Tri-Exchange

Capstone Portfolio

By Group 280209

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01

Present and Justify a Problem and Solution

KEY SECTIONS

a. Egypt Grand Challenge(s)

b. Problem to be Solved

c. Research

d. Other Solutions Already Tried

a

Egypt Grand Challenge(s)

KEY SECTIONS

1. The Clean Water Situation in Egypt and The World
2. Causes of The Problem
3. Governmental Solutions
4. Conclusion

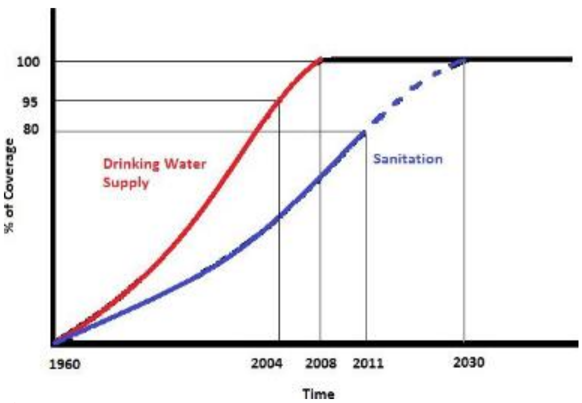


Figure 1.1 Percentage of Coverage of Drinking Water Supply and Sanitation Services since 2004 till 2017

SECTION a.1

The Clean Water Situation in Egypt and The World

More people die in the world as a result of a lack of clean water than as a result of war. Approximately one out of every six people in the world today does not have adequate access to water, and more than double that amount lacks basic sanitation, which necessitates the use of water. Half of the population in some nations does not have access to safe drinking water, resulting in poor health. According to some estimates, approximately 5,000 children die each day from diarrheal diseases around the world, a figure that would reduce drastically if enough water for sanitation was available. Egypt is not excluded in regards of water crisis, as of 2007, more than 100,000 people are facing death or sickness because of the lack of clean water and the situation has gotten worse as of right now.

SECTION a.2

Causes of The Problem

The Egyptian government is continuously working on improving water infrastructure, but bad water infrastructure is not the only problem regarding freshwater resources in Egypt, there are other problems such as The Grand Ethiopian Renaissance Dam and population growth which are the 2 main causes of the lack of clean water in Egypt.

The Grand Ethiopian Renaissance Dam (GERD)

The Grand Ethiopian Renaissance Dam is the most important project for modern Ethiopia, as the country depends entirely on it for its economic development. But it also might vastly increase the water crisis in Egypt and Sudan.

The precise impact of the dam on the downstream countries is not known. But studies indicate that it will severely decrease Egypt's freshwater supply which is already low, as Egypt is one of the most water-scarce countries in the world, as its annual share of water per capita is about 560 m3, which is a great deal below the international standard of 1,000 m3.

Figure 2.1 Construction of The Grand Ethiopian Renaissance Dam (GERD)

Population Growth

Researchers were predicting that Egypt's population will increase from 63.2 million in 1995 to 95.6 million in the year 2026 and that it will reach 114.8 million in the year 2065. These predictions were based on some surveys shown in **Figure 2.2** which show that Egypt has an approximate population growth rate of 1.5 million people every year. The truth is that these predictions were not true. Egypt population have increased drastically in the 21st century in way that made it reach approximately 102 million people in 2020 and it increased to reach approximately 104 million people in 2021. **Figure 2.3** shows the population growth in Egypt in the 21st century.

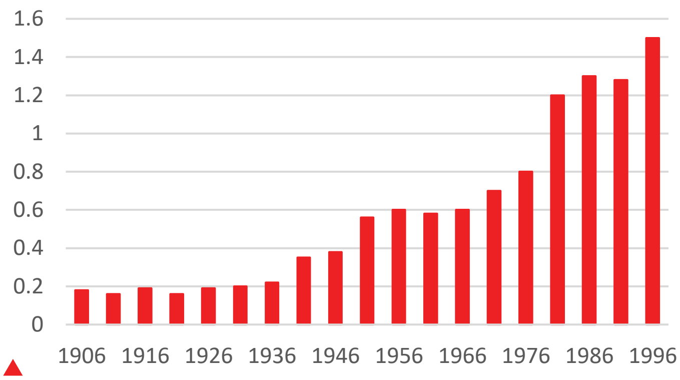


Figure 2.2 Rate of Population Growth in Egypt in Millions

Year	Population	Yearly % change	Yearly change
2020	102,334,404	1.94%	1,946,331
2019	100,388,073	2.00%	1,964,475
2018	98,423,598	2.05%	1,981,007
2017	96,442,591	2.11%	1,995,518
2016	94,447,073	2.17%	2,004,526
2015	92,442,547	2.24%	1,936,262
2010	82,761,235	1.85%	1,447,533

Figure 2.3 Population Growth in The 21st Century.

With the increase in Egypt’s population to over 100 million, Egypt's water consumption has reached between 105 to 110 billion cubic meters per year.

The rapid population increase of 1.5 million people/year multiplies the stress on Egypt’s water supply due to more water requirements for domestic consumption and increased use of irrigation water to meet higher food demands and increasing water-polluting industries.

Inefficient Irrigation

Egypt receives an average of less than 40 mm of rain each year, and just 6% of the nation has fertile land, with the remainder being desert. This leads to overwatering and the use of inefficient irrigation techniques like flood irrigation (an out-of-date irrigation technique in which liters of water are pumped over the crops).

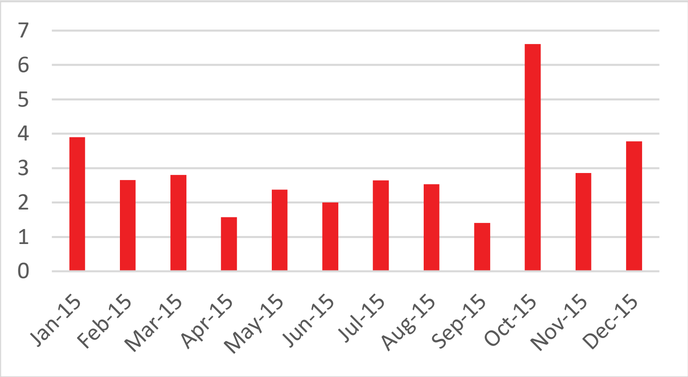


Figure 2.4 Annual rainfall in Egypt in millimeters

The Aswan High Dam, which manages about 29,000 kilometers of canals and sub-canals that reach out into the country's farmlands close to the river, now provides almost all of Egypt's irrigation. This system is inefficient, evaporating up to 3 billion cubic meters of Nile water each year, and could be harmful by not only increasing water and water stress but also creating unemployment.

A further decrease in water supply would lead to a decline in arable land available for agriculture, and with agriculture being the biggest employer of youth in Egypt, water scarcity could lead to increased unemployment levels.

All of this paired with the fact that agriculture consumes around 77% of the entire freshwater supply in Egypt, indicates that inefficient irrigation is a major problem for water supplies in Egypt.

Water Pollution in Egypt

The pollution of the Nile River is a problem that is usually ignored. With so many people relying on the Nile for drinking, agricultural, and municipal purposes, the Nile's water quality should be a top priority. The reality is that the Nile's water is polluted by municipal and industrial waste, with numerous incidents of wastewater leakage, and chemical and toxic industrial waste releasing into the river.

Industry and Water Pollution

With industry consuming about 3% of the national clean water supply in Egypt, it’s one of the most important sectors in Egypt, but it’s also one of the most water-polluting sectors as industrial enterprises, which Egypt has 24,000 of, 700 of which are major industrial facilities, carry away the waste produced by manufacturing into rivers, lakes and oceans.

Metals in the water have been introduced by industrial waste, posing a serious risk to human health, animal health, and agricultural production. Because of the high levels of ammonia and lead, a substantial number of fish die from poisoning.

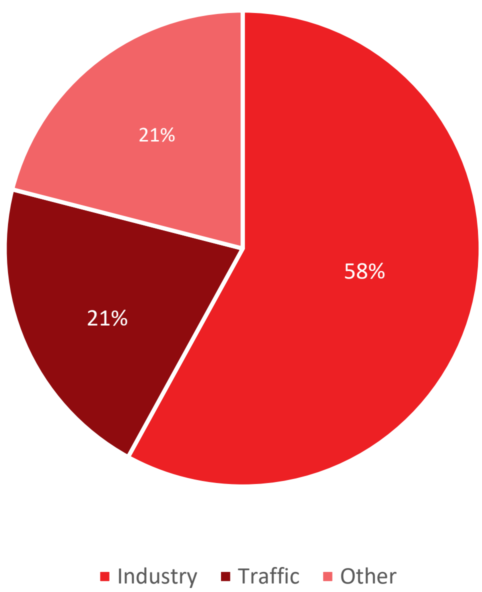
Figure 2.5 Water Pollution Caused by the Release of Industrial Waste in Egypt

Acid Rain

Acid rains occurs by due to conversion of primary acidic pollutants (SO_2 & NO_2) into secondary pollutants (H_2SO_4 & HNO_3 and their salts).

The main sources of acid rains in Egypt are industry, traffic, and other sectors. With industry causing roughly 60% of the total CO_2 emissions in Egypt (as shown in **Figure 2.6**)

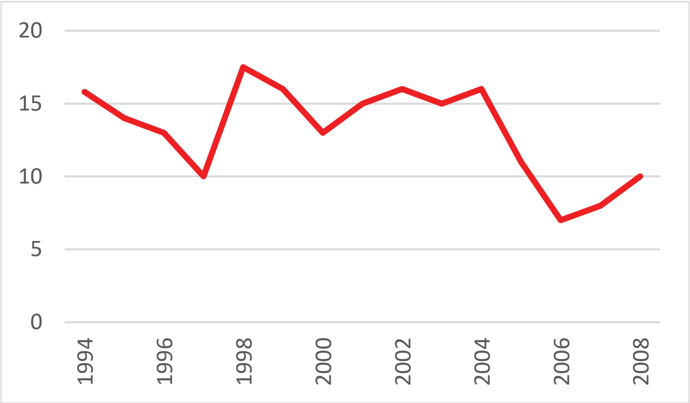
Acid rains generally end up in soil or water supplies. This leads to polluting soil or crops that are sold for domestic use or used in food or medical industries, and polluting the Nile River or sinking into ground water, which can severely damage national health.



▲
Figure 2.6 CO_2 Emissions in Egypt

Agriculture and Water Pollution

Agriculture is one of the, if not the, most important economic sector(s) for Egypt. As it contributes 11.3% of the country's GDP. It accounts for 28% of the jobs. 55% of the employment in Upper Egypt is agriculture-related. More than 50% of exports are from agriculture, and more than 50% of the Egyptian industry consists of agriculturally based sectors.



▲
Figure 2.7 The Value of Total Agricultural Export Percentages of The Total Export in Egypt.

Agriculture in Egypt is in serious trouble. Labor productivity has declined. In 1974 for the first time in history, Egypt became a net importer of agricultural commodities. The growth rate of land yields for cereal crops, cotton, and sugar cane has declined and slowed. Food imports have increased from 1,305,700 metric tons of wheat and maize in 1970 to 3,376,900 metric tons in 1976, while exports declined from 654,500 and 285,300 metric tons, respectively, in 1970, to 211,000 and 165,200, in 1970, to 211,000 and 165,200, in 1976.

Using untreated water for irrigation has damaged agricultural production quality and quantity, as bacteria and metals in the water hinder plant growth, particularly in the Nile Delta, where pollution levels are highest.

The origins of the problem can be largely traced back to both, soil pollution and the Egyptian water crisis.

The main agricultural source of water pollution in Egypt is the overuse of fertilizers, pesticides and herbicides. This fact paired with the fact agricultural runoffs send these toxic chemicals into the Nile River makes the Nile a polluted river which may spell doom for the generations to come.

Soil Pollution

Soil pollution definition is the presence of toxic chemicals (pollutants or contaminants) in the soil in high enough concentrations to be of risk to human health and/or the ecosystem. Additionally, even when the levels of contaminants in soil are not of risk, soil pollution may occur simply because the levels of the contaminants in soil exceed the levels that are naturally present in soil (in the case of contaminants that occur naturally in soil).

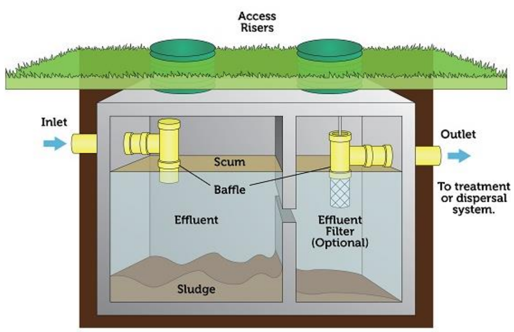
Soil pollution is mainly caused by water pollution, and soil absorbance of fertilizers and pesticides.

Domestic Use and Water Pollution

Domestic use of water is not directly responsible for water pollution, the problem is not with the use, it is with the way of disposal of pollutants. Although 65% of the Egyptian population is connected to drinking water supply, only 24% of the population is connected to sewage services. So, people rely on primitive means of personal waste disposal such as, septic tanks and latrines. These methods of disposal cause domestic waste to spread into ground water by permeable septic tanks. This is the largest source of groundwater pollution in Egypt.

And even in places which are connected to legitimate sewage systems, sewage water is discharged into the river untreated due to a lack of water treatment plants.

Figure 2.8 ▶ Primitive Sewage Systems (Septic Tanks).



SECTION a.3

Governmental Solutions

Many solutions have been implemented by the Egyptian government to overcome the water crisis, these solutions include:

- The non-stopping negotiations between the country, Sudan, and Ethiopia to reach an agreement for the 3 countries to be content. But no agreement was reached as of right now. The Egyptian Irrigation Minister Mohamed Abdel-Atti said that Addis Ababa lacked a "sincere" political will and intention to reach a deal with Egypt and Sudan in the dispute over the Grand Ethiopian Renaissance Dam (GERD).

- To overcome the problem, The Ministry of Irrigation and Water Resources (MIWR), is in charge of allocating water resources. About 80% of the water resources in Egypt are used by the agriculture sector, with the majority of it coming from the Nile river.

- Institutional Strengthening of the Egyptian Environmental Affairs Agency to Improve its Environmental Policies Formulation and Environmental Management Capabilities

- Industrial Pollution Control (IPC) policy implemented by the Egyptian Environmental Affairs Agency (EEAA).

SECTION a.4

Conclusion

Egypt is currently in a very critical situation regarding freshwater resources. The causes of this problem, whether it is GERD, overpopulation, inefficient irrigation, or pollution, are clear and evident, and they need to be solved as soon as possible because they are severely damaging the economy of Egypt. The government has already started implementing solutions for these problems, but they're not yet enough to solve the problem, and most of them are long-term solutions that will not appear to be beneficial for a long period of time.

b

Problem to be Solved

KEY SECTIONS

1. The Nile River Situation in Egypt
2. Water Resources in Egypt
3. Water Uses in Egypt
4. If the Problem is Solved
5. If the Problem is not Solved

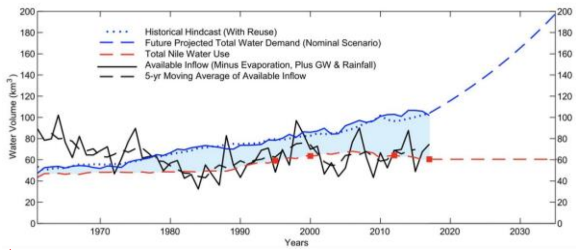


Figure 1.1 Estimated amount of water resources in Egypt.

SECTION b.1

The Nile River Situation in Egypt

Even in ancient times, the Nile River brought food and drinking water to Egypt; the country was based on agriculture, and agriculture was established on the Nile River.

Egypt's Nile-derived surface water resources are currently being fully exploited, and with rising water demand from a growing population, the Grand Ethiopian Renaissance Dam threatening Egypt's share of the Nile River, pollution, and inefficient irrigation, Egypt can no longer rely solely on the Nile.

Figure 1.1 shows that Egypt will import more water than the water supplied by the Nile, according to a study from the MIT department of Civil and Environmental Engineering.

SECTION b.2

Water Resources in Egypt

The problem is that Egypt is completely dependent on the Nile River as the it represents about 95.1% of the conventional water resources in Egypt, which is about 55 BCM. Also, Egypt is facing a water deficit of about 30 BCM. **(Figure 2.1)**

The current strategy of solely relying on Nile River water will no longer be sufficient, and Egypt will soon need to tap into previously untapped water sources or import water from another country.

Egypt's water resources are split into two categories: conventional and non-conventional water resources.

Conventional Water Resources

Conventional water resources are resources that are most used in Egypt, these include the Nile River Annual Flow, Ground water in the Western Desert - which is non-renewable, Flash Floods and rainfalls, and seawater desalination.

Nile River Annual Flow – As illustrated in **Figure 1.2**, the average annual quota of Egypt from the conventional water is limited in the Nile River which is determined as 55.5 BCM according to the 1959 agreement with Sudan.

Ground Water in Western Desert – This accounts for around 1.4 percent of Egypt's total conventional water supply. The entire potential extraction from groundwater in the Western Desert and oasis is around 3.75 BCM/y, with the goal of keeping this groundwater storage sustainable for the next 200 years. Currently, 0.82 BCM/y is being used.

Flash Floods and Rainfalls – Rainfall along the coast and flash floods occurring within short-period heavy storms in the Red Sea area and Southern Sinai provide another 1.0 BCM per year, or about 1.7 percent of all conventional water sources, which are directly used to meet part of the water requirements or used to recharge shallow groundwater aquifers.

Seawater Desalination – Desalination of seawater will be one of the most important ways to the development of water resources in the future. Egypt is blessed with a favorable physical location, bordering the Red Sea on the east and the Mediterranean Sea on the north. This enables desalination to be implemented successfully in various regions along the two beaches, as well as in the Sinai coastal zone. The high prices of desalination are the only remaining factor. When comparing saltwater desalination to hard water desalination (saline or brackish), where salinity levels range from 1,500 to 5,000 ppm, we discover that it is less expensive and more economically viable. The total amount of desalinated water produced each year is 0.3 BCM.

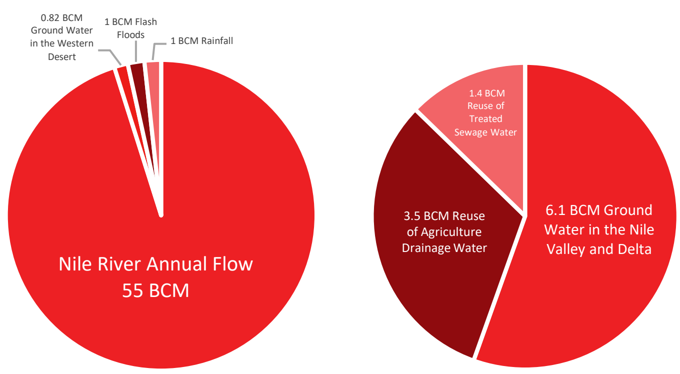


Figure 2.1 Distribution of Convectional and Non-conventional Water Resources in Egypt.

Non-conventional Water Resources

The non-conventional water resources are the resources that are not used that much, and they are mostly wasted potential. They include the renewable groundwater aquifer underlying the Nile valley and delta, the reuse of agricultural drainage water, and the reuse of treated sewage water.

Renewable Ground Water in the Nile Valley & Delta – The amount of the groundwater in the Nile valley & delta is estimated at 6.1 BCM per year, which is renewable and not exploited. This resource can be a main resource in the future when Egypt resorts to using non-conventional water resources.

The Reuse of Agriculture Drainage and Treated Sewage Water – The reuse of agriculture drainage water is about 3.5 BCM per year and the reuse of treated sewage water is about 1.4 BCM per year.

SECTION b.3

Water Uses in Egypt

The water used in Egypt is mainly used in agriculture, industry, and municipal uses. With agriculture representing about 85% of the total water usage which is 40 BCM/year, industry representing 1.64% of the total water use, which is about 0.8 BCM/year, and municipal uses representing about 18.28% of the total use, which is about 9.9 BCM/year.

SECTION b.4

If the Problem is Solved

- Water prices will decrease.
- The Egyptian water resources will increase and be available.
- The Egyptian water deficit will be decreased.
- The amount of arid areas in Egypt will decrease, as they'll be cultivated.
- Urban congestion around the Nile basin will decrease.
- Egypt will grow to be self-dependent in the water department.
- The number of people dying from the lack of proper water sanitation will fall.
- Egypt will not entirely get rid of the nationally produced cereal crops which consume a lot of water, and will not get rid of water-demanding industries.

SECTION b.5

If the Problem is not Solved

- Egypt will be lacking in the water-department.
- Egypt will depend on importing water from outside the country.
- Water prices will drastically increase, which will completely flip the Egyptian economy.
- Arid areas will be dominant in Egypt.
- The number of people dying from the lack of water and sanitation will vastly increase (especially the low-income part of the population).
- The agricultural and industrial sectors in Egypt will fall.

C

Research

KEY SECTIONS

1. Topics Related to the Problem
2. Topics Related to the Solution

▲ **Figure 1.1** The Nile River in Egypt.

SECTION C.1

Topics Related to the Problem

- **Fresh Water Situation in the World** – Fresh water makes only 3% of all water resources, this means that the world is about to experience a shortage of freshwater resources, if we continue to rely on these resources only. The impacts of this shortage are already appearing as the number of deaths caused by the lack of fresh water is rising and the amount of arid land is increasing.

- **Fresh Water Situation in Egypt** – The water situation in Egypt is getting worse and worse recently whether it is because of GERD, population growth, inefficient irrigation, pollution, or water over usage. This led to deficiencies in both the agricultural and the industrial sectors as they consume about 77% and 3% respectively.

- **Conventional Water Resources in Egypt** – Conventional water resources are resources that are most used in Egypt, these include the Nile River Annual Flow, Ground water in the Western Desert - which is non-renewable, Flash Floods and rainfalls, and seawater desalination.

- **Non-conventional Water Resources in Egypt** – The non-conventional water resources are the resources that are not used that much, and they are mostly wasted potential. They include the renewable groundwater aquifer underlying the Nile valley and delta, the reuse of agricultural drainage water, and the reuse of treated sewage water.

- **Water Uses in Egypt** – Water resources in Egypt are mainly used in industry, agriculture, municipal uses, navigation, and public services.

- **The Egyptian Water Deficit** – Egypt is facing an annual water deficit of about 30 BCM because of the sheer dependence on the Nile River.

SECTION C.2

Topic Related to the Solution

- **Ultraviolet (UV) filters** – UV light (minimum level radiation) is passed on water to kill bacteria and other microbes by attacking the DNA in cells. These filters remove pesticides by up to 99%. This filter is effective in removing all types of pathogens, but it is not effective for removing suspended particles, chemicals, taste, smell, or color. It can purify approximately 2000 liters/day.

- **PUR - Flocculant/Disinfectant** – The flocculants/disinfectant powder PUR has been proven to remove the vast majority of bacteria, viruses, and protozoa, even in highly turbid waters. PUR has also been documented to reduce diarrheal disease from 16 to greater than 90% incidence in five randomized, controlled health intervention studies. In addition, PUR removes heavy metals, such as arsenic, and chemical contaminants from water.

- **Solar Distillation** – A solar still can be a cheap and simple piece of shaped plastic or glass, or they can be more highly designed devices. To work, the still allows sunlight to shine through a clear panel onto the impure water. The water heats and evaporates, then condenses on the underside of the panel and runs off into a container of some kind. This simple process takes huge amounts of energy, which is why solar stills can make more sense than stills powered by other fuels.

- **Bamboo Charcoal** – It's a filter made of locally available materials including charred bamboo, gravel and natural adsorbents. "The process we propose is indigenous, eco-friendly, low cost and entails minimum maintenance,". The filter can handle 30 liters of water per hour, and it would be affordable for average households in the region.

- **SODIS** – Solar water disinfection (SODIS) is a water treatment method that uses the sun's energy for disinfection. The most common technique is to expose plastic bottles full of contaminated water to the sun for a minimum of one day. The sun's abundant UV light kills or damages almost all biological hazards in the water.

- **Slow Sand Filters** – Slow sand filters are the oldest type of municipal water filtration, they efficiently and cheaply filter water from turbidity or algae and microorganisms through a bed of porous sand, support gravel layer and a sticky mat of biological matter called “Schmutzdecke Layer”.

- **Schmutzdecke Layer** – The Schmutzdecke layer is a sticky layer of biological matter that forms at the top of a slow sand filter. It forms gradually after using the slow sand filter repeatedly and works on filtering particles by trapping them and biologically degrading organic matter.

- **Activated Carbon Filter** – An activated carbon filter is a proven method to remove organic chemicals, odors, tastes, chlorine or hydrogen sulfide from water. They can’t remove other chemicals like iron and nitrate though, these are removed by other filtering methods like reverse osmosis or electrodialysis.

- **Demineralization** – is the process of removing mineral salts from Water by using the ion exchange process. Mineral ions such as cations of sodium, calcium, iron, copper, etc.., and anions such as chloride, sulfate, nitrate are common ions present in Water.

- **AWG (Atmospheric Water Generator)** – An AWG uses technology to produce potable water from the surrounding air. It works by compressing, cooling down, then expanding ammonia gas until it becomes a liquid with -27 deg. Celsius. Water from the atmosphere condenses and then collected.

- **Distillation** – Distillation is the process involving the conversion of a liquid into a vapor that is subsequently condensed back to liquid form. Distillation is used to separate liquids from nonvolatile solids, such as alcoholic beverages from fermented materials, or to separate two or more liquids with different boiling points, such as gasoline, kerosene, and lubricating oil from crude oil. Other industrial applications include the processing of chemicals like formaldehyde and phenol, as well as seawater desalination.

- **Electrodialysis** – Electrodialysis is a separation method that separates ionic solutes from non-charged solutes. Using a selective membrane, an electrical current, and electrodes, electrodialysis removes metal ions from solutions. Ion-permeable membranes are employed in electrodialysis to extract ionized compounds from liquids.

- **Reverse Osmosis** – Reverse osmosis (RO) is a membrane-based filtration technique that eliminates a wide range of big molecules and ions from solutions by applying pressure to the solution on one side of a selective membrane. As a result, the solute is trapped on the membrane's pressurized side while the pure solvent can pass through. To be "selective," this membrane must not allow large molecules or ions to pass through the pores (holes), but smaller components of the solution (such as the solvent) must flow freely.

- **USP Water Standards** – The water standards used in the pharmaceutical industry.

d

Other Solutions Already Tried

KEY SECTIONS

1. VEOLIA ENTROPIE Multi Effect Distillation
2. Reverse Osmosis Water Treatment Systems
3. Filtering Water with Acoustics Nanotube Technology

SECTION d.1

VEOLIA ENTROPIE Multi Effect Distillation

ENTROPIE are the world's leading experts in desalination of seawater using low-temperature distillation techniques such as:

- Multiple Effect Distillation (MED)
- Multiple Effect Distillation with Thermal Vapor Compression (MED-TVC)
- Multiple Effect Distillation with Mechanical Vapor Compression (MED-MVC)

Multi Effect Desalination, The MED unit is a low-temperature (70°C) evaporator in which sea water is evaporated in one or more (up to 14) evaporation stages to generate pure distillate water.

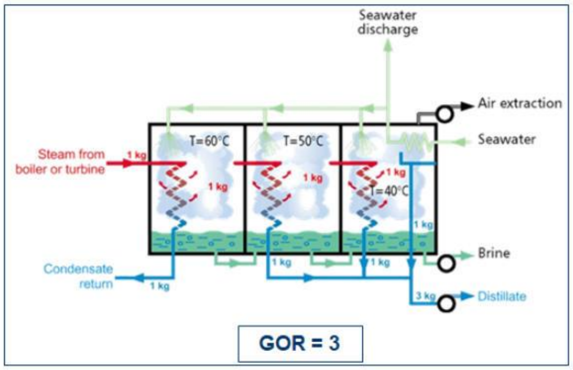


Figure 1.1 An Illustration of Multi Effect Distillation Stages.

How it Works

The MED method is designed to produce distilled water and/or drinkable water using steam or waste heat from power plants or chemical processes.

- Figure 1.1 illustrates a three-cell Multiple Effect Distillation unit.

- The produced steam is condensed on a conventional shell and tubes heat exchanger (distillate condenser) cooled by sea water in the final cell.

- At the condenser's exit, part of the warmed sea water is used to make up the unit, while the rest is discarded to the sea. Brine and distillate are collected from cell to cell until they reach the last one, where centrifugal pumps extract them.

- The Gain Output Ratio (GOR) is a measurement of a unit's thermal efficiency. It is defined as the amount of distillate generated per unit of heating steam required.

▲ Figure 1.2 A 3D Model of a Multi Effect Distillation Plant.

The Advantages

- Very low electrical consumption (less than 1.0 kWh/m3) compared to other thermal processes such as Multi Stage Flash (MSF) or membrane processes (Reverse Osmosis)

- Operate at low temperature (< 70°C) and at low concentration (< 1.5) to avoid corrosion and scaling.

- Produce steadily high purity distillate.

- Do not need complex pre-treatment of sea water and are tolerant to variations of sea water conditions.

- Are highly reliable and simple to operate.

- Reduce civil works cost thanks to reduced footprint.

- Are simple to install with packaged units mounted on skids and delivered ready for use, after easy installation.

- Have a low maintenance cost (no rotating parts except low pressure pumps).

- Operate 24 hours a day with minimum supervision.

- Ideal for coupling with power plants, steam can be used efficiently at pressure as low as 0.35 bar abs or less.

- Can be adapted to any heat source including hot water.

- Allow very high thermal efficiencies and savings in fuel costs.

- Range up to 15 MIGD (68 000 m3/day) per unit.

The Disadvantages

Disadvantages of a multi-stage flash distillation system are a high operating cost when waste heat is not available for the distillation process and relatively high rates of corrosion and scale formation due to high operating temperatures.

Real life Examples

This technology had been applied in many places such as: Damietta (Egypt), Oman, Algeria, Bahrain, Peru, Saudi Arabia, Italy, Curacao, Libya, the United Arab Emirates, and many more.

Figure 1.3 The Multi Effect Distillation Plant in Damietta, Egypt.

Figure 1.4 The Multi Effect Distillation Plant in Oman.

SECTION d.2

Reverse Osmosis Water Treatment Systems

When pressure forces unfiltered water or feed water across a semipermeable membrane, reverse osmosis removes impurities. To provide clean drinking water, water flows from the more concentrated side (more contaminants) of the RO membrane to the less concentrated side (fewer contaminants). The permeate is the fresh water that is produced. The waste or brine is the concentrated water that remains.

Small pores in a semipermeable membrane restrict pollutants while allowing water molecules to pass through. As water travels across the membrane via osmosis, it becomes more concentrated in order to achieve equilibrium on both sides. Reverse osmosis, on the other hand, prevents pollutants from entering the membrane's less concentrated side. When reverse osmosis is applied to a volume of saltwater, for example, the salt is removed and only clean water comes through.

How does a reverse osmosis system work?

A prefilter removes sediment and chlorine from water before forcing it through a semipermeable membrane to remove dissolved particles in a reverse osmosis system. Before entering a dedicated faucet, water departs the RO membrane and flows through a postfilter to polish the drinking water. The quantity of prefilters and postfilters in a reverse osmosis system determines the stages.

Stages of RO systems

A reverse osmosis system is centered on the RO membrane, but it also contains other types of filtration. RO systems have three, four, or five stages of filtration.

A sediment filter and a carbon filter are included in every reverse osmosis water system, in addition to the RO membrane. Depending on whether water travels through them before or after passing through the membrane, the filters are referred to as prefilters or postfilters.

Each type of system contains one or more of the following filters:

- Sediment filter**:** Reduces particles like dirt, dust, and rust.

- Carbon filter**:** Reduces volatile organic compounds (VOCs), chlorine, and other contaminants that give water a bad taste or odor.

- Semi-permeable membrane**:** Removes up to 98% of total dissolved solids (TDS).

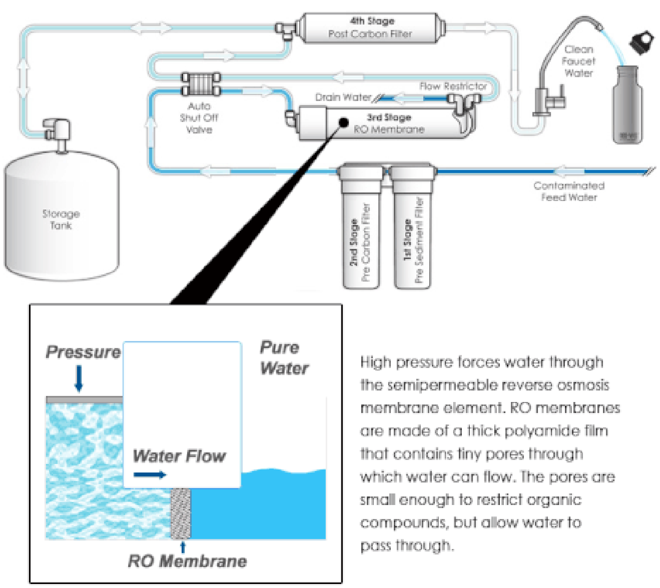


Figure 2.1 Reverse Osmosis Systems

What does a reverse osmosis system remove?

The RO membrane in a reverse osmosis system removes dissolved solids like arsenic and fluoride. For a broad range of reduction, a RO system contains sediment and carbon filtration. The sediment filter in a RO system eliminates dirt and debris, while the carbon filters remove chlorine and foul taste and odors.

Does a reverse osmosis system remove...

- Fluoride? **Yes.**
- Salt? **Yes.**
- Sediment? **Yes.**
- Chlorine? **Yes.**
- Arsenic? **Yes.**
- VOCs? **Yes.**
- Herbicides and pesticides? **Yes.**
- Many other contaminants? **Yes.**

The contaminants listed are some of the most popular ones treated with an RO system, but the system also removes a slew of other contaminants.

- Bacteria and Viruses? **No.**

If your water comes from a city treatment plant, then it should already be microbiologically safe. Reverse osmosis may remove some bacteria, but bacteria could grow on the membrane and potentially enter your water supply. To remove living organisms and viruses, we recommend UV disinfection.

Reverse Osmosis System Advantages

A reverse osmosis system is one of the most comprehensive filtration systems available. It filters out 98 percent of dissolved solids, making it safer to drink. The only alternative drinking water system that decreases TDS is a water distiller, however it is less efficient than a RO system.

- Harmful dissolved contaminants reduced
- Sodium reduced
- Bad tastes and odors reduced
- More environmentally friendly than bottled water
- Easy to install and maintain
- Fits under the kitchen sink

Reverse Osmosis System Disadvantages

Reverse osmosis has several disadvantages that make it impractical for treating all of the water entering your home. The primary disadvantage is the amount of water wasted by the process. For each gallon of water produced, between 2-20 gallons of water are lost as waste.
Reverse osmosis units can be expensive. Cost of a unit along with installation may run from several hundred to one thousand dollars or more.

The RO membranes are subject to decay and require periodic replacement. As they decay, the quality of the treated water becomes poorer. Hard water can shorten the life span of the RO membrane. A water softener might be necessary to keep the membrane working at its best.
Reverse osmosis units should not be used to treat water that contains harmful microorganisms. Small holes in a worn membrane can allow microorganisms to pass through with the treated water.

Real Life Examples

The Reverse Osmosis water treatment systems had been applied in many places, including but not limited to Florida (United Stated), Israel, Saudi Arabia, Pakistan, China, and Australia.

Figure 2.2 A Reverse Osmosis System in Saudi Arabia.

SECTION d.3

Filtering Water with Acoustics Nanotube Technology

NASA's Johnson Space Center researchers have created a filtering system that removes pollutants from water supplies. The concept was originally created to cleanse wastewater for reuse onboard the International Space Station, but it can be used in a variety of circumstances on Earth when drinkable, medical-grade water needs to be collected from a contaminated water supply. The device is unique in that it uses acoustics instead of pressure to force water through small-diameter carbon nanotubes. The technology uses less energy than traditional filtration systems and is well-suited to a wide range of water treatment requirements.

The Technology

This water filtration innovation is an acoustically driven molecular sieve embedded with small-diameter carbon nanotubes. Turning the idea of filtration on its head, this technology pushes water away from contaminants, rather than removing contaminants from water

How It Works

Water enters the device and initially comes into touch with the filter matrix, which can be formed of polymer, ceramic, or metallic compounds depending on the end-use application. Only water molecules travel through the carbon nanotubes in the matrix, leaving bigger molecules and impurities behind. The use of acoustics to help force water through the filter is a unique feature of the technology. Water molecules de-bond and travel through the filter as a result of an oscillator circuit coupled to the filter matrix propagating acoustic vibration. The use of acoustics also eliminates the reliance on gravity to transport water through the device (and hence filter orientation). When the amount of water leaving the system falls below a pre-determined threshold, a cleaning cycle is initiated to clear the silt from the filter's entrance, restoring the system's normal flow rate. The filter system does not require flushing, unlike conventional filtration systems.

Why It Is Better

Existing water filtration technologies are generally plagued by limited performance, high energy consumption, and high costs. New filtration and treatment techniques designed to mitigate these problems generally depend on pressure to drive water through the filtration system. The combination of acoustics and small-diameter carbon nanotubes in this innovation make it an effective and efficient means of producing contaminant-free, clean water.

02

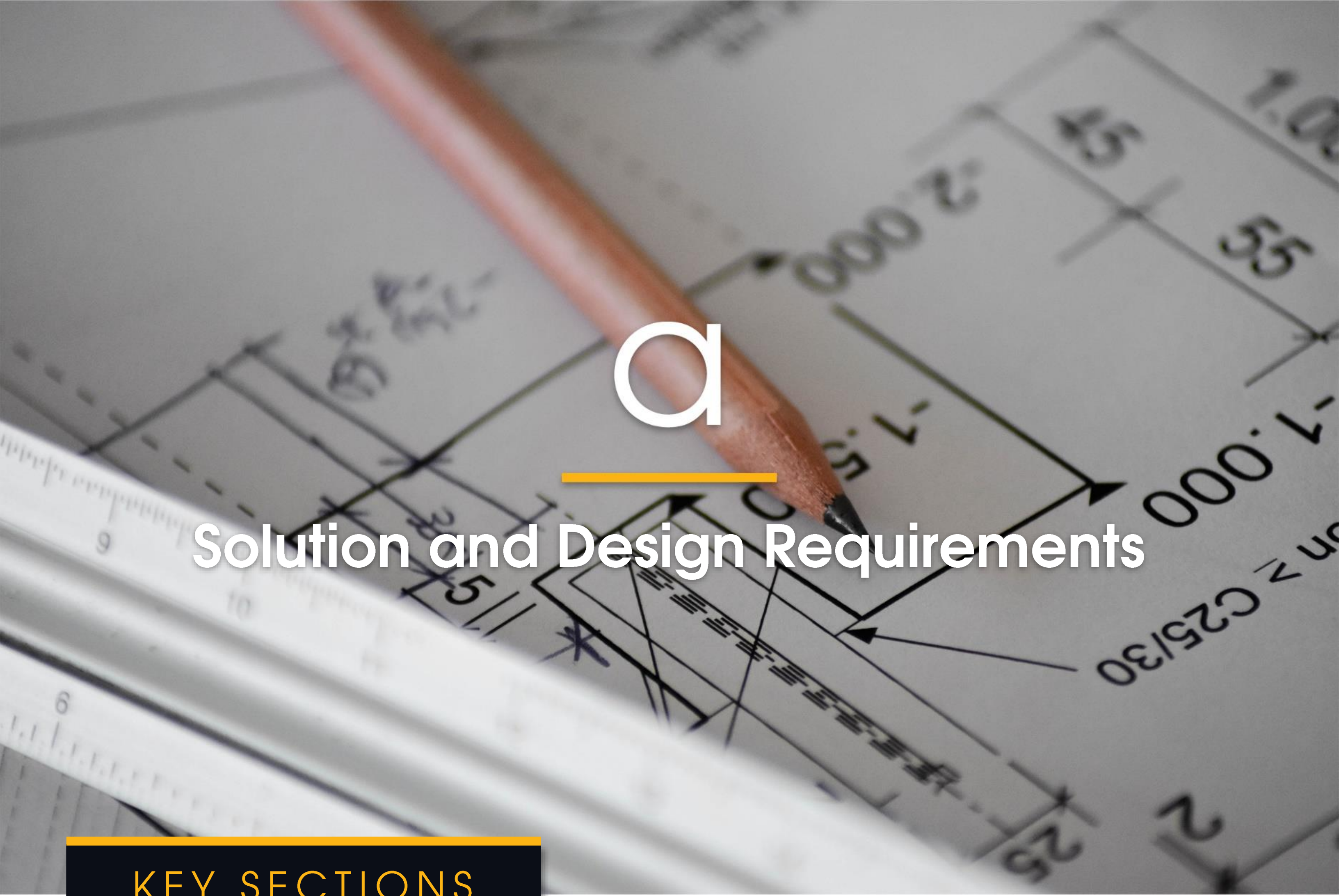
Generating and Defending a Solution

KEY SECTIONS

a. Solution and Design Requirements

b. Selection of Solution

c. Selection of Prototype



a

Solution and Design Requirements

KEY SECTIONS

1. Solution Requirements
2. Design Requirements

SECTION a.1

Solution Requirements

A successful solution requires many features. In our capstone project, we made sure that the solution contains additional characteristics such as:

Effectiveness – The prototype should purify ground water for it to be suitable for the industry of cosmetics. This requirement will be met Using materials that can eliminate the amount of minerals or reduce the TDS percentage in water can increase the prototype's effectiveness.

Low operation cost – Most water treatment projects are costly when it comes to operation, this prototype shouldn't cost that much when operating. This can be achieved by using little amounts of electricity, and making the prototype automatically operating.

Automatic operation – The prototype shouldn't require any human interference for it to function except in maintenance. This will make the process easier and quicker.

Efficiency – The prototype should be efficient in producing treated water than any other main water treatment method (Distillation and Reverse osmosis filters).

Applicability – The prototype should be able to be applied on a large scale and in industrial applications. This can be done by creating a prototype with a modular design that can be applied in a real scale.

Simplicity – The prototype should be simple in design for it to be applied easily in real life, and for it to be modified easily.

Testable – The design requirements of the prototype should be measurable and specific to determine whether the prototype is successful or not.

Durable – Durability is one of the main factors that contribute to the modularity of the solution, which can vastly improve its applicability.

Modified – The solution should be modified, not just a replica of an already existing solution, this will make sure that the solution is a new solution that can make a positive change.

SECTION a.2

Design requirements

The prototype was built to meet 2 main requirements, which are effectiveness, and efficiency.

Effectiveness

Achieving the requirement

The prototype should purify ground water for it to be suitable for the industry of cosmetics, for it to succeed.

The standards of the water used in cosmetics industry are listed in Figure 1.1.

Test	Unit	Product Results
Conductivity	µs/cm	≲ 5 µs/cm
PH		7.00 to 8.50
Sodium	ppm as Na	≲ 1 ppm
Calcium	ppm as CaCO3	≲ 1 ppm
Magnesium	ppm as MgCO3	≲ 1 ppm
Iron	ppm as Fe	≲ 1 ppm
Chloride	ppm as Cl	≲ 1 ppm
silica	ppm as Sio2	≲ 1 ppm
TDS	ppm	≲ 30 ppm

Figure 1.1 USP Water Quality Standards.

If the output water meets the requirements listed in the table above, then the requirement is achieved, and vise-versa.

Why this requirement was chosen

The cosmetics industry was chosen because it's one of the most water-consuming industries, as about 80% of a cosmetic product is pure water.

Groundwater was chosen because 45% of the water used in the cosmetics industry is groundwater, and 34% is river water. So, we wanted to reduce the dependence on river water and convert it to a dependence on groundwater.

Also, groundwater is pretty unexploited in Egypt. So, this project is set to redirect water usage in Egypt from the Nile River to the groundwater resources in Egypt.

Water-efficiency

Achieving the requirement

The prototype should be efficient in producing treated water than any other main water treatment method (Distillation and Reverse Osmosis Systems).

The most efficient distillation system we found is the multi-effect distillation system. This system can output about 1.8 liters of water if the input was 3 liters. So, it has an efficiency of 0.6.

The most efficient reverse osmosis system outputs about 2.4 – 2.1 liters if 3 liters were input, so it has an efficiency of 0.8 – 0.7.

For our prototype to meet this requirement it should attain an efficiency value > 0.8.

Why this requirement was chosen

We chose this requirement because if the prototype meets it, the amount of wasted water in the manufacturing process of cosmetics will be vastly reduced on the long run.

b

Selection of Solution

KEY SECTIONS

1. Introduction
2. Groundwater
3. Cosmetics Industry
4. Multimedia Filter
5. Ion Exchange Unit
6. Pumping System

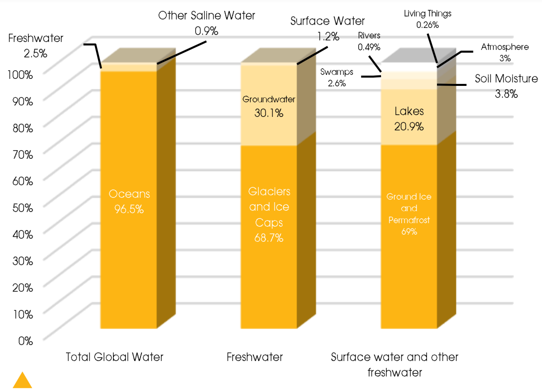


Figure 1.1 Water Resources Distribution in The World.

SECTION **b.1**

Introduction

The solution is to treat ground water to meet USP Pharmaceutical water standards and make it suitable for use in the cosmetics industry. This will be accomplished by the use of a three-stage system that includes a sand filter, a carbon filter, an ion exchange unit, and a pumping system.

SECTION **b.2**

Groundwater

Because of two key characteristics, groundwater was chosen as the main water source for this solution to treat: availability and cost.

Groundwater accounts for around 30.1% of the world's total freshwater resources. So, it is widely available. **(Figure 1.1)**

Groundwater in Egypt is available in eight main hydrological units, which are:

1. Nile Valley and Delta aquifers,
2. Coastal aquifers,
3. Nubian Sandstone aquifer,
4. Moghra aquifer,
5. Tertiary aquifer,
6. Carbonate rocks complex aquifers,
7. Fissured basement complex aquifers and
8. Aquiclude rocks

The groundwater used was retrieved from **Belbes, Sharkya Governorate, Egypt**. Which is in Nile Valley and Delta aquifers. **(Figure 2.1)**

Figure 2.1 Belbes, Sharkiya, Egypt.

This hydrological unit was chosen because it contains the largest (available, not just estimated) amount of groundwater (about 6.2 BCM), and is easily accessible.

Groundwater treatment is also less expensive than seawater treatment since the salinity of groundwater is significantly lower than that of salt water. As a result, the systems used to treat groundwater do not deteriorate as quickly as those used to treat saltwater because the TDS is much lower.

Furthermore, the country's general direction is to consider seawater desalination, as 19 new desalination plants are under construction and are expected to be completed by 2030; however, groundwater treatment is not considered.

SECTION b.3

Cosmetics Industry

The cosmetics industry is a relatively large industry of size valued US$ 341.1 billion in 2020, which is estimated to reach US$ 480.4 Bn by 2030.

The thing with cosmetics is that about 80% of a cosmetic product is water, so, this industry needs a lot of water.

USP Pharmaceutical Water standards

The desired standards for the water outputted from the prototype are the USP Pharmaceutical Water Standards.

These standards are listed in **Figure a.1.1**.

These are the World Health Organization's (WHO) standards for pharmaceutical water, which are also used in the cosmetics industry.

SECTION b.4

Multimedia Filter

A multimedia filter consists of a single vessel half-filled with sand and gravel grains and the other half filled with activated carbon.

This is a way of reducing the cost and area used by the treatment system.

This filter’s purpose is to support the ion exchange unit as it filters a variety of contaminants that will be discussed later in this section.

Sand Filter

A sand filter is a water treatment filter made up of layers of sand arranged in ascending order of coarseness of texture.

They can work with either upward or downward flowing fluids, with the latter being far more common. The fluid can flow under pressure or by gravity alone in downward flowing devices. Pressure sand bed filters, also known as rapid sand bed filters, are commonly used in industrial applications. Gravity-fed filters are widely used in developing countries for water purification, particularly for drinking water (slow sand filters).

There are various types of sand bed filters in general:

- Rapid (gravity) sand filters
- Rapid (pressure) sand bed filters
- Up flow sand filters
- Slow sand filters

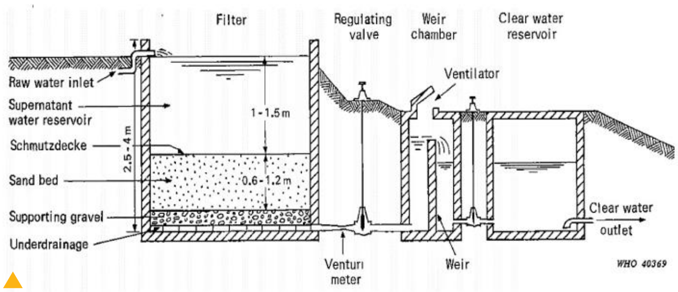


Figure 4.1 Rapid Sand Filter.

Ripening and regeneration are two processes that affect a filter's functionality.

The filter efficiency grows in sync with the quantity of captured particles in the medium at the start of a new filter run. Filter ripening is the term for this procedure. The effluent may not meet quality parameters during filter ripening and must be reinjected at a later stage in the process. Regeneration methods allow the filter medium to be reused. Solids that have accumulated in the filter bed are removed. Backwashing involves pumping water (and air) backwards through the filter system. Backwash water may be reinjected partially in front of the filter process, but produced wastewater must be removed. The backwashing time is determined by the turbidity value behind the filter, which must not exceed a certain threshold, or the head loss across the filter medium, which must also not exceed a certain threshold.

The sand filter to be used for this solution is a rapid pressure sand filter, but rather than using air pressure, a water pump is used.

The size of the used sand grains falls between 0.8 mm and 1.25 mm.

Sand filtration is frequently used in groundwater treatment to remove dissolved iron, and manganese in the groundwater are oxidized by aeration, and the flocs formed are subsequently trapped in the sand filter.

Activated Granular Carbon Filter

Carbon filters work by adsorbing contaminants. Adsorption occurs when pollutants are drawn to the activated carbon surface and kept there, similar to how a magnet attracts and holds iron filings.

Carbon filters can also affect the chemical makeup of some pollutants by acting as a catalyst. Chlorine, organic compounds like pesticides, THMs like chloroform, and many VOCs found in gasoline, solvents, and industrial cleaners may all be removed by activated carbon.

The carbon filter that was used for this solution is a granular activated carbon filter, which is the Aquasorp™ 1000 granular activated carbon filter.

Granular activated carbon (otherwise known as **GAC)** filters have extremely high adsorption capabilities and can remove a wide variety of contaminants.

Figure 4.2 Activated Granular Carbon Filter.

The Aquasorp 1000 granular activated carbon filter has a set of features which are:

- Medium activity product.
- Versatile Adsorption.
- High mechanical strength.
- Good adsorption capacity.
- Potable water grade.

The size of carbon grains in this filter is between 2.36 mm and 1.00 mm.

SECTION b.5

Ion Exchange Unit

Ion exchange units are units composed of resins, which are organic compounds that are used to treat water. There are 2 types of resins, cation resins anion resins.

The anion resin to be used for this solution is the **AMBERJET™ 4200 Cl** anion resin.

This resin's matrix is Styrene divinylbenzene copolymer with Trimethyl ammonium as the functional group. Its regenerant is **NaOH**.

The cation resin to be used is the **AMBERJET™ 1200 H** cation resin.

This resin's matrix is **Styrene divinylbenzene copolymer** with Sulfonate as the functional group. Its regenerant is HCl.

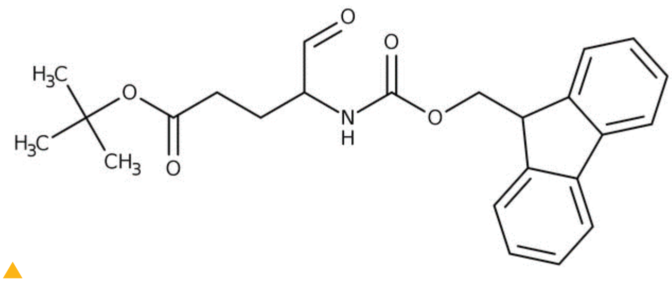


Figure 5.1 Styrene Divinylbenzene Copolymer.

Many contaminants and minerals are removed by anion and cation resins, including NO_3, ClO_4, Arsenic, TOC, Uranium, Barium, Radium. They can also disinfect water by ionically binding halogens as antimicrobial disinfectants. When these two resins are combined, water can be deionized or demineralized.

Regeneration is a process that removes ions that have been captured during the in-service cycle from exhausted (completely loaded) ion exchange resin beads, allowing the resin to continue to be used.

An ion exchange system is made consisting of a bed of resin beads that can pick up hardness or other elements through ion exchange. The resin beads can then be regenerated with a high concentration (10% brine) of salt or another regenerant chemical to restore its capacity, allowing the system to be reused for many years.

Regeneration of an ion exchange resin bed involves multiple processes, including:

- Backwash
- Chemical injection
- Slow rinse
- Fast rinse

Backwashing the system by pouring water backwards through the bottom of the bed is the first stage in regeneration. This raises the bed, allowing dirt, debris, and other insoluble materials to fall out. It also helps in the removal of air pockets from the resin bed and the reclassification of the resin. Backwash is required to reduce pressure drop and maintain a uniform flow in the bed. Backwashing is only done on a regular basis in co-flow systems. Backwashing is done only when necessary in counter-flow systems.

The bed is then settled, and a brine solution or other regenerant chemical is used to regenerate it. This procedure removes any hardness or other ions from the resin and returns it to the proper starting state for a new service cycle.

The slow rinse phase continues to drive regenerant through the bed after regeneration to continue conversion and eliminate the regenerant from the system. After regeneration, the fast rinse is a final rinse with raw water to ensure that water quality is maintained. In counter-flow systems, a recycle step can be used instead of the fast rinse. Any remaining regenerant chemical will be removed by recycling between cation and anion resins.

SECTION b.6

Pumping System

The ion exchange system used in this solution needs a water flow rate of 18 liters/h, so, a pump was integrated into the system.

This pump made the sand filter a rapid pressure sand filter rather than a slow sand filter or a rapid gravity sand filter.

The pump used is the Aqua Chiara UP-9000, it is a 24-volt pump that achieves exactly the required flow rate for the ion exchange system to work.

C

Selection of Prototype

KEY SECTIONS

1. Vessels and Chassis
2. Treatment Components
3. Design Requirements

Figure 1.1 The Prototype.

SECTION C.1

Vessels and Chassis

The prototype is constructed on a framework with the goal of increasing durability and achieving effectiveness, efficiency.

- **Vessels** – The main treatment components lie inside 3 plastic vessels.
- **Pipes** – The first vessel is connected with the second with a steel pipe, and the same goes for the second with the third. The first steel pipe has a switch connected to a silicon pipe, and the same goes for the second, in addition to having a switch between it and the third pipe. On the other hand, the third pipe is connected to a silicon pipe as the main water output. The outlet of every vessel is connected to a pipe with holes smaller than the smallest grain in size of the treatment components inside to prevent them from leaving the vessel with the flow of water.
- **Metal Chassis** – Every component mentioned earlier is connected to a metal bar with steel nails to increase durability; that steel bar is connected to a metal handle to increase mobility.

SECTION C.2

Treatment Components

There are three filter vessels:

1. The first vessel contains 50% sand and gravel grains of sizes between 0.8 mm – 1.25 mm., the remaining 50% contains 50% AquaSorp 1000 Activated Granular Carbon. This combination makes up a multimedia filter, which is a filter that removes bacteria, turbidity, and many contaminants.

2. The second vessel contains 1 kg of the AMBERJET 1200H cation resin. This resin absorbs the negatively charged portions of the dissolved salts in water.

3. The third vessel contains 1 kg of the AMBERJET 4200Cl anion resin. This resin absorbs the positively charged portions of the dissolved salts in water.

In order for the ion exchange system to work properly, it needs two essential processes. The first being regeneration and the second being pumping.

Regenerating the Cation Resin

To regenerate the cation resin, the first and second switches are opened, and the third is closed; 50 mL HCl 37% are injected into the first silicon pipe and are left to collect the particles captured by the resin for about 10 minutes. Then, water is inputted into the system and outputted from the second silicon pipe. This process continues until the TDS of the outputted water reaches 300 PPM.

Regenerating the Anion Resin

To regenerate the anion resin, the second and third switches are opened, and the first is closed; 50 mL NaOH 10% are injected into the second silicon pipe and are left to collect the particles captured by the resin for about 10 minutes. Then, water is inputted into the system and outputted from the third silicon pipe. This process continues until the TDS of the outputted water is ≤ 30 PPM.

Pumping System

The AMBERJET ion exchange system requires a water flow rate of about 18 liters/second to function appropriately. The Aqua Chiara UP-9000 24-volt pump was the pump of choice to feed the system with water and attain the required flow rate. This pump was paired with an automatic switch to prevent the pump from fading out because of the absence of inputs or outputs.

The input of the pump is connected to a pipe from the water source. The output is connected to the automatic switch which is connected to the first vessel input.

Water flows from the water source through the pump and into the first vessel which goes to the second and third then to the output silicon pipe.

SECTION C.3

Design Requirements

As mentioned in SECTION a.1, the design requirements chosen for this project are effectiveness and water efficiency.

This prototype was designed to meet those design requirements.

That's why there are 3 treatment stages, a pumping system, a regeneration system and a sophisticated framework present in this prototype.

03

Constructing and Testing a Prototype

KEY SECTIONS

a. Materials and Methods

b. Test Plan

c. Data Collection

Materials and Methods

KEY SECTIONS

1. Materials
2. Methods
3. Safety Precautions

Item	Quantity	Usage	Image	Cost
Multimedia Filter (Sand: 0.8-1.25 mm) (Activated Carbon: AquaSorb™ 1000)	0.5 Kg Sand and Gravel 0.5 Kg Activated Granular Carbon	Purifying water and removal of odors, suspended matters, floating and sinkable particles.		45 L.E.
Ion Exchange Unit (AMBERJET™ 1200 H cation resin) (AMBERJET™ 4200 Cl anion resin)	1 Kg Cation Resin 1 Kg Anion Resin	The ion exchange unit is the backbone of this solution and can purify water of almost any contaminant.		280 L.E.
Modified Pipes (One pipe for each vessel)	3 Pipes	Modified pipes were used to prevent the small particles of sand, carbon, or resins from entering other vessels with the flow of water.		50 L.E.
Framework	3 Vessels 2 Tanks 2 Steel Pipes 3 Silicon Pipes 1 Metal Chassis 2 Injectors	Vessels for containing the filters, pipes for water to flow in, switches to aid the regeneration process, a metal chassis to increase durability, and injectors for injecting HCl or NaOH to resin vessels.		185 L.E.
Pumping System (Pump: Aqua Chiara UP-9000)	1 Pump 1 Automatic Switch	A Pumping system was used to increase the water flow for the ion exchange unit to work properly and to increase efficiency.		125 L.E. Total Cost: 685 L.E

SECTION a.1

Materials

The materials listed in the previous table are the materials used in constructing the prototype. They were chosen according to both design and solution requirements.

SECTION a.2

Methods

- The used vessels were dismantled and piped together.
- 0.5 kg of activated carbon and 0.5 kg of sand and gravel were put in the first vessel to form a multimedia filter.
- The cation resin (1 kg) was put and regenerated using HCl in the second vessel, the same happened with the anion resin, but in the third vessel, and it was regenerated using NaOH. **(Figure 2.1)**

Figure 2.1
Styrene Divinylbenzene Copolymer.

- The prototype was first made in a staircase form for gravity to control the flow of water, it was tested in that shape for the first time, and the results were recorded.
- Holes for nails were made in the bottom plastic parts of the vessels to connect with the metal chassis.
- The pump's input pipe was connected to the water tank, and the output pipe was connected to the automatic switch and the vessels. The prototype was then tested, and results were recorded.
- The modified pipes were then connected to the output holes of the vessels, the prototype was then tested, and results were recorded.

SECTION a.3

Safety Precautions

When constructing the prototype, some safety precautions were considered to assure the safety of all team members.

These are listed below:

- Wearing masks and gloves.
- Using sharp tools while having an experienced person only.
- Using tools specified for chemistry in doing the chemical reactions and regeneration.
- Regularly sanitizing hands.
- Making sure that there's some sort of distancing between all team members will working.
- Doing chemical reactions in the chemistry lab or the fab lab.
- Cleaning the room after finishing the work.

b

Test Plan

KEY SECTIONS

1. Effectiveness
2. Efficiency

SECTION b.1

Effectiveness

The effectiveness of the prototype was test in 2 main steps. The first is testing if the water flows in and out from the prototype without it leaking or the filters being damaged.

After this step was finished, the output water was to be tested to check if it meets the USP Water Quality Standards **(Figure a.1.1)**. This was done by analyzing the groundwater before it entered the prototype and after it was outputted.

If the prototype failed one of the previous tests, the design requirement is not met and it will be worked on.

SECTION b.2

Efficiency

The water efficiency of the prototype was tested by inputting 3 liters to the prototype and observing the amount of water the prototype outputs. The average output was calculated. The efficiency coefficient then is calculated using the formula "Efficiency= $\frac{Output}{Input}$". This test was done three times.

If the efficiency average was higher than the efficiency coefficient of reverse osmosis systems and multi-effect distillation systems (Efficiency > 0.8), the prototype has successfully achieved this requirement. If lower, then it failed and will be worked on.

The efficiency coefficient of reverse osmosis systems is 0.8 and the efficiency coefficient of multi-effect distillation is about 0.6 - 0.7.

C

Data Collection

KEY SECTIONS

1. Effectiveness Test
2. Efficiency Test

Test	Units	Product Results
Conductivity	µs/cm	≲ 1040 µs/cm
PH		7.55
Sodium	ppm as Na	≲ 77.15 ppm
Calcium	ppm as $CaCO_3$	≲ 85.7 ppm
Magnesium	ppm as $MgCO_3$	≲ 22.34 ppm
Iron	ppm as Fe	≲ 0.03 ppm
Chloride	ppm as Cl	≲ 120 ppm
Silica	ppm as SiO_2	≲ 12.87 ppm
TDS	ppm	≲ 500 ppm

Figure 1.1 Analysis of inputted water before treatment.

SECTION C.1

Tools Used in The Tests

- TDS Measuring Device (Error = ± 0.025)
- PH Measuring Device (Error = ± 0.05)
- Water Analysis Device (Error = ± 0.10)
- Phone Timer
- Lab Graduated Beaker

Effectiveness

The prototype was first tested in the form of a staircase. This test failed because the flow of water caused by gravity was not sufficient.

The prototype was then modified, and a pumping system was added. It was then tested, and the test also failed because some sand, carbon, and resin particles entered other vessels with water flow.

The prototype was modified one last time. Some pipes were added to the inside of the vessels to prevent particles from entering. It was then tested, and it worked properly.

The groundwater retrieved from Belbes, Sharkiya, was analyzed in a lab before entering the prototype. It was then tested after it was outputted from the prototype.

Test	Units	Product Results
Conductivity	µs/cm	≲ 66 µs/cm
PH		7.10
Sodium	ppm as Na	≲ 0.57 ppm
Calcium	ppm as $CaCO_3$	≲ 0.13 ppm
Magnesium	ppm as $MgCO_3$	≲ 0.15 ppm
Iron	ppm as Fe	≲ 0.03 ppm
Chloride	ppm as Cl	≲ 0.20 ppm
Silica	ppm as SiO_2	≲ 0.20 ppm
TDS	ppm	≲ 30 ppm

▲
Figure 1.2 Analysis of inputted water after treatment.

SECTION C.2

Efficiency

Then, 3 liters of water were inputted to the prototype times, and the outputted amount of water was recorded each time. Then the average was calculated. Results are illustrated in **(Figure 2.1)**.

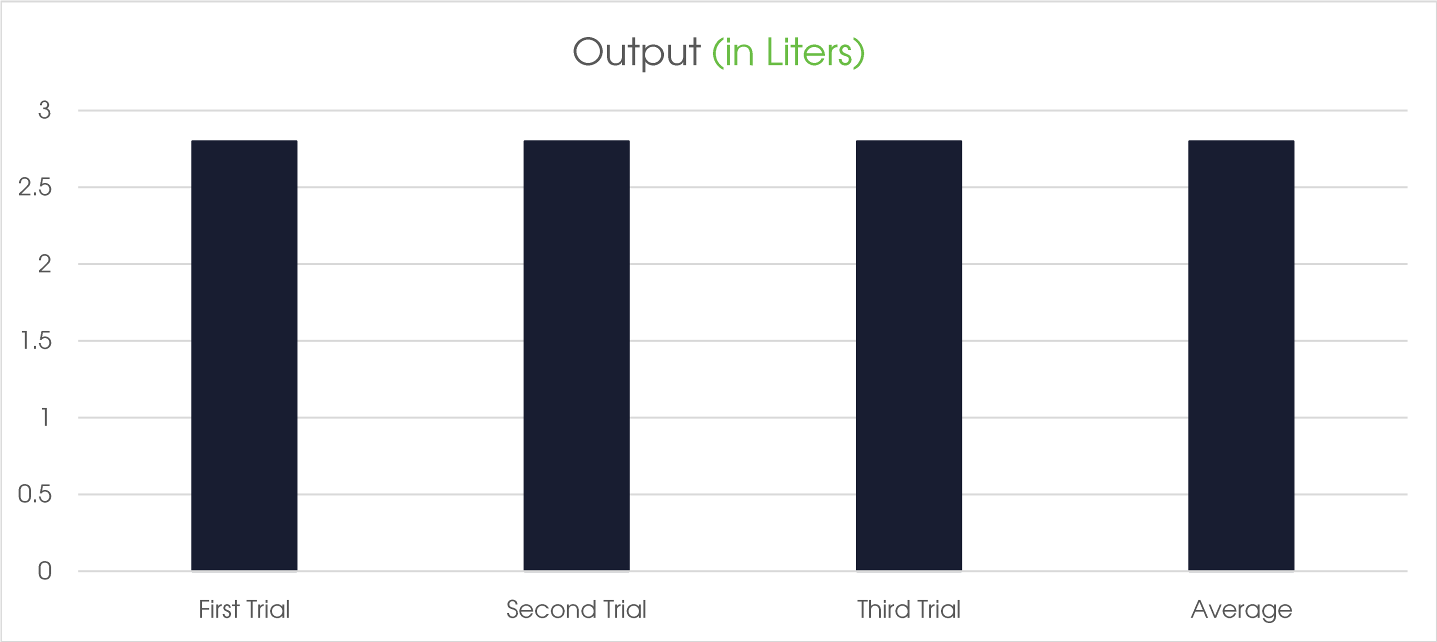


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Figure 2.1 Water output in liters.

04

Evaluation, Reflection, Recommendation

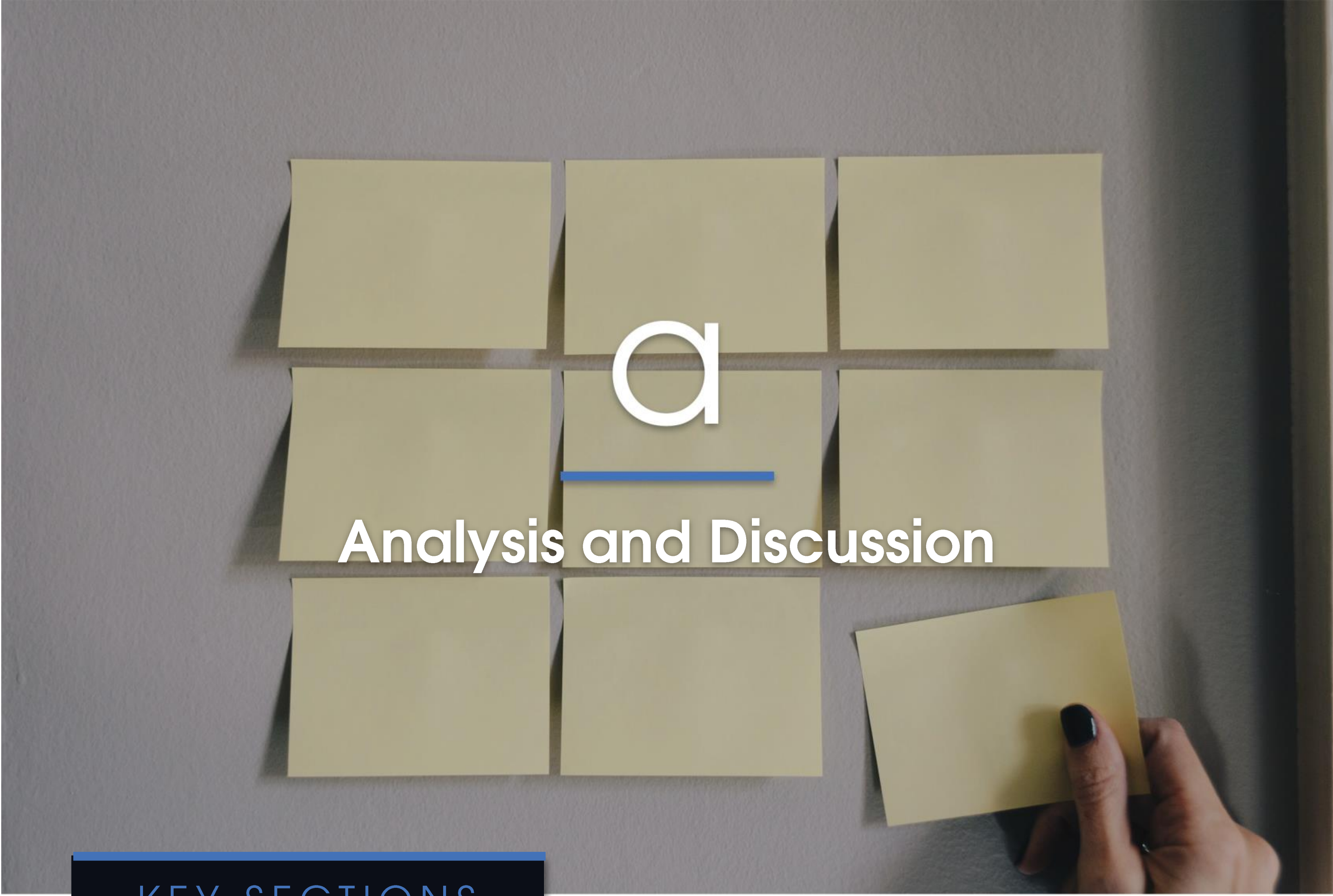
KEY SECTIONS

a. Analysis and Discussion

b. Recommendations

c. Learning Outcomes

d. List of Sources in APA Format



a

Analysis and Discussion

KEY SECTIONS

1. Analysis
2. Conclusions

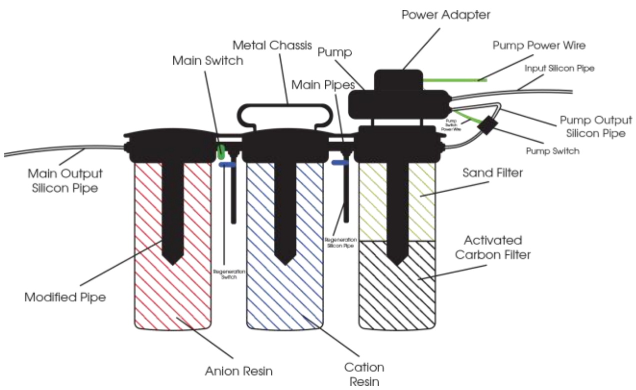


Figure 1.1 Prototype Detailed Illustration.

SECTION a.1

Analysis

The initial intent was to construct the prototype in a staircase-like form for gravity to cause water flow without the need for a pump to lower the cost. The first test proved that this approach is not valid, as the ion exchange unit needs a water flow rate of about 18 liters/h.

So, a pump was added to the system, and the second test was done. The second test aroused a new problem, which is the leakage of the components of each vessel to the following vessel, as the sand and carbon particles leaked to the resins and then leaked to the output water.

Therefore, some pipes were modified to make holes less than 0.8 mm in size (which is the smallest size of sand grains and resin particles present in the system). When the third test was done, these pipes proved to work properly as no components left their vessels.

The final form of the prototype is depicted in **(Figure 1.1)**.

Water analysis proved that the prototype is effective as the outputted water meets the USP Water Quality Standards listed in Figure a.1.1. The conductivity of the outputted water is less than 5 µs/cm, but it appears as it is less than 66 µs/cm in the analysis because of the limitations of the device used in the analysis.

Also, the results of the efficiency test were constant at 2.8 liters, which means that the efficiency coefficient is $\frac{2.8}{3.0} = 0.93$, which is higher than the best alternative treatment methods: Multi-effect distillation, Reverse osmosis systems, which have efficiency coefficients of 0.6 and 0.8, respectively.

The prototype successfully achieved the two specified design requirements. They were achieved mainly by the components of the main filters present in the system.

Multimedia Filter

The sand filter removed turbidity and large flocs. The activated carbon filter removed chlorine, odors, and organic chemicals, commonly present in groundwater aquifers because of the primitive ways of human-generated pollutants disposal such as septic tanks.

(Figure a.2.3)

The multimedia filter functions as a support for the ion exchange unit to decrease the number of contaminants that the unit will have to remove.

Ion Exchange Unit

On the other side, resins are the main player in this system, as they removed any present minerals or ions, which purified the water and made it valid for use in the cosmetics industry.

A significant advantage of ion exchange systems is that it can be regenerated. Regeneration means the removal of captured ions and minerals for the unit to retain its efficiency without the need to change it completely.

Regeneration of the AMBERJET 1200H cation resin happens by injecting about 50 mL of 37% HCl in the resin and leaving it for 5-7 minutes, then washing the resin until all the HCl comes out.

The same goes for the AMBERJET 4200Cl anion resin but using 50mL of 10% NaOH rather than HCl.

Resins are supposed to undergo regeneration process once they are first operated and when the water quality begins to deteriorate, which happens approximately every six months, it can happen later or earlier depending on the used water and usage periods.

This solution can vastly flip the water situation to be in favor of Egypt, as groundwater represents about 30.1% of freshwater resources in the world, which will solve the water problem in Egypt as the country will be able to utilize groundwater as a main source of water and decrease its dependence on the Nile, which has caused many problems already and cannot be sufficient for the country anymore.

SECTION a.2

Conclusion

By all counts, and with proven results, it can be said, with no doubts, that ion exchange systems, if applied, will put the Egyptian water crisis to an end. Being a treatment method that purifies water to the same level, if not better, than other main water treatment methods, and with higher efficiency and lower amounts of wastewater, it has several advantages, including regeneration, which can extend the life of the system without having to replace all of the resins. Multimedia filters can also help resins last longer by acting as a supportive component.

Because resins require a flow rate of 18 liters/h to function properly, this system cannot be built in a staircase form without a pumping system. Additionally, the particles present in multimedia filters and ion exchange units can leak into the outputted water due to their small sizes, so a method to prevent them from leaking is required. The approach used in this project was to add pipes with holes smaller than those particles. It was an effective approach.

The prototype met the design requirements and proved that constructing ion exchange systems is a viable and reliable solution.

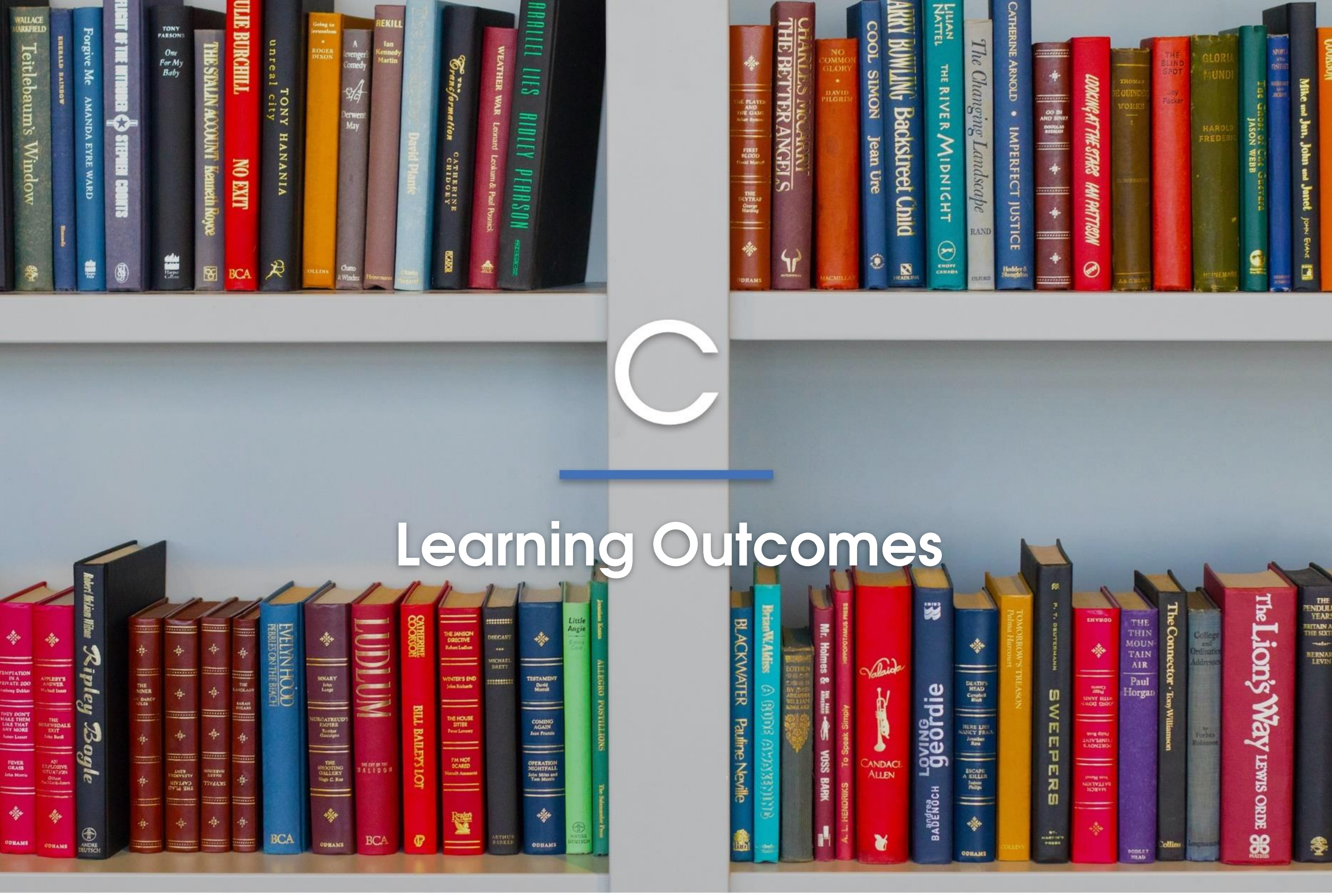
Recommendations

- It’s recommended to use PVC pipes rather than steel pipes because they have a lot of advantages, such as corrosion resistance, leak-free joints, low cost, and long life.
- Using a renewable energy source to feed the pump is more efficient and is recommended.
- Using hydraulic heads and pumps to feed resin vessels with their regenerants will make the process much easier.
- If the work on this project is to be continued by another team, it is advised that they put a design requirements list for the project to meet.
- It is advised for any team that will continue the work on this project to put in mind the safety precautions while working on it.
- If any team is to continue the work on this project, they must do deep research about the concepts involved as they are complex and vast.
- Although it’s better for the project to be applied in industrial institutions near groundwater, the project can filter any type of water, but it will just affect the estimated life.
- Some devices can turn pure water into drinking water; these can be added if the output water is used for drinking. These devices add minerals needed by the human body because pure water is not suitable for drinking and can be harmful in the long run.
- This solution is modular, so if the prototype was to be applied in the real world, it would have to scale according to the size of the industry. If it was a small industry, it should remain the same size or increase slightly, and it should be scaled according to water needs if it is a large industry.

How Did This Project Effect the Team?

Every capstone project, as usual, fosters new skills and qualities in each team member, and this project especially has benefited us the most as it made us:

- Acquire a better understanding of Egypt's water situation and the various approaches to resolving it.
- Gain a better understanding of different water treatment processes and compare them.
- Learn about the various uses and types of water in Egypt.
- Learn more about Egypt's water resource distribution.
- Improve our ability to communicate, collaborate, write, negotiate, and study.
- Develop a problem-solving mindset.
- Discover how to locate rare and difficult-to-find materials.



Learning Outcomes

Es 2.01: Studied the distribution of fresh water on the surface of the earth, and we learned that groundwater represents about 30% of the total freshwater and that surface water represents about 1.2%. We concluded that groundwater should be used because it is available in larger quantities and is more suitable than surface water and this project.

*Also, studied the water cycle and learned that rainwater and surface water infiltrate the soil, filter through layers of rocks, and leak into the aquifers as groundwater. We used that same principle to make a sand filter in our prototype

Es 2.03: Learned about all the water uses and what fields water is used in. On that, we determined the use of the water we would focus on.

Es 2.04: Learned the primary water pollutants and the filtration methods that work with them. This helped us in choosing our solution.

Ch 2.01: Learned about PPM, which is a way of expressing concentrations of highly diluted solutions. Learned also about TDS which is a measure of the dissolved combined content of all substances present in a liquid. These two concepts were crucial in our test plan and the analysis before and after water treatment.

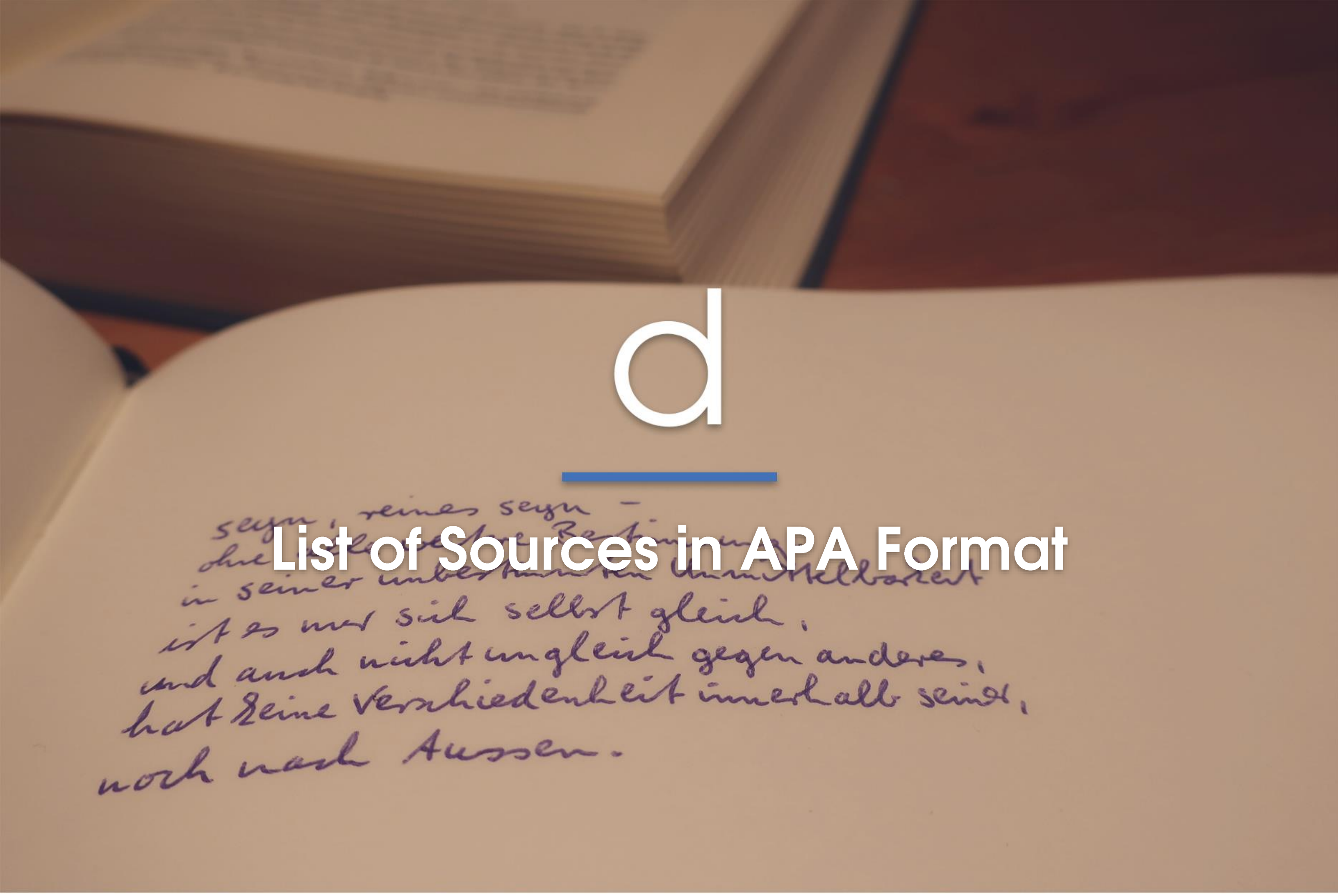
Ch 2.03: Learned about acidic and basic salts and which ones are in the water we used. This helped us determine the amount and concentration of acids and bases used in the regeneration process of the ion exchange system (resins) present in our prototype.

Ph 2.03: Used Ohm's Law to determine the amount of current the pump consumes.

Ma 2.01, 2.02: Used polynomial and rational functions to model the data collected from the tests conducted and to make relations between this data.

Me 2.01: Used the laws of static friction to determine the pipes with the lowest friction coefficients for the flow of water to be higher.

Bi 2.01: Learned that there are some cereal crops such as wheat and rice. These are the most grown plants in Egypt, and they use a lot of water. To lower this consumption, these crops were genetically modified. This was one of the prior solutions that inspired us the most in generating our solutions.



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