RISK AND ETIOLOGY
Infectious agents in contaminated drinking water most commonly associated with the potential for causing illness in a wilderness setting include bacteria, viruses, and protozoa. The main reason for treating drinking water is to prevent gastrointestinal illness from fecal pollution with enteric pathogens. Appearance, odor, and taste do not reliably estimate water safety. Risk for waterborne illness depends on the number of organisms consumed, which is determined by the volume of water, concentration of organisms, and treatment system efficiency (Boxes 45.1 and 45.2).

Specific Etiologic Agents
Viruses
- The infectious dose of enteric viruses is only a few infectious units in the most susceptible people.
- Many other viruses are capable and suspected of waterborne transmission, and more than 100 different virus types are known to be excreted in human feces.

Protozoa
- Protozoa that cause enteric disease most often in wilderness travelers and that may be passed via waterborne transmission are *Giardia lamblia* and *Cryptosporidium parvum*.
- *Giardia* cysts have been found as frequently in pristine water and protected sources as in unprotected waters.
- Many of the species seemingly capable of passing *Giardia* cysts to humans, including dogs, cattle, ungulates (deer), and beavers, are present in wilderness areas.

Chemical Hazards
Chemical hazards are also an alarming source of pollution in surface water. Wilderness users must consider the possible presence of chemical, as well as microbiologic, contaminants.

DEFINITIONS
- Disinfection, the desired result of field water treatment, means the removal or destruction of harmful microorganisms.
- Pasteurization is similar to disinfection, but specifically refers to the use of heat, usually at temperatures below 100° C (212° F), to kill most pathogenic organisms.
- Sterilization is the destruction or removal of all life forms.
Purification is the removal of organic or inorganic chemicals and particulate matter to remove offensive color, taste, and odor. Note that purification may not remove or kill enough microorganisms to ensure microbiologic safety.

**HEAT**

- Easy to use except when fuel is limited.
- Enteric pathogens, including cysts, bacteria, viruses, and parasites, can be killed at a temperature well below boiling (Table 45.1).

**BOX 45.1 Waterborne Enteric Pathogens**

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Viruses</th>
<th>Protozoa</th>
<th>Parasites</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Escherichia coli</em></td>
<td></td>
<td>Giardia lamblia</td>
<td></td>
</tr>
<tr>
<td><em>Shigella</em></td>
<td>Hepatitis A</td>
<td>Entamoeba histolytica</td>
<td></td>
</tr>
<tr>
<td><em>Campylobacter</em></td>
<td>Hepatitis E</td>
<td>Cryptosporidium</td>
<td></td>
</tr>
<tr>
<td><em>Vibrio cholerae</em></td>
<td>Norovirus</td>
<td><em>Blastocystis hominis</em></td>
<td></td>
</tr>
<tr>
<td><em>Salmonella</em></td>
<td>Poliovirus</td>
<td><em>Isospora belli</em></td>
<td></td>
</tr>
<tr>
<td><em>Yersinia enterocolitica</em></td>
<td></td>
<td><em>Balantidium coli</em></td>
<td></td>
</tr>
<tr>
<td><em>Aeromonas</em></td>
<td></td>
<td><em>Acanthamoeba</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Cyclospora</em></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
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<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
• Thermal death is a function of both time and temperature; therefore, lower temperatures are effective with longer contact times.
• The boiling point decreases with the lower atmospheric pressure present at high elevations (Table 45.2).
• The majority of the time required to raise the temperature of water to its boiling point works toward disinfection, so water

Table 45.1 Heat

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does not impart additional taste or color to water</td>
<td>Does not improve the taste, smell, or appearance of poor-quality water</td>
</tr>
<tr>
<td>Single-step process that inactivates all enteric pathogens</td>
<td>Fuel sources may be scarce, expensive, or unavailable</td>
</tr>
<tr>
<td>Efficacy is not compromised by contaminants or particles in the water, as happens with halogenation and filtration</td>
<td>Does not prevent recontamination during storage</td>
</tr>
<tr>
<td>Can pasteurize water without sustained boiling</td>
<td></td>
</tr>
</tbody>
</table>

Relative susceptibility of microorganisms to heat: protozoa > bacteria > viruses.

Table 45.2 Boiling Temperatures at Various Altitudes

<table>
<thead>
<tr>
<th>ALTITUDE (FT)</th>
<th>ALTITUDE (M)</th>
<th>BOILING POINT</th>
</tr>
</thead>
<tbody>
<tr>
<td>5,000</td>
<td>1,524</td>
<td>95°C (203°F)</td>
</tr>
<tr>
<td>10,000</td>
<td>3,048</td>
<td>90°C (194°F)</td>
</tr>
<tr>
<td>14,000</td>
<td>4,267</td>
<td>86°C (186.8°F)</td>
</tr>
<tr>
<td>19,000</td>
<td>5,791</td>
<td>81°C (177.8°F)</td>
</tr>
</tbody>
</table>

• Thermal death is a function of both time and temperature; therefore, lower temperatures are effective with longer contact times.
• The boiling point decreases with the lower atmospheric pressure present at high elevations (Table 45.2).
• The majority of the time required to raise the temperature of water to its boiling point works toward disinfection, so water
is safe to drink by the time it has reached a full rolling boil. For an extra margin of safety, keep the water covered and hot for several minutes after boiling.

- Pasteurization (at subboiling temperatures with extended contact times) has been successfully achieved using solar heating. A solar cooker constructed from a foil-lined cardboard box with a glass window in the lid can be used for disinfecting large amounts of water by pasteurization. This could be a low-cost method for improving water quality, especially in refugee camps and disaster areas.

- When no other means are available, using hot tap water as drinking water may prevent traveler’s diarrhea in developing countries. As a rule of thumb, water too hot to touch is within the pasteurization range. However, lukewarm tap water can contain pathogenic microorganisms.

**FILTRATION, ADSORPTION, AND CLARIFICATION (Fig. 45.1)**

**Filtration**

- Field filters that rely solely on the mechanical removal of microorganisms may be adequate for cysts and bacteria but may not reliably remove viruses unless tested for this function.
• They have the advantages of being simple and requiring no holding time.
• Most viruses adhere to larger particles or clump together into larger aggregates that may be removed by a filter. Filters are often expensive and can add considerable weight and bulk to a backpack.
• Some devices are designed as purely mechanical filters, whereas others combine filtration with granular activated carbon (GAC).
• The size of a microorganism is the primary determinant of its susceptibility to filtration.
• All filters eventually clog from suspended particulate matter, present even in clear streams, requiring cleaning or replacement of the filter. Flow can be partially restored to a clogged filter by back flushing or surface cleaning, which removes the larger particles trapped near the surface.

Microfiltration, Ultrafiltration, and Nanofiltration
• In general, portable filters for water treatment can be divided into microfiltration with pores down to 0.1 \( \mu m \), ultrafiltration that can remove particles as small as 0.01 \( \mu m \), and nanofiltration with pore sizes as small as 0.001 \( \mu m \) or less.
• Microfilters are effective for removing protozoa and bacteria, algae, most particles, and sediment, but allow dissolved material, small colloids, and some viruses to pass through.
• Ultrafiltration membranes are required for complete removal of viruses, colloids, and some dissolved solids.
• Nanofilters can remove other dissolved substances, including sodium chloride, from water. All filters require pressure to drive the water through the filter element. The smaller the pore size, the more pressure required.
• Some ceramic filters now remove 99% to 99.9% of viruses.

Adsorption Using Granular Activated Carbon
Granular carbon (i.e., charcoal) is widely used for water treatment and is the best means for removing toxic organic and inorganic chemicals from water (including disinfection by-products) and for improving odor and taste. GAC also removes radioactive contamination.
• Some, but not all, viral particles, bacteria, and protozoan cysts are removed by GAC filters.
• GAC does not kill microorganisms.
• No reliable means are available for determining precisely when GAC saturation is reached. Presence of unpleasant taste or color in the water can be the first sign that the charcoal is ineffective. To test the activity of the charcoal, one may filter iodinated water or water tinted with food coloring. With regular use, the lifetime of GAC is probably measured in months; it is substantially longer with infrequent use.
• With increasing industrial and agricultural contamination of distant groundwater, final treatment of drinking water with GAC may be important for some wilderness users.
Reverse Osmosis
- A reverse osmosis filter uses high pressure (100 to 800 psi) to force water through a semipermeable membrane that filters out dissolved ions, molecules, and solids.
- Reverse osmosis is generally used for desalinating water.
- It may also be used to remove biologic contaminants.
- Small hand-pumped reverse osmosis units have been developed. High price and slow output currently limit their use by land-based wilderness travelers.
- It is an essential survival item for ocean travelers.

Forward Osmosis
Osmotic pressure also can be used to draw water through a membrane to create highly purified drinking water from low-quality source water, including brackish water. These products use a double-chamber bag or container with the membrane in between. Clarification of cloudy water can be achieved by sedimentation, coagulation-flocculation (C-F), or adsorption (Table 45.3).
- Large particles settle by gravity over 1 to 2 hours in sedimentation. Although filters remove particulate debris, thus improving the appearance and taste of “dirty” water, they clog quickly if the water contains large particles.
- Smaller suspended particles can be removed by C-F. This is accomplished in the field by adding alum (aluminum potassium sulfate). Alum is used in the food industry as a pickling powder.

<table>
<thead>
<tr>
<th>TECHNIQUE</th>
<th>PROCESS USES</th>
<th>ADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sedimentation</td>
<td>Settling by gravity of large particulates</td>
<td>Greatly improves water aesthetics; however, requires a long time</td>
</tr>
<tr>
<td>Coagulation-flocculation</td>
<td>Removes suspended particles, most microorganisms, some dissolved substances</td>
<td>Simple process, easily applied in field Greatly improves water quality Improves efficacy of filtration and chemical disinfection</td>
</tr>
<tr>
<td>Activated charcoal</td>
<td>Removes organic and some inorganic chemicals</td>
<td>Removes toxins, such as pesticides, and removes chemical disinfectants Improves taste of water</td>
</tr>
<tr>
<td>Filtration</td>
<td>Physical and chemical process</td>
<td>Removes microorganisms If charcoal stage, may improve taste and remove chemicals</td>
</tr>
</tbody>
</table>
and is nontoxic. C-F will remove contaminants that cause an unpleasant color and taste, some dissolved metals, and some microorganisms.

**CHEMICAL DISINFECTION (Tables 45.4 and 45.5)**

**Halogens (Chlorine and Iodine)**

Worldwide, chemical disinfection is the most widely used method for improving and maintaining microbiologic quality of drinking water. Halogens, chiefly chlorine and iodine, are the most common chemical

<table>
<thead>
<tr>
<th>Table 45.4 Water Disinfection Techniques and Halogen Doses</th>
<th>Added to 1 L or Quart of Water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>IODINATION TECHNIQUES</strong></td>
<td><strong>AMOUNT FOR 4 PPM</strong></td>
</tr>
<tr>
<td>Iodine tabs</td>
<td>½ tab</td>
</tr>
<tr>
<td>Tetracycline hydroyperiodide</td>
<td></td>
</tr>
<tr>
<td>EDWGT</td>
<td></td>
</tr>
<tr>
<td>Potable Aqua</td>
<td></td>
</tr>
<tr>
<td>Globaline</td>
<td></td>
</tr>
<tr>
<td>2% Iodine solution (tincture)*</td>
<td>0.2 mL or 4 gtt</td>
</tr>
<tr>
<td>10% Povidone-iodine solution*†</td>
<td>0.35 mL or 7 gtt</td>
</tr>
<tr>
<td>Saturated solution: iodine crystals in water</td>
<td>13 mL</td>
</tr>
<tr>
<td>Saturated solution: iodine crystals in alcohol</td>
<td>0.1 mL or 2 gtt</td>
</tr>
<tr>
<td><strong>CHLORINATION TECHNIQUES</strong></td>
<td><strong>AMOUNT FOR 5 PPM</strong></td>
</tr>
<tr>
<td>Sodium hypochlorite (household bleach 5%)†</td>
<td>0.1 mL or 2 gtt</td>
</tr>
<tr>
<td>Calcium hypochlorite (Redi-Chlor [½ g tab])</td>
<td>½ tab/2 qt</td>
</tr>
<tr>
<td>Sodium dichloroisocyanurate (AquaClear)</td>
<td>1 tab (8.5 mg NaDCC)</td>
</tr>
<tr>
<td>Chlorine plus flocculating agent (Chlor-Floc)</td>
<td>1 tab</td>
</tr>
</tbody>
</table>

*Measure with dropper (1 drop = 0.05 mL) or tuberculin syringe.
†Povidone-iodine solutions release free iodine in levels adequate for disinfection, but scant data are available.
EDWGT, Emergency drinking water germicidal tablet; gtt, drops; ppm, parts per million.
disinfectants used in the field; however, chlorine dioxide is available in small-use applications. These agents are active against bacteria, viruses, *Giardia*, and cysts of amebae, excluding *Cryptosporidium*.

**Factors Affecting Halogen Disinfection** *(Table 45.6)*

**Concentration and Demand**
Disinfection with halogens depends on the following:
- The concentration of halogen
- The amount of time the halogen is in contact with the water (contact time)
- The water temperature (cold slows reaction time)
- The presence of organic contaminants in the water, which react with halogen and decrease its disinfectant action
- Water pH

**Cold and Concentration** *(See Table 45.5)*
Use four parts per million (ppm) as a target concentration for surface water, and allow extra contact time, especially if the water is cold. In cold water, the contact time or dose should be increased; in polluted water, the dose must be increased.

If there is no urgency, time can be increased instead of dose. Data for killing *Giardia* in very cold water (5° C [41° F]) with both chlorine and iodine indicate that contact time must be prolonged three to four times, not merely doubled, to achieve high levels of inactivation. If feasible, raising the temperature by 10°C to 20°C (18°F to 36°F) allows a lower dose of halogen and more reliable disinfection at a given dose.

**Contaminants**
- In cloudy water that will not settle out by sedimentation, the halogen dose should be at least 8 ppm. Ideally, use C-F to clarify the water before halogenation, and then use a smaller amount of halogen.

---

**Table 45.5**  Recommendations for Contact Time With Halogens in the Field

<table>
<thead>
<tr>
<th>Concentration of Halogen</th>
<th>5°C (41°F)</th>
<th>15°C (59°F)</th>
<th>30°C (86°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 ppm</td>
<td>240</td>
<td>180</td>
<td>60</td>
</tr>
<tr>
<td>4 ppm</td>
<td>180</td>
<td>60</td>
<td>45</td>
</tr>
<tr>
<td>8 ppm</td>
<td>60</td>
<td>30</td>
<td>15</td>
</tr>
</tbody>
</table>

**Note:** Data indicate that very cold water requires prolonged contact time with iodine or chlorine to kill *Giardia* cysts. These contact times have been extended from the usual recommendations in cold water to account for this and for the uncertainty of residual concentration.
### Table 45.6 Factors Affecting Halogen Disinfection

<table>
<thead>
<tr>
<th>EFFECT</th>
<th>COMPENSATION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary Factors</strong></td>
<td></td>
</tr>
<tr>
<td>Concentration</td>
<td>Measured in milligrams per liter (mg/L) or the equivalent, parts per million (ppm); higher concentration increases rate and proportion of microorganisms killed.</td>
</tr>
<tr>
<td>Contact time</td>
<td>Usually measured in minutes; longer contact time ensures higher proportion of organisms killed.</td>
</tr>
<tr>
<td><strong>Secondary Factors</strong></td>
<td></td>
</tr>
<tr>
<td>Temperature</td>
<td>Cold slows reaction time.</td>
</tr>
<tr>
<td>Water contaminants, cloudy water (turbidity)</td>
<td>Halogens react with organic nitrogen compounds from decomposition of organisms and their wastes to form compounds with little or no disinfecting ability, effectively decreasing the concentration of available halogen. In general, turbidity increases halogen demand.</td>
</tr>
<tr>
<td>pH</td>
<td>The optimal pH for disinfection is 6.5–7.5. As water becomes more alkaline, approaching pH 8.0, much higher doses of halogens are required.</td>
</tr>
</tbody>
</table>
Several simple color strip tests are available for field use, like those used for swimming pools and spas to measure the amount of free (residual) halogen in water. Testing in the wilderness for halogen residual may be reasonable for large groups but is not practical for most. Smell of chlorine usually indicates some free residual. Color and taste of iodine can be used as indicators. Above 0.6 ppm, a yellow to brown tint is noted.

**pH**

The optimal pH for halogen disinfection is 6.5 to 7.5. As water becomes more alkaline, approaching pH 8.0, much higher doses of halogens are required.

**Pathogen Sensitivity**

- Bacteria are extremely sensitive to halogens.
- Viruses and *Giardia* require higher concentrations or longer contact times.
- *Cryptosporidium* cysts are extremely resistant to halogens.
- The resistance of *Cryptosporidium* will require an alternative to halogens or a combination of methods to ensure removal and inactivation of all pathogens.
- Relative resistance between organisms is similar for iodine and chlorine.
- The physical state of the microbes also determines their susceptibility. Microbes that are aggregated in clumps or embedded in other matter or organisms may be shielded from disinfectants.

**Chlorine**

Chlorine has been used as a disinfectant for 200 years. The CDC-WHO Safe Water System for household disinfection in developing countries provides a dosage of 3.75 mg/L of sodium hypochlorite with a contact time of 30 minutes, sufficient to inactivate most bacteria, viruses, and some protozoa that cause waterborne diseases.

**Iodine**

Iodine is effective in low concentrations for killing bacteria, viruses, and cysts and in higher concentrations against fungi and even bacterial spores, but it is a poor algicide.

**Recommendations**

- Available data suggest the following:
  - High levels of iodine, such as those produced by recommended doses of iodine tablets, should be limited to periods of 1 month or less.
  - Iodine treatment that produces a low residual (1 mg/L or less) appears safe, even for long periods in people with normal thyroid function. This would require very low doses of iodine added to the water or an activated charcoal stage to remove residual iodine.
• Persons planning to use iodine for a prolonged period should have the thyroid gland examined and thyroid function measured to ensure that a state of euthyroidism exists.
• The following groups should not use iodine for water treatment because of their increased susceptibility to thyroid problems:
  • Pregnant women
  • Persons with known hypersensitivity to iodine
  • Persons with a history of thyroid disease, even if controlled by medication
  • Persons with a strong family history of thyroid disease (thyroiditis)
  • Persons from areas with chronic dietary iodine deficiency

**Improving the Taste of Water Disinfected With Halogens**

• Add flavoring to the water only after adequate contact time. Iodine will react with sugar additives, thereby reducing the free iodine available for disinfection.
• Use charcoal (GAC) to remove halogen after adequate contact time.
• Reduce the concentration and increase the contact time in clean water. For a small group of people, use a collapsible plastic container to disinfect water with low doses of iodine during the day or overnight.
• Iodine and chlorine taste and iodine color can be removed by chemical reduction. In addition, a much higher halogen dose (shorter contact time) can be used if followed by chemical reduction. To remove iodine and chlorine taste and iodine color by chemical reduction:
  • Add a few granules per liter of ascorbic acid (vitamin C, available in powder or crystal form) or sodium thiosulfate (nontoxic) after the required contact time (reduces iodine or chlorine to iodide or chloride, which has no taste or color).

**Superchlorination-Dechlorination**

• High doses of chlorine are added to the water in the form of calcium hypochlorite crystals to achieve concentrations of 30 to 200 ppm of free chlorine.
• These extremely high levels are above the margin of safety for field conditions and rapidly kill all bacteria, viruses, and protozoa and could kill *Cryptosporidium* with overnight contact times.
• After at least 10 to 15 minutes, several drops of 30% hydrogen peroxide solution are added. This reduces hypochlorite to chloride, forming calcium chloride and oxygen.
• The minor disadvantage of a two-step process is offset by excellent taste.
• This is a good technique for highly polluted or cloudy water and for disinfecting large quantities. It is the best technique for
storing water on boats or for emergency use. Water is then dechlorinated in needed quantities when ready to use.

- The ingredients can be easily obtained and packaged in small Nalgene bottles.

**MISCELLANEOUS DISINFECTANTS**

**Chlorine Dioxide** *(Table 45.7)*

- Chlorine dioxide is capable of inactivating most waterborne pathogens, including *Cryptosporidium parvum* oocysts, at practical doses and contact times.
- It is at least as effective a bactericide as chlorine and in many cases is superior.
- It is far superior as a virucide.
- It does not form chlorinated compounds in the presence of organics and is efficacious over a wide pH range.
- Cost-effective and portable chlorine dioxide treatment products include Micropur MP1, Aquamira, and Miox.

**Mixed Species Disinfection (Miox Purifier)**

- Passing a current through a simple brine salt solution generates free available chlorine, as well as other “mixed species” disinfectants that have been demonstrated effective against bacteria, viruses, and bacterial spores.
- The resulting solution has greater disinfectant ability than a simple solution of sodium hypochlorite.
- It has even been demonstrated to inactivate *Cryptosporidium*.
- Potential for malfunction and battery depletion exists.

**Silver**

Silver ion has bactericidal effects in low doses. The literature on antimicrobial effects of silver is confusing and contradictory.

<table>
<thead>
<tr>
<th>Table 45.7 Chlorine Dioxide</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ADVANTAGES</strong></td>
</tr>
<tr>
<td>Effective against all microorganisms, including <em>Cryptosporidium</em></td>
</tr>
<tr>
<td>Low doses have no taste or color</td>
</tr>
<tr>
<td>Portable device now available for individual and small-group field use and simple to use</td>
</tr>
<tr>
<td>More potent than equivalent doses of chlorine</td>
</tr>
<tr>
<td>Less affected by nitrogenous wastes</td>
</tr>
</tbody>
</table>

Relative susceptibility of microorganisms to chlorine dioxide: bacteria > viruses > protozoa.
• The use of silver as a drinking water disinfectant has been much more popular in Europe, where silver tablets (Micropur) are sold widely for field water disinfection.
• Silver ion has not been approved by the Environmental Protection Agency (EPA) for this purpose in the United States, but was approved as a water preservative to prevent bacterial growth in previously treated and stored water.
• Micropur Forte tablets release free chlorine for disinfection and silver for prolonged persistence of antimicrobial activity.
• Silver impregnation of filters may inactivate pathogens that pass through the filter pores or limit bacterial growth in the filter itself (bacteriostatic). Ceramic filters coated with silver have higher removal rates of bacteria than non-coated filters.

**Potassium Permanganate**
Potassium permanganate is a strong oxidizing agent with some disinfectant properties.
• It is used in municipal disinfection to control taste and odor.
• It has been used in a 1% to 5% solution as a drinking water disinfectant and is still used for this purpose in some countries, as well as for washing fruits and vegetables.
• Although potassium permanganate clearly has disinfectant action and is frequently used in some parts of the world, it cannot be recommended for point-of-use water disinfection unless no other means are available, because quantitative data are not available for viruses and no data are available for protozoan cysts.
• Packets of 1 g to be added to 1 L of water are sold in some countries.

**Hydrogen Peroxide**
Hydrogen peroxide is a strong oxidizing agent but a weak disinfectant. Although hydrogen peroxide can sterilize water, lack of data for protozoal cysts and quantitative data for dilute solutions prevents it from being useful as a field water disinfectant.

**Ultraviolet Light and Sunlight**
• Using sufficient doses, all waterborne enteric pathogens are inactivated by ultraviolet (UV) radiation (Table 45.8).
• UV treatment does not require chemicals and does not affect the taste of the water.
• UV works rapidly, and an overdose to the water presents no danger.
• UV light has no residual disinfection power; water may become recontaminated, or regrowth of bacteria may occur.
• Particulate matter can shield microorganisms from UV radiation.
• Portable field units, such as SteriPEN and AquaStar UV Portable Water Purifier, require a power source (battery, human powered, and solar-charged units are available). Users must prefILTER or clarify cloudy water.
A new technology is the SolarBag.
- The SolarBag disinfects 3 L at a time and can be used several times per day, on sunny or cloudy days.
- It uses sunlight to activate a mesh insert coated with titanium dioxide.
- For disinfection, the bag is placed flat or hanging in direct sunlight.
- Disinfection requires 1 to 2 hours on a sunny day and 2 to 4 hours on a cloudy day.
- For unknown water sources, a food-safe dye can be used as a tracer and timer. When the color has cleared, the water has been disinfected.
- No chemicals or pumps are required, and it can be reused.
- A unique, low-tech approach uses a simple solar disinfection (“SODIS”) technique (see http://www.sodis.ch/).
- Transparent bottles (e.g., clear plastic beverage bottles), preferably lying on a dark surface, are exposed to sunlight for a minimum of 4 hours. Because ultraviolet radiation is reduced at increasing water depth, the containers used for SODIS should not exceed a water depth of 10 cm (4 inches).
- Oxygenation induces greater reductions of bacteria, so agitation is recommended before solar treatment in bottles.
- Where strong sunshine is available, solar disinfection of drinking water is an effective, low-cost method for improving water quality and may be of particular use in refugee camps and disaster areas.
- With a water temperature of 30° C (86° F), 6 hours of midlatitude midday summer sunshine are required to achieve a 3-log reduction of fecal coliforms.
- Treatment efficiency can be improved if bottles are exposed on sunlight-reflecting surfaces such as aluminum or corrugated iron sheets. Use of a simple reflector or solar cooker can achieve pasteurization temperatures of 65° C (149° F).

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective against all microorganisms</td>
<td>Requires clear water</td>
</tr>
<tr>
<td>Imparts no taste</td>
<td>Does not improve water aesthetics</td>
</tr>
<tr>
<td>Portable device now available for individual</td>
<td>Does not prevent recontamination during storage</td>
</tr>
<tr>
<td>and small-group field use; simple to use</td>
<td>Expensive</td>
</tr>
<tr>
<td>Available from sunlight</td>
<td>Requires power source</td>
</tr>
<tr>
<td></td>
<td>Requires direct sunlight, prolonged exposure; dose</td>
</tr>
<tr>
<td></td>
<td>low and uncontrolled</td>
</tr>
<tr>
<td>Method</td>
<td>BACTERIA</td>
</tr>
<tr>
<td>---------------</td>
<td>----------</td>
</tr>
<tr>
<td>Heat</td>
<td>+</td>
</tr>
<tr>
<td>Filtration</td>
<td>+</td>
</tr>
<tr>
<td>Halogens</td>
<td>+</td>
</tr>
<tr>
<td>Chlorine dioxide</td>
<td>+</td>
</tr>
</tbody>
</table>

*Most filters make no claims for viruses. Reverse osmosis is effective. The General Ecology filtration system claims virus removal.
†Eggs are not very susceptible to halogens but have very low risk of waterborne transmission.
• Effects can also be enhanced by adding small amounts of hydrogen peroxide, lemon juice, or lime juice.

CHOOSING THE PREFERRED TECHNIQUE (Table 45.9)
• The best technique for disinfection for either an individual or a group depends on the number of persons, space and weight available, quality of source water, personal taste preferences, and availability of fuel.
• Optimal protection for all situations may require a two-step process of filtration or C-F and halogenation because halogens do not kill Cryptosporidium and filtration misses some viruses.
• Heat works as a one-step process, but it will not improve the taste and appearance of water.