USING A DECISIONMAKING SYSTEM TO EVALUATE DRINKING WATER TREATMENT ALTERNATIVES

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Water, Earth's most precious resource covers 70% of it, but only a small percentage is available for consumption. Without water, life can not exist. Without water, our deployed soldiers can not execute their contingency missions. Currently, our soldiers consume bottled water to prevent disease from contaminated water. However, consuming bottled water comes at a price and according to a 2003 DoD study, that price is $4.69 a gallon [8]. This may seem high, but this water must be convoyed to our soldiers. In addition, these convoys are exposed to improvised explosive devices along the supply routes and securing the cargo is a difficult task [1]. For planning purposes, the average soldier consumes 2 gallons of potable water per day. Therefore 20,000 soldiers equates to over 40,000 gallons of water or $150,000 per day. While the military has the capability to treat indigenous water supplies, typically the treated water is used for hygiene purposes, not for drinking.

The military has the capability of producing clean and disease free water through The Reverse Osmosis Water Purification Unit (ROWPU). The ROWPU is a skid mounted, mobile, or air transportable unit capable of purifying fresh, brackish, and salt water at a rate of 600 gallons per hour [9]. It weighs 3.5 tons, requires a 22- kilowatt power source and can operate for 20 continuous hours a day. The ROWPU works in three stages. The first stage coagulates suspended solids. The second stage forces the water through a finer set of filters. The third stage, chlorination accomplishes the disinfection. The filter elements are critical to the operation of the ROWPU and have a service life between 1,000 to 2,000 hours [6]. Therefore, the filters limit how long the ROWPU can operate. Pretreating the water can extend ROWPU filter service life.

Ultrafiltration (UF) and nanofiltration (NF) provides a potential water pretreatment solution. UF and NF are pressure-driven processes that separate impurities from water by forcing water through a membrane where pore size determines what constituents are separated from the water. The spiral wound and hollow fiber technologies are the most widely available [2].

In addition to pretreatment, post treatment of water can be accomplished to disinfect the water prior to consumption versus chlorination which requires additional supplies, increasing convoy exposure. Two types of post treatment technologies exist that have a small footprint and rely on power to operate. These two types are electrodeionization and ultraviolet disinfection.

Electrodeionization (EDI) is a continuous and chemical-free process to remove ionized and ionizable species from feed water using direct current. EDI is typically used to polish RO permeate and to replace conventional ion exchange mixed beds, thereby eliminating the need to store and handle hazardous chemicals [3].

Deciding which pre and post treatment technologies that should be implemented can be a difficult task. Many decision analysis tools exist one of which is Choosing by Advantages (CBA). CBA uses three sound decision-making concepts: alternatives, attributes, and advantages. The method is meant to be simpler than other decision-making tools because it does not consider disadvantages like most other decision tools [7]. The suggested alternatives are evaluated based on their relative advantages, considering their disadvantages is double-counting. Therefore, the CBA decision-making process is less time consuming and more focused on selecting the best option from a list of attributes and advantages.

Table 1 shows UF hollow fiber is more advantageous than UF spiral wound pretreatment alternatives. UF hollow fiber has more options for physical backwash and chemical cleanings. UF hollow fiber operates at a lower pressure and can have a longer service life. It has a larger pre-filter requirement and can work in both dead end and crossflow modes. Finally, UF hollow fiber has a lower power consumption.

Our recommendation is to include both pre- and post-treatment alternatives to achieve the longest serving, highest quality water. This treatment train would be UF hollow fiber, followed by reverse osmosis and then disinfected using electrodeionization. According to Knops et al., "pilot tests have shown that with UF [hollow fibers] as pretreatment RO cleaning frequency can be virtually eliminated." Because of the reduced RO fouling and reduced cleaning with harsh chemicals, cleaning frequency can be reduced and the RO membrane lifetime will be increased [4]. Combined with RO pre-treatment, EDI removes more than 99.9% of ions from the water [5]. EDI has low energy, operating, and maintenance costs. EDI's small footprint makes it well-suited for use in deployed locations.

The views expressed in this paper are those of the authors and do not reflect the official policy or position of the United States Air Force, The Department of Defense, or the United States Government.

References:
[1] Bowen, Jennifer A. "U.S. Mission in Afghanistan Depends on Supply Chain," McClatchy, 4 November 2009, http://www.mcclatchydc.com/2009/11/04/78367/us-mission-in-afghanistan-depends.html.
[2] Crown Solutions Incorporated. "Filtration UF, MF, NF." Excerpts from unpublished article. Vandalia OH, August 2003.
[3] DOW Water and Process Solutions. Product Form No. 795-00006-0608XBBI. USA: The Dow Chemical Company, June 2008.
[4] Knops, Frans, Stephan van Hoof, Harry Futselaar, and Lute Broens. "Economic evaluation of a new ultrafiltration membrane for pretreatment of seawater reverse osmosis," *Desalination*, 203: 300-306 (April 2007).
[5] *Lenntech Water Treatment Solutions.* Electrodeionization. The Netherlands: Lenntech Water treatment & purification Holding B.V., February 2010 http://www.lenntech.com/library/edi/edi.htm.
[6] Pike, John. "Reverse Osmosis Water Purification Unit (ROWPU)," GlobalSecurity.org. 23 December 2009. http://www.globalsecurity.org/military/systems/ground/rowpu.htm.
[7] Suhr, Jim. *Choosing By Advantage: Making Choices Correctly.* Utah: Decision Innovations, 2008.
[8] United States Army Center for Health Promotion and Preventive Medicine (USACHPPM). *Executive Summary Water Quality Information Paper NO. 31-034 Use of Bottled Water for Deployment Support.* MCHB-TS-EWS. Maryland: GPO, 2003.
[9] United States Marine Corps. *Operators' Manual: Water Purification Unit, Reverse Osmosis, 600 GPH Trailer Mounted Flatbed Cargo, 5 ton 4 Wheel Tandem ROWPU Model 600-1 and 600 GPH Skid Mounted ROWPU Model 600-3.* TM08580A-10/1. Washington: HQ USMC, 5 March 1991.

Table 1: Pre-Treatment CBA Analysis

Attributes	UF Hollow Fiber	UF Spiral Wound
Attribute: Physical Backwash Criteria: Ability to perform physical backwash is better	Possible	Not generally
Advantage	More Options	
Importance	70	
Attribute: Chemical Cleanings Criteria: The more chemical cleaning options the better	CIP or CEB	CIP possible
Advantage	More Options	
Importance	80	
Attribute: Operating Pressures Criteria: Lower pressure range is more desirable	5-30 psi	20-100 psi
Advantage	Less Pressure	
Importance	90	
Attribute: Membrane Life Criteria: Less variation increases predictability	7-10 years	8 years
Advantage		More Predictable
Importance		60
Attribute: Pre-filter Requirements Criteria: The ability to remove a smaller size particle will extend the life of the filter	100-500 micron strainer	5 micron cartridge filter
Advantage	Smaller is Better	
Importance	50	
Attribute: Operating mode Criteria: More operating modes support more water sources	Dead-end or Crossflow	Crossflow
Advantage	More Options	
Importance	60	
Attribute: Valves Criteria: Less controls promotes simple operation	Requires several valves for backwash sequence	Can be operated with manual valves
Advantage		More Simple
Importance		60
Attribute: Control Criteria: Less controls promotes simple operation	Requires transmitters to monitor performance	Simple indicators for manual adjustment
Advantage		More Simple
Importance		70
Attribute: Break Tank Criteria: No break tank will reduce time and footprint	Requires break tank to to continuously feed RO when off-line for backwash	Operates continuously so no break tank before RO system is required
Advantage		Less Interpretation is Better
Importance		70
Attribute: Availability of Membrane Replacement Criteria: More available options for purchasing replacement filters can save money and time	Each system is proprietary, with spare membranes only available from manufacturer	Spirals are a standard size, with replacements available from several vendors
Advantage		More Options
Importance		90
Power Consumption Criteria: Lower energy consumption reduces cost	0.2-0.3 kWh/kgal	0.2-0.8 kWh/kgal
Advantage	Less Power is Better	
Importance	90	
Total Importance	**440**	340