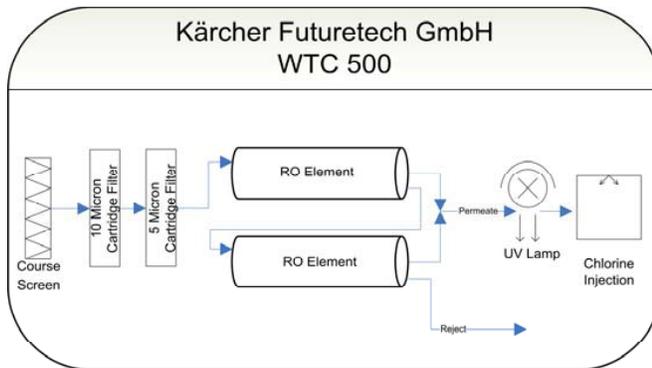
Pre-Filter Set : \$33

Karcher Futuretech  
49 7195 14 2452  
www.kaercher.com

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

The vendor provided **independent test data** of the system in accordance with a German treatment performance protocol verifying 6-log bacterial reduction. Due to the treatment mechanism, mechanical size exclusion, adequate removal of cysts, would also be expected based on this testing. Based on general knowledge of the treatment technologies—Reverse Osmosis, Ultraviolet (UV), and chlorine—the system should be capable of consistently reducing all three classes of microbial pathogens in water, bacteria, viruses, and cysts to the required 6-, 4- and 3-log minimum reductions, when used as directed. High pressure reverse osmosis membranes (ROMs), as employed in the WTC 500, are known to provide broad spectrum chemical reduction. **A chlorine injection component in the system provides a disinfectant residual.**

## SYSTEM OPERATION



*Setup & Operation.* Setup and operation requires the user to establish a raw water intake, emplace the raw water pump, connect suction and water supply lines, connect a 400V 50Hz AC power supply, prepare the chlorine solution, connect product and reject hoses, and turn on the unit and allow it to run. ROMs will require flushing of preservative at first use

*Cleaning & Maintenance.* Cleaning and maintenance involves filter cartridge cleaning and replacement, cleaning of the ROMs, cleaning of the quartz sleeve protecting the UV lamp, UV lamp replacement, and

maintaining the chlorine injection system. Without additional prefiltration, the cartridge filters will require regular replacement in turbid waters. General guidance for UV lamps is annual replacement.

*Storage.* There are no special requirements for short term storage. For long-term storage, a preservative should be added to the RO membranes to include antifreeze when applicable. On start up after short term storage allow the unit to run for a minimum of 10 minutes before water is consumed or place in storage containers. After long term storage, water can be consumed after unit is run for 45 minutes.

## OPERATIONAL EVALUATION

The treatment module as depicted in the center schematic (reverse) and the above flow diagram can be used independently but is more practically part of a larger platform such as the trailer pictured in the margin on the reverse side. Such a platform would include a generator, additional prefiltration, and a raw water pump. While creating a more complete platform, operationally, these additions inherently increase weight, cube, and the operational footprint. The WTC 500 was ranked among the most complex and may require experienced operators at a minimum for initial setup and maintenance.



# Spectra Aquifer Portable

## Operational and Technical Evaluation Summary

The Spectra Aquifer

(b) (5)

(b) (5)



**Technical Specs:**  
 0.1 gallon per minute  
 Reverse Osmosis  
 Treats most waters,  
 including Saltwater  
 AC, DC, Solar

**Features:**  
 Packaged in a Poly Case  
 50 ft inlet, 25 ft product hose  
 Energy recovery system

**Dimensions:**  
 16 x 32 x 22 in.  
 70 lbs



PALLET



FOOTLOCKER



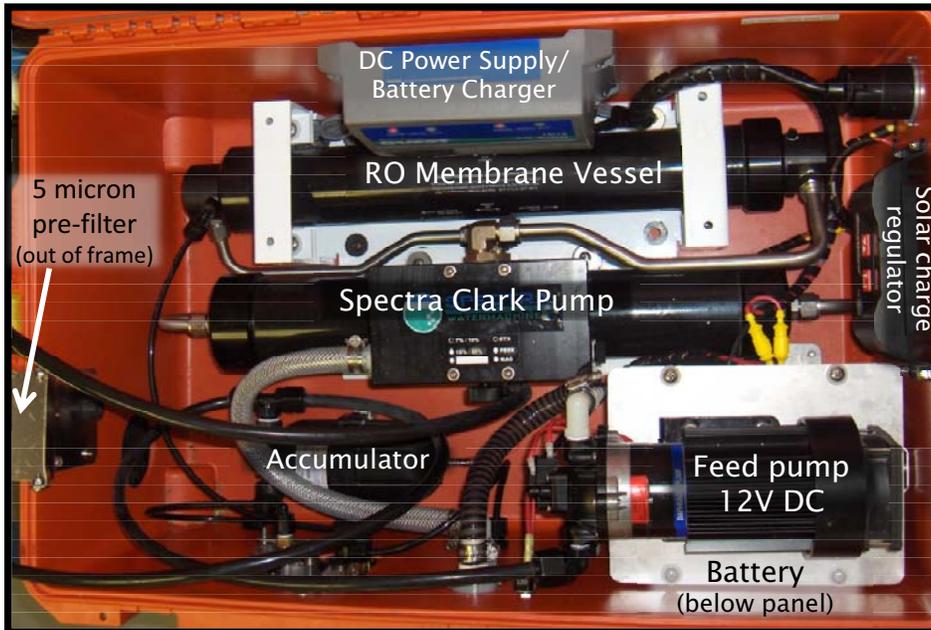
BRIEFCASE

System Cost: \$7,995

Pre-Filter: \$12

Spectra Watermakers,  
 Inc  
 415-526-2780

[www.spectrawatermakers.com](http://www.spectrawatermakers.com)



This briefcase-sized unit, weighing about 70 pounds, is capable of producing 0.1 gallons per minute (gpm) from fresh and salt water sources. It is the heaviest of the similar sized units evaluated. Treatment consists of pre-filtration for sediment reduction; and reverse osmosis membrane filtration for reduction of pathogens, salts and chemicals. Pre-filtration is provided by a single replaceable 5-micron cartridge filters. The system requires an alternating or direct current (AC/DC) power source, or solar module that not included. The system includes a battery which provides short term operation.

### Advantages

- Expected to provide adequate treatment of microbial pathogens based on technology.
- Multiple power sources.
- High pressure reverse osmosis known to reduce chemicals.

### Disadvantages

- Complexity to maintain or repair is estimated to be among the highest of systems evaluated.
- Heaviest and largest briefcase device.
- Produces < 150 gallons in a 10 hour day.

For more information contact:

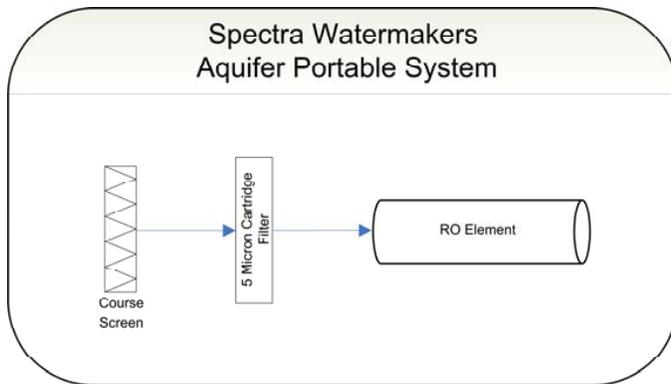
**Water Supply Management Program  
 U.S. Army Public Health Command (Provisional)**

410.436.3919  
[water.supply@amedd.army.mil](mailto:water.supply@amedd.army.mil)

Use of commercial vendor and product names does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

No data verifying the effectiveness of this system in reducing microbial pathogens was available. The treatment components of the system – 5-micron sediment filter cartridge, and RO – do not have independent third-party treatment certifications. Based on general knowledge of the treatment technologies used, the system should be capable of consistently reducing cysts, bacteria, and viruses to the required 3-log, 6-log, and 4-log minimum reductions. High pressure reverse osmosis membranes (ROMs), as employed in the Aquifer, are also known to provide broad spectrum chemical reduction. **Additional treatment such as chlorine would be necessary to provide a disinfectant residual.**



## SYSTEM OPERATION

*Setup & Operation.* Setup and operation requires the user to locate the system within 50 feet (< 10 feet vertical) of a water source, connect a power source and inlet/outlet hoses, open the pressure relief valve and allow the system to run for 20 minutes to purge the storage chemicals (first start post-storage only). For routine use, prime the pump with pressure relief valve open, close the pressure relief valve, and run the system for 5-10 minutes to verify ROM performance prior to producing water for consumption. The vendor recommends using the included TDS meter to verify ROM performance.

TDS as a performance indicator will only be apparent in salt and brackish raw water sources where TDS should be greater than 90% reduced in the product water.

*Cleaning & Maintenance.* Cleaning and maintenance involves filter cartridge cleaning and replacement, and cleaning the membranes. Prefilter cleaning is triggered by reduced flow and a drop in pressure, indicated on the front panel gauge. Membranes need to be cleaned only when feed pressure begins to rise due to fouling. Two proprietary cleaning compounds are recommended for membrane cleaning.

*Storage.* There are no special requirements if the unit will be in operation within five days. For long-term storage the vendor recommends a proprietary cleaning compound to be used to flush the system. A different proprietary compound is recommended as antifreeze. The prefilter should be removed prior to any long term storage to avoid biological growth.

## OPERATIONAL EVALUATION

Compared to other SUWPs of its size, The Spectra Aquifer Portable is heavy, 70 lbs versus an average of 50 lbs. It was one of only two high pressure RO technologies, the other weighing near the average. Being completely contained in a protective case, however, makes the Aquifer portable and convenient to setup and teardown. Consider these attributes when comparing this and other briefcase-sized SUWPs:

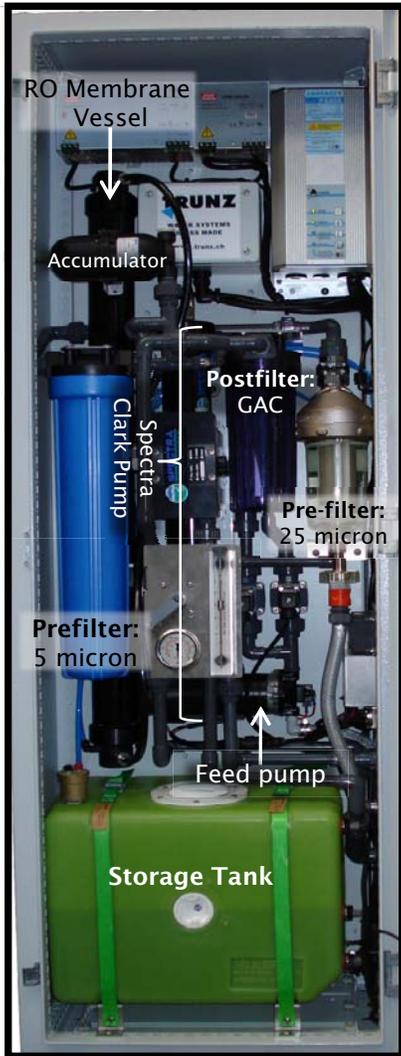
- Proprietary sourcing of components
- RO offers desalination, therefore broader source flexibility; will significantly reduce production rate
- Limited prefiltration capacity, may impact use in turbid waters or require additional equipment
- Built in power regulator for connection to solar panel power source



# Spectra Salt Water Module (SWM 1500)

## Operational and Technical Evaluation Summary

The Spectra S (b) (b) (5) (b) (5) (b) (5)  
 (b) (5)  
 (b) (5)



This footlocker-sized unit weighing about 350 pounds is capable of producing 0.3 gallons per minute (gpm) from fresh and salt water sources. Treatment consists of pre-filtration for sediment reduction; reverse osmosis membrane filtration for reduction of pathogens, salts, and chemicals; and carbon adsorption for taste and odor reduction. Pre-filtration is provided by a self-scrubbing and automated backwashing 25-micron filter followed by a replaceable 5-micron cartridge filter. The system does not include a disinfection module. The system requires an alternating or direct current (AC/DC) power source or may be powered by a solar array, not included.

### Advantages

- Expected to provide adequate treatment of microbial pathogens based on technology.
- Ranked most durable and resistant to environmental conditions among similar size systems.
- Technologies present to reduce chemical contaminants and objectionable tastes and odors.

### Disadvantages

- Production rate <300 gallons per 10 hour day, lowest of similar sized systems.
- Complexity to maintain or repair is estimated to be among the highest of systems evaluated.

**Technical Specs:**  
 0.3 gallons per minute  
 Reverse Osmosis  
 Treats most waters,  
 including Saltwater  
 AC, DC, Solar

**Features:**  
 Packaged in a metal cabinet  
 60 ft inlet tubing with  
 submersible pump  
 Energy recovery system  
 Self-cleaning prefilter

**Dimensions:**  
 71 x 20 x 16 in.  
 350 lbs.



PALLET



FOOTLOCKER



BRIEFCASE

System Cost: \$16,605

Pre-Filter Set : \$34

Spectra Watermakers, Inc  
 415-526-2780  
[www.spectrawatermakers.com](http://www.spectrawatermakers.com)

For more information contact:

**Water Supply Management Program**  
**U.S. Army Public Health Command (Provisional)**

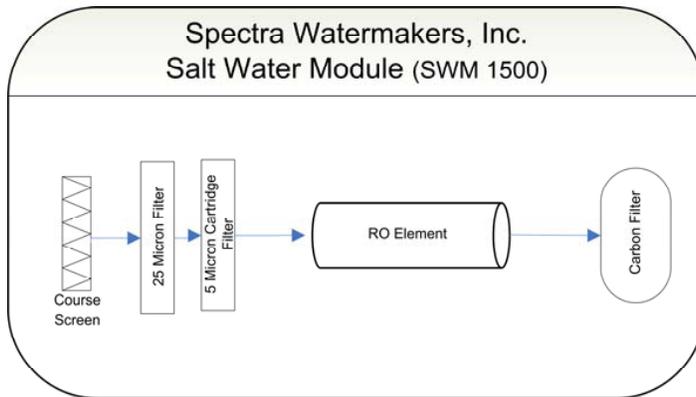
410.436.3919  
[water.supply@amedd.army.mil](mailto:water.supply@amedd.army.mil)

Use of commercial vendor and product names does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

No data verifying the effectiveness of this system in reducing microbial pathogens was available. The treatment components of the system – sediment filter cartridge, reverse osmosis (RO) membrane, and carbon filter – do not have independent third-party treatment certifications. Based on general knowledge of the primary treatment technology used, RO, the system should be capable of consistently reducing microbial pathogens in water. The system does not include a disinfectant treatment barrier. **Additional treatment such as chlorine would be necessary to provide a disinfectant and residual.**

## SYSTEM OPERATION



*Setup & Operation.* Setup and operation requires the user locate the system on an improved surface, deploy the feed pump and inlet/outlet hoses, and connect to a 110V / 220V AC or 24V DC power source. The vendor recommends placing the unit on a concrete surface. The unit, weighing 350 pounds, will require seven (7) personnel to move. The self-priming feed pump and raw water line provide 65 feet of down-well service if necessary. The unit is equipped with a tank level switch which may be used to control production, if a product water tank is employed. The RO

membrane (ROM) requires a 30 minutes flush at initial startup to remove storage chemicals. The activated carbon and 5µm filters are installed after this period.

*Cleaning & Maintenance.* The system has an onboard 42 liter product storage tank used for backwashing the ROM every twelve hours and at the conclusion of operations. The 25 micron prefilter is also equipped with an automated scrubbing and flushing feature. The 5µm prefilter must be changed manually indicated by a pressure differential across the filter greater than 1 bar (14.5 psi). The vendor recommends replacing the activated carbon filter every three months. The vendor recommends water quality surveillance to verify treatment efficacy. Operators should consult their local preventive medicine authority or the contacts on the front of this document for further guidance.

*Storage.* For long-term storage the RO membrane must be cleaned and preserved and all O-rings greased. If the system will be stored in freezing conditions antifreeze, per manufacturer specifications should be used in preservation.

## OPERATIONAL EVALUATION

Compared to other SUWPs of its size, the Spectra Watermakers Salt Water Module (SWM 1500) may be complex to maintain and require more operator hands-on time. Consider these attributes when comparing this and other footlocker-sized SUWPs:

- Proprietary sourcing of components
- RO offers desalination, therefore broader source flexibility; will significantly reduce production rate
- Design likely drives semi-fixed installation, not ideal for transient short term employment



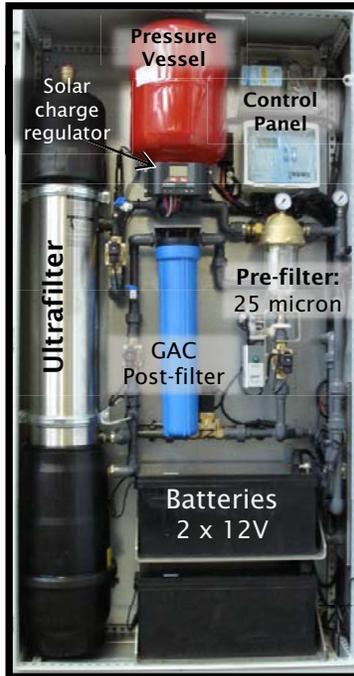
# Spectra Solar Ultrafiltration (SSUF 20000)

## Operational and Technical Evaluation Summary

The Spectra Solar

(b) (5)

(b) (5)



This pallet-sized unit weighing about 900 pounds is capable of producing 1.5 gallons per minute (gpm) from a freshwater source. Treatment consists of filtration for sediment reduction; ultrafiltration for fine particulate and microbial pathogen reduction; and carbon adsorption for reduction of objectionable tastes and odors and some chemical contaminant reduction. Pre-filtration is provided by a self-scrubbing and automated backwashing 25-micron mechanical filter. The system is powered by the included 400 watt solar panel. The battery bank provides an advertised 200 amp hours of power.

### Advantages

- Expected to provide adequate treatment of microbial pathogens based on technology.
- Routine operation estimated to require minimal effort.
- Automated backflushing of filters.

### Disadvantages

- Complexity to maintain or repair is estimated to be among the highest of systems evaluated.
- Low interoperability due to multiple proprietary items .
- Heavy (900 lbs).

For more information contact:

**Water Supply Management Program**  
**U.S. Army Public Health Command (Provisional)**

410.436.3919  
 water.supply@amedd.army.mil



**Technical Specs:**  
 1.5 gallons per minute  
 Ultrafiltration  
 Treats Freshwater Only  
 Solar

**Features:**  
 Packaged in metal cabinet  
 60 ft inlet tubing with  
 submersible pump  
 Self-cleaning prefilter  
 Backwashing ultrafilter

**Dimensions:**  
 71 x 16 x 39 in.  
 900 lbs.



PALLET



FOOTLOCKER



BRIEFCASE

**System Cost: \$26,560**

Pre-Filter Set: \$21  
 UF Membrane: \$75

Spectra Watermakers,  
 Inc

415-526-2780

[www.spectrawatermakers.com](http://www.spectrawatermakers.com)

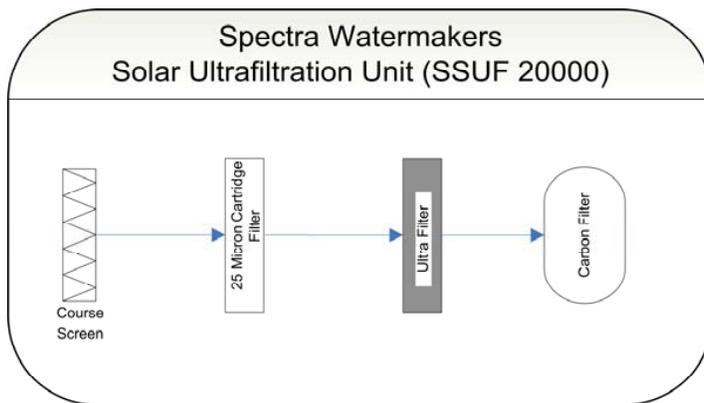
Use of commercial vendor and product names does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

No data was available to confirm the effectiveness of the complete system as packaged in reducing microbial pathogens in water. The primary treatment component of the system – the (b) (4) ultrafilter (UF) – has been independent third-party tested and certified to NSF/ANSI 53 and 42 for cyst reduction and particulate reduction, respectively. The (b) (4) ultrafilter is further advertised to have successfully met the requirements of the USEPA Guide Standard and Protocol for Testing Microbiological Water Purifiers. The details of this testing were not available, but indicates potential for the unit to adequately reduce viral, bacterial, and protozoan contaminants in water. Furthermore, based on general knowledge of the treatment technology, the system should be capable of consistently reducing bacteria, viruses, and protozoa to the required 6-log, 4-log, and 3-log minimum reductions. The system does not include a disinfectant treatment barrier.

**Additional treatment such as chlorine would be necessary to provide a disinfectant and residual.**

## SYSTEM OPERATION



*Setup & Operation.* Setup and operation requires the user to locate the system near a fresh-water source on an improved surface, assemble the solar array, deploy the feed pump, and connect the power cables and inlet/outlet hoses. The vendor recommends an **experienced operator for initial installation**. The vendor recommends placing the unit on a concrete surface. The unit, weighing 900 pounds, will require material handling equipment (MHE) to move. The self-priming feed pump and raw water line provide 65 feet of down-well service if necessary. The UF

membrane requires a 30 minutes flush at initial startup to remove storage chemicals. The activated carbon filter should be installed after this period.

*Cleaning & Maintenance.* The UF module has a programmable backwash cycle. The 25 micron prefilter is also equipped with an automated scrubbing and flushing function based on pressure differential. The vendor recommends replacing the activated carbon filter every three months. The vendor recommends water quality surveillance to verify treatment efficacy. Operators should consult their local preventive medicine authority or the contacts on the front of this document for further guidance.

*Storage.* For long-term storage, the UF membrane must be cleaned and preserved and all O-rings greased. If the system will be stored in freezing conditions antifreeze, per manufacturer specifications should be used in preservation.

## OPERATIONAL EVALUATION

Compared to other SUWPs of its size, The Spectra Solar Ultrafiltration was judged the most complex to operate. Consider these attributes when comparing this and other pallet-sized SUWPs:

- Proprietary sourcing of components
- Potential requirement for experienced operator
- Design likely drives semi-fixed installation, not ideal for transient short term employment

(b) (4)

(b) (4)

(b) (4)

Spectra Solar Ultrafiltration (SSUF 20000)  
Operational and Technical Evaluation Summary



# Spectra Fresh Water Module (FWM 22000)

## Operational and Technical Evaluation Summary

The Spectra Fresh (b) (5)  
 (b) (5) (b) (5)



This pallet-sized unit weighs about 550 pounds and is capable of producing 3.7 gallons per minute (gpm) from a freshwater source. Treatment consists of pre-filtration for sediment reduction; ultrafiltration for fine particulate and microbial pathogen reduction; and carbon adsorption for reduction of objectionable tastes and odors and some chemical contaminants. Pre-filtration is provided by a series of three self-scrubbing and automated backwashing mechanical filters. The system requires an alternating current (AC) power source, not included.

**Advantages**

- Expected to provide adequate treatment of microbial pathogens based on technology.
- Routine operation estimated to require minimal effort.
- Automated backflushing of filters

**Disadvantages**

- Complexity to maintain or repair is estimated to be among the highest of systems evaluated.
- Low interoperability due to multiple proprietary items.

For more information contact:

**Water Supply Management Program  
 U.S. Army Public Health Command (Provisional)**

410.436.3919  
 water.supply@amedd.army.mil



**Technical Specs:**  
 3.7 gallons per minute  
 Ultrafiltration  
 Treats Freshwater Only  
 110/220 V AC

**Features:**  
 Packaged in Metal Cabinet  
 60 ft inlet tubing with  
 submersible pump  
 Self-cleaning prefilter  
 Backwashing ultrafilter

**Dimensions:**  
 45 x 63 x 20 in.  
 550 lbs



PALLET



FOOTLOCKER



BRIEFCASE

**System Cost: \$26,000**

Pre-Filter Set: \$37  
 UF Membrane: \$75

Spectra Watermakers,  
 Inc  
 415-526-2780

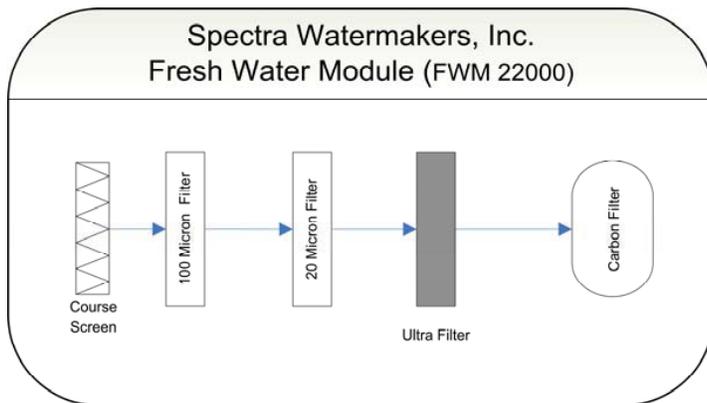
[www.spectrawatermakers.com](http://www.spectrawatermakers.com)

Use of commercial vendor and product names does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

No data was available to confirm the effectiveness of the complete system as packaged in reducing microbial pathogens in water. The primary treatment component of the system – the (b) (4) ultrafilter (UF) –has been independent third-party tested and certified to NSF/ANSI 53 and 42 for cyst reduction and particulate reduction, respectively. The (b) (4) ultrafilter is further advertised to have successfully met the requirements of the USEPA Guide Standard and Protocol for Testing Microbiological Water Purifiers. The details of this testing were not available, but indicates potential for the unit to adequately reduce viral, bacterial, and protozoan contaminants in water. Furthermore, based on general knowledge of the treatment technology, the system should be capable of consistently reducing bacteria, viruses, and protozoa to the required 6-log, 4-log, and 3-log minimum reductions. The system does not include a disinfectant treatment barrier. **Additional treatment such as chlorine would be necessary to provide a disinfectant and residual.**

## SYSTEM OPERATION



*Setup & Operation.* Setup and operation requires the user to locate the system near a fresh-water source on an improved surface, deploy the feed pump, and connect the power cables and inlet/outlet hoses. The vendor recommends an **experienced operator for initial installation.** The unit, weighing 550 pounds, will require material handling equipment (MHE) to move. The self-priming feed pump and raw water line provide 65 feet of down-well service if necessary. The UF membrane requires a 30 minutes flush at initial startup to remove storage chemicals. The activated carbon filter should be installed after this period.

*Cleaning & Maintenance.* The UF module has a programmable backwash cycle. The 100 and 20 micron prefilters are also equipped with an automated scrubbing and flushing function based on pressure differential. The vendor recommends replacing the activated carbon filter every three months. The vendor recommends water quality surveillance to verify treatment efficacy. Operators should consult their local preventive medicine authority or the contacts on the front of this document for further guidance.

*Storage.* For long-term storage, the UF membrane must be cleaned and preserved and all O-rings greased. If the system will be stored in freezing conditions antifreeze, per manufacturer specifications should be used in preservation.

## OPERATIONAL EVALUATION

Compared to other SUWPs of its size, The Spectra Solar Ultrafiltration was judged among the most complex to operate. Consider these attributes when comparing this and other pallet-sized SUWPs:

- Proprietary sourcing of components
- Potential requirement for experienced operator
- Design likely drives semi-fixed installation, not ideal for transient short term employment

(b) (4)



# Global LS3 M5000

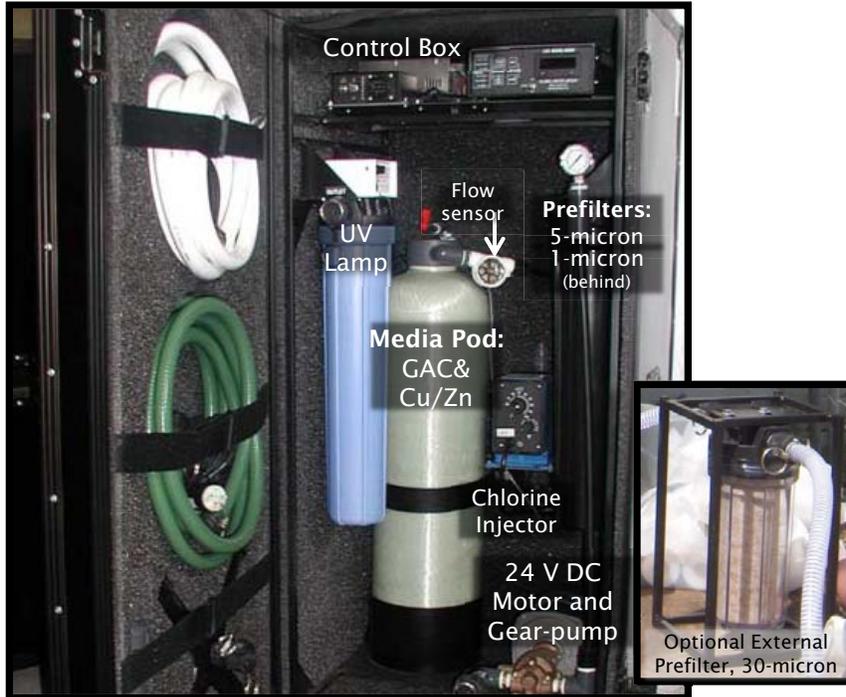
## Operational and Technical Evaluation Summary

The Global LS3 M5000

(b) (5)

(b) (5)

(b) (5)



This footlocker-sized unit weighing about 290 pounds is capable of producing 3.5 gallons per minute (gpm) from a fresh water source. Treatment consists of filtration for sediment, fine particulate, and some microbial pathogen reduction; oxidation-reduction (redox) for chemical reduction; carbon adsorption, both for chemical contaminant and taste and odor reduction; and chlorine and ultraviolet (UV) light for microbial pathogen inactivation. Filtration is provided by replaceable 30, 5, and 1-micron cartridge filters. Chlorine disinfection is by way of a liquid dosing pump and a user supplied concentrated hypochlorite solution (bleach). The system is powered by alternating or direct current (AC/DC), or an optional solar array, not included.

### Advantages

- Anticipated to provide adequate pathogen reduction based on redundant technologies.
- Multiple technologies targeting chemical contaminant reduction.
- Multiple power sources.

### Disadvantages

- Prefilter capacity expected to be severely impaired by turbid waters.
- Effort to maintain chlorine residual.
- Low confidence that system will maintain desired production rate.

For more information contact:

**Water Supply Management Program  
U.S. Army Public Health Command (Provisional)**

410.436.3919  
water.supply@amedd.army.mil



### Technical Specs:

3.5 gallons per minute  
Multimedia with UV  
Treats Freshwater Only  
AC, DC, Solar (not included)

### Features:

Packaged in a Reinforced Case  
10 ft inlet and product hose  
1/3 HP DC Pump  
Multiple prefilters

### Dimensions:

48 x 24 x 24 in.  
290 lbs



PALLET



FOOTLOCKER



BRIEFCASE

System Cost: \$21,000

Filter Set: \$1,335

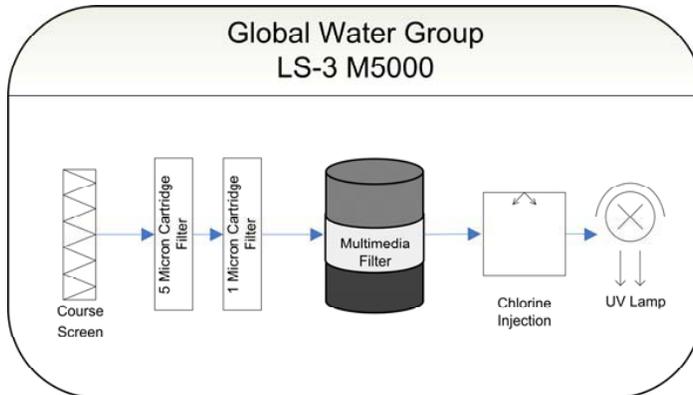
Global Water Group, Inc  
866-733-8686

www.globalwater.com

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

No data showing the effectiveness of this system in reducing microbial pathogens was available, nor do the individual components have independent third-party treatment certifications. The treatment components of the system include 5- and 1-micron sediment filter cartridges, a multimedia filter consisting of redox resin and granular activated carbon (GAC), chlorine, and UV. Based on general knowledge of these technologies, the combined mechanism of mechanical filtration and disinfection should be capable of consistently reducing cysts and bacteria to the required 3-log and 6-log minimum reductions, respectively, when the system is used as directed. The system employs two disinfection technologies capable of reducing viruses to the required 4-log minimum reduction. **Regular operator surveillance** is necessary to maintain proper chlorine dosing. Product water should be **stored prior to consumption** to allow chlorine contact time.

## SYSTEM OPERATION



*Setup & Operation.* Setup and operation requires the user to locate the system near the fresh-water source, connect the inlet and outlet hoses, prepare the chlorine solution, set the chlorine dosing pump, connect to a power source, and turn on the unit. The UV light has a two-minute warm up. A timer-actuated valve prevents water from being pumped during this period. The vendor further recommends discarding the first 10 minutes of production. The system contains 20 feet of inlet hose, but should be placed as close to the water source as practical to facilitate the self-priming pump. The vertical suction capacity of the pump is unknown.

*Cleaning & Maintenance.* Cleaning and maintenance involves filter cartridge cleaning and replacement, multimedia filter replacement, cleaning of the quartz sleeve protecting the UV lamp, UV lamp replacement, and cleaning the pump. The cartridge filters will require routine replacement, as often as daily. Reduced flow through the system indicates clogging and the need for filter replacement. The media filter is rated for 250 to 600 thousand gallons of water before replacement. Cleaning the UV quartz sleeve is recommended every time the filters are cleaned or replaced. UV lamps should be changed after 9,000 hours of operation. Users must also maintain the chlorine solution, injection pump, and associated injection tubing.

*Storage.* For long-term storage the system should be drained with the exception of the multimedia filter. Remove used filters, drain sumps, wipe with disinfectant, and dry prior to reassembling. On start up after either short or long term storage, allow the unit to run for a minimum of 10 minutes before water is consumed or placed in storage containers.

## OPERATIONAL EVALUATION

The Global Water LS3 M5000 is a scalable system, available from the manufacturer in a range of water capacities from 2,500 to 8,000 gallons per day. The following were noted through the course of evaluation and should be considered when comparing this and other footlocker-sized SUWPs

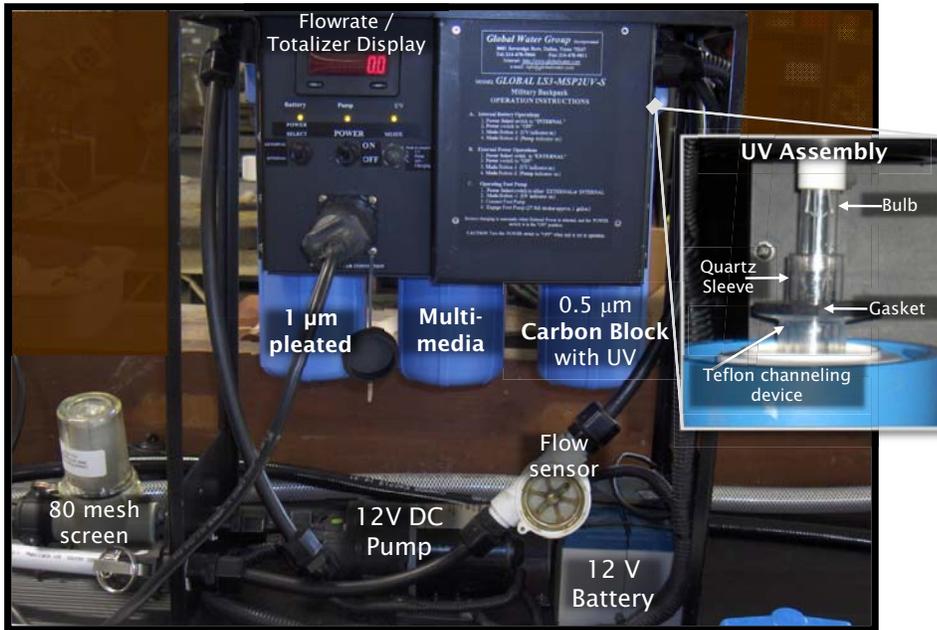
- Time, effort and expense of additional filters; likely doubles necessary cube. The vendor does offer accessory kits with an estimated 12 months worth of cartridge filters, \$1070.
- Anticipated to be effective against all three pathogens and technology present for chemical removal
- Effort required managing chlorine dosing and maintaining necessary residual
- Durability of the quartz sleeve surrounding the UV lamp, anecdotal evidence of frequent breakage during shipment



# Global LS3 MSP2UV

## Operational and Technical Evaluation Summary

The Global LS3 MS [redacted] (b) (5)  
 [redacted] (b) (5)  
 [redacted] (b) (5)



### Technical Specs:

1 gallon per minute  
 Multimedia, carbon block with UV  
 Treats Freshwater Only  
 AC, DC, Solar, Foot Pump

### Features:

Packaged in a Rucksack  
 8 ft inlet and product hose  
 Foot Pump  
 Single 1 micron prefilter

### Dimensions:

15 x 8 x 21 in.  
 50 lbs



PALLET



FOOTLOCKER



BRIEFCASE

System Cost: \$7,200

Filter Set: \$190

Global Water Group, Inc  
 866-733-8686  
[www.globalwater.com](http://www.globalwater.com)

This briefcase-sized unit weighing about 50 pounds is capable of producing 1 gallons per minute (gpm) from a freshwater source. Treatment consists of filtration for sediment, fine particle, and some microbial pathogen reduction; oxidation-reduction (redox) for chemical reduction; carbon adsorption, both for chemical contaminant and taste and odor reduction; and ultraviolet (UV) light for microbial pathogen inactivation. Filtration is provided by a replaceable 1-micron ( $\mu\text{m}$ ) cartridge filter and a  $0.5\mu\text{m}$  carbon block filter. Redox media and granular activated carbon (GAC) make up the center multi-media filter. The system can be powered by alternating or direct current (AC/DC) power source, a provided mechanical pump, or an optional solar array.

### Advantages

- Anticipated to provide adequate reduction of bacteria and cysts based on technology.
- Multiple technologies targeting chemical contaminant reduction.

### Disadvantages

- Not expected to provide adequate treatment of viral pathogens.
- Not encased during operation, susceptible to damage.
- Prefilter capacity expected to be severely impaired by turbid waters.

For more information contact:

**Water Supply Management Program**  
**U.S. Army Public Health Command (Provisional)**

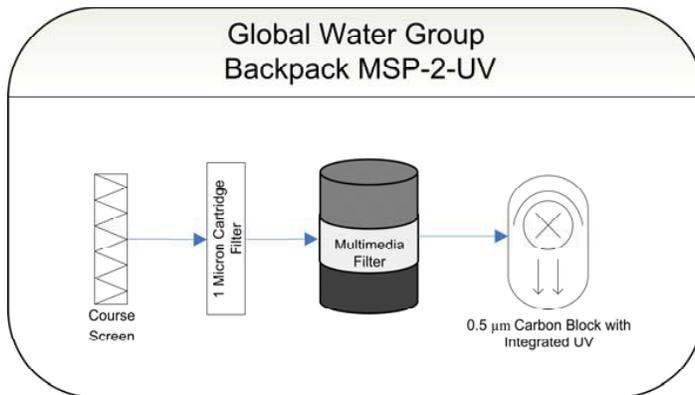
410.436.3919  
[water.supply@amedd.army.mil](mailto:water.supply@amedd.army.mil)

Use of commercial vendor and product names does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

No data was available to confirm the effectiveness of this system in reducing microbial pathogens. The treatment components of the system – 1-micron sediment filter cartridge, multimedia filter canister, ultraviolet (UV) reactor, and 0.5-micron carbon block filter – do not have independent third-party treatment certifications. Based on general knowledge of the treatment technologies used, the system should be capable of consistently reducing cysts to the required 3-log minimum reduction when used as directed. However, the system, as packaged, is not expected to consistently reduce bacteria and viruses the required 6-log and 4-log reductions, respectively. **Additional treatment such as chlorine disinfection is necessary** to achieve adequate virus and bacteria reductions. Because disinfection is provided by UV, this system **does not provide a disinfectant residual**.

## SYSTEM OPERATION



*Setup & Operation.* Setup and operation requires the user to **locate the system within 8 feet of a fresh-water source**, connect the inlet and outlet hoses, connect a 110/220V AC or 12V DC power source, use the included batteries, or optional foot-pump. The optional foot pump can be used if a power source is not available, but will not power the UV. The vendor operations manual instructs the user to select the AC power voltage if applicable, select internal (battery) or external power, and rotate the power selector 'ON.' The UV lamp requires a 2 minute warm-up per vendor instruction. The pump will also operate at a higher speed for the first two minutes to prime the unit. A mode switch provides for stopping the pump while still providing power to the UV

lamp.

*Cleaning & Maintenance.* Cleaning and maintenance involves filter cartridge cleaning and replacement, multimedia filter canister replacement, cleaning of the quartz sleeve protecting the UV lamp, and UV lamp replacement. Filter change is instructed based upon flowrate. When the flow rate reaches 0.75 gallons per minute, filter change is directed. It may be necessary to replace all three (3) filter cartridges to regain initial flow. The proprietary multimedia filter is rated at 5,000 hours of usage before replacement, but this is likely based on the adsorption capacity of the media, not mechanical clogging. Users may find on turbid water that more **frequent service** is necessary. Cleaning the UV quartz sleeve is recommended every time the unit is serviced, to include filters changes. UV lamps should be changed annually.

*Storage.* There are no special requirements if the unit will be in operations within three days. The unit is mounted in an open frame and may require shelter to prevent damage from environmental conditions including freezing temperatures. For long-term storage, the system should be drained and filters cleaned and dried. On start up after either short or long term storage allow the unit to run for a minimum of ten (10) minutes before water is consumed or placed in storage containers.

## OPERATIONAL EVALUATION

The Global Water LS3 BP SP UV is likely susceptible to environmental conditions due to the open construction. The following were noted through the course of evaluation and should be considered when comparing this and other briefcase-sized SUWPs

- Time, effort and expense of additional filters; likely doubles necessary cube. The vendor does offer accessory kits with 6 months consumables and common failure items, \$745
- Multi-media filter and carbon block filter should improve the taste of the treated water and should provide some reduction of chemicals
- Durability of the quartz sleeve surrounding the UV lamp, anecdotal evidence of frequent breakage during shipment
- The system contains a UV indicator light; UV failure also stops pump
- Unit must be located very near water source or water transported to unit for treatment
- Operator must provide product water storage and distribution equipment

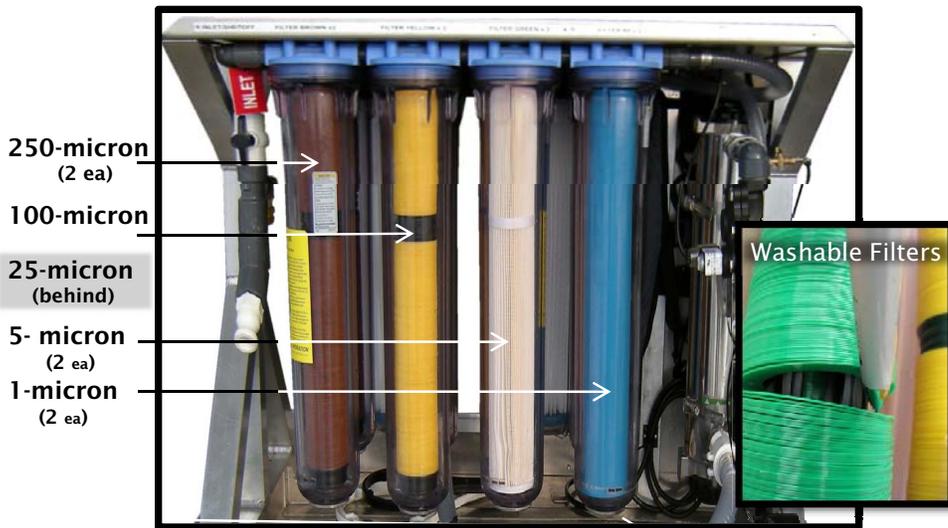


# Global Hydration Can Pure™ P3- 2008A

## Operational and Technical Evaluation Summary

The Can Pure™ P3- (b) (5)

(b) (5)



This footlocker-sized unit weighing about 448 pounds is capable of producing 4.5 gallons per minute (gpm) from a freshwater source. Treatment consists of filtration for sediment, fine particle, and some microbial pathogen reduction; and ultraviolet (UV) light for disinfection of microbial pathogens. Filtration is provided by eight cartridge filters ranging in effective pore size from 250-microns to 1-micron absolute. Four stages employ filters which are washable and reusable, see inset. Additional contaminant-specific filters are available. The UV assembly incorporates multiple monitors including UV dose and lamp life. Audible and visible alarms signal faults and automatically stop water flow. The system is powered by a fuel (Diesel/JP-8) driven pump with integral 12V generator.

### Advantages

- Multiple system components certified for microbiological performance.
- Process failure indicator employs UV intensity monitor and UV failure.
- Redundant prefiltration capacity with one of a kind clean and reuse capacity.
- Powerful raw water pump with longest in class water supply lines.

### Disadvantages

- Fuel driven pump may require maintenance.
- Limited capacity for reduction of chemical contaminants or objectionable taste and odor.

For more information contact:

**Water Supply Management Program**  
**U.S. Army Public Health Command (Provisional)**

410.436.3919  
 water.supply@amedd.army.mil



**Technical Specs:**  
 4.5 gallons per minute  
 Microfiltration with UV  
 Treats Freshwater Only  
 Diesel or JP-8 Fuel

**Features:**  
 Packaged in Metal Cabinet  
 125ft inlet, 35ft product hose  
 Stainless Steel pump/gen-set  
 Certified UV system

**Dimensions:**  
 39 x 23 x 31 in.  
 448 lbs



PALLET



FOOTLOCKER



BRIEFCASE

**System Cost: \$47,305**  
**Consumable Filter Set: \$88**

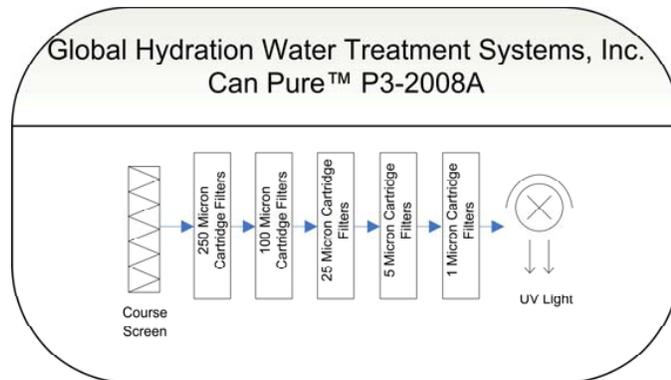
Global Hydration  
 Water Treatment Systems, Inc.  
 807-577-0030  
 www.globalhydration.com

™ Can Pure is a trademark of Global Hydration Systems, Inc, Ontario, Canada. Use of trademarked name does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

No data verifying the effectiveness of the complete system as packaged to reduce microbial pathogens was available. The primary treatment components of the system –1-micron filter and UV –have NSF/ANSI 53 and 55 certifications respectively. Testing and certification of the 1 µm absolute filter indicates it is capable of consistently reducing microbial cysts to the required 3-log minimum reduction. The UV certification indicates proven disinfection performance versus microbiologically contaminated waters. Certification further indicates the component has been evaluated for the performance of a system-fault indicator, i.e. an alarm. Because disinfection is provided by UV, this system **does not provide a disinfectant residual**. The vendor offers sodium dichloroisocyanurate (NaDCC) tablets which could be used for chlorine disinfection and would provide multiple treatment barriers for bacterial and viral pathogens.

## SYSTEM OPERATION



*Setup & Operation.* Setup and operation requires locating the system near a fresh-water source, assembling the diesel-powered pump within 20 feet of the source, and allowing the UV light to warm-up for 5 minutes. The pump needs to be manually primed by filling the chamber with water. The pump has sufficient head to draw water vertically if necessary, such as from a well. The unit weight, 448 pounds will require as many as nine (9) personnel to download and maneuver. The vendor recommends two persons for setup procedures, to include removing the case covers and placing the pump. The user will plug in the UV system once the filtration sumps are filled with water, beginning the warm-up period. An

automatic solenoid valve will open once the UV dose is stabilized as determined by the onboard UV sensor.

*Cleaning & Maintenance.* Maintenance involves filter cleaning and replacement of disposable filters, cleaning of the quartz sleeve that protects the UV lamp, and UV lamp replacement. Four (4) of the eight (8) cartridge filters are 100% washable and reusable. Reduced flow through the system and increased pressure differential indicate clogging and the need for filter replacement or cleaning. Cleaning the UV quartz sleeve as well as the filter housings is recommended each time filters are changed. The operating manual states the UV lamp has a 2 year service life. There is a timer/counter identifying UV hours of use.

*Storage.* Long term storage involves draining the entire system and disinfecting all hoses and fittings with a chlorine solution. No recommendations are made for short term storage. The unit will need to be protected from extreme environmental conditions including freezing.

## OPERATIONAL EVALUATION

The Can Pure™ P3-2008A modular design and one of kind cleanable prefilters are advantageous to maintaining productions and reducing the logistics of consumables. The diesel-powered pump and longest provided water lines offer greater flexibility compared to other SUWPs in the footlocker size. Consider these attributes when comparing the P3-2008A and other footlocker-sized SUWPs:

- Certified components for cyst reduction and disinfection of microbiological contaminants in water
- Diesel/JP8-powered pump will require resourcing fuel and maintenance, but will eliminate the need for external electrical power
- Process failure indicator employs UV intensity monitor and UV failure; shutdown of water flow upon trigger
- Vendor operations manual provides detailed system instructions and water quality testing procedures

<sup>TM</sup> Can Pure is a trademark of Global Hydration Water Treatment Systems, Inc, Kakabeka Falls, Ontario, Canada. Use of trademarked names does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

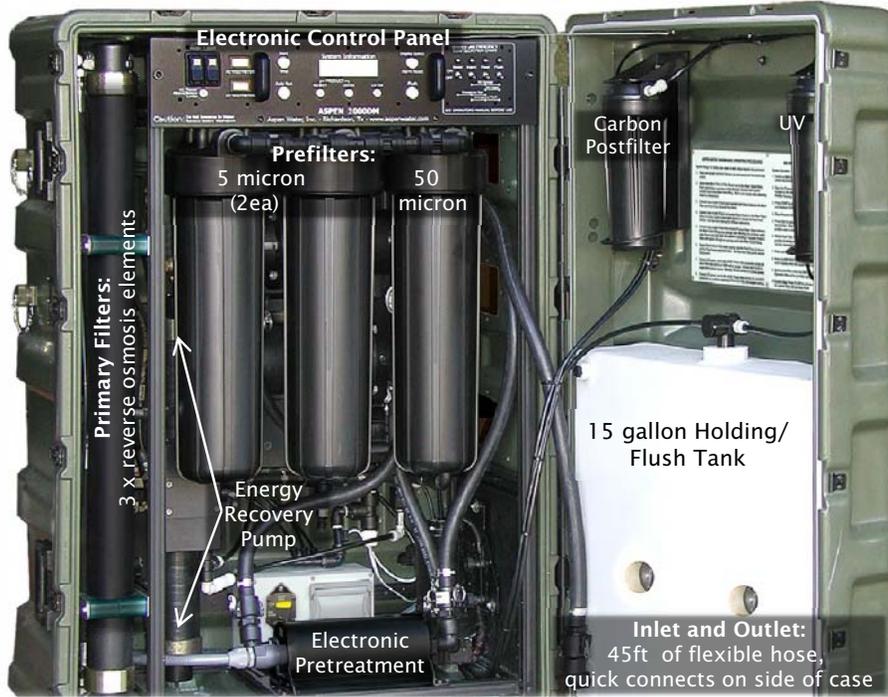


# Aspen 2000DM (ROWPU)

## Operational and Technical Evaluation Summary

The Aspen 2000DM

(b) (5)  
(b) (5)



This footlocker-sized system weighs approximately 450 pounds and produces 1.3 gallons per minute (gpm) from a freshwater source and 0.7 gpm from a salt water source. Treatment consists of pre-filtration for sediment reduction; reverse osmosis for microbial pathogen, dissolved salts, and chemical removal; carbon adsorption for taste and odor reduction; and UV for disinfection of microbial pathogens. Filtration is provided by replaceable 50-micron and 5-micron cartridge filters; three reverse osmosis membranes; and a granular activated carbon filter. The system has the flexibility to run on 120/240 V single phase alternating or 24 V direct current (AC or DC) power.

### Advantages

- Verified performance for reduction of bacteria, cysts, and viruses.
- Robust technology for removal of chemicals and dissolved salts.
- Expected to reduce objectionable taste and odors.

### Disadvantages

- Complexity.
- Concern of UV quartz sleeve breakage during transport.
- No disinfectant residual, without optional equipment.

For more information contact:

**Water Supply Management Program  
U.S. Army Public Health Command (Provisional)**

410.436.3919  
water.supply@amedd.army.mil



### Technical Specs:

0.7-1.3 gallon per minute  
Reverse Osmosis and UV  
Treats most waters, including Saltwater  
AC or DC

### Features:

Wheeled poly case  
45 ft inlet & product hoses  
Camlock fittings  
Self priming pump  
Progressive prefiltration

### Dimensions:

48 x 35 x 25 in. per case  
420 lbs. treatment unit



PALLET



FOOTLOCKER



BRIEFCASE

**System Cost: \$68,000**

Pre-Filter Set : \$122  
ROM : \$435 each

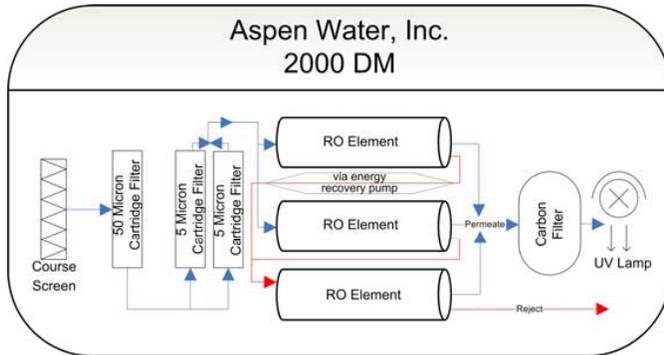
Aspen Water, Inc  
972-889-9500

[www.aspenwater.com](http://www.aspenwater.com)

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

This system was tested against NSF Protocol P248, Emergency Military Operations Microbiological Water Purifiers. The Protocol requires the following minimum microbiological reductions under strict water quality conditions: 6 log (99.9999%) bacteria, 4 log (99.99%) viruses, and 3 log (99.9%) protozoa. **Testing results for the Aspen 2000DM verify adequate treatment** for bacteria, viruses, and cysts. Because disinfection is provided by UV, this system **does not provide a disinfectant residual**. **Additional treatment such as chlorine disinfection** is recommended to provide a residual in any product water not consumed immediately.

## SYSTEM OPERATION



*Setup & Operation.* Setup and operation requires the user to locate the unit within 20 feet of the raw water source; assemble the external filter screen; connect the inlet, permeate, and brine discharge hoses; connect a power source; turn on “Main” power switch and “Light” power switch; open the pressure relief valve; and press “Start.” Run the system for 20 minutes to purge the system of storage chemicals. Press “Start” again to begin water production. The unit weight, 450 pounds will require as many as nine (9) personnel to download and maneuver. The vendor recommends two persons for startup operations.

*Cleaning & Maintenance.* Cleaning and maintenance involves filter cartridge replacement, cleaning the reverse osmosis membranes (ROMs), and UV system maintenance. Pre-filter replacement is triggered by an alarm and filter life may be monitored on the system display. ROMs need to be cleaned when feed pressure begins to rise due to fouling or production drops by 10-15%. Two proprietary cleaning compounds are recommended for membrane cleaning. The GAC post-filter should be replaced every six months or when objectionable taste or odor occurs. The UV quartz sleeve should be cleaned periodically with filter replacement and the UV bulb replaced every 8000 hours. A “UV Good” light indicates operation of the lamp. The system display provides hours of operation.

*Storage.* There are no special requirements if the unit will be in operation within two days. For long-term storage, the vendor recommends draining and cleaning all pre-filter sumps, cleaning the ROMs as above, and using a proprietary storage compound to flush the system and preserve the ROMs. A different proprietary compound is recommended as antifreeze.

## OPERATIONAL EVALUATION

The Aspen 2000DM was operationally tested by the Aberdeen Test Center to a rigorous military specific test plan. The positive results of this testing suggest the system should withstand the extreme conditions of military operations. This testing Consider these attributes when comparing the Aspen 2000DM and other footlocker-sized SUWPs:

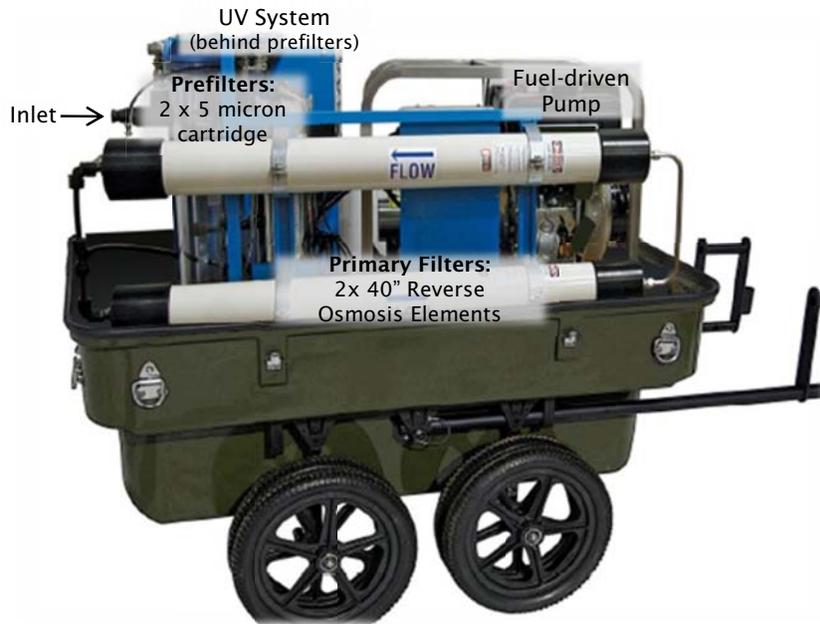
- Most flexibility in power supply options
- Weight and cube of system
- High pressure RO provides desalination and known chemical reduction technology
- User interface provides monitoring and warning of faults
- Need for skilled operator due to complexity; somewhat mitigated by comprehensive operations manual which provides detailed system instructions
- Operational and maintenance costs: Prefilters, \$122; ROM, \$435 ea; GAC, \$44; UV assembly, \$78



# Global Hydration Can Pure™ SR2007B

## Operational and Technical Evaluation Summary

The Can Pure™ SR (b) (5)



This pallet-sized system weighs approximately 629 pounds and produces 1.8 gallons per minute (gpm) from a freshwater source and 1.7 gpm from a saltwater source. Treatment consists of pre-filtration for sediment reduction; reverse osmosis (RO) for microbial pathogen, dissolved salts, and chemical reduction; and UV followed by batch disinfection with AQUATABS® chlorine tablets for microbial pathogen inactivation. Pre-filtration is provided by dual disposable 5-micron cartridge filters followed by dual 40 inch seawater RO membranes. The system uses a fuel (JP-8 or diesel) driven high pressure pump and requires an additional raw water pump, not included.

### Advantages

- Anticipated to provide adequate treatment of bacteria, cysts, and viruses.
- Robust technology for removal of chemicals and dissolved salts.
- Process failure indicator employs UV intensity monitor and UV failure.
- Unique carriage platform or encapsulated skid.

### Disadvantages

- Fuel driven pump may require maintenance.
- Concern of UV quartz sleeve breakage during transport.
- Weight and mobility of unit.

For more information contact:

**Water Supply Management Program  
U.S. Army Public Health Command (Provisional)**

410.436.3919  
water.supply@amedd.army.mil



### Technical Specs:

1.7 gallon per minute  
Reverse Osmosis with UV  
Treats most waters,  
including Saltwater  
Fuel Driven

### Features:

Wheel cart or metal skid  
20 ft inlet product hoses  
Certified UV system

### Dimensions:

57 x 34 x 48 in.  
629 lbs.



System Cost: \$68,894

Pre-Filter Set : \$24  
ROM : \$779 each

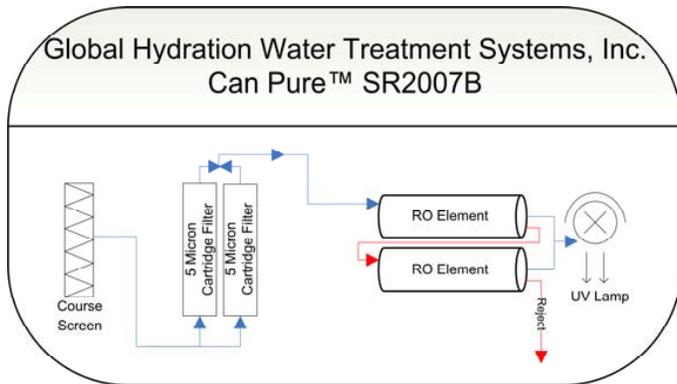
Global Hydration Water  
Treatment Systems, Inc.  
807-577-0030  
www.globalhydration.com

™ Can Pure is a trademarks of Global Hydration Water Treatment Systems, Inc, Kakabeka Falls, Ontario, Canada. AQUATABS® is a registered trademark of Mendentech, Wexford, Ireland . Use of trademarked name does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

No data verifying the effectiveness of the complete system as packaged in reducing microbial pathogens was available. The primary disinfectant component of the system (b) (4) ultraviolet reactor – has been tested and certified to NSF/ANSI 55. Certification indicates effective microbial pathogen reduction and performance of a system-fault indicator, i.e. an alarm. Based on general knowledge of the treatment technologies used, reverse osmosis (RO), UV, and chlorine, the system should be capable of consistently reducing cysts, bacteria, and viruses the required 3-log, 6-log and 4-log reductions, respectively, when used as directed. This system **does provide a disinfectant residual** through batch disinfection using AQUATABS® sodium dichloroisocyanurate tablets provided with the unit.

## SYSTEM OPERATION



*Setup & Operation.* Setup and operation requires the user to install the UV lamp; check sample ports; attach inlet and outlet hoses; establish feed water supply; start the pump; and adjust concentrate and permeate flow valves. A 30 minute purge is required upon first use and after storage. The onboard pump is dedicating to pressurizing the feed water for the RO module. An additional pump must be sourced to provide a minimum raw water feed rate of 5 gallons per minute at 15 pounds per square inch (psi).

*Cleaning & Maintenance.* Cleaning and maintenance involves filter cartridge cleaning and replacement, and

cleaning the membranes. The cartridge filters may be cleaned and reused by washing/flushing with clean water. Pre-filters will require **frequent replacement** in turbid waters. The vendor recommends additional pre-filtration modules, such as the Can Pure™ 2008A, in highly turbid waters. Membranes need to be cleaned only when feed pressure begins to rise due to fouling.

*Storage.* Super-chlorination of the system with used membranes in place is recommended prior to long term storage, greater than 7 days. The membranes should be discarded afterwards and valves opened to allow the system to dry. The vendor recommends removing the RO membranes and sealing them with plastic wrap or in bags for short term storage of 7 days or less.

## OPERATIONAL EVALUATION

Compared to other SUWPs, the Can Pure™ SR2007B is the most robust pallet-sized system evaluated for the reduction of chemical and microbial contaminants in water. Consider these attributes:

- Certified component for disinfection of microbiological contaminants in water
- Diesel/JP8-powered pump will require resourcing fuel and maintenance, but may eliminate the need for external electrical power
- High pressure RO provides potential for desalination and broad spectrum chemical reduction
- Process failure indicator employs UV intensity monitor and UV failure; shutdown of water flow upon trigger
- Vendor operations manual provides detailed system instructions and water quality testing procedures
- High purchase cost of unit and replacement membranes: set of RO membranes, \$1558

(b) (4)

(b) (4)

(b) (4)

(b) (4)

Can Pure is a trademark of Global Hydration Water Treatment Systems, Inc, Kakabeka Falls, Ontario, Canada.

Global Hydration Can Pure™ SR2007B  
Operational and Technical Evaluation Summary

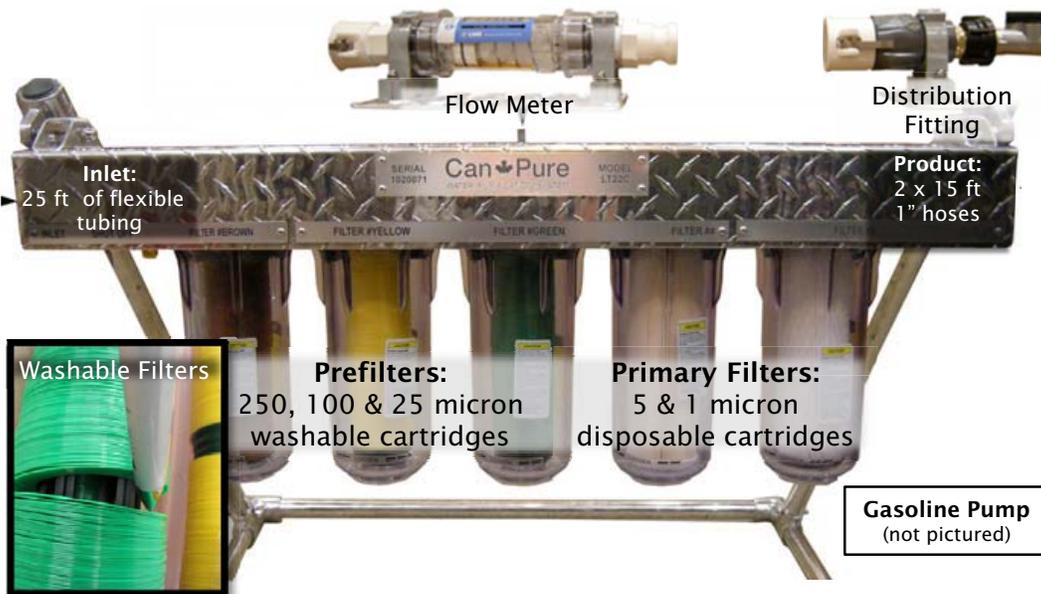


# Global Hydration Can Pure™ LT22c™

## Operational and Technical Evaluation Summary

The Can Pure™ LT 22c™

(b) (5)



### Technical Specs:

4 gallons per minute  
 1µm absolute filtration  
 Batch Cl<sub>2</sub> disinfection  
 Treats Freshwater Only  
 Fuel Driven

### Features:

Collapsible frame  
 Separate raw water pump  
 with 25 ft vertical lift  
 Washable filters

### Dimensions:

37 x 18 x 15 in.  
 100 lbs.



PALLET



FOOTLOCKER



BRIEFCASE

This footlocker-sized system weighs approximately 100 pounds and produces four (4) gallons per minute (gpm) from a freshwater source. Treatment consists of multistage cartridge filtration for sediment and some microbial pathogen reduction; 1-micron (µm) absolute filter for cyst reduction; and batch disinfection with AQUATABS® sodium dichloroisocyanurate (NaDCC) tablets for reduction of bacteria, cysts, and viruses. Filtration is provided by 250-micron, 100-micron, and 25-micron washable cartridges followed by disposable 5-micron and 1-micron cartridge filters. The system has a gasoline powered pump that is included.

### Advantages

- Redundant prefiltration capacity with one of a kind clean and reuse capacity.
- Anticipated to provide adequate treatment of bacteria, cysts, and viruses.
- Simple to operate.
- Provides a disinfectant residual.

### Disadvantages

- Some assembly of filtration system components and support stand required.
- No technology to remove chemical contaminants or objectionable taste and odor.
- Fuel driven pump may require maintenance.

For more information contact:

**Water Supply Management Program**  
**U.S. Army Public Health Command (Provisional)**

410.436.3919  
 water.supply@amedd.army.mil

System Cost: \$9750  
 Consumable Filter Set : \$44

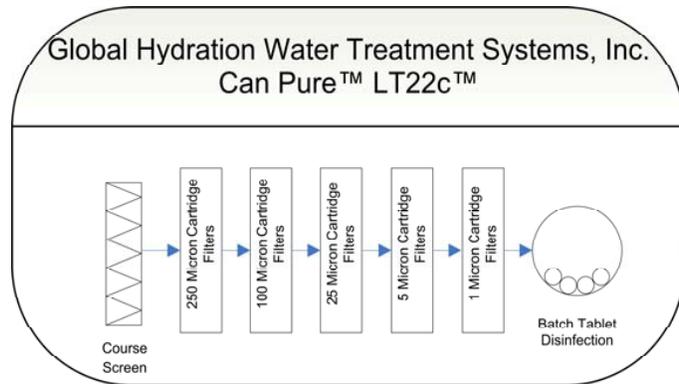
Global Hydration Water  
 Treatment Systems, Inc.  
 807-577-0030  
 www.globalhydration.com

™ Can Pure and LT-22c are trademarks of Global Hydration Water Treatment Systems, Inc, Kakabeka Falls, Ontario, Canada. AQUATABS® is a registered trademark of Mendentech, Wexford, Ireland. Use of trademarked names does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

No data verifying the effectiveness of the complete system as packaged to reduce microbial pathogens was available. The 1-micron absolute filter has been tested and certified to NSF/ANSI 53. Certification indicates the filter is capable of reducing microbial cysts to the required 3-log minimum reduction. The use of batch chlorine disinfection using sodium dichloroisocyanurate (NaDCC) tablets is expected to provide significant reduction of bacteria and viruses. Based on this information, the Can Pure™ LT22c™ should be capable of consistently reducing cysts, bacteria, and viruses the required 3-log, 6-log and 4-log reductions, respectively, when used as directed in unchallenging waters. This system **does provide a disinfectant residual** through use of AQUATABS® NaDCC tablets provided with the unit.

## SYSTEM OPERATION



*Setup & Operation.* Setup and operation involves assembly of the filtration system and support stand, connecting inlet and outlet hoses, locating the gasoline powered pump within 25 vertical feet of a fresh water source, priming the pump, and checking all valves before turning the pump on. The vendor recommends a one minute flush at startup. Batch disinfection is accomplished using Aquatabs® NaDCC tablets in 5 gallon or larger collection containers that are not provided with the unit. A 30-minute contact time is recommended by the manufacturer after disinfection. Chlorine test strips are provided to verify the residual concentration after contact time.

*Cleaning & Maintenance.* Maintenance involves cleaning the washable 250, 100, and 25-micron filters and replacement of disposable cartridges. The filters may require **frequent washing and replacement** in turbid waters. Reduced flow through the system indicates clogging and the need for filter washing or replacement. The washable filters last indefinitely, while replacement of disposable filters will vary depending on water source conditions. The supplied gasoline powered pump will require routine refueling during operation.

*Storage.* Long term storage involves draining the filter housings; disposal of wet disposable filters; cleaning all interior parts with warm soapy water; drying all parts; and disassembly of the system components and support stand.

## OPERATIONAL EVALUATION

Compared to other SUWPs of its size, the Can Pure™ LT-22c™ Portable Water Purification Unit is simple to operate. Consider these attributes:

- Certified component for reduction of cysts
- One of very few evaluated systems to provide disinfectant residual
- Modular design is convenient for storage and transport, will require on site onsite assembly of approximately 30 minutes
- Least expensive of comparably sized SUWPs
- Burden of filter maintenance and cost mitigated by use of washable pre-filters
- Vendor operations manual provides detailed system instructions and water quality testing procedures

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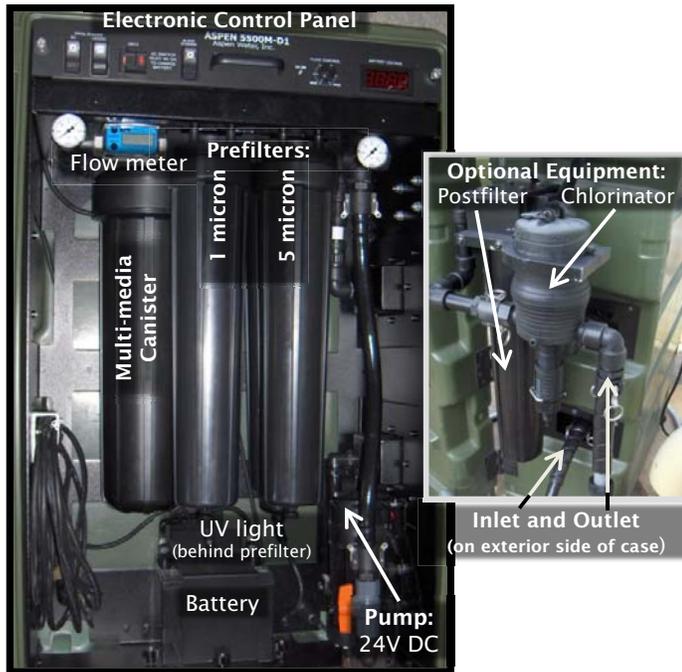


# Aspen 5500M

## Operational and Technical Evaluation Summary

The Aspen 5500M

(b) (5)



### Technical Specs:

3.5 gallons per minute  
Multimedia and UV  
Treats Freshwater only  
AC or DC

### Features:

Wheeled poly case  
30 ft inlet & product hoses  
Camlock fittings  
Extended use case  
Variable speed, self-priming pump

### Dimensions:

43 x 28 x 21 in. per case  
330 lbs. combined weight



PALLET



FOOTLOCKER



BRIEFCASE

This footlocker-sized system weighs approximately 220 pounds and produces 3.5 gallons per minute (gpm) from a freshwater source. Treatment consists of mechanical filtration for sediment, fine particle, and some microbial pathogen reduction; oxidation-reduction (redox) and carbon adsorption, both for chemical, taste, and odor reduction; and ultraviolet (UV) light for disinfection of microbial pathogens. 5-micron and 1-micron replaceable cartridge filters provide the mechanical filtration before the replaceable multi-media canister: a mixed bed of copper-zinc granular media and granular activated carbon (GAC). The system can be powered by 90-260 V single phase alternating or 12/24 V direct current (AC/DC) and includes a battery with an advertised run capacity of 4 hours. An optional solar battery charging system can be purchased separately.

### Advantages

- Expected to provide adequate treatment of cysts and bacteria.
- Multiple power sources and shutdown if UV lamp burnout/breakage occurs.
- Among the most durable of footlocker-sized system evaluated.

### Disadvantages

- Concern of UV quartz sleeve breakage during transport.
- Additional treatment may be required to provide adequate reduction of viruses.
- No disinfectant residual, without optional equipment.

For more information contact:

**Water Supply Management Program**  
**U.S. Army Public Health Command (Provisional)**

410.436.3919  
water.supply@amedd.army.mil

System Cost: \$28,000

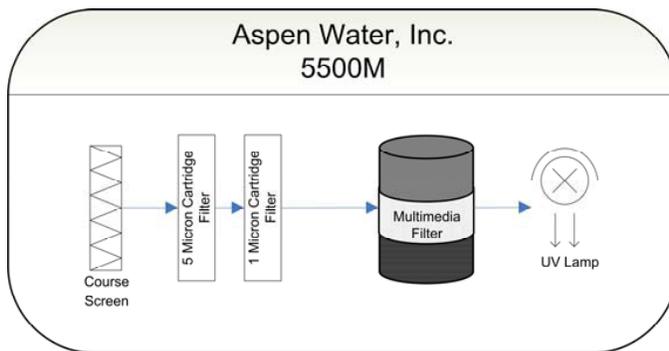
Filter Set: \$270

Aspen Water, Inc  
972-889-9500  
www.aspenwater.com

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

No data showing the effectiveness of this system in reducing microbial pathogens was available. Based on general knowledge of the treatment technologies used—nominal 1-micron cartridge filter, redox, carbon adsorption, and UV—the system should be capable of consistently reducing cysts and bacteria the required 3-log and 6-log reductions, respectively, when used as directed. However, the system is not expected to consistently reduce viruses the required 4-log. Highly turbid waters may interfere with the UV efficacy to inactivate bacterial and protozoan (cyst) pathogens as well. Because disinfection is provided by UV, this system **does not provide a disinfectant residual**. **Additional treatment such as chlorine disinfection** is recommended to provide a residual in any product water not consumed immediately. The vendor offers additional equipment which may improve the microbial reduction performance of the unit, including a nano-alumina post filter and inline chlorinator.

## SYSTEM OPERATION



*Setup & Operation.* Setup and operation requires the user to locate the system within 30 feet (12 foot vertical max) of the fresh-water source, connect the inlet and outlet hoses, connect to an AC or DC power source or use the included batteries (4-hrs of run), and turn on the unit and allow it to run for 5 to 10 gallons to flush the filters before consumption.

*Cleaning & Maintenance.* Cleaning and maintenance involves filter cartridge replacement, multimedia filter canister replacement, cleaning of

the quartz sleeve, UV lamp replacement, and cleaning the pump. Pre-filter cartridge life will vary greatly dependent on water quality; **frequent replacement** is likely in turbid waters. The multimedia canister is rated for 30, 000-60, 000 gallons, depending on water quality. Cleaning the UV quartz sleeve is recommended every time the system is apart for filter changes or maintenance. UV lamps should be changed after a maximum volume of 750, 000 gallons.

*Storage.* There are no special requirements for short-term storage, unless the unit is to be transported. The vendor recommends draining the unit before transport. The onboard pump can be used to push the majority of water from the filter sumps by removing the inlet hose from the water source. For long-term storage the system should be drained as above, filters discarded, and system disinfected per operations manual.

## OPERATIONAL EVALUATION

Compared to other SUWPs of its size, The Aspen 5500 is simple to operate. The following were noted through the course of evaluation and should be considered when comparing this and other footlocker-sized SUWPs:

- Time, effort, and expense of frequent filter replacement in challenging waters
- Optional equipment: post filter for organic and turbidity reduction, chlorinator for secondary disinfection
- Can operate using pressure from an existing pressurized water system, bypassing onboard pump
- More expensive than comparable, non-reverse osmosis based, SUWPs; purchase cost does include comprehensive extended use case

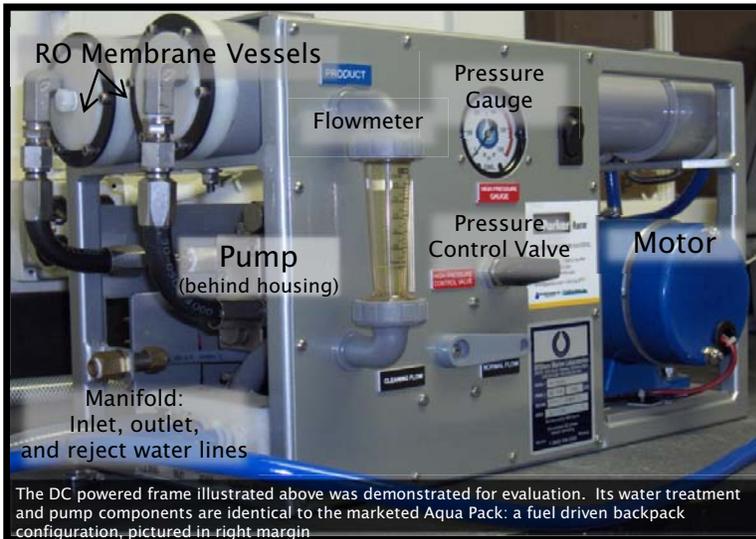


# Village Marine Tec.™ Aqua Pack

## Operational and Technical Evaluation Summary

The Village Marine [REDACTED]

(b) (5)



This briefcase-sized system weighs approximately 53 pounds and produces 0.2 gallons per minute (gpm) from a freshwater or seawater source. The weight is on average with other briefcase sized systems evaluated. Treatment consists of high pressure reverse osmosis (RO) filtration for reduction of fine particles, microbial pathogens, chemicals, and dissolved salts. Filtration is provided by two thin film composite RO membranes in series. The system is currently marketed with a fuel driven motor, the vendor has a 24 V Direct Current (DC) motor available.

### Advantages

- Anticipated to provide adequate removal of bacteria, cysts, and viruses.
- Robust technology for removal of chemicals and dissolved salts.
- Confidence that vendor support will meet user needs.

### Disadvantages

- Minimal power flexibility.
- Among lowest water production rates of briefcase-sized systems evaluated.
- No disinfectant residual.
- Noise of fuel driven motor.

For more information contact:

**Water Supply Management Program  
U.S. Army Public Health Command (Provisional)**

410.436.3919  
water.supply@amedd.army.mil



**Technical Specs:**  
0.2 gallon per minute  
Reverse Osmosis  
Treats most waters,  
including Saltwater  
Fuel Driven

**Features:**  
Backpack Style  
Titanium Pump  
Single 5 micron prefilter

**Dimensions:**  
17.5 x 25 x 13 in.  
53 lbs.



PALLET



FOOTLOCKER



BRIEFCASE

System Cost: \$5000

Pre-Filter: \$12

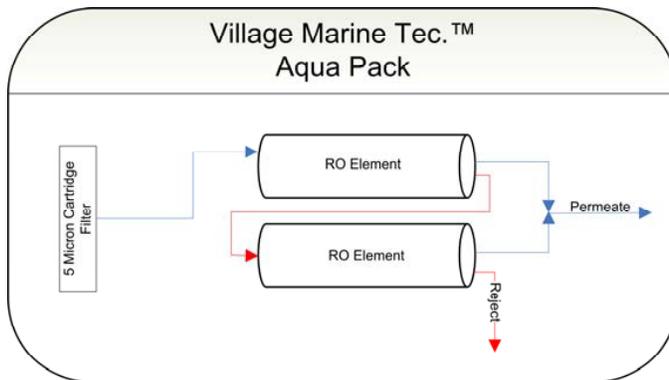
Parker Racor  
Village Marine Tec.  
800-421-4503  
www.villagemarine.com

™ Village Marine Tec. is a trademark of Parker Intangibles LLC, Cleveland, Ohio . Use of trademarked name does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

## EFFECTIVENESS AGAINST MICROBIAL PATHOGENS

No data verifying the effectiveness of this system in reducing microbial pathogens was available. The reverse osmosis membrane (ROM) does not have independent third-party certification. Based on general knowledge of the treatment technology used, the system should be capable of consistently reducing cysts, bacteria, and viruses to the required 3-log, 6-log, and 4-log minimum reductions. High pressure RO, as employed by the Aqua Pack, is also known to provide broad spectrum chemical reduction. **Additional treatment** such as chlorine is necessary to provide a **disinfectant residual**, and would provide an additional microbial pathogen barrier.

## SYSTEM OPERATION



*Setup & Operation.* Setup and operation requires the user to locate the system near the water source, fuel the motor or connect a power source or, connect inlet/outlet hoses, open the high pressure regulator, prime the pump, start the unit, adjust the high pressure regulator to establish permeate flow, and allow the system to run for at least 5 minutes to purge the storage chemicals (first start and post-storage only). The vendor recommends using the included total dissolved solids (TDS) meter to test water quality and ROM performance. TDS as a performance indicator will only be apparent in salt

and brackish raw water sources where TDS should be greater than 90% reduced in the product water.

*Cleaning & Maintenance.* Cleaning and maintenance involves filter cartridge cleaning and replacement, and cleaning the membranes. Prefilter cleaning is triggered by reduced flow and pressure. **Frequent prefilter replacement** may be necessary in turbid waters. Membranes need to be cleaned when flow cannot be recovered and feed pressure begins to rise. Two proprietary cleaning compounds are recommended for membrane cleaning.

*Storage.* There are no special requirements if the unit will be in operation within seven days. For short-term storage, but greater than seven days, the unit should be flushed with unchlorinated fresh water. Long-term storage requires ROM cleaning and preservation; refer to the vendor operations manual. According to the vendor, the membranes should have a service life between 3 and 5 years under normal conditions and with proper maintenance.

## OPERATIONAL EVALUATION

Compared to other SUWPs of its size, the Village Marine Tec.™ Aqua Pack will require moderate effort to operate, less than one hour per ten hours of operation. It was one of only two high pressure RO systems of briefcase size. Consider these attributes when comparing this and other briefcase-sized SUWPs:

- Limited prefiltration capacity, may impact use in turbid waters or require additional equipment
- Proprietary sourcing of components
- RO offers desalination, therefore broader source flexibility; reduced production rate compared to non-RO systems of similar size
- May require additional raw water feed pump

™ Village Marine Tec. is a trademark of Parker Intangibles LLC, Cleveland, Ohio. Use of trademarked name does not imply endorsement by the US Army but is intended only to assist in identification of a specific product.

**APPENDIX G**  
**TECHNOLOGY SUMMARIES**

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**APPENDIX G**

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**ANNEX A TO APPENDIX G**  
**CARBON NANOTUBES IN DRINKING WATER TREATMENT**

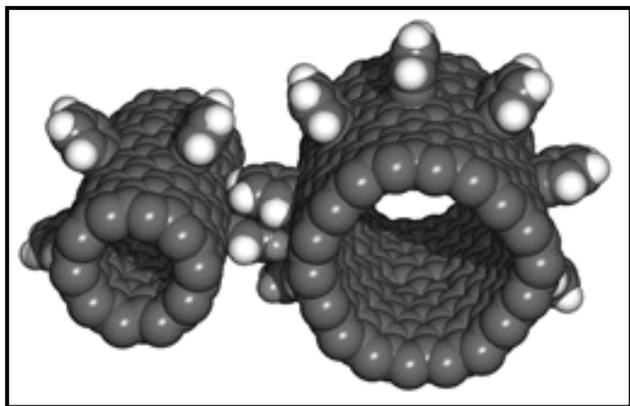
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## *Just the Facts...*

## *Carbon Nanotubes in Drinking Water Treatment*

### What are Carbon Nanotubes?

Carbon nanotubes are very thin, hollow cylinders made of carbon atoms. They are about 10,000 times thinner than a human hair. Carbon nanotubes are produced using various thermal processes to strip carbon atoms from carbon-bearing materials and use them to form a hexagonal network of carbon atoms that is rolled up into a cylinder, or tube. Carbon nanotubes have exceptional thermal, electrical, and mechanical properties, allowing for potential wide applications in numerous industries (references 1, 2).



**Figure.** Computer simulation of carbon nanotubes.

**Source:** NASA Ames Research Center, Center for Nanotechnology; [www.ipt.arc.nasa.gov/carbonnano.html](http://www.ipt.arc.nasa.gov/carbonnano.html)

### How are Carbon Nanotubes Used for Treating Drinking Water?

Researchers suggest that carbon nanotubes could provide a significant advantage over current membrane technologies, such as reverse osmosis and ultrafiltration. The unique properties of carbon

nanotubes would allow water molecules to pass through the interior of the cylinders while chemical and microbial contaminants could not. This is a filtration process called size exclusion. This could be accomplished at a high rate of flow with very little energy (pressure) input to “push” the water through the nanotubes – thus a big advantage over current membrane technologies. Additionally, research has shown carbon nanotubes have a strong ability to adsorb many types of chemical and microbial contaminants (references 3-6).

While research shows significant potential for using carbon nanotubes in drinking water treatment, currently their use is limited. The main reason is the inability to construct very well-defined carbon nanotube arrangements where the carbon nanotubes would be lined up facing one direction all right next to each other in a filtration device. Current carbon nanotube production results in their formation in “mats of ropes” where the ropes are bundles of carbon nanotubes pointing in different directions (references 1, 7). This production technique prevents the water from passing through the interior of the carbon nanotubes, thereby limiting their use for drinking water treatment.

Even so, there are drinking water treatment products already developed that use carbon nanotube technology. One manufacturer has developed carbon nanotube filters to take advantage of their useful properties in light of the current inability to construct well-defined carbon nanotube arrangements. The filter consists of a mat or mesh of carbon nanotubes stacked on each other, pointing in different directions, and wrapped around a carbon block filter structure (reference 8). This resulting filter is one with very small pore openings that is on the micrometer scale, but larger than the interior nanometer pore openings of the carbon nanotubes.

## Do Carbon Nanotubes Pose Any Human Health or Environmental Health Risks?

Health risks, both human and environmental must be considered for any new technology produced or employed on an industrial or commercial scale. The properties that make carbon nanotubes attractive for numerous applications may also make it a potential health risk concern. Current research on human and environmental health risks is limited. Results are conflicting and inconsistent making it difficult to draw any conclusions. There are concerns that carbon nanotubes may interfere or damage DNA, could cause harmful effects to organs if introduced into the body, and could adversely affect natural ecosystems (references 2, 9-13). The bottom line is carbon nanotubes may cause adverse human or environmental health effects but further studies are necessary to determine the impact, if any, carbon nanotubes have on humans and the environment.

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**ANNEX B TO APPENDIX G**  
**ULTRAVIOLET (UV) DISINFECTION IN**  
**DRINKING WATER TREATMENT**

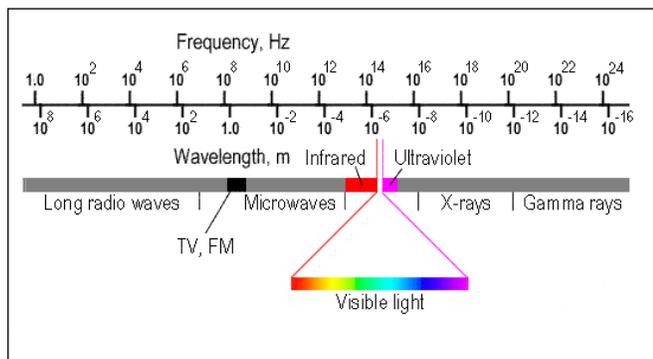
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# Just the Facts...

## Ultraviolet (UV) Disinfection in Drinking Water Treatment

### What is UV?

Ultraviolet light (UV) is a form of energy called electromagnetic radiation. UV light is a small part of the entire electromagnetic spectrum made up of other types of radiation including visible light, x-rays, radio waves, and microwaves, all at different wavelengths. UV light is electromagnetic radiation with wavelengths in the range of 100-400 nanometers (nm). In contrast visible light is in the range of 400-700 nm. So UV light is not visible.



**Figure. The Electromagnetic Spectrum.**

**Source:**

<http://www.sentinelarchiving.com/ARTICLES/electromag.htm>

### How does UV Disinfection Work?

UV light has germicidal properties that were discovered as early as 1887. Much research has been conducted that shows UV light at certain wavelengths can inactivate microorganisms (references 1, 2). UV light with wavelengths from 200-300 nm inactivates most microorganisms,

with the greatest amount of inactivation occurring around 260 nm. For UV light, inactivating microorganisms is different than killing them. UV light doesn't damage or destroy cellular structures like chemical disinfectants do (e.g., chlorine, ozone, chlorine dioxide). Rather, UV light prevents microorganisms from reproducing by damaging their deoxyribonucleic and ribonucleic acids (DNA and RNA). Microorganisms that cannot reproduce cannot infect and are thereby inactivated. In general, viruses are most resistant to UV disinfection compared to protozoan cysts (e.g., *Cryptosporidium*) and bacteria.

### How is UV used in Drinking Water Treatment?

Using UV light in drinking water treatment requires the generation and application of UV light in a way to maximize its effectiveness. All UV drinking water treatment devices require power to generate UV light. When a UV lamp is turned on, mercury in the lamp is "excited" and takes on energy. The mercury quickly discharges that extra energy in the form of UV light. Mercury is a necessary component of UV lamps because it emits light in the germicidal wavelength (200-300 nm). However, there are new UV light-emitting-diodes (UV LEDs) being developed that do not use mercury and show promise as effective UV disinfection devices (References 3, 4).

A UV device used in drinking water treatment typically consists of a UV lamp, a clear quartz sleeve to protect the lamp and allow the UV light to penetrate the water, and in some cases a means to measure the intensity of UV light produced. Having the ability to measure UV light intensity is

important since certain water quality characteristics can reduce intensity and UV intensity degrades the more the lamp is used. Additionally, the UV device is designed to ensure all the water being treated is channeled through the device as close to the quartz sleeve as possible to ensure the water receives the longest amount of exposure possible at the maximum UV intensity. UV devices work best when treating clear water, so UV devices are typically located after filtration treatment processes. The effectiveness of UV light is highly dependent on the turbidity, or cloudiness, of the water and any color present in the water. In highly turbid or colored water the UV light won't be able to penetrate through the water. A well-designed UV device will incorporate indicators of operation to measure the UV intensity, or UV dose, provided to the water and will also include indicators of lamp function (on/off).

UV devices can be scaled to fit any size or type of drinking water treatment need, from small handheld devices to large systems capable of treating millions of gallons per day. A number of commercially available water treatment systems designed to fulfill the needs of the military squad-sized unit incorporate UV as a disinfectant. These water purifiers are meant to be portable and therefore present inherent risk of breakage or damage to the UV device during transport. Care must be exercised when transporting a UV device and they should be closely inspected prior to operation to ensure no damage has occurred.

A significant disadvantage of using UV for disinfection is its inability to provide a residual. If UV disinfected water is to be stored a chemical disinfectant such as chlorine or iodine, capable of providing a long-lasting disinfectant residual, should be added to the stored water to prevent recontamination.

### **Are there any Health Risks from using UV?**

There are three potential health risks associated with using UV devices – formation of disinfection byproducts; mercury exposure due to UV lamp breakage; and direct exposure to UV light

generated by the UV device. All these potential health risks are generally considered minimal. While there is evidence that UV can produce disinfection byproducts, UV produces far fewer disinfection byproducts compared to other chemical disinfectants typically used in drinking water treatment (e.g., chlorine, ozone, chlorine dioxide). Disinfection byproducts may cause adverse health effects if consumed in sufficient quantities for long periods of time.

Most UV lamps used in drinking water treatment contain between 5 milligrams (mg) and 400 mg of mercury. There is a concern if a UV lamp breaks during operation the mercury could enter the treated water and be ingested. Most UV devices have safety mechanisms installed to alarm or stop treatment or water flow if a UV lamp breaks or loses power for any reason. Additionally, if the quartz sleeve is not damaged or broken it may prevent mercury from entering the water if the lamp breaks. While this is a concern, the potential health risk from ingesting mercury is low.

The health risks from direct exposure to UV from sunlight are well documented. There is a concern that a user could be exposed to UV light when using or maintaining a UV device. However, this poses a slight risk as UV devices are designed to operate in enclosed vessels and include safety mechanisms to prevent UV light exposure during maintenance.

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### References

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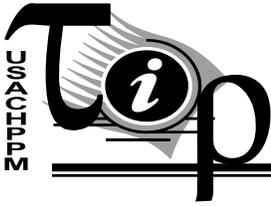
**ANNEX C TO APPENDIX G**  
**NANOALUMINA FIBER FILTERS IN**  
**DRINKING WATER TREATMENT**

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**ANNEX D TO APPENDIX G**

**CHLORINE DISINFECTION IN THE USE OF  
INDIVIDUAL WATER PURIFICATION DEVICES**

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## Chlorine Disinfection in the Use of Individual Water Purification Devices

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Technical Information Paper #31-002-0306

### PURPOSE

This information paper provides an in-depth review of chlorine as a disinfectant in potable water supplies. This paper is intended to assist the reader in evaluating the disinfection capabilities of Individual Water Purification Devices (IWPDs) using chlorine to kill or inactivate disease-causing bacteria, viruses, and protozoan cysts.

### REFERENCES

Appendix A contains a list of references.

### INTRODUCTION

#### Background

Understanding the disinfection capabilities of chlorine to kill or inactivate disease-causing microorganisms is important in protecting Soldiers, who are considering using this technology, from acute health threats posed by these microorganisms. Soldiers deployed beyond traditional field drinking water supplies must have access to potable water. Using IWPDs is one way to provide potable water in these situations. These IWPDs must protect the Soldier from acute microbial health threats. The U.S. Environmental Protection Agency (USEPA) Guide Standard and Protocol for Testing Microbiological Water Purifiers (reference 1) provides performance standards by which an IWPD using chlorine can be evaluated. The performance standards are a minimum 6-log reduction/inactivation of bacteria, 4-log reduction/inactivation of viruses, and 3-log reduction/inactivation of protozoan cysts. Chlorine-using IWPDs meeting these standards are considered effective against disease causing bacteria, viruses, and protozoan cysts. Some IWPD manufacturers test their devices using this protocol. This is the best way to evaluate the IWPDs disinfection capabilities. In the absence of that testing data, this information paper can be used to gain an understanding of chlorine disinfection capabilities and help determine if an IWPD using chlorine could successfully meet the EPA Guide's minimum performance standards.

#### General

Chlorine has long been identified as an effective and efficient disinfection agent. One-time, emergency chlorination of water supplies has been practiced for over 100 years, with the first continuous use of chlorine for water supply disinfection occurring in Boonton, New Jersey, in 1908 (references 2 and 3). Chlorine and its derivatives represent the most widespread compound

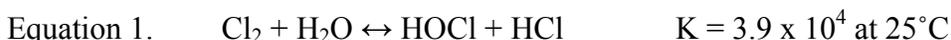
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used for disinfection in the United States. There are several Commercial-Off-The-Shelf (COTS) IWPDs that use chlorine for disinfection, including Chlor-Floc™, which was tested by an Army agency and found to be a safe alternative to iodine tablets (reference 4). These IWPDs may either rely on chlorine disinfection alone or combine chlorine disinfection with filtration to remove pathogenic organisms from water.

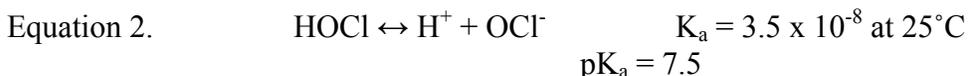
## CHLORINE CHEMISTRY IN WATER.

### General

Chlorine is added to water in one of three forms: elemental chlorine (chlorine gas), sodium hypochlorite solution or calcium hypochlorite powder, also called high-test hypochlorite (HTH). Chlorine gas reacts rapidly with water to form two compounds - hypochlorous acid (HOCl) and hydrochloric acid (HCl) as follows (reference 5):



The forward hydrolysis reaction is virtually complete at pH greater than 4 and chlorine solutions up to 100 mg/L (dilute solutions), as expected with the magnitude of the equilibrium constant (K) (reference 6). Hypochlorous acid, the active chlorine form in disinfection reactions, is a weak acid that further dissociates into two components, the hydrogen ion (H<sup>+</sup>) and the hypochlorite ion (OCl<sup>-</sup>), as follows (reference 5):



As shown in Figure 1, both HOCl and OCl<sup>-</sup> species are present to some extent at pH values between 6.5 to 8.5 (reference 3), with equal distribution at pH 7.5 (reference 6). The dissociated hypochlorite ion (OCl<sup>-</sup>) predominates at higher pH values, while the undissociated hypochlorous acid (HOCl) predominates at lower pH values. Hypochlorous acid is more reactive than the hypochlorite ion, and a much stronger disinfectant (reference 2). Thus, a lower water pH promotes more efficient disinfection. In general, a water pH of less than 8 is recommended for chlorine disinfection (reference 6). Chlorine will react with many naturally occurring organic compounds in water to produce undesirable disinfectant by-products (DBPs), which may have adverse effects generally associated with long-term exposure (reference 5). Two groups of DBP compounds, trihalomethanes (THMs) and haloacetic acids (HAAs), are currently regulated by the EPA.

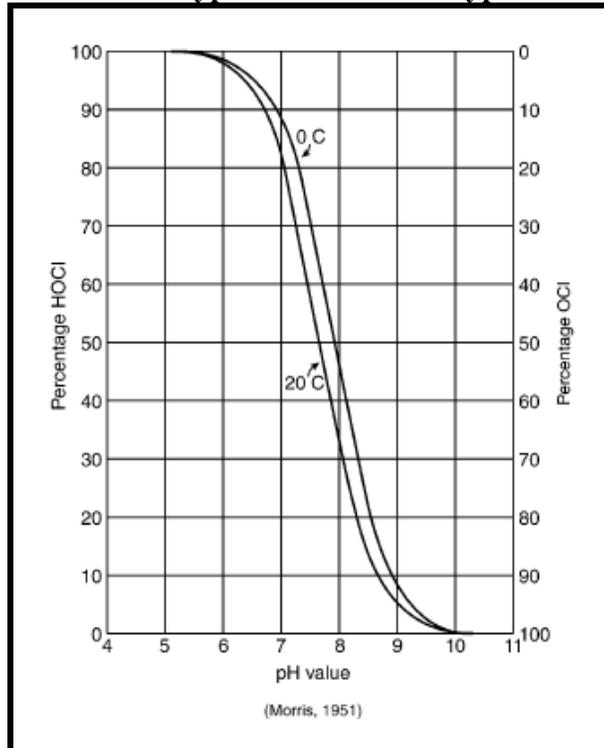
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™ Chlor-Floc is a trademark of Control Chemical, D/B/A Deatrick and Associates Inc., Alexandria, VA. Use of trademarked products does not imply endorsement by the U.S. Army, but is intended only in identification of a specific product.

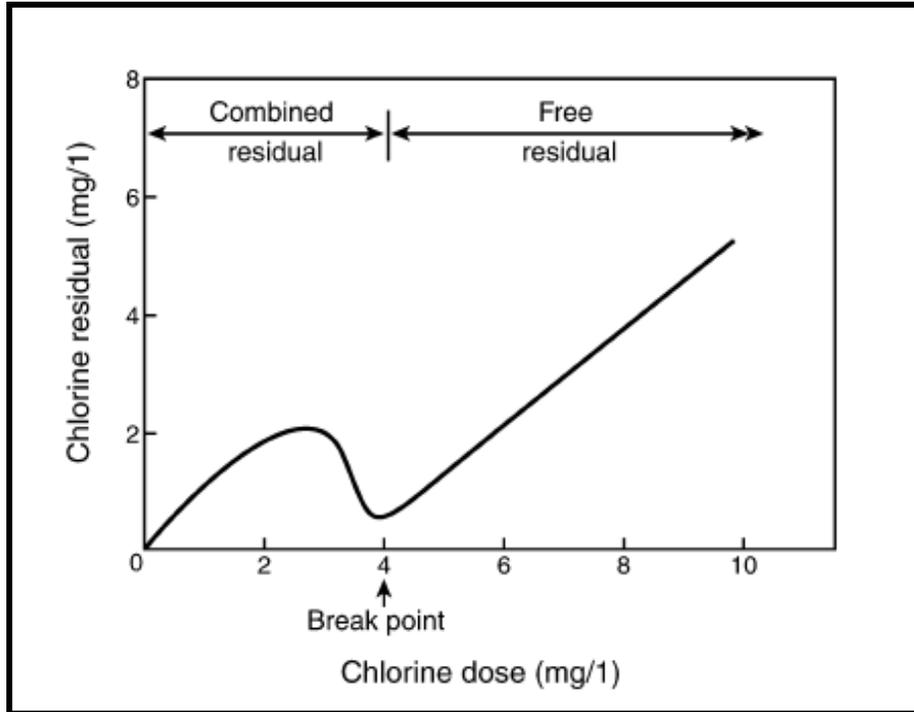
### Chlorine Demand

As a strong oxidant, chlorine will combine with many other substances, including ferrous iron, manganese, ammonia and other inorganic and organic material, in water (reference 7). In aqueous solutions with pH 7.0 to 8.5, HOCl reacts rapidly with ammonia to form inorganic chloramines (termed combined chlorine) in a series of competing reactions (reference 5). These reactions are instantaneous, with no appreciable disinfection occurring until this initial “chlorine demand” is met. Subsequent addition of chlorine will result in establishment of a free available chlorine [(FAC), which includes HOCl and OCl] residual. Figure 2 shows the “breakpoint chlorination” curve, which is unique for each water source. Thus, the chlorine dosage should be adequate to satisfy the chlorine demand of the source water, but not excessive beyond the breakpoint, as taste and odor problems may occur.

**Figure 1. Distribution of Hypochlorous Acid/Hypochlorite versus pH**



**Figure 2. Breakpoint Chlorination Curve**



## IWPD Forms

### *General*

Chlorine is available in various forms, including calcium hypochlorite (solid), sodium hypochlorite (solution) and as pure chlorine gas. For hand-held IWPDs, chlorine takes the form of either calcium hypochlorite tablets or sodium hypochlorite (including household bleaches). Calcium hypochlorite (chlorinated lime, tropical bleach, bleaching powder, 'HTH') is a powder containing between 30 and 70% available chlorine. It must be stored carefully to prevent deterioration, and although it can cause burns, is generally safe to handle and transport (reference 8). Sodium hypochlorite solutions contain about 1 to 18% chlorine and are thus mostly water. Sodium hypochlorite solution must be stored carefully to prevent deterioration and can cause burns (reference 8).

### *Chlorine Stabilizers*

Ultraviolet rays in sunlight degrade free chlorine compounds in water and significantly decrease disinfection efficacy over time. Chlorine concentrations may be reduced by

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one-half when exposed to sunlight for only 1 hour (reference 9). To mitigate these effects, chlorinated derivatives of cyanuric acid, termed isocyanurates, are used to prolong the lifetime of free chlorine in water that is exposed to sunlight. The isocyanurate compound, originally introduced for swimming pool chlorine sanitation in 1960, dissociates in water to form both cyanuric acid, which “stabilizes” free chlorine compounds, and hypochlorous acid, the active disinfectant (reference 9). Chlorine concentrations may be prolonged 3 to 10 times longer in water when cyanuric acid is present in sufficient quantities (reference 9). Studies have shown that cyanuric acid does not interfere with disinfection conditions (reference 10) at concentrations used in drinking water. Some chlorine-using IWPDs may use isocyanurates to prolong chlorine residual in the treated water.

## **DISINFECTION CAPABILITIES.**

### **General**

Chlorine is effective at inactivating bacteria and viruses, and under certain circumstances, *Giardia* (reference 5). However, chlorine has little impact on *Cryptosporidium* oocysts at typical water treatment concentrations (up to 5 mg/L) (reference 5). Chlorine’s general disinfection capability with respect to microorganisms can be illustrated in the following way from most effective to least effective:

bacteria > viruses > *Giardia* cysts > *Cryptosporidium* oocysts

The rate of disinfection, or destruction, of microorganisms in water is generally described by the Chick-Watson law (Equation 3, references 11 and 12), which is the basis for the CT values widely used today to determine disinfectant germicidal efficiency. The CT factor is defined as the product of the residual disinfectant concentration (C, in mg/L) and the contact time (T, in minutes) that the residual disinfectant is in contact with the water.

Equation 3. 
$$\ln \frac{N}{N_0} = -\alpha C^n t$$

Where: N = number of microorganisms at time t

$N_0$  = initial number of microorganisms

$\alpha$  = inactivation constant

C = disinfectant concentration, moles/L

n = constant of dilution, usually close to 1.0

t = time, min

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Chlorine's disinfection capability decreases with decreasing temperature and increasing pH. The EPA has published extensive CT tables for virus and *Giardia* inactivation, for different temperature, pH, and chlorine residual conditions (reference 13). Turbidity can also have negative effects on chlorine disinfection because particles can shield microorganisms from chlorine. Turbidity particles also typically increase organic content, resulting in higher source water chlorine demand (reference 6).

### **Environmental Effects on Disinfection Capability**

#### *Effect of pH on Disinfection Capability*

Since the germicidal efficiency of HOCl is much higher than that of OCl<sup>-</sup>, as pH increases, the CT requirement for a given log-reduction increases. Most research has confirmed that chlorine is more biocidal at low, rather than high pH, and the pH effect is more profound for chlorine than other disinfectants, such as chlorine dioxide, ozone, and even combined chlorine (chloramines) (reference 5). Virus inactivation studies have shown that 50% more contact time is required at pH 7.0 than at pH 6.0 to achieve comparable inactivation, and that raising the pH from 7.0 to 9.0 requires a six-fold increase in contact time for comparable viral inactivation (references 5 and 14). However, some viruses have been shown to be more sensitive to chlorine at high, rather than low, pH (references 5 and 15). In these cases, the increased disinfection efficiency may be due to OCl<sup>-</sup> forming neutral ion pairs with sodium, potassium, and lithium.

#### *Effect of Temperature on Disinfection Capability*

Temperature, over the range appropriate for drinking water, affects the rate of disinfection reactions according to the Arrhenius equation, with colder water slowing inactivation rates. For chlorine, and all other disinfectants, pathogen inactivation effectiveness increases as water temperature rises (reference 5). Additionally, for a given CT value, a low C and a high T is more effective than the reverse (i.e., a high C and a low T), underscoring the importance of temperature in disinfection efficacy (reference 5). Virus studies showed that the contact time must be increased by two to three times when the temperature is lowered by 10° C to achieve similar inactivation levels (reference 16).

#### *Effect of Turbidity on Disinfection Capability*

Particles responsible for turbidity can surround and shield pathogenic microorganisms from free chlorine, thus decreasing inactivation efficiency. One study investigated indigenous coliform bacteria associated with particulate matter and the protective effects that the particles may have in shielding disinfection. Using sieve and nylon screens to separate particle fractions, coliform bacteria associated with the < 7-µm fraction were

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inactivated more rapidly than the  $> 7\text{-}\mu\text{m}$  fraction when exposed to 0.5 mg/L free chlorine at pH 7.0 and 5° C (reference 17). The results showed the significance that particle agglomeration and clumping may have on chemical oxidation efficiency. Another study suggested that turbidity impacts on free chlorine disinfection efficiency are magnified at lower temperatures (reference 18). Free chlorine will rapidly oxidize organic matter associated with turbidity; reducing disinfection efficiency since a free chlorine residual will only appear after all organic matter is oxidized. Thus, higher chlorine dosages may be necessary when using IWPDs to overcome organic matter oxidation and still provide disinfection when treating raw, unfiltered water supplies.

### **Bactericidal Efficiency**

Chlorine is an extremely effective disinfectant for inactivating bacteria under normal conditions. A chlorine inactivation study of pathogenic *Escherichia coli* O157:H7E and wild-type *E. Coli* strains was conducted by the EPA (reference 19). The study showed that at a typical water treatment dosage of 1.1 mg/L FAC, pH 7.0, and 5° C, both pathogenic and wild-type *E. coli* strains were inactivated by over 4½ orders of magnitude within 2 minutes (reference 19). The findings indicated that these bacteria were sensitive to chlorine. Certain spore-forming bacteria, such as *Bacillus* or *Clostridium*, may show higher resistance to free chlorine when disseminated as spores (reference 20). Early research in the 1940s involving *E. Coli*, *Pseudomonas aeruginosa*, *Salmonella typhi*, and *Shigella dysenteriae* showed that HOCl is more effective than OCl<sup>-</sup> for inactivation of these bacteria (reference 21). Further research showed HOCl to be 70 to 80 times more effective than OCl<sup>-</sup> for inactivating bacteria (references 5, 22). Highly turbid water may require higher CT (i.e., longer contact time and/or higher dose) to assure adequate bacteriological disinfection.

### **Virucidal Efficiency**

Chlorine has been shown to be a highly effective viricide. One of the most comprehensive virus studies was conducted in 1971 using treated Potomac estuary water (references 5, 23). The tests were performed to determine the resistance of 20 different enteric viruses to free chlorine under constant conditions of 0.5 mg/L free chlorine residual, pH 7.8, and a temperature of 2° C. The study showed the least resistant virus to be reovirus, requiring only 2.7 minutes to achieve 99.99% inactivation (4-log removal). The most resistant virus was a poliovirus, requiring more than 60 minutes for 4-log removal. The CT range required for 4-log removal was 1.4 to 30 mg·min/L, indicating that adequate disinfection should occur with typical chlorine doses of up to 5 mg/L, depending on the chlorine demand of the source water (reference 23). Other viral survival studies were conducted in the 1970's on 20 cultures, including both laboratory

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and field poliovirus strains (references 5, 24) under constant conditions of 0.4 mg/L free chlorine residual, pH 7.0, and a temperature of 5° C. Test results showed that only two poliovirus strains required 10 minutes to achieve 4-log inactivation (CT = 4 mg·min/L), six poliovirus strains required 100 minutes to reach 4-log inactivation (CT = 40 mg·min/L), and 12 poliovirus strains required 1,000 minutes to reach 4-log inactivation (CT = 400 mg·min/L). Thus, higher FAC levels (> 0.4 mg/L) may be needed for shorter contact times to ensure 4-log viral inactivation. The SWTR provides the CT values for 4-log inactivation at various source water temperatures with a typical source water pH range of 6-9 (reference 13). Because of chlorine’s high efficiency in viral inactivation, CT values are typically governed by *Giardia* (protozoan) CT criteria. Highly turbid water may require higher CT (i.e., longer contact time and/or higher dose) to assure adequate viral disinfection.

**Table 1. USEPA SWTR Required CT Values for 4-Log Inactivation of Viruses By Free Chlorine for pH 6-9**

| Temperature (deg C) |   |    |    |    |    |
|---------------------|---|----|----|----|----|
| 0.5                 | 5 | 10 | 15 | 20 | 25 |
| 12                  | 8 | 6  | 4  | 3  | 2  |

### Cysticidal Efficiency

#### *Giardia* cysts

Chlorine has been shown to have limited success inactivating protozoa. Protozoan cysts such as *Entamoeba histolytica* and *Giardia lamblia* are highly resistant to chlorine disinfection and may require prolonged contact times at high chlorine residuals (2-3 mg/l) to achieve 99.9% (3-log) inactivation (reference 20). Past studies have shown that, at 2.5 mg/L free chlorine at 5° C and pH 6, a contact time of 30 minutes was needed to achieve a 2-log reduction; 60 minutes was needed when the pH was increased to 7 (reference 25). Comparative studies have shown the resistance of *Giardia* cysts to chlorine inactivation to be two orders of magnitude higher than that of enteroviruses and more than 3 orders of magnitude higher than enteric bacteria (references 5, 26). Extensive CT requirements for *Giardia* cyst inactivation when using free chlorine have been determined for various pH and temperature conditions (reference 13), and are included in Appendix B. A mathematical model for 99.9% (3-log) *Giardia* inactivation was also developed based on infectivity data (reference 27):

Equation 4. 
$$CT = 0.75 (0.9847 C^{0.1758} \text{pH}^{2.7519} \text{temp}^{-0.1467})$$

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where:

C = the disinfectant residual concentration

temp = the reaction temperature in degrees Celsius

Equation 4 should generally be used under the conditions it was derived: C between 0.44 and 4.23 mg/L; pH between 6 and 8; and temperature between 0.5 and 5° C. However, the CT result would be conservative (more protective) for lower pH values and higher temperatures. The CT result from Equation 4 may be adjusted for higher temperatures by assuming that for each 10°C increase in temperature, the CT decreases by 0.5 (reference 27).

### *Cryptosporidium Oocysts*

Chlorine is not effective for the inactivation of *Cryptosporidium* oocysts at typical water treatment doses (e.g., 5 mg/L). One *Cryptosporidium* study reported that 80 mg/l of free chlorine required 90 minutes to achieve only a 1-log (90%) inactivation of oocysts, and further indicated that conventional disinfection practices would do little to inactivate waterborne *Cryptosporidium* (references 28, 20). Another study showed a 40% (0.2-log) inactivation of *Cryptosporidium* at CT values of both 30 and 3,600 mg·min/L (references 29 and 5). A 1996 study showed no significant *Cryptosporidium* inactivation with free chlorine concentrations ranging from 5 to 80 mg/L at pH 8, a temperature of 22° C, and contact times of 48 to 245 minutes (references 30, 5). The study also reported that, at pH 6.0 and temperature of 22° C, a 1-log *Cryptosporidium* inactivation required a CT of between 3,000 and 4,000 mg·min/L, and a 3-log *Cryptosporidium* inactivation required exposure to 80 mg/L of free chlorine for 120 minutes (references 30 and 5). Therefore, IWPDs using only chlorine disinfection for treatment (i.e., without filtration) should not be relied upon for protection from *Cryptosporidium* contamination. The EPA has not adopted CT tables for *Cryptosporidium* in the proposed Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), choosing instead to concentrate on tighter source protection and more effective *Cryptosporidium* disinfectants, such as chlorine dioxide and ozone (reference 31).

### **CHLORINE TOXICITY**

When added to water, chlorine reacts with natural organic matter in water to form disinfection by-products. Ingestion of chlorine and its halogenated by-products, including THMs and HAAs, can result in adverse health effects when consumed in large enough quantities for long periods of time. The EPA regulates chlorine, total trihalomethane (TTHMs) and (the sum of) five HAAs (HAA5) in drinking water systems that use chlorine for disinfection. The EPA established a maximum residual disinfectant

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level (MRDL) of 4.0 mg/L for chlorine and maximum contaminant levels (MCLs) of 0.80 and 0.60 mg/L for TTHM and HAA5 compounds, respectively (reference 32). Potential health effects from ingestion of water containing free chlorine above 4.0 mg/L include eye, nose and throat irritation, stomach discomfort, nausea and vomiting. Evidence from animal and human studies suggests that chlorine and hypochlorite solutions themselves probably do not contribute to the development of cancer or any toxic effects (reference 33). Potential health effects from ingestion of water with elevated levels of TTHMs over a long period of time include liver, kidney or central nervous system problems, as well as the increased risk of cancer. Some studies also show an association between high levels of TTHMs and an increased risk of early term miscarriage (references 31 and 33). Potential health effects from ingestion of water with elevated levels of HAA5 compounds over a long period of time include the increased risk of cancer (reference 31). Generally, short-term exposure to elevated levels of THMs and HAAs for healthy adults does not result in adverse health effects (reference 34). For IWPD use, the risk of illness and death resulting from exposure to pathogens in drinking water is very much greater than the risks from chlorine and its DBPs (reference 34). However, manufacturer recommended chlorine dosages should be followed to minimize the potential for DBP formation and exposure. Toxicity studies of cyanuric acid, the stabilizing compound in isocyanurates, have shown no carcinogenic, mutagenic or teratogenic effects, even at levels considerably above those typically found in drinking water (reference 35).

## CONCLUSIONS

Chlorine as an IWPD is effective at inactivating bacteria and viruses, and under certain circumstances, *Giardia*. However, chlorine has little impact on *Cryptosporidium* oocysts at typical water treatment concentrations. Individual Water Purification Devices using only chlorine disinfection for treatment (i.e., without filtration) should not be relied upon for protection from *Cryptosporidium* contamination. Colder temperatures, higher pHs, and higher turbidities all tend to have an adverse effect on disinfection capability. Generally, short-term exposure to chlorine DBPs at IWPD manufacturer-recommended chlorine dosages of up to 5 mg/L should not result in adverse health effects. To avoid potential adverse health effects, longer contact times should be used in place of higher chlorine dosages, provided sufficient free available chlorine remains after oxidizing organic matter. Some chlorine-using IWPDs may use isocyanurates to prolong chlorine residual in the treated water. Toxicity studies involving isocyanurate compounds have not shown any adverse human health effects at typical drinking water concentrations. Table 2 provides a summary of the disinfection capabilities of chlorine.

**Table 2. Chlorine Disinfection Capabilities**

| Parameter                       | Chlorine Disinfection  |
|---------------------------------|--|
| General Disinfection Capability | Cysts most resistant. Achieving cyst inactivation will ensure adequate bacteria and virus inactivation. Disinfection capability generally follows:<br>Bacteria > Viruses > <i>Giardia</i> > <i>Cryptosporidium</i> |
| Bacteria                        | Effective at reasonable CT values for IWPD use.  |
| Viruses                         | Effective at reasonable CT values for IWPD use. Use EPA SWTR CT table for recommended CT values (Table 1).   |
| <i>Giardia</i> Cysts            | Effective at reasonable CT values for IWPD use. Use EPA SWTR CT tables for recommended CT values (Appendix B).   |
| <i>Cryptosporidium</i> Oocysts  | Ineffective, even at high CT values. Not practical for IWPD use.   |
| Effect of Temperature           | Colder water temperatures require higher CT values. Use a two-fold increase in CT for every 10°C decrease. Use longer contact time instead of higher dosages to achieve higher CT values.                          |
| Effect of pH                    | Disinfection efficiency increases with decreasing pH. Recommend pH less than 8.0 to ensure presence of hypochlorous acid (HOCl)  |
| Effect of Turbidity             | Higher turbidity generally reduces disinfection capability. Higher dosages may be necessary to ensure the presence of free chlorine after oxidation of organic matter.   |
| Health Effects                  | Chlorine, THMs and HAAs have potential health concerns at elevated levels. IWPD manufacturer-recommended dosages are not likely to cause adverse health effects for healthy adults.                                |

**PREPARED BY:** Brian C. Pickard, Environmental Engineer

**DATED:** March 2006

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**APPENDIX B**  
**CT VALUES FOR INACTIVATION OF**  
***GIARDIA* CYSTS BY FREE CHLORINE**

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**Table B-1. EPA SWTR Required CT Values for 3-Log Inactivation of *Giardia* By Free Chlorine at 0.5 degrees Celsius or Lower**

| pH    | Chlorine Concentration (mg/L) |     |     |     |     |     |     |     |     |     |     |     |     |     |
|-------|-------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|       | ≤ 0.4                         | 0.6 | 0.8 | 1   | 1.2 | 1.4 | 1.6 | 1.8 | 2   | 2.2 | 2.4 | 2.6 | 2.8 | 3   |
| ≤ 6   | 137                           | 141 | 145 | 148 | 152 | 155 | 157 | 162 | 165 | 169 | 172 | 175 | 178 | 181 |
| 6.5   | 163                           | 168 | 172 | 176 | 180 | 184 | 189 | 193 | 197 | 201 | 205 | 209 | 213 | 217 |
| 7.0   | 195                           | 200 | 205 | 210 | 215 | 221 | 226 | 231 | 236 | 242 | 247 | 252 | 257 | 261 |
| 7.5   | 237                           | 239 | 246 | 253 | 259 | 266 | 273 | 279 | 286 | 297 | 298 | 304 | 310 | 316 |
| 8.0   | 277                           | 286 | 295 | 304 | 313 | 321 | 329 | 338 | 346 | 353 | 361 | 368 | 375 | 382 |
| 8.5   | 329                           | 342 | 354 | 365 | 376 | 387 | 397 | 407 | 417 | 426 | 435 | 444 | 452 | 460 |
| ≤ 9.0 | 390                           | 407 | 422 | 437 | 451 | 464 | 477 | 489 | 500 | 511 | 522 | 533 | 543 | 552 |

**Table B-2. EPA SWTR Required CT Values for 3-Log Inactivation of *Giardia* By Free Chlorine at 5 degrees Celsius**

| pH    | Chlorine Concentration (mg/L) |     |     |     |     |     |     |     |     |     |     |     |     |     |
|-------|-------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|       | ≤ 0.4                         | 0.6 | 0.8 | 1   | 1.2 | 1.4 | 1.6 | 1.8 | 2   | 2.2 | 2.4 | 2.6 | 2.8 | 3   |
| ≤ 6   | 97                            | 100 | 103 | 105 | 107 | 109 | 111 | 114 | 116 | 118 | 120 | 122 | 124 | 126 |
| 6.5   | 117                           | 120 | 122 | 125 | 127 | 130 | 132 | 135 | 138 | 140 | 143 | 146 | 148 | 151 |
| 7.0   | 139                           | 143 | 146 | 149 | 152 | 155 | 158 | 162 | 165 | 169 | 172 | 175 | 178 | 182 |
| 7.5   | 166                           | 171 | 175 | 179 | 183 | 187 | 192 | 196 | 200 | 204 | 209 | 213 | 217 | 221 |
| 8.0   | 198                           | 204 | 210 | 216 | 221 | 227 | 232 | 238 | 243 | 248 | 253 | 258 | 263 | 268 |
| 8.5   | 236                           | 244 | 252 | 260 | 267 | 274 | 281 | 287 | 294 | 300 | 306 | 312 | 318 | 324 |
| ≤ 9.0 | 279                           | 291 | 301 | 312 | 320 | 329 | 337 | 345 | 353 | 361 | 368 | 375 | 382 | 389 |

**Table B-3. EPA SWTR Required CT Values for 3-Log Inactivation of *Giardia* By Free Chlorine at 10 degrees Celsius**

| pH    | Chlorine Concentration (mg/L) |     |     |     |     |     |     |     |     |     |     |     |     |     |
|-------|-------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|       | ≤ 0.4                         | 0.6 | 0.8 | 1   | 1.2 | 1.4 | 1.6 | 1.8 | 2   | 2.2 | 2.4 | 2.6 | 2.8 | 3   |
| ≤ 6   | 73                            | 75  | 78  | 79  | 80  | 82  | 83  | 86  | 87  | 89  | 90  | 92  | 93  | 95  |
| 6.5   | 88                            | 90  | 92  | 94  | 95  | 98  | 99  | 101 | 104 | 105 | 107 | 110 | 111 | 113 |
| 7.0   | 104                           | 107 | 110 | 112 | 114 | 116 | 119 | 122 | 124 | 127 | 129 | 131 | 134 | 137 |
| 7.5   | 125                           | 128 | 131 | 134 | 137 | 140 | 144 | 147 | 150 | 153 | 157 | 160 | 163 | 166 |
| 8.0   | 149                           | 153 | 158 | 162 | 166 | 170 | 174 | 179 | 182 | 186 | 190 | 194 | 197 | 201 |
| 8.5   | 177                           | 183 | 189 | 195 | 200 | 206 | 211 | 215 | 221 | 225 | 230 | 234 | 239 | 243 |
| ≤ 9.0 | 209                           | 218 | 226 | 234 | 240 | 247 | 253 | 259 | 265 | 271 | 276 | 281 | 287 | 292 |

**Table B-4. EPA SWTR Required CT Values for 3-Log Inactivation of *Giardia* By Free Chlorine at 15 degrees Celsius**

| pH    | Chlorine Concentration (mg/L) |     |     |     |     |     |     |     |     |     |     |     |     |     |
|-------|-------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|       | ≤ 0.4                         | 0.6 | 0.8 | 1   | 1.2 | 1.4 | 1.6 | 1.8 | 2   | 2.2 | 2.4 | 2.6 | 2.8 | 3   |
| ≤ 6   | 49                            | 50  | 52  | 53  | 54  | 55  | 56  | 57  | 58  | 59  | 60  | 61  | 62  | 63  |
| 6.5   | 59                            | 60  | 61  | 63  | 64  | 65  | 66  | 68  | 69  | 70  | 72  | 73  | 74  | 76  |
| 7.0   | 70                            | 72  | 73  | 75  | 76  | 78  | 79  | 81  | 83  | 85  | 86  | 88  | 89  | 91  |
| 7.5   | 83                            | 86  | 88  | 90  | 92  | 94  | 96  | 98  | 100 | 102 | 105 | 107 | 109 | 111 |
| 8.0   | 99                            | 102 | 105 | 108 | 111 | 114 | 116 | 119 | 122 | 124 | 127 | 129 | 132 | 134 |
| 8.5   | 118                           | 122 | 126 | 130 | 134 | 137 | 141 | 144 | 147 | 150 | 153 | 156 | 159 | 162 |
| ≤ 9.0 | 140                           | 146 | 151 | 156 | 160 | 165 | 169 | 173 | 177 | 181 | 184 | 188 | 191 | 195 |

**Table B-5. EPA SWTR Required CT Values for 3-Log Inactivation of *Giardia* By Free Chlorine at 20 degrees Celsius**

| pH    | Chlorine Concentration (mg/L) |     |     |     |     |     |     |     |     |     |     |     |     |     |
|-------|-------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|       | ≤ 0.4                         | 0.6 | 0.8 | 1   | 1.2 | 1.4 | 1.6 | 1.8 | 2   | 2.2 | 2.4 | 2.6 | 2.8 | 3   |
| ≤ 6   | 36                            | 38  | 39  | 39  | 40  | 41  | 42  | 43  | 44  | 44  | 45  | 46  | 47  | 47  |
| 6.5   | 44                            | 45  | 46  | 47  | 48  | 49  | 50  | 51  | 52  | 53  | 54  | 55  | 56  | 57  |
| 7.0   | 52                            | 54  | 55  | 56  | 57  | 58  | 59  | 61  | 62  | 63  | 65  | 66  | 67  | 68  |
| 7.5   | 62                            | 64  | 66  | 67  | 69  | 70  | 72  | 74  | 75  | 77  | 78  | 80  | 81  | 83  |
| 8.0   | 74                            | 77  | 79  | 81  | 83  | 85  | 87  | 89  | 91  | 93  | 95  | 97  | 99  | 101 |
| 8.5   | 89                            | 92  | 95  | 98  | 100 | 103 | 105 | 108 | 110 | 113 | 115 | 117 | 119 | 122 |
| ≤ 9.0 | 105                           | 109 | 113 | 117 | 120 | 123 | 126 | 129 | 132 | 135 | 138 | 141 | 143 | 146 |

**Table B-6. EPA SWTR Required CT Values for 3-Log Inactivation of *Giardia* By Free Chlorine at 25 degrees Celsius**

| pH  | Chlorine Concentration (mg/L) |     |     |    |     |     |     |     |    |     |     |     |     |    |
|-----|-------------------------------|-----|-----|----|-----|-----|-----|-----|----|-----|-----|-----|-----|----|
|     | ≤ 0.4                         | 0.6 | 0.8 | 1  | 1.2 | 1.4 | 1.6 | 1.8 | 2  | 2.2 | 2.4 | 2.6 | 2.8 | 3  |
| ≤ 6 | 24                            | 25  | 26  | 26 | 27  | 27  | 28  | 29  | 29 | 30  | 30  | 31  | 31  | 32 |
| 6.5 | 29                            | 30  | 31  | 31 | 32  | 33  | 33  | 34  | 35 | 35  | 36  | 37  | 37  | 38 |
| 7.0 | 35                            | 36  | 37  | 37 | 38  | 39  | 40  | 41  | 41 | 42  | 43  | 44  | 45  | 46 |
| 7.5 | 42                            | 43  | 44  | 45 | 46  | 47  | 48  | 49  | 50 | 51  | 52  | 53  | 54  | 55 |
| 8.0 | 50                            | 51  | 53  | 54 | 55  | 57  | 58  | 60  | 61 | 62  | 63  | 65  | 66  | 67 |
| 8.5 | 59                            | 61  | 63  | 65 | 67  | 69  | 70  | 72  | 74 | 75  | 77  | 78  | 80  | 81 |
| 9.0 | 70                            | 73  | 75  | 78 | 80  | 82  | 84  | 86  | 88 | 90  | 92  | 94  | 96  | 97 |

**ANNEX E TO APPENDIX G**

**ELECTROCHEMICALLY GENERATED OXIDANT DISINFECTION  
IN THE USE OF INDIVIDUAL WATER PURIFICATION DEVICES**

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## Electrochemically Generated Oxidant Disinfection in the Use of Individual Water Purification Devices

### Technical Information Paper #31-003-0306

#### PURPOSE

This information paper provides an in-depth review of on-site electrochemically generated oxidants (EGO) as a disinfectant in potable water supplies. This paper is intended to assist the reader in evaluating the disinfection capabilities of Individual Water Purification Devices (IWPDs) using EGO to kill or inactivate disease-causing bacteria, viruses, and protozoan cysts.

#### REFERENCES

Appendix A contains a list of references.

#### INTRODUCTION

##### Background

Understanding the disinfection capabilities of EGO to kill or inactivate disease-causing microorganisms is important in protecting Soldiers, who are considering using this technology, from acute health threats posed by these microorganisms. Soldiers deployed beyond traditional field drinking water supplies must have access to microbiologically safe water. Using IWPDs is one way to provide microbiologically safe water in these situations. These IWPDs must protect the Soldier from acute microbial health threats. The U.S. Environmental Protection Agency (EPA) Guide Standard and Protocol for Testing Microbiological Water Purifiers (reference 1) provides performance standards by which an IWPD using EGO can be evaluated. The performance standards are a minimum 6-log reduction/inactivation of bacteria, 4-log reduction/inactivation of viruses, and 3-log reduction/inactivation of protozoan cysts (typically *Giardia* or *Cryptosporidium*). EGO-using IWPDs meeting these standards are considered effective against disease causing bacteria, viruses, and protozoan cysts. Some IWPD manufacturers test their devices using this protocol. This is the best way to evaluate the IWPDs disinfection capabilities. In the absence of that testing data, this information paper can be used to gain an understanding of EGO disinfection capabilities and help determine if an IWPD using EGO technology could successfully meet the EPA Guide's minimum performance standards.

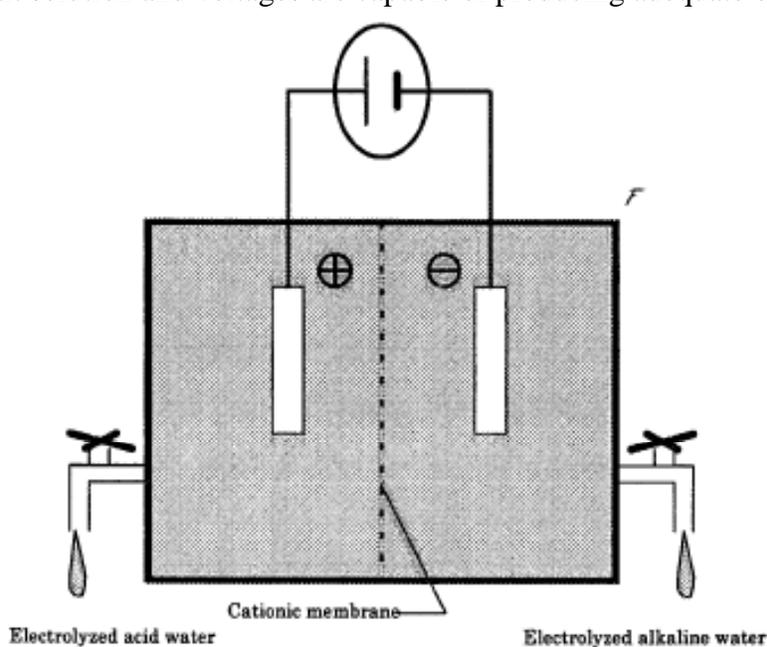
##### General

Electrochemically generated oxidant technology is well established. The technology dates back to the 1930's when it was primarily used for the disinfection of swimming pools (reference 2). Additionally, it is also extensively used in the wastewater and drinking water industries and has more recently been utilized in the food and agricultural industry (reference 3). Currently, there is only one Commercial-Off-The-Shelf (COTS) IWPD product using EGO technology.

## ELECTROCHEMICALLY GENERATED OXIDANT CHEMISTRY

### Electrochemically Generated Oxidant Production

In the simplest sense, EGO is formed by passing an electric current through a brine (NaCl) solution to produce oxidants to be used for disinfection. A reaction cell (also called an electrolytic cell) is where oxidant production occurs. In this cell, filled with a brine solution, are two electrodes (an anode and a cathode). When a voltage is applied between the electrodes, oxidant is produced. There are two basic types of EGO generators (reference 4). The most frequently employed is a two-cell EGO generator in which the anode and cathode are separated by a cationic membrane. A schematic of a two-cell EGO generator is shown in Figure 1. This type of EGO generator produces two solutions, one a low pH, high oxidant concentration solution from the cell containing the anode and a high pH, low oxidant solution from the cell containing the cathode. The second type of EGO generator contains both the anode and cathode in a single reaction cell without a cationic membrane. The current COTS IWPD device uses the single cell EGO generator technology. The oxidant concentration is a function of the voltage applied between the electrodes and the salt (brine) concentration and quality. Higher currents and voltage will produce a stronger oxidant solution and food grade salt is preferred to optimize oxidant generation (references 2 and 5). There are several different EGO generator manufacturers and their reaction cells and operation requirements all differ. However, in general a wide range of salt solution and voltages are capable of producing adequate oxidants.



**Figure 1. Schematic of a Two-Cell EGO Generator.**

Source: Reference 4.

### **Oxidant Composition**

The primary oxidant formed using EGO technology is chlorine in the form of hypochlorous acid, HOCl. It has been suggested that oxidants other than chlorine are produced by this technology such as ozone, chlorine dioxide, hydrogen peroxide, and hydroxyl radicals (reference 6). However, it has been clearly demonstrated in several studies that chlorine is the primary oxidant produced and other oxidants have not been measured at detectable levels (references 7-9).

## **DISINFECTION CAPABILITIES**

### **General**

Because the primary oxidant formed is chlorine, disinfection capabilities are similar, if not identical, to traditional chlorine solutions (i.e., solutions made from sodium hypochlorite, calcium hypochlorite, and chlorine gas). In the majority of research conducted on EGO disinfection effectiveness, the impacts of pH, turbidity, and temperature on disinfection effectiveness are similar to chlorine solutions. The disinfection capabilities of chlorine and the environmental effects on chlorine are well documented in the U.S. Army Center for Health Promotion and Preventive Medicine's (USACHPPM) Chlorine Disinfection Technical Information Paper and are summarized in Table 1 (reference 10). Because chlorine is the primary oxidant produced in EGO technology, this reference will provide the reader with a general understanding of the disinfection effectiveness of the EGO solutions. However, there are also studies suggesting that EGO technology produces a more effective disinfectant than typical chlorine solutions under the same conditions. The following discussion provides information from studies indicating EGO is more effective than typical chlorine solutions.

#### *Disinfection Effectiveness Compared to Chlorine Solutions*

Several studies were conducted comparing the disinfection effectiveness of EGO solutions to typical chlorine solutions. Results were variable. In all cases EGO solutions were as effective or more effective than a chlorine solution as a biocide. One study showed a sodium hypochlorite solution was less effective than EGO when tested at the same chlorine concentration and water quality characteristics (reference 12). This study showed that a sodium hypochlorite solution needed 2-3 times greater CTs (disinfectant concentration times contact time) to achieve the same log inactivations as an EGO solution for various bacteria. The CT is the product of disinfectant concentration (C in mg/L) and contact time (T in min). The CT product is a useful way for comparing alternative disinfectants and the resistance of various pathogens (reference 21). Another study showed an EGO solution provided a 3-log *Cryptosporidium* reduction with CTs of 75 mg-min/L, while a chlorine solution under the same conditions showed no *Cryptosporidium* reduction with a CT of 225 mg-min/L (reference 13). In contrast, other studies showed EGO

solutions to be similar in disinfection effectiveness as chlorine. One study showed that chlorine solutions matched to the properties of EGO solutions were generally as effective as the EGO

**Table 1. Chlorine Disinfection Capabilities (reference 10)**

| Parameter                       | Chlorine Disinfection  |
|---------------------------------|--|
| General Disinfection Capability | Cysts most resistant. Achieving cyst inactivation will ensure adequate bacteria and virus inactivation. Disinfection capability generally follows:<br><i>Bacteria &gt; Viruses &gt; Giardia &gt; Cryptosporidium</i> |
| Bacteria                        | Effective at reasonable CT values for IWPD use.  |
| Viruses                         | Effective at reasonable CT values for IWPD use. Use EPA SWTR CT table for recommended CT values (reference 11).  |
| <i>Giardia</i> Cysts            | Effective at reasonable CT values for IWPD use. Use EPA SWTR CT tables for recommended CT values (reference 11).   |
| <i>Cryptosporidium</i> Oocysts  | Ineffective, even at high CT values. Not practical for IWPD use.   |
| Effect of Temperature           | Colder water temperatures require higher CT values. Use a two-fold increase in CT for every 10° C decrease. Use longer contact time instead of higher dosages to achieve higher CT values.                           |
| Effect of pH                    | Disinfection efficiency increases with decreasing pH. Recommend pH less than 8.0 to ensure presence of hypochlorous acid (HOCl)  |
| Effect of Turbidity             | Higher turbidity generally reduces disinfection capability. Higher dosages may be necessary to ensure the presence of free chlorine after oxidation of organic matter.   |
| Health Effects                  | Chlorine, THMs and HAAs have potential health concerns at elevated levels. IWPD manufacturer-recommended dosages are not likely to cause adverse health effects for healthy adults.                                  |

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solutions in inactivating various pathogenic bacteria (reference 14). Another study showed similar inactivation results of pathogenic bacteria between chlorine solutions and EGO solutions (reference 15). There is also contrasting research between the EGO solutions. In disinfection studies, the general assumption is that greater CTs result in greater disinfection efficacy (i.e., greater log inactivation). However, available research shows EGO solutions with lower chlorine concentrations (i.e., lower CTs) have resulted in greater log inactivations than EGO solutions with higher chlorine concentrations (i.e., higher CTs) (references 12 and 13). Available research indicates variability in effectiveness of EGO solutions compared to chlorine solutions as well as variability in the effectiveness of similar EGO solutions. Therefore, it is difficult to predict the disinfection effectiveness of EGO solutions.

#### *Cryptosporidium Oocyst Disinfection*

Some manufacturers and vendors market EGO technology's ability to inactivate *Cryptosporidium* as a significant advantage over using typical chlorine solutions. It is well established that chlorine, as it is used in drinking water treatment, is not effective at inactivating *Cryptosporidium* oocysts (reference 10). As previously discussed, some research has shown that EGO technology can inactivate *Cryptosporidium* oocysts more effectively (i.e., at lower CTs) than chlorine solutions. However, due to contrasting research, the variable and unpredictable disinfection effectiveness of EGO technology suggests that EGO technology should not be relied upon to consistently provide adequate *Cryptosporidium* inactivation. Using EGO technology as an IWPD should be considered to be as effective as chlorine and, therefore, can be effective against bacteria, viruses, and *Giardia* cysts. Based on available research, EGO technology has the potential to be effective against *Cryptosporidium* oocysts, but because of the disinfection variability shown by the research, EGO technology should not be considered consistently effective against *Cryptosporidium*.

#### *Explanation for Variable Disinfection Effectiveness*

Currently, there are no proven explanations for the variable and unpredictable disinfection effectiveness of EGO technology. The most common hypothesis by authors of studies showing EGO technology's variability and unpredictability is that oxidants other than chlorine (e.g., ozone, chlorine dioxide, etc.) are generated at variable concentrations and are short-lived (references 12, 13, and 16). However, it has been thoroughly demonstrated in other studies that there is no appreciable formation of oxidants other than chlorine (references 7-9).

#### **EGO SOLUTION TOXICITY**

Because the primary oxidant generated by EGO technology is chlorine, toxicity concerns are similar to those for typical chlorine solutions. When added to water, the chlorine in the EGO solution reacts with natural organic matter to primarily form trihalomethane (THM) and

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haloacetic acid (HAA) disinfection by-products (DBPs). Ingestion of chlorine and its halogenated by-products, including THMs and HAAs, can result in adverse health effects when consumed in large enough quantities for long periods of time. The EPA regulates chlorine, total trihalomethanes (TTHMs) and (the sum of) five HAAs (HAA5) in drinking water systems that use chlorine for disinfection. The EPA established a maximum residual disinfectant level of 4.0 mg/L for chlorine and maximum contaminant levels of 0.80 and 0.60 mg/L for TTHM and HAA5 compounds, respectively (reference 17). Potential health effects from ingestion of water containing free chlorine above 4.0 mg/L include eye, nose and throat irritation, stomach discomfort, nausea and vomiting. Evidence from animal and human studies suggests that chlorine and hypochlorite solutions themselves probably do not contribute to the development of cancer or any toxic effects (reference 18). Potential health effects from ingestion of water with elevated levels of TTHMs over a long period of time include liver, kidney or central nervous system problems, as well as the increased risk of cancer. Some studies also show an association between high levels of TTHMs and an increased risk of early term miscarriage (references 17-19). Potential health effects from ingestion of water with elevated levels of HAA5 compounds over a long period of time include the increased risk of cancer (reference 19). Generally, short term exposure to elevated levels THMs and HAAs for healthy adults does not result in adverse health effects (reference 20). For IWPD use, the risk of illness and death resulting from exposure to pathogens in drinking water is very much greater than the risks from chlorine and its DBPs (reference 20). However, manufacturer recommended EGO dosages should be followed to minimize the potential for DBP formation and exposure.

## CONCLUSIONS

The use of EGO technology results in the production of primarily a chlorine disinfectant. For this reason an EGO solution, in general, has the same disinfection effectiveness and experiences the same impact of environmental effects on disinfection effectiveness as typical chlorine solutions. Research shows the disinfection effectiveness of EGO solutions to be variable and unpredictable. In general, the disinfection effectiveness of EGO solutions is as effective, or can be more effective, than typical chlorine solutions. Using EGO technology as an IWPD should be considered to be as effective as chlorine and, therefore, can be effective against bacteria, viruses, and *Giardia* cysts. Based on available research EGO technology has the potential to be effective against *Cryptosporidium* oocysts, but because of the disinfection variability shown by the research, EGO technology should not be considered consistently effective against *Cryptosporidium*. Generally, short term exposure to elevated levels of THMs and HAAs for healthy adults does not result in adverse health effects. For IWPD use, the risk of illness and death resulting from exposure to pathogens in drinking water is very much greater than the risks from exposure to chlorine and its DBPs. However, manufacturer recommended EGO dosages should be followed to minimize the potential for DBP formation and exposure. Table 2 provides a summary of the disinfection capabilities of EGO Solutions.

**Table 2. Summary of Disinfection Capabilities of EGO Solutions.**

| Parameter                      | EGO Solutions   |
|--------------------------------|---|
| General                        | As effective or can be more effective than chlorine. Disinfection capability generally follows:<br><i>Bacteria &gt; Viruses &gt; Giardia &gt; Cryptosporidium</i> |
| Bacteria                       | Effective   |
| Viruses                        | Effective   |
| <i>Giardia</i> Cysts           | Like chlorine, consider providing additional contact time beyond IWRP manufacturer recommended CTs.   |
| <i>Cryptosporidium</i> Oocysts | Effectiveness is variable and unpredictable. Considered not consistently effective...   |
| Effect of Temperature          | Like chlorine, colder temperatures can reduce effectiveness. Higher CTs will ensure for colder temperatures increases effectiveness.                              |
| Effect of pH                   | Like chlorine, higher pH decreases effectiveness. pH less than 8.0 ensures presence of the most effective chlorine species, hypochlorous acid (HOCl).             |
| Effect of Turbidity            | Like chlorine, higher turbidity reduces effectiveness. Higher dosages may be necessary to ensure effectiveness.   |

**PREPARED BY:** Steven H. Clarke, Environmental Engineer

**DATED:** March 2006

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**ANNEX F TO APPENDIX G**  
**FILTRATION IN THE USE OF**  
**INDIVIDUAL WATER PURIFICATION DEVICES**

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## Filtration in the Use of Individual Water Purification Devices

Technical Information Paper #31-004-0306

### PURPOSE

This information paper provides an in-depth review of filtration (including adsorption and ion exchange) as a pathogen and particulate reduction mechanism when treating natural waters. This paper is intended to assist the reader in evaluating the capabilities of Individual Water Purification Devices (IWPDs) using size exclusion, adsorption, and/or ion exchange to reduce disease-causing bacteria, virus, and protozoan cyst populations, as well as turbidity causing particulate matter.

### REFERENCES

Appendix A contains a list of references.

### INTRODUCTION

#### Background

Understanding the ability of filtration to reduce disease-causing microorganisms is important in protecting Soldiers, who are considering using this technology, from acute health threats posed by these microorganisms. Soldiers deployed beyond traditional field drinking water supplies must have access to potable water. Using IWPDs is one way to provide microbiologically safe water in these situations. These IWPDs must protect the Soldier from acute microbial health threats. The U.S. Environmental Protection Agency (EPA) Guide Standard and Protocol for Testing Microbiological Water Purifiers (reference 1) provides performance standards by which an IWPD using filtration can be evaluated. The performance standards are a minimum 6-log reduction/inactivation of bacteria, 4-log reduction/inactivation of viruses, and 3-log reduction/inactivation of protozoan cysts (typically *Giardia* or *Cryptosporidium*). IWPDs meeting these standards are considered effective at reducing disease causing bacteria, viruses, and protozoan cysts. Some IWPD manufacturers test their devices using this protocol. This is considered the best way to evaluate the IWPDs pathogen reduction capabilities. In the absence of that testing data, this information paper can be used to gain an understanding of the advantages as well as limitations of filtration and help determine if an IWPD using filtration could successfully meet the EPA Guide's minimum performance standards.

### **Origin of Filtration for Water Treatment**

For the purpose of this paper, filtration will be used broadly to incorporate separation by (1) granular media, (2) size exclusion (e.g., membranes), (3) electrochemical adsorption (e.g., activated carbon), and (4) ion exchange (e.g., anion, cation exchange). Filtration is a well-studied process for drinking water treatment. Naturally, as groundwater migrates in the subsurface, contaminants are removed from the water due to ionic attraction as well as sieving based on size. Concurrently, contaminants such as iron and manganese may be dissolved into the groundwater and often remain in the dissolved form until pumped to the surface. Similarly, microorganisms are imparted to and extracted from the groundwater during subsurface movement. Surface water (e.g., ponds, lakes, rivers), like groundwater, has ever-changing quality with respect to microorganisms, particulates, chemistry, etc., but is more exposed to human activity, often degrading water quality. To reduce water contaminants and create potable water safe for human consumption, water treatment has included filtration to mimic and better the natural removal of water contaminants. Filtration for water treatment dates back to 2000 b.c.e., where crude sand and charcoal filters were used to provide better tasting water (reference 2). Centuries later Hippocrates designed a cloth bag known as the Hippocrates Sleeve, used to remove sediments from water after boiling. By the end of the Middle Ages water quality began to be linked with disease. In the mid 19<sup>th</sup> century the spread of Cholera was noticeably decreased where sand filtration was utilized (reference 2). The benefits of water filtration for not only increasing water aesthetics, but decreasing the spread of disease, lead to the widespread use of filtration seen today when purifying water for potable use.

### **Current Use of Filtration for Water Treatment**

The original slow sand filtration developed centuries ago has now been replaced with rapid sand filtration using multi-media beds, adsorption, utilizing electrochemical forces to attract contaminants to the media surface, natural and synthetic membranes engineered with distinct pore sizes, and ion exchange, where one ion is removed from the water and replaced with a less offensive ion. Current U.S. Army field water treatment includes several filtration devices such as the Reverse Osmosis Water Purification Unit, Tactical Water Purification System, and Lightweight Water Purifier, designed for large volume water purification. An industry challenge has been to reduce the size of full-scale filtration processes down to individual units, while maintaining treatment efficacy against pathogens and particulate matter, but without excessive maintenance. To date, there have been no IWPDs fielded to the Soldier that have used filtration as the primary mechanism of water purification. Currently fielded emergency drinking water products include an iodine-based disinfection tablet (Globaline™) and a flocculant-chlorine

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™ Globaline is a trademark of Wisconsin Pharmacal Company, Jackson, WI.

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disinfectant based product (Chlor-Floc™). Today, there are several Commercial-Off-The-Shelf (COTS) IWPDs that use filtration as the primary pathogen reduction mechanism.

## **SEPARATION MECHANISMS**

The mechanisms of separation during filtration vary depending on material and design. Overall, several mechanisms may be simultaneously rejecting contaminants. For example, during filtration primarily incorporating size exclusion, adsorption and depth filtration mechanisms are likely aiding in particle retention.

### **Straining**

Straining entails the removal of particles by size exclusion when particles are larger than the void spaces in the filter. Straining is a removal mechanism for virtually all filtration technologies with the importance of this mechanism related to raw water quality and size of particulate matter in reference to pore size.

#### *Straining by Granular Media*

For spherical granular media, close-packed arrangement will remove particles when the ratio of particle diameter to grain diameter is greater than 0.15 (reference 3). For typical slow sand filters, this equates to the removal of particles down to about 15 µm, increasing to 30-80 µm for rapid sand filtration. It should be noted that other mechanisms aid in the removal of smaller particles for these filtration techniques. Specifically, for slow sand filtration a thin slimy layer of particulate sludge forms, termed smutzdecke, effective in trapping particulates and microorganisms at the surface. When particulates form a layer during granular media filtration it may also be termed a cake. Cake filtration is often used to describe straining out particles, often smaller than the media pore size, by this top layer, or build-up, when evaluating granular carbon filtration.

#### *Straining by Membrane Filtration*

Porous membranes contain varying size pores and are rated by their pore size based on nominal, average, and absolute size. Absolute pore size is the size of the largest particle (e.g., glass bead) that will pass through a membrane under specific testing conditions. For membranes with uniform cylindrical pores this rating has meaning, but only under the low pressure conditions tested during pore size determination. Membranes with cylindrical pore structures are called

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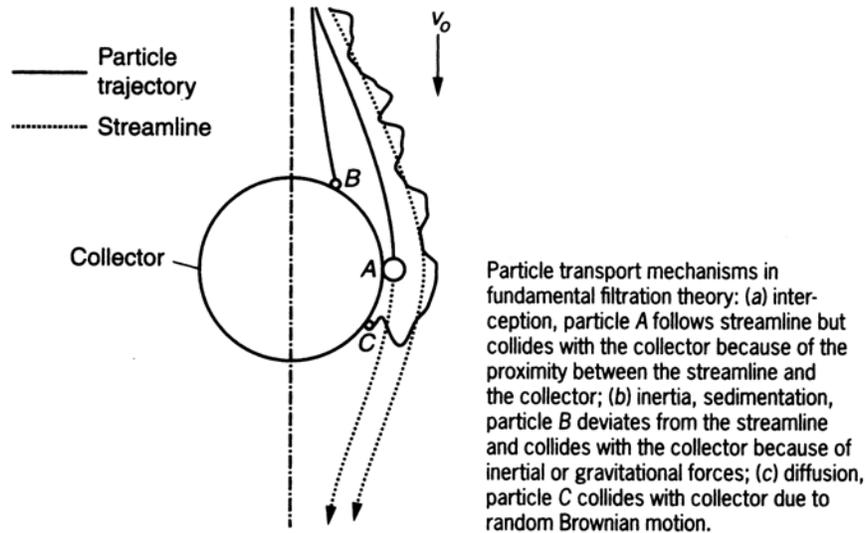
™ Chlor-Floc is a trademark of Control Chemical, D/B/A Deatrick and Associates Inc., Alexandria, VA. Use of trademarked products does not imply endorsement by the U.S. Army, but is intended only in identification of a specific product.

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capillary-pore membranes. Conversely, some membranes are manufactured to create a tortuous path (sponge-like appearance, termed tortuous-pore membranes) where pores of varying size create a path by which depth filtration mechanisms arise as well as size exclusion. In this case, the term absolute pore size has little meaning, and nominal ratings are used. Nominal pore ratings specify the percentage of particles removed of a certain size particle, again usually tested with glass beads (e.g., 80% of 1  $\mu\text{m}$  particles retained). Lastly, membrane pore size can be rated as the average size of all pores. Different pore size testing techniques, as well as varying definitions, create a questionable pore rating system unless proper information on the membrane is noted. For example, it has been noted that certain manufacturers state absolute pore sizes when a membrane can remove 85% of a certain size particle, contrasting the historical definition of an absolute pore rating. Caution, therefore, must be used when evaluating membrane efficacy based solely on stated pore size.

### **Depth Filtration Theory**

Particle removal and retention within depth filters involves Van der Waals forces where two surfaces have attractive forces, in this case between the particle and the media surface. Van der Waals forces are short-ranged, and only become effective when the two surfaces are in close proximity. For particle-media surfaces to come close enough together for these forces to become effective, transport mechanisms must be present. These mechanisms are represented by three different processes, which include interception, inertia and sedimentation, and diffusion. These processes are attributed with most particle removal. As a particle is transported through a filter, if the streamline is within one half or less of the diameter of the particle from the media surface, the particle will be intercepted. Second, as streamlines curve around the media, particles can deviate from the streamline and continue towards the media due to inertia forces. Particles may also deviate from streamlines due to gravitational forces and settle onto the media surface. In both cases, particle will be retained at the media surface. Lastly, particles may deviate from streamlines due to Brownian motion and diffuse to the media surface. The following diagram, Figure 1 (borrowed from reference 3), illustrates the different filtration mechanisms described. Depth filtration is not limited to granular media, but can be applied to microfilters, membranes and carbon filtration as well.



**Figure 1. Filtration Mechanisms.**

Diagram borrowed from reference 3.

### Rejection by Osmotic Membranes

Two solutions in contact with one another with varying solute concentrations naturally try to equilibrate. In water treatment we can use this driving force to equilibrate, by placing a semi-permeable membrane between the two solutions. By engineering the membrane to allow passage of the water molecules through the membrane, yet reject the solutes, the two solutions will naturally equilibrate as the water dilutes the more concentrated side. Flux through the membrane will vary based on solute gradient, temperature, and membrane properties. Common practice in water treatment is to reverse the natural osmotic tendency by pressurizing the influent side, forcing water molecules through the membrane and rejecting the solutes, termed reverse osmosis (RO). Despite use in water treatment for many years, the exact mechanism of water transport and solute rejection is still debated. The underlying question is whether these membranes are non-porous and diffusion driven, or whether they contain very small pores for preferential (size exclusion) convective transport of the solvent. There are several theories, or models, on the rejection mechanisms of osmotic membranes of which three are most commonly accepted.

#### *Solution-Diffusion Model*

The solution-diffusion model describes permeation through a dense membrane that is permeable but non-porous. Water and solutes dissolve into the membrane, diffuse through the solid material, and re-liquefy on the permeate side. In this model, separation occurs due to the different flux of solutes.

### *Pore Flow Model*

This model considers convective flow through a porous membrane. Water and solute flux is coupled with separation occurring due to sieving. Since many solutes, namely salt, are similar in size to water molecules, physical sieving would not be efficient. An apparent limitation of this model is the small pore size required, less than 0.1 nm, for separation to occur.

### *Preferential Sorption-Capillary Flow Model*

This model describes a porous membrane where water is preferentially sorbed to the surface and transported through the membrane due to concentration gradient. Membranes with low dielectric constants prefer water molecules, creating a layer of low solute concentration, in essence blocking the solutes from contact with the membrane surface and therefore preventing passage. Osmotic potential, to pull water across a membrane from a less to more solute concentrated side, has also been applied to IWPDs in a passive form. By using a non-offensive solute on the membrane product side, water will naturally pass across the membrane to the higher solute concentration. Sometimes termed forward osmosis, this process, simply termed osmosis (O) for this paper, utilizes the same pathogen reduction mechanisms as that of conventional RO.

### **Adsorption**

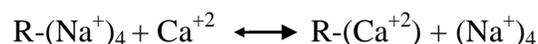
Adsorption is a mass transfer operation in which contaminants present in a liquid phase are accumulated on a solid phase, thereby being removed from the liquid. The constituent being adsorbed is referred to as the adsorbate and the solid onto which the constituent adsorbs is the adsorbent. The degree of adsorption is affected by attraction of the three following interfaces: adsorbate/adsorbent, adsorbate/water, water/adsorbent. The strength of the adsorbate/adsorbent interface as compared to the others will determine adsorption efficacy. Dissolved species are concentrated onto the surface by physical attraction or chemical reaction. Physical adsorption is by nonspecific binding mechanisms such as Van der Waals forces. This binding is reversible, where adsorbates may desorb in response to a decrease in solution concentration. Chemisorption entails specific attraction where chemical binding transfers electrons between the adsorbent and adsorbate. Physical adsorption has weaker forces and bonding energies, operates over longer distances, and is more reversible than chemical adsorption. Chemical adsorbates, which can only form a layer one molecule thick due to specific bonding, may have several different attractive forces. Polar compounds having a slightly positive and negative end and molecules orient themselves to lower their combined free energy, creating a dipole attraction. The negative end attracts the positive end of another molecule forming a dipole-dipole bond. More important to water treatment is the dipole-dipole bond with water, termed hydrogen bonding. These bonds are very strong and are responsible for water being a liquid at room temperature. Hydrogen bonding between the water molecule and adsorbate competes with adsorbate/adsorbent

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attraction. By maximizing physical attraction, covalent bonding and Coulombic forces, all of which are not involved in adsorbate/water, water/adsorbent interaction, we can increase adsorption efficacy. Water pH, molecule size, and adsorbate solubility all play roles in adsorption and affect species (polar, neutral, ionic) differently. Since adsorption is not a primary mechanism for pathogen reduction these interactions will not be further discussed but can be found elsewhere (references 3-5). During the adsorption process, dissolved species are transported into the porous structure of the adsorbent material by diffusion, then adsorbed onto the interior surface of the grain. Porous adsorbent materials have very large internal surface areas (400 – 1500 m<sup>2</sup>/g), and pore volume (0.1 – 0.8 mL/g) (reference 3) creating many sites for adsorption to occur. Three commonly used commercial adsorbents include zeolites (aluminosilicates), synthetic polymeric adsorbents, and activated carbon. A notable affect on adsorption with the most common adsorbent, activated carbon, is water pH. In order for electrostatic interactions to contribute to removal by adsorption, particle-media charges must attract the particle to the media surface. Since most particles in natural waters possess a negative charge, media should possess a positive charge. As pH increases, activated carbon becomes less positive until a point of zero charge (PZC) is reached (reference 4). At a pH above this point, electrostatic interactions repel particles from the surface, inhibiting adsorption. Depending on the carbon used the PZC may range from a pH of less than 4 up to greater than 10 (reference 4).

### Ion Exchange

Ion exchange for drinking water is a process in which ions within the water stream are adsorbed to the surface of resins and exchanged for a less offensive ion that is then imparted into the finished water. A generic representation of softening using a sodium resin is shown below, with R representing the exchange resin.



Similar to adsorption, ion exchange is powered by electrostatic/electrochemical attraction in which ions of opposite charge attract, however, with ion exchange, the presaturant ions on the resin are released into the water. For ion exchange to occur, the presaturant ions cannot be present in the bulk fluid. Natural tendency to equilibrate will favor ions both in the bulk fluid as well as on the resin surface, therefore equilibrium will occur if given enough time (reference 6). Resin beads are usually 0.04 to 1.0 mm in diameter and made by materials such as polystyrene divinylbenzene. Favorable ion exchange resins are reversible, and once all exchange sites are exhausted they can be restored through regeneration, although eventually irreversible fouling will occur. Regeneration usually consists of several bed volumes of highly concentrated regenerant followed by rinse water. To date, the most common use of ion exchange has been for softening, although heavy metal reduction and resins designed for specific ion reduction are also becoming more commonplace. There are four common ion exchange resins, classified as either strong-acid cation, weak-acid cation, strong-base anion, or weak-base anion. The cation

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exchange resins are negatively charged resins often used for calcium and magnesium removal, while the less common anion resins are positively charged for the removal of nitrate and other anions. Both strong-acid and strong-base resins are effective throughout all pH ranges, with the weak-acid and base resins effective only within narrow alkaline and acidic pH regions, respectively. The preference of the ion exchange resin to attract one ion over another is termed its selectivity sequence. Ions are ranked based on separation factors, or the ratio of the affinity of the resin to favor the ion compared to the presaturant ions already attached to the resin. In general, with dilute solutions, ion exchange resins prefer ions with the highest charge and lowest degree of hydration. If both anion and cation removal is required, different resins can be run in series or mixed bed resin columns can be used to produce deionized water. In this case, strong-acid resin of the  $H^+$  form and strong-base resin of the  $OH^-$  form are mixed with the resultant presaturant ions released forming water. In this case no ions are imparted to the finished water. A major drawback of mixed bed resins is that the resin must be separated before regeneration can occur. Since IWPDs are not designed to be regenerated, these drawbacks are not applicable.

## **ROLE OF PATHOGEN IN FILTRATION SEPARATION MECHANISMS**

The primary difference between pathogens for reduction during filtration is size. Approximate sizes are as follow: viruses 0.005 – 0.3  $\mu m$ , bacteria 0.1 -10  $\mu m$ , *Cryptosporidium* oocysts 4 – 6  $\mu m$ , *Giardia* cysts 8 – 12  $\mu m$ . Common filters used in IWPDs have pore sizes between 0.2 and 2  $\mu m$ , although some exist outside of this range. Primary reduction mechanisms for each pathogen vary with purification technology, with generalizations based on pathogen morphology as follows. (1) Based on size exclusion alone, filter retention of *Cryptosporidium* oocysts and *Giardia* cysts is likely for properly functioning devices. It is generally assumed that if a filter can reduce *Cryptosporidium* oocysts then *Giardia* cyst reduction is likely (reference 7). Utilizing filters where the primary means of reduction is by size exclusion, latex microspheres have been used as surrogates, demonstrating the lack of importance of other mechanisms for cyst reduction (references 1, 8). (2) Bacterial reduction by filters is based on adsorption as well as size exclusion (reference 9). Reduction by microporous media with pore sizes of 0.45  $\mu m$  or less will likely provide adequate bacterial reduction based on size exclusion alone. Clean bed filtration, utilizing larger pore sizes will likely not meet the bacterial reduction requirements of references 1 and 10. (3) Due to the extremely small size of viruses, reduction by size exclusion to the levels required in references 1 and 10 is unlikely, unless utilizing very tight membranes such as for osmosis. Extensive literature exists demonstrating viral adsorption onto microporous filters as well as how water quality affects viral reduction (references 9 and 11-24). Particles immersed in aqueous solutions, including viruses, develop a surface charge by adsorbing ions on its surface (reference 11). The charge of viruses has been shown to play a significant role in adsorption onto surfaces and this charge changes with pH. Similar to the ZPC of activated carbon, the pH at which viruses have no net charge is called the isoelectric point (pI). Below this pH, viruses are positively charged, and above this point they are negatively charged. Coupling filters that are positively charged at a pH where the viruses are negatively charged, with the

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difference in charge minimized (e.g., near both pI) promotes the most efficient adsorption (reference 12). From this, it is apparent that no single combination of adsorbent/adsorption conditions exists to give optimum reduction of all viruses for all water qualities (reference 12). Increasing electrostatic and or hydrophobic interactions by the addition of chemicals such as magnesium sulfate (reference 13) or by specially treating the filter to promote a positive charge at natural water pH will increase virus retention (references 14-17). One study investigating coliphage reduction by a 0.2  $\mu\text{m}$  microporous filter, showed reduction based on adsorption as well as size exclusion (reference 9). Initial retention on clean bed filters was based on inertial impaction due to adsorptive forces, resulting in low to moderate reduction and highly affected by flow rates, water quality, and membrane material. As cake formed on the surface the primary reduction mechanism changed to direct interception at the surface due to reduction in pore size (reference 9). Reduction efficacy was less affected by water quality but still showed some susceptibility to changes in flow rate. Virus reduction by adsorption or size exclusion on capillary formed membranes is unlikely to consistently meet the requirements of reference 1.

## **IWPDs USING MEMBRANE FILTRATION**

### **Membrane Filtration**

A membrane is a thin layer of semi-permeable material that is capable of separating materials when a driving force is applied across the surface. This separation into two phases (concentrations) creates a chemical potential between the two sides of the membrane that is based on the physical and chemical properties of the materials being separated. Membranes are not considered to be passive materials but are termed functional materials whose performance characteristics are based on the nature of the elements to be separated and the driving force. Membranes are classified based on the size or molecular weight cutoff (MWCO) of the solutes they are capable of rejecting. Membranes used in water treatment, in order of decreasing pore size/MWCO, are microfilters, ultrafilters, nanofilters, and osmotic membranes. In addition to the pore size, membranes are also classified based on their structure, either symmetric or asymmetric. Symmetric membranes contain consistent pores, porosity, and transport properties. Asymmetric membranes contain complex pore structure with pore size, porosity, and transport properties changing with depth. Asymmetric membranes contain a thin active layer where separation occurs, supported by a thicker, more porous support structure to provide membrane integrity. Currently available IWPDs utilize micro and osmotic membrane filters. Membranes are complex materials and are often difficult to classify due to minor differences in materials and structure. The following information gives general information on the most common types of membranes used in IWPDs. Membrane configurations within IWPDs are commonly oriented as flat sheet, pleated sheet, or hollow fiber. With respect to pathogen reduction efficacy, membrane orientation is not a factor. Due to lack of information provided by manufacturers, and the proprietary nature of IWPDs, not all types of membranes found in IWPDs will be discussed.

### *Polymer Microfilter Membranes*

Polymer microfilter membranes used in IWPDs are thin sheets up to about 200  $\mu\text{m}$  thick or hollow fiber microporous membranes having diameters of 70 to 600  $\mu\text{m}$  and thicknesses similar to thin sheet membranes. These membranes are engineered with specific properties for different applications and can be made of many materials. Common materials may be polycarbonate (PC), cellulose acetate (CA), or polyethersulfone (PES). Each material contains properties that affect membrane performance. In general, increasing hydrophilicity (contact angle less than 90 degrees, e.g., does not repel water molecules) will decrease fouling potential and increase flux. Membranes that are biologically inert, operate over a wide pH and temperature range, and are chemically resistant are the most desirable for water treatment. Detailed descriptions on the production of these membranes can be found in reference 25.

Microbial pathogen reduction mechanism by polymer microfiltration membranes is based on pore structure. Capillary-pore membranes, often made of PC, are thin (about 10  $\mu\text{m}$ ) and consist of uniform cylindrical pores, reject microbes based on size exclusion alone, and are generally given an absolute pore size rating. In theory, these membranes should reject all microbes greater than the pore size, but in practice, defects in pore size manufacturing as well as seams and seals within the device will prevent total rejection of larger organisms. During use, capillary-pore membranes will build-up rejected solids on the surface of the membrane. This build-up will decrease the effective pore size of the membrane and increase headloss. As this clogging increases, so does the ability of the membrane to reject microorganisms. Clean capillary-pore membrane microfilters have pore sizes down to 0.1  $\mu\text{m}$ , which can be expected to reject bacteria and protozoan cysts, but have minimal effect on virus reduction. In contrast to capillary-pore membranes, tortuous-pore membranes are thick (about 150  $\mu\text{m}$ ), consist of sponge-like structure where sieving as well as depth filtration mechanisms dominate, and have increased flux over capillary-pore membranes. These are often made of CA or PES. Pore sizes vary with depth and spatially with direction. In addition to sieving, microbes are adsorbed onto the media as described in the above sections on depth filtration theory and adsorption. Due to more efficient separation mechanisms, these membranes have been shown to retain particles orders of magnitude smaller than the nominal pore size (reference 25). Tortuous-pore membranes, like capillary-pore membranes, have pore sizes down to about 0.1  $\mu\text{m}$ , making these efficient at retaining bacteria and protozoan cysts, but not effective at sieving viruses. Due to the adsorptive nature of these membranes, it has been shown that several log virus reduction can be achieved but results are inconsistent and drop with continued production (references 3 and 25). Polymer microfilter membranes are very effective at reducing particulate matter and based on pore size should be able to reduce water turbidity to below 1 nephelometric turbidity unit (NTU). Due to the small pore size of these membranes they are prone to fouling, especially with the dead-end configurations used in IWPDs. Pre-filtering and a cleanable or backwashable configuration will reduce fouling.

### *Osmotic Membranes*

Osmosis uses pressure, RO or solute gradient osmosis, to drive the solvent through a dense, nonporous membrane (some models consider a porous membrane) that will retain salts and solutes down to very low molecular weights. Natural osmotic pressure induces travel from a less to a more concentrated solution. A pressure, in excess of the osmotic potential, must be applied to reverse this flow (RO). Osmotic potential is a function of the molar concentration of the solute. In essence, smaller molecules create higher osmotic potentials. Pressures to reverse this natural tendency can be high. Twice the osmotic pressure is common in design with seawater separations, with pressures of 5 to 8 MP are typically used. The mechanism of separation for RO is solution/diffusion + exclusion as explained above. Separation is based on the solubility and diffusivity of materials in the membrane. RO membranes are usually made of hydrophilic cellulose acetate materials, cellulose ester plastics, or composites such as a cross-linked polyamide on a polysulfone and fabric base. CA membranes along with other non-composite membranes are termed asymmetric. The entire membrane is composed of the same material with the pore size decreasing as you approach the surface. In nonporous asymmetric membranes, the surface skin is dense with a porous support membrane underneath of the same material. Composite membranes are anisotropic where the top layer and sublayer originate from different material. The top dense layer sits on top of a porous material, usually an asymmetric membrane. Composites can be designed for certain selectivities, but presently are less common than CA. CA membranes can resist a low level chlorine residual, but are very susceptible to biological degradation. RO membranes are very thin ranging from 0.25 to 4  $\mu\text{m}$  to increase flux through the membrane as flux is inversely proportional to membrane thickness. They operate ideally at pH 4 to 6.5 and at temperatures below 30° C. Water flux increases with temperature as long as temperature remains within the ideal range of the membrane material. Membrane configuration may be plate and frame, spiral-wound, tubular, or hollow fine fiber. The most common configuration, spiral-wound, contains sheets of membranes separated by spacer sheets then rolled together around a feedwater spacer. The hollow fine fiber configuration is similar to that used for microfiltration but incorporating tighter membranes. Increased surface area, resulting in higher flux, and less fouling are benefits of the hollow fine fiber design.

Osmotic membranes are classified based on MWCO with mechanisms of removal described in an above section. Measured in dalton, these membranes are capable of rejecting molecules with a mass of > 100 dalton regardless of charge. Generally speaking rejection efficacy favors multivalent ions, branched isomers, and increasing molecular mass. Based on size exclusion alone, osmotic membranes are capable of retaining species as small as 0.0001  $\mu\text{m}$  (reference 26). These membranes can remove most all natural water contaminants known, although no treatment can universally remove everything. Microorganisms, salts, hardness, and organic chemicals, among many others can be removed, whereas most dissolved gases such as hydrogen sulfide and carbon dioxide will not be removed (reference 26). IWPDs utilizing osmotic membranes are historically designed for salt water desalination. With the introduction

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of IWPDs using osmosis, application to fresh water has been considered. Currently, IWPDs using RO or O should be capable of reducing waterborne pathogens (bacteria, cysts, and viruses) to levels considered acceptable for human consumption, as recommended by the EPA (reference 1). Devices using osmotic membranes will produce the lowest NTU water of all membrane materials. IWPDs using RO are historically not designed for natural water purification where turbid water may quickly foul the membrane. RO units will perform most efficient for desalination where particulate matter is not a concern. RO use in IWPDs for natural waters would require very efficient pre-filtering, as by another membrane process such as microfiltration, and is therefore not considered a viable technology. IWPDs using O will also produce extremely low NTU water and will not be affected by particulate matter regardless of natural water turbidity. Since O devices do not use pressure to force water through the membrane, no cake is formed at the media surface and no pre-filtering is required.

### **IWPDs USING CERAMIC MICROFILTRATION**

Ceramic microfilters are made from inorganic ceramic pastes derived from powders of alumina ( $\text{Al}_2\text{O}_3$ ), zirconia ( $\text{ZrO}_2$ ), and titanium ( $\text{TiO}_2$ ). These pastes are extruded and sintered at high temperature to form membrane supports with macro pores. Subsequently, submicronic powders are laid on the supports to create smaller pore diameters. This process creates a symmetric material with high chemical, mechanic, and thermal resistance that can be formed in a variety of shapes including candles, discs, and tubes (reference 27). Pore structure is tortuous path depth filtration with symmetric pores throughout the depth of the filter. With pore sizes down to 0.1  $\mu\text{m}$ , ceramic microfilters are efficient at retaining bacteria and cysts through adsorption and depth filtration mechanisms. At the household level utilizing untreated water sources, ceramic filter use has been shown to reduce coliform bacteria resulting in greater than 70% reduction in cases of diarrhea (reference 28). As with other microfilters, no mechanism exists to adequately reduce virus concentrations. Commercially available ceramic microfilters are often impregnated with silver to discourage microbial growth on the media surface. This is intended solely to limit growth on the media and will have no effect on bulk water pathogen reduction. Ceramic microfilters are very effective at reducing particulate matter and based on pore size should be able to reduce water turbidity to below 1 NTU. Due to the small pore size of these filters they are prone to fouling, especially in dead-end configurations used in IWPDs. For IWPD use, ceramic filters are designed to be mechanically cleaned by scraping particulate build-up from the media surface. The ability to clean this media multiple times makes these filters a very effective, but high maintenance, technology for use with turbid waters. Due to the small pore size of these membranes, pre-filtering is required.

### **IWPDs USING FIBER AND FABRIC FILTRATION**

Fiber and fabric microfilters can be made of compressed or cast fibers such as cellulose papers, woven fabrics, and glass, in addition to numerous other materials (reference 29). The most

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common to IWPDs are fiber microfilters made of material such as borosilicate glass. These filters are symmetric depth filters with pores sizes down to about 0.2  $\mu\text{m}$ . Pathogen reduction follows depth filtration, adsorption, and straining mechanisms. Clean bed pathogen reduction may entail Van der Waals interaction and electrostatic interactions as well as straining based on size exclusion. After continued use, cake formation will likely make straining the predominant rejection mechanism. Consistent reduction of bacteria and cysts based on size exclusion is expected. No mechanisms exist to consistently reduce virus to the standards of reference 1. Fiber and fabric microfilters are very effective at reducing particulate matter and based on pore size should be able to reduce water turbidity to below 1 NTU. Due to the small pore size of these filters they are prone to fouling, especially in the dead end configurations used in IWPDs. With proper design, such as allowing for mechanical cleaning by way of scraping the surface, these filters can be highly effective at treating turbid waters. Non-cleanable filters, requiring replacement once clogged are not as desirable for turbid waters. Due to the small pore size of these membranes, pre-filtering is required.

## **IWPs USING CARBON FILTRATION**

### **Carbon Filtration**

Carbon used for water treatment can be of three different forms; granular, powdered, block. Granular activated carbon (GAC) for water treatment is often made from wood, peat, lignite, coal, or coconut shells. Manufacturing consists of carbonization and activation. Carbonization is conducted in the absence of air at temperatures up to 700° C, while activation, or oxidation, is accomplished at temperatures of 800 – 900° C in the presence of oxidizing gases such as steam or CO<sub>2</sub>. Activation burns off anything volatile, leaving highly porous grains with large surface areas. Grain size varies with typical values between 0.4 mm and 2.5 mm. Powdered activated carbon (PAC) is made of the same materials as the granular form, but activation can entail either gas or chemical processes. The final product is powder with typical particle sizes ranging from 10 to 100  $\mu\text{m}$ . Carbon block is produced by sintering powdered carbon, thermoplastic binders, and other additives. Material is extruded or molded under heat and pressure to form a hollow filter block of just about any shape or size. Absolute control over pore size is possible as well as engineering for specific contaminant reduction. Carbon blocks, unlike GAC, contain increased surface area, do not exhibit channeling, and contain an order of magnitude smaller pore size resulting in increased adsorption capacity (reference 30). Commercially available carbon block is often impregnated with silver to discourage microbial growth on the media surface. This is intended solely to limit growth on the media and will have no effect on bulk water pathogen reduction. When carbon adsorption capacity becomes exhausted, regeneration, involving the desorption of solutes from the media without affecting the media surface, and reactivation, entailing partial regeneration affecting the media surface, are conducted to restore the media for future use.

### **Pathogen Reduction**

GAC has no specific mechanism for pathogen reduction beyond that typical of other granular media (reference 31). Typically larger in size than most filter media, pathogen and particulate removal by GAC is poorly accomplished by the straining and depth filtration mechanisms described in an above section. PAC, like GAC, is used for taste and odor reduction, and is not considered an effective barrier to pathogens. Carbon blocks have been shown to effectively reduce pathogens from water (references 32-34). Pathogen reduction by carbon blocks can follow any of the three generally accepted particle reduction mechanisms for porous media; cake filtration (surface retention), depth filtration, or adsorptive filtration. Depending on pore size, pathogens may be retained based on size exclusion alone. As cake forms on the media surface, exclusion of smaller particles due to decreased pore size is considered a predominant reduction mechanism (reference 33, 34). Carbon block surface charge may play an important role in clean bed filtration. The surface charge of carbon block is based on the pH at which the surface is not charged, called the PZC (reference 4). At pH below this point the surface is positively charged and above this point negatively charged. Since pathogens generally possess a negative charge, as pH decreases, reduction should increase due to electrostatic interactions. It has been shown that initial reduction due to electrostatic or Van der Waals attraction is followed by straining, as the negatively charged particles neutralize the surface of the carbon block (reference 32). When pH was above the PZC, pathogen reduction based on adsorption was ineffective. Proprietary chemically treated carbon blocks are available that have been shown to be capable of reducing bacteria, cysts, and viruses by the requirements of reference 1 (reference 32). Little is known about the proprietary chemical treatment and the exact pathogen kill mechanism is unclear. With respect to available IWPDs, carbon blocks with pore sizes of 1  $\mu\text{m}$  or greater are common. Based on this, cyst reduction would be likely, and except for specially treated carbon blocks, consistent bacterial and viral reduction would not be expected to the reduction requirements of reference 1. Granular carbon filtration will retain some particulate matter based on particle size. As a cake forms on the surface, increased removal will occur. Clean bed granular carbon alone will not likely reduce water to less than 1 NTU. Carbon block filtration will reduce particulate matter with efficacy based on block pore size. Again, particulate size will be a factor in retention within carbon blocks which, as used currently in IWPDs, have a pore size of about 1-2  $\mu\text{m}$ . Granular carbon will not likely be the limiting treatment technology requiring pre-filtering for IWPDs, as an additional pathogen reduction mechanism will be present that will dictate required pre-filtration. To reduce clogging, pre-filtering is beneficial when using carbon block, but not required as shown by current device configurations.

### **IWPs USING ION EXCHANGE**

Ion exchange is not a proven technology for pathogen reduction. IWPDs utilizing ion exchange must employ an additional mechanism to adequately reduce microbial contamination. Microbial growth can occur within ion exchange beds, possibly resulting in increased contamination due to

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microbial growth sloughing into the effluent stream. One non-conventional ion exchange process has shown much promise at inactivating pathogens. Iodine ion exchange resins, primarily of the tri-iodide or penta-iodide form, have been extensively studied and are considered effective at pathogen inactivation through disinfection mechanisms (references 29, 35). Ion exchange is not designed for, and will not be effective at, reducing particulate matter. Pre-filtering is necessary to avoid fouling of the resin.

## **CONCLUSION**

The effectiveness of filtration as the primary mechanism to reduce pathogens in IWPDs is based on the technology used as well as the raw water quality. Filtration utilizing microporous filters primarily reduces pathogens by size exclusion due to surface or depth filtration mechanisms. Adsorptive interactions contribute to pathogen reduction during the initial filtration until cake formation occurs where charge neutralization limits the effectiveness of this mechanism. For IWPDs using size exclusion as the reduction mechanism, bacteria and cyst reduction is possible dependant on pore size. The small size of viruses prevents retention by size exclusion to the reduction requirements for purifying natural water. Adsorption of viruses has also been shown to be inadequate to consistently meet requirements for producing microbiologically safe water. Carbon filtration performs similar to granular or microporous filters with equivalent pore sizes. Proprietary chemically treated carbon surfaces have been shown to meet reduction requirements for microbiologically safe water but may be sensitive to water characteristics such as pH. IWPDs using osmotic membranes are the most effective at reducing pathogens although pressure driven osmotic devices will quickly foul when used with fresh water sources. For IWPDs, filtration will decrease the particulate matter present in turbid water with efficacy based on pore size. The ability of the IWPD to perform properly with turbid water sources is dictated by the pre-filter configuration and ability to clean the media surface.

**Table. Summary of the Pathogen Reduction Efficacy and the Effect of Particulate Matter on IWP Filtration Technologies.**

| Technology               | Summary  |
|--------------------------|--|
| Membrane Microfilter     | Expected effectiveness at reducing bacteria and cysts. Microfilter pore size too large to adequately reduce viruses, requiring additional treatment. Common configurations limit the effectiveness of membrane surface cleaning making this technology susceptible to fouling from particulate matter. Degree of fouling directly related to efficacy of pre-filter. Straining as well as depth filtration mechanisms may be involved in microbial and particulate rejection based on membrane structure.          |
| Ceramic Microfilter      | Expected effectiveness at reducing bacteria and cysts. Microfilter pore size too large to adequately reduce viruses, requiring additional treatment. Ability to scrape rejected material from the microfilter surface enables flow to be restored after fouling. Frequency of cleaning, and length of filter useful life directly related to efficacy of pre-filter. Straining as well as depth filtration mechanisms can be involved in microbial and particulate rejection.                                      |
| Fiber/Fabric Microfilter | Expected effectiveness at reducing bacteria and cysts. Microfilter pore size too large to adequately reduce viruses, requiring additional treatment. Filters designed to be cleanable should provide some ability to restore flow after fouling. Frequency of cleaning, and length of filter useful life directly related to efficacy of pre-filter. Non-cleanable filters highly susceptible to fouling. Straining as well as depth filtration mechanisms may be involved in microbial and particulate rejection. |
| Reverse Osmosis          | Effective at reducing bacteria, viruses, and cysts. Technology is not designed to treat fresh water sources and, therefore, requires very effective pre-filtering to prevent membrane fouling. Not a feasible IWP technology for microbial or particulate reduction of fresh water.  |
| Osmosis                  | Effective at reducing bacteria, viruses, and cysts. Technology is passive, eliminating the fouling effects of turbid water, and eliminating the need for pre-filtration. Slow production of fluid, exacerbated by cold temperatures.   |
| Granular/Powdered Carbon | Not considered effective at reducing bacteria, viruses, or cysts. Granular media is often too large to effectively reduce pathogens based on size exclusion and is not considered effective at depth filtration mechanisms. Powdered carbon is used solely for taste and odor reduction and is not effective at pathogen reduction. Particulate matter affects these technologies similar to conventional granular media.  |
| Carbon Block             | Expected effectiveness at reducing cysts. Consistent reduction of bacteria is not expected due to the pore size of carbon blocks commonly used in  |

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|              |  |
|--------------|--|
|              | IWPs. Not effective at adequately reducing viruses, although proprietary media has shown some promise. Pathogen reduction based on size exclusion and depth filtration mechanisms. Effects of particulate matter similar to other technologies of similar pore size. Pre-filtration and cleanable filters will decrease fouling from particulate matter. |
| Ion Exchange | Not considered effective at reducing bacteria, viruses, or cysts. Iodine ion exchange resins have been proven effective at pathogen inactivation through disinfection mechanisms. Particulate matter fouls ion exchange resin and therefore prefiltration is necessary.  |

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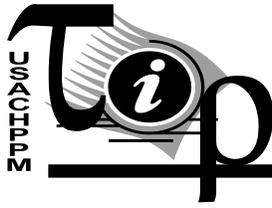
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**ANNEX G TO APPENDIX G**

**ULTRAVIOLET LIGHT DISINFECTION IN THE USE OF  
INDIVIDUAL WATER PURIFICATION DEVICES**

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## Ultraviolet Light Disinfection in the Use of Individual Water Purification Devices

### Technical Information Paper #31-006-0306

#### PURPOSE

This information paper provides an in-depth review of ultraviolet (UV) light for use as a disinfection technology in potable water supplies. This paper is intended to assist the reader in evaluating the disinfection capabilities of UV light-using Individual Water Purification Devices (IWPDs) to inactivate disease-causing bacteria, viruses, and cysts.

#### REFERENCES

Appendix A contains a list of references.

#### INTRODUCTION

##### Background

Understanding the disinfection capabilities of UV light to inactivate disease-causing microorganisms is important in protecting Soldiers, who are considering using this technology, from acute health threats posed by these microorganisms. Soldiers deployed beyond traditional field drinking water supplies must have access to microbiologically safe water. Using IWPDs is one way to provide microbiologically safe water in these situations. These IWPDs must protect the Soldier from acute microbial health threats. The U.S. Environmental Protection Agency (EPA) Guide Standard and Protocol for Testing Microbiological Water Purifiers (reference 1) provides performance standards by which an IWPD that uses UV light can be evaluated. The performance standards are a minimum 6-log reduction/inactivation of bacteria, 4-log reduction/inactivation of viruses, and 3-log reduction/inactivation of protozoan cysts. UV-using IWPDs meeting these standards are considered effective against disease causing bacteria, viruses, and protozoan cysts. Some IWPD manufacturers test their devices using this protocol. This is the best way to evaluate the IWPDs disinfection capabilities. In the absence of that testing data, this information paper can be used to gain an understanding of UV light disinfection capabilities and help determine if an IWPD using UV light could successfully meet the EPA Guide's minimum performance standards. This information paper was developed primarily using information obtained from the EPA's Draft Ultraviolet Disinfection Guidance Manual (reference 2). The manual provides a comprehensive review of available scientific literature concerning UV disinfection in drinking water systems.

b. History of UV Light in Potable Water Applications. The germicidal properties of UV light were discovered in 1887. The first application of UV light in drinking water occurred in

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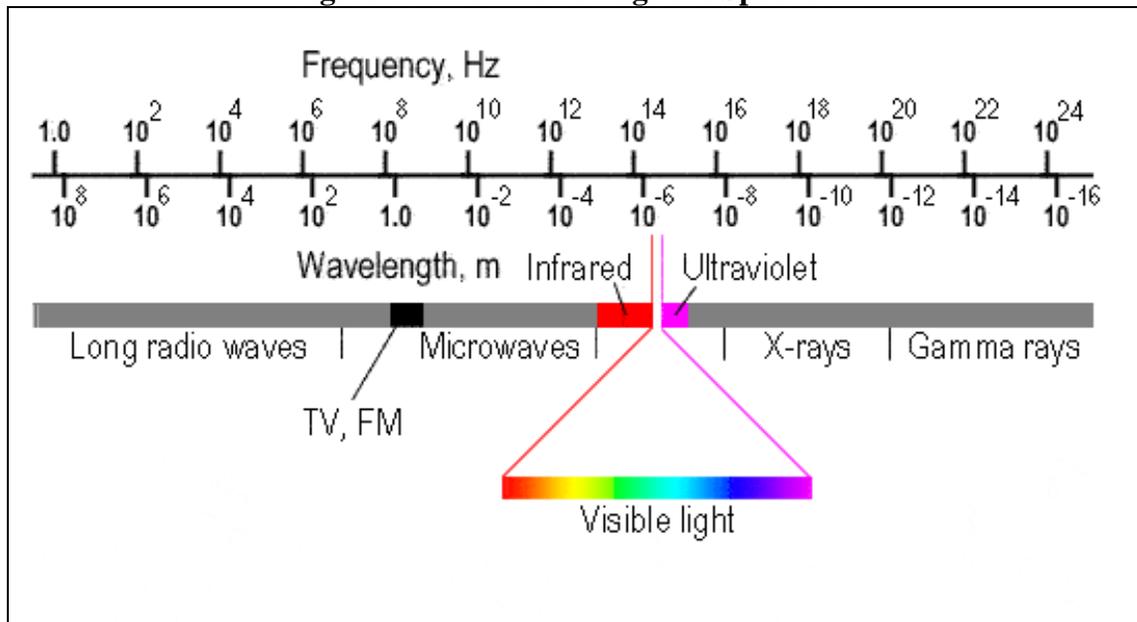
1910 at Marseilles, France. Since then, UV light is used in drinking water systems worldwide primarily for disinfection. Currently there is only one Commercial-Off-The-Shelf (COTS) IWPD using UV light for disinfection. However, as UV research continues, more COTS IWPDs incorporating UV technology may be developed.

## ULTRAVIOLET DISINFECTION

### UV Light Description

In drinking water, UV light is used for disinfection. The use of UV for disinfection involves: (1) the generation of UV light with the desired germicidal properties, and (2) the delivery (or transmission) of that light to microbial pathogens. As Figure 1 shows, UV light lies between x-rays and visible light in the electromagnetic spectrum. The UV spectrum covers the wavelength range from 100-400 nm. UV light at certain wavelengths can inactivate microorganisms. UV light with wavelengths from 200-300 nm inactivates most microorganisms, with the greatest amount of inactivation occurring around 260 nm.

**Figure 1. The Electromagnetic Spectrum.**



Source: <http://www.sentinelarchiving.com/ARTICLES/electromag.htm>

### UV Light Generation

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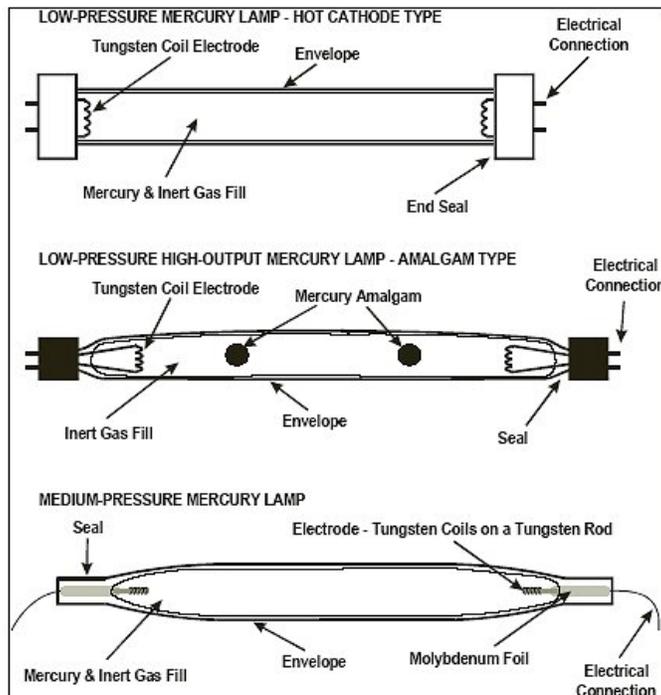
Generation of UV light is similar to the generation of light in a fluorescent lamp. In general, a UV lamp contains an inert gas (e.g., argon) and a small amount of liquid mercury. When a voltage is applied to the lamp, some of the liquid mercury vaporizes. Free electrons and ions then collide with the gaseous mercury atoms, “exciting” the mercury atoms into a higher energy state. Excited mercury atoms have a tendency to return to their ground, or normal, energy state by discharging energy. The energy discharged is in the form of UV light. Mercury is advantageous for UV disinfection applications because it emits light in the germicidal wavelength range (200 – 300 nm). The UV light produced depends on the concentration of mercury atoms in the UV lamp, which is directly related to the mercury vapor pressure. Low pressure mercury vapor produces monochromatic (light at primarily one wavelength) UV light at a wavelength of 253.7 nm. Higher pressure mercury vapor produces UV light at several wavelengths (polychromatic).

## **UV Lamps**

### *UV Lamp Types*

For water treatment systems, there are three general types of UV lamps typically used; low-pressure (LP), low-pressure high-output (LPHO), and medium-pressure (MP). These terms are based on the vapor pressure of mercury when the lamps are operating. LP and LPHO lamps operate at mercury vapor pressures of  $2 \times 10^{-3}$  –  $2 \times 10^{-5}$  pounds per square inch (psi), thereby producing monochromatic UV light at 253.7 nm. MP lamps operate at much higher mercury vapor pressures of 2 – 200 psi and produce polychromatic UV light at a higher intensity. LP and LPHO lamps operate at temperatures of 40 – 200° C, while MP lamps operate at a much higher temperature range of 600-900° C. LP lamps have the lowest power requirements, while LPHO and MP lamps have higher power requirements. Subsequently, LP lamps have the lowest germicidal output (0.2 W/cm), while LPHO and MP lamps have higher germicidal outputs (0.5 – 3.5 W/cm and 5 – 30 W/cm, respectively). Figure 2 shows drawings of LP, LPHO, and MP lamps. There is generally no difference in disinfection capability between these lamps. But there are advantages and disadvantages to each. For example, compared to LP lamps, MP lamps have a higher germicidal output, typically require fewer lamps for a given applications, and would likely be a smaller reactor. There are other types of lamps that can produce UV light such as metal halide lamps, electrode-less mercury vapor lamps, and excimer lamps. However, because these lamps are not commonly used for drinking water UV disinfection application, they are not discussed here. Most UV-using IWPDs will likely use LP lamps due to lower operating temperatures and lower power requirements.

**Figure 2. LP, LPHO, and MP Lamp Drawings.**



Source: Reference 2

### *UV Lamp Breakage*

Lamp sleeves can break. Breakage is a concern due to potential for mercury release. UV lamps contain mercury or an amalgam composed of mercury and another element, such as indium or gallium. LP and MP lamps generally contain elemental mercury, while LPHO lamps generally contain a mercury amalgam. The mercury contained within a UV lamp is isolated from exposure by a lamp envelope and surrounding lamp sleeve. For the mercury to be released, both the lamp and lamp sleeve must break. Breakage can occur when lamps are in operation as well as when not operating but during maintenance. The mercury content in a single UV lamp used for water treatment typically ranges from 0.005 to 0.4 grams (5-400 mg). LP lamps have less mercury (5-50 mg/lamp) compared to LPHO (26-150 mg/lamp) and MP lamps (200-400 mg/lamp). Depending on the state mercury is in (gas, solid, or liquid) when a lamp breaks can be important when determining potential health risks. Mercury in the vapor phase may be released as very fine particles, which may readily dissolve in water, as opposed to solid or liquid mercury that will tend to settle. There is very little information on determining the amount of mercury released relative to the amount of mercury in the lamp prior to breakage. One study involving the breakage of a UV lamp containing 150 mg mercury in a 50 L batch reactor resulted in a concentration of 2.5 ug/L of mercury in the reactor. However, it was not reported whether all

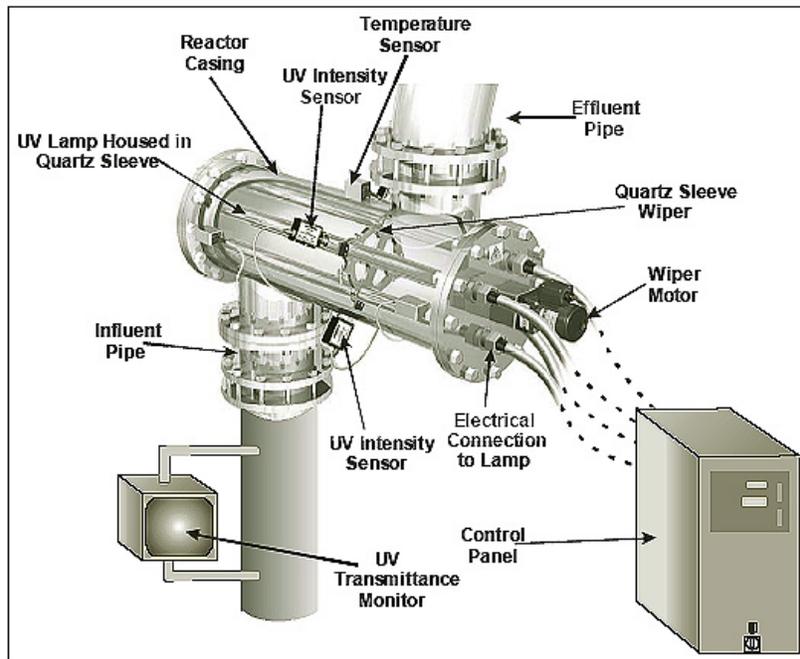
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150 mg of mercury was recovered. For IWPD use, since it is assumed that LP lamps are used, breakage of the lamp during operation may result in contamination of water being treated with 5-50 mg of mercury.

### UV Reactors

In drinking water systems, UV lamps are contained in a UV reactor. UV reactors operate as either batch or continuous flow reactors. Several characteristics must be taken into account when designing, installing, and operating a UV reactor. Among them are water quality characteristics, distance between the lamp and the reactor wall, and the distribution of UV light. Additionally, continuous flow reactors must take into account hydraulic characteristics of water flowing through the reactor. Due to all these characteristics, microorganisms will not all receive the same UV dose. For example, UV lamp placement in a reactor influences UV dose delivery. If the distance between the lamp and the reactor wall is too large (i.e., a large amount of water between the lamp and the reactor wall), microorganisms furthest from the lamp will receive less UV intensity and subsequently a lower UV dose. Figure 3 is a schematic of a continuous flow UV reactor. Most UV-using IWPDs will likely utilize a batch reactor system.

**Figure 3. Continuous Flow UV Reactor Schematic.**



Source: Reference 2.

## **UV Dose**

### *Definition of UV Dose*

In drinking water applications, disinfection using UV light follows the familiar CT concept (disinfectant concentration times contact time). However, instead of using CT to describe UV disinfection, UV dose is used instead. UV dose is defined as the measurement of the energy per unit area that falls upon a surface. UV dose is the product of UV intensity, I, and exposure time, T (IT), similar to the CT concept. UV intensity is usually expressed as mW/cm<sup>2</sup> and exposure time is measured in seconds (s). So UV dose is reported as mWs/cm<sup>2</sup>. However, UV dose is commonly expressed as millijoules per square centimeter (mJ/cm<sup>2</sup>), because 1 mWs = 1 mJ.

### *Estimating UV Dose*

When disinfection test data is not available models can be used to gain an understanding of disinfection capabilities of UV-using IWPDs. Several complex models have been developed to estimate UV intensity delivered to a microorganism. With the estimated UV intensity, the UV dose can be calculated based on various exposure times and compared to UV doses determined in scientific literature. The simplest model used to estimate UV intensity is the radial model:

$$I(r) = (P_L / 2\pi r) \times (e^{-aer})$$

Where:  $P_L$  = UV power emitted per unit arc length of the lamp (mW/cm)

$r$  = Radial distance from the lamp (cm)

$ae$  = Base e absorption coefficient of the water (1/cm).  $ae = 2.303 \cdot A_{254}$

$I(r)$  = UV intensity (mW/cm<sup>2</sup>) at a distance  $r$  from the lamp

Using data provided by the manufacturer on UV power emitted ( $P_L$ ), dimensions of the IWPD UV reactor, and assuming water quality variables to develop an absorption coefficient ( $ae$ ), UV intensity can be calculated. In the absence of good quality IWPD specific testing data, this model can be used to provide a rough evaluation of disinfection capability.

## **Mechanism of UV Disinfection**

### *Inactivating Versus Killing Microorganisms*

When discussing UV light disinfection capabilities, a distinction must be made between inactivating and killing microorganisms. For chemical disinfectants (e.g., chlorine, chlorine dioxide, iodine), inactivating and killing can be considered synonymous terms since chemical disinfectants destroy and damage cellular structures which interferes with metabolism, biosynthesis, and growth. In contrast, UV light does not destroy or damage cellular structures.

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Rather, UV light prevents microorganisms from reproducing. Microorganisms that cannot reproduce cannot infect and are thereby inactivated. Subsequently, when evaluating UV disinfection capability, *Giardia* cyst and *Cryptosporidium* oocyst assays that measure infectivity, not viability must be used. Excystation assays measuring viability are not accurate indicators of UV disinfection capability.

#### *Inactivation Mechanism*

UV light inactivates microorganisms by damaging deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). When DNA and RNA absorb UV light, damage results from the formation of dimers (covalent bonds between the same nucleic acids). Dimers cause faults in the transcription of information from DNA to RNA, which in turn results in disruption of microorganism replication. The microorganism continues to live, but it can't reproduce and therefore is not infective. A microorganism that cannot replicate cannot infect a host. Microorganisms developed two mechanisms to repair damage caused by UV light. These mechanisms are termed light and dark repair. It is possible for microorganisms to repair themselves to the extent where they will become infective again after exposure to UV light. Fortunately, however, most data indicates UV doses typically used in water treatment prevent most repairs. In general, microorganism inactivation by UV light follows first order reaction rates. However, inactivation rates can vary depending on microorganism type, and water quality conditions (e.g., turbidity, particulate matter, and clumping of microorganisms). Lastly, similar to chemical disinfectants and the CT approach to disinfection evaluation, data has shown that UV disinfection follows the law of reciprocity over an intensity range of 1-200mW/cm<sup>2</sup>. For example, a UV dose of 1 mW/cm<sup>2</sup> for 200 sec (i.e., 200 mJ/cm<sup>2</sup>) achieves the same level of inactivation as a UV dose of 200mW/cm<sup>2</sup> for 1 sec (i.e., 200 mJ/cm<sup>2</sup>).

### **Environmental Effects**

#### *Introduction*

UV light can interact with materials potentially reducing disinfection capability. Interactions include absorption, reflection, refraction, and scattering. Absorption is the transformation of light to other forms of energy. When UV light is absorbed, it is no longer available for disinfecting microorganisms. The remaining interactions, reflection, refraction, and scattering, change the direction of UV light and the light is still available for disinfection. UV transmittance and UV absorbance are two related common water quality parameters used to measure these interactions. UV transmittance (UVT), particle content, and constituents that foul lamp sleeves are the most significant water quality factors impacting UV disinfection capability. Water temperature and pH do not generally have an impact on UV disinfection capability.

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*Effect of UVT*

Both UVT and UV absorbance describe the amount of UV light passing through water. They are related by the following equation:

$$\% \text{ UVT} = 100 \times 10^{-A_{254} * d}$$

Where: UVT = UV transmittance at a 254 nm and a 1 cm pathlength  
 $A_{254}$  = UV absorbance at 254 nm based on a 1 cm pathlength (unitless)  
d = distance from UV lamp (cm). When measuring UV absorbance,  
d = 1cm

UVT is affected by turbidity, particulate matter, and natural organic matter (NOM). UVT directly affects dose-delivery, and subsequently disinfection capability. As turbidity increases, UVT decreases and UV absorbance increases. Decreased UVT decreases UV intensity delivered to the microorganism, thereby decreasing disinfection capability. Table 1 illustrates the effect of turbidity on UVT, UV absorbance, UV intensity, and the required exposure time necessary to achieve a UV dose of 5 mJ/cm<sup>2</sup> (reference 3). Notice as turbidity increases, UVT decreases, UV Absorbance increases, and UV intensity decreases. Therefore, to maintain a consistent 5 mJ/cm<sup>2</sup> dose, exposure time must be increased. UV absorbers in typical source waters include humic and fulvic acids, other organics, metals (e.g., iron), and anions (e.g., nitrates, sulfites). Both soluble and particulate forms of these compounds will absorb UV light, subsequently reducing UVT. UVT and UV absorbance will vary over time due to changing concentrations of these compounds. UVT and UV absorbance are more variable in rivers and small lakes and will also vary seasonally. Water systems using coagulation/flocculation, filtration, and oxidation treatment processes will increase UVT by reducing UV absorbing compounds, thereby increasing UV disinfection capability. For water systems considering the use of UV disinfection, UV should be installed after filtration. Installing UV prior to filtration will require higher UV doses to achieve the same level of inactivation due to higher levels of NOM, turbidity, and particulate matter. Particles can reduce UV disinfection capability by absorbing UV light and shielding microbes from UV light. No clear correlations have been observed between the amount of turbidity, its characteristics, and the impact on UV disinfection capability (reference 4). Some studies have demonstrated that turbidities above 10 nephelometric turbidity unit (NTU) and even up to 100 NTU have no impact on UV disinfection (references 1 and 5). While other studies observed reduced UV disinfection capability at turbidities in the 5 NTU range (reference 4). In general, increasing turbidities result in decreasing UV disinfection capability. One study showed increasing turbidities from 0.25 to 20 NTU resulted in a 0.8-log and 0.5-log decrease in inactivation of *Cryptosporidium* and *Giardia*, respectively (reference 3). The type of particle present in water can affect UV disinfection. Particles with higher organic content were observed to protect particle-associated viruses from UV light compared to particles of the same size with no organic content (reference 6).

**Table 1. Effect of Turbidity on UVT, UV Absorbance, UV Intensity, and Exposure Time.**

| <b>Turbidity (NTU)</b> | <b>% UVT</b> | <b>UV Absorbance</b> | <b>UV Intensity (mW/cm<sup>2</sup>)</b> | <b>Exposure time necessary to achieve 5 mJ/cm<sup>2</sup> dose (s)</b> |
|------------------------|--------------|----------------------|---|--|
| 0.25                   | 86           | 0.07                 | 0.40                                    | 12.4   |
| 5.0                    | 78           | 0.11                 | 0.39                                    | 12.8   |
| 10.0                   | 71           | 0.15                 | 0.36                                    | 13.9   |
| 20.1                   | 59           | 0.23                 | 0.33                                    | 15.0   |

#### *Effect of Water Temperature and pH*

An advantage of UV disinfection over chemical disinfectants is that inactivation is generally independent of water temperature and pH. Overall, effect of water temperature is insignificant on UV disinfection capability. Temperature can affect the activity of repair enzymes and nucleic acid configuration, which may result in a very slight increase in UV dose necessary with decreasing temperatures to achieve the same log inactivation. Compared to turbidity, particulate matter, and NOM, the effect of water temperature is insignificant. The water pH has an insignificant effect on UV disinfection capability. Repair and nucleic acid configuration are affected by pH. However, pH within a cell is relatively constant and does not vary with water pH. Studies using MS2 virus showed pH over 6-9 range had no effect on inactivation.

#### *Effect of Fouling Contaminants*

Fouling of UV lamps will reduce UV disinfection capability. Hardness, alkalinity, temperature, iron concentration, and pH all influence fouling. Compounds exhibiting decreasing solubility with increasing temperatures (e.g., CaCO<sub>3</sub>, CaSO<sub>4</sub>, FeCO<sub>3</sub>) are prime contributors to lamp fouling. One study showed at total and calcium hardness levels less than 140 mg/L and iron less than 0.1 mg/L, mechanical cleaning (wiper sweeping) every 15 min to 1 hour during operation of a continuous flow UV reactor was sufficient to overcome impact of sleeve fouling. The Langelier Saturation Index and Calcium Carbonate Precipitation Potential can be used to help indicate fouling potential by indicating the tendency of the water to form a calcium carbonate precipitate. For UV-using IWPDS, fouling of the UV lamp is not expected to be significant. Although groundwaters are primarily associated with high hardness and dissolved solids, there are also surface waters containing high levels of hardness and dissolved solids (reference 7). Most IWPDS would likely be used with surface waters. However, since IWPDS use would be intermittent, not continuous, and the same source would likely not be used consistently, UV lamp fouling is not expected to be a significant factor reducing UV disinfection capability.

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## Bacteria, Virus, and Protozoa Inactivation Capability

### *Microorganism Inactivation Capability*

The effectiveness of UV light on microorganism inactivation varies with different types of microorganisms. Generally, UV light is most effective at inactivating *Cryptosporidium* and *Giardia*, followed by bacteria and then viruses:

*Cryptosporidium* and *Giardia* > Bacteria > Viruses

Interestingly, UV resistance appears to follow microorganism size, with the smallest microorganisms being most resistant. The reason for this may be due to the amount of UV light absorption per cell. With microorganisms larger than 1 micron, the absorption of UV light by the cell can be significant, effectively reducing resistance to UV disinfection. Table 2 is a summary of numerous UV disinfection studies and shows UV doses and corresponding log inactivation for various microorganisms. The most UV resistant viruses of concern in drinking water are adenovirus Type 40 and 41. Because viruses are the most resistant to UV disinfection, dosing is controlled by log inactivation requirements for viruses, not protozoan cysts (reference 4). As Table 2 shows, *Cryptosporidium* and *Giardia* are very sensitive to inactivation by low doses of UV light (reference 8).

**Table 2. UV Dose and Corresponding Log Inactivation by Microorganism.**

| Microorganism Type | Microorganism                 | UV Dose for 3-log inactivation (mJ/cm <sup>2</sup> ) | UV dose for 4-log inactivation (mJ/cm <sup>2</sup> ) |
|--------------------|-------------------------------|--|--|
| Virus              | Adenovirus Type 40            | 90   | 120  |
| Virus              | MS2                           | 52   | 71   |
| Virus              | Poliovirus Type 1             | 23   | 30   |
| Virus              | Hepatitis A                   | 15   | 21   |
| Spore              | <i>Bacillus subtilis</i>      | 61   | 78   |
| Bacteria           | <i>Salmonella enteriditis</i> | 9  | 10   |
| Bacteria           | <i>Salmonella typhi</i>       | 5  | 9  |
| Bacteria           | <i>Escherichia coli</i>       | 6.7  | 8.4  |
| Bacteria           | <i>Vibrio cholerae</i>        | 2.2  | 2.9  |
| Protozoa           | <i>Cryptosporidium parvum</i> | <6   | -  |
| Protozoa           | <i>Giardia lamblia</i>        | <6   | -  |

Adapted from reference 2.

*Development of UV Dose Tables*

Pursuant to the Long Term 2 Enhanced Surface Water Treatment Rule, the EPA proposed UV dose tables for various log inactivation of viruses, *Cryptosporidium*, and *Giardia* (reference 9). The proposed UV doses for 3-log *Giardia* and *Cryptosporidium*, and 4-log virus inactivation are shown in Table 3. Comparing these doses to those in Table 2 shows that the EPA proposed UV doses are higher. These doses are more conservative and were developed to account for uncertainty associated with the inactivation studies of microorganisms in controlled conditions using low turbidity water (less than or equal to 1 NTU). These uncertainties are addressed by applying a safety factor to experimentally determined UV doses. The EPA collected UV inactivation research data conducted over the past 50 years for adenovirus, *Giardia lamblia*, *Giardia muris*, and *Cryptosporidium parvum*. Adenovirus was evaluated because it is considered the most resistant to inactivation by UV light of the pathogenic waterborne viruses. The EPA evaluated 19 studies for these microorganisms. When evaluating UV-using IWPDS that are treating raw, unfiltered waters, higher UV doses than those shown in Table 3 may be necessary to achieve the same level of inactivation. Higher UV doses can be achieved by longer exposure time, removing UV absorbing components (e.g., particulate matter, NOM) from the water prior to UV exposure (e.g., filtration or carbon absorption), or, if possible, increasing UV lamp intensity. Even at higher UV doses, it appears that a UV-using IWPDS can reasonably achieve minimum 6-log bacteria, 4-log virus, and 3-log *Giardia* and *Cryptosporidium* inactivation. For example, treating a turbid water (e.g., 30 NTU) may require a doubling of the EPA proposed UV dose of 186 mJ/cm<sup>2</sup> required for 4-log virus inactivation shown in Table 3 (i.e., a UV dose of 372 mJ/cm<sup>2</sup>) to assure adequate inactivation. Assuming the UV-using IWPDS delivers an average UV intensity of 0.5 mW/cm<sup>2</sup>, an exposure time of 744 seconds (~12 min) is necessary to achieve the required dose.

**Table 3. Proposed UV Dose Requirements for 3-log *Cryptosporidium* and *Giardia* Inactivation and 4-log Virus Inactivation (mJ/cm<sup>2</sup>)**

| <b>3-log <i>Cryptosporidium</i> inactivation</b> | <b>3-log <i>Giardia</i> inactivation</b> | <b>4-log virus inactivation</b> |
|--|--|---------------------------------|
| 12   | 11                                       | 186                             |

**UV TOXICITY**

**Disinfection Byproduct Formation**

A main chronic health concern with chemical disinfectants is the formation of disinfection byproducts (DBPs). Trihalomethanes and haloacetic acids, the only regulated DBPs are not formed during UV disinfection. However, there are studies that show low-level (i.e., ug/L)

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formation of non-regulated DBPs (e.g., aldehydes). The health effects of non-regulated DBPs at the levels formed during UV disinfection has not been widely researched. Use of UV-using IWPDs may result in higher levels of non-regulated DBPs formed since raw, unfiltered waters would contain higher amounts of DBP precursors (e.g., NOM). However, the IWPDs would be used on a short-term basis (i.e., < 3-4 weeks) by healthy adult soldiers. Therefore, exposure to UV-produced DBPs would likely have negligible adverse health effects.

### **Mercury Exposure**

There is a health concern for the potential of mercury exposure due to lamp breakage. As discussed earlier, all UV lamps contain some amount of mercury. Lamps used in water treatment systems reportedly have between 5-400 mg of mercury. The risk associated with a mercury release to the water due to lamp breakage during operation depends on many factors. Little information exists regarding the fate of mercury released to the water as a result of UV lamp breakage. This adds to the uncertainty of the risk of adverse health effects. UV lamp breakage during operation can result in potential ingestion of mercury. The EPA established a maximum contaminant level (MCL) for mercury at 0.002 mg/L. The EPA has found mercury to potentially cause kidney damage from short-term exposures at levels above the 0.002 mg/L MCL (reference 10). UV lamps in IWPDs will contain mercury. Since these IWPDs will most likely utilize LP lamps due to lower power requirements and lower operating temperatures, breaking a UV lamp during operation could result in 5-50 mg of mercury being released into the water being treated. Therefore, there is cause for concern, even for short-term exposure of mercury to healthy soldiers if a UV lamp breaks during operation.

## **CONCLUSIONS**

### **UV Disinfection Capability**

UV disinfection is effective against protozoan cysts, bacteria, and viruses. UV light does not kill microorganisms. Rather, it damages the DNA and RNA and prevents the microorganism from reproducing. When a microorganism cannot reproduce it cannot infect. UV light is most effective against *Cryptosporidium* and *Giardia* followed by bacteria. UV light is least effective against viruses. Turbidity, particulate matter, and NOM are the most significant water quality parameters having the greatest effect on UV disinfection capability. Water temperature and pH have an insignificant effect on UV disinfection capability. Increasing levels of turbidity, particulate matter, and NOM absorb more UV light, making less UV light available for disinfection. Similar to the CT concept, the IT concept [UV intensity ( $\text{mW}/\text{cm}^2$ ) times exposure time (s)], commonly referred to as UV dose ( $\text{mJ}/\text{cm}^2$ ), is used to describe UV disinfection capability. Increasing concentrations of turbidity, particulate matter, and NOM require higher UV doses in the form of increased UV intensity and/or longer exposure times to achieve the same amount of inactivation. Studies evaluating UV disinfection capability indicate UV doses of

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120 mJ/cm<sup>2</sup> are adequate to achieve 4-log virus inactivation of the most resistant viruses. The EPA adds a safety factor and proposes a UV dose of 186 mJ/cm<sup>2</sup> for a 4-log inactivation of viruses. These UV doses will ensure a 3-log *Giardia* and *Cryptosporidium* inactivation and likely ensure a 6-log bacteria inactivation. Most UV lamps used in drinking water applications contain mercury. There is concern of adverse health effects to the consumer as a result of mercury exposure from UV lamp breakage during operation.

### Evaluating UV-Using IWPDs

UV-using IWPDs can be effective against *Cryptosporidium*, *Giardia*, bacteria, and viruses. Since raw, unfiltered waters will be treated, UV doses higher than those proposed by the EPA will likely be required to achieve the same level of inactivation. For example, treating a highly turbid water (e.g., 30 NTU) may require a doubling of the EPA proposed UV dose of 186 mJ/cm<sup>2</sup> required for 4-log virus inactivation (i.e., a UV dose of 372 mJ/cm<sup>2</sup>). Assuming the UV-using IWPD delivers an average UV intensity of 0.5 mW/cm<sup>2</sup>, an exposure time of 744 seconds (~12 min) is necessary to achieve the required dose. This seems reasonable and practical for field use. Models can be used to help understand UV disinfection capabilities of UV-using IWPDs under various water quality conditions likely to be encountered. There is cause for concern for adverse health effects from exposure to mercury if the UV lamp is broken during operation. Since all UV lamps contain mercury and UV-using IWPDs most likely utilize LP lamps due to lower power requirements and lower operating temperatures, breaking IWPD UV lamp during operation may result in up to 5-50 mg of mercury being released into the water being treated. The risk of adverse health effects from UV lamp breakage during operation is uncertain, however, there is cause for concern, even for short-term exposure of mercury to healthy soldiers. Table 4 summarizes UV disinfection capabilities, environmental effects, and potential health concerns with using UV light.

**Table 4. UV Disinfection Capabilities.**

| Parameter                       | UV Disinfection   |
|---------------------------------|---|
| General Disinfection Capability | Viruses most resistant. <i>Giardia</i> and <i>Cryptosporidium</i> least resistant. UV dose will be based on virus inactivation. |
| Bacteria                        | Effective at reasonable UV doses for IWPD use.  |

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|  |   |
|--|---|
| Viruses                                    | Effective at reasonable UV doses for IWPD use. Use proposed EPA UV dose table for recommended doses (Table 3). UV doses higher than those recommended may be necessary based on turbidity, particulate matter, and NOM. |
| <i>Giardia</i> Cysts                       | Effective at reasonable UV doses for IWPD use.  |
| <i>Cryptosporidium</i> Oocysts             | Effective at reasonable UV doses for IWPD use.  |
| Effect of Temperature                      | Negligible effect.  |
| Effect of pH                               | Negligible effect.  |
| Effect of Turbidity/Particulate Matter/NOM | Significant effect. Higher concentrations require higher UV doses to achieve same levels of inactivation.   |
| Health Effects                             | UV lamp breakage during operation may exposure user to unsafe levels of mercury.  |

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**DATED:** March 2006

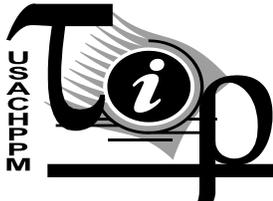
**APPENDIX A  
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**ANNEX H TO APPENDIX G**

**IODINE DISINFECTION IN THE USE OF  
INDIVIDUAL WATER PURIFICATION DEVICES**

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## Iodine Disinfection in the Use of Individual Water Purification Devices

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Technical Information Paper #31-005-0306

### PURPOSE

This information paper provides an in-depth review of iodine as a disinfectant in potable water supplies. This paper is intended to assist the reader in evaluating the disinfection capabilities of Individual Water Purification Devices (IWPDs) using iodine to kill or inactivate disease-causing bacteria, viruses, and protozoan cysts.

### REFERENCES

Appendix A contains a list of references.

### INTRODUCTION

#### Background

Understanding the disinfection capabilities of iodine to kill or inactivate disease-causing microorganisms is important in protecting Soldiers, who are considering using this technology, from acute health threats posed by these microorganisms. Soldiers deployed beyond traditional field drinking water supplies must have access to microbiologically safe water. Using IWPDs is one way to provide microbiologically safe water in these situations. These IWPDs must protect the Soldier from acute microbial health threats. The U.S. Environmental Protection Agency (EPA) Guide Standard and Protocol for Testing Microbiological Water Purifiers (reference 1) provides performance standards by which an IWPD using iodine can be evaluated. The performance standards are a minimum 6-log reduction/inactivation of bacteria, 4-log reduction/inactivation of viruses, and 3-log reduction/inactivation of protozoan cysts (typically *Giardia* or *Cryptosporidium*). Iodine-using IWPDs meeting these standards are considered effective against disease causing bacteria, viruses, and protozoan cysts. Some IWPD manufacturers test their devices using this protocol. This is the best way to evaluate the IWPDs disinfection capabilities. In the absence of that testing data, this information paper can be used to gain an understanding of iodine disinfection capabilities and help determine if an IWPD using iodine could successfully meet the EPA Guide's minimum performance standards.

#### General

Iodine ( $I_2$ ) has long been recognized for its anti-microbial properties. It has been used extensively in the health care industry as an antiseptic and disinfectant (references 2 and 3). The U.S. Army also realized the benefits of iodine as a drinking water disinfectant, issuing iodine-

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based tablets (Globaline™) to American Soldiers in 1952 (references 4 and 5). The Army continues to provide iodine-based tablets in addition to other emergency field drinking water products (i.e., Chlor-Floc™) (reference 6). Today, there are several Commercial-Off-The-Shelf (COTS) IWPD products that use iodine for disinfection.

### **Types of Iodine-based Disinfectants**

Iodine-based disinfection products available today can be divided into two categories; iodine solutions and iodine resins. Iodine solutions are made by adding iodine (e.g., tincture of iodine, a 2% iodine solution), or by adding a tablet containing iodine along with carrier and stabilizing agents to enhance dissolvability (e.g., Globaline, composed of tetraglycine hydroperiodide, sodium acid pyrophosphate and talc, reference 4). Iodine resins are solid-phase iodine disinfectants. Iodine resins are used by passing water through the iodine resin where disinfection occurs through direct contact of the microorganism and the iodine sorbed onto the resin. Iodine resins are generally considered demand-release disinfectants (reference 7). Demand-release iodine resins release iodine to the microorganism after coming into contact with the resin and generally produce a dilute iodine residual (reference 7).

## **IODINE CHEMISTRY**

### **Chemistry of Iodine in Water**

When iodine is added to water, it may remain unchanged or it may hydrolyze into five different species depending on pH and the initial iodine concentration (references 4 and 8). In general, the following reaction occurs when iodine is added to water (reference 9):



In addition to the formation of hypiodous acid (HOI) and iodide ion (I<sup>-</sup>), hypiodite ion (OI<sup>-</sup>), triiodide ion (I<sub>3</sub><sup>-</sup>), and iodate (HIO<sub>3</sub>) may be formed. However, under typical concentrations used in drinking water disinfection, and at typical pH ranges for natural water sources, hypiodite ion, triiodide ion, and iodate are not considered to be formed at any appreciable concentrations (reference 12). The small equilibrium constant indicates a higher concentration of reactants (iodine) compared to the products (hypiodous acid and iodide ion) present at equilibrium. In other words, this equation suggests that in natural waters with typical pH ranges from 5 -8, iodine is present and can be present in significant amounts depending on initial iodine

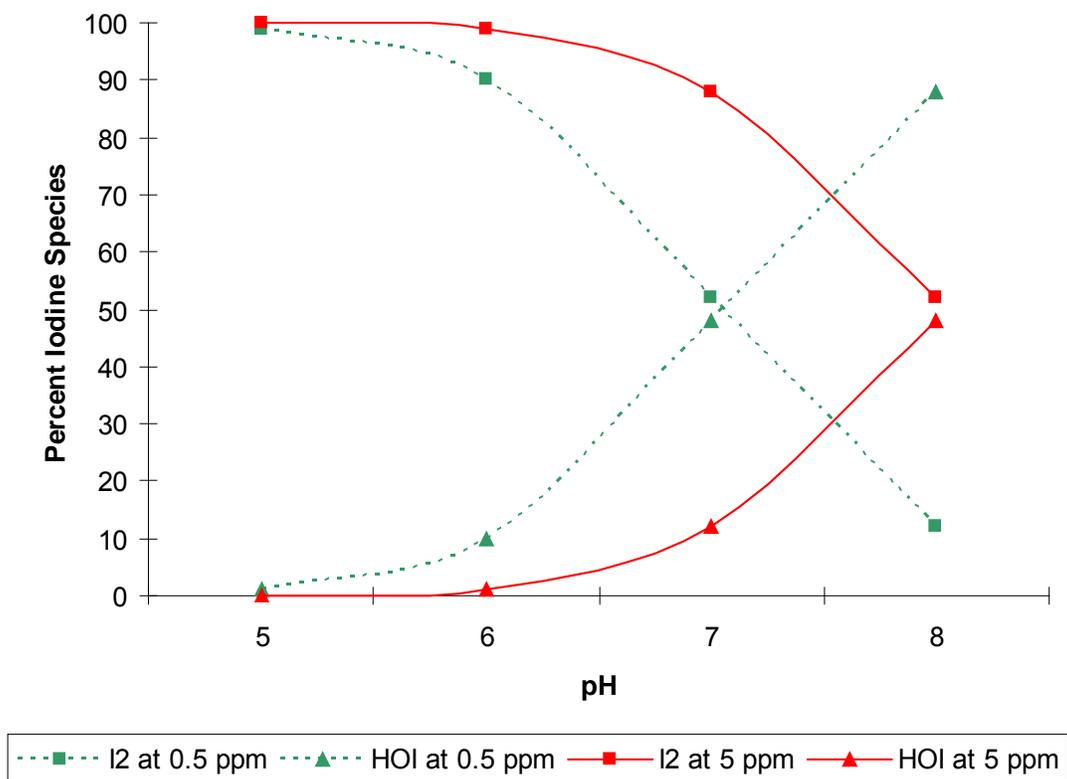
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™ Globaline is a trademark of Wisconsin Pharmacal Co., Jackson, WI.

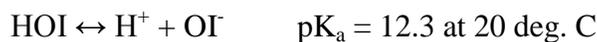
™ Chlor-Floc is a trademark of Control Chemical Co., D/B/A Deatrick and Associates, Inc., Alexandria, VA. Use of trademarked products does not imply endorsement by the U.S. Army, but is intended only in identification of a specific product.

concentration (reference 10). The figure shows the distribution of iodine species at various pH levels and initial iodine concentrations at 25 degrees C (adapted from references 9 and 11).

**Figure. Distribution Diagram of Iodine Species at 25 Degrees Celsius**



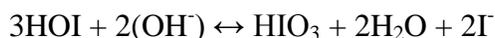
From the figure, we can see that at near neutral to alkaline pH levels (~7+), depending on initial iodine concentration there can be significant concentrations of both iodine and hypiodous acid present. Lower initial iodine doses result in significant concentrations of both iodine and hypiodous acid at near neutral pH levels. At higher pH levels above 8, hypiodous acid dissociates by the following reaction (reference 9):



The production of hypiodite ion (OI<sup>-</sup>) is considered negligible since it would only be present in significant concentrations at pH levels not typically seen in natural waters (i.e., above pH 10)

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(reference 10). Further limiting production of hypiodite ion is the fact that hypiodous acid is unstable at pH levels above 8 and decomposes to iodate and iodide according to the following reaction (reference 10):



### **Iodine Resin Preparation**

Preparation of iodine resins involves binding polyiodide ions to a strong-base anion resin. This creates a positively charged resin. Most microorganisms are negatively charged at typical pH levels (i.e., 5 – 8) encountered in natural waters (references 13 and 14). These opposite charges produce an electrostatic attraction that helps bring the microorganism into direct contact with the iodine resin (reference 15). There are generally two types of iodine resins produced for drinking water treatment, a triiodide ( $\text{I}_3^-$ ) and a pentaiodide ( $\text{I}_5^-$ ) resin.

## **DISINFECTION CAPABILITIES**

### **General**

#### *Iodine Solutions*

Iodine is an effective disinfectant for viruses, bacteria, and many cysts at IWPDP manufacturer-recommended iodine dosages and contact times. In general, iodine is most effective against bacteria, followed by viruses. Iodine is least effective against cysts. Iodine is not an effective disinfectant against *Cryptosporidium parvum* oocysts (references 2, 3, 15 and 16). Most manufacturers of iodine solution IWPDPs recommend dosages between 4 and 16 mg/L with contact times ranging from 20 – 35 minutes, resulting in CTs of 80 – 560 mg-min/L. CT is the product of disinfectant concentration (C in mg/L) and contact time (T in min). The CT product is a useful way for comparing alternative disinfectants and the resistance of various pathogens (reference 26). Because cysts are most resistant, dosages and contact times will be based on inactivation of cysts and CTs will be in the high-end of the 80 – 560 mg-min/L CT range. Compared to other disinfectants such as chlorine and chloramines, iodine reacts less with organic compounds, is less soluble, is least hydrolyzed in water, and is effective over the pH range likely encountered in natural water sources likely to be treated with an IWPDP (references 2, 3 and 17). Together, these characteristics mean that low iodine residuals will persist longer, be more stable, and exert less of a demand in the presence of organic matter compared to chlorine and chloramines (reference 12). It has been established that only iodine and hypiodous acid are capable of biocidal activity. The other iodine species are not effective biocides (references 3, 11, 12 and 16). For these reasons only iodine and hypiodous acid are the iodine species considered in this paper.

### *Iodine Resins*

Like iodine solutions, iodine resins are effective disinfectants against bacteria, viruses, and many cysts. However, the resins have not been proven effective against *Cryptosporidium* oocysts (references 3, 15, 18, 19 and 20). Iodine resins used in IWPDs are generally combined with other treatment processes such as filtration and are not usually used as stand-alone IWPDs. Iodine resin disinfection operates on the theory that iodine binds to the microbe, penetrating and inactivating it. Contact between the microbe and the resin is necessary and is assisted by electrostatic forces (reference 3). Microbes are exposed to high iodine concentrations when passing through the resins, which allow for reduced contact time compared with iodine solutions (reference 16). Iodine resins typically produce a residual of 0.02 - 2 mg/L in water passed through the resin (reference 15). However, the iodine residual is not considered to provide additional disinfection. In most cases, bacteria and viruses are immediately killed or inactivated after coming into direct contact with the iodine sorbed to the resin. For cysts, additional contact time is sometimes necessary after passing through the resin to allow sufficient time for the iodine picked up from the resin to penetrate the cysts and kill or inactivate it. In theory, the iodine residual produced by the resin is not used for disinfection. However, the iodine residual may provide a measure of microbial protection when storing water to prevent microbial growth in the storage container, similar to the maintenance of a disinfectant residual in a distribution system. Of the two types of resins used in drinking water, pentaiodide resin has been shown to have better biocidal capabilities than triiodide resin (reference 7).

## **Environmental Effects on Disinfection Capability**

### *Effect of pH on Disinfection Capability*

In general, the pH of most natural water sources is neutral to mildly acidic, which is within the effective range for chemical disinfectants used for drinking water, including iodine solutions (reference 3). Iodine and hypiodous acid have varying degrees of biocidal effectiveness against various pathogens. Iodine is up to three times more cysticidal and 6 times more sporocidal than hypiodous acid (reference 3). Hypiodous acid, on the other hand, is 40 times more virucidal and up to 4 times more bactericidal than iodine (reference 3). Because the concentration of these iodine species is dependent upon pH and initial iodine dose (see Figure), the following generalizations can be made. Iodine solutions are more effective cysticides and poorer virucides and bactericides at mildly acidic pH levels (< pH 7). Iodine solutions are more effective virucides and bactericides and poorer cysticides at alkaline pH levels (> pH 7). And, because it generally takes much longer to inactivate cysts than bacteria and viruses, iodine solutions used as IWPDs would be most effective at near neutral to mildly alkaline pH levels. However, at pH levels above 8, biocidal capability may drop sharply because HOI becomes unstable and decomposes to iodate and iodide, which are not effective biocides (see iodine chemistry above).

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To use iodine most effectively as a disinfectant, the pH should be near neutral to mildly alkaline to allow adequate levels of both iodine and hypiodous acid (reference 4).

Resins do not appear to be significantly affected by pH levels typically encountered in natural waters. One study using both triiodide and pentaiodide resins showed less than 4-log virus inactivation at extremely low pH levels (pH 2.5 and 3.0) (reference 15). At these low pH levels, it was believed that the viruses lost their negative charge, becoming neutral or positively charged, effectively reducing the electrostatic attraction and subsequently preventing direct contact with the iodine on the positively charged resins. Greater than 4-log virus inactivation was achieved at all higher pH levels (pH 4.0 – 7.0).

#### *Effect of Temperature on Disinfection Capability*

In general, colder water temperatures reduce the disinfection capability of iodine solutions and other chemical disinfectants (references 9, 17 and 21). Cold water temperatures slow disinfection and must be compensated for by longer contact time or higher concentration to achieve comparable disinfection at warmer water temperatures (reference 3). A 2 to 3-fold increase in inactivation rates per 10° C water temperature increase seems a generally accepted rule (reference 3). Studies have shown a significant impact on iodine disinfection capability by temperature. One study showed CT's to provide 2-log inactivation of the *E. Coli* bacteria were 2-9 times higher in colder waters (2-5° C) than in warmer waters of 20-25° C (references 9 and 22). Another study showed a CT 3 times higher was necessary at a 3° C water temperature (CT = 200 mg-min/L) compared to 23° C water temperature (CT = 65 mg-min/L) for a 2-log inactivation of *E. histolytica* cysts (references 9 and 10). Another study using *Giardia* cysts showed CT's up to 3 times higher in 3° C water resulted in only a 1.5-log inactivation compared to CT's at 20° C which resulted in > 2.7-log inactivation (references 7 and 21). These studies show temperature has a significant effect on iodine disinfection capability. Longer contact times and/or higher iodine doses (i.e., increased CT's) are necessary in colder waters. Using a 2-fold CT increase for every 10° C decrease in water temperature is a good estimate to use when determining CT requirements for iodine disinfection capability.

There is limited information on the effect of water temperature on the disinfection capability of iodine resins. Water temperatures do not appear to affect bacteria and virus inactivation when using iodine resins. However, cysts may require additional contact time after passing through a resin to ensure inactivation. One study evaluated water temperature's effect on *Giardia* cyst inactivation by pentaiodide resin (references 7 and 23). The data suggested that additional contact time was necessary to provide a 3-log inactivation after passing through the resin (reference 23). Three minutes additional contact time was necessary at 25° C while more than 40 minutes additional contact time was necessary at 4° C. Although an iodine residual was present in the water after passing through the column, the inactivation of the *Giardia* cysts is likely due to the iodine bound to the cysts after coming into contact with the resin (reference 23).

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Additional contact time of water passed through an iodine resin is recommended to ensure adequate *Giardia* cyst inactivation (3-log).

#### *Effect of Turbidity on Disinfection Capability*

In general, disinfection capability of iodine solutions is reduced since microorganisms can be protected from the iodine by adsorption to or enmeshment in solid particles in water (references 16 and 24). There is limited information discussing the effects of turbidity on the disinfection capability of iodine. Most iodine disinfection studies involving varying turbidities also include other variables that affect iodine disinfection (e.g., pH and temperature). However, some limited information can be extracted. One study indicated turbidity from clays measuring 50-500 mg/L total suspended solids had no measurable effect on iodine disinfection capability, but high concentrations of fine loess (165 – 245 mg/L) interfered with bactericidal capability of iodine (reference 25). This study would indicate that turbidity does have an affect on iodine disinfection capability but not as significant compared to temperature.

Available information on fouling of iodine resins focuses more on the impact of dissolved organic matter and not on turbidity (i.e., solid or particulate matter). Resins will act as filter media and can physically remove particulate matter from water (reference 26). The particulate matter could interfere with the disinfecting capability of the iodine resin by preventing direct contact between the organism and the resin. Dissolved organic matter can have a large impact on iodine resin disinfection. One study indicated dissolved organic matter (measured as total organic carbon) at concentrations of 6 mg/ml (6,000 mg/L) reduced the disinfection capability of a triiodide (I<sub>3</sub>) resin against viruses. The organic matter competed for sites on the resin beads and prevented direct contact between the resin and the virus (reference 20). However, a 10-fold reduction in dissolved organic matter (600 mg/L) did not appear to adversely affect the triiodide's disinfection capability of viruses. Heavy organic matter loading could reduce the disinfection capability of an iodine resin. A pretreatment process to remove/reduce organic matter (particulate and dissolved) will provide better resin disinfection capability in highly turbid waters.

### **Bactericidal Capability**

#### *Iodine Solutions*

Numerous studies indicate iodine is an effective bactericide over the range of temperature and pH expected in natural water sources (references 9, 10, 22 and 27). Very low CT levels, ranging from 0.4 – 2.4 mg-min/L are required to inactivate 2-logs of *E. Coli* over a wide pH range (6 – 9) and temperature range (2 – 37° C) (reference 9). CT's of less than 10 mg-min/L resulted in a 4-log inactivation of *E. Coli* at a near neutral pH (6 – 7) and extreme temperatures (~ 0 – 37° C) (references 9 and 27). These low CT's translate into low iodine residuals and/or short contact

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times. For example, assuming a contact time of 20 minutes, a 0.5 mg/L iodine residual would be necessary to provide 4-log inactivation of *E. Coli* at near neutral pH at any temperature encountered in natural waters (20 min x 0.5 mg/L = 10 mg-min/L). When iodine solutions are used at typical doses for emergency drinking water disinfection (4 – 16 mg/L) and typical recommended contact times (20 – 35 minutes), the resulting CT's of 80 – 560 mg-min/L would likely ensure a 6-log inactivation of bacteria.

### *Iodine Resins*

Data indicate iodine resins may achieve a 6-log inactivation of bacteria. One study showed at least a 4-log inactivation of *Staphylococcus aureus* over a wide pH range of 2.5 – 7.0 using triiodide (I3) and pentaiodide (I5) resins (reference 15). Other studies showed 4 – 9-log removal/inactivation for various pathogenic bacteria including *E. Coli* and *Salmonella typhimurium* using a triiodide resin (references 15 and 19). No significant removal of bacteria by filtration was reported. The effectiveness of resins against bacteria is due to its disinfecting ability and not for the ability to filter, or physically remove bacteria (reference 19). Iodine resins will likely provide a 6-log inactivation of bacteria under most situations.

## **Virucidal Capability**

### *Iodine Solutions*

Several studies also show that iodine solutions are effective virucides (references 9, 10 and 27). Viruses are more resistant to iodine disinfection than bacteria, typically requiring higher CT's than bacteria and in some cases much higher CT's at low pH levels (e.g., 4 – 5), where hypiodous acid (HOI) is not present, and at cold water temperatures (e.g., 5° C) (reference 9). Most studies evaluated the virucidal efficacy of iodine solutions against f<sub>2</sub> virus and Poliovirus. Data indicate 2-log inactivation at near neutral to alkaline pH levels (6 – 10) and various water temperatures (5 – 30° C) occurred at CT's of 15 – 75 mg-min/L with the higher CTs occurring at lower pH levels and colder water temperatures. One study showed a CT of less than 10 mg-min/L resulted in a 4-log inactivation of f<sub>2</sub> virus at a pH of 7 and a very warm water temperature of 37° C (reference 9). Iodine solutions will likely provide a 4-log inactivation of viruses under most natural water conditions expected. Because IWPD dosages and contact times will be based on cyst inactivation, and resulting CTs will be large (80 – 560 mg-min/L), it is likely an IWPD will achieve 4-log virus inactivation under most water quality conditions.

### *Iodine Resins*

Data reviewed indicates iodine resins can likely achieve 4-log virus inactivation levels. Several studies show at least 4-log inactivation of various viruses at pH levels above 3.0 with low turbidity water for both triiodide (I3) and pentaiodide (I5) resins (references 15 and 20). One

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study showed a reduced virucidal capability of a triiodide resin when water containing significant amounts of organic matter (6 mg/ml or 6,000 mg/L organic matter) was tested (reference 20). However, a 10-fold reduction in organic matter (0.6 mg/ml or 600 mg/L) did not appear to affect the triiodide resin's disinfection capability (reference 20). Triiodide and pentaiodide resins will likely provide a 4-log virus inactivation under most natural water quality conditions.

## **Cysticidal Capability**

### *Iodine Solutions*

Most cysts, in particular *Giardia* cysts and *Cryptosporidium* oocysts, appear to be more resistant to iodine disinfection than bacteria or viruses. Achieving adequate cyst inactivation should ensure adequate bacteria and virus inactivation.

There are several studies evaluating the iodine disinfection capability against *Giardia* cysts (references 6, 8, 21 and 28). Overall, the data from these studies indicate that iodine is capable of providing a 3-log *Giardia* cyst inactivation, but additional contact time or higher doses (i.e., higher CT's) are necessary at colder water temperatures and more turbid waters (references 6, 8 and 28). Warmer waters (> 20° C), both clear and cloudy, with pH levels ranging from 6 – 9, resulted in > 2.7 log (~3 log) *Giardia* cyst inactivation with CT's ranging from 45 – 241 mg-min/L. As water temperatures decreased (< 20° C) CT values for > 2.7 log *Giardia* cyst inactivation increased, ranging from 123 – 600 mg-min/L (clear and cloudy waters, pH ranged from 6 – 9). One study recommended CT's ranging from 240 – 720 mg-min/L for colder waters (5 – 15° C) to ensure a 100% inactivation of *Giardia* cysts (reference 17). At colder water temperatures (clear and turbid) achieving a 3-log inactivation of *Giardia* cysts is not likely when using iodine according to recommended instructions (CT's ranging from 80 – 560 mg-min/L). Additional contact time and/or higher iodine dosages, beyond those recommended by IWPD manufacturers, are likely necessary to ensure 3-log *Giardia* cyst inactivation.

There is limited data on *Cryptosporidium* oocyst inactivation by iodine (references 8 and 29). These data indicate iodine solutions are ineffective at inactivating *Cryptosporidium* oocysts. One study indicated a CT of 1,015 mg-min/L is required to achieve a 2-log *Cryptosporidium* oocyst inactivation (reference 29). This CT is far beyond IWPD CT's resulting from using iodine solutions according to manufacturer recommended instructions (CT's ranging from 80 – 560 mg-min/L). This indicates iodine would not be an effective disinfectant against *Cryptosporidium* due to the extremely high iodine dose and long contact times necessary to provide a 3-log inactivation.

### *Iodine Resins*

Pentaiodide resins are much more effective at inactivating *Giardia* cysts than triiodide resins (reference 23). A pentaiodide resin achieved a 3-log *Giardia* cyst inactivation compared to 0.2 – 0.4-log inactivation achieved by triiodide resin under identical experimental conditions (temperatures of 4 and 25° C) (reference 23). Additional contact time after passing through the pentaiodide resin column was necessary to achieve the 3-log inactivation. The 3-log inactivation was achieved within 3 minutes of passing through the column at 25° C (reference 23). More than 40 minutes of additional contact time was necessary at 4° C water temperature to achieve similar inactivation rates (reference 23). Other literature indicates that for adequate cyst inactivation (with the exception of *Cryptosporidium* oocysts) that additional contact time is necessary after passing through the resin (references 3, 7, 15, 16 and 28). Although an iodine residual was present in the water after passing through the column, the inactivation of the *Giardia* cysts is likely due to the iodine bound to the cysts after coming into contact with the resin and not due to the iodine residual (reference 23). The additional contact time indicates *Giardia* cysts are more resistant to iodine resin inactivation compared to bacteria and viruses. There is evidence that *Giardia* cysts can be filtered by the resin. Approximately 65% of *Giardia* cysts passing through a pentaiodide column temporarily adhered to the resin bead surface (reference 23). However, these cysts were subsequently washed off the resin beads after continued use and passed through the pentaiodide resin column. These cysts were inactivated (reference 23). A 3-log inactivation of *Giardia* cysts can be achieved if a pentaiodide resin bed is used and additional contact time is provided after passing through the resin bed. In colder waters, longer contact time is necessary to ensure *Giardia* cyst inactivation. Ensuring adequate *Giardia* cyst inactivation (3-log) will ensure adequate bacteria (6-log) and virus (4-log) inactivation.

Iodine resins are not effective at inactivating *Cryptosporidium* oocysts. One study showed no inactivation of *Cryptosporidium* oocysts that passed through a pentaiodide resin (reference 18). Similar to *Giardia* cysts, there is evidence that *Cryptosporidium* oocysts are filtered by the resin bed (reference 18). This is likely due to electrostatic interactions. Therefore, resins could provide a measure of physical removal of *Cryptosporidium* oocysts. However, like *Giardia* cysts, subsequent use of resins might cause the release or washing off of oocysts from the resin and the oocysts could remain viable. Iodine resins cannot be considered effective for inactivating *Cryptosporidium* oocysts. Additional treatment such as filtration would be necessary to control *Cryptosporidium*.

### **IODINE TOXICITY**

Iodine is not widely used as a disinfectant in typical municipal drinking water systems due to potential adverse health effects caused from excessive iodine intake (reference 30). It's been suggested that chronic (long term) intake of 2 mg/day should be regarded as excessive and

potentially harmful (reference 30). When ingested, iodine is converted to iodide and efficiently absorbed into the body. Most iodide resides in the thyroid gland (reference 30). Excessive amounts of iodine can cause an enlarged thyroid, a condition known as goiter (reference 30). For healthy individuals without pre-existing thyroid conditions or sensitivity to iodine, ingesting iodine concentrations associated with using IWPDs for short periods of time (i.e., 3 months or less) are not likely to experience adverse health effects (reference 31). It is recommended that pregnant women, people with known hypersensitivity to iodine, people with a history (or family history) of thyroid disease, and people from countries or localities with chronic iodine deficiency should not use iodine as a means of water treatment (reference 31).

## CONCLUSIONS

### Iodine Solutions

Iodine solutions are effective disinfectants against bacteria, viruses, and *Giardia* cysts. They are not effective against *Cryptosporidium* oocysts. Temperature appears to have the greatest effect on iodine disinfection capability. *Giardia* cysts are more resistant to iodine disinfection than bacteria or viruses. Achieving adequate *Giardia* cyst inactivation should ensure adequate bacteria and virus inactivation. At colder water temperatures (both clear and turbid), and turbid water at any temperature, additional contact time and/or higher iodine dosages than recommended by IWPD manufacturers are likely necessary to achieve a 3-log inactivation of *Giardia* cysts (and 6-log bacteria and 4-log virus inactivation). CT's up to 720 mg-min/L are recommended for cold waters (5° C) to ensure *Giardia* cyst inactivation. Using iodine solutions to inactivate *Cryptosporidium* oocysts is not practical.

### Iodine Resins

Pentaiodide resins are effective disinfectants against bacteria, viruses, and *Giardia* cysts. Triiodide resins are less effective than pentaiodide resins. Both resins are not effective for inactivating or removing *Cryptosporidium* oocysts. Turbidity and organic matter can reduce the disinfection capability of iodine resins. Similar to iodine solutions, *Giardia* cysts appear to be more resistant to inactivation by iodine resins than bacteria and viruses. Achieving adequate *Giardia* cyst (3-log) inactivation should ensure adequate bacteria (6-log) and virus (4-log) inactivation. Additional contact time is necessary after passing through a pentaiodide resin to ensure *Giardia* cyst inactivation. Provide at least 3 minutes additional contact time for warmer waters (> 20° C). Provide at least 40 minutes additional contact time for colder waters (< 5° C). The table provides a summary of the disinfection capability of iodine resins and solutions.

**Table. Summary of Disinfection Capabilities of Iodine Solutions and Resins.**

| Parameter                      | Iodine Solutions   | Iodine Resins  |
|--------------------------------|--|--|
| General                        | Cysts most resistant. Achieving <i>Giardia</i> cyst inactivation will ensure adequate bacteria and virus inactivation.   | Cysts most resistant. Achieving <i>Giardia</i> cyst inactivation will ensure adequate bacteria and virus inactivation  |
| Bacteria                       | Effective  | Effective  |
| Viruses                        | Effective  | Effective  |
| <i>Giardia</i> Cysts           | Provide additional contact time beyond IWPD manufacturer recommended CTs.  | Pentaiodide resin effective. Triiodide resin not effective. Provide additional contact time after passing through resin.   |
| <i>Cryptosporidium</i> Oocysts | Not effective.   | Not effective.   |
| Effect of Temperature          | Major effect. Increase contact time and/or dose at colder temperatures. CT's up to 720 mg-min/L recommended for <i>Giardia</i> cyst inactivation in colder waters. | Major effect. Increase contact time after passing through pentaiodide resin at colder temperatures. Allow up to 40 minutes additional contact time for <i>Giardia</i> cysts inactivation in colder waters (< 5° C) |
| Effect of pH                   | Minor effect. Generally effective over typical pH levels for natural waters  | Minor effect. Generally effective over pH range typical for natural waters   |
| Effect of Turbidity            | Affects disinfection capability. Provide additional contact time and/or increase iodine dose in more turbid waters.  | Affects disinfection capability. Heavy organic matter loading can significantly reduce disinfection capability.  |

**PREPARED BY:** Steven H. Clarke, Environmental Engineer

**DATED:** March 2006

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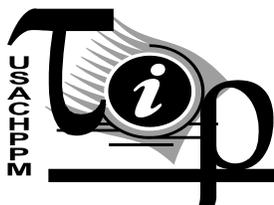
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**ANNEX I TO APPENDIX G**

**CHLORINE DIOXIDE DISINFECTION IN THE USE OF  
INDIVIDUAL WATER PURIFICATION DEVICES**

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## Chlorine Dioxide Disinfection in the Use of Individual Water Purification Devices

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### Technical Information Paper #31-007-0306

#### PURPOSE

This information paper provides an in-depth review of chlorine dioxide as a disinfectant in potable water supplies. This paper is intended to assist the reader in evaluating the disinfection capabilities of Individual Water Purification Devices (IWPDs) using chlorine dioxide to kill or inactivate disease-causing bacteria, viruses, and protozoan cysts.

#### REFERENCES

Appendix A contains a list of references.

#### INTRODUCTION

##### Background

Understanding the disinfection capabilities of chlorine dioxide to kill or inactivate disease-causing microorganisms is important in protecting soldiers, who are considering using this technology, from acute health threats posed by these microorganisms. Soldiers deployed beyond traditional field drinking water supplies must have access to microbiologically safe water. Using IWPDs is one way to provide microbiologically safe water in these situations. These IWPDs must protect the Soldier from acute microbial health threats. The U.S. Environmental Protection Agency (EPA) Guide Standard and Protocol for Testing Microbiological Water Purifiers (reference 1) provides performance standards by which an IWPD using chlorine dioxide can be evaluated. The performance standards are a minimum 6-log reduction/inactivation of bacteria, 4-log reduction/inactivation of viruses, and 3-log reduction/inactivation of protozoan cysts. Chlorine dioxide-using IWPDs meeting these standards are considered effective against disease causing bacteria, viruses, and protozoan cysts. Some IWPD manufacturers test their devices using this protocol. This is the best way to evaluate the IWPDs disinfection capabilities. In the absence of that testing data, this information paper can be used to gain an understanding of chlorine dioxide disinfection capabilities and help determine if an IWPD using chlorine dioxide could successfully meet the EPA Guide's minimum performance standards.

##### General

Chlorine dioxide ( $\text{ClO}_2$ ) was discovered in 1811 (reference 2). It's widely used in numerous industries including wood pulp processes, wastewater treatment, and food processing. Water treatment plants in the United States first used chlorine dioxide in the 1940s for taste and odor control (reference 3). In addition to taste and odor control, many drinking water systems

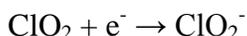
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throughout the world today use chlorine dioxide for disinfection, control of organic disinfection byproducts (e.g., trihalomethanes), and oxidation of iron and manganese. Currently, there are only a few Commercial-Off-The-Shelf (COTS) IWPDs using chlorine dioxide for disinfection.

## CHLORINE DIOXIDE CHEMISTRY IN WATER

### General

Chlorine dioxide exists as an undissociated gas dissolved in water at a near neutral pH range (pH 6-9) (reference 4). Because chlorine dioxide exists as a gas it is vulnerable to volatilization; it can be easily removed from water by turbulent aeration, and is destroyed by ultraviolet light when exposed to sunlight (reference 5). Chlorine dioxide is stable in dilute solution in a closed container in the absence of light (reference 5). One of the advantages of using chlorine dioxide over chlorine for disinfection is the decreased formation of organic disinfection byproducts (DBPs), such as trihalomethanes (reference 3). However, chlorine dioxide is an oxidant and reactions with organic matter form inorganic DBPs including primarily chlorite ion ( $\text{ClO}_2^-$ ) and to a lesser extent chlorate ion ( $\text{ClO}_3^-$ ). Chloride ( $\text{Cl}^-$ ) is also formed to a lesser extent. The reaction of chlorine dioxide in water at pH 6-8 containing organic matter is suggested to be (reference 6):



Chlorine dioxide reacts rapidly. In drinking water, where typical dosages are 0.07 – 2.0 mg/L, chlorite is the predominant reaction product with approximately 50-70% of chlorine dioxide converted to chlorite, and 30% converted to chlorate and chloride (reference 3). Manufacturer recommended dosages for IWPD use may be similar to those used in water systems or may be much higher. Chlorine dioxide IWPD manufacturers recommend dosages from 0.7 – 4 mg/L for most waters and up to 7.5 mg/L when treating cold and/or cloudy waters (references 7 and 8).

### Generation

#### *Chlorine Dioxide Generation for Water Systems*

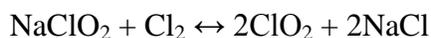
Chlorine dioxide can't be stored commercially or compressed since it is explosive under pressure. Therefore, it must be generated on-site (reference 5). Although there are emerging technologies for chlorine dioxide generation, the two most common methods are (references 2 and 5):

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(1) sodium chlorite – acid generation



(2) sodium chlorite – chlorine generation



### *Chlorine Dioxide Generation for IWPDs*

Chlorine dioxide must also be generated on-site on a much smaller scale or provided in dilute chlorine dioxide solutions for IWPD use. Currently, generating chlorine dioxide on-site for use as an IWPD uses buffered sodium chlorite, generally referred to as “stabilized chlorine dioxide” (references 9 and 10). The sodium chlorite must be “activated” by adding an acid, usually phosphoric or citric acid, resulting in the formation of chlorine dioxide in a reaction similar to the sodium chlorite – acid generation reaction used by water systems (shown earlier). There are health concerns associated with the use of “stabilized chlorine dioxide.” “Stabilized chlorine dioxide” can potentially result in little formation of chlorine dioxide, thereby reducing disinfection capability, and can also potentially result in high concentrations of chlorite, which may cause adverse health effects when ingested and also has no disinfection capability (references 3 and 11). Dilute solutions of chlorine dioxide are also used as IWPDs. These solutions lose chlorine dioxide over time, but can be stable for several months and possibly longer. One study showed dilute chlorine dioxide concentrations (approximately 35 mg/L) exhibited variable losses based on the type of container used for storage (reference 12). For example, a 35 mg/L chlorine dioxide solution stored in a high-density Polyethylene Terephthalate (PETE) container for 45 days resulted in a 3% loss of chlorine dioxide (34 mg/L). In contrast, the same study stored chlorine dioxide in a clear glass container for 31 days which resulted in a 12% gain of chlorine dioxide (39 mg/L) possibly due to continuing formation of chlorine dioxide from chlorite. Another study showed a 6.2% overall gain in chlorine dioxide concentration after 252 days of storage in a PETE container (reference 12).

## **DISINFECTION CAPABILITIES**

### **General**

Chlorine dioxide is an effective disinfectant against bacteria, viruses, and many cysts including the capability to disinfect *Cryptosporidium* with realistic (typical to slightly higher water system) dosages (reference 3). A comparison of CTs required for a 2-log inactivation for *E. Coli* bacteria, Poliovirus 1, and *Giardia* cysts showed *Giardia* cysts were 2-5 times more resistant than Poliovirus 1 and 16-22 times more resistant than *E. Coli* bacteria (reference 13). The CT is the product of disinfectant concentration (C in mg/L) and contact time (T in min). The CT

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product is a useful way for comparing alternative disinfectants and the resistance of various pathogens (reference 28). Poliovirus was 4-11 times more resistant than *E. Coli* bacteria (reference 13). *Cryptosporidium* oocysts are the most resistant, being 8-16 times more resistant than *Giardia* cysts (reference 5). Chlorine dioxide's general disinfection capability with respect to microorganisms can be illustrated in the following way from most effective to least effective:

bacteria > viruses > *Giardia* cysts > *Cryptosporidium* oocysts

Chlorine dioxide is similar to other chemical disinfectants in that its disinfection capability decreases with decreasing temperature, its disinfection capability generally decreases with increasing turbidity, and its disinfection capability is affected by pH (references 3, 4 and 13). Since chlorine dioxide exists as an undissociated gas in water, volatilization and loss of chlorine dioxide and subsequent disinfecting capability is a concern (reference 3). Because chlorine dioxide is an oxidant it will react with organic matter in the water forming primarily chlorite and to a lesser extent chlorate and chloride. Both chlorite and chlorate show no disinfection capabilities and may cause adverse health effects in children, infants, and fetuses (reference 11). Drinking water systems using chlorine dioxide for disinfection are not generally able to provide adequate disinfection per regulations in raw water with high organic carbon (i.e., organic matter) when adding chlorine dioxide in the raw water. This is because the chlorine dioxide is used up by reacting with organic matter, being reduced to primarily chlorite and leaving no chlorine dioxide residual (reference 3). This can be a concern for IWPDs when treating raw, unfiltered water supplies. Higher dosages may be necessary to react with organic matter and provide disinfection.

### **Environmental Effects on Disinfection Capability**

#### *Effect of pH on Disinfection Capability*

Compared to chlorine, chlorine dioxide is a more effective disinfectant across a broader pH range (roughly between 5 and 10) than free chlorine (reference 3). Several studies have shown the effect of pH on chlorine dioxide disinfection capability, with most results indicating disinfection capability generally increases with increasing pH (reference 14). Numerous studies with viruses (e.g., poliovirus, hepatitis A virus) showed CTs required for a 2-log virus inactivation were 13 – 20 times higher at a pH of approximately 6 compared to a pH of 9 and 10 (references 13 and 15). Another study showed CTs up to 90-100 times higher were required for a 4-log virus inactivation at a pH of 6 compared to a pH of 10 (reference 16). Although these studies showed much higher CTs necessary at lower pHs, CTs were still low at the lower pHs (ranging from approximately 3 – 13 mg-min/L). This indicates chlorine dioxide is a highly effective disinfectant over a broad pH range. In contrast to the previous studies, a study on chlorine dioxide disinfection capability against *Cryptosporidium* oocysts indicated pH does not

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appear to have a significant effect on *Cryptosporidium* inactivation (reference 17). The degree of pH effect may be dependent on the targeted organism and in general chlorine dioxide shows an increase in disinfection capability with increasing pH. Chlorine dioxide would likely be effective over the pH range (pH 6-9) for natural, untreated water sources likely to be encountered when using IWPDs.

#### *Effect of Temperature on Disinfection Capability*

Like most chemical disinfectants, chlorine dioxide disinfection capability decreases with decreasing temperatures (reference 5). Cold water temperatures slow disinfection and must be compensated for by longer contact times or higher dosages to achieve comparable disinfection at warmer water temperatures (reference 18). A two to three-fold increase in inactivation rates per 10° C water temperature increase seems a generally accepted rule (reference 18). When considering chlorine dioxide, the U.S. Environmental Protection Agency (EPA) developed CT tables for the Surface Water Treatment Rule (SWTR) by assuming a twofold decrease in CT for every 10° increase (reference 19). Research shows a 2-log inactivation of *E. Coli* required four times higher CT at 5° C compared to 20° C (reference 13). A study using *Naegleria* cysts showed at 5° C a CT twice as high than at 20° C was required to provide a 2-log inactivation (reference 5). Using a two-fold CT increase for every 10° decrease in water temperature is a good estimate to use when determining CT requirements for chlorine dioxide disinfection capability.

#### *Effect of Turbidity on Disinfection Capability*

Turbidity also has an effect on chlorine dioxide disinfection capability. Turbidity in the form of particulate matter, aggregated or clumped microorganisms, and dissolved organic matter can reduce the effectiveness of chlorine dioxide. One study determined that bentonite clay added to produce turbidity levels up to 2.3 nephelometric turbidity units (NTUs) had no adverse effect on chlorine dioxide disinfection of poliovirus. However, at turbidity levels of 3.2 and 14.1 NTU, poliovirus inactivation was noticeably decreased (references 13 and 20). The study suggested that bentonite appeared to offer protection or shield the viruses from chlorine dioxide disinfection. Another study using bentonite reduced chlorine dioxide disinfection capability against *Naegleria* cysts by 11% at turbidities less than or equal to 5 NTU and 25% at turbidities between 5 and 17 NTUs (reference 5). Clumped or aggregated microorganisms are also shown to be more resistant to chlorine dioxide disinfection (reference 5). In the presence of organic matter chlorine dioxide rapidly oxidizes the organic matter and is converted to primarily chlorite, and to a lesser extent chlorate and chloride ion (reference 3). This results in loss of chlorine dioxide residual and an increase in chlorite ion leading to reduced disinfection capability. Turbidity does have an effect on chlorine dioxide disinfection capability. Chlorine dioxide disinfection capability decreases in more turbid waters since microorganisms are protected by solid particles in water, protected by aggregation or clumping, and protected by loss of chlorine

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dioxide residual from oxidation of organic matter. Higher chlorine dioxide dosages may be necessary when using IWPDs to overcome organic matter oxidation and still provide disinfection when treating raw, unfiltered water supplies.

### **Bactericidal Capability**

Chlorine dioxide is an effective bactericide. Research on chlorine dioxide bactericidal capability shows bacteria are less resistant than viruses and cysts (reference 13). Studies using *E. Coli* showed 2-log inactivation occurred very quickly in demand-free waters (i.e., no organic matter present) with CT's all less than 1.0 mg-min/L, ranging from 0.25 – 0.48 mg-min/L, at the coldest water temperatures (5° C) and lowest pH levels (6.5 - 7.0) (i.e., worst case conditions, references 13, 21). Another study estimated CTs of 1 or less at 5° C necessary for a 4-log *E. Coli* inactivation (reference 22). Chlorine dioxide should easily achieve a 6-log bacteria inactivation at low temperatures and low pHs if chlorine dioxide is used for disinfection of more resistant viruses and cysts. Highly turbid water may require higher CT (i.e., longer contact time and/or higher dose).

### **Virucidal Capability**

Chlorine dioxide is an effective virucide. Research shows viruses are more resistant than bacteria but less resistant than cysts (reference 13). Similar to bactericidal capability, viruses are rapidly inactivated (reference 13). Experiments conducted under worst case conditions (5° C water temperature in the 6 – 7 pH range) resulted in CT's of 5.5 mg-min/L for a 2-log Poliovirus 1 inactivation and 12.6 mg-min/L for a 4-log Hepatitis A virus inactivation (references 13 and 16). The SWTR provides the following CT values for 4-log virus inactivation at various water temperatures with pH 6-9 (reference 19):

**Table 1. EPA Surface Water Treatment Rule (SWTR) Required CT Values for 4-Log Inactivation of Viruses by Chlorine Dioxide for pH 6-9**

|  | <b>Temperature (deg C)</b> |          |           |           |           |           |
|--|----------------------------|----------|-----------|-----------|-----------|-----------|
|  | <b>&lt;= 1</b>             | <b>5</b> | <b>10</b> | <b>15</b> | <b>20</b> | <b>25</b> |
|  | 50.1                       | 33.4     | 25.1      | 16.7      | 12.5      | 8.4       |

The data used to develop Table 1 were based on experiments conducted in low turbidity waters under otherwise worst case conditions, 5° C water temperature and pH 6. These CT values are based on low turbidity waters since it is assumed water systems provide disinfection after

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filtration, as the last treatment step prior to distribution. Higher turbidity waters may require higher CT to achieve the same log inactivation. Separate CT values for different pHs were not developed since chlorine dioxide is generally a more effective disinfectant at higher pHs. Therefore, these CT values are more conservative at the higher pHs (reference 19). A safety factor of 2 was applied to the data to determine CT values in Table 1 (reference 19). The CT values at temperatures other than 5° C in the Table were determined by using a two-fold increase in CT for every 10° C decrease (reference 19). Even at cold water temperatures, low pHs, and low turbidity waters, CTs appear realistic and achievable. Based on a typical chlorine dioxide dosage of 2.0 mg/L for a water system, contact times of 4-25 minutes are necessary to achieve CT values in Table 1. A chlorine dioxide dose of 0.8 mg/L [EPA’s Maximum Residual Disinfectant Level (MRDL) for chlorine dioxide] results in contact times of 11-63 minutes which are still reasonable for IWPD use. Highly turbid water may require higher CT (i.e., longer contact time and/or higher dose).

**Cysticidal Capability**

*Giardia Cysts*

Chlorine dioxide is effective against *Giardia* cysts. One study showed CTs ranging from 1.7-17.6 mg-min/L necessary for 2-log *Giardia muris* cyst inactivation (reference 23). The SWTR provides the following CT values for 3-log inactivation of *Giardia* cysts at various water temperatures with pH 6-9 (reference 19):

**Table 2. EPA SWTR Required CT Values for 3-Log Inactivation of *Giardia* Cysts by Chlorine Dioxide for pH 6-9**

| Temperature (deg C) |    |    |    |    |    |
|---------------------|----|----|----|----|----|
| <= 1                | 5  | 10 | 15 | 20 | 25 |
| 63                  | 26 | 23 | 19 | 15 | 11 |

Data used to develop Table 2 were based on experiments conducted in low turbidity waters at pH 7 and water temperatures ranging from 1 - 25° C for 2-log *Giardia* cyst inactivation (reference 19). Determining 3-log inactivation at all temperatures listed in Table 2 required extrapolation using first order kinetics and applying a safety factor of 1.5 (reference 19). Based on Table 2 it appears chlorine dioxide is effective against *Giardia* cysts at realistic and achievable CT values. Based on a typical chlorine dioxide dosage of 2.0 mg/L for a water system, contact times of 6 - 32 minutes, depending on temperature, are necessary to achieve the CT values in Table 2. These contact times are also reasonable for IWPDs. A chlorine dioxide

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dose of 0.8 mg/L (EPA’s MRDL for chlorine dioxide) results in contact times of 14 - 79 minutes which are still reasonable for IWPD use. Highly turbid water may require higher CT (i.e., longer contact time and/or higher dose).

*Cryptosporidium Oocysts*

Chlorine dioxide appears effective against *Cryptosporidium* oocysts at CT values achievable by water systems. Studies show 3-log *Cryptosporidium* inactivation varied from a CT of 70 mg-min/L to 400 mg-min/L under various water quality conditions (reference 5). *Cryptosporidium* is more resistant than *Giardia* cysts; up to 8-16 times more resistant (reference 5). Similar to bacteria, viruses, and other cysts, chlorine dioxide, in general, is more effective against *Cryptosporidium* oocysts at higher pHs and higher temperatures (reference 5). However, there is data suggesting pH has a negligible effect on inactivation of *Cryptosporidium* (reference 17). Pursuant to the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR), the EPA proposed chlorine dioxide CT tables for various log inactivations of *Cryptosporidium* (reference 24) based on studies conducted using low turbidity waters. The proposed CT values for 3-log *Cryptosporidium* inactivation are shown in Table 3. These doses are conservative and were developed using a safety margin to account for variability and uncertainty in the experimental data (reference 24).

**Table 3. EPA Proposed CT Values for 3-Log Inactivation of *Cryptosporidium* Oocysts by Chlorine Dioxide for pH 6-9**

|      |      | Temperature (deg C) |     |     |     |
|------|------|---------------------|-----|-----|-----|
| 1    | 5    | 10                  | 15  | 20  | 25  |
| 1830 | 1286 | 830                 | 536 | 347 | 226 |

Based on a typical chlorine dioxide dosage of 2.0 mg/L for a water system, contact times of 115 - 915 minutes (2 - 15 hours), depending on temperature, are necessary to achieve the CT values in Table 3. For water systems, these CT values are realistic and achievable at warmer water temperatures. Higher than typical chlorine dioxide dosages would be necessary for a water system to achieve the proposed CTs in colder waters (i.e., less than 10° C). Based on this Table, use of an IWPD would be practical in only warmer waters (i.e., above 10° C). Highly turbid water may require even higher CT values (i.e., longer contact time and/or higher dose). Chlorine dioxide is effective against *Cryptosporidium* oocysts in warmer, low turbidity waters.

## **CHLORINE DIOXIDE TOXICITY**

### **Health Effects of Chlorine Dioxide and Chlorite**

Chlorine dioxide and its byproducts, chlorite and chlorate ion can result in adverse health effects when consumed at large enough quantities. The EPA regulates chlorine dioxide and chlorite ion in drinking water for systems using chlorine dioxide for disinfection. The EPA established a MRDL of 0.8 mg/L for chlorine dioxide and a maximum contaminant level (MCL) of 1.0 mg/L for chlorite (reference 25). The most common adverse health effects of chlorine dioxide and chlorite ion are oxidizing effects seen in the blood, either as methemoglobinemia or hemolytic anemia (reference 3). Children, infants, and fetuses, a more susceptible subpopulation may experience adverse neurotoxic effects (reference 26). When a regulated water system using chlorine dioxide is out of compliance with the chlorine dioxide MRDL or chlorite MCL, the EPA considers this to have a significant potential to have serious adverse health effects as a result of short-term exposure (reference 27). However, the short-term adverse health effects are limited to children, infants, and fetuses. It is these groups that may be susceptible to adverse nervous system effects from short-term exposure (reference 27). Health effect data for healthy adults appear to indicate that short-term exposure does not result in adverse health effects. Several clinical studies assessing the acute and subchronic effects of chlorine dioxide, chlorite, and chlorate have been conducted (reference 3). Healthy adults consuming 2.5 mg daily of either chlorine dioxide, chlorite, or chlorate for 12 weeks showed no clinically significant adverse health effects (reference 3). Another study had healthy adults consuming 0.1 to 24 mg/L concentrations of either chlorine dioxide, chlorite, or chlorate daily for 3 weeks, again resulting in no clinically significant adverse health effects. Based on this information, it is not likely that healthy adults consuming water containing chlorine dioxide concentrations recommended by IWPD manufacturers (0.7 – 7.5 mg/L) for a short duration (e.g., < 3 weeks) would experience any adverse health effects from ingestion of chlorine dioxide, chlorite, or chlorate. However, adverse health effects could occur if higher chlorine dioxide dosages are used for treating highly turbid and/or colder water to kill *Cryptosporidium*. To avoid potential adverse health effects, longer contact times should be used in place of higher chlorine dioxide dosages, provided sufficient chlorine dioxide remains after oxidizing organic matter.

### **Health Concerns of Stabilized Chlorine Dioxide**

The use of “stabilized chlorine dioxide” products for IWPD use may expose the user to significant chlorite concentrations. The “activation” of stabilized chlorine dioxide (i.e., sodium chlorite) with an acid can result in high levels of chlorite remaining after activation and relatively low chlorine dioxide concentrations compared to typical chlorine dioxide generating systems (reference 3). Use of these products may result in the direct application of several hundred mg/L of chlorite to the water, much higher than typical drinking water chlorite levels (reference 3).

**CONCLUSIONS**

Chlorine dioxide as an IWPD can be effective against bacteria, viruses, *Giardia* cysts, and to a limited extent, *Cryptosporidium* oocysts. Very high CT values are estimated for a 3-log *Cryptosporidium* inactivation in colder waters, requiring very high chlorine dioxide dosages and/or very long contact times. Colder temperatures, lower pHs, and higher turbidity all tend to have an adverse effect on disinfection capability. Health concerns of ingesting chlorine dioxide and chlorite ion are likely minimal for healthy adults over a short-term duration (e.g., < 3 weeks) for IWPD manufacturer-recommended chlorine dioxide dosages of 0.7 – 7.5 mg/L. However, adverse health effects could occur if higher chlorine dioxide dosages are used for treating highly turbid and/or colder water to kill *Cryptosporidium*. To avoid potential adverse health effects, longer contact times should be used in place of higher chlorine dioxide dosages, provided sufficient chlorine dioxide remains after oxidizing organic matter. IWPDs using “stabilized chlorine dioxide” may result in exposure to high levels of chlorite. Table 4 provides a summary of chlorine dioxide’s disinfection capabilities.

**Table 4. Chlorine Dioxide Disinfection Capabilities**

| Parameter                       | Chlorine Dioxide Disinfection  |
|---------------------------------|--|
| General Disinfection Capability | Cysts most resistant. Achieving cyst inactivation will ensure adequate bacteria and virus inactivation. Disinfection capability generally follows:<br>Bacteria > viruses > <i>Giardia</i> > <i>Cryptosporidium</i> |
| Bacteria                        | Effective at reasonable CT values for IWPD use   |
| Viruses                         | Effective at reasonable CT values for IWPD use. Use EPA SWTR CT table for recommended CT values (Table 1).   |
| <i>Giardia</i> Cysts            | Effective at reasonable CT values for IWPD use. Use EPA SWTR CT table for recommended CT values (Table 2).   |
| <i>Cryptosporidium</i> Oocysts  | Effective at high CT values. Use Table 3 as guide for CT values. If possible, use longer contact times instead of higher dosages to achieve adequate CT values.  |
| Effect of Temperature           | Colder water temperatures require higher CT values. Use a two-fold increase in CT for every 10° C decrease. Use longer contact time instead of higher dosages to achieve higher CT values.                         |

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|                     |  |
|---------------------|--|
| Effect of pH        | Effective over typical pH levels for raw, untreated natural waters. Disinfection capability generally increases with increasing pH.  |
| Effect of Turbidity | Higher turbidity generally reduces disinfection capability. Use longer contact time instead of higher dosages in more turbid waters to achieve CT values. Higher dosages may be necessary to ensure chlorine dioxide remains after oxidation of organic matter.                  |
| Health Effects      | Chlorine dioxide and chlorite are potential health concerns. IWPD manufacturer-recommended dosages are not likely to cause adverse health effects for healthy adults. Exposure to much higher chlorite concentrations may occur when using stabilized chlorine dioxide products. |

**PREPARED BY:** Steven H. Clarke, Environmental Engineer

**DATED:** March 2006

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