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Rainwater Catchment System At Walden West Outdoor Science School

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RAINWATER CATCHMENT SYSTEM AT WALDEN WEST OUTDOOR SCIENCE SCHOOL

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RAINWATER CATCHMENT SYSTEM AT WALDEN WEST OUTDOOR SCIENCE SCHOOL

By

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SENIOR DESIGN PROJECT REPORT

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Department of Civil Engineering
Santa Clara University, Spring 2014

ABSTRACT

Walden West Outdoor Science School is a science camp in the hills of Saratoga where children learn science as it relates to the environment and the importance of using sustainable practices. A full-scale bioswale was designed to capture and reuse the rainwater runoff from the main parking lot and lodge on the site. To encourage future implementation of the design as well as to provide a learning tool for future science camps, a model bioswale was built using materials required in actual bioswale construction. A synthetic water sample was developed to mimic the characteristics of rainwater runoff. The synthetic sample was applied to the model bioswale and water quality analyses were performed on the water collected from the bottom of the model in an attempt to exhibit the effectiveness of bioswales. In addition, a curriculum was created for the students at Walden West to teach them about bioswales and their effects on water quality.

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Chapter 1: Introduction

1.1 *Client Request*

As a group, we determined last spring that we wanted to work on a project that would benefit the community. With the help of Professor Krishnan from the Electrical Engineering Department, we were connected with Richard Reid, the facilities director at Walden West Science School in Saratoga, California. He explained that the site of the science school currently contains a tank, piping, and pump configuration leading to a garden. The site is lacking a water source with which to irrigate the garden by way of this existing system. Richard tasked us with developing a natural and sustainable water source.

1.2 *Location Overview and Mission Statement*

Walden West is a children's science camp in the hills of Saratoga, California. The camp is located at 15555 Sanborn Road, as shown in Figure 1. It offers programs for K-12 students that combine science, sustainability, and the outdoors in day-long science and environmental programs. Walden West summer camps provide outdoor experiences to approximately 8900 students each year. The mission of the camp is to interest children in science through an exploration of scientific processes in nature, with an emphasis on fostering a respect for the environment through the adoption of sustainable practices.

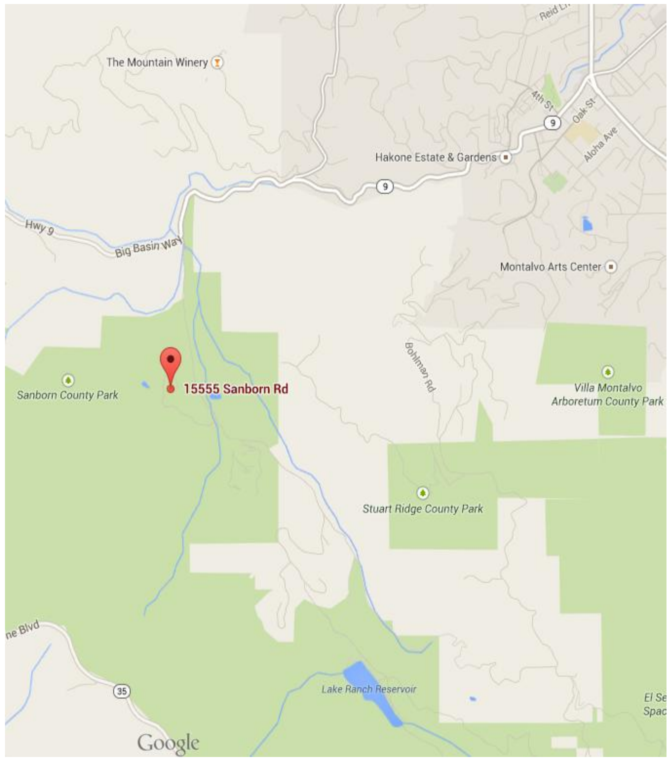

Figure 1: Location of Walden West Science School

A garden at the site is currently being irrigated by potable water, a practice that is incompatible with the goals of the establishment. As can be seen in Figure 2, two tanks are located adjacent to the garden. These tanks combined hold approximately 20,500 gallons of water. Another tank is located in a lower meadow and holds 20,000 gallons of water. A solar powered pump next to this lower tank will be used to pump water fed into the tank back up to the garden through a pipe that runs underground between the two tanks. There is also a pipe located under the beginning of the driveway to the main lodge. As seen in the topographic map in Figure 3, the existing slope of the land directs rainwater runoff from the roof of the main lodge, the parking lot, and the driveway into the meadow. Once discharged from the pipe, the runoff infiltrates into the soil.

Figure 2: Existing system at Walden West

In accordance with the mission of the science school, the existing system requires a natural water source to fill the tanks and irrigate the garden. Because the water will be used to irrigate plants meant for human consumption, it must be free of pollutants that could harm the plants or their produce.

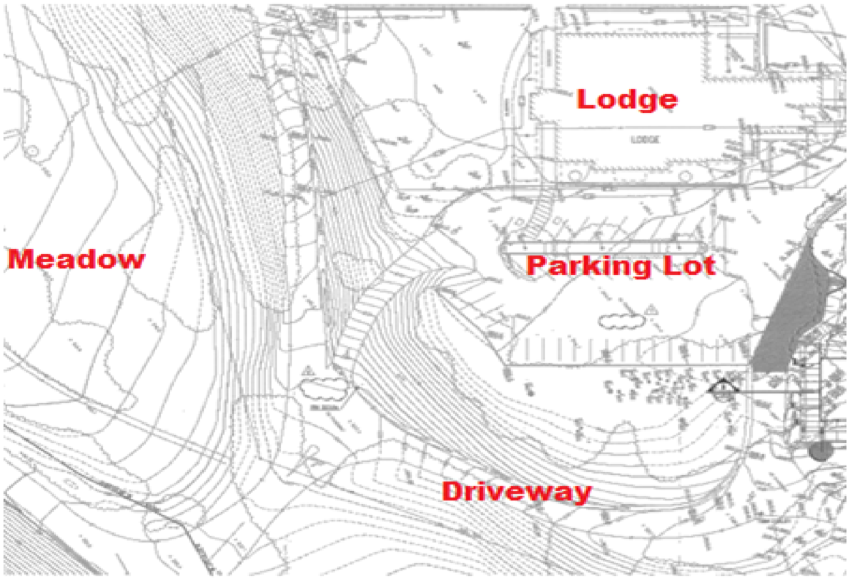

Figure 3: Existing topography of the site

Chapter 2: Water Source Alternatives

2.1 *Current Water Source*

Currently, Walden West is using potable water to irrigate the garden. This is not a viable option because it is limited. The effects of using potable water for irrigation are particularly significant during the recent times of drought throughout California. Using potable water is also not an ideal option for the irrigation of the garden because it does not comply with Walden West's goal to be environmentally conscious. Because potable water is not a recommended option for the irrigation of the garden, several alternative water sources were considered that could be connected to the existing piping, tank, and pump system to irrigate the garden.

2.2 *First Alternative: Pond Water*

The first option considered was the use of water from a nearby pond to irrigate the garden. Research revealed that the water quality was very poor due to eutrophication, as seen in Figure 4. Eutrophication is the process by which a body of water produces excessive algae and plant growth due to high concentrations of nutrients like phosphorous and nitrogen. It would also be necessary to obtain permits to use water from an existing natural water source, which would be a lengthy and potentially unsuccessful process.

Figure 4: Eutrophication in the Walden West pond

2.3 *Second Alternative: Unused Well*

Our next option was to utilize an old, unused well located next to one of the driveways leading up to the main lodge. However, upon observation, the well was deemed unusable. Additionally, permits would be required to use the well water.

2.4 *Third Alternative: Rainwater Runoff*

The final option considered was to capture and reuse rainwater runoff from the site. Sheet flows of rainwater runoff originating from the roof of the main lodge, the main parking lot, and the driveways to the main parking lot are already collected in the drain pipe at the bottom of the driveways and deposited in the meadow. Rainwater runoff would be an unreliable source due to the typically small amount of rain in the Bay Area. Rainwater runoff also has the potential of picking up pollutants from the pavement and rooftop, eroding any soil it comes in contact with, and causing floods as it travels away from its source. However, this option would utilize a natural source of water.

Chapter 3: Solution Development

3.1 *Alternative Selection*

Ultimately, rainwater runoff was chosen as the only feasible irrigation solution that was also environmentally-conscious and sustainable. The solution required the development of ways to clean the runoff of any pollutants picked up from the roof and pavement and to recollect it before distributing it into the existing system. Low Impact Development (LID) measures were investigated to design the purification and recollection elements in compliance with Walden West's mission statement.

The Santa Clara Valley Urban Runoff Pollution Prevention Program C3 Handbook (April 2012), from this point forward referred to as the C3 Handbook, provides LID options in the form of Best Management Practices (BMPs) for addressing rainwater runoff, as shown in Figure 5. BMPs are approved elements of site development to prevent runoff from impervious surfaces from causing erosion or flooding. From the BMPs listed in the C3 Handbook, a bioswale was selected as the option that best addressed the particularities of rainwater runoff use at Walden West.

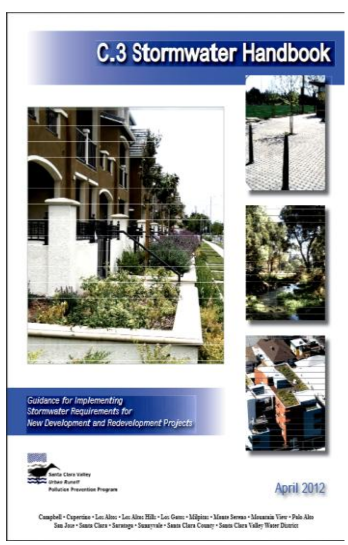

Figure 5: The C3 Handbook

3.2 *Bioswale*

A bioswale is a landscape element designed to collect and filter rainwater runoff. Bioswales are commonly included in new developments in the Bay Area, and several have been installed on Santa Clara University's campus, including the one next to the Patricia A. and Stephen C. Schott Admission and Enrollment Services Building shown in Figure 6.

Figure 6: Bioswale on Santa Clara University campus

From the bottom upward, a bioswale consists of the following minimum layers:

- 12 inches of Caltrans Standard Section 68-1.025 Class 2 Permeable gravel or equivalent
- an optional 2 inches of pea gravel
- 18 inches of bioretention soil mix
- 2 inches of mulch
- drought-resistant plants

Specifications for the content of the bioretention soil mix required by the C3 Handbook are provided in Appendix A, as well as tables of approved plants summarized from tables in the C3 Handbook. Runoff is either allowed to filter through the bioswale layers into the native soil or is collected in a perforated pipe located in the gravel layer at the bottom of the bioswale to be reused or deposited in the storm drain system, as illustrated in Figure 7. An overflow riser is often installed with an opening at the level of the maximum ponding depth to deposit runoff from storms larger than the design storm directly into the storm drain system, preventing the surrounding land from flooding. As the intent of the bioswale at Walden West is to collect as much rainwater runoff as possible, the underdrain is located near the very bottom of the gravel layer, and a waterproof fabric lines the bioswale to prevent any water from escaping into the native soil, as shown in Figure 8.

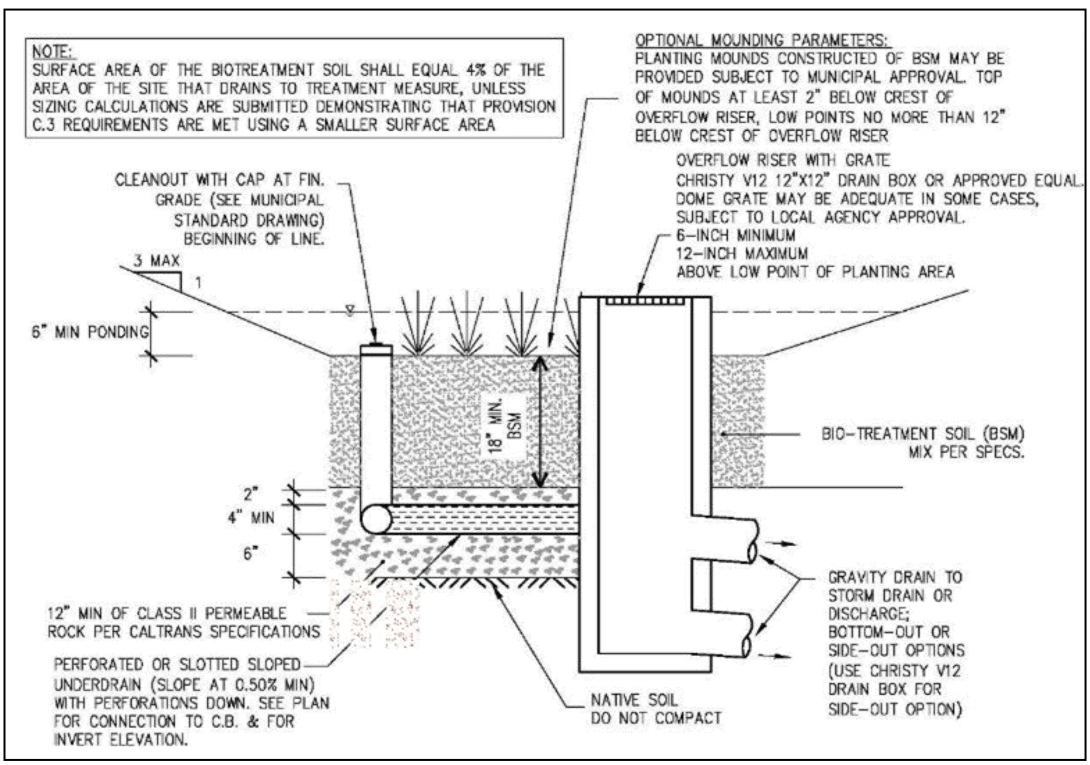

Figure 7: Typical bioswale cross-section

[Source: C3 Handbook]

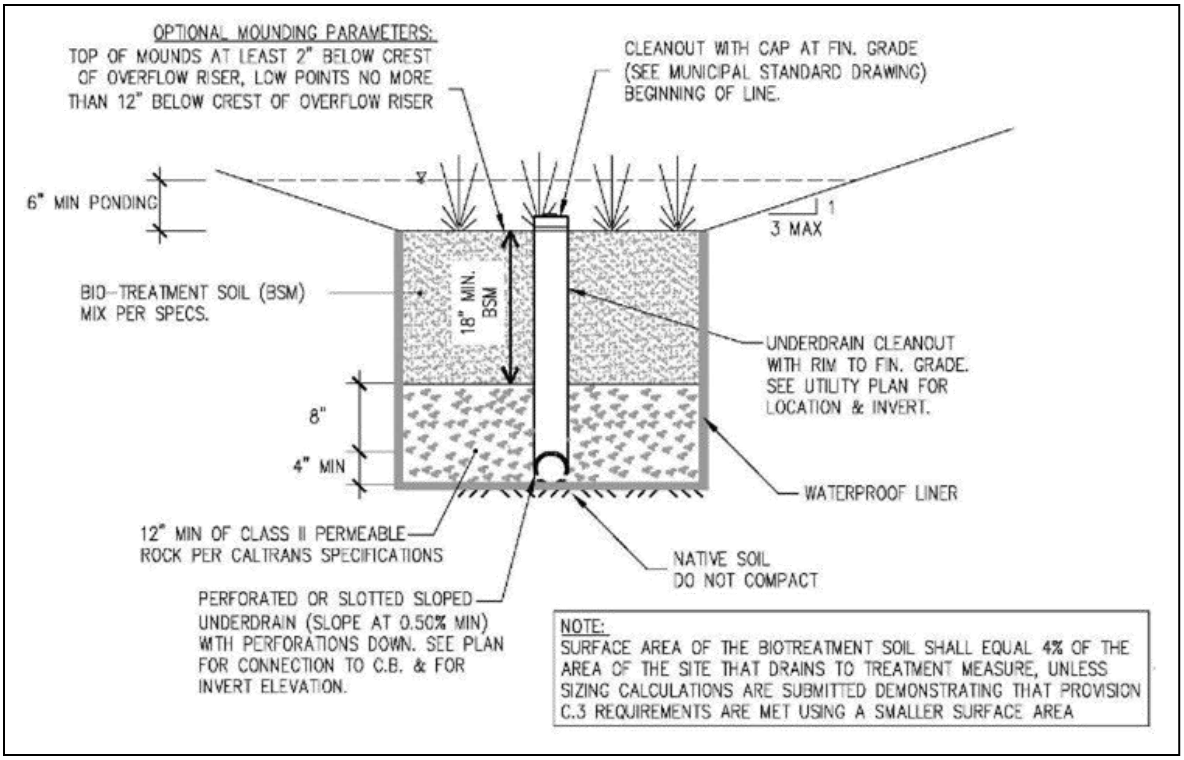

Figure 8: Bioswale cross-section with waterproof lining and a deep underdrain

[Source: C3 Handbook]

3.3 *Design Process*

The C3 Handbook enumerates a design process for a bioswale. Section 5.1 classifies a bioretention area as both a flow-based and a volume-based treatment measure. A bioswale qualifies for the combination method due to the fact that it both allows runoff to flow from the surface of its soil to its underdrain and has the capacity to detain a volume of runoff as it infiltrates.

All resources from the C3 Handbook used in the combination flow and volume design are provided in Appendix B of this document, while the preliminary design calculations can be found on page C-1 of the appendix. The required volume of the total runoff to be treated was first calculated. Using the topographic maps of the site in AutoCAD, approximations of the impervious and pervious areas from which runoff will likely flow were made, as shown in Figures 9 and 10. The pervious drainage area was approximated at 18,000 square feet and included a grassy median and a grassy slope between the parking lot and the driveway. The impervious drainage area was estimated at 36,200 square feet and included the lodge roof, parking lot, and driveways. The percent imperviousness was then calculated to be 66.7%.

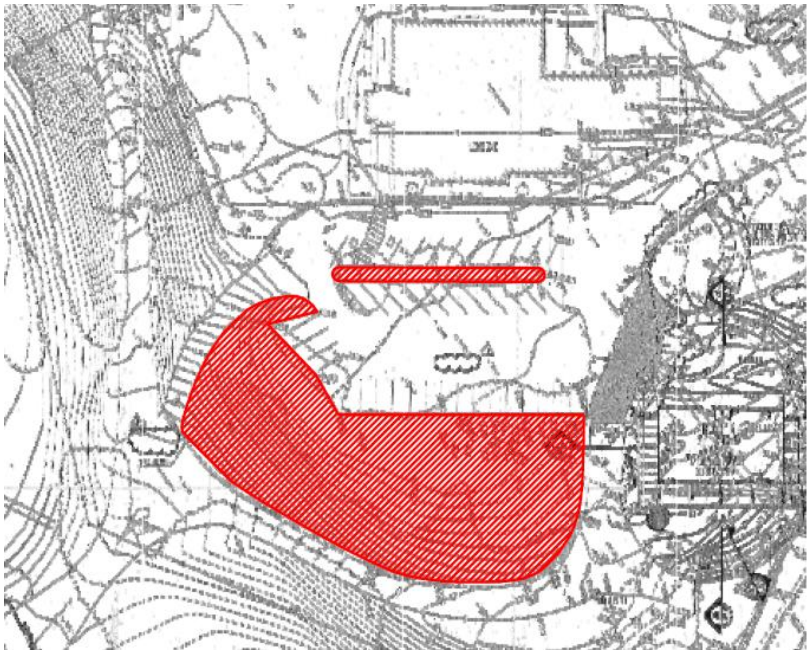

Figure 9: Pervious drainage areas

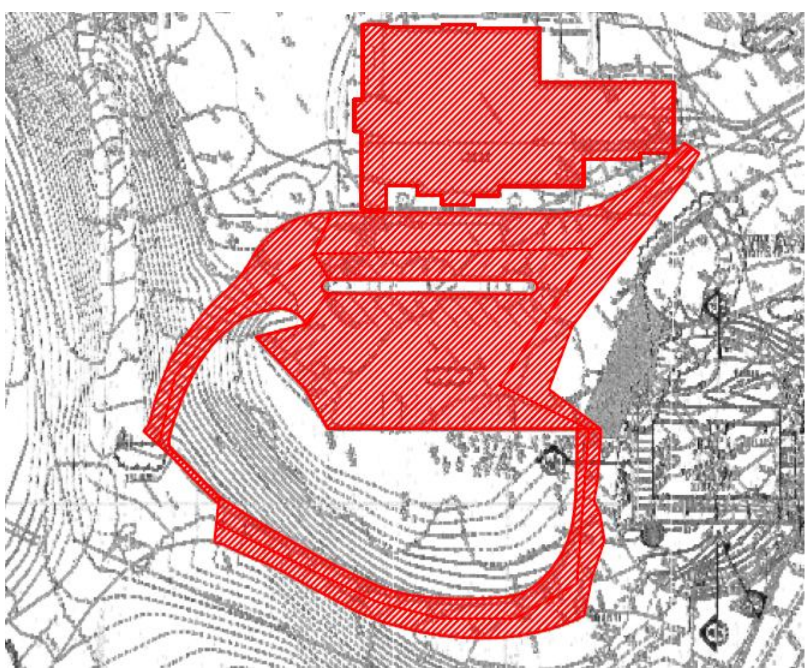

Figure 10: Impervious drainage areas

Next, a rain gage correction factor was determine to be the ratio of Walden West's mean annual precipitation, MAP_{site}, to the San Jose airport's mean annual precipitation, MAP_{gage} with the help of figures obtained from Appendix B of the C-3 Handbook. From the figure on page B-1 of the appendix of this document, MAP_{site} was determined to be 43.0 inches. The C3 Handbook contains a list of four rain gages, of which the closest one to Walden West was identified as the San Jose Airport rain gage. From the figure on page B-2 of the appendix of this document, MAP_{gage} was listed as 13.9 inches. From the two mean annual precipitations, the rain gage correction factor was found to be 3.09 from the following equation:

$$Correction\ Factor = MAP_{site}/MAP_{gage}, \tag{1}$$

The soil type was classified as loam with the aid of Figure B-1 in Appendix B of the C3 Handbook. An average slope of 0.0447 was estimated using the same topographic maps in AutoCAD from which the drainage areas were estimated. The rain gage, soil type of the site, percent imperviousness, and average slope of the drainage area were used to determine a unit basin storage volume of 0.4 inches from curves on the bottom of page B-2 and on page B-3 of the appendix. The water quality design volume was then found to be 5,600 cubic feet according to the following equation:

$$Water\ Quality\ Design\ Volume = \\ Rain\ Gage\ Correction\ Factor\ X\ Unit\ Basin\ Storage\ Volume\ X\ Drainage\ Area, \tag{2}$$

This was the volume-based calculation. Next, the duration of a typical rain event was estimated to be two hours by dividing the unit basin storage volume by the constant 0.2 inches/hour rainfall intensity recommended by the Urban Runoff Program. The surface of the bioswale was approximated to be 3% of the total impervious surface area feeding the system with runoff, which resulted in an area of 1,090 square feet.

The estimated area of 1,090 square feet was multiplied by the bioswale design surface loading rate of 5 inches per hour and the duration of the typical rain event of two hours to determine the runoff volume that filters through the treatment soil. The result, 905 cubic feet, was subtracted from the water quality design volume of 5,600 cubic feet to find the volume of water that would pond on the surface of the bioswale as the rest was infiltrating through. The ponding volume, 4,690 cubic feet, was divided by the estimated 1,090 square foot surface area to find the ponding depth. After converting to inches, the ponding depth was 51 inches. The estimated area was then adjusted and the steps thereafter repeated until the ponding depth was between 6 and 12 inches. The adjustment process resulted in a 3,025 square foot required bioswale surface area necessary to satisfy the maximum ponding depth of 12 inches.

Upon proposing the 3,025 square foot bioswale to the client, he requested that the bioswale be downsized to 2,000 square feet. Although this would violate the required ponding depth range with a ponding depth of 24 inches, a spillway next to the bioswale was considered as an optional addition. Any overflow of the bioswale could be directed to the spillway, where it would be retained until it infiltrated into the native soil. The inclusion of a spillway would prevent water deposited above the ponding depth of the bioswale from flooding and eroding the surrounding land.

3.4 AutoCAD Design

AutoCAD Civil 3D offers an option to integrate a Google Earth image into a file, and then design land development elements like a bioswale. A topographical map from Google Earth was loaded into the CAD file so that wherever the cursor was placed along the map, an elevation was generated for that point, like the point in Figure 11. A 40’ x 50’ bioswale was drawn in the meadow at Walden West, located arbitrarily near the storage tank, as shown by the green and red rectangle in Figure 11. The bottom surface of the bioswale was put at the correct distance from the top surface to account for the summation of all of the required material thicknesses in a bioswale according to the C3 Handbook. Different locations for the bioswale in the meadow could be analyzed using this tool.

Figure 11: AutoCAD and Google Earth integration

Once elevations of the top and bottom surfaces of the bioswale were specified, a profile of the excavation relative to the actual topography was generated, as seen in Figure 12. The profile could be moved up or down to change the amount of cut and fill necessary on the project, which was also calculated by the program, as seen in the textbox in Figure 13. This tool could be used to determine exactly where and how much to excavate when constructing the bioswale.

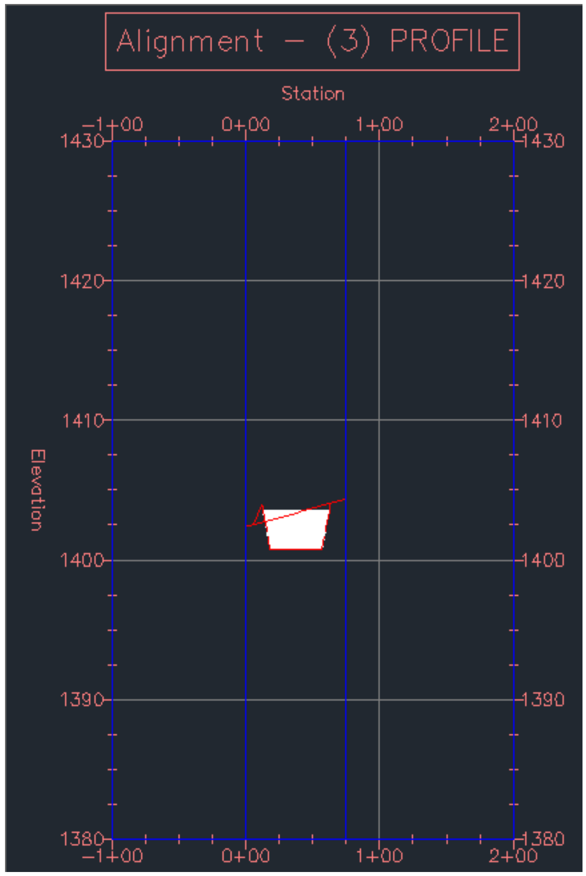

Figure 12: Profile of the design bioswale set against the existing topography

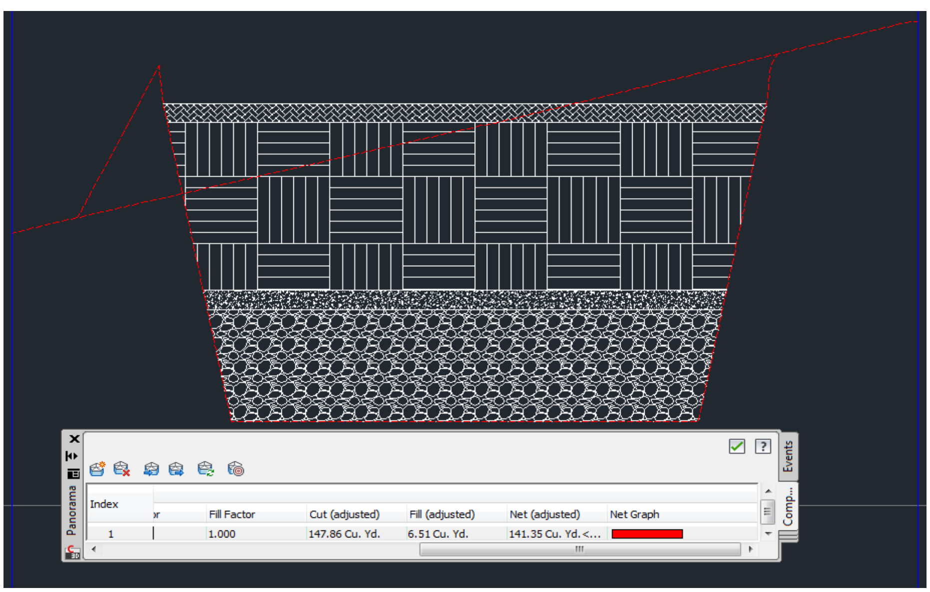

Figure 13: Cut and fill values calculated by AutoCAD

3.5 Material Quantities

In order to construct a 2,000 square foot bioswale according to the C3 Handbook, 82 cubic yards of Class 2 Permeable gravel, 123 cubic yards of bioretention soil mix, and 14 cubic yards of mulch were needed. A 10 millimeter by 20 foot by 100 foot waterproof fabric was also needed to prevent the runoff water from seeping out of the gravel layer into the native soil before it could be collected for reuse. It was estimated that 80 drought-resistant plants would be needed. One portable water sampler would be used for water quality testing. All required materials and their corresponding quantities are summarized in Table 1.

Table 1: Amount of materials needed for the 2,000 square foot bioswale

Materials	Quantity
Plants (drought resistant)	80
Portable Water Sampler	1
Bioswale Soil (CY)	123
Fabric (mm x ft x ft)	10 x 20 x 100
Gravel (CY)	82
Mulch (CY)	14

3.6 Budget

As shown in Table 2, the full-scale bioswale would cost roughly $17,500 to both construct on the Walden West property and perform proper water quality testing on. Materials for the bioswale, consisting of Class 2 Permeable gravel, bioretention soil mix, mulch, waterproof fabric, and drought resistant plants, would cost approximately $13,400. It was necessary for the gravel and soil mixes to comply with the C3 Handbook requirements, and thus they were more expensive than normal soil and gravel mixes. The excavator used to construct the bioswale would cost roughly $500. A portable sampler to be used to test water quality would cost approximately $2,000. A 10% contingency of $1600 was added to account for any unanticipated expenditures. Approximate tax and transportation costs were factored into all prices shown in Table 2. As the senior design team, along with other volunteers as needed, would construct the bioswale, labor was not accounted for in the budget.

Table 2: Product costs for the 2,000 square foot bioswale

Product	**Estimated Price**
Excavator	$500
Waterproof Fabric	$200
Class 2 Permeable Gravel	$6700
Bioretention Soil Mix	$5400
Mulch	$300
Drought Resistant Plants	$800
Portable Water Sampler	$2000
Contingency	$1600
TOTAL	**$17,500**

Chapter 4: Funding Restrictions and Scope Change

4.1 Funding Constraints

To fund the construction and water quality analysis of the full-scale bioswale, proposals were submitted for the Santa Clara University Engineering Undergraduate Programs Senior Design Project Funding and the Roelandts Grants in Science and Technology for Social Benefit. However, responses from these funding opportunities only resulted in $1,500 – less than 10% of the estimated budget. After consideration of the amount of funding still outstanding, as well as the time period available to obtain additional funding and complete the project, it was determined that the most feasible option was to consider alternate ways to use the funding to accomplish the goals of the project.

4.2 Alternative Selection

The first alternative considered was to construct a much smaller bioswale in the meadow than the one designed, with a waterproof lining big enough to fit the full-scale design. The inclusion of the full-scale waterproof lining would allow the bioswale to be expanded by Walden West or a future senior design team at a later date when funding became available. Overflow of the much smaller bioswale would be likely and had a possibility of eroding the surrounding land, so the first alternative would necessitate the construction of a large spillway of an overflow pipe directing the overflow to another location on the site.

The second alternative considered was to make a model of a column of the bioswale with which water quality tests could be performed. Results of the tests could prove to Walden 000West that a bioswale would be the best option to supply their irrigation system. The model would also provide a more visual teaching aid for the students of future science camps than an actual bioswale in the ground, because a viewing pane could be installed to allow them to see the layers of a bioswale. Ultimately, it was determined that funds attained from Santa Clara University would be put to better use by making the model.

Chapter 5: Construction of Bioswale Model

5.1 Design

To create a model that could be tested but also allowed for viewing and transport, a 2' x 2' x 3' open-topped Plexiglas box reinforced on three of the four sides and the bottom by wood framing was designed. The components of the model can be seen in Figure 14.

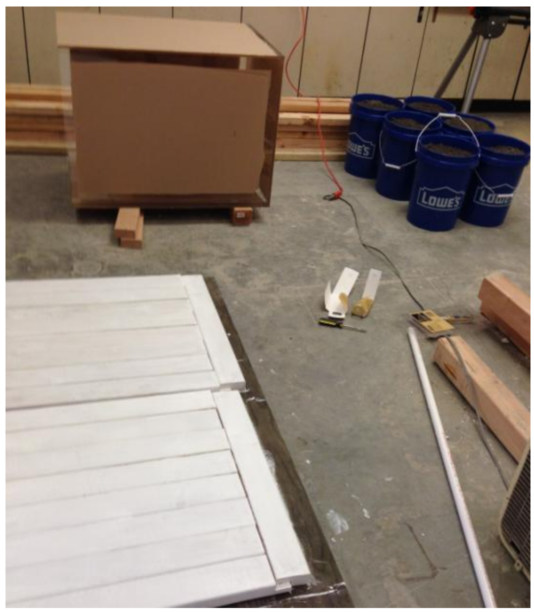

Figure 14: Components of the model construction

First, the maximum stress that the bioswale materials would apply to the sides of the box was estimated using the following equation:

$$\sigma_c = \Sigma(\gamma_i t_i), \tag{3}$$

where σ_c is the stress in psf, γ_i is the unit weight of a material layer in pcf, and t_i is the thickness of the corresponding material layer in feet. The material layers and their unit weights are illustrated in Figure 15. As seen in the model calculations on page C-4 of the appendix, the maximum stress applied to a side of the box, assuming that each layer of material was fully saturated with water, was found to be 491 psf, which was converted to 3.42 psi.

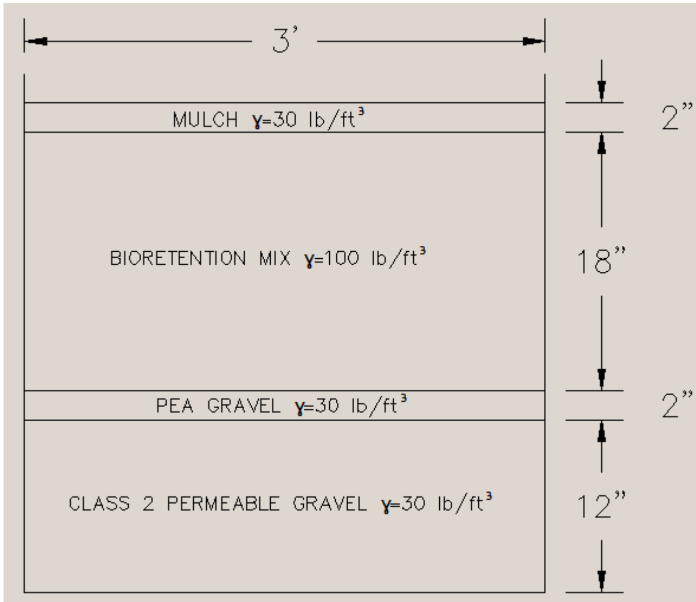

Figure 15: Dimensioned material layers of the bioswale model with their unit weights

The calculated maximum stress that would be applied to any one side of the box was then applied to a 1 inch thick and 34 inch tall section of the box as a distributed load that increased uniformly from 0 psi at the top of the section to 3.42 psi at the bottom of the section. An illustration of this section can be seen in Figure 16.

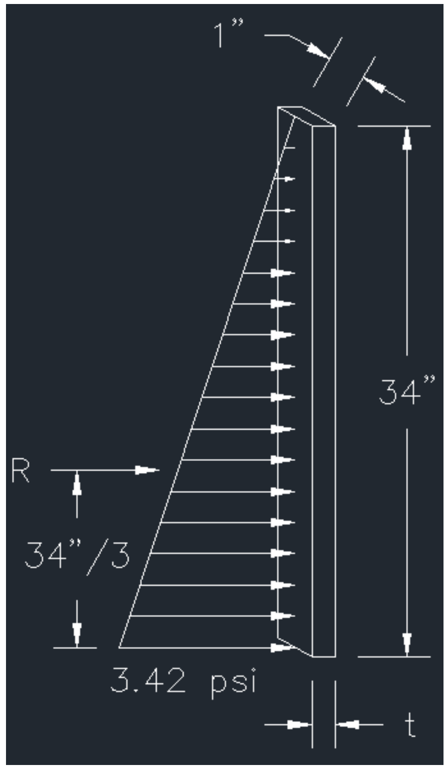

Figure 16: 1” thick, 34” tall design section of the Plexiglas box

The resultant force, acting at one third of the section height from the bottom of the section, was found using the following equation:

$$R = \sigma_c * w * \frac{h}{2}, \tag{4}$$

where R is the resultant force in lbs, σ_c is the stress in psi, w is the width of the section in inches, and h is the height of the section in inches. The resultant force was found to be 58.1 lbs.

The resultant force was converted into a moment applied at the bottom of the section of Plexiglas by multiplying by the length of the lever arm between the location of the resultant force and the bottom of the section, as described in the following equation:

$$M = R * l, \tag{5}$$

where M is the moment in lb-in, R is the resultant force in lbs, and l is the length of the lever arm in inches, which was equal to one third of the height of the section. An illustration of this layout is shown in Figure 17. The resulting moment was 659 lb-in.

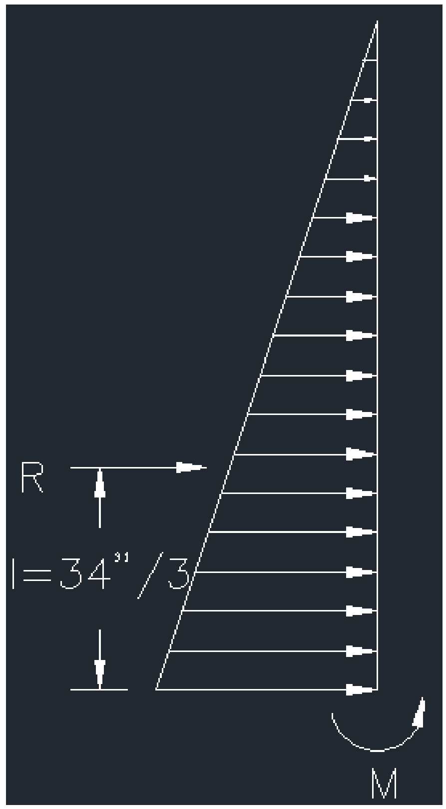

Figure 17: Moment at the base of the Plexiglas section

The following equation was used to generate the moment of inertia of a cross section of the Plexiglas section in terms of t, the unknown thickness of the Plexiglas pane in inches:

$$I = \frac{wt^3}{12}, \tag{6}$$

where I is the moment of inertia of the cross section in inches to the fourth and w is the width of the section in inches. The moment of inertia was found to be $\frac{t^3}{12}$ inches to the fourth.

The strength of the Plexiglas, found in the TAP Plastics material specifications on page D-1 of the appendix, was divided by a factor of safety of 2 to obtain the allowable stress to be applied to the Plexiglas panes:

$$\sigma_a = \frac{\sigma_y}{FS}, \tag{7}$$

where σ_a is the allowable stress in psi, σ_y is the yield stress in psi obtained from the specifications, and FS is the factor of safety. An allowable strength of 5,000 psi was determined.

The required thickness in inches of each Plexiglas pane, t, was then solved for in the following equation:

$$\sigma_a = \frac{\mathrm{M*c}}{\mathrm{I}}, \tag{8}$$

where σ_a is allowable strength of the Plexiglass, M is the moment in lb-in applied by the bioswale materials to the Plexiglass, c is the distance from the center of mass of the Plexiglas section to its outer fiber, in this case equal to $\frac{t}{2}$, and I is the moment of inertia of the cross section in inches to the fourth, previously solved in terms of t. The required thickness of each pane of Plexiglas to resist the lateral load applied by the bioswale materials was found to be 0.89 inches.

A rough estimate of the weight of the bioswale materials, W, was obtained by multiplying the maximum stress of the materials, σ_c, by the surface area of the bottom of the box, A:

$$W = \sigma_c * A, \tag{9}$$

The resulting weight estimate was 1,970 lbs.

5.2 Material Quantities and Construction

The closest Plexiglas thickness TAP Plastics offered to the calculated required design thickness of 0.89 inches was 1 inch Plexiglas. The cost of a 2' x 2' x 3' open-topped Plexiglas box custom made at TAP Plastics with panes of 1 inch Plexiglas on all sides was quoted at $1500- the entire amount of funds available for the model construction and testing. To remain within the budget, every side of the box other than the viewing pane was downsized to 3/8" thickness and wood framing was constructed to support the other three sides and the bottom of the box. 2 x 4 planks of untreated Douglas Fir lumber were used to construct side and bottom panels that could be screwed together in a support frame. The panels were painted with 2-in-1 outdoor primer and paint in order to protect the wood in an outdoor environment.

Figure 18 shows the 1" diameter perforated pipe that was installed along the bottom edge of the 1" thick pane of the box to collect water after it drained through the bioswale materials. The pipe extended out of a 1" diameter hole in a side pane cut by TAP Plastics and ended in valve secured with PVC glue. The surface between the PVC pipe and the Plexiglas was sealed with caulk used on roofs in order to ensure that the box did not leak, as shown in Figure 19.

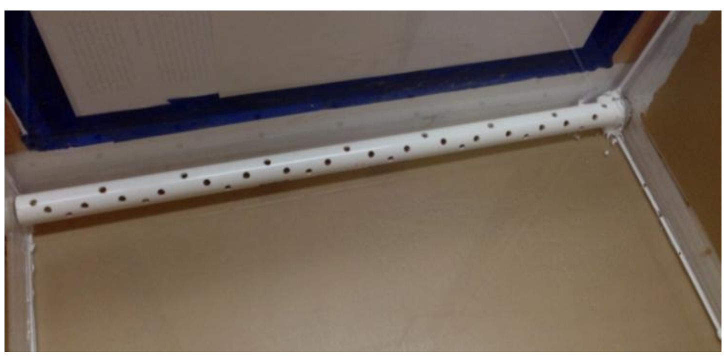

Figure 18: Perforated PVC pipe to collect drainage water from the model

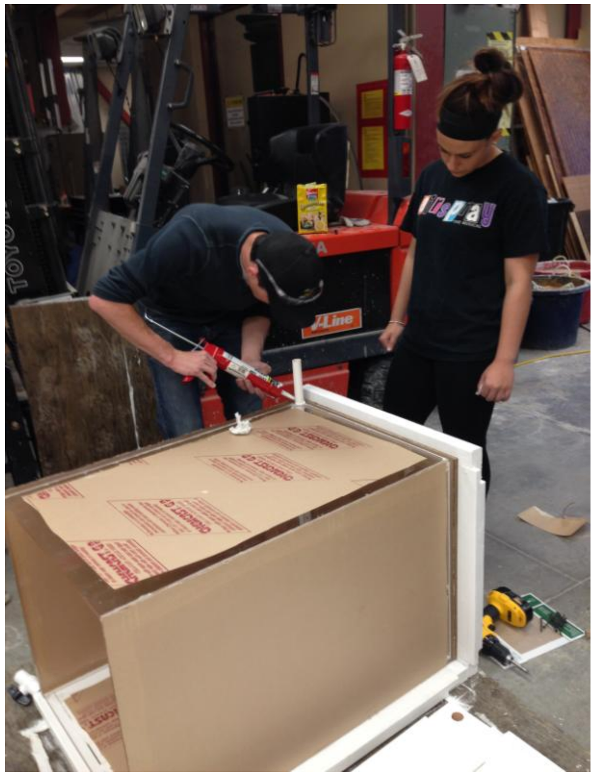

Figure 19: Caulking around the PVC pipe outlet prevented leaking

From the estimation of the weight of the bioswale materials of 1,970 lbs, four industrial strength wheels, each with a 600 lb capacity, were ordered under the assumption that the additional weight of the Plexiglas box, the wood framing, and any miscellaneous building components would not be greater than the 430 lb difference between the bioswale material weight and the combined capacity of the wheels. The manufacturer specifications for the wheels are provided on page D-7 of the appendix.

Once the pipe wood framing was screwed around the Plexiglas box, including an additional sheet of plywood between the bottom surface and the bottom framing for added support, the wheels were screwed at each corner of the bottom panel of wood framing. A 1”x4” plank of lumber was attached between the back of the bottom pane and the back wheels in order to tilt the box slightly forward. The slight slope was added to cause water that reached the bottom Plexiglas surface to flow into the perforated pipe located along the bottom front edge of the box.

Once the box was righted onto its wheels, the sides were marked at the required levels for each bioswale material, and each material was put into the box up to the corresponding marking, as can be seen in Figure 20. First, 12" of Class 2 Permeable gravel was added, followed by 2" of pea gravel, both of which were donated by West Coast Aggregates, Inc. Next, 18" of bioretention soil, which was donated by TMT Enterprises, was added. Finally, the drought resistant plants were planted, and a 2" layer of mulch was spread around them. A cover for the viewing window was installed with hinges and hooks to keep light from encouraging the growth of algae in the moist layers through the viewing window. The material quantities used to construct the model are summarized in Table 3.

Figure 20: Filling the model with the Class 2 Permeable Gravel layer

Table 3: Amount of materials needed for the 2'x2'x3' bioswale model

Materials	**Quantity**
Plants (drought resistant)	5
Plexiglas (ft x ft x ft)	2 x 2 x 3
Plywood Siding (ft x ft)	(2) 4x8
2x4 Lumber for Framing (10' Sections)	14
1" PVC Pipe (ft)	2
1" PVC Fitting	1
1" PVC Valve	1
Bioswale Soil (ft^3)	6
Class 2 Permeable Gravel (ft^3)	4
Pea Gravel (ft^3)	0.67
Mulch (ft^3)	0.67
Wheels	4
Cans of Paint	2
Plywood Cover (ft x ft)	2 x 3
Hinges	2
Hooks	2

5.3 Budget

The model bioswale cost approximately $1,320 to construct and to perform water quality testing. The Plexiglas box was made at TAP Plastics for $889. TMT Enterprises donated the bioretention soil for the model, while West Coast Aggregates donated both the Class 2 Permeable gravel and the pea gravel. The gravel and soil mixes comply with the C3 Handbook requirement, and thus are more expensive than normal soil and gravel mixes. The industrial strength wheels were ordered online and cost $36. All of the other construction items cost around or under $100 and were obtained at Lowe's or Home Depot. The breakdown of the model budget can be seen in Figure 21.

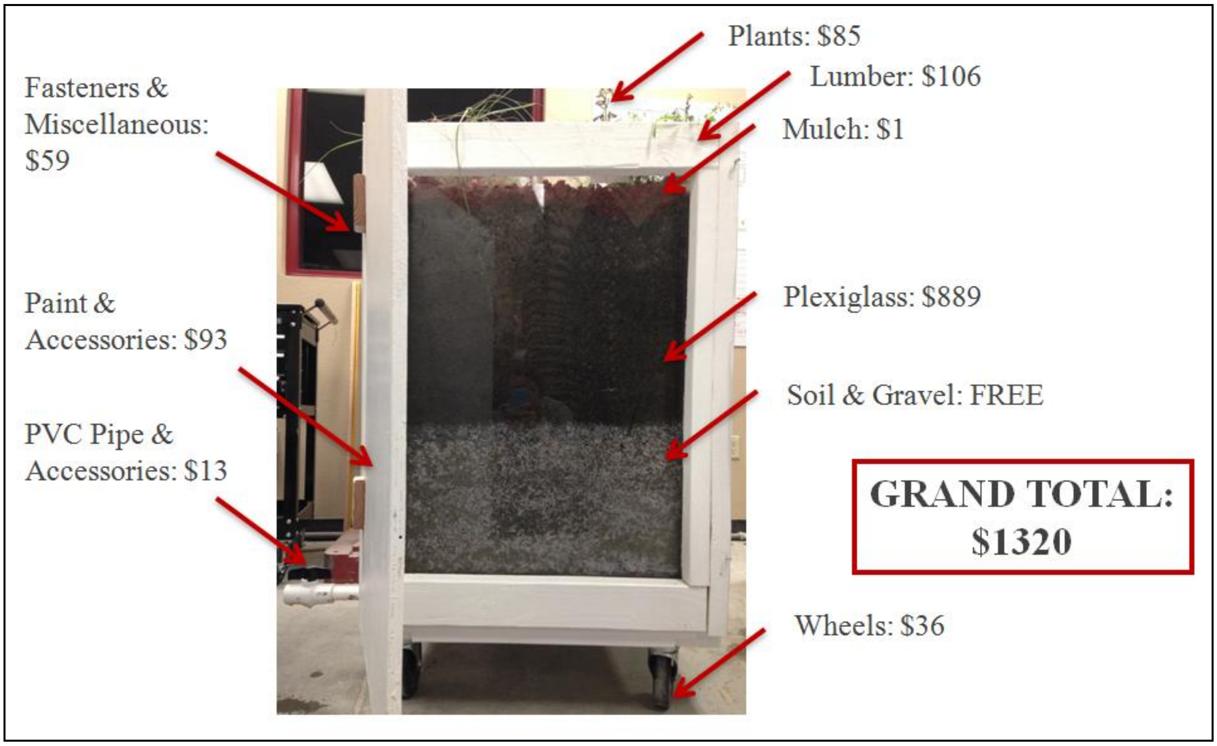

Figure 21: Bioswale model budget

Chapter 6: Water Quality Analyses

6.1 Synthetic Water Sample Design

In order to determine the effectiveness of a bioswale, a synthetic water sample was designed to run through the bioswale model. The synthetic water sample was designed to contain levels of pollutants equal to or greater than what would be present in a worst-case scenario rainwater runoff. Four 5-gallon synthetic water samples were mixed, coming to a total of 20 gallons. Water quality tests were performed on each sample before and after it was put through the model.

Design calculations for the synthetic mix are provided on page C-4 of the appendix. 37.4 pounds of water from the Guadalupe River in San Jose, California was used as the base of each 5-gallon synthetic water sample. This base was chosen because it is a natural water source. Ten percent, or approximately 4.2 pounds, of each 5-gallon sample consisted of tap water in order to add additional nutrients, as shown in Figure 22.

Figure 22: Ten percent of each 5-gallon sample was tap water

In order to add high levels of phosphorus and nitrogen to the synthetic sample, stock solutions of sodium phosphate and potassium nitrate were created. The amount of phosphorus in the stock solution of sodium phosphate was calculated by using the following equation:

$$C_P * \frac{FW_{H_{15}O_{11}Na_2P}}{FW_P} = X_P, \tag{10}$$

where C_P is the desired concentration of phosphorus in the stock solution, $FW_{H_{15}O_{11}Na_2P}$ is the formula weight of sodium phosphate, FW_P is the formula weight of phosphorus, and X_P is the amount of phosphorus in the stock solution. The desired concentration of phosphorus was 1 gram per liter. The formula weight of sodium phosphate was 268.07 grams. The formula weight of phosphorus is 31 grams. The amount of phosphorus in the stock solution was 8.647 grams in 1 liter of water.

The next step was to find the amount of phosphorus needed in the 5-gallon sample, which was calculated using the following equation:

$$S * P_S = S_P, \tag{11}$$

where S is the total amount of sample, P_S is the desired concentration of phosphorus in the synthetic sample, and S_P is the amount of phosphorus in the synthetic sample. The total amount of sample was five gallons. The desired concentration of phosphorus was 0.6 milligrams per liter, and the amount of phosphorus in the synthetic sample was 11.356 milligrams. The following equation was used to determine the amount of stock solution to add to the synthetic mix:

$$X_{SS} = \frac{S_P}{C_P}, \tag{12}$$

where X_{SS} is the amount of stock solution to add to the synthetic mix, which was 11.356 milliliters.

The amount of nitrogen in the stock solution of potassium nitrate was calculated by using the following equation:

$$C_N * \frac{FW_{KNO_3}}{FW_N} = X_N, \tag{13}$$

where C_N is the desired concentration of nitrogen in the potassium nitrate stock solution, FW_{KNO_3} is the formula weight of potassium nitrate, FW_N is the formula weight of nitrogen, and X_N is the amount of nitrogen in the potassium nitrate stock solution. The desired concentration of nitrogen was 1 gram per liter. The formula weight of potassium nitrate is 101.1 grams. The formula weight of nitrogen is 14.0067 grams. The amount of nitrogen in the potassium nitrate stock solution was 7.218 grams in 1 liter of water.

The next step was to find the amount of nitrogen needed in the 5-gallon sample, which was calculated using the following equation:

$$S * N_S = S_N, \tag{14}$$

where N_S is the desired concentration of nitrogen in the synthetic sample and S_N is the amount of nitrogen in the synthetic sample. The desired concentration of nitrogen was 3.0 milligrams per liter and the amount of nitrogen in the synthetic sample was 56.78 milligrams. The following equation was used to determine the amount of potassium nitrate stock solution to add to the synthetic mix:

$$Y_{SS} = \frac{S_N}{C_N}, \tag{15}$$

where Y_{SS} is the amount of potassium nitrate stock solution to add to the synthetic mix, which was 56.78 milliliters.

8.647 grams of sodium phosphate was added to 1 liter of water to create a stock solution with a concentration of 0.6 milligrams of phosphate. 11.356 milliliters of the sodium phosphate stock solution was mixed into each 5-gallon synthetic water sample to obtain a high level of phosphorus.

Similar to the sodium phosphate, 7.218 grams of potassium nitrate was added to 1 liter of water to create a stock solution with a concentration of 3 milligrams of nitrogen. 56.7813 milliliters of the potassium nitrate stock solution was mixed into each 5-gallon synthetic water sample to obtain a high level of nitrogen. Figure 23 shows the measurement of the stock solution quantities using a pipet and electronic scale. Fine soil was added to each 5-gallon synthetic sample to make it more turbid. Once it was created and mixed, water quality tests were performed on each sample.

Figure 23: Adding stock solutions to the synthetic water sample

6.2 Water Quality Testing

Once each 5-gallon synthetic water sample was created and tested, it was pumped onto the surface of the model bioswale, allowing it to infiltrate to the drainage pipe at the bottom, as shown in Figure 24. It was then collected and retested. The water quality tests performed on the water sample before and after it went through the model included tests for total dissolved solids, pH, turbidity, hardness, phosphate-phosphorus, and nitrate- nitrogen.

Figure 24: Model test set-up

6.3 Total Dissolved Solids

Total dissolved solids, or TDS, describes the amount of organic and inorganic particles that are in a solution, like salts. Limiting this quantity is desirable in water that is intended to be reused or put in the storm drain system. Figure 25 is a graph of the results of the model testing compared to ideal levels of TDS. The blue diamonds represent the TDS levels of the synthetic water sample before it was put in the model, which averaged at 376 mg/L NaCl. The red squares show the output levels of TDS, which averaged at 1266 mg/L NaCl, indicating that the model added TDS to the water as it filtered through. This was most likely due to salts coming from the soil or mulch. It was hypothesized that additional flushing would clean the salts from the model and enable the model to decrease the levels of TDS in water. The green line represents the maximum desirable TDS level in irrigation, which is 500 mg/L NaCl. The purple line represents the typical TDS level in runoff, which is 120 mg/L NaCl. This indicates that the synthetic solution had more inorganic and organic particles than typical runoff; however, the output still did not meet irrigation standards.

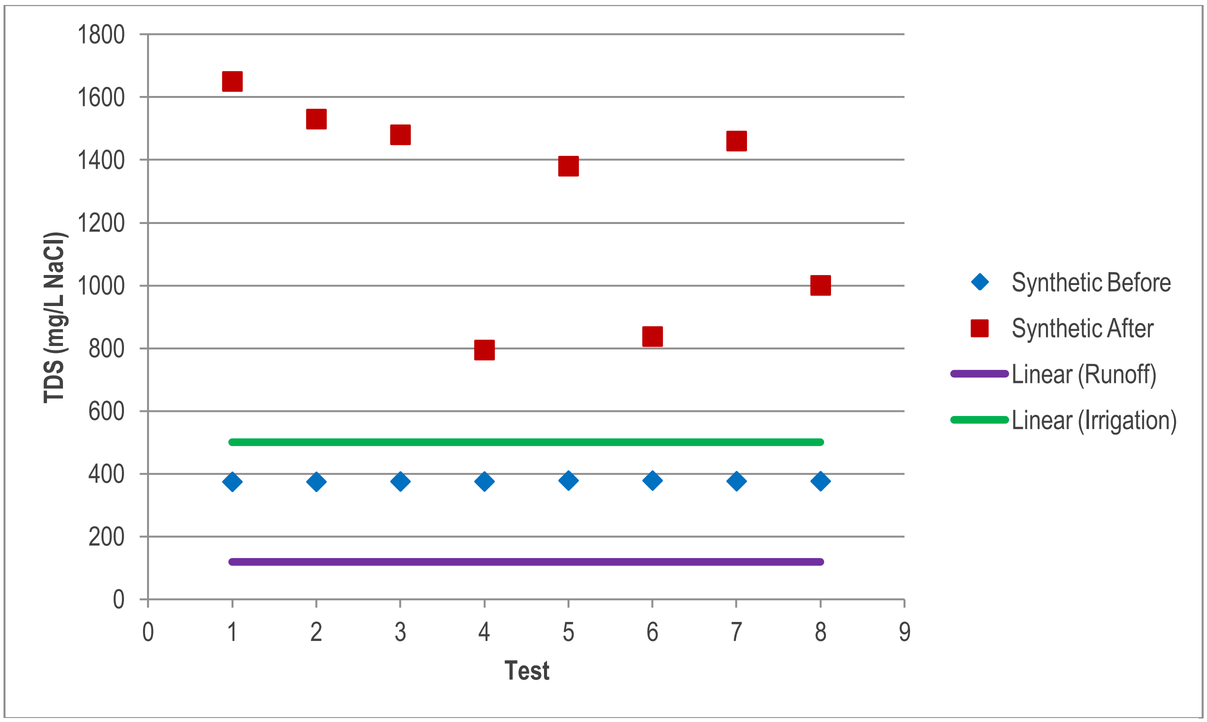

Figure 25: Results of TDS testing

6.4 pH

The pH of a solution indicates how acidic or basic a liquid is. It is desirable that water to be reused or deposited in the storm drain system is neither significantly acidic nor significantly basic, as either can have negative effects. Figure 26 illustrates the results of pH testing. The synthetic water sample, again represented by the blue diamonds, had an average pH of 7.8 before entering the model. After passing through the model, the red squares show that the pH decreased slightly to an average value of 7.2. The orange line indicates the maximum pH allowed in a storm drain system, in which pH should be within the range of 6.0-9.0. The green line shows the maximum level for irrigation water, for which pH should fall in the range of 7.0-8.5. The purple line represents the pH of typical rainwater runoff at 7.0. This graphs shows that the pH of the water sample after it passed through the bioswale model was within the specified ranges for reuse.

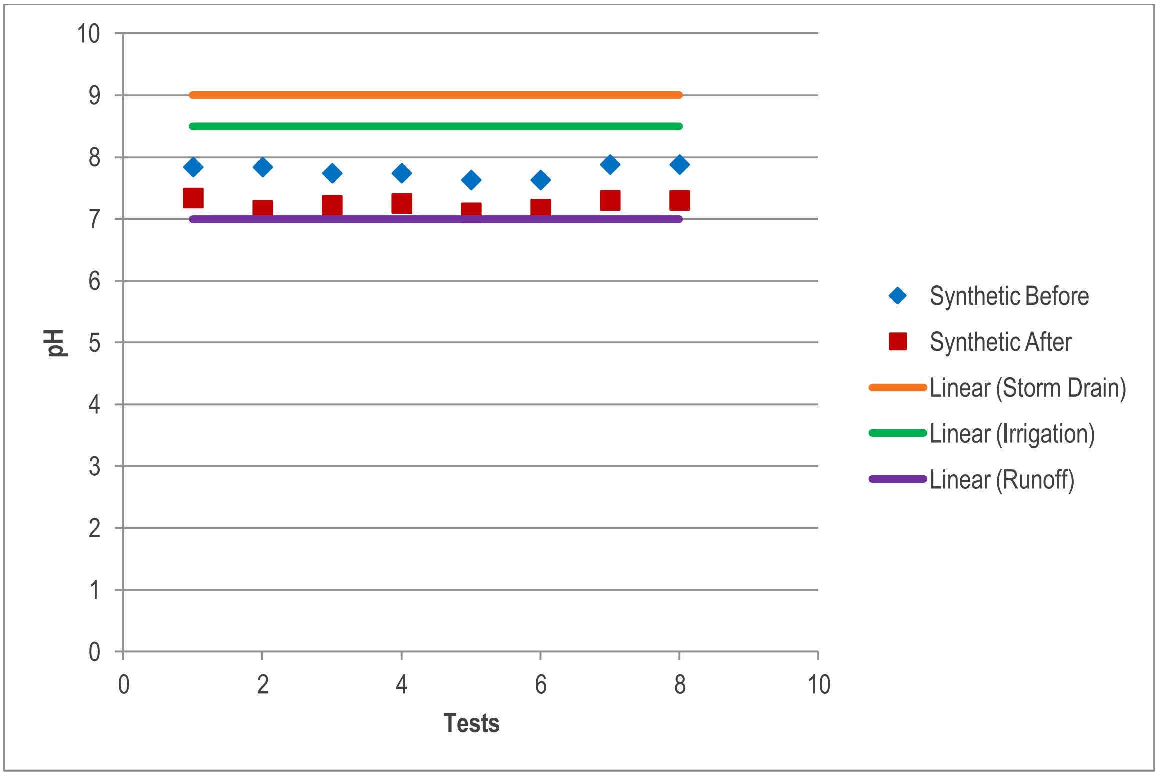

Figure 26: Results of pH testing

6.5 Turbidity

Turbidity indicates how transparent water is, which is a function of how many suspended particles exist within a water sample to deflect light. Clarity is desirable in water that is to be reused or directed into the storm drain system. Therefore, the goal was to decrease turbidity with the bioswale model. As seen in Figure 27, the synthetic water sample had an initial average turbidity of 61 NTU before entering the model, which is indicated by the blue diamonds. After passing through the model, the red squares show that the turbidity decreased to an average of 19.6 NTU. The model therefore succeeded in decreasing the levels of turbidity in the water samples. It was hypothesized that with additional flushing, any dust that existed on the gravels when they were installed in the model would be washed away and the model would decrease turbidity levels to an even greater extent. The orange line indicates the maximum turbidity recommended in a storm drain system at 50 NTU, illustrating that the model succeeded in decreasing turbidity levels of the water samples below the level recommended for reuse.

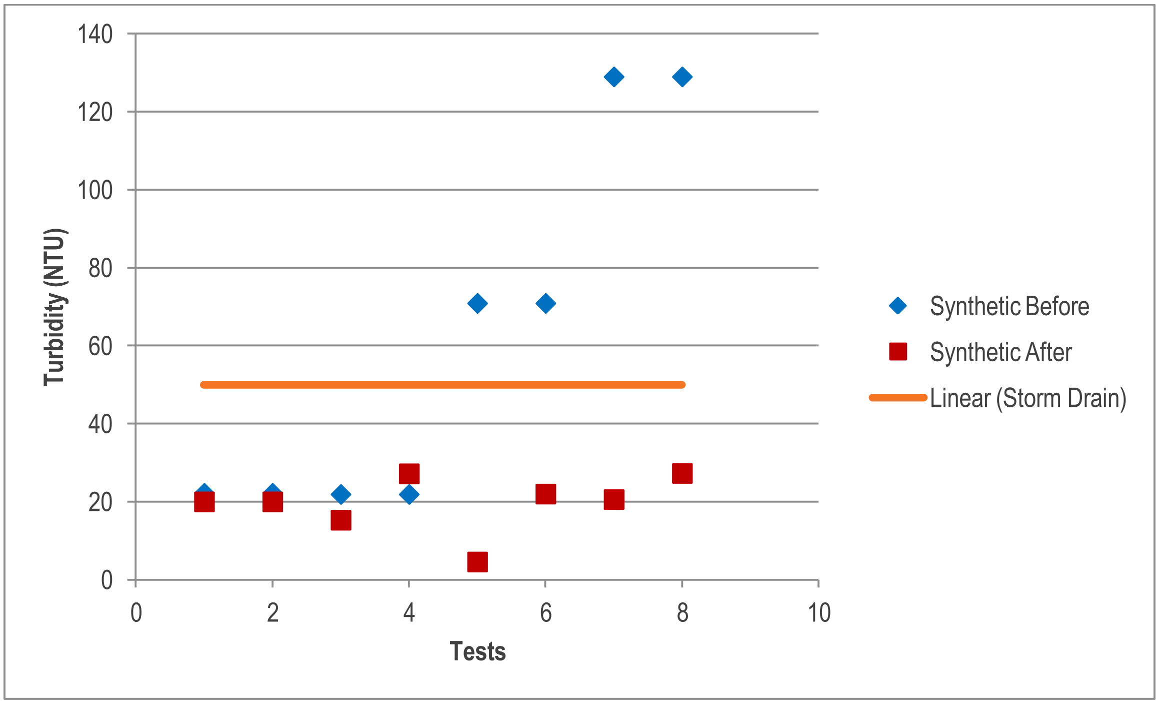

Figure 27: Results of turbidity testing

6.6 Hardness

The hardness of a water sample is an indication of its calcium and magnesium content. For this test, accurate results to indicate the bioswale model's effect on this characteristic were not obtained because the water discharged by the model was tainted with dye from the mulch layer, as shown in Figure 28. The hardness test involved titrating a sample of the water until it changed color, but the dye interfered with the color change. Therefore, the hardness data was not usable as an indication of the effectiveness of the bioswale. From this complication, a recommendation was developed to avoid the use of dyed mulches in bioswale construction.

Figure 28: Discharge water tainted with mulch dye

6.7 Phosphorus

Phosphorus is a nutrient which can produce eutrophication if it exists in water at high enough concentrations. Therefore, it is desirable that the model decreases the levels of phosphorus in the synthetic water sample. Figure 29 illustrates how a common aquarium kit was used to test the phosphate levels in the water samples, which were then converted to phosphate-phosphorous.

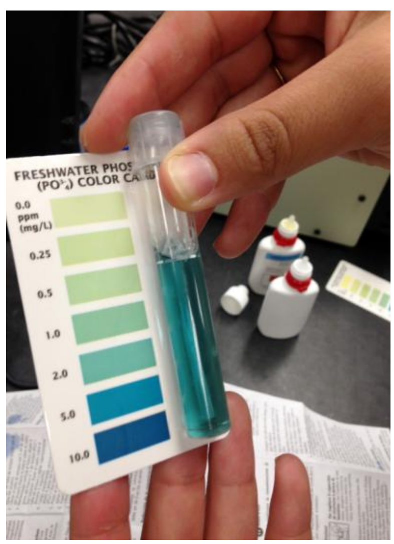

Figure 29: Common aquarium test performed for phosphorus content

As seen in Figure 30, the model either decreased or held the same phosphorus levels in the sample. The average initial phosphorus level was 0.7 mg/L, while the average final phosphorus level was 0.5 mg/L. The orange line represents the maximum level of phosphorus permitted in a storm drain system at 2.0 mg/L, which the results of the discharge water fell well under. The green line represents the typical rainwater runoff level at 0.6 mg/L.

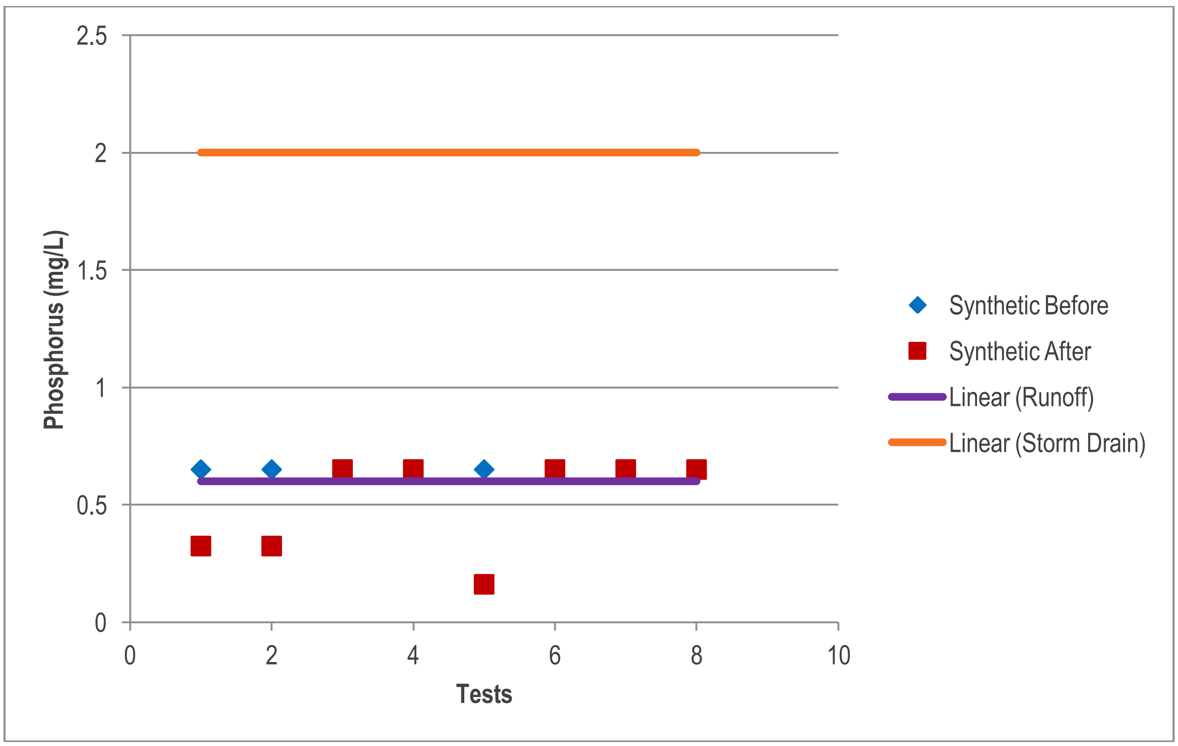

Figure 30: Results of phosphorus testing

6.8 Nitrogen

Like phosphorus, nitrogen is another nutrient that can produce eutrophication. The results of nitrogen testing can be seen in Figure 31. The input of the synthetic sample had an average nitrogen level of 9 mg/L and the output had an average nitrogen level of 1.7 mg/L. The model was effective in reducing the levels of nitrogen in the water sample. The purple line represents the level of nitrogen in typical rainwater runoff at 2 mg/L.

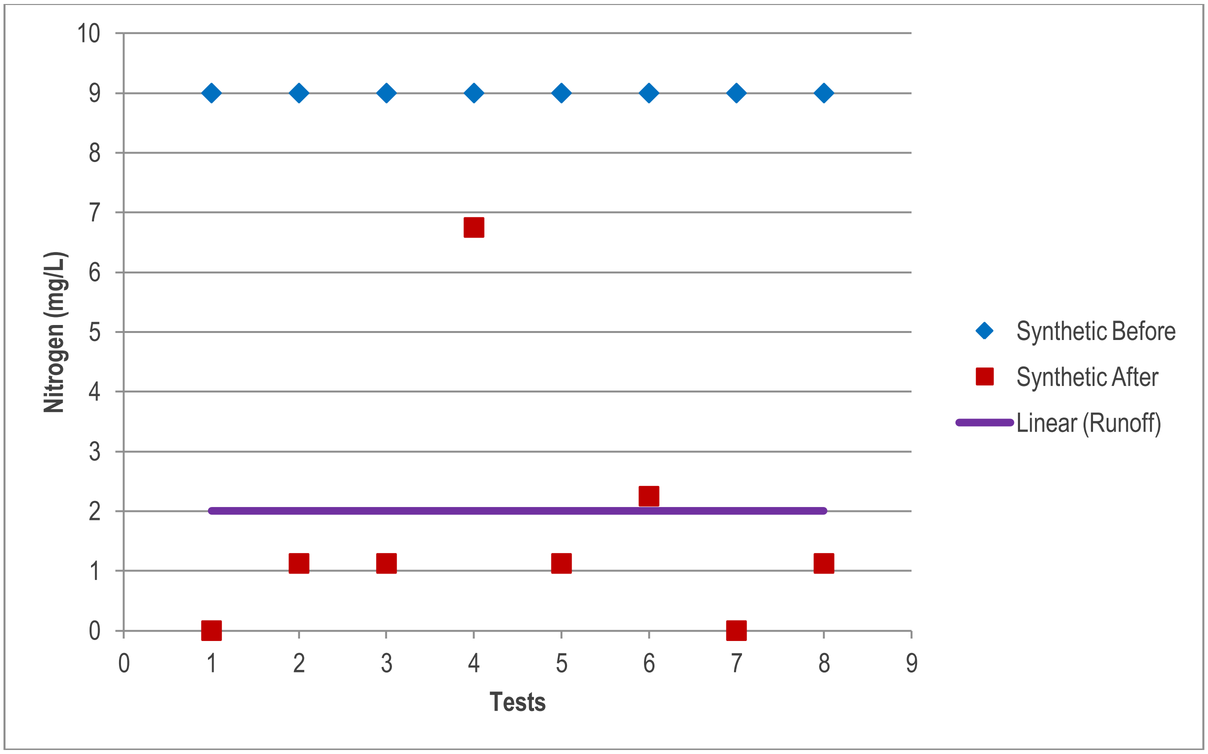

Figure 31: Results of nitrogen testing

Chapter 7: Curriculum

7.1 Demonstrations

The bioswale model will be presented to the children who attend future science camps at Walden West. The product will teach them about the harm caused by the uncontrolled runoff from man-made additions to the environment like parking lots and structures, the problems with using chemical processes to improve the quality of water, and the benefits of the capture and natural filtration of water. The goal of the model demonstration is to provide the children of this community with a strong scientific and sustainable background, which will allow them the opportunity to make a strong impact in their own communities.

For the model demonstration, students should split into teams of 2 or 3. Each team should be provided with a five-gallon bucket full of water. Each team should choose an initiation point for their rainwater runoff within the impervious drainage area on the Walden West site. A five-gallon bucket will be placed at the discharge pipe in the meadow. The water will be poured from their initiation point so that it drains toward the discharge point. When the water stops flowing from the discharge pipe, initial phosphate and nitrate tests will be performed on the water collected by using the testing kits supplied. Next, the students will pour the collected water into the top of the bioswale model provided by Santa Clara University. Once the water has infiltrated through the model, the discharge will be collected in a five-gallon bucket. The nitrate and phosphate tests will be repeated on the water discharged from the model. Students will see the difference in phosphate and nitrogen levels from before infiltration and after infiltration.

For younger age groups, a project was created involving simplified bioswales in order to explain the concept of filtration. Small holes are poked in the bottom of a plastic cup with a sharp pencil, pen, or scissors. The cups is filled halfway full with gravel. The rest of the cup is filled with soil, leaving half an inch of space between the top of the soil and the rim of the cup. A second cup is then filled with water and stirred with approximately half a tablespoon of glitter. The glitter symbolizes all of the pollutants that can be found in rainwater runoff, like organic/inorganic particles and excess nutrients. Holding the gravel and soil-filled cup over a third cup, the glittery water is poured onto the top surface of the soil, allowing the water to infiltrate completely through the cup. All discharge is collected in the third cup. The students will be able to see that the glitter representing the pollutants does not make it through the bioswale.

7.2 Supplementary Materials

Supplementary materials will be provided for the students to enable them to learn even more about bioswales and their purpose. These materials include a word search, a crossword puzzle and a cross section of a bioswale which can be decorated by layer. These materials will help the students better understand the contents and purpose of a bioswale. The supplementary materials can be found in Appendix E.

Chapter 8: Non-Technical Issues

8.1 Political Issues

Construction of bioswales has become a very common part of development around buildings in urban areas. Because the project was designed to be constructed at Walden West, which is part of the Santa Clara County Office of Education, the project had the support of local government. The project accommodated the goals of Santa Clara University's Civic Engagement learning objectives 1.1 and 1.2. In addition, a bioswale is a sustainable landscape development. The sustainable system would provide an educational model for the children at Walden West, which generated additional support for this project. Because the project was small, there were no additional permits required of the design team at Walden West.

8.2 Environmental Issues

The project was subject to the requirements of the Santa Clara Valley Urban Runoff Pollution Prevention Program (SCVURPPP) and fell under the jurisdiction of the City of Saratoga. Long-term negative environmental impacts were not anticipated, as the material being added is SCVURPPP-approved gravel, soil, mulch, waterproof liner, and plants. Using approved materials ensured the bioswale was sustainable because high quality promotes a long life of usefulness before the materials' filtering capabilities are depleted and replacement is required. The project addressed environmental issues associated with rainwater runoff, including flooding and erosion, by providing a means to contain and reuse runoff in a way that prevented erosion from occurring and utilized flooding in a controlled fashion.

8.3 Economic Issues

Square footage costs of bioswales are typically between \$3-\$10. Some economic benefits of bioswales include the need for fewer storm sewers and reducing the amount of land area needed for detention. Bioswales are known to be an efficient and cost-effective infrastructure investment. Because adequate funding could not be supplied, a bioswale model was constructed. The design team attempted to stay within the budget afforded by the funds provided by Santa Clara University while attaining all goals of the project in the best way possible.

8.4 Safety Issues

The design of a bioswale does not have any significant safety risks. However, if the full-scale model were constructed, safety would become the number one factor for the design team. All construction would be done in accordance with OSHA standards for construction and excavation. During construction, all required precautions would be taken to ensure the safety of the individuals involved with the project. Once the project is constructed, all displaced soil would be graded back to at or near ground level to ensure no lingering safety issues after the construction is complete.

Safety played a huge role in the design of the model bioswale. The bioswale model was constructed on locking wheels to ensure that it did not move during model demonstrations to campers at Walden West. In addition, the wood framing was sanded before it was painted, and all screws and nails were safely lodged in the model to guarantee that the model was safe for children to be around.

8.5 Aesthetic Issues

Although the success of the project focuses on functionality instead of looks, the aesthetics of the bioswale remain important in fulfilling the intended use of the product. A goal of Walden West is to promote environmental consciousness. To meet this goal, the bioswale design would need to be made visually appealing to attract the attention of the camp's visitors, generate curiosity and learning about rainwater runoff, and encourage people to take actions in water conservation and reuse in the world around them. A bioswale that is dry and dead or otherwise ill designed would not make people inclined to be more water-conscious and/or install a bioswale on their own properties. Therefore, things like the placement of the bioswale on the site and the arrangement of the plants within the installment would need to be considered before the actual bioswale was constructed to ensure that it blended into the natural settings in an attractive way.

Similarly, the model bioswale was designed and constructed in such a way as to make it aesthetically appealing to the children who would be learning from it. Extra money was spent to make one side of the Plexiglas box thicker so that it could function as a viewing pane. Through this pane, the students can see the different layers of the bioswale and understand the filtration process. The wood framing was painted white and the Santa Clara University seal was painted on the front cover of the model to make it more visually appealing, as shown in Figure 32.

Figure 32: Improving the aesthetics of the model

8.6 Ethical Issues

To accommodate the goals of Walden West as articulate in their mission statement and those of Santa Clara University as set out in their Science, Technology, and Society (STS) learning objectives, a curriculum was established for the bioswale model. The teaching materials will ensure that the campers take away knowledge about water consciousness and reuse. The curriculum recognizes the sustainable features of a bioswale, the sciences behind runoff, infiltration, and irrigation, the harm that can be caused by water displaced by manmade elements, and the importance of being conscious of water use and reuse. By producing such a curriculum, the design team acted ethically in relation to the missions of Santa Clara University and Walden West by promoting a respect for nature in a fashion that may be continued after this senior design project is completed.

Chapter 9: Recommendations for Walden West

9.1 Result Implications

Based on the water quality testing results, a bioswale is a good method to improve water quality to a level suitable for irrigation. It is recommended that Walden West install the bioswale in the meadow, but note that this would most likely only partially satisfy the water demand for the garden. This is because rainwater is an unpredictable supply. Therefore, it is recommended that Walden West continue to explore additional options, such as the on-site pond, to get the garden completely off of well water.

9.2 Lessons Learned

Several facts about bioswale construction were gained through the execution of the project. Water quality results revealed that the use of dyed mulch in bioswales is not recommendable, as the dye can leach off of the mulch and remain in the water as it filters through the layers. It is, however, recommended that the gravel layers be thoroughly rinsed before being installed in a bioswale in order to reduce the potential for high initial turbidity levels due to dust and miscellaneous debris. Bioswales should also be flushed several times and tested to verify that they are producing water that meets desired qualifications before their resultant water is put to use.

Chapter 10: Conclusion

In summary, all of the goals initially set forth in this senior design project were accomplished. A potential water source to complete Walden West's existing system was investigated, and recommendations were made regarding its future implementation based on results obtained through model testing. Additionally, a teaching tool was created for future science camps in the form of the bioswale model, and a curriculum was developed to aid in the teaching of children grades K-12 about the concepts behind rainwater runoff reuse.

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Appendix A

Bioretention Soil Mix Requirements and Approved Plants

Appendix

C

Soil Specifications

This appendix contains the biotreatment soil specifications that were submitted to the Regional Water Board on December 1, 2010, as required by Provision C.3.c.i.(2)(a)(vi) of the MRP and adopted by the Water Board on November 28, 2011. The MRP requires that regional specifications approved by the Water Board be used in biotreatment measures beginning December 1, 2011.

Specifications for Soils for Biotreatment or Bioretention Facilities

Soils for biotreatment or bioretention areas shall meet two objectives:

- Be sufficiently permeable to infiltrate runoff at a minimum rate of 5" per hour during the life of the facility, and
- Have sufficient moisture retention to support healthy vegetation.

Achieving both objectives with an engineered soil mix requires careful specification of soil gradations and a substantial component of organic material (typically compost).

The San Francisco Regional Water Board has developed specifications for a bioretention soil mix. Local soil products suppliers have expressed interest in developing 'brand-name' mixes that meet these specifications. At their sole discretion, municipal construction inspectors may choose to accept test results and certification for a 'brand-name' mix from a soil supplier. Updated soil and compost test results may be required; tests must be conducted within 120 days prior to the delivery date of the bioretention soil to the project site.

Typically, batch-specific test results and certification will be required for projects installing more that 100 cubic yards of bioretention soil.

SOIL SPECIFICATIONS

Bioretention soils shall meet the following criteria. "Applicant" refers to the entity proposing the soil mixture for approval by a Permittee.

1. General Requirements

   Bioretention soil shall achieve a long-term, in-place infiltration rate of at least 5 inches per hour. Bioretention soil shall also support vigorous plant growth.

   Bioretention Soil shall be a mixture of fine sand, and compost, measured on a volume basis:

   60%-70% Sand

   30%-40% Compost

1.1. Submittals

The applicant must submit to the municipality for approval:

A. A sample of mixed bioretention soil.

B. Certification from the soil supplier or an accredited laboratory that the Bioretention Soil meets the requirements of this guideline specification.

C. Grain size analysis results of the fine sand component performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils.

D. Quality analysis results for compost performed in accordance with Seal of Testing Assurance (STA) standards, as specified in Section 1.4.

E. Organic content test results of mixed Bioretention Soil. Organic content test shall be performed in accordance with by Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, "Loss-On-Ignition Organic Matter Method".

F. Grain size analysis results of compost component performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils.

G. A description of the equipment and methods used to mix the sand and compost to produce Bioretention Soil.

H. Provide the following information about the testing laboratory(ies) name of laboratory(ies) including

1) contact person(s)

2) address(es)

3) phone contact(s)

4) e-mail address(es)

5) qualifications of laboratory(ies), and personnel including date of current certification by STA, ASTM, or approved equal

1.2. Sand for Bioretention Soil

A. General

Sand shall be free of wood, waste, coating such as clay, stone dust, carbonate, etc., or any other deleterious material. All aggregate passing the No. 200 sieve size shall be non-plastic.

B. Sand for Bioretention Soil Texture

Sand for Bioretention Soils shall be analyzed by an accredited lab using #200, #100, #40, #30, #16. #8, #4, and 3/8 inch sieves (ASTM D 422 or as approved by municipality), and meet the following gradation:

Sieve Size	Percent Passing (by weight) Min	Max
3/8 inch	100	100
No. 4	90	100
No. 8	70	100
No. 16	40	95
No. 30	15	70
No. 40	5	55
No. 100	0	15
No. 200	0	5

Note: all sands complying with ASTM C33 for fine aggregate comply with the above gradation requirements.

1.3. Composted Material

Compost shall be a well decomposed, stable, weed free organic matter source derived from waste materials including yard debris, wood wastes or other organic materials not including manure or biosolids meeting the standards developed by the US Composting Council (USCC). The product shall be certified through the USCC Seal of Testing Assurance (STA) Program (a compost testing and information disclosure program).

A. Compost Quality Analysis

Before delivery of the soil, the supplier shall submit a copy of lab analysis performed by a laboratory that is enrolled in the US Composting Council's Compost Analysis Proficiency (CAP) program and using approved Test Methods for the Evaluation of Composting and Compost (TMECC). The lab report shall verify:

1) Feedstock Materials shall be specified and include one or more of the following: landscape/yard trimmings, grass clippings, food scraps, and agricultural crop residues.

2) Organic Matter Content: 35% - 75% by dry wt.

3) Carbon and Nitrogen Ratio: C:N < 25:1 and C:N >15:1

4) Maturity/Stability: shall have a dark brown color and a soil-like odor. Compost exhibiting a sour or putrid smell, containing recognizable grass or leaves, or is hot (120F) upon delivery or rewetting is not acceptable. In addition any one of the following is required to indicate stability:

a. Oxygen Test < 1.3 O2 /unit TS /hr

b. Specific oxy. Test < 1.5 O2 / unit BVS /

c. Respiration test < 8 C / unit VS / day

d. Dewar test < 20 Temp. rise (°C) e.

e. Solvita® > 5 Index value

5) Toxicity: any one of the following measures is sufficient to indicate non-toxicity.

a. NH4- : NO3-N < 3

b. Ammonium < 500 ppm, dry basis

c. Seed Germination > 80 % of control

d. Plant Trials > 80% of control

e. Solvita® > 5 Index value

6) Nutrient Content: provide analysis detailing nutrient content including N-P-K, Ca, Na, Mg, S, and B.

a. Total Nitrogen content 0.9% or above preferred.

b. Boron: Total shall be <80 ppm; Soluble shall be <2.5 ppm

7) Salinity: Must be reported; < 6.0 mmhos/cm

8) pH shall be between 6.5 and 8. May vary with plant species.

B. Compost for Bioretention Soil Texture

Compost for Bioretention Soils shall be analyzed by an accredited lab using #200, 1/4 inch, 1/2 inch, and 1 inch sieves (ASTM D 422 or as approved by municipality), and meet the following gradation:

Sieve Size	Percent Passing (by weight) Min	Max
1 inch	99	100
1/2 inch	90	100
1/4 inch	40	90
No. 200	2	10

C. Bulk density: shall be between 500 and 1100 dry lbs/cubic yard

D. Moisture Content shall be between 30% - 55% of dry solids.

E. Inerts: compost shall be relatively free of inert ingredients, including glass, plastic and paper, < 1 % by weight or volume.

F. Weed seed/pathogen destruction: provide proof of process to further reduce pathogens (PFRP). For example, turned windrows must reach min. 55C for 15 days with at least 5 turnings during that period.

G. Select Pathogens: Salmonella <3 MPN/4grams of TS, or Coliform Bacteria <10000 MPN/gram.

H. Trace Contaminants Metals (Lead, Mercury, Etc.) Product must meet US EPA, 40 CFR 503 regulations.

I. Compost Testing

The compost supplier will test all compost products within 120 calendar days prior to application. Samples will be taken using the STA sample collection protocol. (The sample collection protocol can be obtained from the U.S. Composting Council, 4250 Veterans Memorial Highway, Suite 275, Holbrook, NY 11741 Phone: 631-737-4931, www.compostingcouncil.org). The sample shall be sent to an independent STA Program approved lab. The compost supplier will pay for the test.

VERIFICATION OF ALTERNATIVE BIORETENTION SOIL MIXES

Bioretention soils not meeting the above criteria may be evaluated on a case by case basis. Alternative bioretention soil must meet the following specification: "Soils for bioretention facilities must be sufficiently permeable to infiltrate runoff at a minimum rate of 5 inches per hour during the life of the facility, and must provide sufficient retention of moisture and nutrients to support healthy vegetation."

The following guidance is offered to assist municipalities with verifying that alternative soil mixes meet the specification:

1. <u>General Requirements</u>

   Bioretention soil shall achieve a long-term, in-place infiltration rate of at least 5 inches per hour. Bioretention soil shall also support vigorous plant growth.

   1.1. Submittals

   The applicant must submit to the municipality for approval:

   A. A sample of mixed bioretention soil.

   B. Certification from the soil supplier or an accredited laboratory that the Bioretention Soil meets the requirements of this guideline specification.

   C. Certification from an accredited geotechnical testing laboratory that the Bioretention Soil has an infiltration rate between 5 and 12 inches per hour as tested according to Section 1.2.

   E. Organic content test results of mixed Bioretention Soil. Organic content test shall be performed in accordance with by Testing Methods for the Examination of Compost and Composting (TMECC) 05.07A, "Loss-On-Ignition Organic Matter Method".

   F. Grain size analysis results of mixed bioretention soil performed in accordance with ASTM D 422, Standard Test Method for Particle Size Analysis of Soils.

   G. A description of the equipment and methods used to mix the sand and compost to produce Bioretention Soil.

   H. Provide the following information about the testing laboratory(ies) name of laboratory(ies) including

   1) contact person(s)

   2) address(es)

   3) phone contact(s)

   4) e-mail address(es)

   5) qualifications of laboratory(ies), and personnel including date of current certification by STA, ASTM, or approved equal

1.2. Bioretention Soil

A. Bioretention Soil Texture

Bioretention Soils shall be analyzed by an accredited lab using #200, and 1/2" inch sieves (ASTM D 422 or as approved by municipality), and meet the following gradation:

Sieve Size	Percent Passing (by weight) Min	Max
1/2 inch	97	100
No. 200	2	5

B. Bioretention Soil Permeability testing

Bioretention Soils shall be analyzed by an accredited geotechnical lab for the following tests:

1. Moisture – density relationships (compaction tests) shall be conducted on bioretention soil. Bioretention soil for the permeability test shall be compacted to 85 to 90 percent of the maximum dry density (ASTM D1557).

2. Constant head permeability testing in accordance with ASTM D2434 shall be conducted on a minimum of two samples with a 6-inch mold and vacuum saturation.

MULCH FOR BIORETENTION FACILITIES

Mulch is not required by this guidance but is recommended for the purpose of retaining moisture, preventing erosion and minimizing weed growth. It should be noted that projects subject to the State's Model Water Efficiency Landscaping Ordinance (or comparable local ordinance) will be required to provide at least two inches of mulch. Aged mulch, also called compost mulch, reduces the ability of weeds to establish, keeps soil moist, and replenishes soil nutrients. Aged mulch can be obtained through soil suppliers or directly from commercial recycling yards. Apply 1" to 2" of composted mulch, once a year, preferably in June following weeding.

Compared to green wood chip or bark mulch, aged mulch has somewhat less of a tendency to float into overflow inlets during intense storms. Bark or wood chip mulch may be used on the side slopes of basins above the maximum water line. The project landscape architect may also specify another type of non-floating mulch, subject to approval by the local jurisdiction.

Scientific Name	**Common Name**
Iris douglasiana	Pacific Coast Iris
Juncus patens	blue rush
Aristida purpurea	purple three-awn
Bouteloua gracitis	blue grama
Chondropetalum tectorum	cape rush
Deschampsia cespitosa	tufted hairgrass
Deschampsia cespitosa ssp. holciformis	Pacific hairgrass
Elymus glaucus	blue wild rye
Festuca californica	California fescue
Leymus triticoides	creeping wildrye
Linum usitatissimum	flax
Melica imperfecta	coast range melic
Muhlenbergia rigens	deergrass
Nassella pulchra	purple needlegrass
Allium spp.	wild onion
Clarkia spp.	Clarkia
Epilobium densiflorum	dense spike-primrose
Eschscholzia californica	California poppy
Limonium californicum	marsh rosemary
Linanthus spp.	linanthus
Lotus scoparius	deerweed
Mimulus aurantiacus	common monkeyflower
Mimulus cardinalis	scarlet monkeyflower
Monardella spp.	coyote mint
Nepeta spp.	catmint
Penstemon spp.	bearded tongue
Thymus pseudolanuginosus	woolly thyme
Arctostaphylos densiflora 'McMinn'	manzanita 'McMinn'
Arctostaphylos uva-ursi ’Emerald Carpet’	manzanita ‘Emerald Carpet’
Baccharis pilularis ‘Twin Peaks’	coyote brush prostrate
Buddleia spp.	butterfly bush
Calycanthus occidentalis	spicebush
Carpenteria californica	bush anemone
Ceanothus hearstiorum	ceanothus
Ceanothus spp.	ceanothus
Cephalanthus occidentalis	buttonbush
Cornus stolonifera (same as C. sericea)	redtwig dogwood

Scientific Name	**Common Name**
Heteromeles arbutifolia	toyon
Holodiscus sp.	oceanspray
Mahonia aquifolium	Oregon grape
Mahonia repens	creeping Oregon grape
Prunus ilicifolia	holleyleaf cherry
Rhamnus Californica	coffeeberry
Ribes aureum	golden currant
Rosa californica	California wild rose
Rubus ursinus	California blackberry
Salvia clevelandi	Cleveland sage
Salvia leucophylla	purple sage
Salvia sonomensis	creeping sage
Sambucus mexicana	elderberry
Santolina spp.	santolina
Stachys spp.	lambs ear
Styrax officinalis redivivus	California snowdrop
Trichostema spp	wooly blue curls
Acer circinatum	vine maple
Acer macrophyllum	big leaf maple
Acer negundo* v. Californicum	box elder
Alnus rhombifolia	white alder
Alnus rubra	red alder
Betula nigra	river birch
Chilopsis sp.	desert willow
Corylus cornuta v. Californica	California hazelnut
Fraxinus latifolia	Oregon ash
Gleditsia triacanthos	honey locust
Platanus racemosa	western sycamore
Populus fremontii	Fremont's cottonwood
Quercus lobata	valley oak
Salix laevigata	red willow
Salix lasiolepis	arroyo willow
Salix lucida ssp. lasiandra	shining willow

Source: Appendix D C3 Handbook

Appendix B

C3 Handbook Bioswale Design Resources

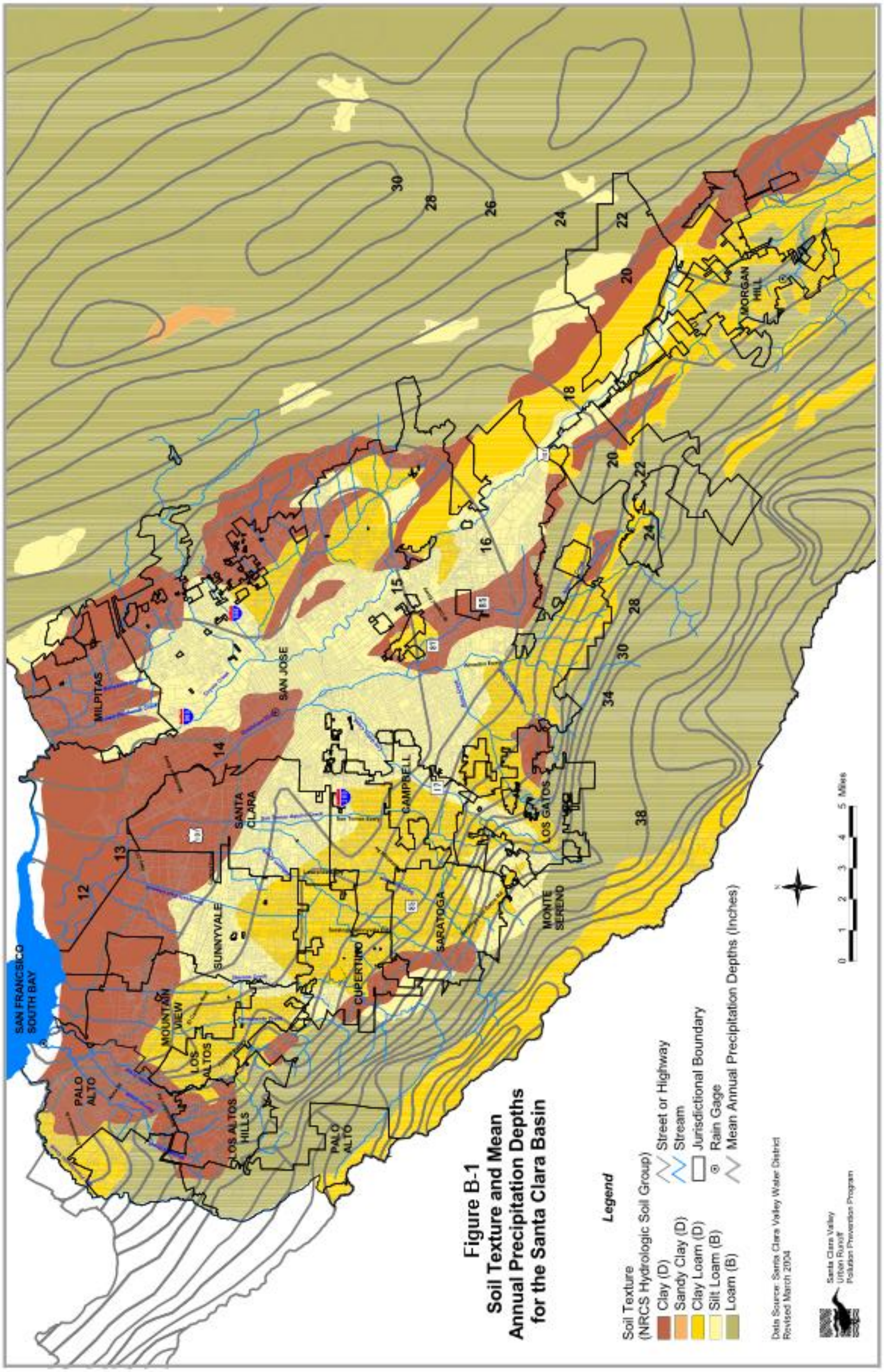
Figure B-1
Soil Texture and Mean
Annual Precipitation Depths
for the Santa Clara Basin
Legend
Soil Texture
(NRCS Hydrologic Soil Group)
Clay (D)
Sandy Clay (D)
Clay Loam (D)
Silt Loam (B)
Loam (B)
Street or Highway
Stream
Jurisdictional Boundary
Rain Gage
Mean Annual Precipitation Depths (Inches)
Data Source: Santa Clara Valley Water District
Revised March 2004
Santa Clara Valley
Urban Runoff
Pollution Prevention Program
0 1 2 3 4 5 Miles
SAN FRANCISCO
SOUTH BAY
PALO ALTO
MOUNTAIN VIEW
LOS ALTOS
LOS ALTOS HILLS
SUNNYVALE
CUPERTINO
SARATOGA
MONTE SERENO
SANTA CLARA
CAMPBELL
LOS GATOS
MILPITAS
SAN JOSE
MORGAN HILL
12
13
14
15
16
18
20
22
24
26
28
30
34
38

Table 5-2 Reference Rain Gages	
Rain Gage	**Mean Annual Precipitation (MAP_{gage})**
San Jose Airport	13.9
Palo Alto	13.7
Gilroy	18.2
Morgan Hill	19.5

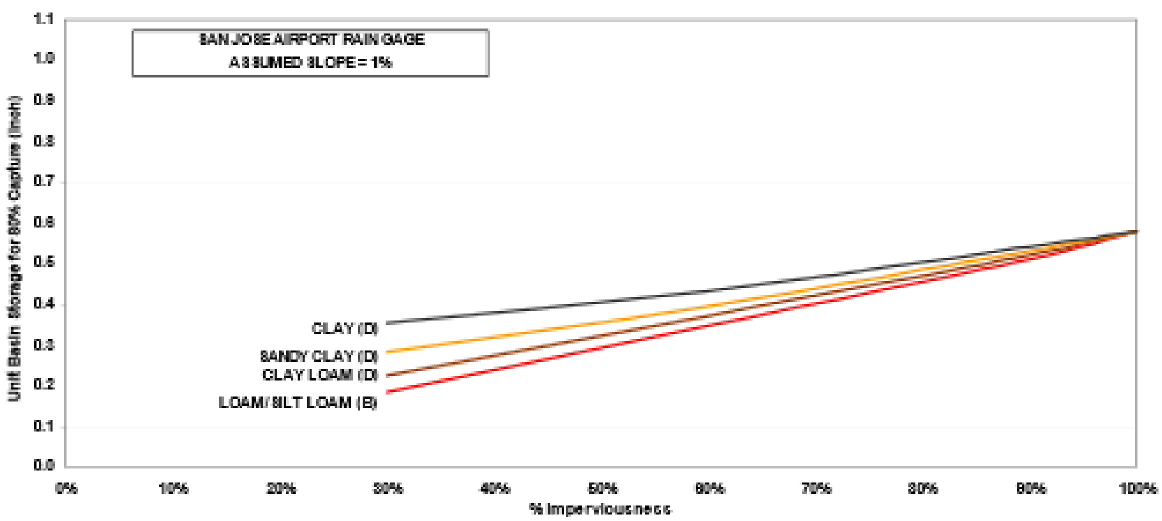

Figure B-2 Unit Basin Volume for 80% Capture - San Jose Airport Rain Gage

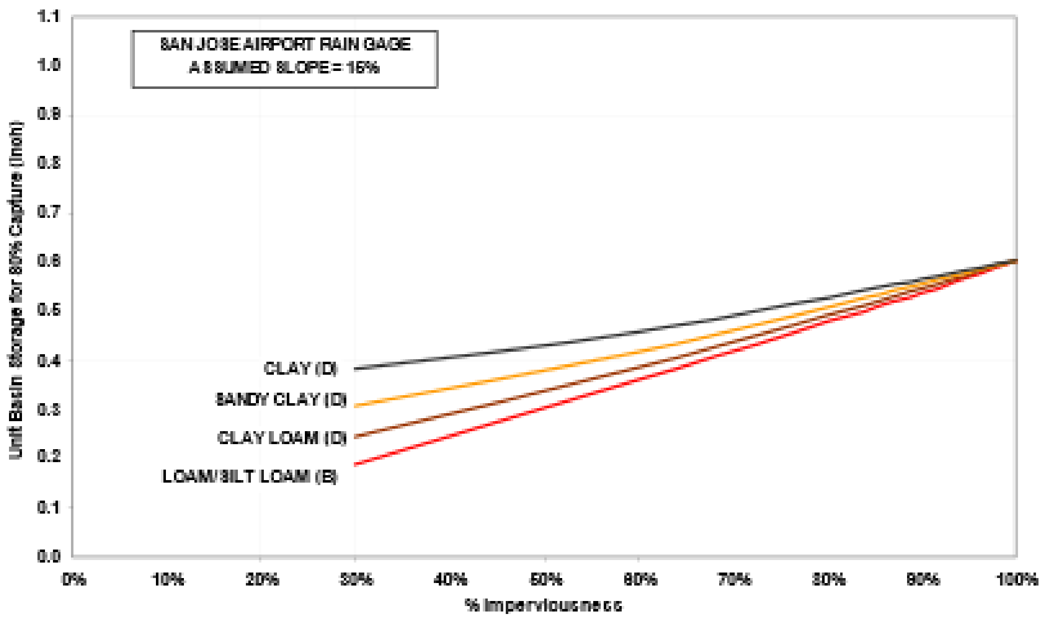

Figure B-5 Unit Basin Volume for 80% Capture - San Jose Airport Rain Gage

Appendix C

Supporting Calculations

Full-Scale Bioswale Design Calculations

Area Pervious= 18,083.77 ft^2

Area Impervious= 36,213.24 ft^2

$$\text{Percent Imperviousness} = \frac{\text{Area Impervious}}{(\text{Area Impervious}+\text{Area Pervious})}(100)$$
$$= \frac{36{,}213.24}{(36{,}213.24+18{,}083.77)}(100)$$
$$= 66.7\%$$

MAP_{site}= 43 in.

MAP_{gage}= 13.9 in.

$$\text{Rain Gage Correction Factor} = \frac{MAP_{site}}{MAP_{gage}} = \frac{43}{13.9} = 3.09$$

Soil Type= Loam

Average Slope= 0.0447

Unit Basin Storage Volume= 0.4 in.

Water Quality Design Volume =

Rain Gage Correction Factor x Unit Basin Storage Volume x Drainage Area

=3.09 x 0.4 x (36,213.24 + 18,083.77)/12= 5,599 ft^3

Rainfall Intensity= 0.2 in./hr

$$\text{Duration of Rain Event} = \frac{\text{Unit Basin Storage Volume}}{\text{Rainfall Intensity}} = \frac{0.4}{0.2} = 2 \text{ hrs}$$

Full-Scale Bioswale Design Calculations – Continued

Preliminary Estimate of Bioswale Surface Area= 0.3 x Area Impervious= 0.3 x 36,213.24

$= 1{,}086\ ft^2$

Volume of Runoff that Filters through Treatment Soil= Preliminary Estimate of Bioswale Surface Area x Design Surface Loading Rate x Duration of Rain Event

$=1{,}086 \times \frac{5}{12} \times 2 = 905\ ft^3$

Volume Remaining After Treatment= Water Quality Design Volume – Volume of Runoff that Filters through Treatment Soil

$= 5{,}599 - 905 = 4{,}694\ ft^3$

Average Ponding Depth= $\frac{\text{Volume Remaining After Treatment}}{\text{Assumed Bioretention Area}}(12) = \frac{4{,}694}{1{,}086}(12) = 51.8\text{ in.} > 12 in.$

$\Rrightarrow$ REVISE SURFACE AREA ESTIMATE AND REDESIGN

Bioswale Model Plexiglas Box Thickness and Weight Calculations

Maximum Saturated Bioswale Material Applied Stress= $\sigma_c = (\gamma_{mulch} + \gamma_{water})t_{mulch} + (\gamma_{soil}+\gamma_{water})t_{soil} + \left(\gamma_{pea\ gravel} + \gamma_{water}\right)t_{pea\ gravel} + (\gamma_{Class\ 2\ Permeable} + \gamma_{water})t_{Class\ 2\ Permeable}$

$= (30+62.4)\ (\frac{2}{12}) + (100+62.4)\ (\frac{18}{12}) + (120+62.4)\ (\frac{2}{12}) + (140+62.4)\ (\frac{12}{12})$

$= 491.8\ \text{lb/ft}^2\ (\frac{1'}{12"})^2 = 3.42\ \text{psi}$

Resultant Force on 1" wide, 34" tall, t" thick Plexiglas Section= $R = \sigma_c * w * \frac{h}{2}$

$= (3.42)\ (1)\ (\frac{34}{2})$

$= 58.1\ \text{lbs}$

Moment at Bottom of Plexiglas Section= $M = R * l$

$= (58.1)\ (\frac{34}{3})$

$= 659\ \text{lb-in.}$

Moment of Intertia of Cross Section of Plexiglas Section= $I = \frac{wt^3}{12} = \frac{(1)t^3}{12} = \frac{t^3}{12}$

Plexiglas Allowable Stress= $\sigma_a = \frac{\sigma_y}{FS} = \frac{10{,}000}{2} = 5{,}000\ \text{psi}$

Design Thickness Solution= $\sigma_a = \frac{M*c}{I}$

$5{,}000 = \frac{659*(\frac{t}{2})}{(\frac{t^2}{12})}$

$t = 0.89\text{in.}$

Weight of Bioswale Materials= $W = \sigma_c * A = (3.42)\ (24)\ (24) = 1{,}970\ \text{lbs}$

Synthetic Water Sample Mix Design Calculations

Sodium Phosphate = $H_{15}O_{11}Na_2P$

Sodium Phosphate Formula Weight = $FW_{H_{15}O_{11}Na_2P}$ = 268.07 g

Amount of phosphorus in stock solution = $C_P * \frac{FW_{H_{15}O_{11}Na_2P}}{FW_P} = X_P,$

$$= 1\frac{g}{L}P * \frac{268.07g}{31g}$$

=8.647 g in 1 L water

Amount of phosphorus needed in 5 gallon sample = $S * P_S = S_P,$

$$= \frac{18.9271L}{1} * \frac{0.6mgP}{1L}$$

= 11.356 mg of phosphorus

Amount of stock solution to add to synthetic mix = $\frac{S_P}{C_P} = X_{SS}$

$$= \frac{11.356mgP}{1mgP/mL}$$

= 11.356 mL

Potassium Nitrate = KNO_3

Potassium Nitrate Formula Weight = KNO_3 = 101.1 g

Amount of nitrate in stock solution = $C_N * \frac{FW_{KNO_3}}{FW_N} = X_N,$

$$= 1\frac{g}{L}N * \frac{101.1g}{14.0067g}$$

= 7.218 g in 1 L water

Synthetic Water Sample Mix Design Calculations – Continued

Amount of nitrogen needed in 5 gallon sample = $S * N_S = S_N$,

$$= \frac{18.9271L}{1} * \frac{3mgN}{1L}$$

= 56.7813 mg of nitrogen

Amount of stock solution to add to synthetic mix = $\frac{S_N}{C_N} = Y_{SS}$

$$= \frac{56.7813mgN}{1mgN/mL}$$ = 56.7813 mL

Appendix D

Manufacturers' Catalog Information

Physical Properties of Acrylite® GP ACRYLIC SHEET

Property[a]		ASTM Method	Typical Value (.236" Thickness)[b]
Mechanical	Specific Gravity	D 792	1.19
	Tensile Strength	D 638	10,000 psi (69 M Pa)
	Elongation, Rupture		4.2%
	Modulus of Elasticity		400,000 psi (2800 M Pa)
	Flexural Strength (Rupture)	D 790	16,500 psi (114 M Pa)
	Modulus of Elasticity		475,000 psi (3300 M Pa)
	Compressive Strength (Yield)	D 695	18,000 psi (124 M Pa)
	Modulus of Elasticity		430,000 psi (2960 M Pa)
	Shear Strength	D732	9,000 psi (62 M Pa)
	Impact Strength		0.4 ft. lbs/in. of notch
	Izod Milled Notch	D 256	(21.6 J/m of notch)
	Rockwell Hardness	D785	M-94
	Barcol Hardness	D 2583	49
	Residual Shrinkage[c] (Internal Strain)	D 702	2%
Optical (Clear Material)	Refractive Index	D 542	1.49
	Light Transmission, Total	D 1003	92%
	UV Transmission		0 at 320 nanometers
	Haze		Less than 1%
Thermal	Forming Temperature	—	340-380°F (170-190°C)
	Deflection Temperature under load, 264 psi	D 648	210°F (99°C)
	Vicat Softening Point	D 1525	239°F (115°C)
	Maximum Recommended Continuous Service Temperature	—	180°F [d] (82°C)
	Coefficient of Linear Thermal Expansion	D 696	0.000040 in/in-°F (0.000072 m/m-°C)
	Coefficient of Thermal Conductivity (k-Factor)	Cenco-Fitch	1.3 BTU/(Hr) (Sq. Ft.) (°F/in.) (0.19 w/m·K)
	Flammability (Burning Rate 3mm thickness)	D 635	1.2 in/min. (30.5 mm/min.)
	Self-Ignition Temperature	D 1929	910°F(490°C)
	Specific Heat @ 77°F	—	0.35 BTU/(lb.) (°F) (1470 J/Kg·k)
	Smoke Density Rating (3mm thickness)	D 2843	11.4%
Electrical	Dielectric Strength		
	Short Time (0. 1 25"-thickness)	D 149	430 volts/mil (17 KV/mm)
	Dielectric Constant		
	60 Hertz	D 150	3.5
	1,000 Hertz		3.2
	1,000,000 Hertz		2.7
	Dissipation Factor		
	60 Hertz	D 150	0.06
	1,000 Hertz		0.04
	1,000,000 Hertz		0.02
	Volume Resistivity	D 257	1.6 x 10^{16} ohm-cm
	Surface Resistivity	D 257	1.9 X 10^{15} ohms
Water Absorption	24 hrs @ 73°F	D 570	0.2%
	Weight Gain during Immersion		0.2%
	Soluble Matter Lost		0.0%
	Water Absorbed		0.2%
	Dimensional Change during Immersion		0.2%
Long Term Water Absorption	Weight Gain during Immersion	D 570	
	7 days		0.5%
	14 days		0.6%
	21 days		0.8%
	35 days		1.0%
	48 days		1.1%
Odor		—	None
Taste		—	None

NOTES: (a) Typical values: should not be used for specification purposes.
(b) Values shown are for 6mm thickness unless noted otherwise. Some values will change with thickness.
(c) Difference in length and width, as measured at room temperature, before and after heating above 300°F.
(d) It is recommended that temperatures not exceed 180°F for continuous service, or 200°F for short, intermittent use.

Acrylite® GP
ACRYLIC SHEET

ACRYLITE® GP acrylic sheet is a cell-cast acrylic sheet made to exacting standards. It offers excellent optical characteristics, thickness tolerances, light stability, and low internal stress levels for consistent performance.

Colorless ACRYLITE GP sheet carries an exclusive 10-year limited warranty on light transmission, your assurance of a quality product. A printed copy of the warranty is available from CYRO Industries or wherever ACRYLITE® acrylic sheet is sold.

In addition to colorless sheet, a wide range of transparent, translucent and opaque colors are also available.

Characteristics

ACRYLITE GP sheet is a lightweight, rigid thermoplastic material that has many times the breakage resistance of standard window pane glass. It is highly resistant to weather conditions. ACRYLITE GP sheet can be easily sawed, machined, thermoformed, and cemented. It is suitable for most commercial applications and is ultraviolet light absorbing up to approximately 360 nanometers.

For greater ultraviolet light transmission, ACRYLITE® OP-1 or ACRYLITE® OP-4 acrylic sheet may be used. For greater ultraviolet light absorption, ACRYLITE® OP-2 acrylic sheet filters out more of the UV radiation than regular ACRYLITE GP sheet grades.

For security applications, ACRYLITE GP 1.25" sheet may be used.

Because of its unique properties, ACRYLITE GP acrylic sheet is ideal for a wide range of applications, such as:

- Merchandising Displays
- Lighting Fixture Diffusers
- Decorative Paneling
- Security Glazing
- Aquariums
- Hockey Rinks
- Industrial and School Glazing
- Shower Enclosures
- Skylights
- Signs

Availability

ACRYLITE GP sheet is available in thicknesses from .060" to 2" (1.5 mm to 50 mm) and in more than 40 standard sizes from 36" x 48" to 72" x 120" (1.83 m x 3.05 m). Sheets can be furnished masked with paper or polyethylene film, or half-masked.

Colorless sheets and over 50 standard colors are available from distributors across the country. Custom colors can be made to order.

ACRYLITE GP sheet is also available with a non-glare, matte surface as ACRYLITE® GP P-95 and ACRYLITE® GP DP-9 acrylic sheet. Both retain the same physical properties of standard ACRYLITE GP sheet with the addition of the matte surface. ACRYLITE GP P-95 sheet offers a one-sided textured non-glare surface, while ACRYLITE GP DP-9 sheet offers the same surface on two sides.

Safety

ACRYLITE GP sheet is more impact-resistant than glass. If subjected to impact beyond the limit of its resistance, it does not shatter into small slivers but breaks into comparatively large pieces. ACRYLITE GP sheet meets the requirements of ANSI Z 97.1 for use as a Safety Glazing material in Buildings (for thicknesses 0.080" [2.0 mm] to 0.500" [1 2.7mm]).

Weather Resistance

Acrylic offers better weather resistance than other types of transparent plastics. ACRYLITE GP sheet will withstand exposure to blazing sun, extreme cold, sudden temperature changes, salt water spray and other harsh conditions. It will not deteriorate after many years of service because of the inherent stability of acrylic. ACRYLITE GP sheet has been widely accepted for use in skylights, school buildings, industrial plants, aircraft glazing and outdoor signs.

Dimensional Stability

Although ACRYLITE GP sheet will expand and contract due to changes in temperature and humidity, it will not shrink with age. Some shrinkage occurs when ACRYLITE GP sheet is heated to forming temperature.

Light Weight

ACRYLITE GP sheet is less than half the weight of glass, and 43% the weight of aluminum. One square foot of 1/8" (3.0 mm) thick ACRYLITE GP sheet weighs less than 3/4 pound (1/3 kilogram).

Rigidity

ACRYLITE GP sheet is not as rigid as glass or metals. However, it is more rigid than many other plastics such as acetates, polycarbonates, or vinyls. Under wind load, a sheet will bow and foreshorten as a result of deflection. For glazing installations, the maximum wind load and the size of the window must be considered when the thickness of the panel and the depth and width of the glazing channels are to be determined.

If ACRYLITE GP sheet is formed into corrugated or domed shapes, rigidity is increased and deflection minimized.

Cold Flow

Large, flat ACRYLITE GP sheet may deform due to continuous loads such as snow, or even from its own weight if not sufficiently supported. Increased rigidity obtained by forming will minimize cold flow.

Strength and Stresses

Although the tensile strength of ACRYLITE GP sheet is 10,000 psi (69 MPa) at room temperature (ASTM D638), stress crazing can be caused by continuous loads below this value. For most applications, continuously imposed design loads should not exceed 1,500 psi (10.4 MPa).

Localized, concentrated stresses must be avoided. For this reason, and because of thermal expansion and contraction, large sheets should never be fastened with bolts, but should always be installed in frames.

All thermoplastic materials-including ACRYLITE GP sheet-will gradually lose tensile strength as the temperature approaches the maximum recommended for continuous service. For ACRYLITE GP sheet, the maximum is 180°F (82°C).

Expansion and Contraction

Like most other plastics, ACRYLITE GP sheet will expand 3 times as much as metals, and 8 times as much as glass. The designer should be aware of this rather large coefficient of expansion. A 48" panel will expand and contract approximately .002" for each degree fahrenheit change in temperature. In outdoor use, where summer and winter temperatures differ as much as 100°F, a 48" sheet will expand and contract approximately 3/16". Glazing channels must be of sufficient depth to allow for expansion as well as for contraction.

ACRYLITE GP sheet also absorbs water when exposed to high relative humidities, resulting in expansion of the sheet. At relative humidities of 100%, 80%, and 60%, the dimensional changes are 0.6%, 0.4% and 0.2%, respectively.

Heat Resistance

ACRYLITE GP sheet can be used at temperatures from -40°F (-40°C) up to +200°F (93°C), depending on the application. It is recommended that temperatures not exceed 180°F for continuous service, or 200°F for short, intermittent use. Components made of ACRYLITE GP sheet should not be exposed to high heat sources such as high wattage incandescent lamps, unless the finished product is ventilated to permit the dissipation of heat.

Light Transmission

Clear, colorless ACRYLITE GP sheet has a light transmittance of 92%. It is warranted not to lose more than 3% of its light-transmitting ability in a 10-year period. Contact CYRO Industries for the complete warranty.

ACRYLITE OP-1 and ACRYLITE OP-4 sheet (ultraviolet transmitting) transmit more ultraviolet light in the range from 240 to 380 nanometers than regular ACRYLITE GP sheet grades. ACRYLITE OP-2 sheet (ultraviolet filtering) absorbs more radiation in the ultraviolet range below 400 nanometers than regular ACRYLITE GP sheet grades. It is used to protect art objects and documents from the damaging effects of ultraviolet light.

Solar Energy Control

Transparent colored ACRYLITE GP sheet can be used to reduce glare and solar energy transmittance. Sheets are available in a wide range of colors with light transmittance values from approximately 6% to 79%. This broad selection enables the designer to choose a color which provides adequate daylight while, at the same time, controls glare and solar heat buildup.

Translucent white and translucent colored ACRYLITE GP sheet diffuses light. Colorless, textured sheet also diffuses light to some extent.

Chemical Resistance

ACRYLITE GP sheet has excellent resistance to many chemicals including:
- solutions of inorganic alkalies such as ammonia
- dilute acids such as sulfuric acid up to a concentration of 30%
- aliphatic hydrocarbons such as hexane

ACRYLITE GP sheet is not attacked by most foods, and foods are not affected by it.

It is attacked, in varying degrees, by:

- aromatic solvents such as benzene and toluene
- chlorinated hydrocarbons such as methylene chloride and carbon tetrachloride
- ethyl and methyl alcohols
- some organic acids such as acetic acid
- lacquer thinners, esters, ketones and ethers

For a listing of the resistance of ACRYLITE GP sheet to more than 70 chemicals, refer to the table on page 7.

Formability

ACRYLITE GP sheet will soften gradually as the temperature is increased above 210°F (99°C). At temperatures from 340°F to 380°F (171°C to 193°C), 'it becomes soft and pliable and can be formed into almost any shape using inexpensive molds. The optimum forming temperature within this range depends on thickness and desired depth of draw. ACRYLITE GP sheet will typically shrink 1.5% when heated without a frame. As the sheet cools, it will harden and retain the formed shape.

Because ACRYLITE GP sheet is a thermoplastic material, heating a formed part to temperatures above 210°F (99°C) may cause it to revert to its original flat condition.

Cutting and Machining

ACRYLITE GP sheet can be sawed with circular saws or band saws. It can be drilled, routed, filed and machined much like wood or brass with a slight modification of tools. Cooling of the cutting tool is recommended to keep the machined edge of the sheet as cool and stress free as possible. Heat buildup should be avoided because it could lead to stress crazing. Tool sharpness and "trueness" are also essential to prevent gumming, heat buildup and stresses in the part.

Laser Cutting

Laser technology is rapidly being accepted by the industry for quick and accurate cutting, welding, drilling, scribing, and engraving of plastics.

CO_2 lasers focus a large amount of light energy on a very small area which is extremely effective for cutting complex shapes in acrylic sheet. The laser beam produces a narrow kerf in the plastic allowing for close nesting of parts and minimal waste. CO_2 lasers vaporize the acrylic as they advance resulting in a clean polished edge but with high stress levels; annealing acrylic sheet after laser cutting is recommended to minimize the chance of crazing during the service life of the part.

Cementing

ACRYLITE GP sheet can be cemented using common solvent cements or polymerizable cements. The most critical factor is the edge of the part to be cemented. The edge must have been properly machined so as to have a square flat surface and no stresses. Annealing of the part prior to cementing is recommended. Cement and cement fumes should not contact formed or polished surfaces.

Annealing

To eliminate stresses caused by machining and/or polishing, annealing is recommended. ACRYLITE GP sheet may be annealed at 180°F (82°C) with the heating and cooling times determined by the sheet thickness. An approximate guideline is: annealing time in hours equals the sheet thickness in millimeters and the cool-down period is a minimum of 2 hours ending when sheet temperature falls below 140°F. For example, 1/8" (3 mm) ACRYLITE GP sheet would be heated for 3 hours at 180°F (82°C) and slowly cooled for at least 2 hours.

Flammability

ACRYLITE GP sheet is a combustible thermoplastic. Precautions should be taken to protect the material from flames and high heat sources. ACRYLITE GP sheet usually burns rapidly to completion if not extinguished. The products of combustion, if sufficient air is present, are carbon dioxide and water. However, in many fires sufficient air will not be available and toxic carbon monoxide will be formed, as it is from other combustible materials. We urge good judgement in the use of this versatile material and recommend that building codes be followed carefully to ensure it is used properly.

Other properties related to flammability:

- Burning rate is 1.2 inches per minute (for 3 mm thickness) according to ASTM D 635.
- Smoke density: Measured by ASTM D 2843 is 11.4%.
- Self-ignition temperature is 910°F (488°C) when measured in accordance with ASTM D 1929.

While these test data are based on small scale laboratory tests frequently referenced in various building codes, they do not duplicate actual fire conditions.

ACRYLITE GP sheet meets the requirements of the following building codes for use as a Light Transmitting Plastic:

- NES (See National Evaluation Services, Inc., Report # NER-582)
- ICBO (See ICBO Evaluation Services, Inc., Evaluation Report #3715-CC2 Classification)
- BOCA and SBCCI (Accept National Evaluation Services, Inc., Report # NER-582)

Thermal Conductivity

The thermal conductivity of a material-its ability to conduct heat-is called the k-Factor. The k-Factor is an inherent property of the material and is independent of its thickness and of the surroundings to which it is exposed.

The k-Factor of ACRYLITE GP sheet is: $\frac{1.3\ \text{B.T.U.}}{(\text{hour})\ (\text{sq. ft.})\ (°\text{F /inch})}$ or $\frac{0.19\ \text{W}}{\text{m.K}}$

Whereas the k-Factor is a physical property of the material, the U-Factor—or overall coefficient of heat transfer—is the value used to calculate the total heat loss or gain through a window.

The U-Factor is the amount of heat, per unit time and area, which will pass through a specific thickness and configuration of material per degree of temperature difference between each of the two sides.

This value takes into account the thickness of the sheet, whether the sheet is in a horizontal or vertical position, as well as the wind velocity.

U-Factors are based on specific conditions (e.g., single-glazed or double-glazed installations) and are different for summer and winter.

Listed below are U-Factors for several thicknesses of ACRYLITE GP sheet for single-glazed, vertical installations, based on the standard ASHRAE* summer and winter design conditions.

U-Factors—BTU/hour sq. ft. F° (w/m² • K)

ACRYLITE GP Sheet Thickness mm	inches	Summer Conditions	Winter Conditions
3.0	.118	0.98 (5.56)	1.06 (6.02)
4.5	.177	0.94 (5.34)	1.02 (5.79)
6.0	.236	0.90 (5.11)	0.97 (5.51)
9.0	.354	0.83 (4.71)	0.89 (5.05)
31.5	1.25	0.56 (3.18)	0.58 (3.29)

*American Society of Heating, Refrigerating and Air-Conditioning Engineers

The total heat loss or gain through a window (due to temperature difference only) can be calculated by multiplying the area of the window, times the difference between indoor and outdoor temperatures, times the appropriate U-Factor (from Table above). Heat intake through solar radiation must be added to arrive at the total heat gain.

ACRYLITE GP sheet is a better insulator than glass. Its U-Factor or heat transfer value is approximately 10% lower than that of glass of the same thickness. Conversely, its R_T-Factor is about 10% greater.

Thermal Shock and Stresses

ACRYLITE GP sheet is more resistant than glass to thermal shock and to stresses caused by substantial temperature differences between a sunlit and a shaded area of a window, or by temperature differences between opposite surfaces of a window.

Surface Hardness

The surface of plastic is not as hard as that of glass. Therefore, reasonable care should be exercised in handling and cleaning ACRYLITE GP sheet.

Electrical Properties

ACRYLITE GP sheet has many desirable electrical properties and continuous outdoor exposure has little effect on these properties. It is a good insulator with surface resistivity higher than that of most plastics.

Chemical Resistance of Acrylite® GP ACRYLIC SHEET

The table below gives an indication of the chemical resistance of clear ACRYLITE GP sheet. The code used to describe chemical resistance is as follows:

R = Resistant
ACRYLITE GP sheet withstands this substance for long periods and at temperatures up to 120°F (49°C).

LR = Limited Resistance
ACRYLITE GP sheet only resists the action of this substance for short periods at room temperatures. The resistance for a particular application must be determined.

N= Not Resistant
ACRYLITE GP sheet is not resistant to this substance. It is either swelled, attacked, dissolved or damaged in some manner.

Plastic materials can be attacked by chemicals in several ways. The methods of fabrication and/or conditions of exposure of ACRYLITE GP sheet, as well as the manner in which the chemicals are applied, can influence the final results even for "R" coded chemicals. Some of these factors are listed below.

Fabrication-Stress generated while sawing, sanding, machining, drilling, polishing, and/or forming.

Exposure-Length of exposure, stresses induced during the life of the product due to various loads, changes in temperatures, etc.

Application of Chemicals-by contact, rubbing, wiping, spraying, etc.

The table therefore should be used only as a general guide and, in case of doubt, supplemented by tests made under actual working conditions.

Chemical	Code	Chemical	Code
Acetic-Acid (5%)	R	Hydrogen Peroxide (up to 40%)	R
Acetic Acid (Glacial)	N	Hydrogen Peroxide (over 40%)	N
Acetone	N	Isopropyl Alcohol (up to 50%)	LR
Ammonium Chloride (Saturated)	R	Kerosene	R
Ammonium Hydroxide (10%)	R	Lacquer Thinner	N
Ammonium Hydroxide (Conc.)	R	Methyl Alcohol (up to 15%)	LR
Aniline	N	Methyl Alcohol (100%)	N
Battery Acid	R	Methyl Ethyl Ketone (MEK)	N
Benzene	N	Methylene Chloride	N
Butyl Acetate	N	Mineral Oil	R
Calcium Chloride (Sat.)	R	Naphtha (VM&P)	R
Calcium Hypochlorite	R	Nitric Acid (up to 20%)	R
Carbon Tetrachloride	N	Nitric Acid (20%-70%)	LR
Chloroform	N	Nitric Acid (over 70%)	N
Chromic Acid	LR	Oleic Acid	R
Citric Acid (20%)	R	Olive Oil	R
Detergent Solution (Heavy Duty)	R	Phenols	N
Diesel Oil	R	Soap Solution (Ivory)	R
Dimethyl Formamide	N	Sodium Carbonate	R
Dioctyl Phthalate	N	Sodium Chloride	R
Ether	N	Sodium Hydroxide	R
Ethyl Acetate	N	Sodium Hypochlorite	R
Ethyl Alcohol (30%)	LR	Sulfuric Acid (up to 30%)	R
Ethyl Alcohol (95%)	N	Sulfuric Acid (Conc.)	LR
Ethylene Dichloride	N	Toluene	N
Ethylene Glycol	R	Trichloroethylene	N
Formaldehyde (40%)	R	Turpentine	LR
Gasoline (Regular, Leaded)	LR	Water (Distilled)	R
Glycerine	R	Xylene	N
Heptane	R		
Hexane (Commercial Grade)	R		
Hydrochloric Acid	R		
Hydrofluoric Acid (40%)	N		

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Part Number	5125
Item Weight	5.6 pounds
Product Dimensions	7.9 x 7.7 x 3.6 inches
Origin	Imported (China)

Additional Information

ASIN	B008S52OHQ
Customer Reviews	13 reviews 3.8 out of 5 stars
Best Sellers Rank	#9,753 in Home Improvement (See top 100) #8 in Home Improvement > Hardware > Furniture Hardware > Casters > Plate Casters
Shipping Weight	5.6 pounds (View shipping rates and policies)
Date First Available	January 8, 2013

Appendix E

Educational Curriculum

Glitter Bioswale

Overview: This project involves making simplified bioswales in order to explain the concept of filtration to younger age groups.

Materials:

- Plastic Cups
- Gravel
- Soil
- Glitter
- Pencil/Scissors

Directions:

1. Poke small holes in the bottom of a plastic cup with a sharp pencil, pen, or scissors (adults help younger children).

2. Fill the cup halfway full with gravel.

3. Fill the rest of the cup with soil, leaving half an inch of space between the top of the soil and the rim of the cup.

4. Fill a second cup with water, add approximately half a tablespoon of glitter to the water, and stir. Explain that the glitter symbolizes all of the bad things that can be found in rainwater runoff, like organic/inorganic particles and excess nutrients.

5. Holding the gravel and soil-filled cup over a third cup, slowly pour the glittery water onto the top surface of the soil and allow the water to infiltrate completely through the cup, collecting all of the discharge in the third cup.

6. Note how much of the glitter, or bad things, makes it through the bioswale. Discuss.

Bioswale Model Testing

Overview: In this activity, older students are encouraged to locate initiation points of rainwater runoff on the Walden West site, trace the routes of runoff to a point of discharge, collect the runoff, and discover a change in water quality after the runoff is filtered through a bioswale column.

Materials:

- 5 gallon buckets
- Water
- Phosphate Test Kit (like those used for in aquarium)
- Nitrate Test Kit (like those used for in aquarium)

Directions:

1. Split the group up into teams of 2-3, and provide each team with a five gallon bucket full of water.

2. Allow each team to choose an initiation point for their rainwater runoff within the highlighted area:

   Place a five gallon bucket at the end of the pipe at the discharge point into the meadow, as indicated in the above image.

3. Instruct each team to slowly pour their water from their initiation point, making adjustments if the water is not flowing toward the discharge point. If there is a small number of teams, move the initiation points closer to the discharge point to account for lost and ensure that enough discharge is collected for testing.

4. Once water stops flowing from the discharge pipe, perform initial tests on the water collected using the phosphate and nitrate testing kits. Discuss why excessive nitrogen and phosphorus are detrimental to a water source (eutrophication)

5. Slowly pour the collected water into the top of the bioswale model provided by Santa Clara University.

6. Making sure the discharge pipe is open, collect the discharge in a five gallon bucket.

7. Repeat the nitrate and phosphate tests on the water discharged from the model. Note the difference that the model has made on the phosphate and nitrate levels in the "rainwater runoff".

8. Discuss other ways that bioswales are used to purify rainwater runoff (TDS, turbidity, pH, etc.), and typical uses for the water once it exits a bioswale (irrigation, storm drain system, infiltration into native soils).

Bioswale Word Search

Directions: Circle the following words in the letter block below:

BIOSWALE	PLANTS	CONTAMINANTS	SUSTAINABILITY	EUTROPHICATION
GRAVEL	REUSE	INFILTRATION	RAINWATER	IRRIGATION
MULCH	SOIL	NITROGEN	PURIFICATION	PHOSPHORUS
QUALITY	RUNOFF	TURBIDITY		

R	L	T	P	E	B	Z	Z	T	L	S	O	C	S	S	S	L	U	E	V
N	A	E	V	R	U	V	G	T	T	J	V	Y	T	U	U	V	J	L	L
I	U	I	V	I	Y	T	I	L	A	U	Q	N	N	R	S	G	G	S	G
R	O	Y	N	A	D	V	R	K	N	R	C	I	A	O	T	Q	H	L	V
T	E	K	W	W	R	I	V	O	L	H	N	X	L	H	A	A	M	S	M
G	F	U	H	N	A	G	I	V	P	F	L	A	P	P	I	H	B	S	O
U	J	I	S	I	U	T	O	N	I	H	A	I	G	S	N	V	E	X	T
S	Y	S	B	E	A	U	E	L	A	Q	I	T	Q	O	A	X	W	R	H
O	S	H	T	G	E	W	T	R	Y	N	Y	C	J	H	B	B	I	G	I
I	T	F	I	N	K	R	T	G	I	U	A	C	A	P	I	Z	R	K	B
L	C	R	Y	G	A	T	C	T	W	S	T	H	E	T	L	Q	A	S	I
L	R	O	F	T	P	N	R	T	A	Y	B	Q	U	J	I	T	X	G	O
I	R	C	I	D	F	O	I	A	D	N	V	E	A	B	T	O	T	E	S
G	E	O	F	F	G	K	V	M	X	C	Z	U	B	Q	Y	P	N	L	W
W	N	X	O	E	S	Q	Y	D	A	T	U	R	B	I	D	I	T	Y	A
B	L	N	N	A	R	K	N	O	I	T	A	C	I	F	I	R	U	P	L
M	U	L	C	H	B	R	T	I	W	P	N	A	P	A	P	X	N	W	E
R	P	K	Q	Y	B	B	V	E	K	I	H	O	B	Z	B	F	P	B	D
F	X	F	S	Q	N	X	G	M	U	E	H	W	C	L	A	X	Y	L	I
A	R	J	U	M	A	K	O	Q	N	K	J	C	W	M	V	S	Z	H	D

Mini Bioswale

Overview: In this activity, younger students are encouraged to consider the types of materials that make a bioswale an effective filter.

Materials:

- Worksheet
- Liquid Glue (stronger than Elmer's)

Directions:

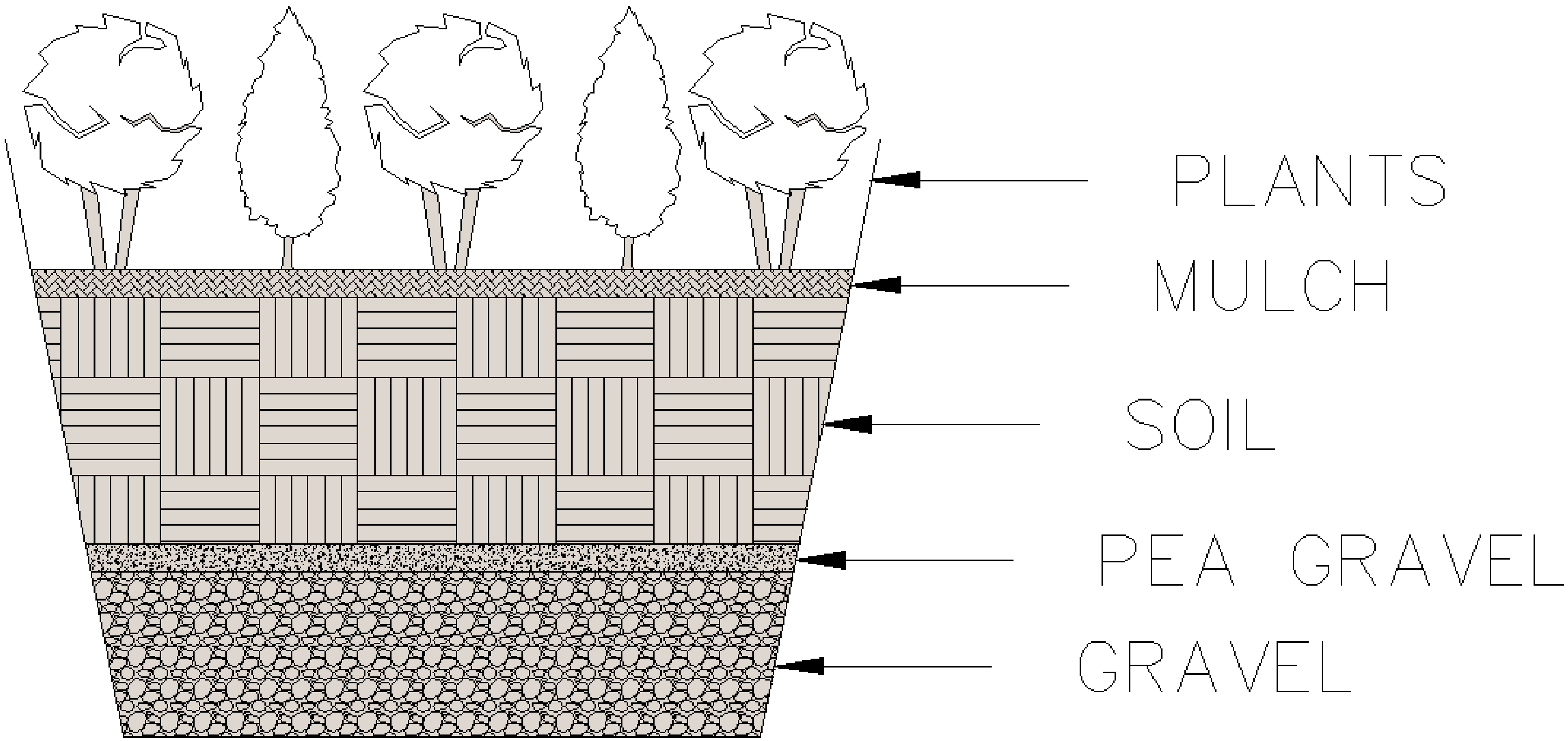
1. Give an overview of what a bioswale is, specifically what material comprises each layer (gravel at the bottom, then soil, then mulch, then plants).

2. Give the students time for a mini scavenger hunt around Walden West ground to collect the materials that they think belong in a bioswale.

3. Allow the students to glue the materials they collected in the correct region of the bioswale figure below.

4. Encourage each student to present their bioswale and explain their choice for each of the layers

MINI BIOSWALE PROJECT



Bioswale Crossword Puzzle

Across

2. The top layer of a bioswale

3. The bottom layer of a bioswale

4. The second layer of a bioswale from the bottom

7. A depression in the earth filled with specific layers of gravel, soil, mulch, and plants through which rainwater runoff is filtered

8. A nutrient that can initiate eutrophication in water when present in excess

10. A nutrient that can initiate eutrophication in water when present in excess

11. Environmental consciousness

12. A determination of how suitable water is for a specific use based on its contents, such a nutrients and particles (2 words)

13. How transparent water is, which is a function of how many suspended particles exist within it to deflect light

14. A process by which excessive plant and algae growth in bodies of water is initiated by large amount of nutrients

15. The act of a liquid seeping into and through a material like soil

16. The act of watering plants

17. Rainwater that has flowed down slopes from initial landing point

Down

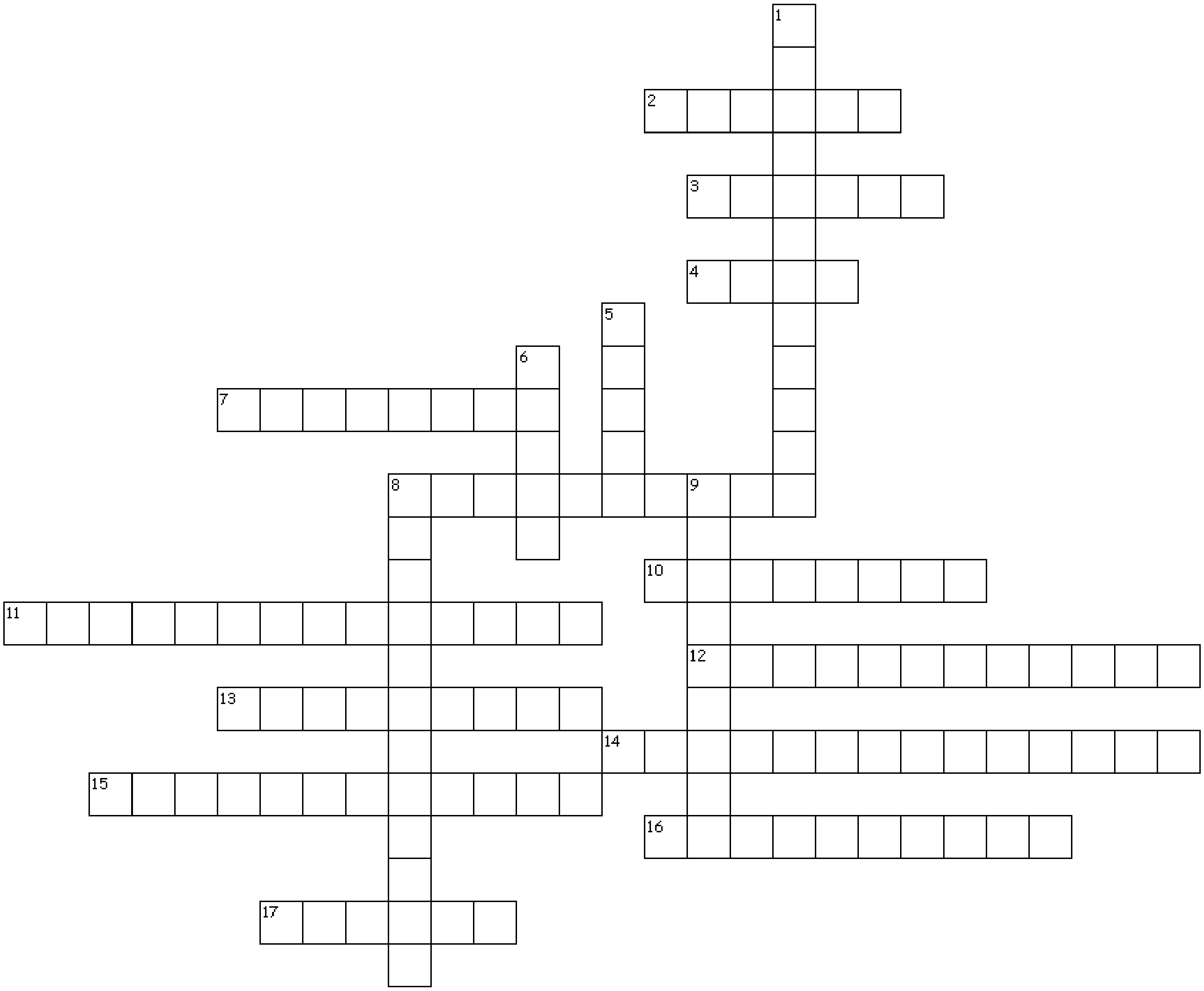
1. Pollutants

5. The third layer of a bioswale from the bottom

6. To make use of something that has already been used in a different capacity

8. The act of cleaning undesirable elements from something

9. Precipitation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