# Achieving U.S. Safe Drinking Water Standards Using Distillation Desalination

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Distillation as a desalination technology is not commonly used in the United States for producing potable drinking water. Reverse osmosis (RO), which uses thin film membranes, has been the preferred choice. Distillation has been labeled as more expensive because of the perceived higher usage of energy associated with heating water and higher capital costs.

Today's distillation technologies, which include Multi-Effect Distillation (MED) and Mechanical Vapor Compression (MVC), can be cost-competitive, especially when they are collocated with a power plant or resource-recovery facility such as an incinerator or refinery, where a source of waste steam is available. Thermal technologies can utilize this steam—which would otherwise be lost in the form of stack gases, cooling-water streams, or low-pressure exhaust steam—as a primary or supplemental source of heat for distillation.

This is accomplished, in part, by the use of thermo-compressors and vacuum ejectors. The vacuum ejectors lower the effective temperature needed to achieve boiling from 100° C (212° F) at 1.0 absolute atmosphere to below 70° C (158° F) at 0.34 absolute atmosphere.

The EcoEléctrica Power Plant, located on Puerto Rico's southern coast, is the first facility of its type combining a 507-megawatt power plant, a liquid natural-gas terminal, and a seawater distillation desalination facility—all financed in a single project. The power plant consists of two gas-combustion turbines and one steam turbine. Each produces waste steam, a byproduct that is used by two 3,785 $m^3$/day (1-mgd) MED units to distill seawater from the Caribbean Sea, producing cooling water for a nearby power plant and potable drinking water for EcoElectrica and the Puerto Rico Aqueduct Sewer Authority (PRASA) for distribution to surrounding communities.

As a commonwealth of the United States, Puerto Rico requires its drinking-water providers to meet all regulations as issued and enforced under the Safe Drinking Water Act (SDWA). Included in these regulations are the Primary Drinking Water Standards, which list limits referred to as Maximum Contaminant Levels (MCLs) for 83 contaminants and specified treatment techniques for nine other contaminants. The U.S. Environmental Protection Agency (EPA) has also established Secondary Drinking Water Standards and an Unregulated Contaminant List, neither of which are enforced but are provided as goals.

## Desalination Plant Description

**Figure 1** shows a process diagram of EcoEléctrica's seawater desalination water-treatment plant. The plant includes:

(1) Intake Structure
(2) Pretreatment/preconditioning
(3) Multi-effect distillation (MED) units
(4) Raw water storage tank
(5) Remineralization system
(6) Chlorine disinfection
(7) Service/fire water storage tank
(8) Supply pumps

**Intake Structure:** Seawater is pumped to the desalination plant through an intake structure located approximately 1,000 yards offshore, adjacent to an unloading pier for liquid natural gas. The intake structure is divided into three separate chambers, each provided with a bar screen to remove debris and a submerged centrifugal pump.

**Pretreatment/Preconditioning:** The seawater is first filtered through two course filters to remove medium-to-large solid particles. It is then passed through two ion traps to remove trace amounts of copper and heavy metals that could corrode the aluminum tubes in the distillation units. Inside each ion trap are low-grade aluminum rings that serve as a sacrificial source for corrosion, preventing such corrosion from occurring within the distillation units.

Depending on the water quality, four different chemicals may be added: a disinfectant, a macrofouling inhibitor, a scale inhibitor, and an anti-foam emulsion. A disinfectant is added at the intake structure to minimize the attachment and proliferation of sulfate-reducing bacteria that cause pinhole leaks in the stainless-steel supply lines. A macrofouling inhibitor is also added to control biological fouling. A scale inhibitor is used to minimize the buildup of scale on the heat-transfer tubes. An anti-foam emulsion is added to reduce foaming in the flash chambers caused by high concentrations of certain marine organisms.

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**Multi-Effect Distillation (MED) Units:** Two distillation units manufactured by IDE Technologies Ltd. of Ra'anana, Israel, are used to distill the pretreated/preconditioned seawater. Each unit is capable of producing 1 million gallons of product water or distillate per day (1-mgd). The units utilize IDE's low-temperature, horizontal-tube, falling-film MED process. Each unit consists of a heat-rejection condenser and four

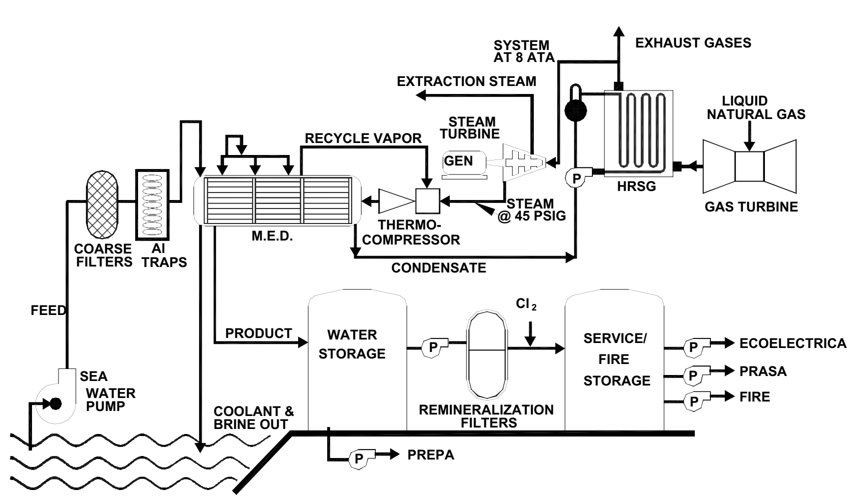


Figure 1: Process diagram of EcoEléctrica's seawater distillation desalination facility

vaporization/condensation effects.

The seawater is fed into the heat-rejection condenser, where it adsorbs the heat rejected from the fourth effect while being de-aerated. The now-preheated seawater is split into two streams: one discharging to the sea with the brine discharge and the other feeding the distillation unit.

Inside each effect are a series of spray nozzles that distribute the seawater over a bank of heated tubes, vaporizing part of the flow into steam. This steam flows through a series of special demisters to the cooler condensing section of the next effect, where it is condensed into the product water or distillate.

The remaining flow, now slightly more concentrated, is pumped to the second, third, and fourth effects, where the spray-vaporization procedure is repeated to produce additional distillate. From the fourth effect (the hottest effect), however, the remaining flow is discharged as a concentrated brine, which is cascaded through a series of flashing tanks where it is cooled before being returned to the sea. The collected distillate is then discharged and pumped to the post-treatment system.

Because the MED units utilize a vacuum to enhance boiling, the temperature of distillate in each effect is lower than would be expected at atmospheric conditions. Distillate water temperatures in each effect are reported as 57.7, 61.2, 64.7, and 67.7° C (Email communications with Ben Yaish Jacky, IDE Technologies, 2000).

The distillate remains at these temperatures for approximately two minutes before becoming mixed with the distillates from the other effects. Since the flow rates from each of the effects are almost equal, an average temperature for the distillate of 62.8° C can be assumed (Email communications with Ben Yaish Jacky, IDE Technologies, 2000).

**Raw-Water Storage Tank:** The distillate streams from the second, third, and fourth effects are combined and pumped into a 250,000-gallon raw-water storage tank. This water supplies the remineralization system, backwash of the remineralization system, and PREPA's South Coast Power Station.

Distillate from the first effect is pumped out separately and discharged to a 100,000-gallon condensate storage tank. This water is polished and stored in a 750,000-gallon demineralized-water storage tank for use as boiler feed water for the power plant.

**Remineralization System:** The distillate is remineralized by passing it through two limestone filters, adding dissolved calcium carbonate into the water. Sulfuric acid is injected to lower the pH of the distillate ahead of the limestone filters, enhancing the dissolution of the calcium carbonate. Caustic soda is then injected to neutralize the pH prior to chlorine disinfection with sodium hypochlorite.

**Service/Fire Water Storage Tank:** The disinfected water is stored in a 400,000-gallon service/fire-water storage tank. A standpipe drain mounted within the tank is used to draw off potable water from the top quarter of the tank, or 100,000 gallons. This water is pumped to EcoEléctrica's service-water and potable-water systems and PRASA. The

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Table 1: Final Primary Drinking Water Contaminant Standards

| Contaminant | Reporting Units | Effective | Maximum Contaminant Level Goal (MCLG) | Maximum Contaminant Level (MCL) | SDWA Compliance Sample (a) | Compliant (yes/no) |
|---|---|---|---|---|---|---|
| **Fluoride Rule (b)** | | | | | | |
| Fluoride | mg/L | Now | 4.0 | 4.0 | <0.050 | yes |
| **Phase I Rule - Volatile Organics (c)** | | | | | | |
| Benzene | mg/L | Now | Zero | 0.005 | <0.00050 | yes |
| Carbon Tetrachloride | mg/L | Now | Zero | 0.005 | <0.00050 | yes |
| p-dichlorobenzene | mg/L | Now | 0.075 | 0.075 | <0.00050 | yes |
| 1,2-dichloroethane | mg/L | Now | Zero | 0.005 | <0.00050 | yes |
| 1,1-dichloroethylene | mg/L | Now | 0.007 | 0.007 | <0.00050 | yes |
| Trichloroethylene | mg/L | Now | Zero | 0.005 | <0.00050 | yes |
| 1,1,1-trichloroethane | mg/L | Now | 0.2 | 0.2 | <0.00050 | yes |
| Vinyl chloride | mg/L | Now | Zero | 0.002 | <0.00050 | yes |
| **Phase II Rule – Inorganics (d)** | | | | | | |
| Asbestos fibers (>10 µm) | MFL (e) | Now | 7 | 7 | <0.20 | yes |
| Barium | µg/L | Now | 2000 | 2000 | <10 | yes |
| Cadmium | µg/L | Now | 5 | 5 | <1.0 | yes |
| Chromium (total) | µg/L | Now | 10 | 10 | <5 | yes |
| Mercury (inorganic) | µg/L | Now | 2 | 2 | <0.20 | yes |
| Nitrate | µg/L | Now | 10 | 10 | 0.11 | yes |
| Nitrite | µg/L | Now | 2 | 2 | <0.050 | yes |
| Nitrate + Nitrite | µg/L | Now | 10 | 10 | 0.11 | yes |
| Selenium | µg/L | Now | 50 | 50 | <2.0 | yes |
| **Phase II Rule – Organics (d, f)** | | | | | | |
| Acrylamide | mg/L | Now | Zero | TT (q) | (g) | NA |
| Alachlor | mg/L | Now | Zero | 0.002 | <0.0010 | yes |
| Aldicarb | mg/L | Delayed | - | - | <0.0020 | NA |
| Aldicarb sulfone | mg/L | Delayed | - | - | <0.0020 | NA |
| Aldicarb sulfoxide | mg/L | Delayed | - | - | <0.0020 | NA |
| Atazine | mg/L | Remanded | - | - | <0.0015 | NA |
| Carbofuran | mg/L | Now | 0.04 | 0.04 | <0.0020 | yes |
| Chlordane | mg/L | Now | Zero | 0.002 | <0.000020 | yes |
| Chlorobenzene | mg/L | Now | 0.1 | 0.1 | <0.00050 | yes |
| 2,4-D | mg/L | Now | 0.07 | 0.07 | <0.00011 | yes |
| o-Dichlorobenzene | mg/L | Now | 0.6 | 0.6 | <0.00050 | yes |
| cis-1,2-dichloroethylene | mg/L | Now | 0.07 | 0.07 | <0.00050 | yes |
| trans-1,2-dichloroethylene | mg/L | Now | 0.1 | 0.1 | <0.00050 | yes |
| Dibromochloropropane | mg/L | Now | Zero | 0.0002 | <0.000020 | yes |
| 1,2-dichloropropane | mg/L | Now | Zero | 0.005 | <0.00050 | yes |
| Epichlorohydrin | mg/L | Now | Zero | TT (g,q) | (g) | NA |
| Ethylbenzene | mg/L | Now | 0.7 | 0.7 | <0.00060 | yes |
| Ethylene dibromide | mg/L | Now | Zero | 0.00005 | <0.000010 | yes |
| Heptachlor | mg/L | Now | Zero | 0.0004 | <0.000030 | yes |
| Heptachlor epoxide | mg/L | Now | Zero | 0.0002 | <0.000010 | yes |
| Lindane | mg/L | Now | 0.0002 | 0.0002 | <0.000010 | yes |
| Methoxychlor | mg/L | Now | 0.04 | 0.04 | <0.000070 | yes |
| Pentachlorophenol | mg/L | Now | Zero | 0.001 | <0.000044 | yes |
| PCB 1016 | mg/L | Now | - | - | <0.00010 | NA |
| PCB 1221 | mg/L | Now | - | - | <0.00010 | NA |
| PCB 1232 | mg/L | Now | - | - | <0.00010 | NA |
| PCB 1242 | mg/L | Now | - | - | <0.00010 | NA |
| PCB 1248 | mg/L | Now | - | - | <0.00010 | NA |
| PCB 1254 | mg/L | Now | - | - | <0.00010 | NA |
| PCB 1260 | mg/L | Now | - | - | <0.00010 | NA |
| PCB Total | mg/L | Now | Zero | 0.0005 | <0.00010 | yes |

# Distillation

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remaining 300,000 gallons are used for fire protection at EcoEléctrica.

## Governing Standards

To be certified for distribution of potable water in Puerto Rico requires compliance with the SDWA's Primary Drinking Water Standards and standards imposed by Puerto Rico's Department of Health. Table 1 lists the regulated contaminants, their maximum contaminant level goals (MCLGs) and maximum contaminant levels (MCLs), and their reporting units. In addition, all chemicals added must be certified by the American National Standards Institute/National Sanitation Foundation International (ANSI/NSF) Standard 60 for potable water use as required by the Puerto Rico's Department of Health.

## Compliance with Maximum Contaminant Levels

Results from one SDWA sample collected after the service/fire-water storage tank, along with an indication of compliance with the primary standards (i.e., yes/no), are listed in the last two columns of Table 1. For the disinfection byproducts listed under Stage 1 of the Disinfectant/Disinfection Byproduct (D/DBP) Rule, seven-day (168-hour) formation potentials with chlorine were performed in the laboratory to ascertain their potential concentrations in the distribution system.

Based on results, the distillation desalination plant complied with all standards listed with an established MCL as currently regulated. For most of the contaminants, analyses indicate levels that are below detection limits. Only for a few, such as nitrate, ethylbenzene, toluene, xylenes, and trihalomethanes, and haloacetic acids, were contaminants detected. All were below current MCLs. Measured seven-day (168-hour) trihalomethane and haloacetic acid formation potentials of 0.0045 and 0.0067 mg/L, respectively, were an order of magnitude less than the MCLs required by Stage 1 of the D/DBP Rule of 0.080 and 0.060 mg/L, respectively.

Because of matrix interferences with seawater, influent concentrations could not be measured for the contaminants, making it impossible to assess removals by distillation. Although not listed, total organic carbon (TOC) concentrations were measured at different stages through the facility. Results showed reductions in TOC concentrations from 4.0 mg/L measured in the seawater to 1.2 mg/L after pretreatment/preconditioning to < 1.0 mg/L after distillation.

## Compliance with Treatment Techniques

Treatment techniques are listed for contaminants that can not be economically or feasibly measured. These include most of the microbiological contaminants such as viruses

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Table 1: Final Primary Drinking Water Contaminant Standards (continued)

| Contaminant | Reporting Units | Effective | Maximum Contaminant Level Goal (MCLG) | Maximum Contaminant Level (MCL) | SDWA Compliance Sample (a) | Compliant (yes/no) |
|---|---|---|---|---|---|---|
| **Phase II Rule - Organics con't. (d, f)** | | | | | | |
| Styrene | mg/L | Now | 0.1 | 0.1 | <0.00050 | yes |
| Tetrachloroethylene | mg/L | Now | Zero | 0.005 | <0.00050 | yes |
| Toluene | mg/L | Now | 1 | 1 | 0.0011 | yes |
| Toxaphene | mg/L | Now | Zero | 0.003 | <0.00018 | yes |
| 2,4,5-TP | mg/L | Now | 0.05 | 0.05 | <0.00022 | yes |
| Xylenes | mg/L | Now | 10 | 10 | 0.00093 | yes |
| **Phase V Rule – Inorganics (h)** | | | | | | |
| Antimony | µg/L | Now | 6 | 6 | <3.0 | yes |
| Beryllium | µg/L | Now | 4 | 4 | <1.0 | yes |
| Cyanide | mg/L | Now | 0.2 | 0.2 | <0.0050 | yes |
| Nickel | µg/L | Remanded | - | - | <10 | NA |
| Thallium | µg/L | Now | 0.5 | 2 | <1.0 | yes |
| **Phase V Rule – Organics (h)** | | | | | | |
| Adipate (di(2-ethylhexyl) | mg/L | Now | 0.4 | 0.4 | <0.0016 | yes |
| Dalapon | mg/L | Now | 0.2 | 0.2 | <0.0011 | yes |
| Dichloromethane | mg/L | Now | Zero | 0.005 | <0.00050 | yes |
| Dinoseb | mg/L | Now | 0.007 | 0.007 | <0.00022 | yes |
| Diquat | mg/L | Now | 0.02 | 0.02 | <0.00040 | yes |
| Dioxin | mg/L | Now | Zero | 30 | <1.5855 | yes |
| Endothall | mg/L | Now | 0.1 | 0.1 | <0.0090 | yes |
| Endrin | mg/L | Now | 0.002 | 0.002 | <0.000020 | yes |
| Glyphosate | mg/L | Now | 0.7 | 0.7 | <0.0060 | yes |
| Hexachlorobenzene | mg/L | Now | Zero | 0.001 | <0.00010 | yes |
| Hexachlorocycle-pentadiene | mg/L | Now | 0.05 | 0.05 | <0.00010 | yes |
| Oxamyl (vydate) | mg/L | Now | 0.2 | 0.2 | <0.002 | yes |
| PAHs (benzo(a)-pyrene) | mg/L | Now | Zero | 0.0002 | <0.00010 | yes |
| Phthalate (di(2-ethlhexyl) | mg/L | Now | Zero | 0.006 | <0.0020 | yes |
| Picloram | mg/L | Now | 0.5 | 0.5 | <0.00011 | yes |
| Simazine | mg/L | Now | 0.004 | 0.004 | <0.0015 | yes |
| 1,2,4-Trichlorobenzene | mg/L | Now | 0.07 | 0.07 | <0.00050 | yes |
| 1,1,2-Trichloroethane | mg/L | Now | 0.003 | 0.005 | <0.00050 | yes |
| **Lead and Copper Rule (i)** | | | | | | |
| Lead | µg/L | Now | Zero | TT (j,q) | <1.0 | yes |
| Copper | µg/L | Now | 1,300 | TT (k,q) | <10 | yes |
| **Standards for Radionuclides (l)** | | | | | | |
| Beta/photon emitters | pCi/L | Now | Zero | 50 | <1.0+/-0.5 | yes |
| Alpha emitters | pCi/L | Now | Zero | 15 | <0.8+/-0.4 | yes |
| Radium 226 | pCi/L | Now | Zero | 20 | <0.3+/-0.2 | yes |
| Radium 228 | pCi/L | Now | Zero | 20 | <0.9+/-0.6 | yes |
| Uranium | µg/L | Now | Zero | 30 | No data | No data |
| **Standards for Arsenic (m)** | | | | | | |
| Arsenic | mg/L | Now | - | 0.01 | <0.0050 | yes |
| **Stage 1 Disinfectant/Disinfection By-Product (D/DBP) Rule (n)** | | | | | | |
| Bromate ion | mg/L | Now | Zero | 0.01 | < 0.005 | yes |
| Chlorite ion | mg/L | Now | 0.8 | 1.0 | <0.010 | yes |
| Total trihalomethanes | | | | | | |
| Chloroform | mg/L | Now | | | 0.0013 (o) | NA |
| Bromoform | mg/L | Now | Zero | | <0.00050 (o) | NA |
| Bromodichloromethane | mg/L | Now | Zero | | 0.0020 (o) | NA |
| Dibromochloromethane | mg/L | Now | 0.06 | | 0.0012 (o) | yes |
| Total | mg/L | Now | Zero | 0.080 | 0.0045 (o) | yes |

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and protozoan cysts. Treatment techniques are also required in cases where the analytical method is either not available or not reliable for a particular contaminant.

The Surface Water Treatment Rule (SWTR), Interim Enhanced Surface Water Treatment Rule (IESWTR), and Long-Term 1 Enhanced Surface Water Treatment Rule (LT1ESWTR) were developed to reduce pathogenic contaminants in drinking water. The SWTR requires systems using surface water to disinfect and physically remove and/or inactivate 3-logs (99.9 percent) of Giardia and 4-logs (99.99 percent) of viruses. The IESWTR expanded on the SWTR by requiring systems to physically remove 2-logs (99 percent) of cryptosporidium and included groundwater systems that are determined to be under the direct influence of surface-water contamination.

Relevant to distillation is the requirement to demonstrate by pilot studies or other means that an alternative filtration technology in combination with disinfection can consistently achieve these stated removals and/or inactivation limits. The LT1ESWTR expands on the IESWTR by requiring systems serving less than 10,000 people to comply.

Distillation can remove microbial contaminants by both physical removal and heat sterilization inactivation. Physical removal occurs as a result of the water being evaporated in one chamber and condensed in another. This change in state from a liquid to a vapor and back to a liquid creates a physical barrier preventing microbial contaminants from transmitting from the feed water to the distillate. Rose, et al (1999), demonstrated using a three-stage, multi-effect

Table 1: Final Primary Drinking Water Contaminant Standards (concluded)

| Contaminant | Reporting Units | Effective | Maximum Contaminant Level Goal (MCLG) | Maximum Contaminant Level (MCL) | SDWA Compliance Sample (a) | Compliant (yes/no) |
|---|---|---|---|---|---|---|
| | | | | | | |
| **Stage 1 Disinfectant/Disinfection By-Product (D/DBP) Rule continued (n)** | | | | | | |
| Haloacetic Acids | | | | | | |
| Monochloroacetic acid | mg/L | Now | Zero | | <0.002 (o) | NA |
| Dichloroacetic acid | mg/L | Now | Zero | | 0.0032 (o) | NA |
| Trichloroacetic acid | mg/L | Now | 0.03 | | 0.0016 (o) | Yes |
| Monobromoacetic acid | mg/L | Now | Zero | | <0.001 (o) | NA |
| Dibromoacetic acid | mg/L | Now | Zero | | 0.0019 (o) | NA |
| Total | mg/L | Now | Zero | 0.060 | 0.0067 (o) | Yes |
| | | | | | | |
| Disinfectants | | | | | | |
| Chlorine | mg/L Cl2 | Now | 4 | 4 | No data | No data |
| Chloramines | mg/L Cl2 | Now | 4 | 4 | < 0.50 | No data |
| Chlorine Dioxide | mg/L ClO2 | Now | 0.3 | 0.8 | No data | No data |
| | | | | | | |
| **Total Coliform Rule (p)** | | | | | | |
| Escherichia coli | NA | Now | Zero | | NA | (q) |
| Fecal coliforms | NA | Now | Zero | TT (r) | NA | (q) |
| Total coliforms | NA | Now | Zero | (s) | NA | (q) |
| | NA | | | | | |
| **Surface Water Treatment Rule (t)** | | | | | | |
| Giardia lamblia | NA | Now | Zero | TT (q) | NA | (q) |
| Heterotrophic bacteria | Colony/mL | Now | Zero | < 500 | NA | (q) |
| Legionella | NA | Now | Zero | TT (q) | NA | (q) |
| Viruses | NA | Now | Zero | TT (q) | NA | (\q) |
| Turbidity | NA | Now | Zero | PS (u) | No Data | No Data |
| | | | | | | |
| **Interim and Long Term 1 Enhanced Surface Water Treatment Rule (u)** | | | | | | |
| Cryptosporidium | NA | Now | Zero | TT (r) | NA | (w) |
| Profiling and Benchmarking | NA | Now | NA | NA | NA | (x) |
| Turbidity | NA | Now | Zero | PS (u) | No Data | No Data |
| | | | | | | |

(a) Safe Drinking Water Act (SDWA) Compliance Sample.
(b) USEPA. "National Primary and Secondary Drinking Water Regulations; Fluoride." Federal Register, 51, 1986: 11396-11412.
(c) USEPA. "National Primary Drinking Water Regulations; Synthetic Organic Chemicals; Monitoring for Unregulated Contaminants." Federal Register, 52, 1987: 25690-2517.
(d) USEPA. "Draft Drinking Water Health Criteria Document for Haloacetonitriles, Chloropicrin, and Cyanogen Chloride". Washington D.C.: Criteria and Standards Divisions, Office of Drinking Water, 1991.
(e) Million of fibers per liter.
(f) USEPA. "National Primary Drinking Water Regulations: Synthetic Organic chemicals." Federal Register, 56, 1991: 30266-30281.
(g) An approved analysis method has not been determined or published.
(h) USEPA "National Primary and Secondary Drinking Water Regulations; Synthetic Organic Chemicals and Inorganic Chemicals; National Primary and Secondary Drinking Water Regulations Implementation." Federal Register, 57, 1992: 31776-31849.
(i) USEPA. "Maximum Contaminant Level Goals and National Primary Drinking Water Regulations for Lead and Cooper." Federal Register, 56, 1991, 26460-26564.
(j) Action level = 0.015 mg/L.
(k) Action level = 1.3 mg/L.
(l) USEPA. "National Primary and Secondary Drinking Water Regulations; Radionuclides: Final Rule." Federal Register, 65, No. 236, 2000: 76708-76753.
(m) USEPA. "National Primary Drinking Water Regulations; Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring; Final Rule." Federal Register. January 22, 2001, Volume 66, Number 14.
(n) USEPA. "Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual." EPA 815-R-99-011. Office of Water (4607). August 1999.
(o) Formation potentials measured after reacting with chlorine for 168 hours.
(p) USEPA. "National Primary and Secondary Drinking Water Regulations; Fluoride." Federal Register, 51, 1989: 22062-22160.
(q) Compliance discussed later.
(r) Treatment Technique (TT) required to achieve compliance with regulation.
(s) No more than 5 percent of the samples per month may be positive. For systems collecting fewer than 40 samples per month, no more than one sample per month may be positive. Every sample that has total coliforms must be analyzed for fecal coliforms. There can not be any fecal coliforms.
(t) USEPA. "Drinking Water: National Primary Drinking Water Regulations; Filtration, Disinfection; Turbidity, Giardia lamblia, Viruses, Legionella and Heterotrophic Bacteria." Federal Register, 54, 1989: 22062-22160.
(u) Performance standards.
(v) USEPA. "Microbial and Disinfection Byproduct Rules Simultaneous Compliance Guidance Manual." EPA 815-R-99-011. Office of Water (4607). August 1999.
(w) USEPA. "National Primary Drinking Water Regulations: Interim Enhanced Surface Water Treatment Rule; Final Rule." Federal Register, 63, 1998: 69478-69521.
(x) Systems are required to develop a disinfection profile for Giardia if their distribution system running annual average for either total trihalomethane or five haloacetic acid concentrations is greater or equal to 0.064 mg/L and 0.048 mg/L, respectively. USEPA. "Disinfection Profiling and Benchmarking Guidance Manual." EPA 815-R-99-013. Office of Water (4607). August 1999.

distillation pilot plant, 5-log (99.999 percent) removal of spiked fluorescent beads, similar in size to cryptosporidium.

Heat sterilization, similar to disinfection, inactivates microbial contaminants, making them non-viable. Spiking with live bacteria and viruses in the same pilot plant, Rose, et al (1999), further demonstrated 2.3-logs (99.5 percent) and 5-logs (99.999 percent) physical removal/heat sterilization inactivation, respectively. In a review of microbial contaminants in foods, Rose and Slifko (1999) report work by Fayer showing greater than 3-log (99.9 percent) inactivation by heat sterilization for cryptosporidium in distilled water held at a temperature of 60° C for a period of one minute. For the average temperature of 62.8° C and average time of two minutes reported for the four-stage MED units, greater than 3.0-log (99.9 percent) inactivation by heat sterilization would also be expected.

Table 2: Secondary Drinking Water Contaminant Standards

| Contaminant | Reporting Units | Effective | Maximum Contaminant Level Goal (MCLG) | SDWA Compliance Sample | Compliant (yes/no) |
|---|---|---|---|---|---|
| | | | | | |
| Aluminum | μg/L | Now | 5-200 | <100 | yes |
| Chloride | mg/L | Now | 250 | 3.2 | yes |
| Color | CU | Now | 15 | <5.0 | yes |
| Copper | μg/L | Now | 1,000 | <10 | yes |
| Corrosivity | NA | Now | Non-corrosive | Slightly corrosive | no |
| Fluoride | mg/L | Now | 2 | <0.050 | yes |
| Foaming Agents | mg/L | Now | 0.5 | <0.10 | yes |
| Iron | μg/L | Now | 300 | <40 | yes |
| Manganese | μg/L | Now | 50 | <5.0 | yes |
| Odor | TON | Now | 3 | <1.0 | yes |
| PH | S.U. | Now | 6.8-8.5 | 7.83 | yes |
| Silver | μg/L | Now | 100 | <10 | yes |
| Sulfate | mg/L | Now | 250 | 65 | yes |
| Total dissolved solids | mg/L | Now | 500 | 180 | yes |
| Zinc | μg/L | Now | 5,000 | <20 | yes |

Based on these reports, it is apparent the combination of physical removal and heat sterilization inactivation provided by the four-stage MED units far exceed the 2-log removal (> 99 percent) of cryptosporidium required by the IESWTR and LT1ESWTR. For giardia and viruses, the disinfection contact time provided by the service/fire-water storage tank is more than adequate to achieve 3-log and 4-log inactivation with chlorine, respectively, without any need for physical removal based on EPA criteria (EPA, 1999). Although, as described, distillation has been demonstrated to provide over 5-logs physical removal/heat sterilization inactivation for both giardia and viruses (Rose et al, 1999), combined with the inactivation provided by chlorine disinfection, total log removals as high as 9-logs (99.9999999 percent) for giardia and viruses are possible.

## Compliance with Secondary Standards

Secondary Drinking Water Contaminant Standards pertain to those contaminants such as taste, odor, and color that may adversely affect the aesthetic quality of the drinking water. **Table 2** lists the Secondary Maximum Contaminant Levels (SMCLs), reporting units, and results from the Safe Drinking Water Compliance Sample, along with an indication of compliance (i.e., yes/no).

SMCLs represent reasonable goals for drinking water and are not enforced by the EPA or the Puerto Rico Department of Health; they are intended as guidelines. Based on the one sample collected, the finished-water quality is well below the SMCLs and, in most cases, below detection limits (as indicated by "<"). The water was slightly corrosive, as indicated by negative Langlier and Saturation Indices of –0.21 and –0.21, respectively. Neutral to slightly positive values are more desirable to minimize copper and lead corrosion in downstream piping. More calcium carbonate can be added by the remineralization filters to make the water less corrosive.

## Conclusions

EcoEléctrica's distillation desalination facility is capable of providing potable water that complies with the SDWA regulations. The two four-stage MED units are capable of producing exceptionally high-quality water that is below detection limits for most of the contaminants listed. Those few contaminants detected were below current regulated levels. Of particular interest was the effectiveness in reducing natural organic matter (NOM), the precursor in the formation of disinfection byproducts. Samples taken at different stages through the facility showed removals from 4.0 mg/L in the seawater to 1.2 mg/L after pretreatment and < 1.0 mg/L as TOC after distillation. Consequently, disinfection byproduct formation potentials, both THMFPs and HAAFPs, which were also measured after seven days reacting with chlorine, were 0.0045 and 0.0067 mg/L respectively, below Stage 1 D/DBP limits.

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