STREAMLINE

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HUMBOLDT STATE UNIVERSITY
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1 Problem Formulation

1.1 Introduction

Section 1 of this document will discuss the Objective Statement of the project and describe the Black Box model of the design. In the Black box model, a problem is posed and in the end a solution is found, creating a system of problem and solution. The project detailed herein will occur at Zane Middle School in Eureka, California. The Principal, Jan Schmidt, has contracted the resolution of a faulty rainwater drainage system at the school.

1.2 Objective

The objective of this project is the reparation of rainwater drainage system at Zane Middle School. Currently the system overflows from the volume of rain it receives, creating “waterfalls” in the student quad. The criteria of the reparation will be set by the client, Zane Middle School of Eureka, California.

Figure 1: The Black Box Diagram serves as an explanation of Zane middle school’s water runoff situation both before and after the solution.

2 Problem Analysis and Literature Review

2.1 Introduction to Problem Analysis

The problem analysis describes the parameters of the project. Included in the problem analysis are the criteria, specifications, considerations and production volume. Criteria are weighted based on their pertinence to the design. The specifications and considerations are additional conditions that further constrain the design.

2.2 Specifications

The specifications act as a guide to follow throughout the design process so as to produce a product that will adhere to the needs of the client. The specifications are as follows:

- The total cost of the project after completion should cost no more than $400.00.
- By the end of the project the rainwater runoff from the courtyard awning will drain properly and will no longer overflow into the courtyard.
- The final project will abide by county building codes, so as to provide a safe and compliant design.

2.3 Considerations

Considerations are facts that are taken into account during the entire design process. For our client, and therefore our team, the major consideration is making the new design function with the existing drainage system. In addition to this, it needs to be kept in mind that the area where the design solution will be implemented is frequently occupied by students.

2.4 Criteria

The following criteria are the factors that will be used to determine the preference of one design over others when choosing a final design. The criteria are listed with their weight on a scale of 1 - 10, 10 meaning that this is the highest criteria for selection and 1 meaning the lowest criteria for selection. The constraints are how the ranking of each design will be determined for each criteria.

Table 1: Project Criteria and Constraints

Criteria	Weight	Constraints
Efficacy	10	Better designs will drain water from the gutter system faster
Implementable	9	Better designs will be easier to implement at all locations on site
Maintainability	8	Better designs will be easier to maintain or repair
Durability	7	Better designs will last longer
Safety	7	Better designs will minimize risk to students and faculty
Aesthetics	6	Better designs will be aesthetically pleasing
Cost	4	Better designs will minimize cost

2.5 Usage

The design will be implemented as a single unit at Zane Middle School. The design moves rainwater from the awning roof surrounding the student quad to the storm drain. Zane Middle School maintenance staff will clean and maintain the implemented design.

2.6 Production Volume

One prototype of the design will be built. Any plans to reproduce the design will be initiated by the administration at Zane Middle School following a probationary period of the prototype.

2.7 Literature Review

2.7.1 Introduction to Literature Review

This literature review summarizes previous research significant to the development of a solution to prevent excess rainwater from flowing off the roof and onto the quad of Zane Middle School. Topics of research included are client criteria, institutional policies, existing storm drain designs, materials, properties of water, and site conditions. Full references for all research are provided in Appendix A.

2.7.2 Client Criteria

Zane Middle School's criteria for this project are that it be effective, replicable, low-cost, and aesthetically pleasing. It is the school's wish that we prioritize a solution that renders the current system operable over a modification to displace the excess water ('Jan Schmidt Interview' 2015).

2.7.3 Institutional Policies

The following section details the various institutional policies that pertain to our design. These institutional policies are designated as either State Building Codes or State Plumbing Codes.

2.7.3.1 Building Codes

The solution designs proposed during the course of this project must comply with the City of Eureka's building code. The applicable codes can be categorized at general codes and those pertaining to the safety of construction of public schools, and roof assemblies and rooftop structures. These codes are detailed in this section.

2.7.3.1.1 General

The City of Eureka has adopted the 2013 edition of the California Building Code Title 24 as the official city building codes (City of Eureka 2015). All construction projects within the City of Eureka must be assigned to Seismic Design Categories E and F (City of Eureka 2015). Projects must utilize a nominal design wind speed of 85 miles per hour, and with the consideration that all exposure sources are present (City of Eureka 2015).

2.7.3.1.2 Safety of Construction of Public Schools

According to the 'Definition' Section of the 2013 California Building Codes, the project at Zane Middle School is a retrofit, which is defined as "the construction of any new element or system, or alteration of any existing element or system required for the rehabilitation of the building" (California Building Codes 2013). The project is further categorized under section 4-308 as a "Reconstruction or alterations project not in excess of $25,000 in cost" (California Building

Codes 2013). This budgetary limit does not include the cost of work classified as maintenance. Categorized as such, this project does not require approval from the Division of the State Architect. Should the school board authorize and implement the design and construction of the project, the school board "assumes responsibility for employing an architect or a registered engineer to prepare the plans and specifications and for adequate inspection of the materials and work of construction to ensure compliance with the currently effective provisions of Title 24, C.C.R." (California Building Codes 2013).

2.7.3.1.3 Roof Assemblies and Rooftop Structures

According to Section 1503.4 of the California Building Codes, locations with roof drainage systems are required to have secondary roof drains or scuppers to ensure that water will not buildup in the event that the primary drains fail (California Building Codes 2013). The quantity, size, location and elevation of scuppers should be designed to prevent water buildup reaching a level exceeding the maximum load determined for the roof. Any gutters placed on the outside of the building should be constructed with "noncombustible material or a minimum of Schedule 40 plastic pipe" (California Building Codes 2013).

2.7.3.2 Plumbing Code

Due to the nature of the problem, all designs must be implementable within California Plumbing Codes. The standards that must be met can be categorized as general plumbing codes and those specifically related to storm drainage systems. All codes referenced come from the 2013 Edition of the California Plumbing Codes.

2.7.3.2.1 General

The project at Zane Middle School will rely upon an alternative engineered design. This design should still provide an equivalent level of quality, strength, effectiveness, fire resistance, durability, and safety as the plumbing code describes. All materials and components that are designed and installed must be utilized in accordance with the instructions from the manufacturer (California Plumbing Codes 2013). A registered professional engineer must indicate on the design documents that the system, including the parts, is an alternative engineered design so construction permits will indicate that it has been approved as such (California Plumbing Codes 2013).

2.7.3.2.2 Storm Drainage

Areas having rainwater are required to drain into a designated storm sewer system or, should one not be available, into a combined sewer system (California Plumbing Codes 2013). Rainwater may also be disposed of in an alternative location provided it is deemed satisfactory by the organization, office or individual responsible for enforcing the requirements of the California Plumbing Codes. Under no circumstances should storm water be drained into sewers utilized in sanitary drainage. When the area in question is a roof, the location and sizing of drains and gutters should be complimentary with the structural design and pitch of the roof (California Plumbing Codes 2013). These drainages shall be designed to be fully functional during an hour-long storm with 100 year returns. The rates given for Eureka, California are a maximum of 1.5 inches per hour, or 0.016 gallons per minute per square foot (California Plumbing Codes 2013). Scuppers, if used for secondary drainage, must be at least 4 inches in height and a width equal to the circumference of the storm drain required for the area (California Plumbing Codes 2013). The roof is also required to have a secondary drain system located at least 2 inches above the roof surface. The maximum height of this secondary system shall be designed to be of a height that would prevent excessive ponding of water on the roof. This secondary system of drains shall connect to either the combined sewer system or to its own separate piping system (California Plumbing Code 2013).

2.7.4 Drainage Designs

2.7.4.1 Introduction

In this section you will find various descriptions of different roof water runoff management systems. The systems being detailed are conventional, siphonic, and green. Each system manages rainwater run off in a different manner. Maintenance and solutions to overflow will also be included.

2.7.4.2 Conventional

Conventional roof drainage systems are comprised of three components: gutters, outlets, and rain water pipes. Conventional systems rely on sufficient flow capacities of both the gutters and the outlets, in order to move water away from certain areas to a point where it can be discharged. Aside from blockage, improper design of outlets is one of the most common reasons for flooding. Consideration of maintenance needs often results in large enough channels, but too few, or not large enough drainage pipes. Undersized drains result in overflow (R.W.P May, 1997).

2.7.4.3 Siphonic

Siphonic roof drainage systems utilize gravity and an air purging system to create a negative pressure within the drainage system, resulting in “full-bore,” meaning with maximum speed, draining (S Arthur, GB Wright, 2005). Siphonic systems rely on foolproof designs and are largely dependent on initial design specifications. Siphonic systems have specific working conditions, which must be designed into the roof system in which they are placed. Rainfall intensity, effectiveness of sealed outlets (so as to prevent air from entering the system), priming time, and integration with existing designs are all deterrents of siphonic drainage systems (R.W.P. May, 1997). As a result of these complications siphonic systems are often overly complicated and do not work in many applications and may require more maintenance than that of a traditional system (S Arthur GB Wright, 2005).

2.7.4.4 Green

Green roofs are becoming increasingly widespread, and are more often used in European countries (Baron, 2006). Green roof designs allow for most of the water to be captured by the roof of a building and utilized. Roofs utilizing such a design do not require primary runoff systems. Falling rainwater soaks into a membrane, which is then used by plants for evapotranspiration. This effect of evapotranspiration helps cool both the roof and building below. The protective layering that these plants provide help lengthening the life of the roofing material by creating a plant cover. Manufactured substrate is utilized to optimize the weight of the green roof and plant health. Weight is often a concern for green roofs and technology is being developed to create substrates with lower densities to limit the weight. When properly designed, green roofs have the potential to create a system with no runoff (Compton, 2006). The high initial cost is what often deters a green roof drainage management system from being implemented (Baron, 2006).

2.7.5 Maintenance

2.7.5.1 Conventional

Drainage systems often do not receive the maintenance necessary to up keep proper function. Failure to upkeep maintenance often results in flooding and damage to existing systems. Conventional gutter systems utilize an open top which allows for leaves and other organic materials to travel into the system. Due to this, conventional gutter systems often need to be cleaned annually and sometimes more often. Maintenance of conventional systems can be costly, as it requires several man-hours to clean a large-scale system (Wiliey, 2002).

2.7.5.2 Siphonic

Siphonic systems typically utilize smaller inlets and outlets. As a result these systems require an active maintenance plan. If neglected these systems often fail, resulting in overflow run off and damage to the system. An example given by Scott Arthur states that a symphonic system in use at Thomson Thomas house has a high maintenance cost as a result of gulls roosting on the rooftop. The guano, feathers, and bodies of these birds get caught in the system, fouling it up (S Arthur, 2004).

2.7.5.3 Green

Green roofs require extensive maintenance to ensure that they both survive and thrive. More often than not the water provided by rainfall is not enough to support the plants of a green roof system. In order for the roof to be effective it is important that the plants that make up this roof be healthy. Currently there are no known herbicides or insecticides that are recognized as safe for the underlying membrane. As a result weeds can often be detrimental to the ecosystem of the green roof. An ignored patch of weeds can readily ruin a membrane (Curtland 2013). It is also noted that it can be necessary to fertilize the roof even well after it has been put in place (Griswold 2010).

2.7.6 Solutions to Overflow

2.7.6.1 Gutter Head

In many circumstances overflow of a gutter is due to improperly sized drainpipes. Gutter heads fix this issue by allowing draining water to be stored before being drained down the drainage pipe. By installing a properly designed drainage box, a gutter head with an internal funnel can utilize a down pipe of any size (Stephenson 1981).

2.7.6.2 Gutter Guard

Another method of preventing gutters from clogging is the use of gutter guards. Gutter guards utilize screens that filter debris like leaves and pine needles out of drainage systems. Gutter guards are easy to install. Gutter guards typically snap into place and are mostly effective. This solution is ideal if blockage is preventing a gutter system from draining. Various manufactures produce gutter guards of similar design (Consumer Reports 2010).

2.8 Construction

2.8.1 Piping Materials

The purpose of piping in the Zane middle school project is to transport water from the gutter to the drains effectively without creating waterfalls over the side. For water transportation there are many effective materials when considering cost and ease of use as factors.

2.8.1.1 Chromed copper/copper piping

Chromed copper piping is usually used in diameters of 3/8 inch or less. Its bright shiny finish makes it good for being exposed outside, being aesthetically pleasing to the eyes. Another positive aspect of copper is that it is easily recyclable and because of its high resale value it doesn't end up in the landfill. Copper is commonly used as a building material because of its flexibility and resistance to corrosion.

2.8.1.2 Chlorinated polyvinyl chloride (CPVC)

CPVC is very easy to work with because of the many parts that exist for use with it and the variety of possible joint connections. It would be easy to maneuver around so that the water can be transported to where it needs to go. Methods for cutting CPVC include using a hack saw or tubing cutter. The CPVC pipe is commonly used because of its resistance to hot water. CPVC also is great for handling the pressure that occurs from the water flowing through the pipe.

2.8.2 Welding

There are four main types of welding: oxy-acetylene, arc welding, Metal Inert Gas (MIG) welding and tungsten inert gas welding (TIG). TIG will not be looked at in this document because it is used to weld aluminum and other more delicate types of metals (Cooper, 2014).

2.8.2.1 Oxy-Acetylene Welding

Oxy-Acetylene welding requires the use of oxygen gas mixed with a gas comprised of acetone. The resulting mixture produces an incredibly hot flame that melts metal into a puddle that is then maneuvered to join two pieces of metal. While moving the puddle a rod of metal filler is dipped into it to add strength and material to form strong welds. This form of welding is more difficult when working with larger pieces of steel and is more often used for cutting through thick metal (Cooper, 2014).

2.8.2.2 Arc Welding

Arc welding is commonly found in industrial applications because of the strong bonds that can be created. Arc takes advantage of the electrical current flowing through the metal that is being welded. The piece being welded has a clamp supplying electricity and the welder uses another clamp, with opposite electrical flow, to hold a rod of ceramic coated steel that is charged. The advantage of arc welding is that you can switch the settings of the rod output to DC positive or negative and also to AC. Changing the current type switches the flow of electricity producing different weld types. Another advantage of Arc is that it is portable because it requires no gas for shielding the welds from the outside air. All the shielding gas is produced from the arc and the ceramic coating being heated (Cooper, 2014).

2.8.2.3 Metal Inert Gas (MIG) Welding

The welder uses a gun that feeds wire with electrical current to bond the two individual metals together. This is most commonly used on cars and in TV shows because of ease of use. A disadvantage is that MIG requires a shielding gas to protect the welds and transporting a gas cylinder is very hard. Therefore it is restricted to welding shops (Cooper, 2014).

2.9 Properties of Water

This section provides pertinent information regarding the properties of water. Topics included are water density, useful unit conversions related to water, water pressure, and water adhesion.

2.9.1 Water Density

Water density is variable to its conditions; at different temperatures water exhibits less weight (USGS, 2014).

Table 2: Water Density at Varied Temperatures

Temperature	Density	Weight	
°F/°C	grams/cm^3	pounds/ft^3	kilograms/liter
32°/0°	0.99987	62.416	0.999808
39.2°/4.0°	1	62.424	1
40°/4.4°	0.99999	62.423	0.999921
50°/10°	0.99975	62.408	0.999681
60°/15.6°	0.99907	62.366	0.999007
70°/21°	0.99802	62.3	0.99795
80°/26.7°	0.99669	62.217	0.996621
90°/32.2°	0.9951	62.118	0.995035
100°/37.8°	0.99318	61.998	0.993112
120°/48.9°	0.9887	61.719	0.988644
140°/60°	0.98338	61.386	0.983309
160°/71.1°	0.97729	61.006	0.977223
180°/82.2°	0.97056	60.586	0.970495
200°/93.3°	0.96333	60.135	0.96327
212°/100°	0.95865	59.843	0.958593

2.9.2 Conversions

Table 4 in Appendix C contains equivalent measurements of water in units of area, mass, volume, density, pressure, and flow rate. When looking at construction materials or evaluating how the project will perform under varying conditions, these conversions will be used to take proper measurements and perform calculations.

2.9.3 Pressure

An important aspect of the project is the transportation of water. Water exerts various forces where it flows like pressure and weight. The pressure of water relevant to this project is the pressure of the water through the downspout. This can be calculated with the equation $Pressure = \frac{Force}{Area}$ (Meriam, J., and Kraige, L. 2007). Due to the nature of the current system at Zane Middle School, which will be explained in section 2.10.2.4 of this document, the water pressure may not be adequate to move water through the system. This is why an understanding of the water pressure is important to the project.

2.9.4 Adhesion

A water molecule is polar due to its oppositely charged hydrogen and oxygen elements. Hydrogen atoms in the water molecule form a slight positive charge while the oxygen has a slight negative charge making the molecule exhibit dipolar properties, so it has positive and negatively charged poles. Due to this polarity of charges, water forms slight bonds between water molecules, called cohesion, and between other charged molecules, called adhesion (Perlman n.d.).

2.10 Site Conditions

This section covers topics regarding the project site conditions. Topics included are climate data for the site, land surveying information and methodology, as well as a site description.

2.10.1 Climate

The yearly average rainfall for Eureka, California is 60.196 inches based on data collected from the years 1900 thru 2009 (Western Regional Climate Center). Ninety percent of the yearly rainfall in Eureka occurs during the months October through April (National Weather Service 2014). The month where the most precipitation falls is December, with an average of 8.12 inches of rainfall (National Weather Service n.d.). As of 2014, the National Oceanic and Atmospheric Association (NOAA) reported a maximum amount of rainfall of 6.79 inches occurring in one calendar day on December 27, 2002 (National Weather Service 2014). The maximum amount of rainfall in one hour was 1.20 inches, falling on October 29, 1950 (Puffer 1998).

2.10.2 Surveying

This section provides a general explanation of what land surveying is used for. Following this, it details a couple of the more common methods of land surveying. The last section provides a general project site description.

2.10.2.1 General
Surveying land and structures is the method of modeling and mapping points using data collected on the site. This information includes elevation, distances, heights, lengths, and relative positions of points in a given area using various tools. This allows for the collection of the data necessary to model and map a location that may have structures or other formations (Brinker and Minnick 1995). Tools most frequently used to survey an area include a Theodolite, a Real Time Kinematic device (RTK), or a Total Station, to measure angles, distances, and relative elevations between points which can be compiled to form a topographic layout of an area (Brinker and Minnick 1995). All of these devices are mounted on leveled tripods to ensure stability therefore increasing accuracy (Brinker and Minnick 1995).

2.10.2.2 Theodolite
A Theodolite is a surveying device used to measure directions and distances between relative points. This tool is used in tandem with a traditional Theodolite as a reference ruler. The theodolite is held perpendicular to the ground by an assistant while another person reads the measurements from the theodolite to the ruler (Brinker and Minnick 1995). These measurements are then used to calculate distances and elevations (Arrowsmith n.d.). Various Theodolite device variations exist including a traditional Theodolite, a Total Station and a Real Time Kinematic device (RTK) (Engineering.purdue.edu n.d.). A Total Station does not necessitate the use of a reference ruler for taking measurements (Arrowsmith n.d.). An RTK uses a rover station which is used in conjunction with a movable reference receiver which sends data and corrections to the rover and creates data with increased precision over traditional methods (Wanninger 2008).

2.10.2.3 3-Dimensional (3D) Scanning with Drones
3-D scanning generates a data cloud and image of an area that includes data for elevation of the ground surface, global position (GPS) and images of the area scanned (Service-drone.com n.d.). By creating such an image and developing many data points to form a data cloud of many of the individual points, elevation profiles of an area can be documented and compiled with software to generate a 3D model of the area (Neitzel and Klonowski 2011). 3-D scanning can be done using small unmanned aerial vehicles (UAVs), sometimes referred to as drones. Images taken by the UAV are used in conjunction with a data cloud made up of specifically positioned points about the area surveyed and GPS to create an elevation profile that can be accurate up to 6 millimeters (Service Drone n.d.). From this data a 3-D image can be compiled with software (Service Drone n.d.).

2.10.2.4 Site Survey and Description
Ahron Cervania visited the project site in February 2015. The area of the design project at Zane Middle School includes an awning that is attached to two separate buildings and forms an awning with two sides, and another awning directly across from these which forms 3 sides of a square. The northernmost awning has a length of 95 feet and a width of 18 feet. The awning

that is attached to the northernmost one and covers the eastern portion of the structure is 60 feet long and 18 feet wide. The southernmost awning is 80 feet long and 8 feet wide. Encompassed by these structures is a courtyard frequented by students and faculty. The roof that encompasses the courtyard has a short lip which encloses the whole roof. To allow water to flow off this roof 6 spouts are located along the roof creating paths for water to cross the lip. These spouts point toward the concrete courtyard. Spouts are connected to gutters which are bypassed by small rectangular openings on the end of the spouts that face the courtyard. The gutters which also serve as the supports for these awnings are directed to a central drain system under the school which diverts the water to city storm drains. 40 feet to the east of the northernmost awning is a storm drain which lies at a low point within the relative area.

3 Search for Alternative Solutions

3.1 Introduction

This section provides the methods used to develop alternative solutions to the problem at Zane Middle School. Following this, each of the alternative designs developed is detailed with a description and a visual aid.

3.2 Brainstorming

Brainstorming sessions were led to develop the following eight alternative designs. The notes of these brainstorm sessions are included in Appendix B. The first brainstorming session was held on March 5, 2015 in the Dennis K. Walker Greenhouse. During this session, all ideas for potential design solutions were listed. The second brainstorming session was held March 8, 2015 in Room 13 of the Science D Building. The purpose of the second brainstorm session was to narrow down the list of ideas through the synthesis or dismissal of ideas. From these brainstorming sessions, the final set of alternatives to be considered was generated.

3.3 Alternative Solutions

The following alternative solutions are the result of the brainstorming sessions. Each potential design has been given a title, as well as a written description of the design and its features. Each design is accompanied by a diagram to provide a visual aid. These solutions will be rated based on each of the project criteria and the weight of the criteria, the final design will be chosen. The list of alternative solutions to be considered are the following:

1. ExoSpout
2. The Gutter Gutter
3. Streamline
4. H_2Out of the Quad
5. Head On The Gutter
6. Gutter Guard
7. Roof Reduction

8. Touched By An Angle

3.3.1 ExoSpout

The ExoSpout is an addition to the current roof drainage system. The ExoSpout increases the drainage speed of the current system, preventing the overflow into the Quad area. The addition consists of an external downspout connecting the roof gutter to the storm drain. This connection to the storm drain will be made at the storm drain access point used for maintenance. Entry to the storm drain for cleaning is possible through the access door located at the base of the external downspout. The mesh cover inside the external downspout expedites the cleaning process.

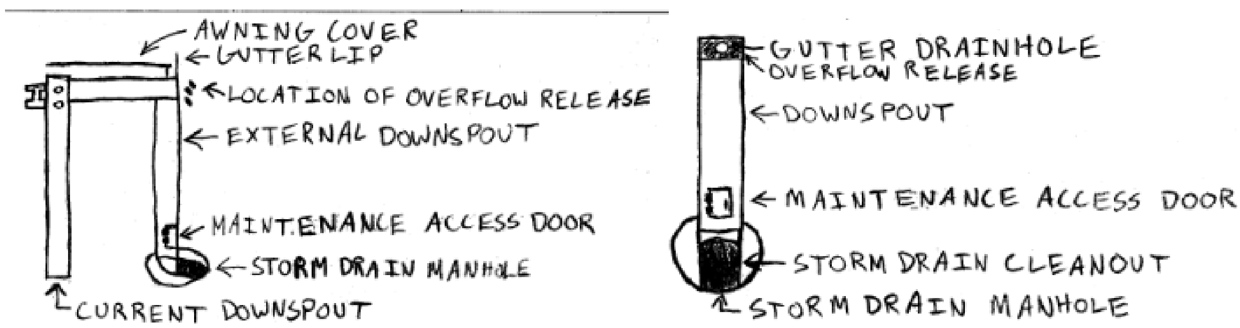


Figure 2: The ExoSpout design consists of an additional downspout added to the roof drainage system at Zane Middle School. The ExoSpout connects the gutter drain directly to the municipal storm drain via a manhole located at the base of the downspout. Drawing by Ahron Cervania.

3.3.2 The Gutter Gutter

The Gutter Gutter is a tool that simplifies the cleaning process for the roof drainage system at Zane Middle School. The current design for the gutters and downspouts is difficult for the school maintenance staff to clean. The build-up of debris blocks the drains and necessitated the creation of a water outlet into the Quad area of the school. The Gutter Gutter is in essence a digging tool, made to the specifications of the gutter, which the maintenance staff had had difficulty in purchasing.

3.3.3 Streamline

The Streamline attaches to both the horizontal support directly below the gutter drain and to the vertical drain pipe. The box is the same width as the beams of the awning that it attaches to. The Streamline creates an angled channel through the gutter box, allowing for the water to flow through. This angled channel will increase the rate of drainage from the roof to the vertical drain pipe. The gutter box is built with six pieces of welded sheet metal and affixed using bolts to the horizontal and vertical supports of the awning. Rainwater from the gutter flows into the gutter box through the existing hole in the gutter into the drainpipe and then through a similarly sized outlet hole into the gutter box. The gutter box fits like a wedge between the vertical and horizontal supports of the awning creating an angled, hollow section between the two. The box rests flush with the supports and creates no suspended bars or corners. The shape of the gutter box will be a triangular wedge. The box increases the angle and speed the flow of water from the hole in the gutter to the vertical downspout connected to the main drain. Creating a greater angle for water to flow, will rapidly move water from the gutter to the drain. Incorporated in this design will be a mesh drain cover over the top of the hole that connects the gutter box to the horizontal support.

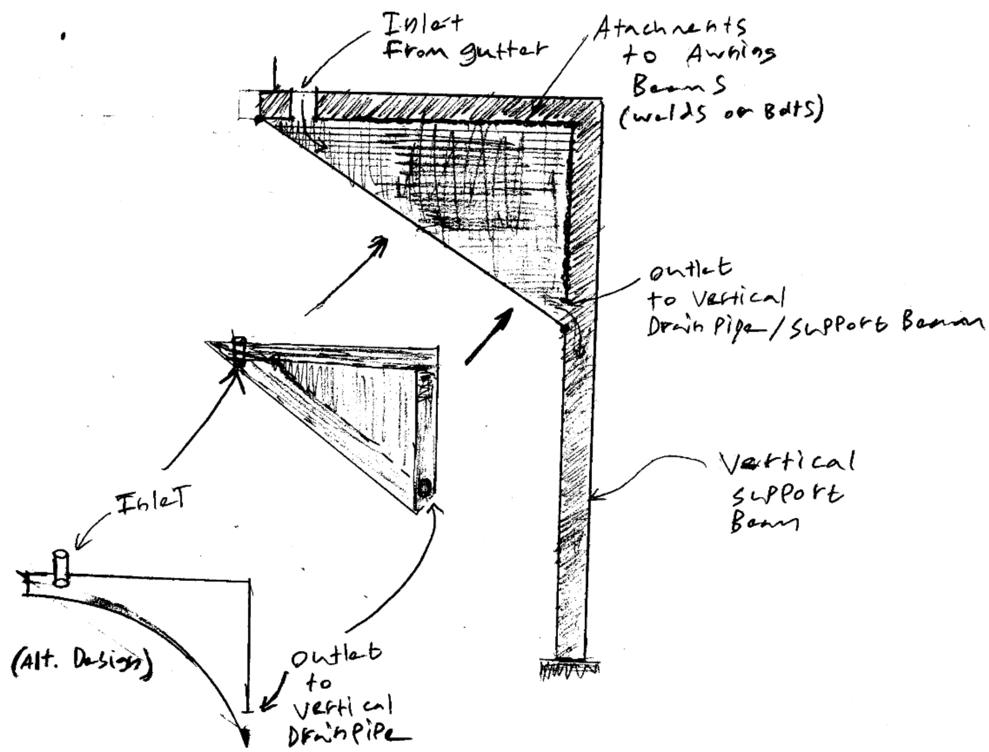


Figure 3: The Streamline will increase the angle of flow of rainwater from the gutter to the vertical drain pipe and act as an alternative reservoir. Drawing by Abraham Aufdermauer

3.3.4 H_2Out of the Quad

A diversion of water from the roof to the drain behind the buildings requires an external drainage pipe fitted to the gutter. The pipe runs from the edge of the roof nearest to the drain. The path of the pipe goes alongside the building at an angle. This angle creates an adequate flow rate to move the water over the distance from the building to the drain. The pipe runs parallel from the building to the drain, either as a buried pipe or above ground. Multiple pieces of piping make up this drain system with points of attachment connecting the piping to the wall and awning.

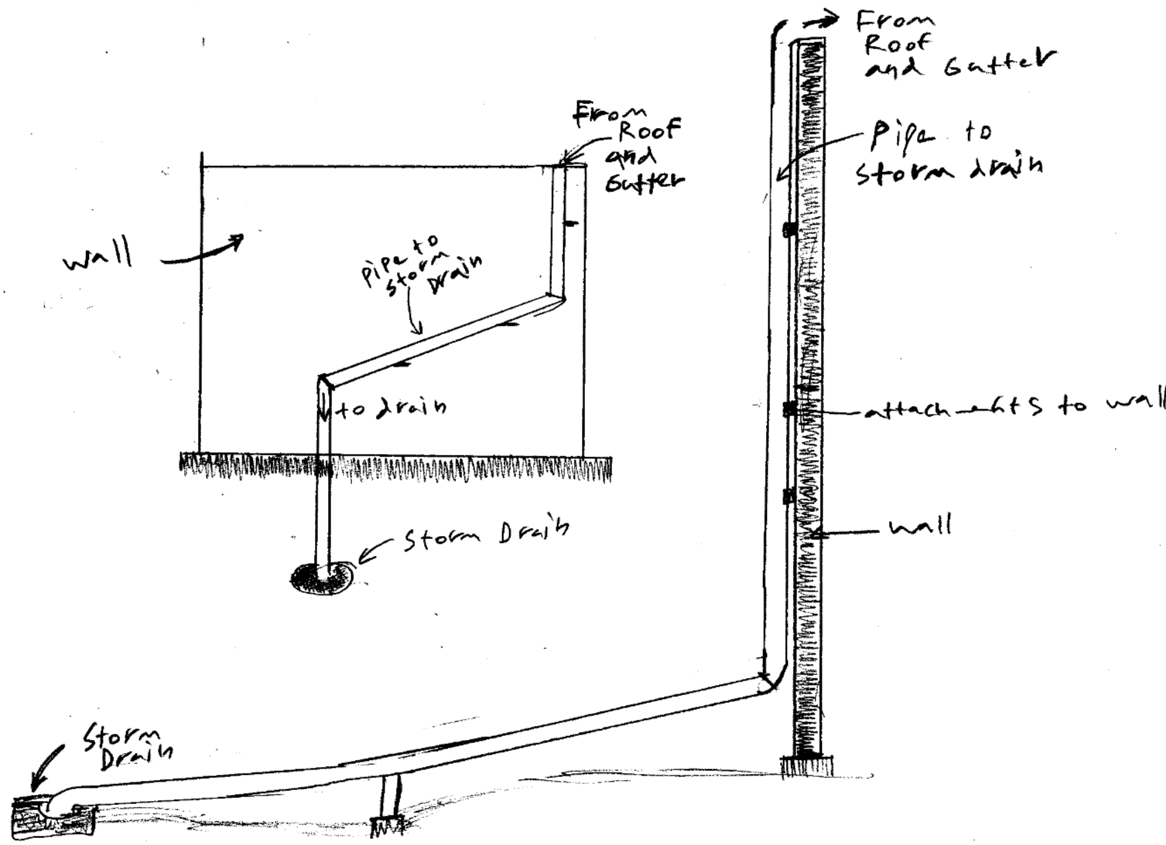


Figure 4: The H2Out of the Quad design. An external drain pipe moves water from the awning away from the courtyard and instead directly to the main storm drain. Drawing by Abraham Aufdermauer.

3.3.5 Head on the Gutter

The Head on the Gutter is a simple design that is designed to integrate into the existing system with as little modification as possible to the existing down spout. In Figure 5 below several features are labeled. These mounts ensure the rigidity of the system. The gutter heads extra volume provides an area in the gutter system for more water to be stored before draining. Higher volume results in higher pressures, the added volume adds a new level of pressure into the downspouts ensuring that all water will be drained. Within the gutter head lays a screen, the screen just before the downspout prevents debris from ever entering the downspout. In addition, the added volume gives considerable thought to maintenance staff. The protrusion from the current gutter system gives the maintenance staff more room to get into the system in order to clear the screen of debris. An overflow hole of approximately 2 inches in diameter ensures that water will not become trapped within the system, which can become a danger in itself.

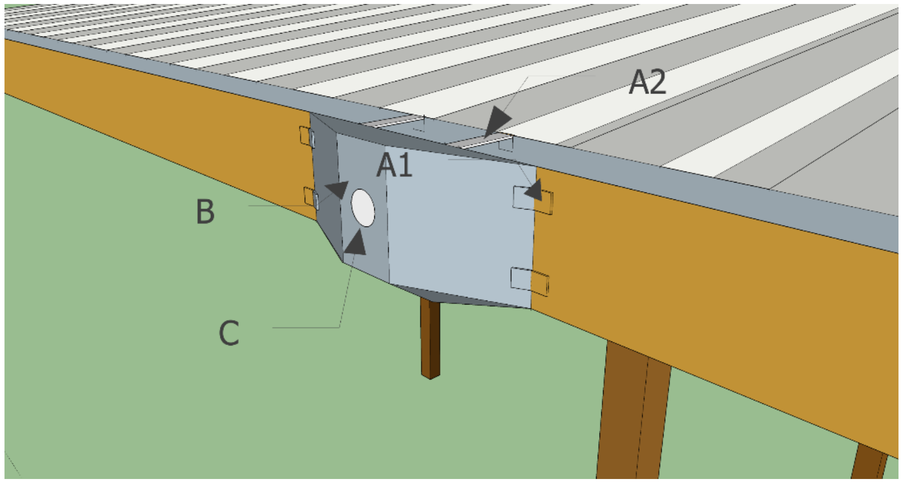


Figure 5: A diagram of the Head on the Gutter. B marks the gutter head itself, markers A1 and A2 mark the fixtures holding this system up, and marker C points out the overflow hole. Drafted by Zachary Ramsey.

3.3.6 Gutter Guard

The gutter guard features a screen the lays across the entire length of the system. The screens prevent any debris from entering the system. Instead debris will simply wash over the top onto the ground below. Figure 6 below shows the Gutter Guard, which is essentially a metal screen. The end cap of the Gutter Guard prevents water from flowing out of the system. The Gutter Guard cuts maintenance to a minimum.

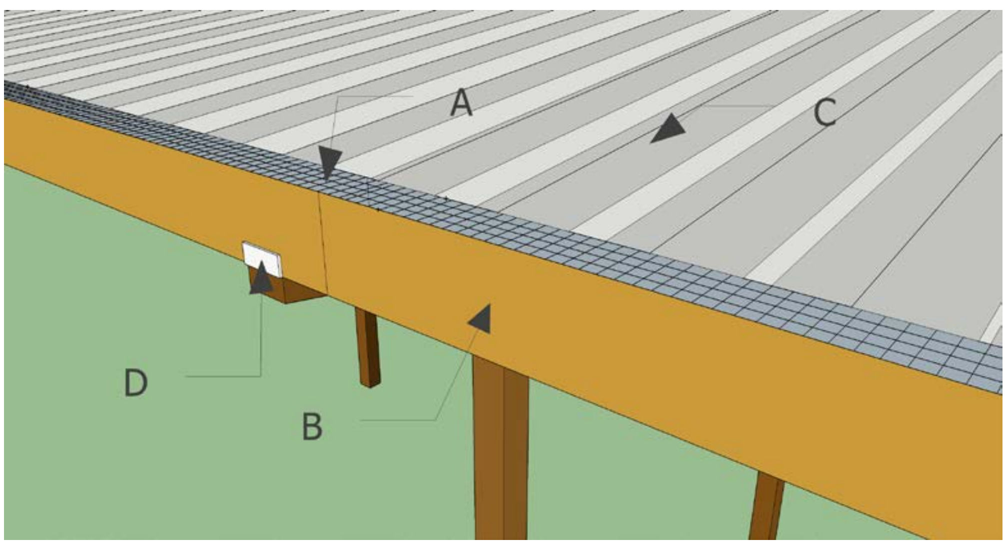


Figure 6: The Head on the Gutter design. ***A*** *marks the gutter guards themselves.* ***B*** *marks the existing gutter system.* ***C*** *marks the existing awning, and D marks the necessary end cap. Drafted by Zachary Ramsey.*

3.3.7 Roof Reduction

The Roof Reduction creates a more accessible drainage system for cleaning by removing excess sheet metal abutting the gutter. The roof has ridges or channels so the water can run across the roof and into the gutter. Water flowing from the roof deposits debris that clogs the drains causing backups. The debris remains in the gutters as they are difficult to access due to the overhanging sheet metal of the roof. By cutting the sheet metal back only a few inches, maintenance would be able to clean the gutter out so that the water does not back up and run out of the gutters, bypassing the clogged drains. Trimming of this overhanging sheet metal is done using metal shears or power tools.

Figure 7: On the right of the figure between the grey metal and the silver sheet metal roofing, is the inaccessible gutter. The silver metal in the picture will be cut in order to increase access to the gutter. Picture by Ahron Cervania.

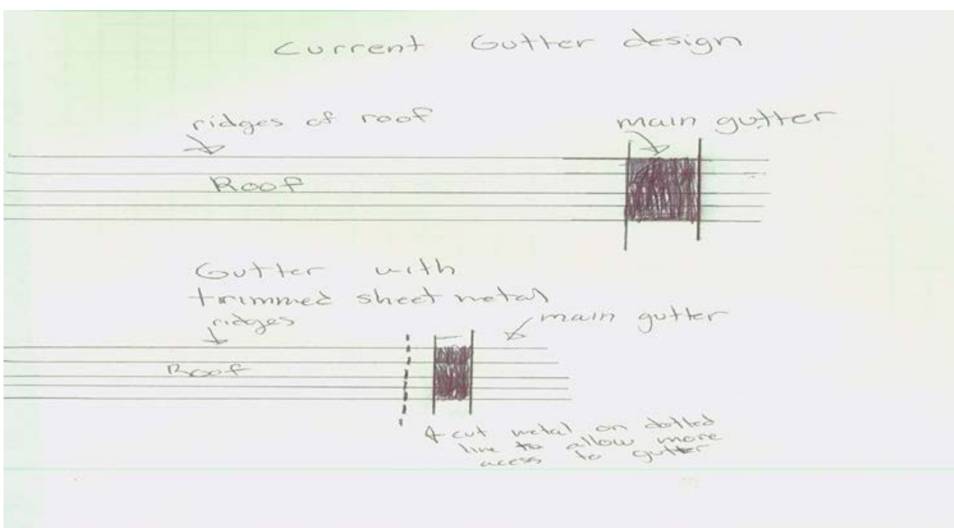


Figure 8: This figure shows the proposed cuts that will be made to open more access to the gutter for easier cleaning. Drawing by Jake Cooper.

3.3.8 Touched by an Angle

Rainwater flowing from the roof to the main gutter system deposits debris into the gutter system shown between the silver roof paneling and the grey exterior edge in Figure 9. This debris creates a backup of water that cannot be dealt with because the main gutter is inaccessible. Changing the angle of the exterior gutter wall from 90 degrees to 135 degrees by bending the metal outwards, would allow someone with either their hands or a tool to reach into the gutter to effectively clean it. This alternative solution does not require the removal of any material, and would allow greater access to the gutter for maintenance.

Figure 9: The picture shows one section of the awning roof and the gutter along the edge farthest from the wall of the adjacent building. It can be seen from the photo that the gutter opening is narrow. Picture taken by Ahron Cervania.

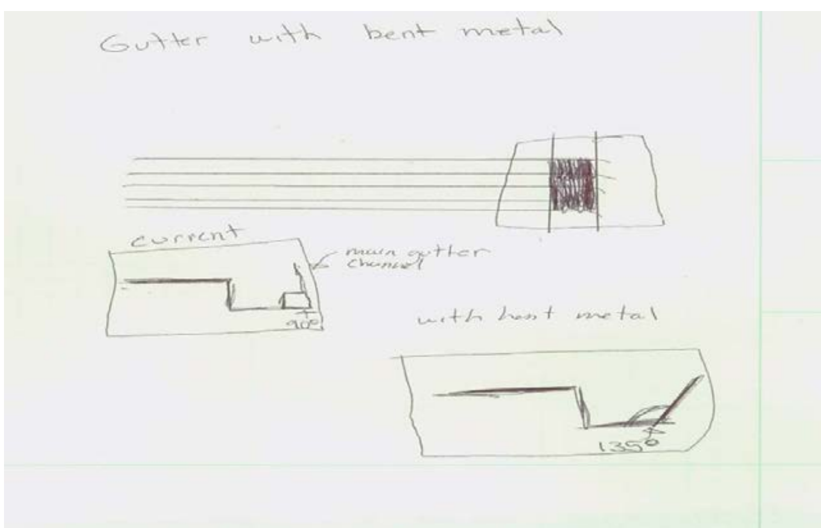


Figure 10: The gutter would be more accessible if the edge of the gutter was bent to an angle greater than the current 90 degrees. Drawing by Jake Cooper.

4 Decision Phase

4.1 Introduction

Through the decision process outlined in Section 4 a design was decided upon that meets both the needs of the client and follows the design criteria. The process utilizes a Delphi Matrix to evaluate which of the alternative solutions presented in Section 3 provides the best solution to the Problem Statement. The criteria used in the Delphi Matrix to decide on a final design are described in section 4. Also discussed and included in this section are the alternative design solutions, the decision process, and a discussion of the final design.

4.2 Criteria

Criteria are the standards used to determine which one of the alternative designs will be presented to the client. The definitions of each of the criteria as they apply to the designs are as follows:

Efficacy – The design increases the speed of drainage of the water from the roof as well as reduce the amount of water backing up on the roof and in the gutter due to inadequate flow to the downspouts.

Implementable – The design will be installed using the preexisting structure and makes the least amount of changes to the original structure.

Maintainability – The design is easily accessible and maintainable by the school's staff.

Durability – The structure is resistant to corrosion due to the amount of rain that flows through the system. Once in place the project must stay secure until deliberately removed.

Safety – The design cannot be anything that children can hurt themselves on. This means the design has no sharp edges and must also have no ledges that someone can hang from.

Aesthetics – The project blends in with the original drainage design and have a professional appearance.

Cost – Minimize cost through optimization of materials used.

4.3 Solutions

Section 3 provides details on the following alternative solutions, which are judged by the decision process described. The alternative solutions are:

- ExoSpout
- The Gutter Gutter
- Roof Reduction
- Touched By An Angle
- Streamline

- H2Out of the Quad
- Gutter Guard
- Head on the Gutter

4.4 Decision Process

Through the decision process a design is decided upon. To decide on a final design solution that will be presented to the client a Delphi Matrix is used. The Delphi Matrix in Figure 11 includes the weighted criteria, on a scale from 1-10 with 10 being the most important, and individual scores for each alternative design based on how well they adhere to each criterion. These individual scores are multiplied by the weight of the criteria to create weighted scores for each alternate design. For each alternate design the individual scores based on each criterion will be summed for a final score. The individual scores, based on the weighted criteria will be summed and the design with the highest cumulative score will be chosen as the solution to be proposed to the client who will be included in the final decision.

Criteria		Solutions							
List	Weight	Exospout	The Gutter Gutter	Roof Reduction	Touched By An Angle	Streamline	H_2Out of the Quad	Gutter Guard	Head on the Gutter
Efficacy	10	36 / **360**	26 / **260**	9 / **90**	11 / **110**	46 / **460**	48 / **480**	26 / **260**	19 / **190**
Implementable	9	30 / **270**	43 / **387**	37 / **333**	19 / **171**	47 / **423**	23 / **207**	48 / **432**	42 / **378**
Maintainability	8	26 / **208**	50 / **400**	50 / **400**	50 / **400**	33 / **264**	16 / **128**	47 / **376**	30 / **240**
Durability	7	23 / **161**	34 / **238**	50 / **350**	32 / **224**	30 / **210**	18 / **126**	16 / **112**	34 / **238**
Safety	7	17 / **119**	41 / **287**	25 / **175**	26 / **182**	40 / **280**	27 / **189**	50 / **350**	44 / **308**
Aesthetics	6	14 / **84**	27 / **162**	30 / **180**	27 / **162**	47 / **282**	7 / **42**	46 / **276**	23 / **138**
Cost	4	23 / **92**	34 / **136**	43 / **172**	50 / **200**	45 / **180**	15 / **60**	48 / **192**	45 / **180**
Totals:		**1294**	**1870**	**1700**	**1449**	**2099**	**1232**	**1998**	**1672**

Figure 11: Delphi Matrix of Alternative Solutions.

4.5 Final Decision

The Delphi Matrix concluded that the Streamline design is the best solution. The Streamline design scores high in the criteria for efficacy, implementability, safety and aesthetics. The Streamline is easily implemented due to its integration with the existing structure. By removing the waterfalls and increasing the flowrate of the rainwater from the gutter into the downspout, the Streamline solves the problems with the existing system in the most effective manner. The aesthetics of the Streamline as an integrated system that blends into the existing awning structure make it an effective solution. The implementation of the design would also be relatively low-cost for the school, and could potentially be completed with community donations and recycled materials.

5 Specification of Solution

5.1 Introduction

This specification section includes the specifications of the final design solution, the Streamline integrated gutter box. Section 5 will address the various components of the Streamline and include details on how it functions with the existing awning system. Included in this section is a breakdown of the hours spent both designing and building the Streamline gutter box. A list of materials used and their individual and total costs also is shown in this section. The cost section also includes the projected maintenance hours. Last is a description of how to implement the Streamline gutter box and the details of its performance gathered through testing.

Figure 12: Streamline integrated gutter box installed at Zane Middle School.

5.2 Streamline Description

The Streamline is an integrated, aluminum gutter box situated intermediary to the downspout and the main gutter of the awning at Zane Middle School. The external dimensions of the Streamline relative to the downspout and gutter are shown in Figure 13. The Streamline acts as a secondary reservoir for the drainage system, below the gutter, as well as a direct passage for water to travel to the downspout. From the gutter rainwater flows into the Streamline through a two inch diameter hole and out at the bottom of the box through a hole with a diameter of two inches into the downspout. The increased volume of water created in the Streamline as it fills increases the pressure at the outflow into the downspout increasing the drainage speed of the storm water system. The angled pitch of the Streamline downward at a significant grade insures water flows rapidly into the vertical downspout.

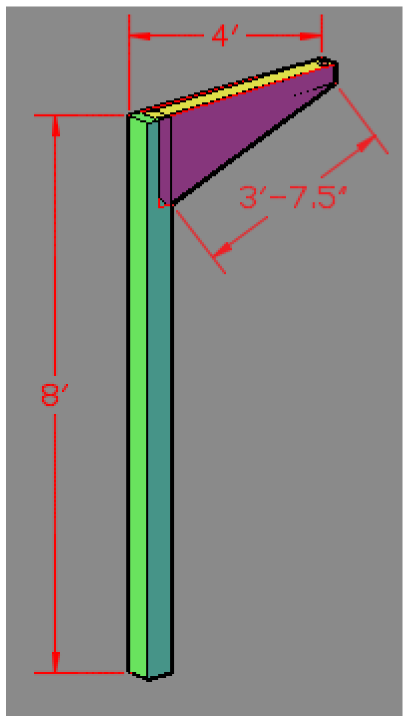


Figure 13: Major external dimensions of the Streamline. The yellow portion is the original gutter for the awning, and the green is the original downspout. The purple is the Streamline shown in position. CAD by Ahron Cervania.

5.2.1 Inlet

From the main gutter that lines the awning, rainwater flows into the Streamline gutter box through two, two inch diameter circular openings cut into either side of the horizontal drainage element below the gutter offset one inch from the edge. Rainwater bypasses the existing portion of the drainage system from the gutter, instead flowing into the Streamline gutter box.

5.2.2 Gutter Box

The Streamline gutter box consists of three sheets of aluminum upcycled from two four feet by four feet aluminum street signs. The aluminum signs were striped of paint and powder coated to match the preexisting structure's color as well as improve the Streamline's durability. Two triangular side pieces of the gutter box were cut from the signs to the dimensions specified. The two side pieces mount to the bottom rectangular panel by a series of bolts. In order for the gutter box to snuggly fit with the existing awning structure, the width of the rectangular component was tapered. The corners inside the gutter box are sealed with Vulkem polyurethane preventing leaking. The gutter box is attached to the existing downspout and horizontal connector below the gutter by 21 self-tapping screws where the box is sealed with Vulkem. The bottom bracket is mounted to the pillar by two bolts. All the screws and bolts used are easily removable, allowing maintenance of the gutter box. The gutter box is hollow, and if needed can act as a reservoir when water starts to back up. The increased volume of water being stored will result in three times the original downwards pressure on the water flowing from the Streamline gutter box into the downspout. Instead of a reservoir with a six inch depth there will now be an 18 inch depth of water adding pressure to the drainage flow into the downspout.

Figure 14: A sideview of the Streamline's gutterbox prior to installation. Photo by Ahron Cervania.

5.2.3 Outflow

The outflow portion of the new Streamline rainwater drainage system consists of the altered downspout of the original drainage system. The dimensions of the downspout are 4-inch x 4-

inch x 8-foot. To make the downspout compatible with the added Streamline gutter box, a 2-inch diameter hole was drilled into the downspout approximately 6 feet off the ground, where the lowest interior edge of the Streamline meets the downspout. This allows the rainwater to pass from the Streamline to the storm drains via the downspout.

5.3 Implementation and Use

Installation of the Streamline gutter box requires a sealant, self-tapping screws, machine screws, flat washers, nuts and a hole saw. First, the sides and base panel of the Streamline are joined together with machine screws, flat washers, and nuts. The interior seams where the triangular side panels meet the bottom, rectangular panel are sealed with a polyurethane sealant and allowed to dry. After the interior sealant has dried, the inflow and outflow holes must be created using the hole saw in appropriate positions for the system. Both outflow and inflow holes are 2 inches in diameter and are cut into the existing horizontal and vertical downspout section of the existing system. Polyurethane sealant should be applied to all seams between the Streamline and the current system. The Streamline should then be positioned carefully against the gutter and the downspout to ensure proper alignment. Hold the gutter box in place while self-tapping screws are used to attach the Streamline to the gutter and downspout. After all screws have been attached, the Streamline has been successfully installed. The utilization of the Streamline requires no action on the part of the client, as gravity provides all the necessary force for the work of the Streamline.

5.4 Cost Analysis

This section will provide a breakdown of the project's costs both in man-hours and currency.

5.5 Design Costs

The design cost is defined as the time spent by Team Livewire on each step of the design process. Design costs are presented in hours and includes the problem formulation, problem analysis, possible solutions, final decision, construction, and installation. Figure 15 is a detailed graphical representation of the time spent on the production of Streamline. Given detailed instructions, it is estimated thirty hours of labor would be required to reproduce Streamline.

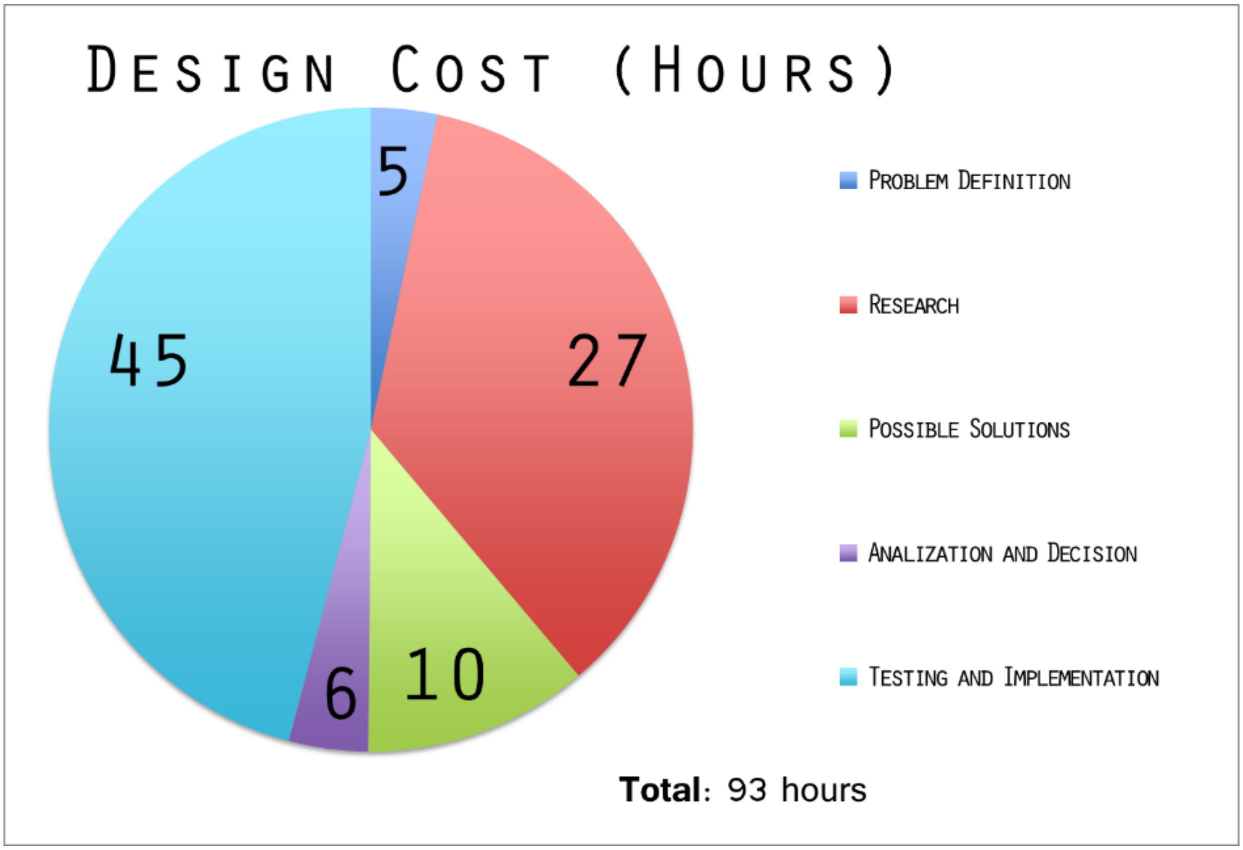


Figure 15: Design cost pie chart of design hours including individual categories and total.

5.5.1 Materials Cost

Materials costs encompass the dollar amount spent on the construction of Streamline. A couple companies donated most of the equipment required for the construction of the streamline. Special consideration is given to John Ramsey of J&W Powder coating, for supplying necessary equipment and donation of powder. Wade Ramsey of Sarmentos Fabrication for access to equipment and help in construction of necessary components of Streamline's design. Figure 16 below provides an itemized cost list for the project.

Item Name	Quantity	Unit Price ($)	Item Total ($)
#4 Screw	40	0.17	6.80
#4 Washer	40	0.19	7.60
#4 Nut	40	0.17	6.80
Screws	10	0.15	1.50
Screws	10	0.11	1.10
Screws	10	0.12	1.20
Aluminum Sign	2	Donation	52.50
Bronze Powder	16 ft^2	Donation	96.00
Screws	4	0.14	0.56
Tapping Screw	24	0.12	2.88
Vulkem 116	1	Donation	N/A
	Project Total		**$176.94**

Figure 16: Total cost of items used to build and install the Streamline.

5.5.2 Maintenance Cost

Streamline is designed with maintenance in mind, ensuring easy upkeep. Streamline allows for easy snaking of the gutter systems down pipe, which ensures that most debris will be easily cleaned from the system. In the unlikely scenario that a snake will not suffice, Streamline can easily be uninstalled allowing full access to the drainage way. Being a water system sufficient sealing is always of concern. Vulkem 116 is used to ensure a watertight fit. If a leak were to occur Vulkem might need to be reapplied to the system, in this event Streamline would need to be removed from the drainage system. Vulkem could then be applied to the interior of Streamline. Figure 17 below describes various scenarios and their estimated time of maintenance.

Leak	Approximately 3 hours to uninstall streamline form the gutter system, clean Streamline, and reapply Vulkem 116.
Clogged	Ideally a snake would be used before removing Streamline. If the snake were insufficient, approximately 2 hours would be needed to uninstall Streamline.

Figure 17: Description of possible maintenance needs and time necessary to complete each maintenance task.

5.6 Testing

The Streamline has undergone natural testing through a series of five storms since it was installed. The Streamline has performed well and as expected through all storms. Zane Middle School's administration has reported satisfaction with the success and efficacy of the Streamline. Formal testing has been undertaken which included timing the speed at which five gallons of water drained through the Streamline. The results of this testing are summarized in Table 3 below. It was found through the testing that on average the flow rate through the system was 1.34 liters per second. The volume of water used in the testing greatly exceeded the volume of rainwater that could flow through the Streamline during a maximum rainfall event. Based on the rainfall data for Eureka and the testing results, it was found that the Streamline is capable of accommodating large volumes of rainfall during extreme rainfall events.

Table 3: Results of Streamline Testing

RUN	TEST VOLUME	DRAIN TIME
1	19 Liters	40 Seconds
2	19 Liters	32 Seconds
3	19 Liters	22 Seconds
4	19 Liters	29 Seconds
5	19 Liters	24 Seconds

6 Appendices:

6.1 Appendix A. References

California Building Codes. (2013). International Code Council, Washington, D.C., 37,76,725.

California Plumbing Codes. (2013). International Codes Council, Washington, D.C., 43, 192, 364.

City of Eureka (2015). 'City of Eureka Website - Adopted Construction Codes/Design Guidelines'. <http://www.ci.eureka.ca.gov/depts/building/code.asp> (Feb. 20, 2015).

'Jan Schmidt Interview'. (2015). Zane Middle School

Meriam, J., and Kraige, L. (2007). Engineering mechanics. Wiley, Hoboken, NJ.

Arrowsmith, R. (n.d.) 'Total Station Document'. *Activetectonics.asu.edu*, <http://activetectonics.asu.edu/TotalStation/document.html> (Feb. 22, 2015)

Brinker, R., and Minnick, R. (1995). *The Surveying Handbook*, Chapman & Hall, New York.

Copper.org,. (n.d.). 'Copper Facts'. <http://www.copper.org/education/c-facts/facts-print.html> (Feb. 25, 2015).

Engineering.purdue.edu. (n.d.). 'Transits and Theodolites'. <https://engineering.purdue.edu/~asm215/topics/theodlit.html> (Feb. 18, 2015).

Neitzel, F., and Klonowski, J. (2011). 'Mobile 3D mapping with a low-cost UA V system'. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XXXVIII(1/C22), 1-6.

Perlman, H. (n.d.). 'Adhesion and Cohesion Water Properties, USGS Water Science School'. *Water.usgs.gov* <http://ww.service-dro, <http://water.usgs.gov/edu/adhesion.html> (Feb. 21, 2015).

Puffer, A. (1998). *Climate of Eureka, California*. NEXRAD Weather Service Office, Eureka.

Service Drone. (n.d.) 'Surveying and Geo-Mapping | MULTIROTOR by serice-drone.com'. ne.com/en/production/surveying> (Feb. 20, 2015).

Veera, S. (2015). 'Introduction to Home Plumbing Material'. Academia.edu, <http://www.academia.edu/4229542/Introduction_to_Home_Plumbing_Material> (Feb. 25, 2015).

Wanniger, L. (2008). 'Introduction to Network RTK'. <http://www.wasoft.de/e/iagwg451/intro/introduction.html> (Feb. 19, 2015).

Western Regional Climate Center. (n.d.). ‘California Climate Tracker’. <http://wrcc.dri.edu/monitor/cal-mon/frames_version.html> (Feb. 21, 2015).

National Weather Service (n.d.). ‘National Weather Service – NWS Eureka’. <http://www.wrh.noaa.gov/climate/monthdisp.php?p+temperature&stn=KEKA&mon=12&wfo=eka&year=2013> (Feb. 20, 2015)

National Weather Service (2014). ‘Eureka All Time Records’. <http://www.wrh.noaa.gov/eka/climate/records.php> (Feb. 23, 2015).

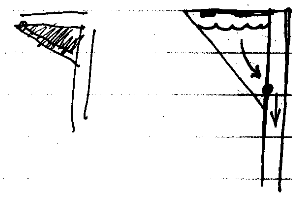
6.2 Appendix B. Brainstorm Session Notes

3/5/15

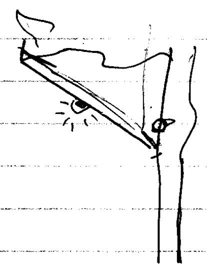
AHRON Carvania, Abe Aufdermauer, Jake Cooper

Brainstorming: Zack Ramsey.

- ~~Remove sheetmetal from edge~~
- Modify angle of downspout
- Gutterbox/head
- Adding railings and netting cleaning tool



- ~~Gutterguard nests~~
- Diverting water to storm drain
- adding downspout to gutter
- create new drains and connect to downspout
- triangular gutterbox connected to downspout



- ~~Cloud seeding~~
- ~~Giant umbrella~~
- ~~New awning → design~~
- gutter expansion
- external downspout
- Pipe down to cleanout w/ cleaning opening
- Modular design incorporated with many possible design solutions
- Logos incorporation
- Falcon gargoyles
- Integrate lighting, maybe solar powered into design

6.3 Appendix C: Tables

Table4: Water Related Conversions. Information cited from California Plumbing Codes 2013.

AREA			
Symbol	**When You Know**	**Multiply By**	**To Find**
ac	acre	43560	square feet
in^2	square inch	6.4516×10^{-4}	square meter
ft^2	square foot	0.09	square meter
yd^2	square yard	0.84	square meter
mi^2	square mile	2.59	square kilometer
MASS			
Symbol	**When You Know**	**Multiply By**	**To Find**
oz	ounce	28.35	gram
lb	pound	0.45	kilogram
VOLUME			
Symbol	**When You Know**	**Multiply By**	**To Find**
in^3	cubic inch	16.39	cubic meter
ft^3	cubic foot	0.03	cubic meter
yd^3	cubic yard	0.76	cubic meter
gal	gallon	3.78541×10^{-3}	cubic meter
DENSITY			
Symbol	**When You Know**	**Multiply By**	**To Find**
lbm/in^3	pound mass per cubic inch	2.7680×10^4	kilogram/cubic meter
lbm/ft^3	pound mass per cubic ft	1.6018x 10	kilogram/cubic meter
PRESSURE			
Symbol	**When You Know**	**Multiply By**	**To Find**
Pa (or N/m^2)	Pascals (or Newtons per square meter)	1.4503×10^{-4}	pounds per square inch
FLOW RATE			
Symbol	**When You Know**	**Multiply By**	**To Find**
gpm	gallon per minute	2.23 x 10-3	cubic feet per second
acre*in/hr	acre-inch per hour	1	cubic feet per second
acre*ft/hr	acre-foot per hour	12	cubic feet per second
m^3/s or cms	cubic meters per second	35.3	cubic feet per second