ARCHIMEDES SCREW PUMP

THE AMENDERS

Chandler Ichikawa, Jack Rovai,
Sarah Shaghasi, Richard Williams
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Table of Contents

List of Figures

List of Tables

1 Problem Formulation

1.1 Introduction

The 'Problem Formulation' section outlines the overall background of the spring 2015 Engineering design course project. The client is Joan Crandell, a 6th grade teacher at Zane Middle School, which is located in Eureka, California. Zane Middle School is focused on STEAM subjects which includes Science, Technology, Engineering, Art and Math. Joan needs a classroom device that demonstrates how water is moved by applying engineering principles. This will provide students with a hands-on mechanism that will teach the students about engineering water transportation. The black box model shown in Figure 1.1 depicts the state of the world without a water movement device, the solution, and the state of the world with a water movement device.

1.2 Objective

The objective is to create an interactive model which demonstrates the various ways of moving water throughout history. Junior high students will be able to experiment with the different technologies to gain a better understanding of the properties of water and how water can be moved.

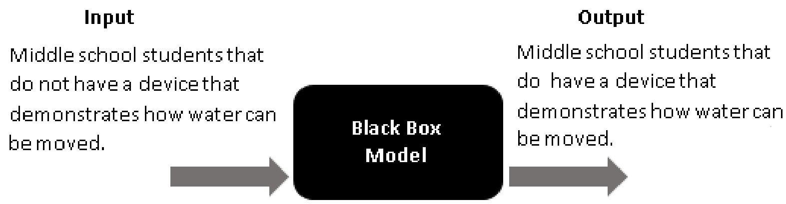

Figure 1-1 Black box model demonstrating the state of the world without a water movement device, and the state of the world with a water movement device.

2 Problem Analysis

2.1 Introduction

In this section the analysis of the specific problem is outlined. The initial problem analysis identifies specifications and considerations, criteria and constraints, usage, and production volume. The goal of the Amenders is to produce a water moving device that serves as a learning tool for the 6th graders at Zane Middle School.

2.2 Specifications and considerations

Specifications and considerations of the design were developed by the client and team to satisfy requirements provided by the client. Specifications and considerations are addressed below.

2.2.1 Specifications

Required specifications for the water moving device are:

- Interactive and Demonstrable.
- Fit on provided counter top area (3ft x 4ft).
- Drainage outlet for device container.
- Relatively easy to move with two people.
- Encompass Next Generation Science Standards and STEAM.

2.2.2 Considerations

Required considerations for the water moving device are:

- Related to 6th grade Zane Middle School curriculum.
- Time efficient setup and breakdown.

2.3 Criteria

This section outlines criteria and their respective constraints and weights, as developed by the client and team. The following are all depicted in Table 2.1.

Table 1. A table detailting the criteria, andd their repsective constraints and values of importance

Criteria	Constraints	Rate
Educational Value	Will provide students with a better understanding of how water is moved.	10
Safety	Will not jeopardize safety of users.	10
Durability	Will last for 5 years with reasonable care and maintenance.	9
Inspiration	Device usage promotes inquisitive interjections.	8
Ease of Use	Usable without prior understanding.	7
Aesthetics	Allows users to visually observe the process.	6
Setup Time	Set up time not to exceed 10 minutes.	5
Cost	Less than $400 total.	1

2.4 Usage

The water moving device will be used to demonstrate how water can be moved. The device will primarily be used indoors on a countertop surface, but will include handles for convenient and safe transport. The design of the water moving device will enable the users to interact with and manipulate components of the device to gain understanding of specific methods. This design aims to deliver understanding of water moving devices through demonstrations and interactive features. The device is likely to be used twice per year per class.

2.5 Production volume

At least one water moving device will be included in the final product. The device shall be reproducible, and its components will be constructed and used in conjunction to create a system. This design aims to create a water moving device that will be used as an interactive model to convey understanding of how water is moved.

2.6 Literature Review

The literature review contains background information ~~used to create~~on water transporting~~demonstration~~ models. Research topics include water movement technologies, the history of the water movement technologies, methods and materials, school safety, and children's learning. Reference citations are given in the American Society of Civil Engineers (ASCE) format.

2.7 Client Constraints

T~~T~~he client, Joan Crandell, requests that~~would like~~ the model to displays different technologies for the movement of water. The model will teach different water moving methods, how they work, why they're relevant today, and their histories~~, and be interactive~~. Small groups of sixth graders will be using the model, and the model needs to be interactive and aesthetically pleasing to them. The model will be stored in an empty classroom, and needs to fit on the counter in her classroom~~.~~ (Crandell 2015).

2.8 Methods

There are numerous methods of moving water. Various methods were researched to develop an overall understanding of how to move water.

2.8.1 Required Input Energy

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With the various developing water moving devices came demand for increased output and efficiency. In general, moving water requires energy. To increase output, energy (or the capacity to do work), is required and the rate at which that energy is used up is referred to as power (Fraenkel 1986). It is important to understand the difference between energy and power. An example of power is a kilowatt (kW) while an example for energy is the product of power over a given time, a kilowatt –hour (kWh). One kWh is roughly equivalent to the power of two horses being put to work over the course of one hour (Fraenkel 1986).

2.8.2 Animals and Water Lifting Devices

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The first recorded devices utilizing animals for water moving was called a *mohte,* as seen in Figure 1. This consisted of mounting ropes to an animal that would walk a straight line, down sloped ground, towing up a sack of water from the local well (Oleson 1984). Improving on the mohte was the circular *mohte*, which had animals walking about in a circle, requiring less supervision (Oleson 1984). Developing from the circular *mohte* came the versatility of the sweep. *Sweeps* attach the animal to the point of rotation, which creates the work input for the water moving devices. Sweeps are applied to many water moving devices such as water wheels, hand pumps, and Archimedes screws (Fraenkel 1997).

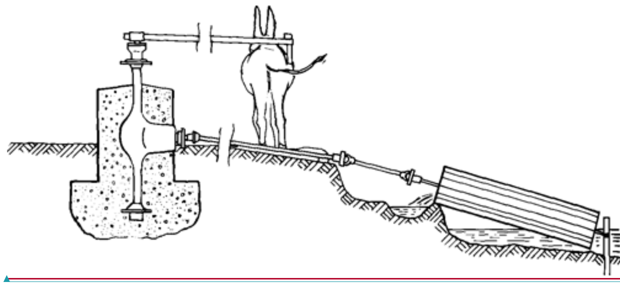

Figure 2-1 Sweep attached to mule driving Archimedes screw.

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2.7.1

2.7.2 Methods

2.7.3 There are numerous methods of moving water so various methods were researched to develop an overall understanding of how to move water.

2.7.4 Buckets

2.7.5 Water is essential for life and societies have been developing methods of moving and controlling water in order to survive. Before recorded history people used containers like buckets and pots to move water (Soth & Clendenon 2007). Water moving devices require energy input from sources such as animals, humans, water and wind. Ancient Mesopotamian and Egyptian cultures were some of the first recorded societies to successfully control the flow of water for irrigation using canals as seen in figure 1 (May's, 2010). Egyptians used a *shaduf*, seen in figure 2, which utilized buckets strung from rods that could pivot to move water from canals or bodies of water to fields at higher elevations using a counter weight mechanism (Soth & Clendenon 2007).

2.7.6

2.7.7 Figure 1: Egyptian canal.

2.7.8 http://www.holidaytoegypt.co.uk/egyptpictures/egypt-best-time-of-year-3-400.jpg

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2.7.9 

2.7.10 Figure 2: Shaduf on banks of a canal.

2.7.11 http://2.bp.blogspot.com/_j5Z7r6cHn0Q/SyJ3K3_6FSI/AAAAAAAAAAU/403x2wSMK6s/s1600-h/shaduf.gif

2.7.12 Wheels and paddles

2.7.13 Improving on the bucket and sting systems were the Persians who applied a string of multiple attached buckets that were strung across a wheel. The strings of buckets, having lots of excess slack in the string, are rotated using the large wheel and dipped one at a time into the water for retrieval pictured below in figure 3 (Fraenkel 1986). Paddle wheels apply scoops to the ends of the wheel structure and provide an area for the operator to apply force (bmy foot) to create rotation. The paddle wheel, displayed below in figure 4, is typically utilized for low lifting needs such as irrigation for rice paddy fields or anything less than 0.5m above the water source (Fraenkel 1997).

2.7.14

2.7.15 Figure 3: Persian Wheel

2.7.16 http://indiawaterportal.org/sites/indiawaterportal.org/files/uploads/2008/01/img_0052.JPG

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2.7.17 

2.7.18 Figure 4: Paddle Wheel

2.7.19 http://www.waterencyclopedia.com/images/wsci_04_img0458.jpg

2.7.20 Required Input Energy

2.7.21 With the various developing water moving devices came demand for increased output and efficiency. To increase output, energy ,(or the capacity to do work), is required and the rate at which that energy is used up is referred to as power (Fraenkel 1986). It is important to understand the difference between energy and power. An example of power is a kilowatt (kW) while an example for energy is the product of power over a given time, a kilowatt –hour (kWh). One kWh is roughly equivalent to the power of two horses being put to work over the course of one hour (Fraenkel 1986).

2.7.22 Animals and water lifting devices

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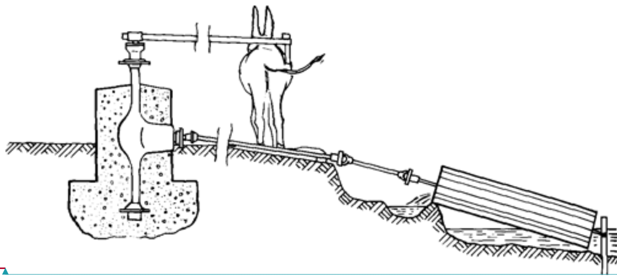

2.7.25 Figure 5: Sweep attached to mule driving Archimedes Screw

2.7.26 http://www.fao.org/docrep/010/ah810e/AH810E144.gif

2.7.27

2.7.28 Materials

2.7.29 Water friendly materials were explored to gain better insight into the materials that are best fit for long durations in aquatic environments. As we have learned from past cultures, wood

2.7.30 Friction Coefficients

2.7.31 Friction coefficients are dimensionless values that define the ratio of the force of friction between two bodies and the force pressing them together (Kolle 2009). Friction coefficients are dimensionless because all the units cancel when applying dimensional analysis. Though static and kinetic frictions exists, kinetic friction will be of focus.

2.7.32 *Ff (frictional force) = μ (frictional coefficient) Fn (normal force)*

2.7.33 Hardware

2.7.34 Manufactures of hardware have created polymer coatings for hardware to protects screws, nails, bolts and fixtures from corrosion due to water or chemically treated materials. It is suggested that to protect against rusting and breakdown when submerged in water, hardware with numerous polymer coatings is recommended. In general, hardware of this nature iIs more costly than typical untreated hardware (Kolle 2009).

2.7.35 Wood

2.7.36 Wood is a relatively inexpensive and high in toughness thanks to the intricately woven cellulose fibers it contains. Wood has a high specific strength because of its low density, which also makes it easy to transport. Two pieces of wood have a frictional coefficient between 0.25 and 0.5. Hardware such as nails and screws do no jeopardize the strength of wood, revealing a high resistance to stress. When used in water, wood is said to be dimensionally unstable because of how water morphs the dimensions of it (warping). Water also decreased woods strength when wet and makes it more susceptible to rotting. (Pemberton 2004 -2014).

2.7.37 HDPE

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2.7.38 High-density polyethylene (HDPE) is a thermoplastic created from petroleum. HDPE, among many uses, is used in production of piping and cylinders. HDPE has a low water absorption, about 0.01% and a Plexiglas on Plexiglas yields a frictional coefficient between 0.25 and 0.3.

2.7.39 Acrylic (Plexiglas)

2.7.40 "Plexiglas" or methyl methacrylate (PMMA) is a trade name for acrylic glass. PMMA has a maximum water absorption ratio of 0.3 – 0.4% by weight causing tensile strength to decrease as water is absorbed. PMMA transmits between 90 and 92% visible light given a 3-millimeter thickness and has a friction coefficient with itself of 0.8. PMMA has a maximum bending load of 148 MPa and a maximum compressive strength of 124 MPa. MPa's stand for Mega Pascal's, which is a standard unit of pressure and equal to approximately 145 PSI or 145 pounds per square inch (Nave 2000). Using metal saw blades and drill bits designed for acrylic is highly recommended. When cutting acrylic materials there is a high chance for fractures to occur if proper equipment is not used.

2.7.41 Models of Water Moving Devices

2.7.42 Here are smaller scaled models of water moving devices built by people around the world. The design and possible hardware used will with be addressed if provided.

2.7.43 Aqueduct

2.7.44 Water Wheel

2.7.45 Ram Pump

2.7.46 Archimedes Screw

2.7.47 Moving Water through the Centuries

2.7.48 Throughout the centuries, people have discovered many creative ways of transporting water in order to survive in areas that weren't necessarily next to a water source. Some pre-historic methods of moving water are still used today, and we are constantly improving our methods to become more efficient and reliable.

2.7.492.8.3 Pre-historic times

During prehistoric times, the shaduf, aqueduct, and several forms of the water wheel were invented. These devices were used for domestic use and for irrigating lands. Summary needed

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2.7.49.12.8.3.1 The Shaduf

During pre-historic time, at around 2000 BC, a hand operated device called a Shaduf was used in Egypt for lifting water. The Shaduf consists of a long, tapering wooden pole, which the operator pulls down on to fill the container and allow the counterweight to raise the filled container. Sometimes multiple shadufs were mounted on top of each other to raise the water to higher levels. Today the Shaduf is still being used in Egypt, India, and some other countries.Water is essential for life and societies have been developing methods of moving and controlling water in order to survive. Before recorded history people used containers like buckets and pots to move water (Soth & Clendenon 2007). Water moving devices require energy input from sources such as animals, humans, water and wind. Ancient Mesopotamian and

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Figure 2-2 Shaduf

http://www.ancientvine.com/avimage/shaduf_ref.jpg

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~~2.7.49.2~~2.8.3.2 The Water Wheel

The Egyptian water wheel was invented by the Romans around 600-700 BC. It consisted of a wooden wheel and was powered by water and fitted with buckets that lifted water for irrigating nearby lands. Waterwheels driven by camels have been used in Afghanistan and other Asian countries to lift water for irrigation and domestic use. In Sudan, an ox-driven system has been used as a simple irrigation device for centuries. These animal powered water wheels are still in use in some countries today.

~~different version of the Egyptian wheel is the Persian wheel. It consists of a massive series of pots that are unequal in weight and turned over two pulleys. Because of this, the Persian wheel is classified as a pump rather than a water wheel.~~ Improving on the bucket and sting systems were the Persians who applied a string of multiple attached buckets that were strung across a wheel. The strings of buckets, having lots of excess slack in the string, are rotated using the large wheel and dipped one at a time into the water for retrieval pictured below in Figure 3 (Fraenkel 1986). Paddle wheels apply scoops to the ends of the wheel structure and provide an area for the operator to apply force (by foot) to create rotation. The paddle wheel, displayed below in Figure 4, is typically utilized for low lifting needs such as irrigation for rice paddy fields or anything less than 0.5m above the water source (Fraenkel 1997).

Figure 2-3 Persian Wheel

http://indiawaterportal.org/sites/indiawaterportal.org/files/uploads/2008/01/img_0052.JPG

Figure 2-4 Paddle Wheel

http://www.waterencyclopedia.com/images/wsci_04_img0458.jpg

The water wheel is mainly used to generate hydropower. A water wheel consists of large metal or wooden wheels that contain paddles, or buckets that transport water. The force of the water pushes the entire wheel and generates power. The flowing channel of water from which the water wheel utilizes is called the mill race. When the mill race runs under the water wheel, this is called an undershot water wheel; when the mill race runs over the water wheel, this is called an overshot water wheel (Water Wheels, 2015).

2.8.4 Undershot water wheel

An undershot water wheel is placed above the mill race as shown in Figure 5. The water hits the paddles, and the wheel is turned, thus, generating power (Muller, 1899).

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Figure 2-5 Undershot water wheel

http://www.forteachersforstudents.com.au/site/wp-content/uploads/Engineers/WaterWheels/Images/waterwheel-undershot-colour.jpg

2.8.5 Overshot water wheel

An overshot water wheel is below the mill race as shown in Figure 6. The water collects in the top-most bucket, and when full, pushes the wheel downward so that other buckets may be filled. This continuing action effectively turns the water wheel. This type of water wheel takes advantage of vertically transporting water. Water is displaced from a certain height, to a lower height while simultaneously generating power. The overshot water wheel is more efficient than the undershot water wheel because it utilizes the weight of the falling water to help push the wheel (Muller, 1899).

Figure 2-6 Overshot water wheel

http://www.forteachersforstudents.com.au/site/wp-content/uploads/Engineers/WaterWheels/Images/waterwheel-overshot-colour.jpg

~~2.7.50 Figure 6: Persian water wheel~~

~~2.7.50.1~~2.8.6 Aqueducts

Aqueducts allowed communities to live in places where they normally wouldn't be able to survive because they would be too far from a water source. Aqueducts could take the form of underground tunnels, networks of canals and surface channels, covered clay pipes or monumental bridges. The first long-distance canal systems were constructed in the Assyrian

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Empire in the 9th century BCE. In the 7th century BCE a wide canal crossed a 280m long bridge to bring water to Nineveh, and water was brought through a 537m tunnel to supply Jerusalem. (Cartwright, 2012)

Aqueducts utilize gravity to move water as shown in Figures 7 and 8. Pipes are laid on an appropriate and steady gradient so that water may flow through. The optimal slope is considered the shallowest gradient that will keep water flowing (How Aqueducts Work, 2009). In general a gradient of 0.5m in 1km is used (Hodge, 1992). If water must cross a large valley, than an aqueduct bridge, or an inverted siphon is used. The siphon allows pressure to build up, and push the water up an incline to reach its destination (How Aqueducts Work, 2009).

Figure 2-7 Aqueducts

http://www.history.com/news/history-lists/10-innovations-that-built-ancient-rome

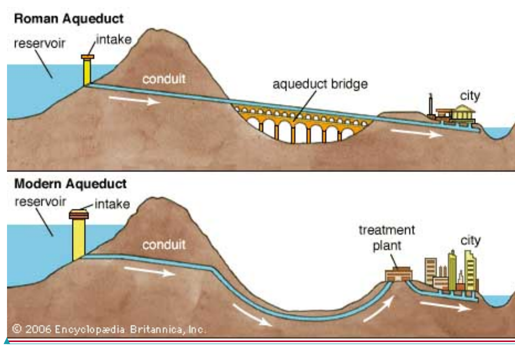

Figure 2-8 Schematic of a Roman and modern aqueduct system

http://www.crystalinks.com/romanaqueductsdiagram.jpg

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~~2.7.51~~2.8.7 Ancient times

~~ummary needed~~During ancient times, the Archimedes screw and the rope pump were invented. Both of these devices utilized physical labor to transport water.

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~~2.7.51.1~~2.8.7.1 *The Archimedes Screw*

The Archimedes screw, which was described but not necessarily invented by ancient Greek mathematician Archimedes, is made out of wood and contains curves of thin and flexible willow or wicker branches so that a screw is created. It was mainly used for drainage and irrigation of Agricultural lands in the Nile Delta area and is still used for pumping wastewater and granular materials. (Nicos, 2014). The Archimedes screw utilizes physical labor to transport water. An Archimedes screw consists of a helix that is contained in a pipe as shown in Figure 9. The lower end of the device is placed under water at about a 45 degree angle, and the handle is turned to rotate the helix. The rotations of the helix collect small amounts of water in the threads that are raised upwards (How Stuff Works, 2009).

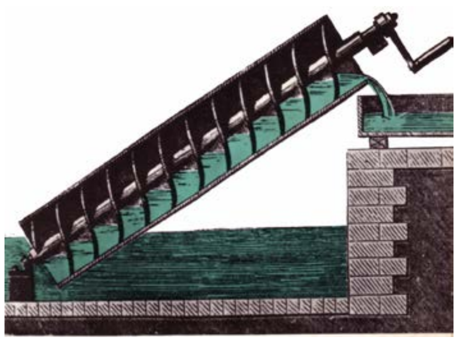

Figure 2-9 Archimedes Screw

http://www.glogster.com/schrmit/archimedes/g-6kq0rhdb2nck48nobb9ofa0

2.8.7.2 Rope Pump

A rope pump utilizes physical labor to transport water from a well as shown in Figure 10. A loop of rope is thread through a pipe, which is attached to a pulley and a crank. When the crank is turned, the rope rotates and brings water from a well to the outlet of the pipe (Implementation, 2015). In general, there are three types of rope pumps: flexible valve rope pumps, rigid valve rope pumps, and valveless rope pumps (WHO, 2015).

2.8.7.2.1 Flexible valve rope pump

Flexible valves are made from flexible materials such as bicycle wheel tubing. The tubing is placed approximately 20 cm apart on the entire length of the rope (WHO, 2015).

2.8.7.2.2 Rigid valve rope pump

Rigid valves generally use washers that fit the size of the pipe being used. The washers are placed about a half of a meter apart (WHO, 2015).

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2.8.7.2.3 Valveless rope pump

Valveless rope pumps use only the rope to transport water. The fast moving motion of the rope, combined with friction allows the water to stick to the rope and be transported to the outlet. This type of pump is the easiest to make, but is less efficient than the other pumps (WHO, 2015).

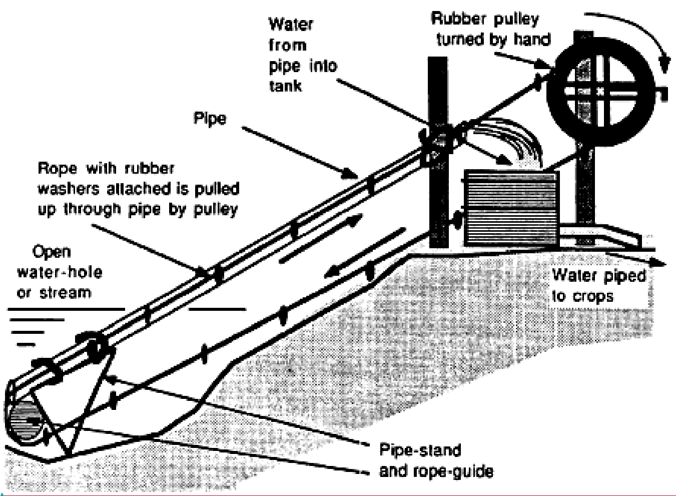

Figure 2-10 Schematic of a rope pump

http://www.unep.or.jp/ietc/Publications/TechPublications/TechPub-8a/Afri93.gif

The Force Pump

The force pump was invented in Alexandria, by the engineer Ktesivius. The pump was composed of two cylinders with pistons that would move by means of connecting rods attached to opposite ends of a single lever. The pump was used in many different ways: in wells for pumping water, in fire extinguishers, and it was also used as a mining apparatus. (Mays, 2010)

2.7.52 Medieval times

Summary needed

2.7.52.1 Windmills

During the Medieval times, windmills for water pumping were invented. The earliest known design is the vertical axis system which was developed in Persia around 500-900 AD. (Nicos, 2014).

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Today's application

As centuries go by, we continue to find ways to make our water systems more efficient and reliable. Many of the methods that were used centuries ago are still in use today, and the principles that they were based on are at the foundation of our most recent inventions.

Aqueduct

Aqueducts utilize gravity to move water. Pipes are laid underground on an appropriate and steady gradient so that water may flow through. The optimal slope is considered the shallowest gradient that will keep water flowing (How Aqueducts Work, 2015). In general a gradient of 0.5m in 1km is used (Hodge, 1992). If water must cross a large valley, than an inverted siphon is used. The siphon allows pressure to build up, and push the water up an incline to reach its destination (How Aqueducts Work, 2015).

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Water wheel

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Undershot water wheel

An undershot water wheel is placed above the mill race. The water hits the paddles, and the wheel is turned, thus, generating power (Muller).

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Overshot water wheel

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Rope Pump

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Rigid valve rope pump

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Valveless rope pump

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Archimedes Screw

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2.8.8 Materials

Water friendly materials were explored to gain better insight into the materials that are best fit for long durations in aquatic environments. Explored water friendly material options consisted of: Hardware, wood, HDPE, and acrylic.

2.8.8.1 Hardware

Manufacturers of hardware have created polymer coatings to protect screws, nails, bolts and fixtures from corrosion due to water or chemically treated materials. It is suggested that to protect against rusting and breakdown when submerged in water, hardware with numerous polymer coatings is recommended (Kolle 2009). In general, hardware of this nature is more costly than typical untreated hardware (Kolle 2009).

2.8.8.2 Wood

Wood is relatively inexpensive and durable thanks to the intricately woven fibers it contains. Generally, wood has a high specific strength because of its low density, although high density woods do exist, low density wood makes for easy transport (Pemberton. 2004 -2014). Typically, two pieces of wood have a frictional coefficient between 0.25 and 0.5 (Gratton et al. 2006). Hardware such as nails and screws do not jeopardize the strength of wood; this indicates a high resistance to stress (Gratton et al. 2006). When used in water, wood is said to be dimensionally unstable because of how the water can morph its shape (warping). Additionally, water decreases the strength of wood when wet and makes it more susceptible to rotting. (Pemberton 2004 -2014).

2.8.8.3 HDPE

High-density polyethylene (HDPE) is a thermoplastic, meaning it can change shape with increased heat. HDPE is generally made from petroleum and among its many uses, is one of the main materials used in the production of piping and cylinders. HDPE has a low water absorption of about 0.01% (Mujal-Rosas et al. 2012).

2.8.8.4 Acrylic (Plexiglas)

"Plexiglas" or methyl methacrylate (PMMA) is a trade name for acrylic glass. PMMA has a maximum water absorption ratio of 0.3 – 0.4% by weight causing tensile strength to decrease as water is absorbed. Plexiglas on Plexiglas yields a frictional coefficient between 0.25 and 0.3. PMMA transmits between 90 and 92% visible light given a 3-millimeter thickness and has a friction coefficient with itself of 0.8. PMMA has a maximum bending load of 148 MPa and a maximum compressive strength of 124 MPa (Wooster. 1942). It's widely known among the scientific community that MPa stands for Mega Pascal, which is a standard unit of pressure equal to approximately 145 PSI or 145 pounds per square inch (Nave 2000). Employees at Arcata's local Ace Hardware suggest using metal saw blades and drill bits designed for acrylic material. When cutting acrylic materials there is a high chance for fractures to occur if proper equipment is not used (Wooster. 1942).

~~2.8~~2.9 School Safety

In the state of California, students have the right to safe schools (California State Board of Education 2001). Students will not learn effectively unless they are free from physical and psychological harm. It is up to the school boards, superintendents, school administrators and their staff to ensure that their school is safe. Each school must create an annual plan for safety (California State Board of Education 2001).

~~2.9~~2.10 Teaching Middle School Students

One way to help students be successful is to understand how students think. Once the student thought process is understood, student lessons can be tailored to take advantage of that knowledge.

Students tend to think in an intuitive, imaginative, and inventive manner (Blakemore 1995). To take advantage of this knowledge, students should be put into learning situations that have opportunities for them to think intuitively. Providing a variety of activities and adding new elements to old activities can allow students to explore new situations and think creatively.

It is important to encourage social interactions between students during activities (Wiggens 2014). Not only does it satisfy some students who enjoy social interaction, it allows other students who may more hesitant to interact with others, a chance to improve their social skills (Blakemore 1995).

Many students prefer hands on learning (Wiggens 2014). Many students want to get the information in a detailed way then given a chance to apply what they just learned in an interactive way (Wiggens 2014).

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Although, many students will prefer to think imaginatively, others may prefer to think analytically or emotionally. Every student is different, and there should be an opportunity to succeed in the way they tend to think. Differences between individuals shouldn't be aggravated. Many students want to feel like an individual, yet be included in the group (Blakemore 1995).

3 Alternative Solutions

3.1 Introduction

The Alternative Solutions section includes brainstorming session information as well as descriptions of the eight alternative solutions. The alternative solutions each include different variations of the design criteria provided in section 2.

3.2 Brainstorming

The Amenders held a brainstorming session on February 26, 2015, which is documented in the appendix of this document. All the team members attended a meeting where ideas were shared through sketches and discussion. A total of eight solutions were formed during the brainstorm. The solutions primarily focused on fulfilling the criteria, and specifications outlined from meetings with the client, Joan Crandell.

3.3 Alternative Solutions

The following alternative solutions for the Water Transportation Demo Device are listed below and will be described in detail in this section.

- Closed System
- Two Shaduf Closed system
- Mirrored Technologies
- Quad Technologies
- All in One Design
- Lake System
- Stepwise Closed System
- The X

3.3.1 Closed System

The Closed System is a combination of three water transportation devices that utilize three different means of moving water: a shaduf, an aqueduct, and a rope pump. A reservoir constructed of Plexiglas is located 2 ft. from the base, as shown in Figure 4.1. A shaduf composed of wood pieces, wire, and a small metal bucket is located adjacent to the reservoir. An aqueduct constructed of PVC pipe is located under the shaduf. The aqueduct rests on a T-clip that allows the slope of the aqueduct to be manipulated. Located at the outlet of the aqueduct is the second Plexiglas reservoir. The second reservoir acts as a well for the rope pump that is partially contained within it. The rope pump is constructed of: PVC pipe, rope, washers, and a rotating wheel with a handle. The outlet of the rope pump drains water back into the first reservoir. This design's use of Plexiglas offers itself as an easy to use visual learning tool. Along with this, there is a potential for two users to interact simultaneously with the device.

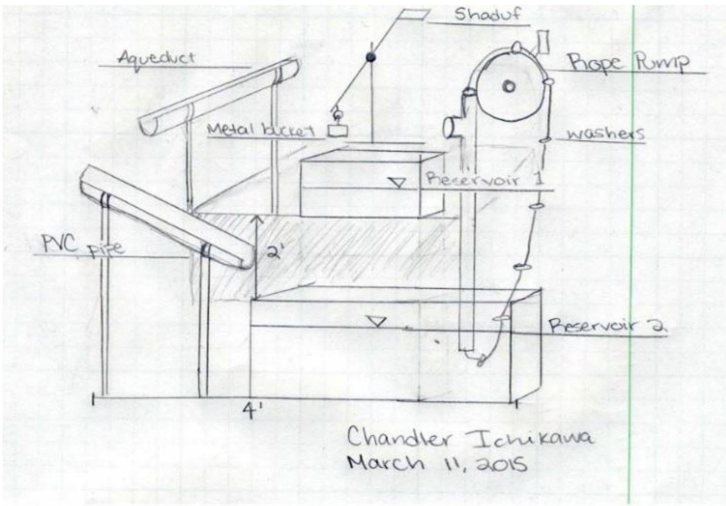


Figure 3-1 Closed System design utilizing a shaduf (upper middle), two aqueducts (left side), rope pump (right side), and two reservoirs (right side).

3.3.2 Two Shaduf Closed System

The Two Shaduf Closed System is a water transportation devices that utilizes three ways of water transportation: two shadufs, an aqueduct, and a rope pump. A reservoir constructed of Plexiglas is located 2 ft. from the base, as shown in Figure 4.2. Two shadufs composed of wood pieces, wire, and small metal buckets are located adjacent to the reservoir. One shaduf utilizes a larger metal bucket, which allows it to move a larger volume of water. Along with this larger bucket is a counter weight with a large mass on the opposite end of the large bucket. An aqueduct constructed of PVC pipe is located under the two shadufs. The aqueduct rests on a T-clip that allows the slope of the aqueduct to be manipulated. Located at the outlet of the aqueduct is the second Plexiglas reservoir. The second reservoir acts as a well for the rope pump that is partially contained within it. The rope pump is constructed of: PVC pipe, rope, washers, and a rotating wheel with a handle. The outlet of the rope pump drains water back into the first reservoir. While this design also provides an aesthetically pleasing and visual learning tool, it allows for a total of three users to interact with it at the same time.

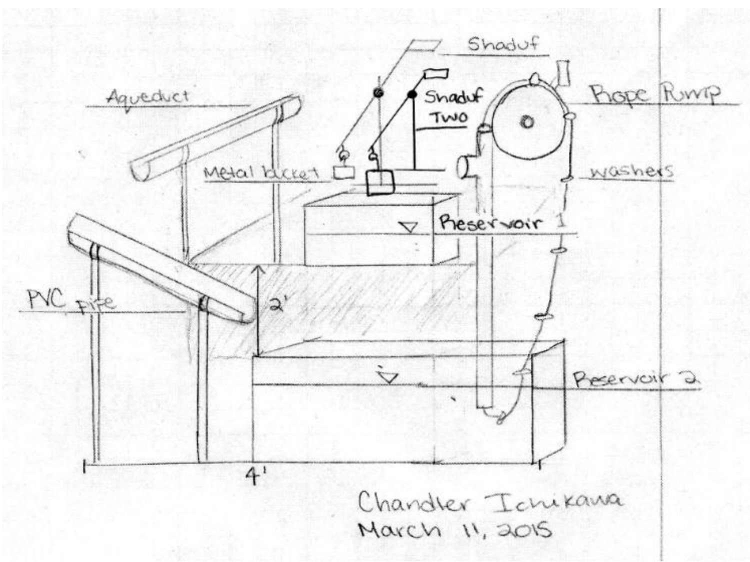


Figure 3-2 Two Shaduf Closed System utilizing two shadufs (upper middle), two aqueducts (left side), and a rope pump (right side)

3.3.3 Mirrored Technologies

The mirrored technologies system, shown in Figure 4-3, includes a river located perpendicular to the longest edges of our container, an elevated reservoir on each side of the river (total of 2 reservoirs), one shaduf, one Archimedes screw, and two aqueducts. The 4' x 2' x 8"container is composed of half inch thick Plexiglas with a river basin 2' x 10" x 8" running perpendicular across the two longest edges. One shaduf made of a wooden base, two wooden dowels, one bearing for dowel pivoting, a small bucket for water, counterbalance weight, and a metal pin to enable pivoting is placed along the river edge. An Archimedes screw is located directly opposite the shaduf, mirroring it on the other side of the river banks. The Archimedes screw is made from a PVC pipe backbone, which has an interactive lever arm (for rotation) affixed to the top end of it. A modified fork support is anchored to the dry land and supports the lever arm shaft protruding from the PVC pipe; the fork support helps maintain the angle (between 30 and 40 degrees) of the screw, as well as continuous rotation of the lever arm. Half inch tubing is mounted to the PVC backbone with waterproof tape and wound up the backbone, acting as the vessel for the water and a visual learning experience. A point of rotation is also anchored to the river floor to ensure the screw maintains placement. Directly behind both the shaduf and screws is an elevated reservoir that receives the influent water from its respective device. The aqueduct, constructed of PVC pipe, is affixed to the reservoirs and transports the water back to the river. The aqueducts, made of PVC pipe, are supported by anchored columns containing T-clips, which enable users to manipulate the angle of each aqueduct. This design offers simultaneous two user interaction.

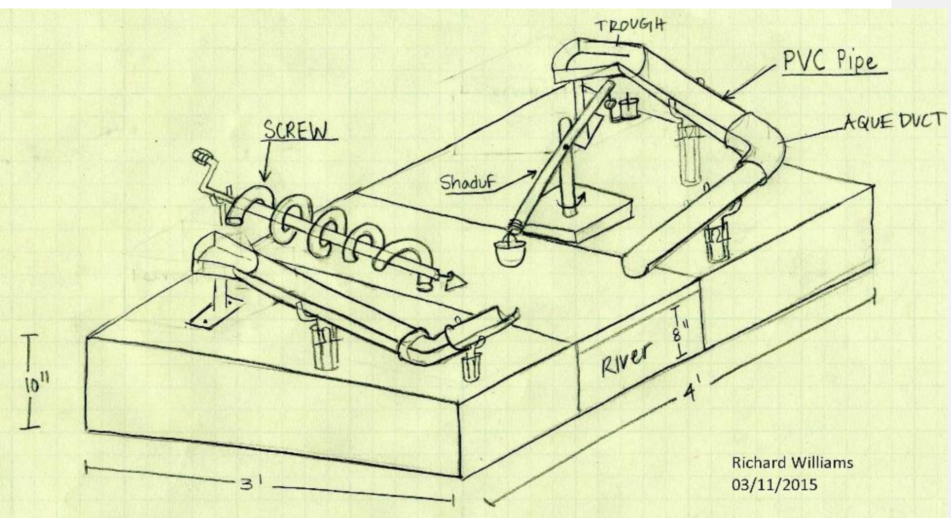


Figure 3-3 Mirrored Technologies design encompassing a shaduf (right side of river), Archimedes screw (left side of river), and two aqueducts (both side of river).

3.3.4 Quad Technologies

The Quad technologies system, shown in Figure 4-4 is composed of a river, two elevated reservoirs on each side of the river, two shadufs, two Archimedes screws, and four aqueducts. The 4' x 2' x 8"container is made of half inch thick plexiglas with a river basin 2' x 10" x 8", running perpendicular across the two longest edges. Two shadufs composed of a wooden base, two wooden dowels, one bearing for dowel pivoting, two different sized buckets, counterbalance weights, and a metal pin to enable pivoting, are each located on one side of the river. The first Archimedes screw is located directly opposite the first shaduf, mirroring it on the other side of the river banks. A second screw is located opposite the second shaduf. The Archimedes screws are made from PVC pipe backbones, which have interactive lever arms (for rotation) affixed to the top ends of the pipes. A modified fork support is anchored to the dry land and supports the lever arm shaft protruding from the PVC pipe; the fork support helps maintain the angle (between 30 and 40 degrees) of the screws, as well as continuous rotation of the lever arms. Half inch tubing is mounted to the PVC backbone with waterproof tape and wound up the backbone, acting as the vessel for the water and a visual learning experience. A point of rotation is also anchored to the river floor to ensure the screws maintain safety and proper placement. Directly behind all water moving devices are elevated reservoirs that receive the influent water from their respective device. The four aqueducts, constructed of PVC pipe, are affixed to the reservoirs and transport the water back to the river. The aqueducts, made of PVC pipe, are supported by anchored columns containing T-clips, which enable users to manipulate the angle of each aqueduct. This design offers the option of simultaneous four user interaction.

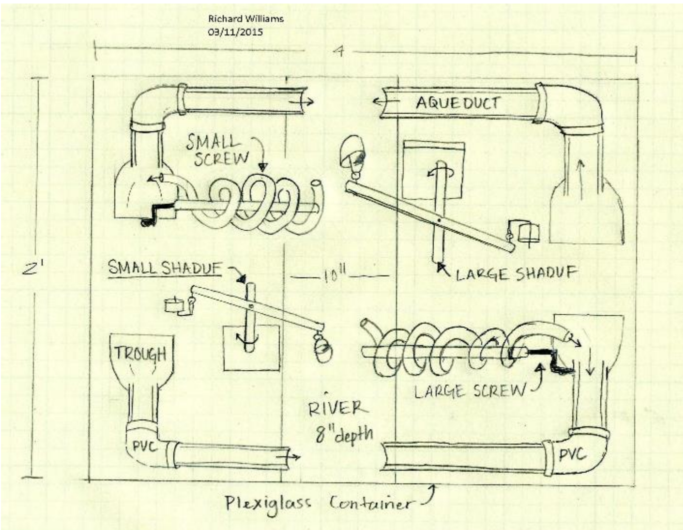


Figure 3-4 Mirrored Technologies 2.0 design encompassing two shadufs, two Archimedes screws, and four aqueducts

3.3.5 All in One Design

The All in One Design, shown in Figure 4-5, is a water transportation system with the purpose of demonstrating to 6th graders various methods of moving water throughout history. The All in One Design includes three shadufs, three Archimedes screws, three rope pumps, and three aqueducts. For each of the water movement technologies there is a large, medium, and small scale version so that students can experiment with different variables associated with each water movement technology. The All in One Design features a platform with an area of 2' by 7'. The platform is divided into four sections, each 1' by 3.5', to separate each water movement technology. The shaduf section contains two water reservoirs on both sides of shadufs, shown in Figure 3-5. The shadufs are built from wooden dowel, twine, plastic cups, wooden supports, and counter weight. The Archimedes screw section has two water reservoirs. One water reservoir is raised 6" and contains outflows to allow the water to flow back into the storage reservoir. Each Archimedes screw is built with wooden columns supporting a rotating rod. The rod has plastic transparent tubing wrapped around like a screw, for visual learning. The rope pump section, has the rope pumps built over water reservoir on a platform, and has small buckets for the pumped water to be gathered, and replaced into the storage reservoir. The aqueduct section will contain one water reservoir, and buckets to bring the water to top of the aqueducts shown in Figure 3-5. The aqueducts will be fixed and built from PVC pipe and wooden supports. The platform is raised to allow the system to be used in most areas, and has two handles attached at each end to allow for easy transport.

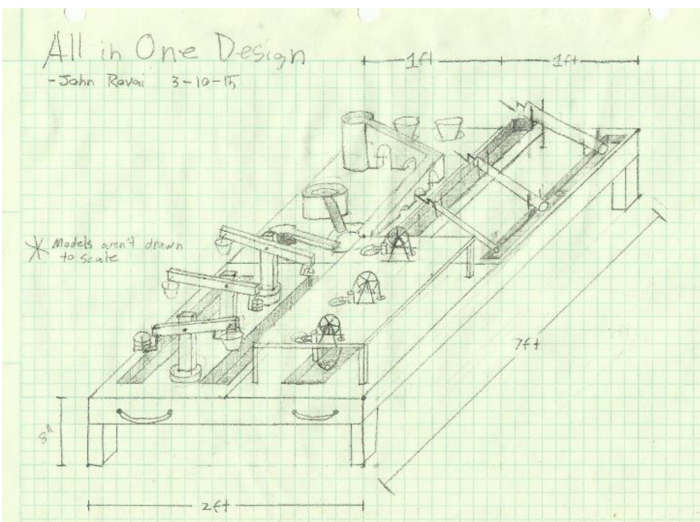


Figure 3-5 The All in Design features three shadufs (bottom left), aqueducts (upper left), Archimedes screws (upper right), and rope pumps (bottom right). Each device has three versions to allow users to observe how changing different variables affects each device

3.3.6 Lake System

The Lake System is a water transportation demonstration device, as seen in Figure 4-6. The Lake System is a platform, with an area of 2.5' by 4', with a lake water reservoir in the center of the platform surrounded by four water transportation systems. There are two Shadufs, and two Archimedes screws. The shadufs are built from wooden dowel, twine, plastic cups, wooden supports, and counter weight. Each Archimedes screw is built with wooden columns supporting a rotating rod. The rod has plastic tubing wrapped around like a screw. Each device is paired with its own aqueduct to allow the water to flow back into the lake reservoir. The platform is built to look like a natural lake landscape, to show how each device might be used in a real world application. The platform is raised to allow the system to be used in most areas. Handles are at the ends to make the system easier to transport. All materials are chosen on the basis of safety, while all the devices are easily manipulates for ease of use and understanding.

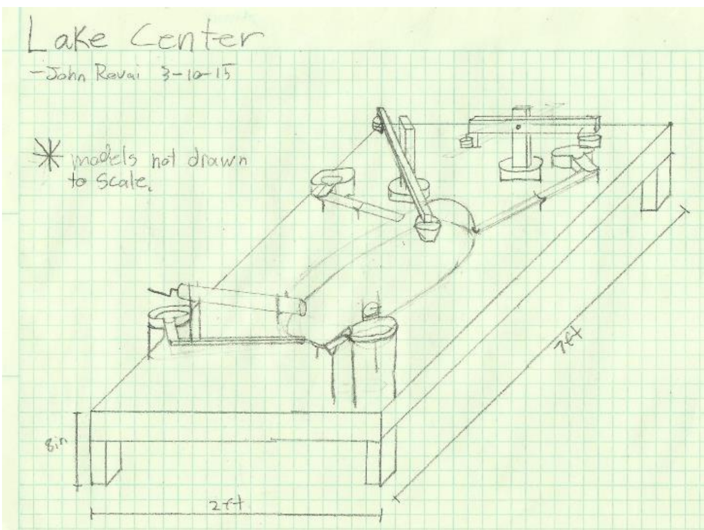


Figure 3-6 The Lake Center design contains four water moving devices. There are two shadufs (upper right) and two Archimedes screws (lower left). Each of the devices are paired with an aqueduct (bottom right) to allow the water to flow back into the lake reservoir.

3.3.7 Stepwise Closed System

The Stepwise Closed System is a water transportation demonstration device designed to expose 6th graders to various methods of transporting water throughout history. It consists of two aqueducts, an Archimedes screw, and a shaduf, as seen in Figure 4-7. There is a reservoir at the lower elevation, another reservoir at a higher elevation, and a city in between the two reservoirs. The system demonstrates how water can be lifted from the low reservoir to the city using a shaduf, and how water can then be lifted from the city to the high reservoir using the Archimedes screw. The means in which water moving is demonstrated encompasses physical and visual learning. The city contains a separate mini-reservoir for each water moving device. The aqueduct is used to create two closed systems, using gravity to transport water from the city back to the low reservoir, and from the high reservoir back to the city. The system rests on top of a platform with wheels affixed to the bottom so that it's easy to transport. The shadufs are made from wood, twine, and plastic, while the Archimedes screw is made up of wooden columns, a rod, and plastic tubing to wrap around the rod like a screw. All materials used are selected on the basis of safety and functionality for the users.

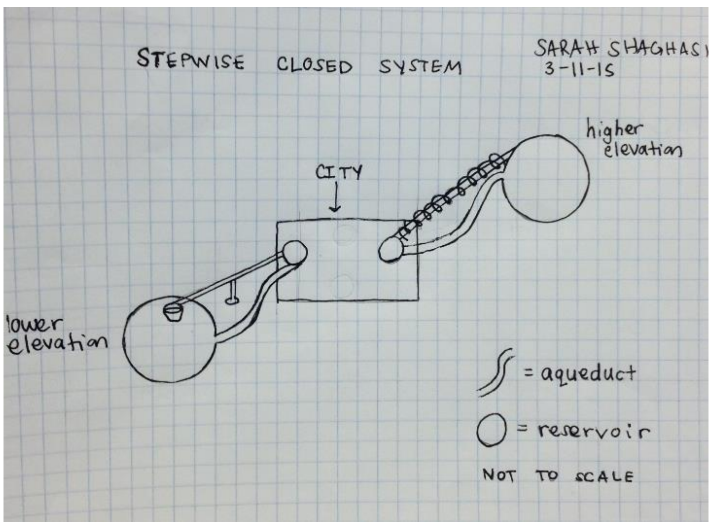


Figure 3-7 Closed system containing two aqueducts (left and right side), a shaduf (left side), and an Archimedes Screw (right side).

3.3.8 The X

The X is a water transportation demonstration device designed to expose 6th graders to various methods of transporting water throughout history. It consists of two aqueducts, two Archimedes screws, and two shadufs, as seen in Figure 4-8. There are two reservoirs at low elevations, two reservoirs at high elevations, and a city in between the two reservoirs. The system demonstrates how water can be lifted from the lower reservoir to the city by using a shaduf, and how water can then be lifted from the city to the higher reservoir using the Archimedes screw. The purpose of the additional shaduf and Archimedes screw is to demonstrate how varying the length or diameter of a water moving device can affect its capabilities. The city will contain a separate mini-reservoir for each water moving device. The aqueduct will be used to create four closed systems, using gravity to transport water from the city back to the low reservoirs, and from the high reservoirs back to the city. The system rests on top of a platform with wheels so that it's easy to transport. All the materials were selected on the basis of safety and functionality of the users. The shadufs are made from wood, twine, and plastic, while the Archimedes screw is made up of wooden columns, a rod, and plastic tubing to wrap around the rod like a screw.

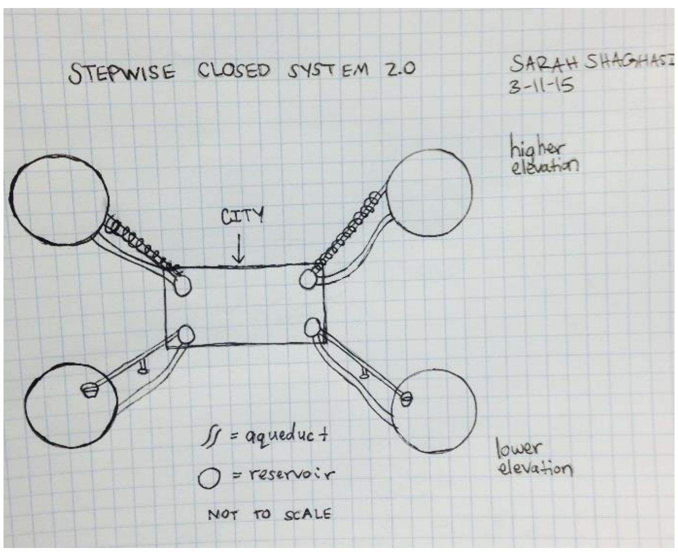


Figure 3-8 A closed system containing four aqueducts (one at each corner), two shadufs (bottom half), and two Archimedes Screws (upper half).

4 Final Decision

4.1 Introduction

The final decision was to implement the Archimedes Screw Pump. This decision was reached based on the feedback our team received from our participation in Zane Middle

School's first annual Galileo Day. Zane Middle School invited our team to Galileo Day to showcase the Archimedes screws and shaduf prototypes to the students at Zane for their feedback. After Galileo Day it was apparently obvious that the students preferred the Archimedes Screw over the shadufs and wanted the screw to be proportionally larger. Our team then when back to the drawing board to consider client criteria, and how well the alternative solutions met the criteria. A Delphi Matrix was implemented to determine which model best suited the weighted criteria.

4.2 Criteria

The following criteria have been explicitly defined in order to select the alternative solution that best fits the needs of the client.

- Educational Value: The amount of learning that is achieved through operating the device.
- Safety: The solution should not pose any threat to any person operating the device.
- Durability: How long the device will last without having to replace any of its parts.
- Inspiration: Device usage promotes inquisitive interjections.
- Ease of Use: The level of ease to operate the device.
- Aesthetics: The level of visual appeal.
- Setup Time: The amount of time required setup and breakdown the device is less than 10 minutes.
- Cost: The amount of money that is spend building the device as well as maintaining parts for the next 10 years.

4.3 Alternative Solutions

Alternative solutions were evaluated to determine which solution best fit the criteria list. The alternative solutions are described in detail in Section 3 and are listed below:

1. Closed System
2. Two Shaduf Closed System
3. Mirrored Technologies
4. Quad Technologies
5. All in One Design
6. Lake System
7. Stepwise Closed System
8. The X

4.4 Decision Process

To determine the solution best suited to the client's needs, all solutions were numerically rated in the Delphi Matrix shown in Table 2. The Delphi Matrix ranks on a scale from 0-50 high for each criteria for each alternative solution. The criteria are weighted on a scale of 0-10 high of their importance to the client. A numerical score was calculated by multiplying the weighted criteria and the solution ranking. These numbers were summed for each design and respective criteria. The scores were then compared and the highest score is used as the optimal solution. The Lake System scored the highest, with a total of 2934.

Table 2. Delphi Matrix for all criteria and designs excluding the Archimedes Screw Pump (actual final design).

Criteria		Solutions							
List	*Weight*	*Closed System*	*Two Shaduf Closed system*	*Mirrored Technologies*	*Mirrored Technologies 2.0*	*All in One Design*	*Lake System*	*Stepwise Closed System*	*Stepwise Closed System 2.0*
Educational Value	10	30 / 300	40 / 400	42 / 420	45 / 450	50 / 500	45 / 450	35 / 350	40 / 400
Ease of Use	9	40 / 360	40 / 360	35 / 315	30 / 270	25 / 225	40 / 360	42 / 378	40 / 360
Level of Fun	9	28 / 252	32 / 288	33 / 297	35 / 315	35 / 315	35 / 315	35 / 315	37 / 333
Durability	9	38 / 342	35 / 315	35 / 315	32 / 288	25 / 225	35 / 315	40 / 360	38 / 342
Cost	1	35 / 35	34 / 34	35 / 35	30 / 30	20 / 20	34 / 34	33 / 33	30 / 30
Setup Time	5	45 / 225	45 / 225	45 / 225	45 / 225	25 / 125	45 / 225	40 / 200	37 / 185
Aesthetics	7	30 / 210	34 / 238	40 / 280	42 / 294	35 / 245	45 / 315	45 / 315	45 / 315
Inspiration	10	35 / 350	38 / 380	35 / 350	42 / 420	38 / 380	45 / 450	35 / 350	38 / 380
Safety	10	47 / 470	45 / 450	45 / 450	44 / 440	40 / 400	47 / 470	45 / 450	45 / 450
	Total	2544	2690	2687	2732	2435	2934	2751	2795

4.5 Final Decision

The Delphi Matrix aided in selecting the final decision, the Lake System. Overall, each individual score was high. Notably, Educational Value, Ease of Use, Inspiration, and Safety scored very high and were the most heavily weighted criteria. The Lake System incorporates two variable sized Archimedes Screws, and shadufs, as well as a system of aqueducts. The Lake system solution was decided upon before the team's participation in Zane Middle Schools first annual Galileo Day. After receiving feedback from the students at Zane's Galileo Day, it was apparent that the students were much more interested in the Archimedes Screw and suggested that a single large screw would be of great interest. This feedback from the students prompted the team to go back to the drawing board and analyze our criterion. After careful consideration and taking into account our clients criteria, the team arrived at a new better suited final solution. This final solution is an Archimedes screw that is approximately ten times larger than the screws that were considered before. This solution offers a greater amount of inspiration and allure to the potential users, while still offering itself as a great visual learning tool.

5 Specifications of Solution

5.1 Introduction

Section 6 addresses specifications for the solution that pertain to the details of the final design. The specifications for the Archimedes Screw Pump solution include a solution description, cost analysis, recreation, implementation and device usage, results, and discussion. The solution description provides figures, descriptions, and design illustrations pertaining to the components of the Archimedes Screw Pump. Cost analysis includes design cost, via pie chart, materials cost, and maintenance cost. The recreation section offers information on steps to recreate the final solution. Implementation and device usage focuses on setup protocol, proper operation, and device storage. The results include prototype feedback, solution functionality as a learning tool, and the amount of water that can be moved over a known time. The discussion explores some activities the users could participate in when using the Archimedes Screw Pump.

5.2 Solution Description

The Archimedes Screw Pump, shown in Figure 5-1, is the final design solution that demonstrates how water is moved. The design, modeled after a conventional Archimedes screw, uses energy input by the user through a lever arm attached to the top end of the screw. The final design employs four major components, an Archimedes Screw, two reservoirs, and an adjoining frame. The screws main cylinder is composed of 4” diameter PVC pipe that is 5’ long with two caps at either end of the cylinder. From one end, as seen in Figure 5-2, a lever arm made of 1” diameter PVC pipe and 3 elbows servers as the lever arm. At the opposite end is a male pivot attachment used for fastening to the submerged pivot point, embedded in the reservoir. 1.5” diameter circular tubing is wrapped around the 4” diameter PVC pipe with an 8” distance from the tubing to either end of the capped cylinder. The main supporting structure, seen in Figure 5-3 is composed of two 2 x 6” wooden boards that create a ladder shaped supporting frame. This frame acts as a pivot for the screw and stabilization between the screw and water reservoir. The initial water reservoir, depicted in Figure 5-1, utilizes an upcycles Rubber Made storage bin. Additionally, embedded in the bottom of the initial reservoir is a pivot mount, shown in Figure 5-5, containing the female pivot attachment for the corresponding pivot hardware mounted on the bottom of the screw. The terminal reservoir is also composed of Plexiglas with the same dimensions as the initial reservoir. This terminal reservoir is elevated by a wooden platform, seen in Figure 5-4, which raises the reservoir 3-feet. The complete setup of the Archimedes Screw Pump is pictured in Figure 5-1.

Figure 5-1 the completed Archimedes Screw Pump

Figure 5-2 the lever arm of the screw

Figure 5-3 the frame and support of the Archimedes Screw Pump

Figure 5-4 the terminal reservoir to catch pumped water

Figure 5-5 the internal pivot in the first reservoir

Figure 5-6 the vinyl tubing wrapped around the pipe to create an “Inside out Screw”

5.2.1 Archimedes Screw Pump

The main backbone of the Archimedes screw is a 5’ PVC pipe, which has a cap fastened on both ends using PVC cement glue. Affixed to the bottom cap is a male pivot attachment, shown in Figure 5-5. The pivot attachment provides stabilization for the screw, as well as a fixed continuous rotation of the backbone. Wrapped around the diameter of the backbone is the 1.5” diameter tubing that acts as the vessel for moving the water. At the end of each tube, a small top section of the tubes diameter is sliced off, as shown in Figure 5-6, to enable an area for fastening the screw to the PVC pipe. The tubing is fasted 8” from the bottom of the screw to allow for clearance and smooth rotation of the PVC backbone. After the first end of the tubing is fastened, the tubing is then wrapped around the backbone continuously and secured 8” below the top of the screw as outlined above. On the top backbone cap, a half-inch hole is drilled out. The hole on the top of the backbone cap is used to mount and cement glue a 1” diameter PVC pipe, which acts as the lever arm for rotating the screw, shown in Figure 5-2. The lever arm is composed of three 1” diameter PVC pipes and two PVC elbows, all secured with cement glue as shown in Figure 5-2.

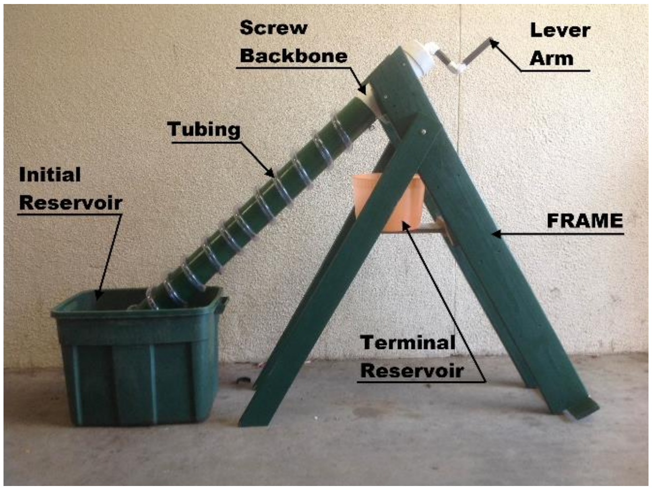


Figure 5-7 Completed Archimedes Screw with labels

5.2.2 Frame (Base)

The frame component, seen in Figure 5.3, provides support and acts as a pivot point for improved rotation of the backbone. The frame is composed of two 2 x 6” wooden boards and two stabilizing legs. All members are attached with 1/2” bolts and nuts. The vertical component of the frame, depicted in Figure 5.3, provides a point of rotation for the screw. This vertical member is tilted at a forty-five degree angle and is supported by two 2 x 4” boards fasted on each side of the frame Figure 5.3.

5.2.3 Reservoirs

The reservoirs are both 2’ x 3’ x 2’ and made of upcycled Rubber Made storage bins. The initial reservoir contains a pivot mount, depicted in Figure 5-5, which is attached to the bottom of the initial reservoir. A rubber pipe reducer serves as the pivot mount and provides a fixed point for rotation and constant stabilization for the screw. The terminal reservoir, labeled in Figure 5-4 is elevated by a wooden platform, seen in Figure 5-4, which raises the reservoir 3 ‘.

5.3 Cost Analysis

The cost analysis section details the design, implementation, and the projected maintenance cost maintenance cost of the design chosen in Section 4.

5.3.1 Design Cost

The design cost is the number of hours it took the team to complete the Archimedes Screw Pump. The design cost shown in Figure 5-8 is the amount of time in hours spent on each section of the design process. The majority of time spent was on prototyping during implementation totaling 150 hours. There were a total of four prototypes built before the final solution was reached. Different solutions had to be tried before the best solution was found. The final solution changed midway through adding more hours to implementation. The second most time was spent on the literature review. Many different subject were researched since several water moving devices were considered. In the end the total number of hours spent on the project was 210 hours.

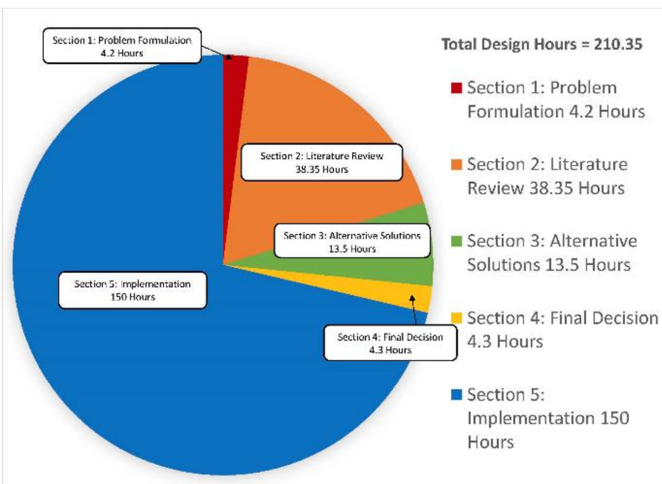


Figure 5-8 pie chart detailing the amount of time it took it design and implement the final solution. It took 210 design hours to complete the Archimedes Screw Pump. The majority of hours were spent on implementation.

5.3.2 Cost of Materials

The materials were purchased by the team with support from Zane Middle School. The costs are detailed in Table 2 which shows the number of items purchased, the individual cost of each item, and the cost. The Archimedes Screw Pump cost a total $62.37 staying far under the budget of 400 dollars. The low cost relative the budget was achieved by getting many materials donated from the local community. The most expensive items are the PVC reducer, and the vinyl tubing costing $15.00 and $21.93 respectively.

Table 3. A table accounting for the monetary costs for each piece of the project

Material cost of Archimedes Screw			
Item	**Amount**	**Price**	**Cost**
1/2" PVC Elbow	2	$ 0.49	$ 0.98
Screws	4	$ 0.23	$ 0.92
1/2" X 2' PVC	1	$ 1.39	$ 1.39
4" PVC Cap	1	$ 3.99	$ 3.99
2 oz. Gorilla Glue	1	$ 4.99	$ 4.99
Sand Paper	1	$ 1.49	$ 1.49
5/8 ID X 7/8 OD Vinyl Tube	17	$ 1.29	$ 21.93
PVC Reducer	1	$ 15.00	$ 15.00
Box Deck Screws	1	$ 5.00	$ 5.00
PVC Cement	1	$ 7.00	$ 7.00
PVC 2' X 2' X 1/4" Sheet	1	Donated	N/A
1.5"x1' PVC Pipe	1	Donated	N/A
5 Gallon Plastic Tote	2	Donated	N/A
1 Gallon Plastic Bucket	1	Donated	N/A
2"X4"x 8' Lumber	3	Donated	N/A
Washers	8	Donated	N/A
Bolts	4	Donated	N/A
Nuts	2	Donated	N/A
Oil Based Paint	1	Donated	N/A
		Total Cost	$ 62.69

5.3.3 Cost to Maintain

Since the Screw will only be used a few times per year there are very little maintenance costs. Before and after use the screws, and bolts should be checked and tightened if needed as seen in Figure 5-9. The device should be cleaned once a year. The total estimated maintenance costs are 1.5 hours a year shown in Table 4.

Table 4. A table displaying the number of hours needed to maintain the Archimedes Screw Pump

Action	Hours
Tighten Frame Hardware	1.0
Tighten Screw Hardware	0.5
Total Hours	**1.5**

Figure 5-9 a screw being tightened on the Archimedes Screw Pump

5.4 Device Usage

Operating the Archimedes Screw Pump is very easy. The first step is to assemble the stand, and the main reservoir shown in Figure 5-10. Next, grab the screw and place it into the reducer and lay the other end of the screw into the slot on the stand shown in Figures 5-3, 5-5, and 5-10. Then, loosen the wing nuts on the shelf of the stand for the terminal reservoir. Place the terminal reservoir on the shelf and fill the main reservoir with water. Fill the main reservoir until the water is completely covering the tubing. Now the screw is ready. Simply rotate the screw lever handle counter-clockwise and begin to watch the water move up the screw and into the terminal reservoir. When finished, pick up the screw, holding it vertically above the main reservoir to let all the water flow out. Now grab the terminal reservoir and empty it into the main reservoir. Next either dump the main reservoir in a desired location or release the valve on the main reservoir to let the water out. Lastly, lower the terminal reservoir shelf by again loosening the wing nuts then tightening them again when the desired level for storage is reached. Finally put the remaining pieces away. The setup time is approximately 3 minutes and 45 seconds, and the cleanup time is 3 minutes as seen in Table 5.

Figure 5-10 the stand of the Archimedes Screw Pump for set up

Figure 5-11 the slot on the Stand to support the Archimedes Screw Pump during rotation

Table 5. A table displaying the setup time (3 minutes and 45 seconds) and the cleanup time (3 minutes and 5 seconds)

Setup Time [minutes]	Clean up Time [minutes]
3.75	3.08

5.5 Results

The results section displays the team's findings after building the Archimedes Screw Pump. The results section features qualitative results from testing the screw with students as well as some quantitative results from further testing.

5.5.1 Feedback: Galileo Day

A prototype of the Archimedes Screw was introduced to several middle school students at Zane Middle School's first annual Galileo day, which took place on April 3rd, 2015. A booth containing two Archimedes screws, and another water moving device called a shaduf was set up (as seen in figure 5-12). The students were interested in both devices, but they seemed to gain much more educational insight from the Archimedes Screw. Based on the feedback from the students a large Archimedes Screw was chosen because it provoked more of a scientific curiosity among the students, which led them to experiment and ask questions about the device. Galileo day was a success because it proved our device to be interesting and thought provoking for students, and also showed what needed to be done to make the Archimedes Screw Pump more successful.

Figure 5-12 an Archimedes Screw prototype at Zane Middle Schools First Annual Galileo day

5.5.2 Further Testing

Additional testing was performed to confirm that the final Archimedes Screw Pump will be successful. First, the average number of rotations every 30 seconds was found. A series of 5 trails were performed with two different users. The average was found to be 38.2 rotations every 30 seconds shown in Table 6. The next thing tested was the amount of water that the screw could move in two minutes. After 3 trials it was found that the average amount of water that the screw could move was 1.04 liters every two minute. From the raw data it was calculated that over two minutes on average a person would rotate the screw 152.2 times, and move 1.04 liters of water. On average a person will move 6.58 ml of water per rotation at an average flow rate of 8.68 cm^3/sec shown in Table 7. Clearly the Archimedes Screw Pump is successful at moving water easily and consistently.

Table 6. Raw data from testing the Archimedes Screw Pump

Trial	Rotations in 30 Seconds	Amount of water moved in 2 minutes [liters]
1	43	1.08
2	38	1.00
3	33	1.05
4	39	N/A
5	38	N/A
Average	38.2	1.04

Table 7. Major results from testing the Archimedes Screw

Number of rotations required to move one liter of water	152
Amount of water moved per rotation [ml/ rotation]	6.58
Average flow Rate [cm^3/sec]	8.68

6 References

Ayalon, Etan, Udi Milo, and Nes Ziona. "Typology and Chronology of Water-Wheel ("sāqiya") Pottery Pots from Israel." *Israel Exploration Journal* 50: 216-26. Print.

Blakemore, C. L. (1995). “Learn How Middle School Students Think.” *Strategies*, 8, 11-14.

Brain, Marshall. (2010). “*How Aqueducts Work – A Roman Technology That Marked the Height of Their Engineering Prowess”*. Web. 23 Feb. 2015. <http://www.brainstuffshow.com/blog/how-aqueducts-work-a-roman-technology-that-marked-the-height-of-their-engineering-prowess/>.

California State Board of Education. (2001) “School Safety, Discipline, and Attendence Policy #01-02 [online] Available http://www.cde.ca.gov/be/ms/po/documents/policy01-02-mar2001.pdf, February 25, 2015

Cartwright, Mark. (2012) "Aqueduct." *Ancient History Encyclopedia*. N.p. Web. 19 < https://prezi.com/c0dxkekis1bx/ancient-roman-architecture>Feb. 2015

Chiemi Ishiyama, Yoshito Yamamoto and Yakichi Higo. (2005). Effects of Humidity History on the Tensile Deformation Behaviour of Poly(methyl –methacrylate) (PMMA) Films. MRS Proceedings, 875, O12.7 doi:10.1557/PROC-875-O12.7.

Crandell, J. (2015). Personal Communication. February 24. 2015, Arcata, Ca.

Fraenkel, P.L. (1986).*Water Lifting Devices*. Tech. no. 43. ROME: FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, 1986. Print.

Fraenkel, Peter. (1997). *Water-pumping Devices: A Handbook for Users and Choosers*. London: Intermediate Technology, 1997. Print.

Gratton, Luigi M., and Silvia Defrancesco. (2006). "A Simple Measurement of the Sliding Friction Coefficient." *Physics Education* 41.3 (2006): 232-35. *IOP Science*. Web. 20 Apr. 2015.

Hodge, Trevor. (1992). “Roman Aqueducts and Water Supply.”Gerald Duckworth & Co. Ltd., 1992. London. Print.

HowStuffWorks.com. (2009), "Archimedes\\u0027 Screw" 24 August 2009 <http://science.howstuffworks.com/archimedes-screw-info.htm> 03 May 2015

Kolle, Jefferson. (2009). "Fighting Fastener Corrosion." *Deckmagazine*. Professional Deck Builder, 01 May 2009. Web. 23 Feb. 2015.

Mays, L. W. (2010). *Ancient water technologies*. Dordrecht, The Netherlands: Springer

Mays, Larry W. (2015). "Irrigation Systems, Ancient." *Water Encyclopedia Science and Issues*. Copyright © 2007-2015 Advameg, Inc, 2015. Web. 19 Feb. 2015. <http://www.waterencyclopedia.com/Hy-La/Irrigation-Systems-Ancient.html>.

Mujal-Rosas, R., M. Marin-Genesca, J. Orrit-Prat, A. Rahhali, and X. Colom-Fajula. (2012). "Dielectric, Mechanical, and Thermal Characterization of High-density Polyethylene Composites with Ground Tire Rubber." *Journal of Thermoplastic Composite Materials* 25.5 (2012): 537-59. *SAGE Journals*. Web. 20 Apr. 2015.

Muller W. (1899), *Die eisernen Wasserräder, Erster Teil: Die Zellenräder* & *Zweiter Teil: Die Schaufelräder* (The iron water wheels, Part 1: the cell wheels & Part 2: the paddle wheels, in German), Veit & Comp., Leipzig.

National Institute for Occupational Safety and Health. (2004). "Occupational Health and Safety Surveillance." *Journal of Occupational and Environmental Hygiene*, 1(6), D66-D67.

Nave, Carl R. (2002) "Physical Units." *Physical Units*. American Association of Physics Teachers, 2000. Web. 23 Feb. 2015.

Oleson, John P. (1984). *Greek Ad Roman Mechanical Water-lifting Devices: The History of a Technology*. United Kingdom and Europe: D. Reide, 1984. Print.

Pemberton, Sonya. "Wood as an Engineering Material. (2004-2015)." - *TLP Library The Structure and Mechanical Behaviour of Wood*. University of Cambridge, 2004 - 2015. Web. 22 Feb. 2015.

Russo, Ralph . (2004). "Comments (0)." *Aqueduct Architecture: Moving Water to the Masses in Ancient Rome*. Yale National Initiative, n.d. Web. 21 Feb. 2015. <http://teachers.yale.edu/curriculum/viewer/new_haven_06.04.04_u>.

San Diego Plastics. Inc. (2015). "Acrylic Plastic Sheets or "Plexiglas" - Its Uses, Handling and Cutting." *Acrylic Plastic or Plexiglas*. San Diego Plastics. Inc, n.d. Web. 22 Feb. 2015.

Soth, Philip, and Cindy Clendenon. (2015). "Pumps, Traditional." *Water Encyclopedia Science and Issues*. N.p., 2015. Web. 21 Feb. 2015. <http://www.waterencyclopedia.com/Po-Re/Pumps-Traditional.html>.

Theodossiou, VNicos. (2014). "Evolution of Water Pumps through the Centuries with Emphasis on Hellenic Civilizations." March 2014 Web. 22 Feb. 2015. <http://www.academia.edu/8629990/Evolution_of_water_pumps_through_the_centuries_with_emphasis_on_Hellenic_Civilizations

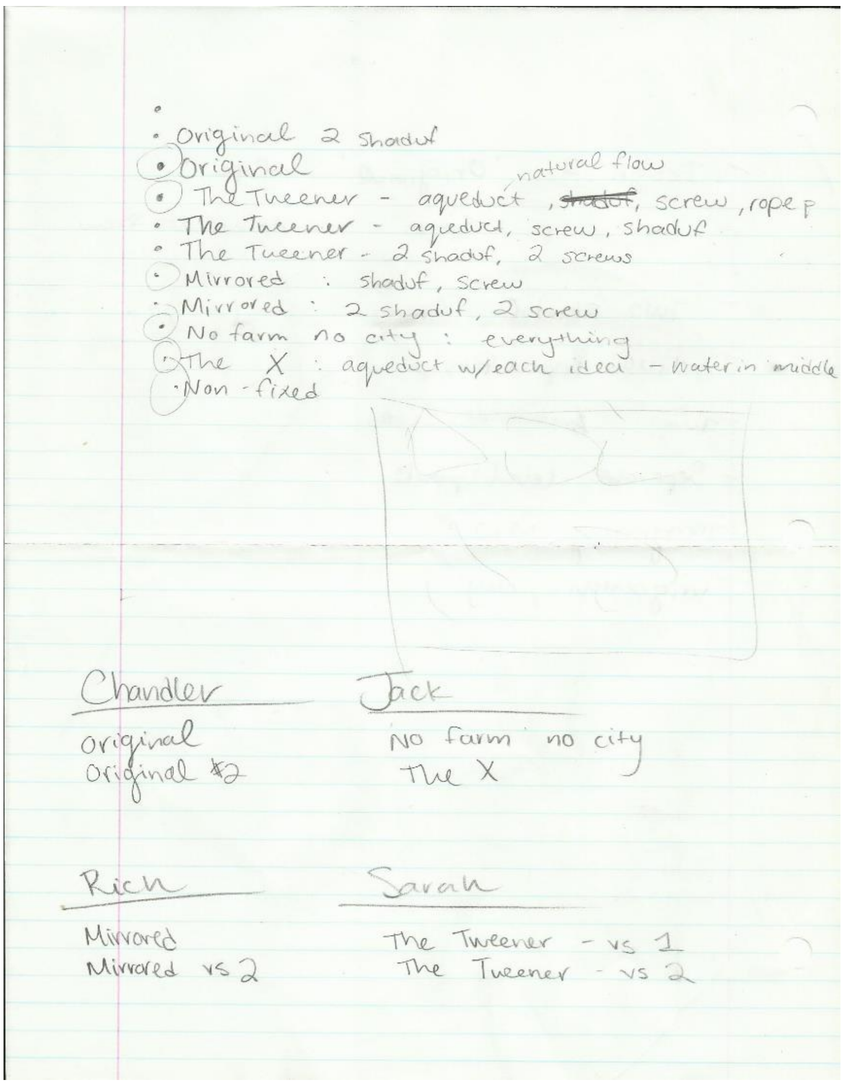
WHO, World Health Organization. (1997). *Linking Technology Choice with Operation and Maintenance for Low-cost Water Supply and Sanitation*. The Hague: IRC International Water and Sanitation Centre, 1997. Print.

Wiggens, Grant. (2014). “Students Learn Best When You Do This.” [Online] Available http://www.teachthought.com/learning/students-learn-best/

Wooster, Charles B. (1942). "Plexiglas and Other Acrylic Resins." *Journal of Chemical Education* 19.9 (1942): 430. *Journal of Chemical Education*. Web. 21 Apr. 2

7 Appendices

7.1 Appendix A: Brainstorm Session 1



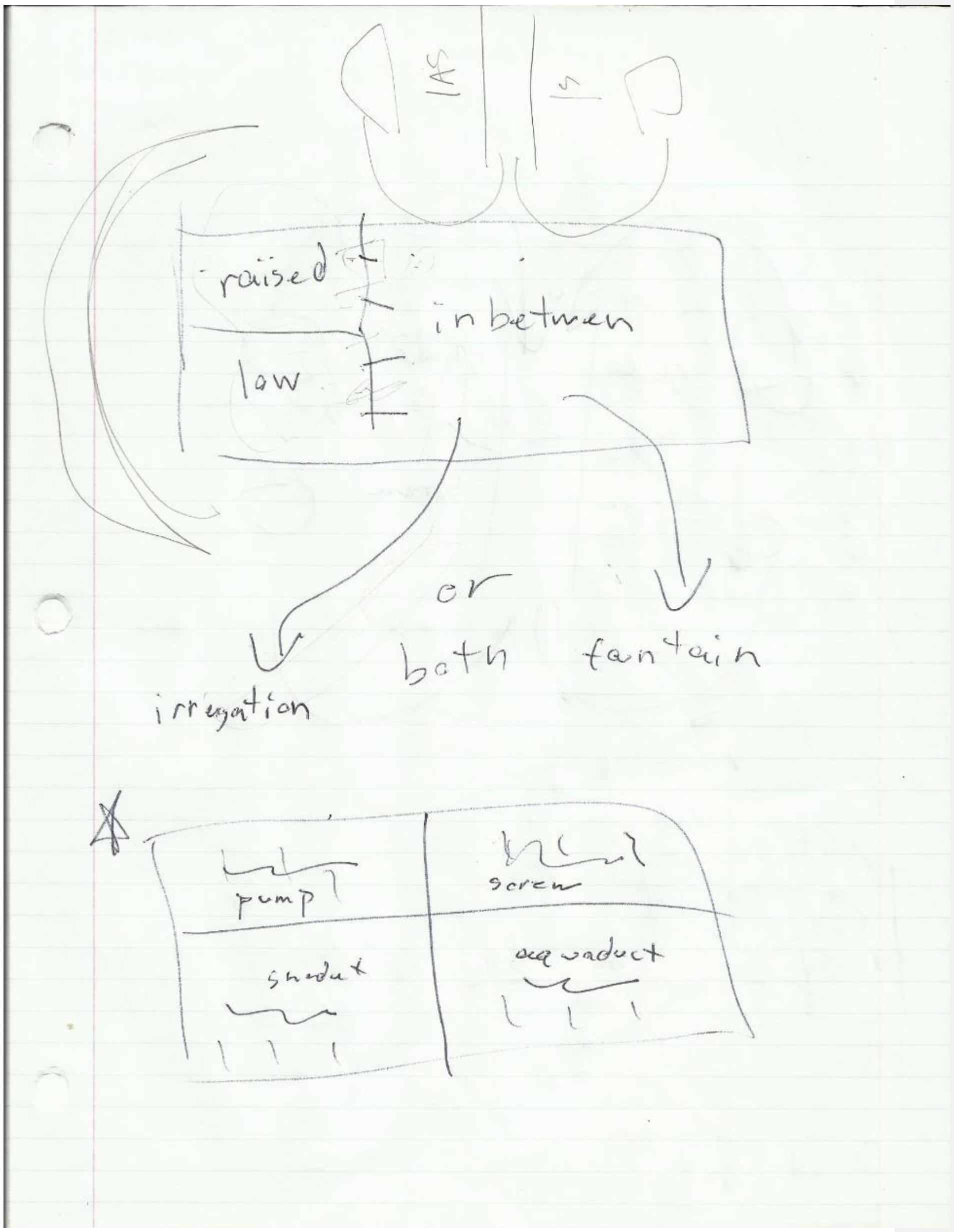
- Original 2 shaduf
- Original
- The Tweener - aqueduct natural flow, ~~shaduf~~, screw, rope p
- The Tweener - aqueduct, screw, shaduf
- The Tweener - 2 shaduf, 2 screws
- Mirrored : shaduf, screw
- Mirrored : 2 shaduf, 2 screw
- No farm no city : everything
- The X : aqueduct w/each idea - water in middle
- Non-fixed

Chandler
original
Original #2

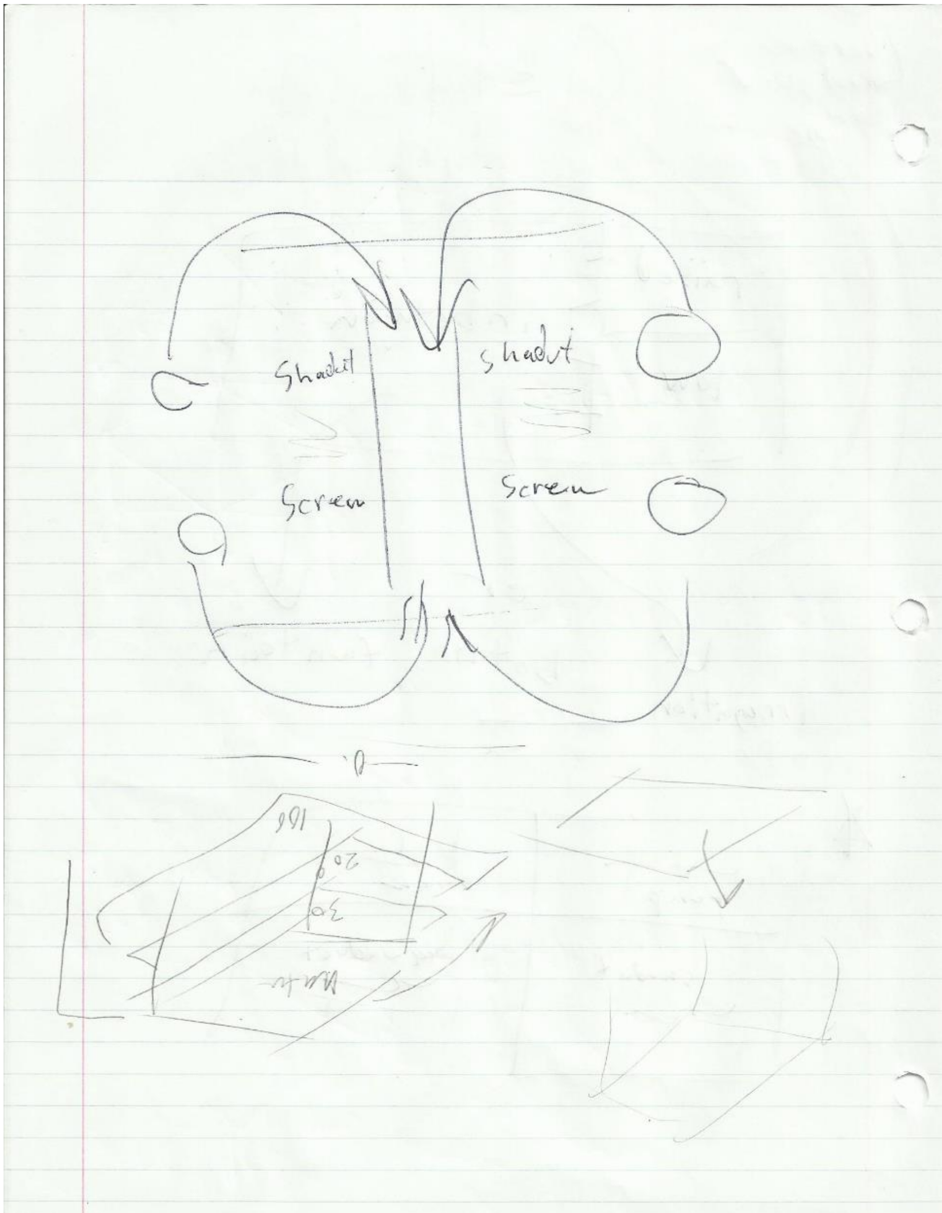
Jack
No farm no city
The X

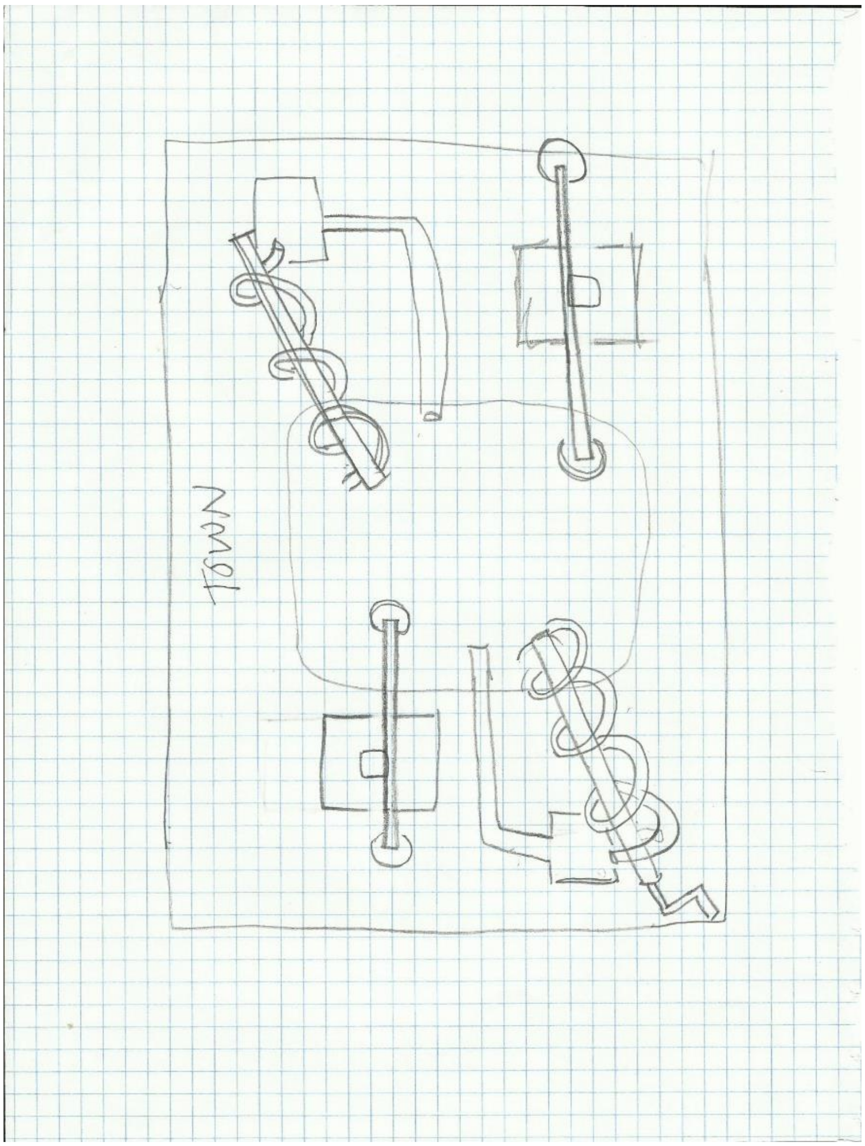
Rich
Mirrored
Mirrored vs 2

Sarah
The Tweener - vs 1
The Tweener - vs 2

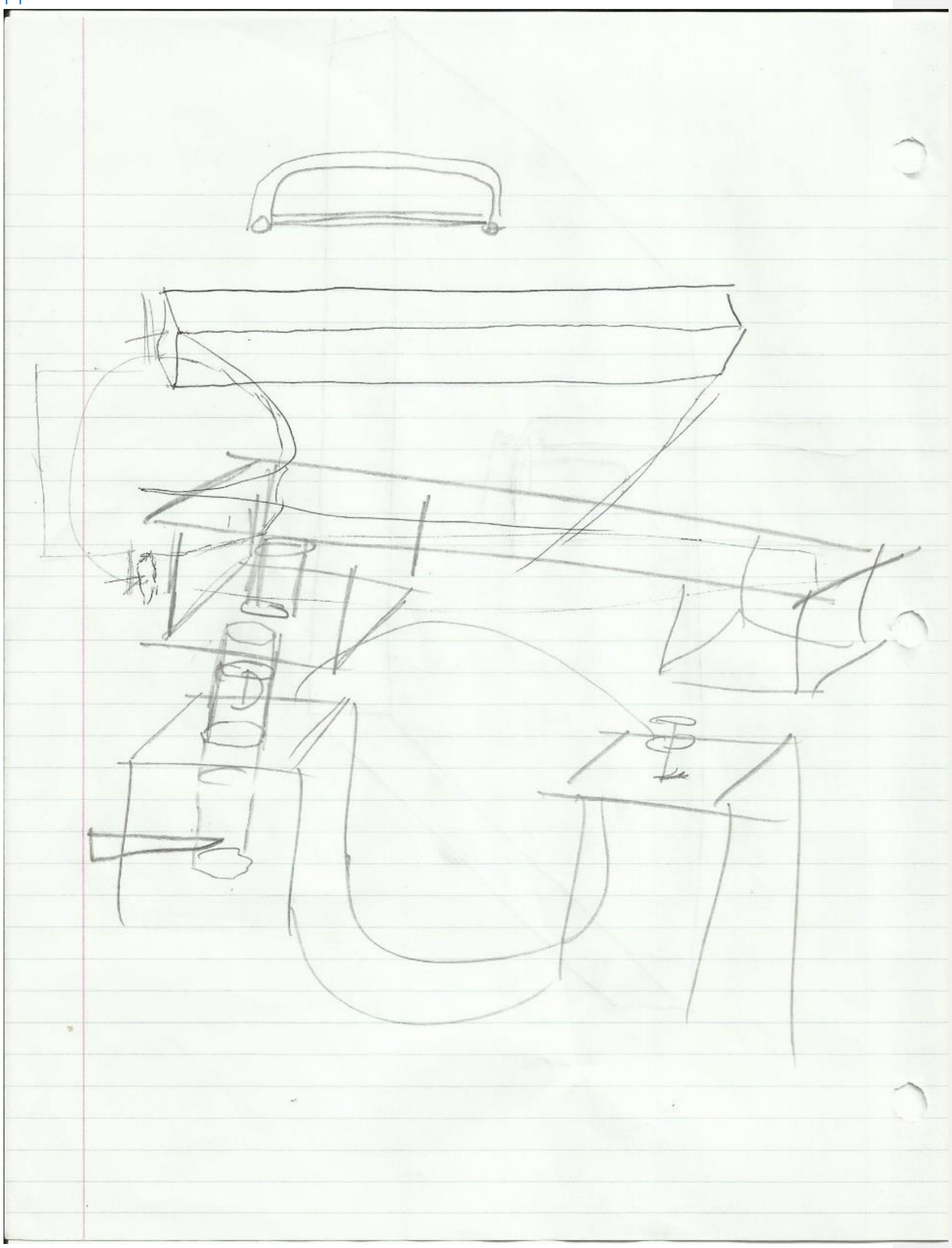


IAS
raised
inbetwen
low
or
both
fantain
irrigation
pump
screw
aqwaduct


Shadut
shadut
Screw
Screw


TOWN

7.2 Appendix B: Brainstrom Session 2




How can we make base easy to move?
6" of space
Some bearing / bushing
better delivering system
a rotation joint
6
4 Sunday afternoon
tub
pli wood
pipe
more
tubing
caps
elbows