Executive Summary Report

Solar Powered Membrane Distillation

Prepared For
Texas A&M University AggiE-Challenge Program

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Executive Summary

The purpose of this report was to create a design that is low cost, simplistic, efficient, and reliable utilizing a non-grid energy source in order to improve water quality. The steps taken in order to complete these requirements included focusing on a design concept, identifying the basic scientific principles involved, doing reverse engineering and a comparative study of current designs as well as identifying their bottlenecks. Based on the completed tasks, the final design is a membrane distillation system. This system incorporates the benefits of air gap membrane distillation, sand filtration and thermal heat pumps into one system powered by solar energy.
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Introduction

The current need for clean water in rural and developing areas is incredibly vast and demands global attention. Living in a developed society, such as the United States, the problem of accessing clean drinking water is non-existent. However, this problem deserves the attention of an epidemic and millions globally require aid. Of the nearly 7 billion people that populate this Earth, approximately 780 million of them lack access to an improved water source—equating to about 1 in 9 people. As a result, more than 3.4 million die every year from water, sanitation, and hygiene-related causes. The women and children living in these undeveloped areas are often forced to walk hours each day to retrieve this dirty, infested water. This is valuable time that should be spent on education, work, and community development. The UN claims that the average person requires a minimum of 20 liters of clean water a day for their drinking and sanitation purposes. Because these areas lack the infrastructure and resources to accomplish this, there is a large demand for innovation to solve this immense problem. Many methods, designs, and products currently exist on the market striving to provide for these people, largely through the work of NGOs. The team working on this Aggie-E-Challenge has decided to explore the technology surrounding membrane distillation. Membrane distillation has small energy requirements, which is advantageous in developing regions with unstable or no power grids. Also, because of the often low accessibility to source water, a membrane distillation system is promising due to its impressive efficiencies.

Need Statement and Analysis

After several iterations of the need statement for the project, the final need statement was arrived at: create a low cost, simplistic, efficient, and reliable system to improve water quality utilizing a
non-grid energy source. This need statement can be further analyzed and decomposed into the following sections:

1. **Low cost** – The design must be sufficiently cheap to manufacture such that it could reasonably be purchased and maintained in a developing region.

2. **Simplistic** – The design must be intuitive

3. **Efficient** – The system must improve upon pre-existing designs.

4. **Reliable** – Once deployed the design must be able to run without downtime for several years.

5. **Water quality** – The water which has been processed by the design must be significantly safer for use than the starting source.

6. **Non-grid energy source** – The design must be able to operate without being connected to any electrical power grid.
**Function Structure**

Based on the need statement that was developed earlier, the following function structure was developed and is displayed in Figure 1.

![Function Structure Diagram](image)

**Figure 1. Function Structure**
Analysis of Function Structure

FR 1: Remove Particles

Removal of particles and solids is essential to the overall purity of the water. While these contaminants may not necessarily pose a significant risk to health, they will cloud and discolor the water, and also foul its taste. Presence of such particles would render the water undesirable for human consumption. Possible methods to remove these particles include, but are not limited to, filtration (bio-sand, or carbon), evaporation/distillation, use of a centrifuge, and decanting.

FR 2: Remove Harmful Organisms

Dangerous microorganisms, as listed by the EPA and shown in Appendix I, include Cryptosporidium, Giardia lamblia, Legionella, total coliforms (such as E. Coli), total bacteria, and enteric viruses. Ingestion of harmful microorganisms can cause sicknesses such as Gastrointestinal illness (diarrhea, vomiting, cramps), and Legionnaire’s Disease (a type of pneumonia). While these diseases are easily treated in developed countries, in third world countries such sicknesses frequently result in death, especially in children. Possible methods to eradicate harmful microorganisms include UV Radiation, chemical treatment (chlorine or iodine), boiling, and bio-sand filtration.

FR 3: Remove Chemicals

There are two types of chemical contaminants that can be found in water: organic and inorganic. Inorganic contaminants are chemicals such as heavy metals, nitrates and nitrites, arsenic, fluoride, and cyanide. The list of organic chemical contaminants is much more extensive, but includes things such as benzene derivatives, and halogen
substituents. A complete list of harmful chemicals can be viewed in Appendix I. Unlike consumption of pathogens, consumption of chemical contaminants causes permanent and lasting health problems. These problems include, but are not limited to, increased risk of cancer, liver problems, kidney problems, thyroid problems, damage to the nervous system, and damage to the circulatory system. Possible methods for addressing chemical contamination are carbon filtration and evaporation/distillation.

**FR 4: Provide Energy**

**FR 4.1: Generate Energy**

In order to satisfy the non-grid energy source requirement of the need statement it is essential for the design to generate its own energy. This can be achieve by utilizing natural energy such as solar or wind energy, or human generated energy such as a generator powered by a human crank. The amount of energy which will be required by the design will be directly related to the embodiment of the design, and thus it is not possible to determine a specific performance requirement for this functional requirement at this time.

**FR 4.2: Store Energy**

It may also be desirable for the design to have the capability to store energy. This would be especially desirable if the design utilizes a natural energy source such as solar or wind energy. This would allow the device to function even if that energy source were not present at a specific time. As with FR 4.1, due to the wide range of energy requirements possible in different designs it is not possible to determine a specific performance requirement at this time.
FR 5: Collect Water

**FR 5.1: Process Water**

In order to improve water quality, as stated in the need statement, it is essential that the design be able to collect and process water. This can be either automated, such as collecting rain water, or manual, such as pouring water into the design. As with FR 4, it is currently unclear how much water it is desirable for the design to process. This design requirement will be based upon, among other things, the cost and efficiency of the design and will be explicitly defined at a later point.

**FR 5.2 Store Water**

If the design utilizes an automated method of water collection, such as collecting rain water, it may be desirable for the design to be able to store some quantity of water so that water is still available in between rainfall. The quantity of water that the design should be able to store will be a function of the climate of the area where the design will be deployed and how frequent rainfall is in that area.

### Project Management

In order to successfully complete the project, it was broken down into several essential tasks. These tasks are outlined in Table 1.

**Table 1. Description of Required Tasks**

<table>
<thead>
<tr>
<th>Task</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Create Need Statement</td>
</tr>
<tr>
<td>2</td>
<td>Detailed Process Description Using Scientific Principles</td>
</tr>
<tr>
<td>3</td>
<td>Development of Functionality of Design</td>
</tr>
<tr>
<td>4</td>
<td>Reverse Engineering and Comparative Study of Available Designs</td>
</tr>
<tr>
<td>5</td>
<td>Identification of Bottlenecks and Opportunities in Existing Designs</td>
</tr>
<tr>
<td>6</td>
<td>Candidate for Improved Design and Detailed Development</td>
</tr>
</tbody>
</table>
After the tasks given above were identified, a schedule was generated in order to ensure that the project tasks are completed in a reasonable time frame. This schedule is detailed in Figure 2.
Figure 2. GANTT Chart of Project
Solar Powered Membrane Distillation

In the function structure developed earlier and shown in Figure 1, several performance requirements for the design were designated as design dependent. Now that a specific design concept has been selected it is possible to define these performance requirements.

The World Health Organization [1] and Living Water International [2] both state that as a minimum a person needs 20L of clean water per day in order to meet their drinking, cooking, and sanitation needs. If it is assumed that this system must supply a small community of 100 people with water, then the performance requirement for FR 5.1 is 2000 L/Day. The work of Alklaibi et al [3] indicates that in order to provide the permeate flux needed for FR 5.1, it is necessary to have a feed water flow of 7 L/min with a temperature difference between the hot and cold sides of the system of 55 °C. Therefore the system must be able to generate enough energy to heat the cool incoming water by at least 55 °C, which is then the performance requirement for FR 4.1. For FR 5.2, the system must have sufficient static head to produce a flow rate of 7 L/min. This system will not have any energy storage capabilities and thus FR 4.2 does not apply. A list of functional requirements and their performance requirements can be viewed in Table 2.

### Table 2. List of Performance Requirements for Each Functional Requirement

<table>
<thead>
<tr>
<th>Functional Requirement</th>
<th>Title</th>
<th>Performance Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Remove Particles</td>
<td>&lt;250 ppm total dissolved solids</td>
</tr>
<tr>
<td>2</td>
<td>Remove Harmful Organisms</td>
<td>EPA Standard</td>
</tr>
<tr>
<td>3</td>
<td>Remove Chemicals</td>
<td>EPA Standard</td>
</tr>
<tr>
<td>4.1</td>
<td>Generate Energy</td>
<td>Sufficient energy to raise water temperature by 55°C</td>
</tr>
<tr>
<td>4.2</td>
<td>Store Energy</td>
<td>N/A</td>
</tr>
<tr>
<td>5.1</td>
<td>Process Water</td>
<td>2000 L/Day</td>
</tr>
<tr>
<td>5.2</td>
<td>Store Water</td>
<td>Sufficient static head to provide 7 L/min of feed water flow</td>
</tr>
</tbody>
</table>
**Scientific Operating Principles**

This design concept operates mainly on the scientific principles of membrane distillation, radiative heat transfer, and static head. Membrane distillation is the method utilized by the system to improve water quality and thus satisfies FRs 1 through 3 as it is capable of removing particles, harmful organisms, and chemicals. Membrane distillation also contributes to satisfying FR 5.1 as it is crucial to the processing of water in the system. FR 4.1 is satisfied through radiative heat transfer which provides a temperature differential in the system for distillation and through static head which provides flow through the system. Static head also satisfies FR 5.1 and FR 5.2 as it provides the flow which allows water to be processed and in order to have static head some water must be stored. These scientific principles are described in further detail below.

**Membrane Distillation**

Membrane distillation is a process which utilizes a hydrophobic membrane with a temperature differential across the membrane to achieve water purification at relatively low temperature gradients. The driving force for the purification aspect of membrane distillation is the partial vapor pressure difference between the two sides of the membrane, which is the result of a temperature differential between the two sides of the membrane. Because the “pure” side of the membrane is at a cooler temperature than the feed water, some of the water will have a tendency to pass through the membrane as a vapor. The reason only the vapor phase is able to pass through the membrane is due to the surface tension of liquid water, which is directly related to the water’s polarity.

**Radiative Heat Transfer**

A basic schematic of how solar radiation works for this application is shown in Figure 3.
Figure 3. Schematic of Solar Radiation

The basic law governing radiative heat transfer is the Stefan-Boltzmann Law which is shown in Equation 1.

\[ q = \varepsilon \sigma T^4 A \]  

(1)

where \( q \) is the heat transfer per unit time, \( \varepsilon \) is the emissivity of the body, \( \sigma \) is the Stefan-Boltzmann constant, \( T \) is the temperature of the body, and \( A \) is the area of the body.

Radiation from the sun will pass through the atmosphere, through which some energy will be lost to reflection and absorption. The radiation will then strike the mirror, which current technology has the ability to make 94% reflective. This reflected energy will then be absorbed by the pipe, minus some reflection. The absorbed energy will then be transmitted via conduction and convection to the fluid moving through the pipe. Some assumptions which will be made in the analysis of this system are that the sun is a black-body and that external convective heat transfer on the pipe is negligible.
**Static Head**

Static head is a basic physical principle which relies upon gravitational potential energy, as given by Equation 2

\[ PE = mgh \]  

(2)

where m is mass, g is gravitational acceleration, and h is height. Equation 2 shows that if there is a static mass of fluid at a higher elevation than downstream piping in a system it will create a pressure differential which will then produce flow through the system.

**System Schematic and Design**

It is believed that membrane distillation is advantageous for this design because the low temperature gradient required for the process is ideal for being powered by solar energy. The solar energy used to power this process will be captured using a parabolic mirror which will reflect the sun’s radiation to heat water which is flowing through a pipe located at the focal point of the mirror. A basic schematic of the proposed design can be seen in Figure 4.
There are several different forms of membrane distillation, direct contact membrane distillation (DCMD), air gap membrane distillation (AGMD), and vacuum membrane distillation (VMD). This design will utilize air gap membrane distillation as it is the most versatile and the easiest to implement. While both DCMD and VMD can allow for higher permeate fluxes than AGMD these membrane distillation methods are difficult to implement in a sustainable fashion. DCMD requires that there be a pure water stream which can run on the pure side of the membrane. This is difficult to implement as it would require a pump to move this pure water stream, and would also require pure water.
from some other source to begin the process. The difficulty with VMD is that it requires that a vacuum be held on the pure water side of the system, which is very energy intensive.

In order to show that AGMD could provide the necessary permeate flux, a brief analysis of the system was performed. Taking the performance requirement from FR 5.1, the system must be able to provide 2000 L of clean water per day. Other studies have shown that there are approximately 7 hours of usable sunlight each day [4], which then means that the system must be able to have a flow rate of 286 L/hr while in operation. If there is a total membrane area of 10m² then there must be a permeate flux of 28.6 L/m²/hr. This permeate flux is similar to those achieved by Liu et al. using AGMD [5]. From this analysis it is shown that the currently proposed system should be able to generate the necessary permeate fluxes to meet the necessary production rates.

**Comparative Study of Existing Design**

The proposed system was also compared to an existing solar powered membrane distillation plant in order to highlight areas that needed to be improved in the proposed design. The system which was analyzed is a test system which was installed in Aqaba, Jordan [4] and run for one year. A flow sheet of the plant is shown in Figure 5.
While this plant utilizes the same fundamental scientific concepts to increase water quality as the design proposed by the team, it is believed that there are several areas of potential improvement in the design.

The first area for improvement is in the solar collector field. As can be seen in Figure 6, the solar collectors which are used are an array of flat plates which then transfer heat through conduction. This is an inefficient use of the available energy as a significant amount of energy must be wasted heating the significant volume of the collectors.

Furthermore, titanium was used in the construction of the array, which makes the system extremely cost prohibitive. The currently proposed design seeks to avoid this bottleneck by using a parabolic mirror will focus light on a pipe running through the focal point of the mirror. This pipe will have the water to be heated running through it. This will result in a more efficient use of energy as the mirror will allow for more light to be directed to the water and will avoid unnecessary heat of metal.
Another bottleneck of this system is the heavy reliance on photovoltaic (PV) cells to power pumps and valves. This results in making the system significantly less reliable than desirable as PV cells, pumps, and sophisticated magnetic valves all are liable to fail in harsh conditions and require significant cost and expertise to repair. The currently proposed designed seeks to eliminate these concerns by using the static head of the water to drive the system. The dirty water will be placed into the system manually at the high point of the system, which will then allow the system to run without any machinery or electronics which are liable to break.

**Functional Modeling**

In order to best represent the functional decomposition of the solar powered membrane distillation system, a functional model was created. In the functional model, the importance of each component was specified through their respective sub-functions. Their intended sub-functions were identified in terms of input/output mass, energy, signal, and force, which show
how all components may affect one another as well as the system as a whole. The following diagram in Figure 7 displays a detailed representation of the functional model of the solar powered membrane distillation system.

Figure 7. Functional Model of Solar Powered Membrane Distillation System.

Based on the figure above, components 1 through 2 are all related through the input force each component exerts on the frame. Also, it is worth mentioning that the water serves as both an input and output mass for components 2 through 8. Additionally, the thermal pump is the only component for which mass, energy, and signal are inputs.
House of Quality Matrix

In order to know how well the solar powered membrane distillation system design is meeting customer requirements, a house of matrix was created. Furthermore, this matrix creates a connection between the design and the costumer. In other words, it helps the designer understand the level of importance of each requirement to the costumer as well as how well other companies are meeting these requirements. The following Figure 8 represents the House of Quality Matrix for the solar powered membrane distillation system design where the customer needs have been rated on a scale ranging from 1 to 5 where 5 represents the highest level of importance to the customer.
Figure 8. House of Quality Matrix
**System Mock-Up**

In order to visually demonstrate and gain a greater understanding of how main components in the membrane distillation system design can work together, a simple model was built using several available materials. The following Figure 9 shows the resulting membrane distillation system model.

![Figure 9. Model of Solar Powered Membrane Distillation System Design.](image-url)

In addition, each of the main constituents in the model was numbered according to their corresponding components in Figure 9, giving an idea of where each component will be located.
Concluding Remarks

Almost 780 million people on earth have limited access to an improved water source resulting in the death of approximately 3.4 million people every year from water, sanitation, and hygiene-related causes. This poses a global health problem that urgently needs attention. Above all, the main purpose of this project is to ultimately be part of the solution. As part of the project, a low cost, efficient, simplistic and reliable system utilizing a non-grid energy source was to be designed. Furthermore, the process to reach this goal was started by choosing membrane distillation as the design concept and finalized with the creation of a membrane distillation system design based on an analysis of information gathered during the process, such as areas of improvement in current designs. Consequently, the result of this process was a solar powered membrane distillation system combined with sand filtration as well as the use of a thermal heat pump powered by solar energy which is to be collected with the aid of a parabolic mirror.
Appendix I: EPA Drinking Water Regulations [6]
<table>
<thead>
<tr>
<th>Contaminant</th>
<th>MCL or TT (mg/L)</th>
<th>Potential health effects from long-term exposure above the MCL</th>
<th>Common sources of contaminant in drinking water</th>
<th>Public Goal (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cryptosporidium (or Microspora)</td>
<td>0.2</td>
<td>None (damage to thyroid problems)</td>
<td>Discharge from wastewater treatment facilities, discharge from plants and medicine industries</td>
<td>0.2</td>
</tr>
<tr>
<td>OC 240</td>
<td>0.07</td>
<td>Kidney, liver, cardiovascular problems</td>
<td>Runoff from herbicide use on crops</td>
<td>0.07</td>
</tr>
<tr>
<td>Delugine</td>
<td>0.2</td>
<td>None, kidney changes</td>
<td>Runoff from herbicide use on crops</td>
<td>0.2</td>
</tr>
<tr>
<td>L,2-Dichloro-3,4-Dichlorophenol (DDC)</td>
<td>0.05</td>
<td>Reproductive difficulty, increased risk of cancer</td>
<td>Runoff from herbicide use on crops</td>
<td>0.05</td>
</tr>
<tr>
<td>Asbestos</td>
<td>0.01</td>
<td>None (exposure to asbestos)</td>
<td>Discharge from industrial chemical factories</td>
<td>0.01</td>
</tr>
<tr>
<td>L,2-Dichloro-3,4-Dichlorophenol (DDC)</td>
<td>0.005</td>
<td>Increased risk of cancer</td>
<td>Discharge from industrial chemical factories</td>
<td>0.005</td>
</tr>
<tr>
<td>1,1,2-Trichloroethane</td>
<td>0.005</td>
<td>Liver problems</td>
<td>Discharge from industrial chemical factories</td>
<td>0.005</td>
</tr>
<tr>
<td>2,3,3-Trichloro-1,1,1-Tetrafluoroethane (Perchloro)</td>
<td>0.005</td>
<td>Liver problems</td>
<td>Discharge from industrial chemical factories</td>
<td>0.005</td>
</tr>
<tr>
<td>1,4-Dichlorobenzene</td>
<td>0.05</td>
<td>Increased risk of cancer</td>
<td>Discharge from industrial chemical factories</td>
<td>0.05</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0.05</td>
<td>None (exposure to chlorine)</td>
<td>Discharge from industrial chemical factories</td>
<td>0.05</td>
</tr>
<tr>
<td>Dioxin D,L,A,Y,1,6-PCDDs</td>
<td>0.0000000</td>
<td>Reproductive difficulty, increased risk of cancer</td>
<td>Emissions from forest destruction and other environmental factors, discharge from industrial chemical factories</td>
<td>0.0000000</td>
</tr>
<tr>
<td>Phenytoin</td>
<td>0.05</td>
<td>None (exposure to Phenytoin)</td>
<td>Discharge from industrial chemical factories</td>
<td>0.05</td>
</tr>
<tr>
<td>Phenytoin</td>
<td>0.05</td>
<td>None (exposure to Phenytoin)</td>
<td>Discharge from industrial chemical factories</td>
<td>0.05</td>
</tr>
<tr>
<td>Epichlorohydrin</td>
<td>0.05</td>
<td>Increased cancer risk, stomach problems</td>
<td>Discharge from industrial chemical factories</td>
<td>0.05</td>
</tr>
<tr>
<td>Ethylene oxide</td>
<td>0.05</td>
<td>None (exposure to Ethylene oxide)</td>
<td>Discharge from industrial chemical factories</td>
<td>0.05</td>
</tr>
<tr>
<td>Ethylene oxide</td>
<td>0.05</td>
<td>None (exposure to Ethylene oxide)</td>
<td>Discharge from industrial chemical factories</td>
<td>0.05</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.05</td>
<td>None (exposure to Formaldehyde)</td>
<td>Discharge from industrial chemical factories</td>
<td>0.05</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.05</td>
<td>None (exposure to Formaldehyde)</td>
<td>Discharge from industrial chemical factories</td>
<td>0.05</td>
</tr>
<tr>
<td>Methanol</td>
<td>0.05</td>
<td>None (exposure to Methanol)</td>
<td>Discharge from industrial chemical factories</td>
<td>0.05</td>
</tr>
<tr>
<td>Methanol</td>
<td>0.05</td>
<td>None (exposure to Methanol)</td>
<td>Discharge from industrial chemical factories</td>
<td>0.05</td>
</tr>
<tr>
<td>Fluoride</td>
<td>4.6</td>
<td>None (exposure to Fluoride)</td>
<td>Water contamination which results in oral and dental problems</td>
<td>4.6</td>
</tr>
<tr>
<td>Giardia lamblia</td>
<td>4.7</td>
<td>Short-term economic, gastrointestinal illness</td>
<td>Runoff from industrial chemical factories</td>
<td>4.7</td>
</tr>
<tr>
<td>Cryptosporidium</td>
<td>4.7</td>
<td>None (exposure to Cryptosporidium)</td>
<td>Runoff from industrial chemical factories</td>
<td>4.7</td>
</tr>
<tr>
<td>Haloacetic acids (HAA7)</td>
<td>0.05</td>
<td>Increased risk of cancer</td>
<td>Production of drinking water distribution</td>
<td>0.05</td>
</tr>
<tr>
<td>Haloacetic acids (HAA7)</td>
<td>0.05</td>
<td>Increased risk of cancer</td>
<td>Production of drinking water distribution</td>
<td>0.05</td>
</tr>
<tr>
<td>Haloacetic acids (HAA7)</td>
<td>0.05</td>
<td>Increased risk of cancer</td>
<td>Production of drinking water distribution</td>
<td>0.05</td>
</tr>
<tr>
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<td>0.05</td>
<td>Increased risk of cancer</td>
<td>Production of drinking water distribution</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Abbreviations:
- **ICOC**: Inorganic Chemicals
- **OC**: Organic Chemicals
- **M**: Microorganisms
- **R**: Radionuclides
- **D**: Disinfectant Byproducts

Legend:
- **D**: Disinfectant
- **ICOC**: Inorganic Chemical
- **OC**: Organic Chemical
<table>
<thead>
<tr>
<th>Contaminant</th>
<th>MCL or TP (mg/L)</th>
<th>Potential health effects from long-term exposure above the NCL</th>
<th>Common sources of contaminant in drinking water</th>
<th>Public Health Goal (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brothlylcholine</td>
<td>0.05</td>
<td>Leukemia and lymphoma, increased risk of cancer</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.05</td>
</tr>
<tr>
<td>Neurotoxins</td>
<td>0.05</td>
<td>Kidney or nervous system damage</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.05</td>
</tr>
<tr>
<td>Lead</td>
<td>10 ppm</td>
<td>Intestinal and neural damage. Fetal death, mental retardation, and other neurological problems</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.05</td>
</tr>
<tr>
<td>Mercury (inorganic)</td>
<td>0.05</td>
<td>Kidney damage</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.05</td>
</tr>
<tr>
<td>Mercury (organic)</td>
<td>0.05</td>
<td>Kidney damage</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.05</td>
</tr>
<tr>
<td>Nickel (measured as Ni)</td>
<td>50</td>
<td>Intestinal and nervous system damage</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.5</td>
</tr>
<tr>
<td>Nitrites (measured as Nitrogen)</td>
<td>11</td>
<td>Intestinal and nervous system damage</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.5</td>
</tr>
<tr>
<td>Nitrogen (measured as Nitrogen)</td>
<td>11</td>
<td>Intestinal and nervous system damage</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.5</td>
</tr>
<tr>
<td>Trichloroethylene</td>
<td>0.05</td>
<td>Skin damage, irritation, systemic problems, increased risk of cancer</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.05</td>
</tr>
<tr>
<td>Tetrachloroethylene</td>
<td>0.05</td>
<td>Skin damage, irritation, systemic problems, increased risk of cancer</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.05</td>
</tr>
<tr>
<td>Toluene</td>
<td>0.5</td>
<td>Nervous system injury</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.5</td>
</tr>
<tr>
<td>Total Coliforms</td>
<td>1,000</td>
<td>Intestinal problems, increased risk of cancer, skin problems</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>1,000</td>
</tr>
<tr>
<td>Total Coliforms (FCM)</td>
<td>1,000</td>
<td>Intestinal problems, increased risk of cancer, skin problems</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>1,000</td>
</tr>
<tr>
<td>Toxic Halogenated Compounds</td>
<td>0.05</td>
<td>Kidney, liver, or nervous system problems, increased risk of cancer</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.05</td>
</tr>
<tr>
<td>Vinyl Chloride</td>
<td>0.05</td>
<td>Kidney, liver, or nervous system problems, increased risk of cancer</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.05</td>
</tr>
<tr>
<td>Volatile Carcinogenic</td>
<td>0.05</td>
<td>Kidney, liver, or nervous system problems, increased risk of cancer</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.05</td>
</tr>
<tr>
<td>Volatile Nitrosamines</td>
<td>0.05</td>
<td>Kidney, liver, or nervous system problems, increased risk of cancer</td>
<td>Discharge from metal finishing and agricultural chemicals</td>
<td>0.05</td>
</tr>
</tbody>
</table>

**Legend:**
- **E:** Disinfectant
- **R:** Inorganic Chemical
- **OC:** Organic Chemical
- **M:** Microorganism
- **DF:** Disinfection Byproduct
- **CF:** Radionuclides
<table>
<thead>
<tr>
<th>Contaminant</th>
<th>MCL or TP (mg/L)</th>
<th>Potential health effects from long-term exposure above the MCL</th>
<th>Common sources of contaminant in drinking water</th>
<th>Public Health Goal (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manganese</td>
<td>0.05</td>
<td>Taint in water, taste, and odoriness</td>
<td>Soil runoff</td>
<td>0.05</td>
</tr>
<tr>
<td>Uranium</td>
<td>0.03</td>
<td>Increased risk of cancer, kidney toxicity</td>
<td>Uranium in natural deposits</td>
<td>0.03</td>
</tr>
<tr>
<td>Vinyl chloride</td>
<td>0.002</td>
<td>Increased risk of cancer</td>
<td>Leaching from PVC pipes, discharge from plastic factories</td>
<td>0.002</td>
</tr>
<tr>
<td>Nitrates (natural)</td>
<td>10</td>
<td>Short-term exposure, chronic health effects (e.g., diarrhea, vomiting, constipation)</td>
<td>Human and animal food waste</td>
<td>10</td>
</tr>
<tr>
<td>Xylenes (total)</td>
<td>0.005</td>
<td>Neurotoxic damage</td>
<td>Discharge from petrochemical factories</td>
<td>0.05</td>
</tr>
</tbody>
</table>

**Notes:**
- M: Metal
- R: Radionuclides
- O: Organic Chemical
- I: Inorganic Chemical
- D: Disinfectant Byproduct
- M: Microorganism
- K: Radionuclides
Appendix II: References