Runoff Drainage System Design

USDA-ARS

1301 N Western, Stillwater, OK, 74074

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Huling, Hanna

Short, Caroline

Spitler, Hannah

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Problem Statement

The United States Department of Agriculture-Agricultural Research Service (USDA-ARS) has an ongoing stormwater runoff problem that causes sidewalks in front of doorways to flood and become hazardous. A moderate slope of bare soil and patchy grass carries runoff beside two buildings potentially causing further damage to the foundation of the buildings. CH2 Consulting will provide the USDA-ARS with a sustainable stormwater management plan to effectively minimize flooding on their property.

Figure 1. USDA-ARS Site Location in Stillwater, OK

Statement of Work

Customer Desirables

The USDA-ARS in Stillwater, Oklahoma asked CH_2 Consulting to solve a drainage issue that is affecting two buildings and a storage area on their rented property. It was requested that the solution be aesthetically pleasing and that the trees in front of the buildings be left intact, if possible.

Task Background

Detailed plans for data collection and physical testing will involve photographing the site during a rain event, soil sampling, surveying the USDA-ARS site, and modeling runoff. During a rainfall event, photographs and video will be captured to determine any runoff patterns and areas of ponding. The period of performance is from August 2014 to April 2015 with approximately 6 hours of work per week.

A few site considerations are as follows. USDA-ARS does not own the property on which the runoff will be drained. Permission will need to be obtained from the property owner (Oklahoma State University) before the design can be implemented. CH_2 Consulting contacted Call Before You Dig to determine the approximate location of underground lines, pipes, and cables. WinTR-55, watershed hydrology modeling computer software, will be used to determine the peak runoff of the site.

Deliverables

At the end of the spring semester, CH_2 Consulting will present the USDA-ARS with two detailed design options. CH_2 Consulting will communicate the benefits of each design to the USDA-ARS. A visual map of the site will be presented for reference.

Preliminary Testing and Modeling

Design Constraints

Call Before You Dig was contacted to determine the location of any buried cables or gas lines. Figure 9 shows where the Oklahoma Natural Gas gas line is buried, and where the ATT/D buried cable is located near the Environmental Laboratory. Oklahoma Natural Gas lines are typically buried 18 inches below the surface. However, construction companies generally handle the buried lines themselves (Bruce Keller, personal communication, 3 April 2015). Therefore, the design is not impacted by the buried lines.

Figure 2. Buried gas line and buried cable locations

After implementing the design solution, the peak flow of the watershed must not be greater than the original peak flow of the watershed, and the time of concentration (t_c) should not decrease (Mike Buchert, personal communication, November 20, 2014).

The City of Stillwater Standards has a section regarding stormwater collection system construction plan requirements. Portions of this section include general requirements, construction plan requirements, and requirements for drainage reports and plans (City of Stillwater Standards, 2011). However, after meeting with City of Stillwater Stormwater Programs Manager, Cody Whittenburg, it was determined that the USDA-ARS site was too small to have to comply with City of Stillwater stormwater management and construction standards.

Soil Sampling

Soil samples were taken following the Oklahoma Cooperative Extension Service guidelines. We collected soil cores from the top six inches of soil using a soil core sampler. We compiled twenty soil cores from the land in front of the warehouse building and mixed the samples thoroughly. A composite sample was put into a soil testing bag and submitted to the Soil, Water, and Forage Analytical Laboratory (SWFAL) at Oklahoma State University. The same procedure was followed to take a sample from the land in front of the environmental laboratory building. The second sample was also submitted to SWFAL. Both samples were analyzed for soil texture and nutrient analysis. The results are displayed below in Table 1 and Table 2.

Table 1. Soil texture results from SWFAL

Sample Location	Texture	Sand (%)	Silt (%)	Clay (%)
Environmental Laboratory	Loam	43.8	30	26.3
Warehouse	Clay Loam	40	30	30

Table 2. Nutrient analysis results from SWFAL

Sample Location	pH	Surface Nitrate (lbs/A)	Phosphorus Index	Potassium Index
Environmental Laboratory	7.5	3	18	386
Warehouse	7.8	5	6	354

Modeling

Program Background

Runoff modeling was performed to determine surface runoff from the watershed at the USDA-ARS site. It is important to calculate runoff for storm events of different sizes so the runoff drainage solution is designed for the maximum peak runoff. The program chosen to calculate runoff was WinTR-55 because it is applicable to small watershed hydrology. Parameters used to calculate runoff are 24-hour rainfall precipitation (inches), approximate area, slope, length, hydrologic soil group, land use details, and Manning's roughness coefficient for the watershed. Figure 3 shows the 24-hour rainfall precipitation data for Payne County acquired for one to one hundred-year storm events using a type two rainfall distribution curve. As seen in Figure 4, Stillwater, Oklahoma is located in the white portion of the map therefore indicating a type II rainfall distribution.

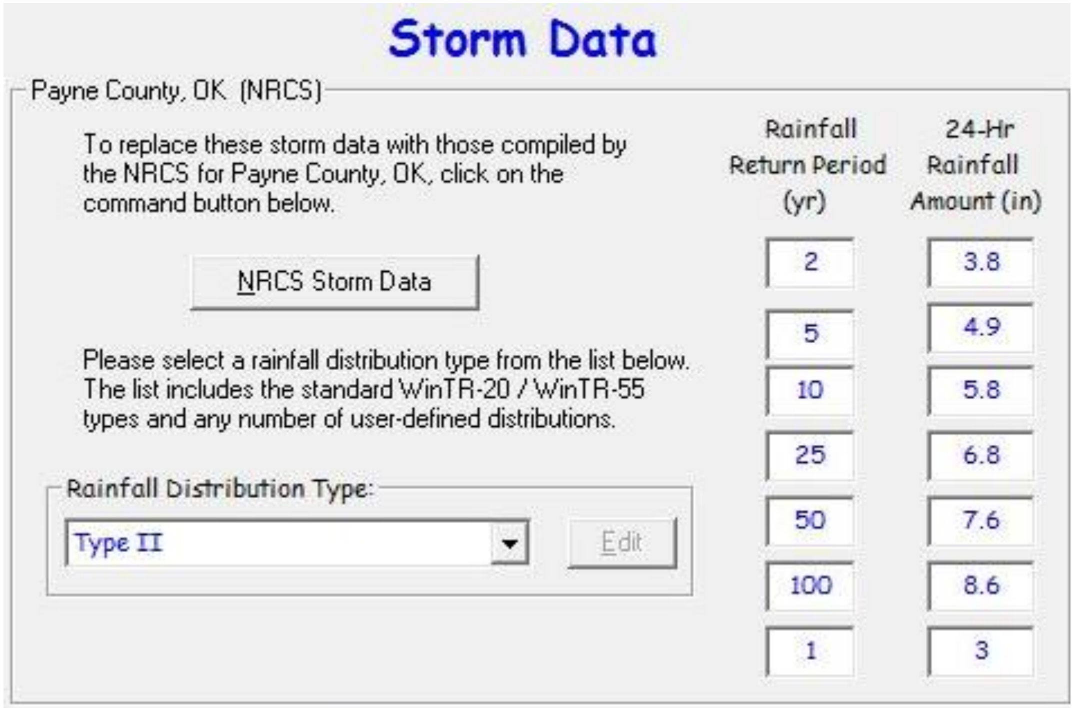


Figure 3. NRCS 24-Hour rainfall data for various rainfall return periods in Payne County, Oklahoma

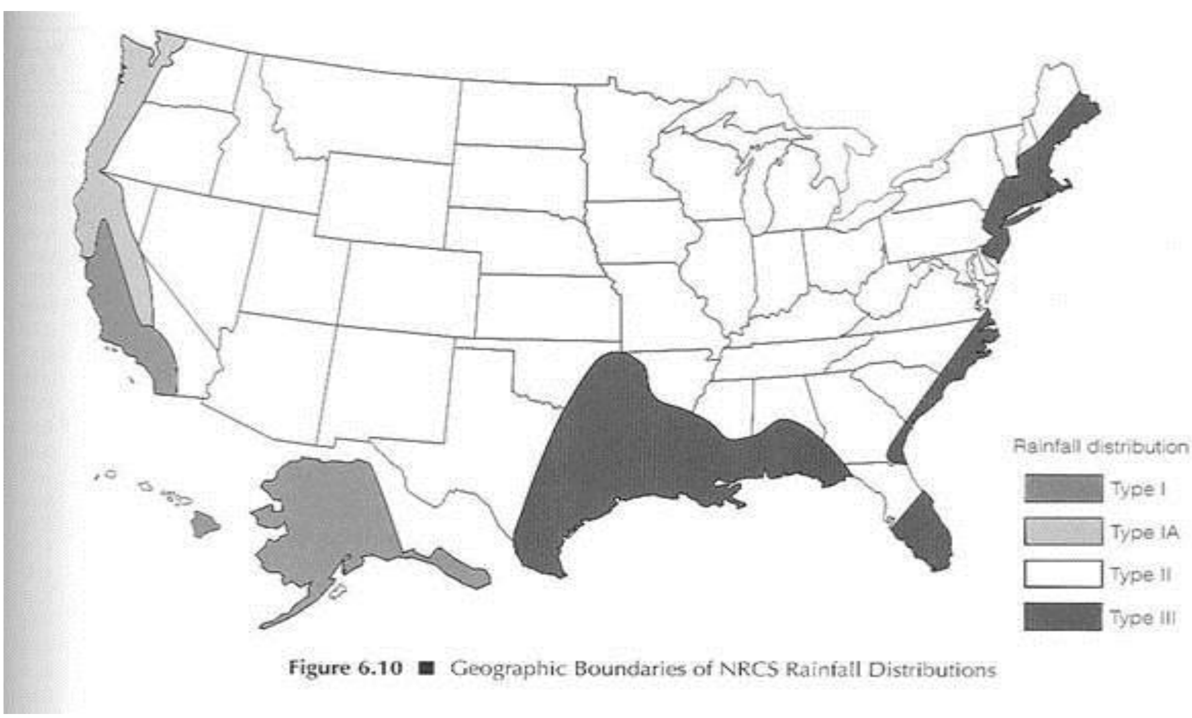


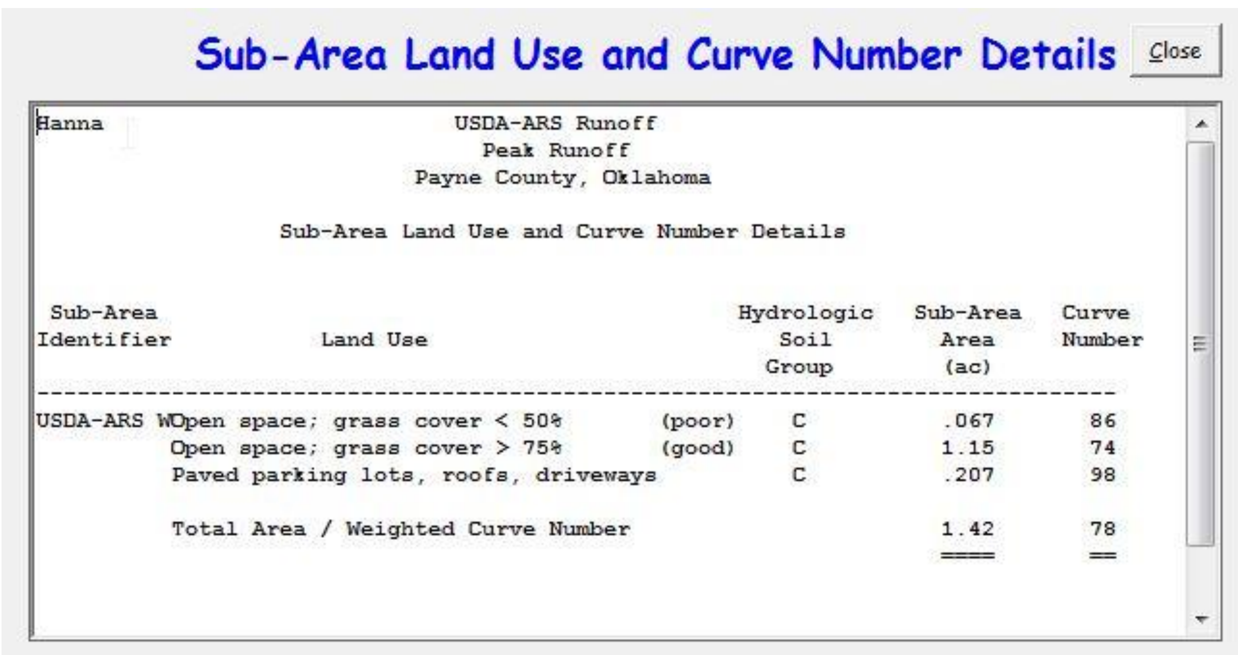
Figure 4. NRCS Rainfall distribution map of the United States of America

Curve Number

Watershed Curve Number

Google maps, Google Earth, and a Trimble Juno 3B handheld device were used to calculate the approximate area, length, and slope of the watershed. Figure 5 shows the approximate area of the entire watershed outlined in orange. Figure 6 shows how sub areas of the watershed were used to calculate a weighted curve number (CN) for the different characteristics of the land, $CN = \sum \frac{A_i CN_i}{\sum A_i}$. A weighted CN is a function of soil group, soil cover, and antecedent moisture content (AMC) and can be used to predict direct runoff or infiltration from rainfall excess. Different sub areas were chosen based upon the land use details. The three different land use details are open space with good grass cover (> 75% grass cover), open space with poor grass cover (<50% grass cover), and impermeable roofs. The open space with good grass cover corresponds to the grass behind the buildings, CN = 74, poor grass cover corresponds to the bare soil in front of the buildings, CN = 86, and the roof corresponds to the area of the buildings, CN = 98. A curve number closer to 100 corresponds to impervious land or land where water cannot infiltrate. The watershed corresponds to a weighted CN of 78, and a total area of 1.42 acres.

Figure 5. Area of Watershed



Sub-Area Land Use and Curve Number Details

Close

Hanna USDA-ARS Runoff
Peak Runoff
Payne County, Oklahoma

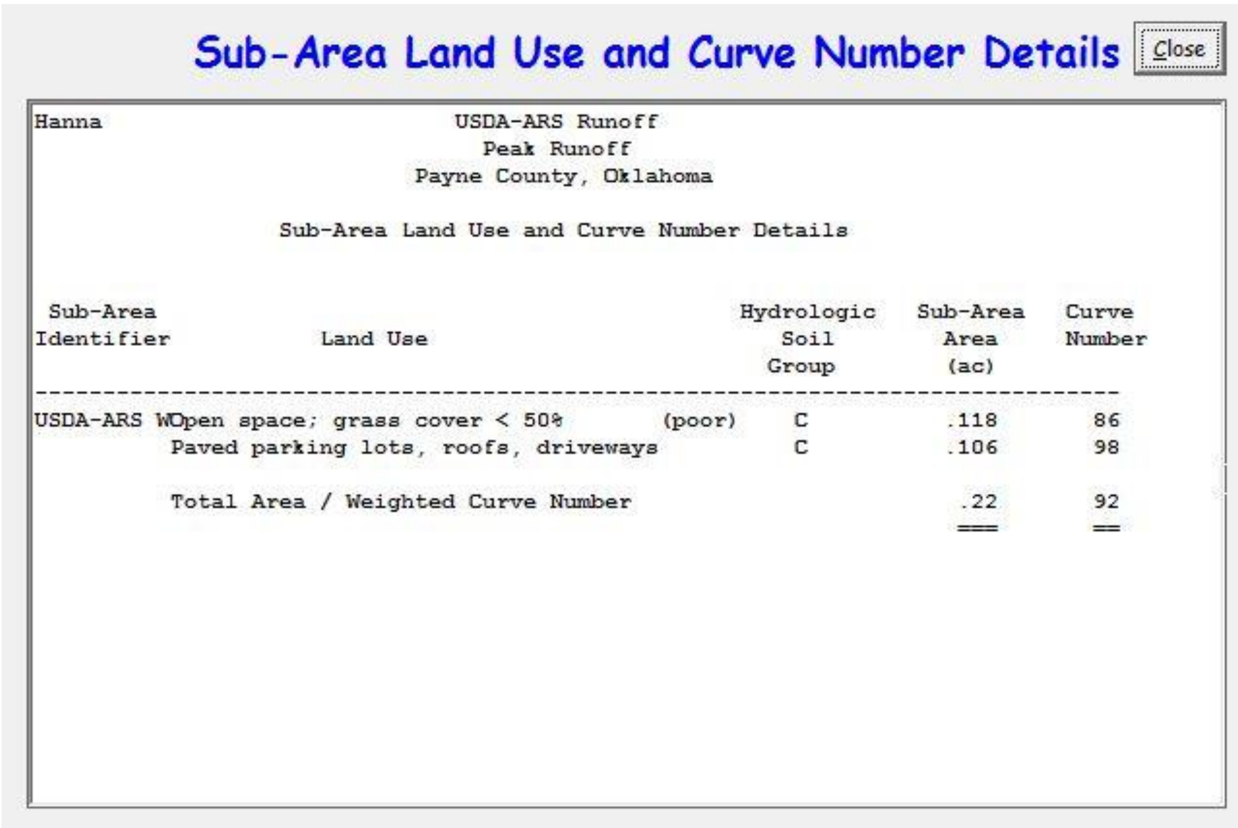
Sub-Area Land Use and Curve Number Details

Sub-Area Identifier	Land Use		Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
USDA-ARS W	Open space; grass cover < 50%	(poor)	C	.067	86
	Open space; grass cover > 75%	(good)	C	1.15	74
	Paved parking lots, roofs, driveways		C	.207	98
	Total Area / Weighted Curve Number			1.42	78

Figure 6. Weighted curve number details produced in WinTR-55

French Drain Curve Number

A handheld measuring wheel was used to calculate the approximate area in front of the buildings. Figure 17 shows the different sub areas that were chosen to describe the land details. The land details include poor grass cover (<50% grass cover) corresponding to the bare soil in front of the buildings, CN = 86, and paved parking lots, roofs, and driveways which corresponds to a CN = 98. The weighted CN for the French drain design is 92 with a total area of 0.224 acres. This weighted curve number will be used in the calculation to estimate the runoff that the French drain will withhold in front of the building.



Sub-Area Land Use and Curve Number Details

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USDA-ARS Runoff
Peak Runoff
Payne County, Oklahoma

Sub-Area Land Use and Curve Number Details

Sub-Area Identifier	Land Use		Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
USDA-ARS W	Open space; grass cover < 50%	(poor)	C	.118	86
	Paved parking lots, roofs, driveways		C	.106	98
	Total Area / Weighted Curve Number			.22	92

Figure 7. French Drain Design weighted CN details produced in WinTR-55

Time of Concentration

Watershed Time of Concentration

Length and slope of the watershed were used to calculate the time of concentration (t_c), a parameter most often used to determine the longest travel time to reach the discharge point (Fox, 2014b). The NRCS method was chosen to calculate t_c because it is a built-in function with WinTR-55: $t_c(\text{min}) = \frac{L_{sc}}{V_{sc}} = \frac{L_{sc}}{\left(\frac{1}{n}\right)*{S_o}^{1/2}R^{\frac{2}{3}}}$. Figure 8 displays how this function assumes the first 100 ft of the watershed is considered to be sheet flow, which subsequently transitions to shallow concentrated flow for the remaining length of the watershed. The first 100 ft of sheet flow corresponds to a short grass Manning's roughness of 0.15, and the following 339 ft of shallow concentrated flow corresponds to an unpaved Manning's roughness. Time of concentration was calculated to be 0.14 hours for the entire watershed.

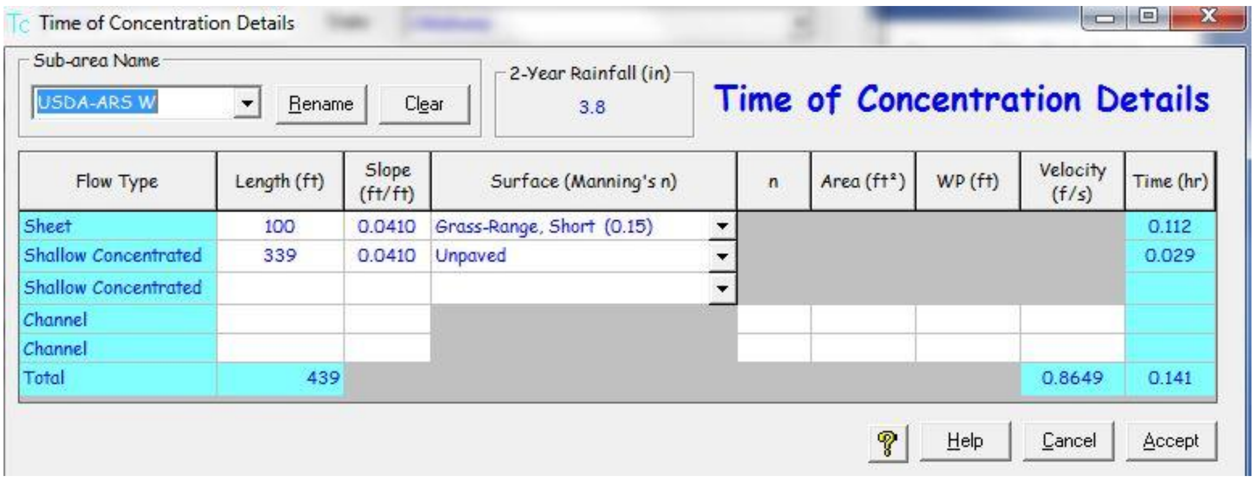

Figure 8. Time of concentration details produced in WinTR-55

French Drain Time of Concentration

Length and slope of the area in front of the buildings was used to calculate the time of concentration (t_c). Figure 9 shows the time of concentration as 0.295 hours and the velocity that the French drain should handle as 0.2006 ft/s.

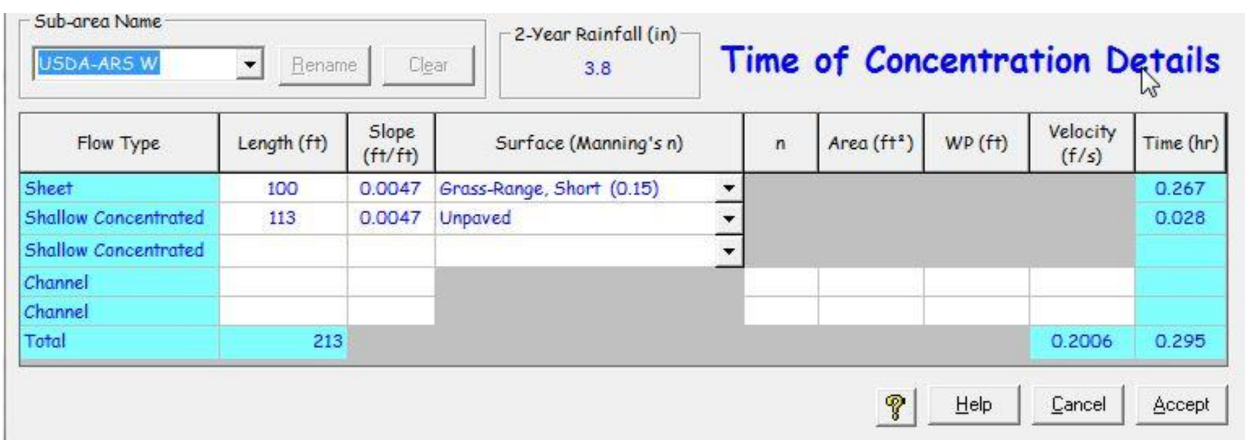

Figure 9. Time of concentration details produced in WinTR-55

Peak Runoff Hydrographs

Watershed Peak Runoff Hydrographs

Peak runoff was calculated for 1, 2, 5, 10, 25, 50, and 100-year, 24-hour rainfall events. These rainfall events were chosen to develop a widespread description of the watershed characteristics over an extended period of time. The table in Figure 10 shows the highest peak flow of 11.94 cfs will occur over a time of 11.96 hours during the 100-year storm event. Because of this, the runoff drainage solution will be designed for the maximum peak flow capacity corresponding with the 100-year storm event. Figure 11 shows the hydrograph for the various years. This figure also illustrates that peak flow occurs during the 100-year storm event and the minimum flow occurs during the 1-year storm event.

Hydrograph Peak/Peak Time Table

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Peak Runoff
Payne County, Oklahoma

Hydrograph Peak/Peak Time Table

Sub-Area or Reach Identifier	Peak Flow and Peak Time (hr) by Rainfall Return Period 2-Yr (cfs) (hr)	5-Yr (cfs) (hr)	10-Yr (cfs) (hr)	25-Yr (cfs) (hr)	50-Yr (cfs) (hr)	100-Yr (cfs) (hr)	1-Yr (cfs) (hr)
SUBAREAS							
USDA-ARS W	3.52	5.37	6.94	8.71	10.14	11.94	2.27
	11.97	11.96	11.96	11.96	11.96	11.96	11.97
REACHES							
OUTLET	3.52	5.37	6.94	8.71	10.14	11.94	2.27

Figure 10. Peak flow and peak flow time table produced in WinTR-55

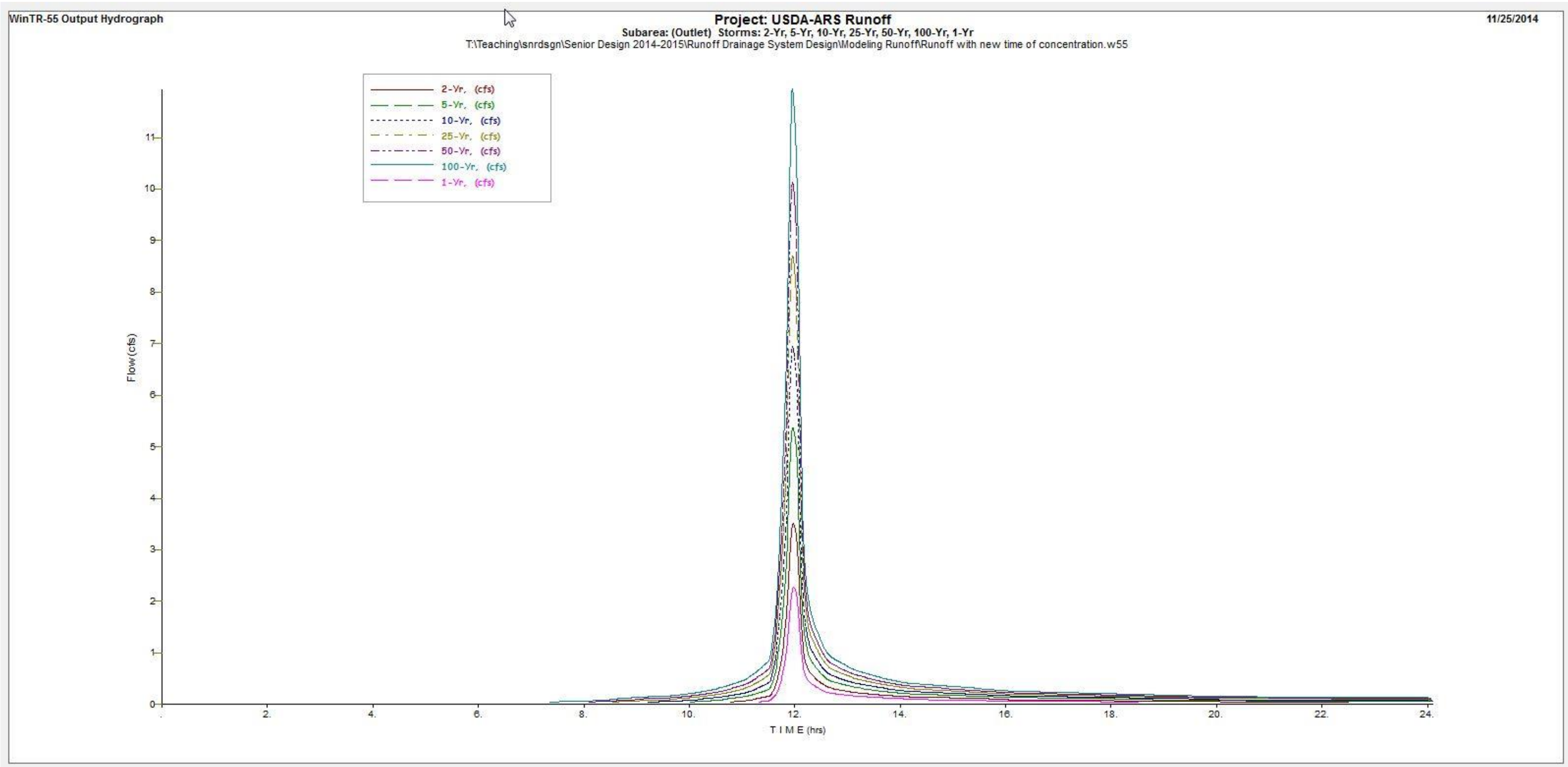

Figure 11. Peak flow hydrograph as produced in WinTR-55

Runoff Hydrographs for Area in Front of Buildings French Drain

The area in front of the building's peak runoff was calculated in order to determine how much runoff in front of the buildings that the drainage system would have to handle. A French drain was determined to be the best way to handle the flow in front of the buildings, as discussed in design solution 2 section. Peak runoff that the French drain should handle was calculated for 1, 2, 5, 10, 25, 50, and 100-year, 24-hour rainfall events. The French drainage design will be designed to handle the highest peak flow of 1.77 cfs that was calculated to occur over a time of 12.06 hours during the 100-year storm event. This flow is specific to the area in front of the buildings where the French drain will be located. This peak flow can be seen in Figure 12. Figure 13 illustrates the hydrograph for the peak flow that is to be handled in the 100-year storm event, as well as the 1-year storm event. These years were chosen to show the minimum peak flow the design should handle and the maximum peak flow the design should handle.

Hydrograph Peak/Peak Time Table

Close

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USDA-ARS Runoff
Peak Runoff
Payne County, Oklahoma

Hydrograph Peak/Peak Time Table

Sub-Area or Reach Identifier	Peak Flow and Peak Time (hr) by Rainfall Return Period 2-Yr (cfs) (hr)	5-Yr (cfs) (hr)	10-Yr (cfs) (hr)	25-Yr (cfs) (hr)	50-Yr (cfs) (hr)	100-Yr (cfs) (hr)	1-Yr (cfs) (hr)
SUBAREAS							
USDA-ARS W	0.71	0.96	1.16	1.38	1.55	1.77	0.54
	12.06	12.06	12.06	12.06	12.06	12.06	12.06
REACHES							
OUTLET	0.71	0.96	1.16	1.38	1.55	1.77	0.54

Figure 19. French Drain peak flow and peak flow time table produced in WinTR-55

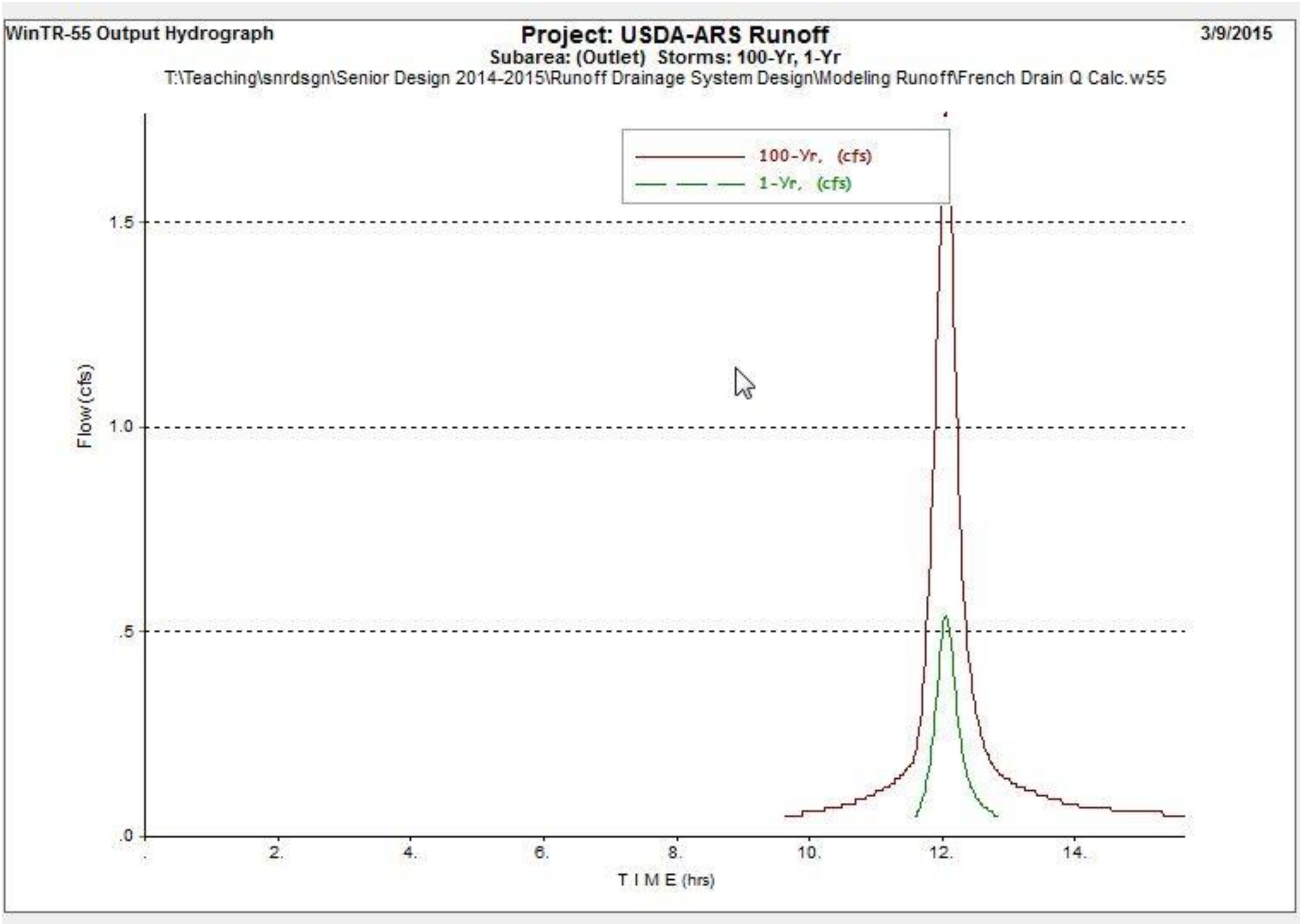

Figure 20. Peak flow hydrograph that the French drain should handle for years 1 and 100

Technical Analysis

A wide variety of techniques have been developed to handle stormwater runoff. Common methods are listed below.

Grass Channel

A grass-lined channel is a shaped (typically v-shaped, trapezoidal, or parabolic) ditch that directs stormwater runoff to an outlet (EPA, 2014a). To increase runoff storage and reduce water velocity, check dams and excavated depressions may be included in the design of the channel. Grass-lined channels are used where the flow is low (EPA, 2014a).

Vegetated Channel Discussion

In December of 2014, we proposed designing a vegetated channel from the edge of the Environmental Laboratory down to the creek on the southwest corner of the property. A vegetated channel can reduce stormwater velocity and promote stormwater infiltration. Shape of the channel will be determined based on flow and ease of maintenance. It is aesthetically pleasing, but removing the soil to build the vegetated channel is extremely costly. If a vegetated channel were to be constructed at the USDA-ARS site, a construction company would need to implement the channel characteristics. It can be maintained by mowing and removing sediment deposits as necessary.

Design method and validation requirements described in Haan et.al. (1994). In the design process, flow would be calculated using Manning's equation. $Q = \frac{1.486}{n} A R_h^{\frac{2}{3}} S_o^{\frac{1}{2}}$, Q is the flow, n is Manning's roughness coefficient, A is the area, R_h is the hydraulic radius, and S_o is the slope. The channel was designed to handle the flow of the entire watershed, about 12 cfs, as calculated using WinTR-55. These calculations are shown in the modeling section of this report. A trapezoidal channel was designed for after speaking with Dr. Garey Fox (Fox, 2015). Minimum freeboard requirement of 30 cm. Freeboard can be calculated using the following equation: $F = 0.152 + \frac{V^2}{2g}$, where F represents the freeboard in meters, V represents the velocity in m s^{-1}, and g is the gravitational acceleration constant, 32.2 ft s^{-2} (Haan et. al., 1994).

To perform the calculations, a flow of 12 cfs was used since the bottom of the channel would have to be able to handle the flow from the entire watershed (11.94cfs). The land slope was calculated to be 10 degrees. To minimize disturbance of the land, the channel was designed to have the same slope. The side slopes were set to 6:1 for ease of mowing (Mike Buchert, personal communication). A cover of Bermuda grass (easily accessible in Oklahoma) was chosen. For a more conservative estimate, the maximum velocity was set at 1.5 m/s. (The maximum velocity corresponds to an easily erodible soil value, even though the soil at the site is not easily erodible.) In order to maintain the velocity requirements, a channel with a depth of 2.0 ft, a top width of 28.0 ft, and a base of 4.0 ft is required (see appendix F). This was rejected as impractical, as the width of the channel takes up a large amount of space and would require 8000 ft^3 of soil to be removed.

French Drain

Generally French Drains include a permeable drainage pipe surrounded by a filter cloth and buried with gravel. However, some sources show only a trench filled with gravel without a drainage pipe (see Figure 21). The filling material does not have to be gravel specifically, but can be any sort of rock, stone, or coarse aggregate. French Drains are applicable right outside of external walls of buildings to prevent water from accessing the foundation. It is important to note French drains will eventually clog and require some ongoing maintenance to drain properly

(Nusite Waterproofing, 2012). Typically, French drains are 1.5 feet deep and 10-12 inches wide (Fairfax County, Virginia, 2013).

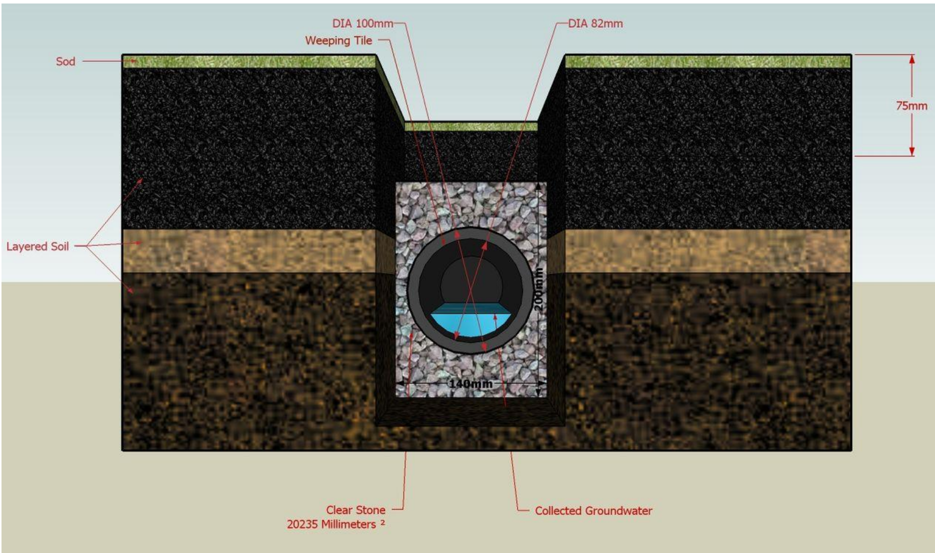

Figure 21. French Drain design (Wikipedia, 2014)

Rainfall Harvesting

Stormwater runoff is directed into a storage container for future use in rainfall harvesting (Stringer, et. al, 2014.). Typically, stormwater is diverted away from buildings through pipes connected from the gutters to a storage area (usually a cistern or a rain barrel). It is important to consider how the collected stormwater will be used, the reliability of the system, the catchment area size and location, and the intended storage type and size necessary (Stinger et. al, 2014).

Plants and Grasses

Rill erosion is the removal of soil by concentrated water through small channels. Research highlights the usefulness of a strong vegetative cover, such as sod, on the topsoil In order to reduce soil loss the influence of grass root density and root length needs to be considered. As described by Baets et. al. (2005) soil erosion rates can be reduced to 0-10% in soil cross sectional occupation by grass roots. In addition to decreasing rill erosion, grass roots can increase the topsoil resistance against erosion and reduce soil detachment rates.

There is high durability in the application of sod because grass requires little long-term maintenance, but it would require a great deal of watering when first planted. Long-term maintenance cost would be minimal, but the initial cost of the sod will need to be discussed with the client. Tall fescue turfgrass is being considered as the grass of choice, due to its ability to grow in shady drought-tolerant conditions.

Drought-Tolerant Plant Selections for Oklahoma provides more information on plants suitable for Oklahoma (Snyder et. al., 2014). This article gives more specific information about native plants for Oklahoma including sizes, light requirement, season of interest, and comments. This list is specific to drought-tolerant plants.

Environmental and Societal Impacts

Our proposed solutions will affect the local society of the workers at the USDA-ARS Stillwater location. With the implementation of our solutions, the runoff and ponding next to the Warehouse and Environmental Laboratory buildings will be decreased. This will reduce and hopefully eliminate a possible breeding ground for mosquitoes. Also, additional rust buildup along the side of the buildings will be reduced and ultimately prevented. The sidewalks leading into the buildings will be safer and less hazardous during rainfall events.

With the implementation of any of our proposed solutions also comes an environmental impact. There is the possibility of uprooting trees, and replanting new trees. This could result in habitat loss and habitat relocation for any species that made their home in those trees. Additionally, grasses and plants will be implemented to make our design aesthetically pleasing. This could provide resources and new habitat space for local species.

Engineering Design Concepts

Design Solution 1: Gutter Repair with Storage Tanks

Guttering

Two guttering companies provided estimates for the gutter repair and replacement. Custom Gutters Incorporated quoted a price of $1,848.00 to clean out the entire system and repair all the seams and spouts. The USDA-ARS currently has trapezoidal guttering on both buildings, and to replace the entire system with new trapezoidal gutters, the estimate was $11,080.00. A second estimate was provided by Able Seamless Guttering, Inc. The estimate was $1,600.00 to clean out the entire system and repair all the seams and spouts. Therefore, Able Seamless Guttering should be used for the gutter repair.

Storage Tanks

The simplest effective solution would be to repair the gutters and install storage tanks. The gutters on the north half of each building would drain into a storage tank for potential later use. There would be two storage tanks beside each of the two buildings that are 600 gallons each. WinTR-55 was used to model the flow coming off of the roof. The amount that would flow into the storage tanks is 0.35 cfs in a 100-year storm event. The volume of the storage tank would handle a 1.3" rain event. This was calculated by dividing the volume of the storage tanks by the area of half of the roof ($1500ft^2$). The same method can be applied to calculate what size storm event a change in storage tank volume can withhold if the client were to choose a different sized storage tank.

Fescue

An option with this solution would be to add Oklahoma fescue sod to slow the runoff and increase the aesthetic appeal of the site.

Design Solution 2: French Drain

French Drain

A French drain will be implemented in front of the two buildings. Typically a French drain is about 10-12 inches wide and has a depth of about 1.5 feet (Fairfax County, Virginia, 2013). Manning's equation was used to calculate the slope of the trench, size of the trench, and size of the perforated PVC pipe. $Q = \frac{1.486}{n} AR_h^{\frac{2}{3}} S_o^{\frac{1}{2}}$. The flow and slope were set equal to X, which allowed for a minimal elevation drop of 1.5 feet with an 8 inch diameter permeable PVC pipe. The derivatives of Manning's equation that were used to calculate these dimensions are as follows: $Q_x = 0.0084 * X$ ft^2/s. $\int S_x dx = \int [\frac{n}{1.486} * \frac{Qx}{ARh^{2/3}} x]^2$

This approach will allow for a design with a circular pipe and varying flow. A construction company will need to be hired to build the French drain. Appendix E1 illustrates the French drain design that will transmit varying flow along the pipe. The design consists of a rectangular trench 210 feet long by 12 inches wide by 18 inches deep (315 ft^3). An even distribution of 2 inches of sand (35 ft^3) will be transported to the bottom of the trench followed by the placement of the 8 inch perforated PVC pipe on grade. Two clean outs will be placed every 70 feet along the 8 inch diameter perforated PVC pipe to allow for maintenance cleaning. This distance was chosen to allow for plumbers to effectively use their equipment to clean the debris that may accumulate in the French drain. The clean outs will consist of PVC sweep T's that are 4 inches in diameter with a 4 inch diameter cap at the top to avoid infiltration from the above surface. Pea gravel (3/8 inch diameter) with an infiltration of 0.16 ft/s will be applied on top of the sand and perforated pipe in order to promote infiltration to the pipe (Morris and Johnson, 1967). It is assumed that the infiltration through the gravel will be unit gradient gravity flow, and will allow for the designed infiltration of 0.005 ft/s to effectively reach the permeable pipe. To reduce clogging of the gravel and perforated pipe, filter fabric will be applied around the perimeter of the trench (770 ft^2) and perforated pipe (440 ft^2). The total area of filter fabric needed for the French drain design is 1210 ft^2. Appendix E2 shows the retail cost breakdown of the French drain design. It can be seen that the cost of materials to build the French drain design is approximately $4,121. This cost analysis does not include labor cost.

- Advantages: Simple design concept, effectively carries stormwater away from the foundations of the building to a pre-existing creek on the property.
- Disadvantages: Requires uprooting the trees in front of the building ($4,625) (Christopher Martin, personal communication, 20 February 2015). Plant new trees in another location after uprooting the old trees. French drain is not as aesthetically pleasing as other design concepts if gravel is left within eyesight. The design will need to be bid out to a construction company because the cost of the French drain is above $3,000.

Sod

Along with the French drain, fescue sod would be added to the area in front of the buildings. The fescue sod would increase the cover of the area in front of the building, increase topsoil resistance, promote infiltration, and decrease erosion. This would result in a higher time of concentration and a slowing of the peak runoff.

Gutter Repair

As with the first design, the gutters will undergo repair. This will decrease the amount of water escaping the gutters from leaks. This in turn will decrease the amount of water that ponds in the front of the building.

Tree Removal

There are nine trees in front of the Environmental Laboratory and Warehouse buildings. If the trees are left in place, there is a risk of either the roots damaging the perforated pipe or the installation of the French drain damaging the roots of the trees. Therefore, it is recommended to remove the trees before installing the French drain. Nate’s Tree Service in Stillwater, OK was contacted to receive an estimate for the work. To remove the maximum of nine trees that would be in the way of the French drain, Nate’s quoted a price of $4,625.

Comparison

Table 3. Cost Breakdown of Design Solution 1.

Design 1					
Component	**Quantity**	**Cost (individual)**	**Total cost**	**Advantages**	**Disadvantages**
Rain tank	4	$438.99	$1756.00 + shipping	· Simple · Cost effective · Minimizes runoff · Potential Green Points	· Possibility of ponding · Less aesthetically pleasing
Gutter Repair (Able Seamless Guttering)	-	-	$1600.00		
Sod (optional)	5112 ft^2	$220/500 ft^2	$2,198.00		
Sum			$5,554.00		

Table 4. Cost Breakdown of Design Solution 2 (French drain cost breakdown can be seen in red writing)

Design 2					
Component	**Quantity**	**Cost (individual)**	**Total cost**	**Advantages**	**Disadvantages**
Gutter Repair (Able Seamless Guttering)	-	-	$1600.00	· Effectively captures runoff · Transports runoff away from buildings · Improves safety of USDA-ARS employees · Sustainable Design able to withhold 100-year storm event	· Complex Design (compared to design 1) · Construction costs will be required · Expensive Total cost > $3,000 · Design will need to be bid out
Fescue Sod	5112 ft^2	$215/500 f^{t2}	$2198.00		
Stillwater Sand and Gravel (Course Sand)	2 Tons	$25	$50		
Stillwater Sand and Gravel (3/8'' Pea Gravel)	10 Tons	$28	$280		
Lowe's & Locke Supply Co. Filter Fabric & PVC	Drainage Filter Fabric; 8'' 45^o PVC Wye; 4'' 45^o PVC elbow; 4'' PVC Pipe and Cleanout Cap; 8'' Schedule 40 PVC	-	$1,593.00		
Sum French Drain			$4,121.00		
Tree Removal			$4,625.00		
Sum			$10,346.00		

Project Budget

Our project expenses are listed below:

Table 5. Current and future expenses

Item	Amount	Individual Cost	Total Cost
SWAFL - Soil Texture and Nutrient Analysis of Soil Samples	2	$20.00	$40.00
Ag Duplicating	2	$77.00	$154.00
OSU Motor pool Vehicle	1		$45.00
		Total:	**$239.00**

Acknowledgements

We would like to thank the following people for their assistance with our project: Dr. Paul Weckler for his guidance throughout the semester, Dr. Sherry Hunt and Linda Gronewaller at the USDA-ARS for challenging us with this project, Dr. John Long for allowing us to borrow the Total Station surveying system and his assistance throughout the surveying process, Dr. Garey Fox for assisting us with the WinTR-55 modeling software, Dr. Glenn Brown for helping us with the design considerations for the French Drain, our freshmen team (Tony Blackbear, Ty Fisher, Derek Hurst, and Bailey Poe) for helping us with the collection of soil samples and surveying, the Soil, Water, and Forage Analytical Laboratory for analyzing our soil samples, Chuck Cassidy and OSU Physical Plant Services, Christopher Martin and Landscape Install Services, Mike Buchert and Long Range Facilities Planning, and Bruce Keller from Centennial Construction.

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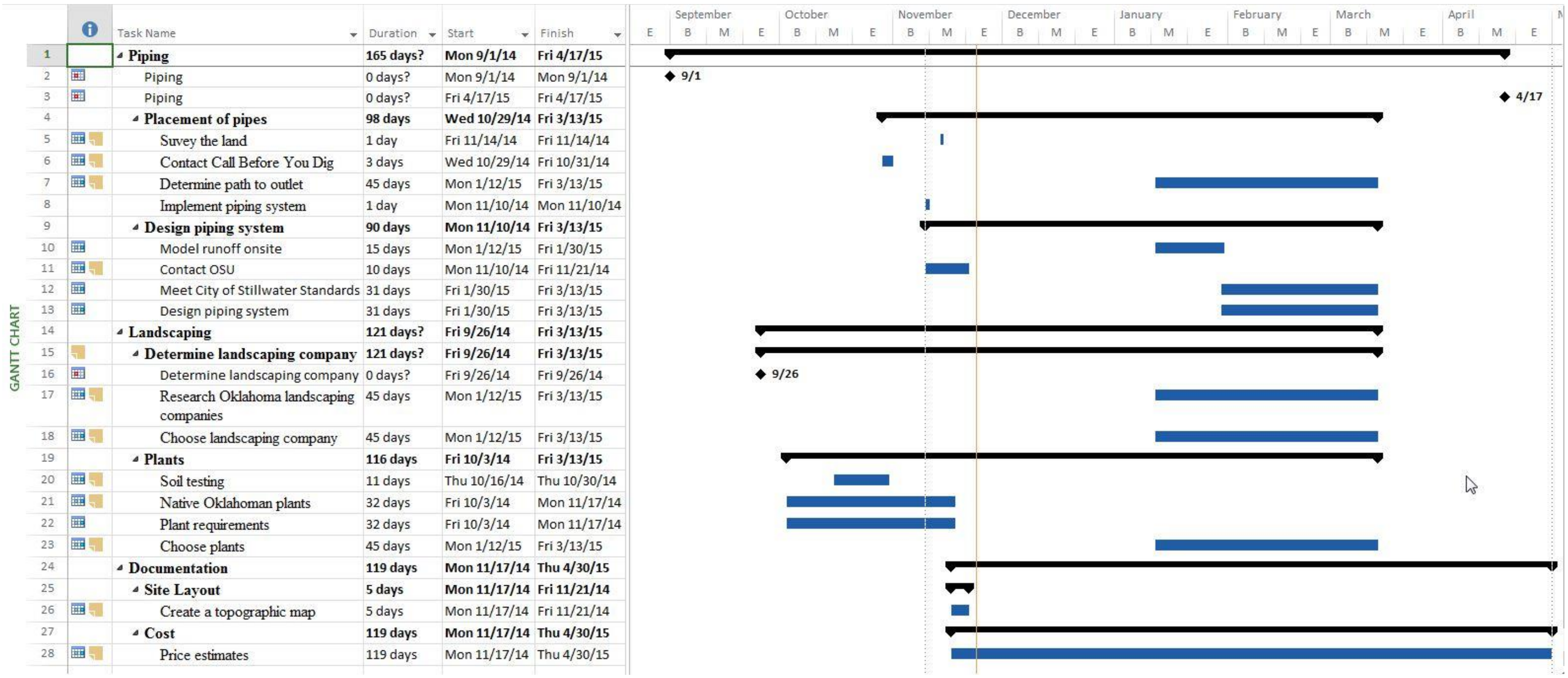
Appendices

Appendix A. WinTR-55 modeling

Table A-1. WinTR-55 model results for half of a roof onsite.

Runoff from roof							
Payne County, Oklahoma							
SUBAREAS							
Half of roof	2-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr	1-Yr
Peak flow (cfs) by rainfall return period	0.15	0.2	0.24	0.28	0.31	0.35	0.12
Peak time (hr.)	11.92	11.92	11.93	11.93	11.92	11.93	11.93
REACHES							
OUTLET (cfs)	0.15	0.2	0.24	0.28	0.31	0.35	0.12

Appendix B. Gantt Chart



	Task Name	Duration	Start	Finish
1	**Piping**	**165 days?**	**Mon 9/1/14**	**Fri 4/17/15**
2	Piping	0 days?	Mon 9/1/14	Mon 9/1/14
3	Piping	0 days?	Fri 4/17/15	Fri 4/17/15
4	**Placement of pipes**	**98 days**	**Wed 10/29/14**	**Fri 3/13/15**
5	Suvey the land	1 day	Fri 11/14/14	Fri 11/14/14
6	Contact Call Before You Dig	3 days	Wed 10/29/14	Fri 10/31/14
7	Determine path to outlet	45 days	Mon 1/12/15	Fri 3/13/15
8	Implement piping system	1 day	Mon 11/10/14	Mon 11/10/14
9	**Design piping system**	**90 days**	**Mon 11/10/14**	**Fri 3/13/15**
10	Model runoff onsite	15 days	Mon 1/12/15	Fri 1/30/15
11	Contact OSU	10 days	Mon 11/10/14	Fri 11/21/14
12	Meet City of Stillwater Standards	31 days	Fri 1/30/15	Fri 3/13/15
13	Design piping system	31 days	Fri 1/30/15	Fri 3/13/15
14	**Landscaping**	**121 days?**	**Fri 9/26/14**	**Fri 3/13/15**
15	**Determine landscaping company**	**121 days?**	**Fri 9/26/14**	**Fri 3/13/15**
16	Determine landscaping company	0 days?	Fri 9/26/14	Fri 9/26/14
17	Research Oklahoma landscaping companies	45 days	Mon 1/12/15	Fri 3/13/15
18	Choose landscaping company	45 days	Mon 1/12/15	Fri 3/13/15
19	**Plants**	**116 days**	**Fri 10/3/14**	**Fri 3/13/15**
20	Soil testing	11 days	Thu 10/16/14	Thu 10/30/14
21	Native Oklahoman plants	32 days	Fri 10/3/14	Mon 11/17/14
22	Plant requirements	32 days	Fri 10/3/14	Mon 11/17/14
23	Choose plants	45 days	Mon 1/12/15	Fri 3/13/15
24	**Documentation**	**119 days**	**Mon 11/17/14**	**Thu 4/30/15**
25	**Site Layout**	**5 days**	**Mon 11/17/14**	**Fri 11/21/14**
26	Create a topographic map	5 days	Mon 11/17/14	Fri 11/21/14
27	**Cost**	**119 days**	**Mon 11/17/14**	**Thu 4/30/15**
28	Price estimates	119 days	Mon 11/17/14	Thu 4/30/15

Figure B-1. Gantt Chart of Design Project

Appendix C. Work Breakdown Structure

The following is a work breakdown structure for the project.

WBS 1.0 Piping System

Different pipes are being considered based on the topographic requirements of the land. Pipes being considered are corrugated HDPE plastic pipes.

Different types of corrugated HDPE plastic pipes being considered are as follows.

- Type C: Corrugated exterior and interior
- Type S: Smooth interior and corrugated exterior
- Type D: Essentially smooth interior connected to a smooth outer wall

The piping system may be used in conjunction with a channel.

WBS 1.1 - Placement of Pipes

CH_2 Consulting potentially plans to implement an underground piping system that carries runoff to a creek at the southeast portion of the USDA-ARS property. Alternatively, the piping system may be used alongside a channel.

WBS 1.1.1 - Survey the Land

CH_2 Consulting plans to survey the USDA-ARS site using a Total Station. The Total Station will measure distances, angles of elevation, and elevation. This data will be uploaded to ARC GIS or AutoCAD so it can be transformed into a topographic map.

WBS 1.1.2 - Contact Call Before You Dig

CH_2 Consulting contacted Call Before You Dig to get utility lines marked on the USDA-ARS property. This was done in order to determine if soil tests could be safely taken at the site without hitting any utility lines and to determine if there are utility lines that would interfere with construction of an underground piping system. The different color utility lines and their meanings are listed below.

- Yellow: Gas line
- Orange: Communication lines (Phone, AT&T, SuddenLink)
- Blue: Water lines
- Red: Electric and power lines
- Green: Sewer
- Purple: Irrigation water
- White: Excavation
- Pink: Survey

WBS 1.1.3 - Determine Path to Outlet

CH_2 Consulting will use the topographic map to analyze the slopes and other characteristics of the land to determine the most efficient path for the runoff drainage system solution.

WBS 1.1.4 - Construction company implements piping system

The construction company selected will implement the runoff drainage system CH_2 Consulting designs. Requirements to be considered for the construction company are which construction companies Oklahoma State University uses, cost of the possible construction companies, and which construction company the USDA-ARS ultimately prefers to use.

WBS 2.0 Landscaping

Provide aesthetically pleasing landscape that decreases runoff on site.

WBS 2.1 - Determine landscaping company

CH_2 Consulting will work with the USDA-ARS and Oklahoma State University Physical Plant to determine the optimal landscaping company for the project.

WBS 2.1.1 – Research Oklahoma landscaping companies

Oklahoman landscaping firms will be researched to find the firms that provide needed services for the project. Quality and cost of the services will be considered. If necessary, Physical Plant will provide a list of suitable landscaping companies.

WBS 2.2.2 – Choose landscaping company

CH_2 Consulting will present findings to the USDA-ARS and finalize the landscaping company for the project.

WBS 2.2 – Plants

CH_2 Consulting will determine the type of vegetation for the site that will promote infiltration and decrease runoff while being aesthetically pleasing.

WBS 2.2.1 – Soil testing

The soil on site will be tested to determine soil texture and available nutrients.

WBS 2.2.2 – Native Oklahoman plants

Native Oklahoman plants will be reviewed to find plants that grow optimally in the soil on site. A list of these plants will be created.

WBS 2.2.3 – Plant requirements

Native Oklahoma plants will be narrowed down to those that grow well in site conditions. Maintenance and nutrient requirements of the plants will be considered.

WBS 2.2.4 – Choose plants

Optimal plants options will be presented to the USDA-ARS and a selection of plants for the site will be determined.

WBS 3.0 - Documentation

Produce a topographic map and cost breakdown estimates for the runoff drainage design solution. This work is complete when the topographic map and cost breakdown estimates are released to Dr. Sherry Hunt and Linda Gronewaller.

WBS 3.1 - Site Layout

In order to determine where to place the drainage system a site layout will be determined using Google Earth and a topographic map.

WBS 3.1.1 – Create topographic map

The data acquired from surveying the site will be uploaded to ARC GIS or AutoCAD so it can be transformed into a topographic map. The BAE 1012 freshmen team will perform this task.

WBS 3.2 – Cost

In order to provide the best solution to the stormwater runoff problem at the USDA-ARS, CH2 Consulting will take into account the cost of the various solutions.

WBS 3.2.1 – Obtain Price Estimates

CH2 Consulting will obtain price estimates from the chosen landscaping company for the plants and labor and also the construction company for the piping, construction, and labor.

WBS 4.0 Channel

Provide channel design and specifications to implement a channel to carry runoff to a nearby outlet. Channel may be used in conjunction with a piping system.

WBS 4.1 - Determine channel type

CH_2 Consulting will determine the type of channel (grass-lined or paved) to be used.

WBS 4.1.1 – Decide location of channel

CH_2 Consulting will establish the location of the channel on site.

WBS 4.1.2 – Design channel

CH_2 Consulting will design the channel using methodology from Dr. Garey Fox's *Design of Open Channels.* The channel may be used alongside a piping system.

WBS 4.1.3 – Implement channel

An Oklahoma State University Physical Plant-approved construction company will implement the channel.

Appendix D. Topographic Map

Figure D-1. Topographic Map of USDA-ARS. The Environmental and Warehouse Buildings are seen in white and the runoff will be transported down gradient of these buildings.

Appendix E. Project Schedule

Table E-1. Task List used for Gantt chart

Task Name	Duration	Start	Finish
Piping	**165 days**	**Mon 9/1/14**	**Fri 4/17/15**
Piping	0 days	Mon 9/1/14	Mon 9/1/14
Piping	0 days	Fri 4/17/15	Fri 4/17/15
Placement of pipes	**98 days**	**Wed 10/29/14**	**Fri 3/13/15**
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Create topographic map	5 days	Mon 11/17/14	Fri 11/21/14
Cost	**119 days**	**Mon 11/17/14**	**Thu 4/30/15**
Price estimates	119 days	Mon 11/17/14	Thu 4/30/15

Appendix F. French Drain AutoCAD Drawing

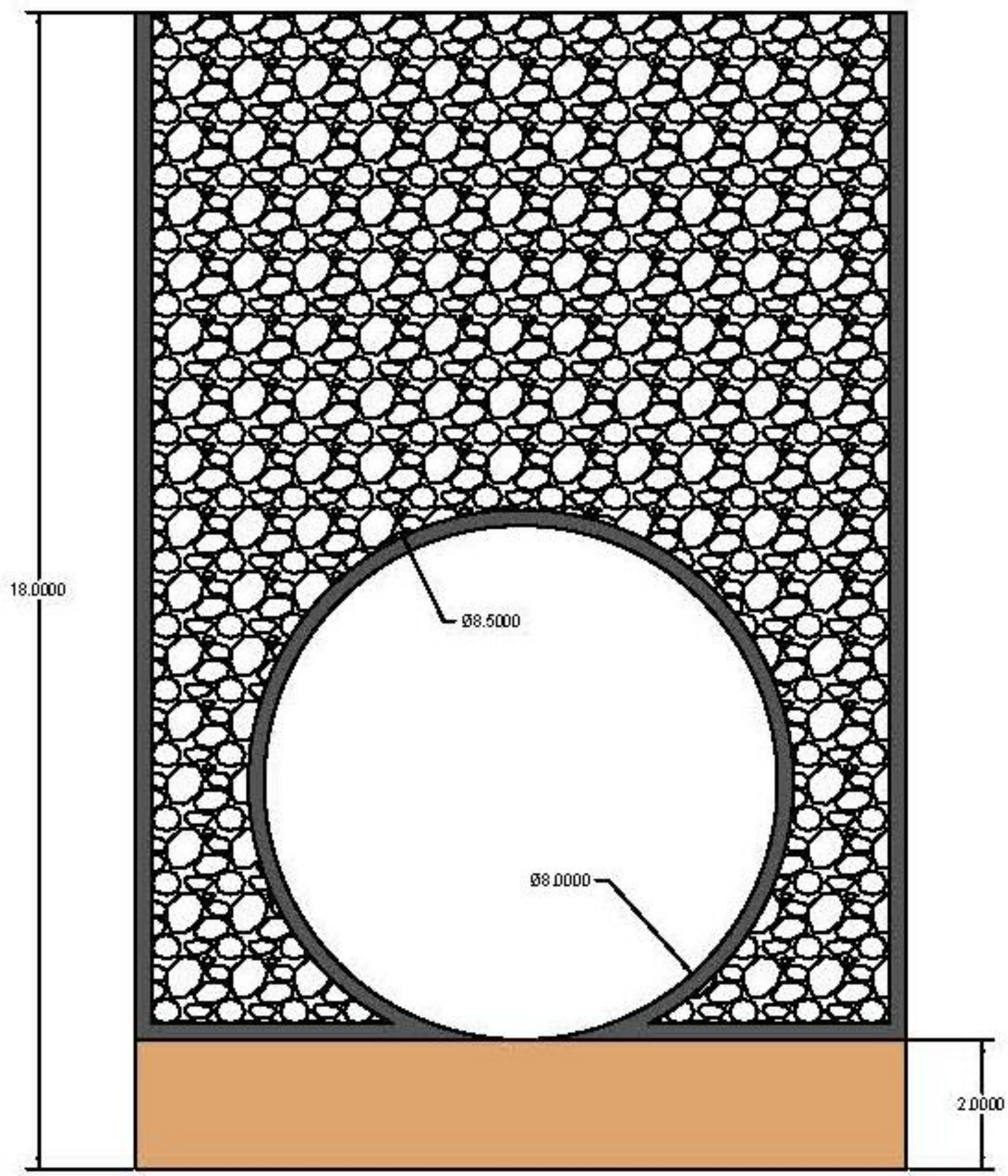

Figure F-1. AutoCAD drawing of the cross-section of the French Drain (dimensions in inches)

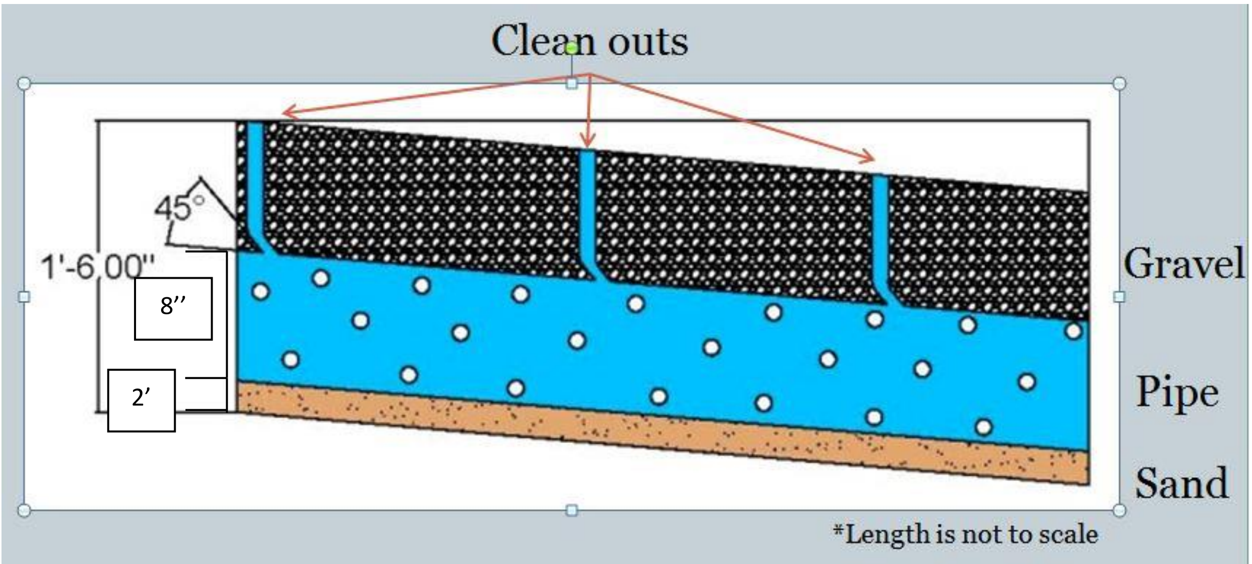

Figure F-2. AutoCAD drawing of the profile of the French Drain (dimensions in inches and feet). Length is 210 feet. Sweep T's will be placed every 70 feet. Pipe will be perforated. Filter cloth will surround the pipe, and perimeter of the French Drain trench.

Appendix G. French Drain Cost Analysis

Material	Company	Cost $	Per Area or Volume	Area or Volume needed	Design Cost $
Tall Fescue Grass	Green Acres Sod	215	500 ft^2	5112 ft^2	2198.16
Corse Sand	Stillwater Sand & Gravel	25	ton picked up	35 ft^3 = 2 tons	50
3/8 " Pea Gravel	Stillwater Sand & Gravel	28	ton picked up	206 ft^3 = 10 tons	280
Drainage Filter Fabric	Agriculture Solutions	73	4' X 300'	1210 ft^2 = 2 rolls	146
8" 45^o PVC Wye #R0569	Locke Supply Co.	35.35	1 Wye	3 Wyes	106.05
4" 45^o PVC Elbow #R0862	Locke Supply Co.	5.66	1 Elbow	3 Elbows	16.98
4" PVC Pipe #R0078	Locke Supply Co.	22.61	10'	2 feet	22.61
Concrete pavers	Lowe's	0.82	1	10	8.2
4" Cleanout Cap #R1026	Locke Supply Co.	9.41	1 Flush-Fit Cap	3 Caps	28.23
8 " Schedule 40 PVC Pipe	Lowe's	114.97	20'	210	1264.67
Item# 431148 Model #: PVC 0400 0800					
				Total Cost $	4129.10

Appendix H. Vegetated Channel – Further Discussions

The vegetated channel has a surface area of the channel is 13,000 ft^2. Sod costs \$215/500 f^{t2}.

Therefore, sodding the entire channel would cost \$5,590.

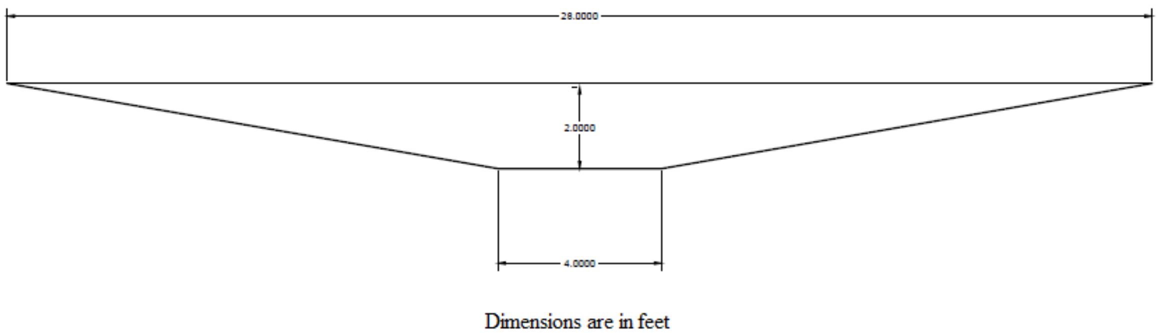

Figure H-1. Grass-lined channel illustration (Virginia DEQ, 2014)

Appendix I. Maps

Map of USDA-ARS site in relation to the City of Stillwater.

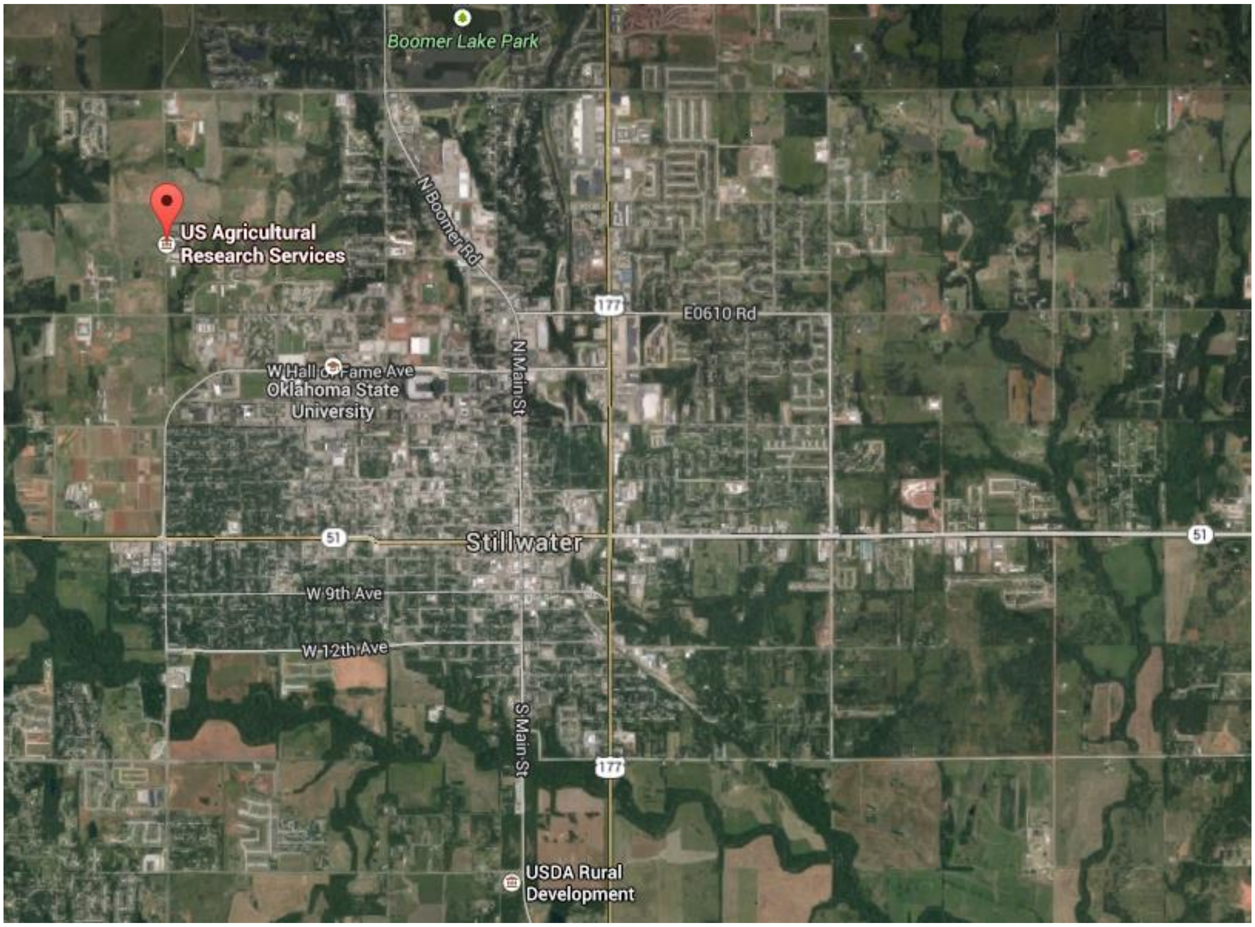

Figure I-1. Stillwater, OK (Google Maps, 2015)

Figure I-2. USDA-ARS site zoomed in (Google Maps, 2015)

Figure I-3. Location of French drain