Runoff Drainage System Design

USDA-ARS

1301 N Western, Stillwater, OK, 74074

5/6/2015

Huling, Hanna

Short, Caroline

Spitler, Hannah

Table of Contents

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.

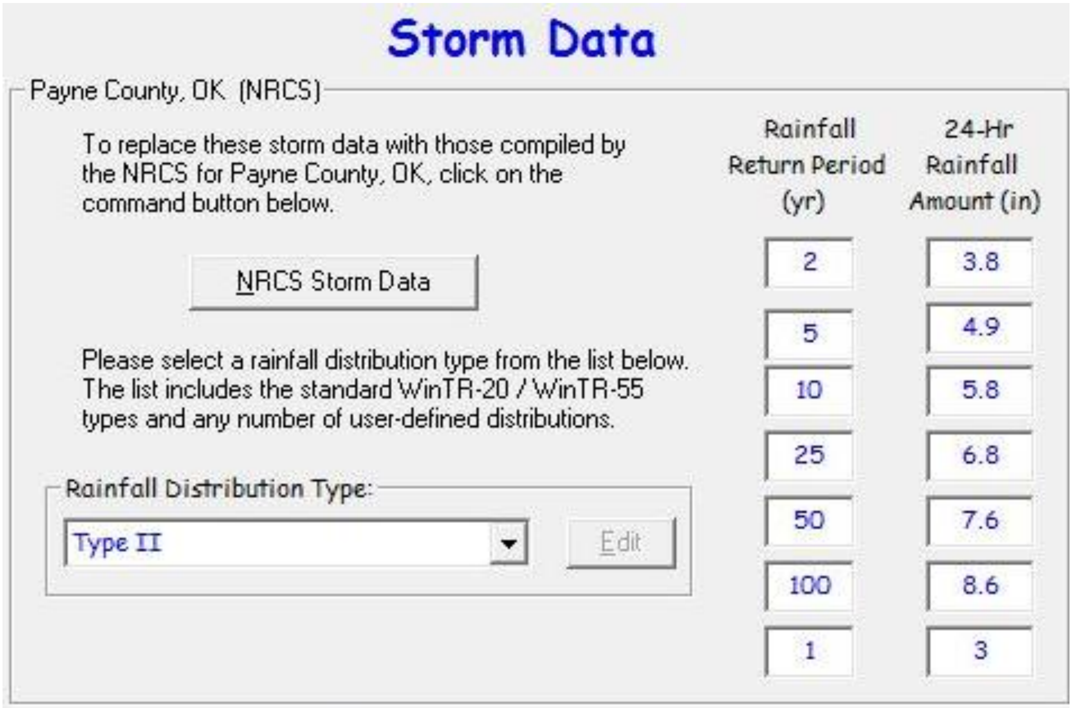


Figure 3. NRCS 24-Hour rainfall data for various rainfall return periods in Payne County, Oklahoma

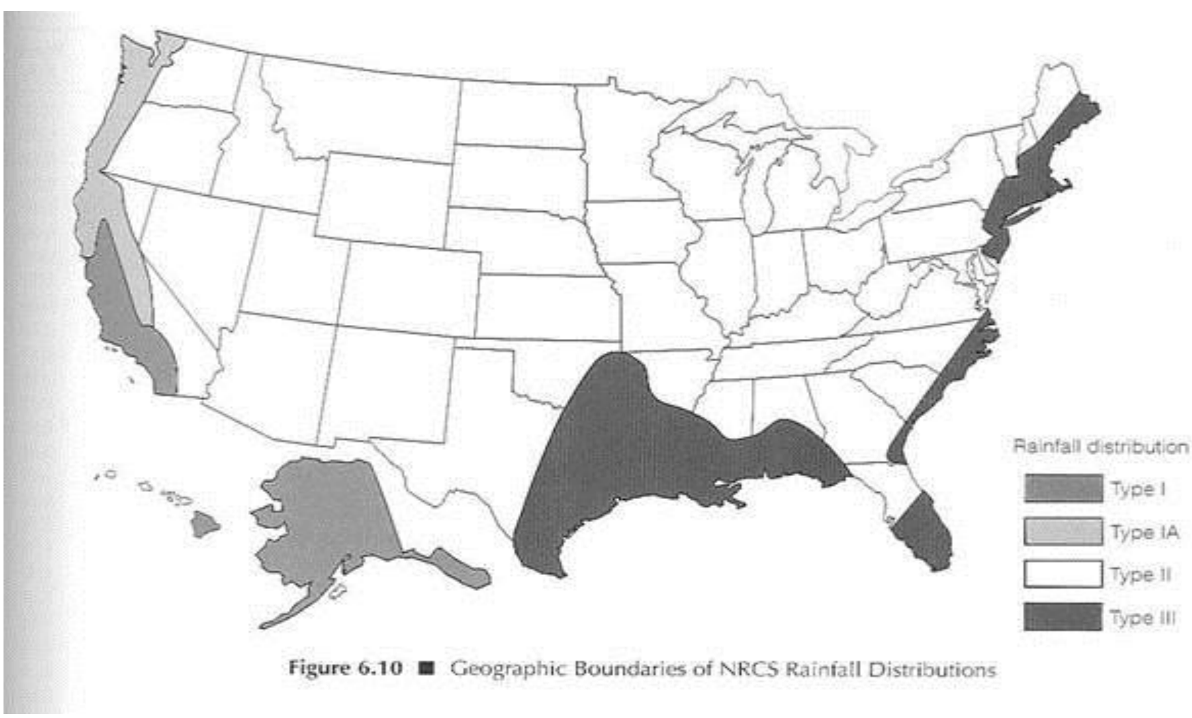


Figure 6.10 ■ Geographic Boundaries of NRCS Rainfall Distributions

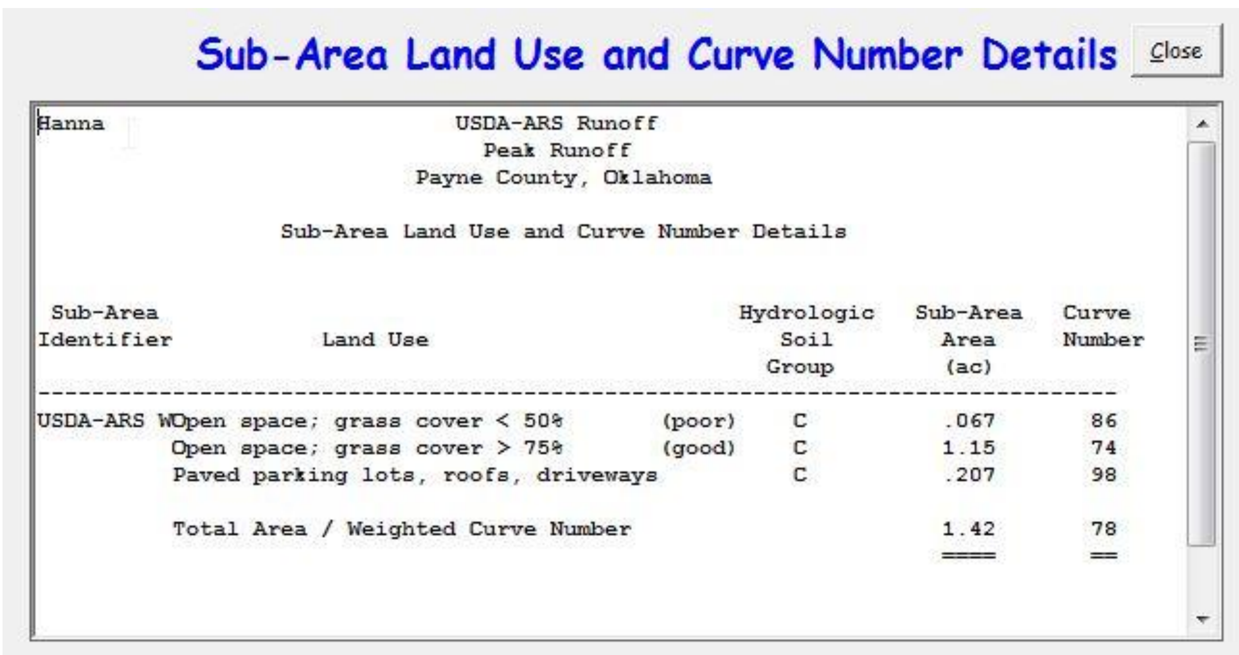
Figure 4. NRCS Rainfall distribution map of the United States of America

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

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USDA-ARS Runoff
Peak Runoff
Payne County, Oklahoma

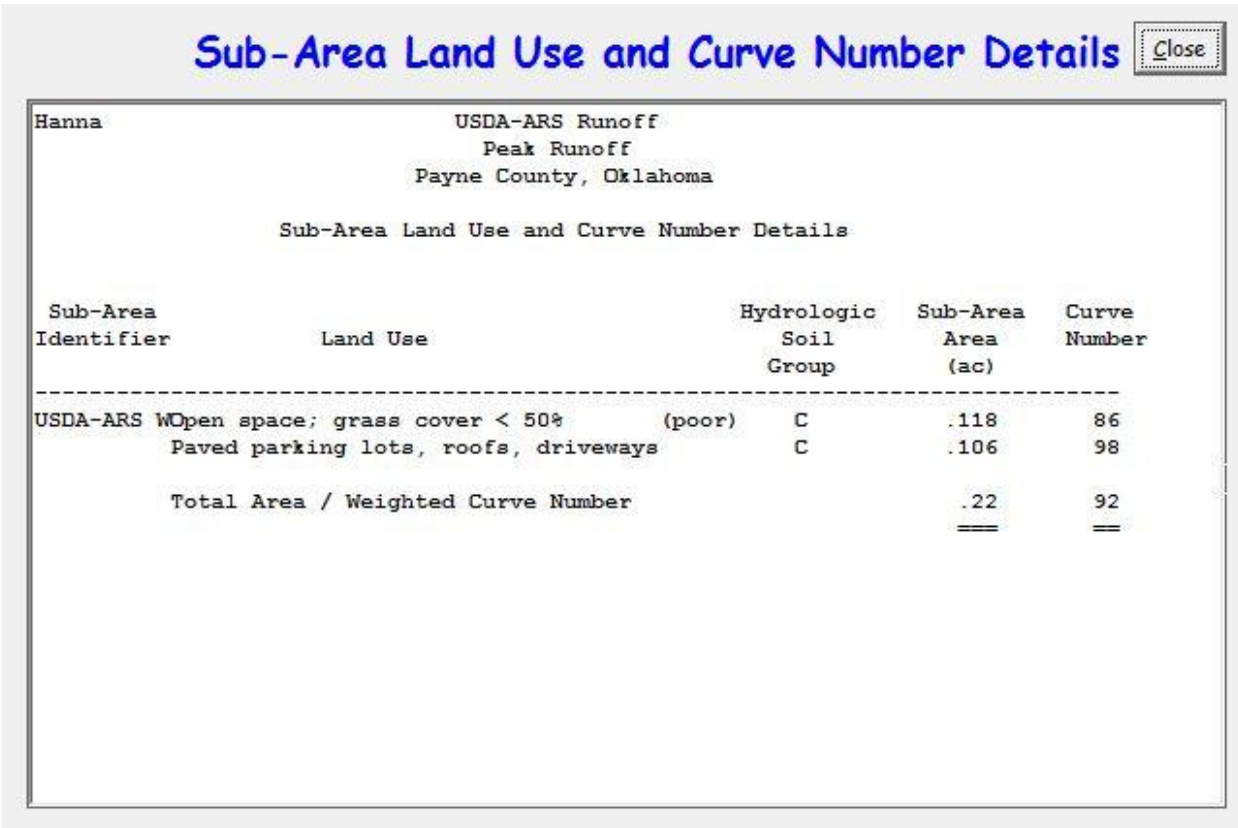
Sub-Area Land Use and Curve Number Details

Sub-Area Identifier	Land Use		Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
USDA-ARS W	Open space; grass cover < 50%	(poor)	C	.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

Close

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Peak Runoff
Payne County, Oklahoma

Sub-Area Land Use and Curve Number Details

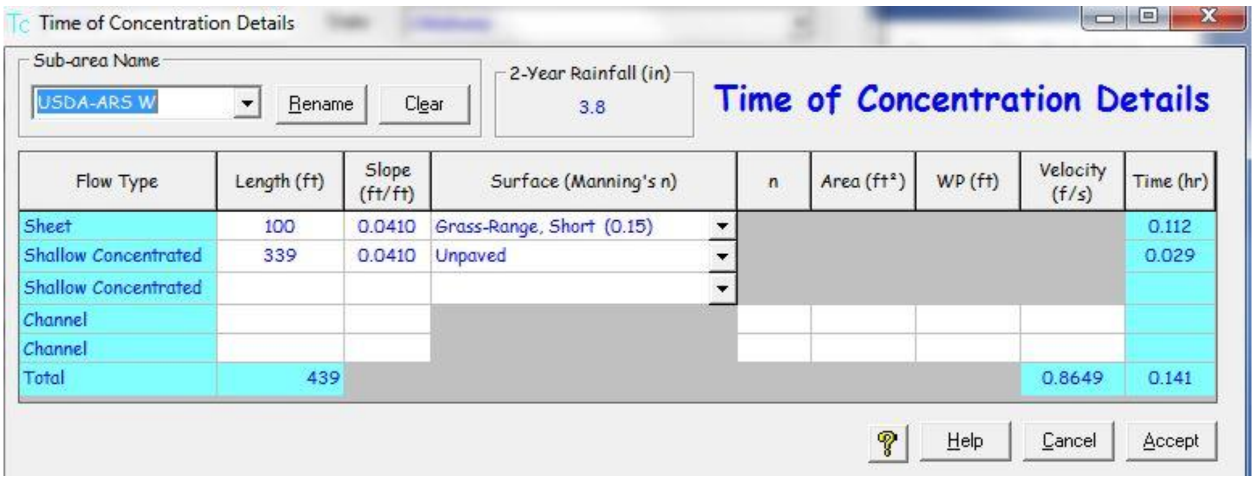
Sub-Area Identifier	Land Use	Hydrologic Soil Group	Sub-Area Area (ac)	Curve Number
USDA-ARS W	Open space; grass cover < 50% (poor)	C	.118	86
	Paved parking lots, roofs, driveways	C	.106	98
	Total Area / Weighted Curve Number		.22	92

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.


Time of Concentration Details

Sub-area Name: USDA-ARS W | Rename | Clear

2-Year Rainfall (in): 3.8

Time of Concentration Details

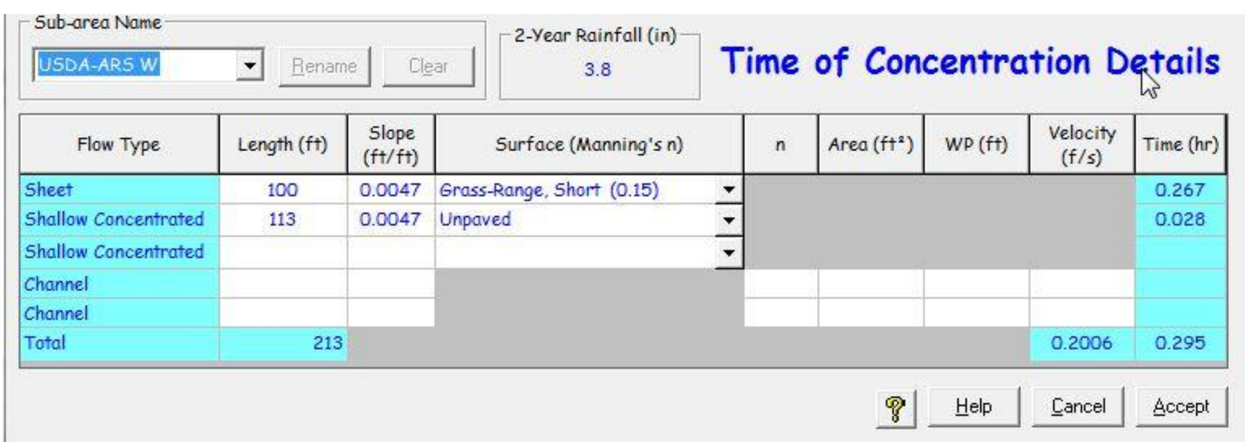
Flow Type	Length (ft)	Slope (ft/ft)	Surface (Manning's n)	n	Area (ft²)	WP (ft)	Velocity (f/s)	Time (hr)
Sheet	100	0.0410	Grass-Range, Short (0.15)					0.112
Shallow Concentrated	339	0.0410	Unpaved					0.029
Shallow Concentrated								
Channel								
Channel								
Total	439						0.8649	0.141

Help | Cancel | Accept

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.


Sub-area Name: USDA-ARS W | Rename | Clear

2-Year Rainfall (in): 3.8

Time of Concentration Details

Flow Type	Length (ft)	Slope (ft/ft)	Surface (Manning's n)	n	Area (ft²)	WP (ft)	Velocity (f/s)	Time (hr)
Sheet	100	0.0047	Grass-Range, Short (0.15)					0.267
Shallow Concentrated	113	0.0047	Unpaved					0.028
Shallow Concentrated								
Channel								
Channel								
Total	213						0.2006	0.295

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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	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)
	Peak Flow and Peak Time (hr) by Rainfall Return Period						
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

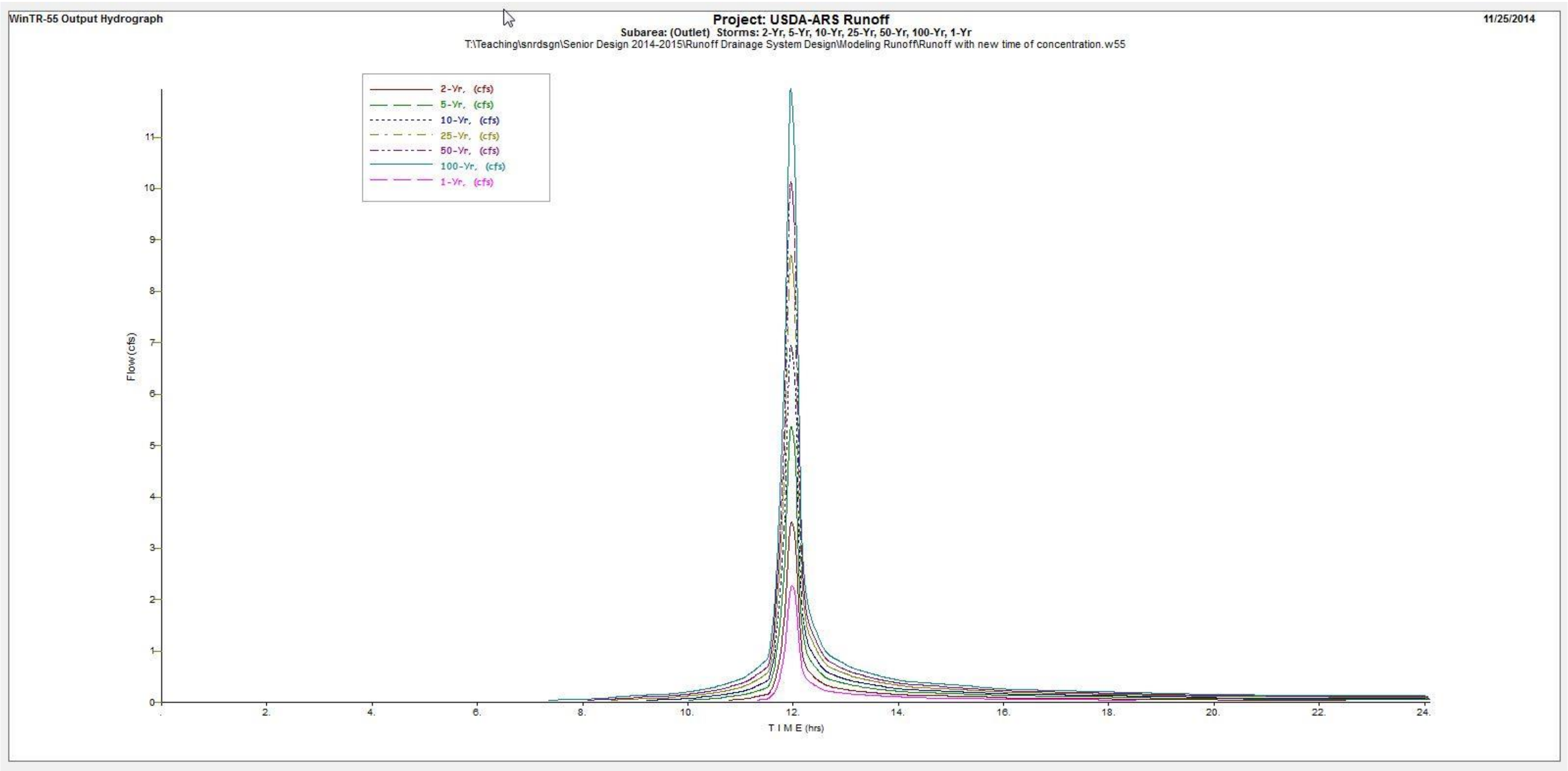

Figure 11. Peak flow hydrograph as produced in WinTR-55

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 12.06	0.96 12.06	1.16 12.06	1.38 12.06	1.55 12.06	1.77 12.06	0.54 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

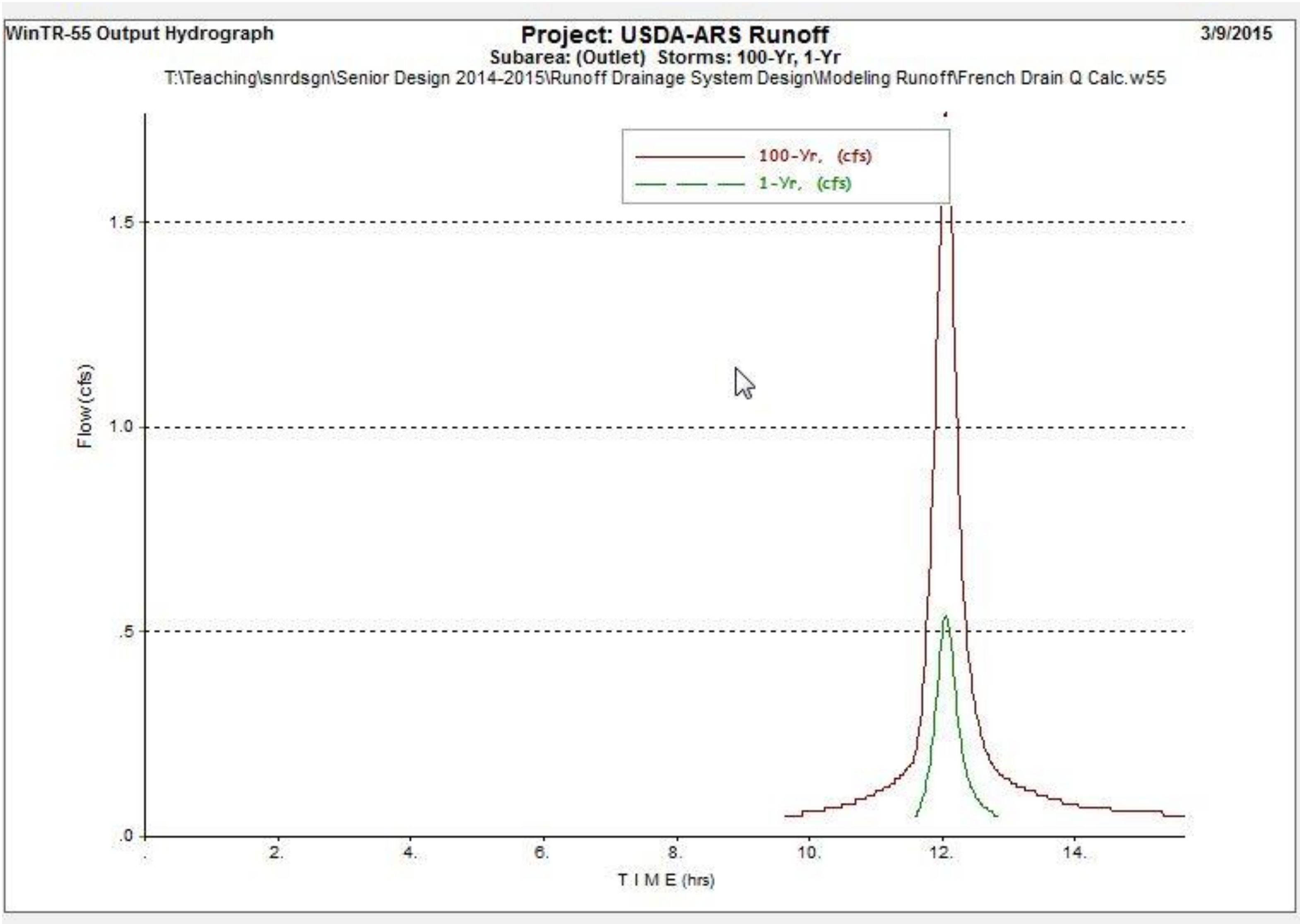

Figure 20. Peak flow hydrograph that the French drain should handle for years 1 and 100

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).

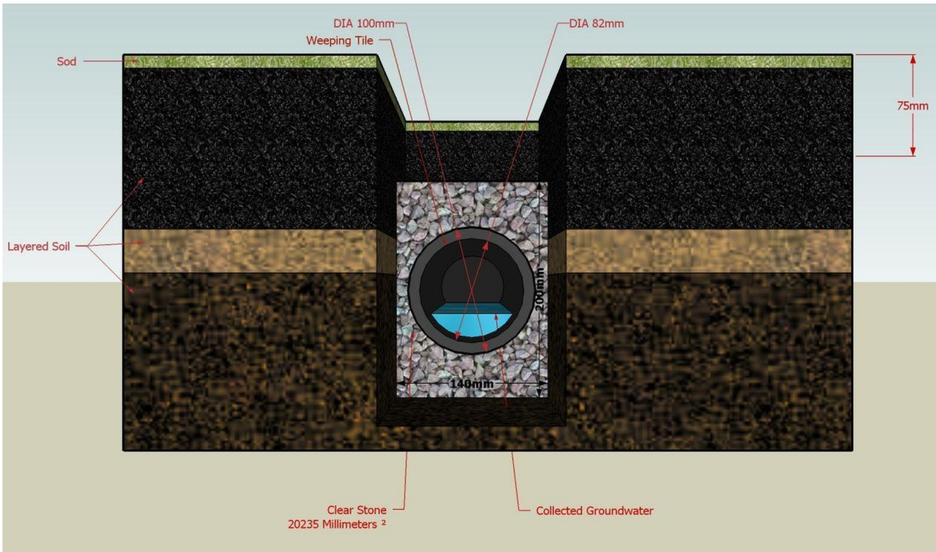

Figure 21. French Drain design (Wikipedia, 2014)

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. $Q = \frac{1.486}{n} A R_h^{\frac{2}{3}} S_o^{\frac{1}{2}}$. 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° PVC Wye; 4'' 45° 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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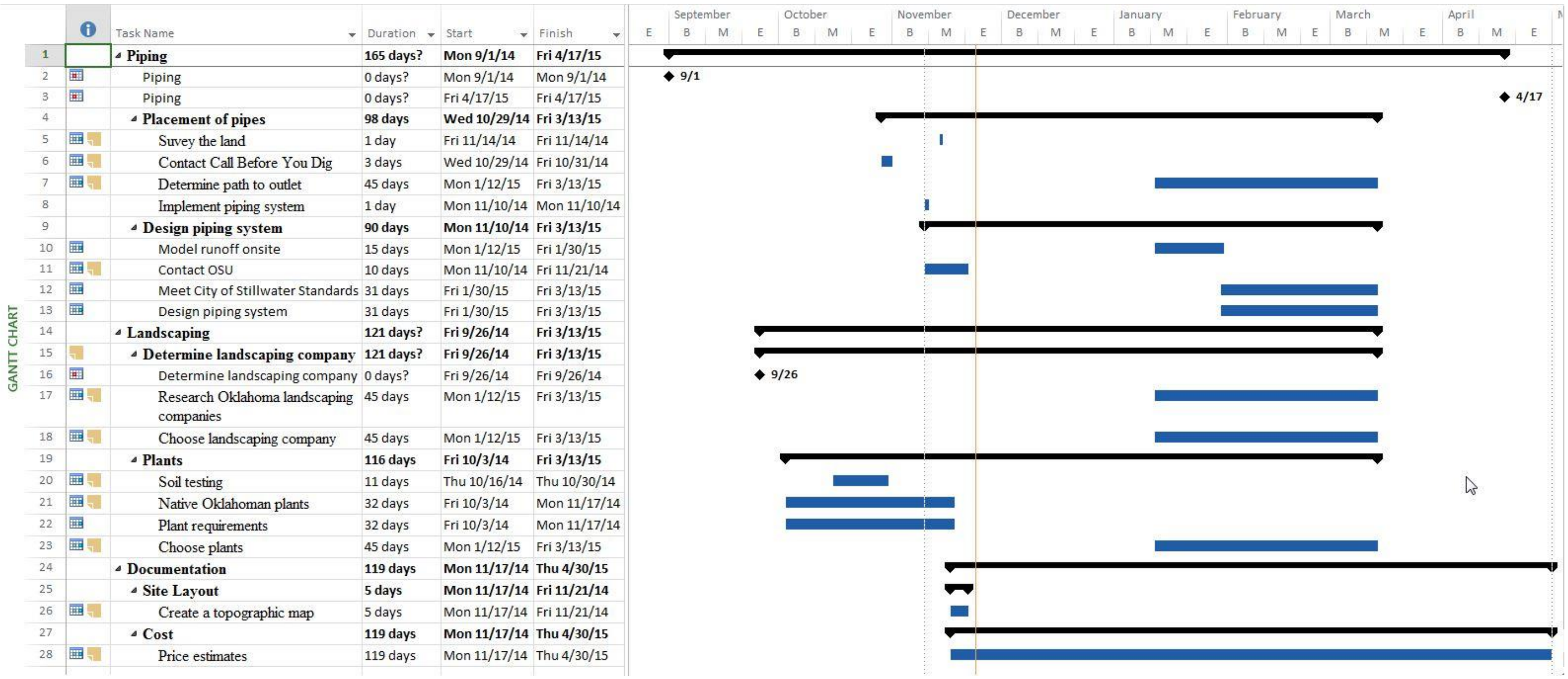
Appendices

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**
Survey the land	1 day	Fri 11/14/14	Fri 11/14/14
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Determine path to outlet	45 days	Mon 1/12/15	Fri 3/13/15
Implement piping system	1 day	Mon 11/10/14	Mon 11/10/14
Design piping system	**90 days**	**Mon 11/10/14**	**Fri 3/13/15**
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Contact OSU	10 days	Mon 11/10/14	Fri 11/21/14
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Documentation	**119 days**	**Mon 11/17/14**	**Thu 4/30/15**
Site Layout	**5 days**	**Mon 11/17/14**	**Fri 11/21/14**

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

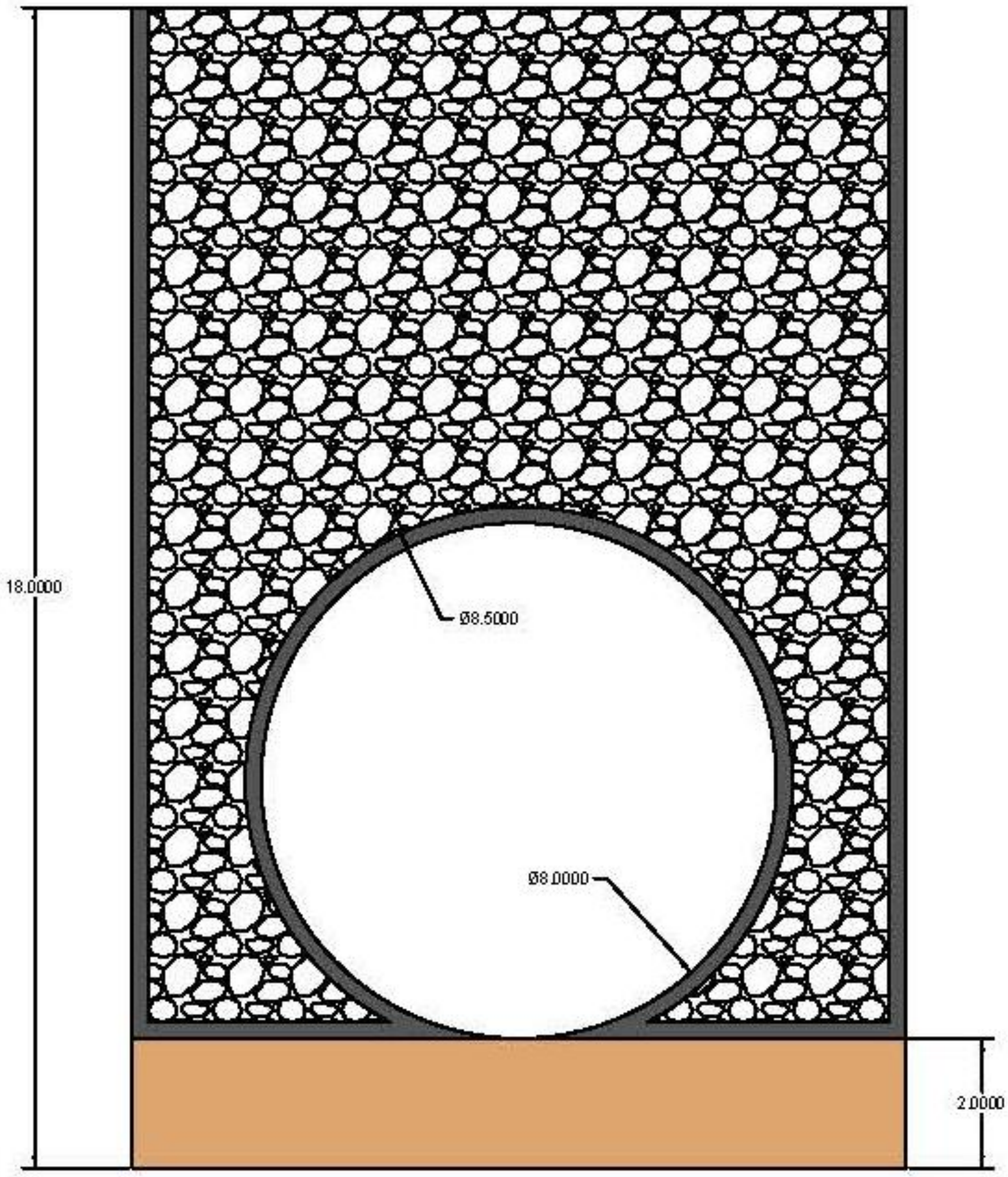


Figure F-1. AutoCAD drawing of the cross-section of the French Drain (dimensions in inches)

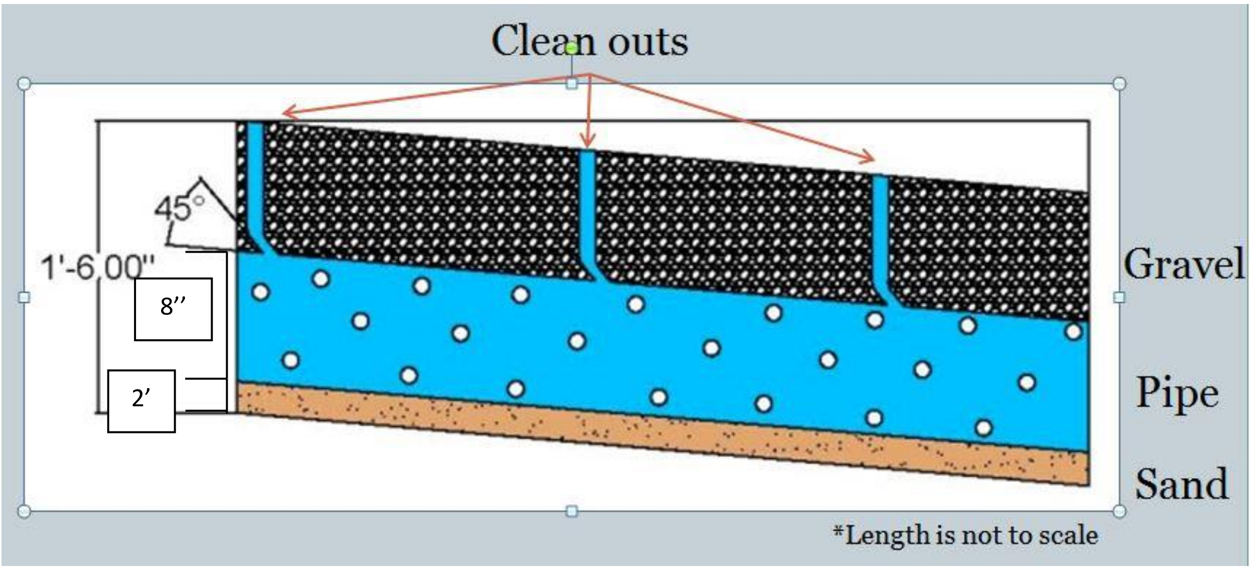


Figure F-2. AutoCAD drawing of the profile of the French Drain (dimensions in inches and feet). Length is 210 feet. Sweep T's will be placed every 70 feet. Pipe will be perforated. Filter cloth will surround the pipe, and perimeter of the French Drain trench.

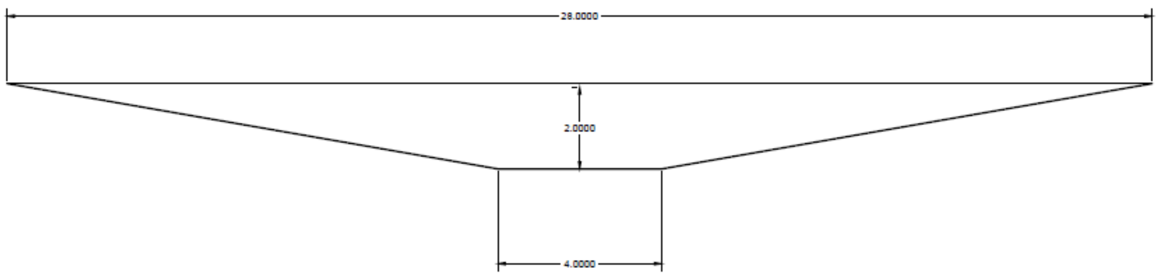
Appendix G. French Drain Cost Analysis

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.



Dimensions are in feet

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.

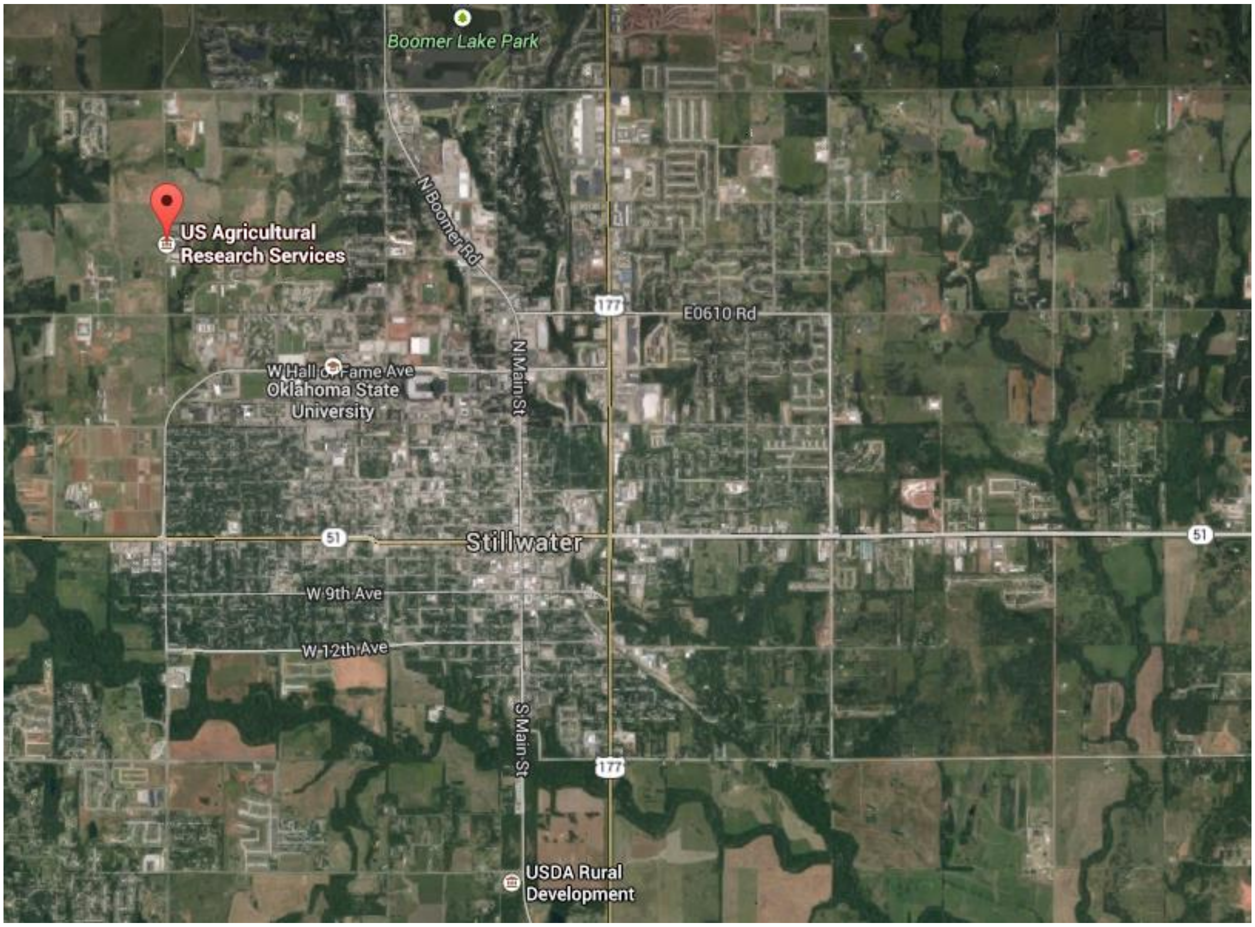


Figure I-1. Stillwater, OK (Google Maps, 2015)

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

Figure I-3. Location of French drain

USDA-ARS Runoff Drainage System Design

HANNA HULING
CAROLINE SHORT
HANNAH SPITLER

CH2 Consulting

Overview

- Introduction
- Problem Statement
- Modeling and Data Collection
- Solutions
- Comparison

Client: USDA-ARS

- The United States Department of Agriculture Agricultural Research Service (USDA-ARS)
  - The largest agricultural research organization in the world
- Stillwater - 2 Research Units
  - Wheat, Peanut and Other Field Crops Research
  - Hydraulic Engineering Research Unit

Problem Statement

- The United States Department of Agriculture-Agricultural Research Service (USDA-ARS) has an ongoing stormwater runoff problem that causes sidewalks and doorways to flood becoming hazardous.

Site Location

- USDA-ARS Location:
  1301 N Western
  Stillwater, OK 74075
- South side of property:
  - Warehouse
  - Environmental Laboratory buildings
- Nearby creek on SE corner of property

USDA-ARS site (Google Earth, 2014)

Topographic Map

USDA-ARS Site

- The USDA-ARS rents the site from Oklahoma State University (OSU)
- OSU is the property owner
- Considered private property
- Meet City of Stillwater Standards for modifying property and OSU requirements

Site Visit

Customer Requests

- Details
  - Solution should be aesthetically pleasing
  - Trees in front of the buildings can be removed if needed
  - The flow can be directed to a creek on the southeast portion of the property
  - If possible, itemize costs below $3,000 so solution doesn't have to be bid out

Design Specifications

- Model 1 to 100-year, 24-hour rainfall event
  - Current Q_p
- Peak flow (Q_p) after development ≤ current Q_p
- After development t_c ≥ current t_c
  - t_c :Time needed for water to flow from the most remote point of the watershed to the watershed outlet point.
- Cannot construct on a regulatory flood plain

Soil Sampling

6 inches below the surface

20 random samples

Soil Sample Results

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

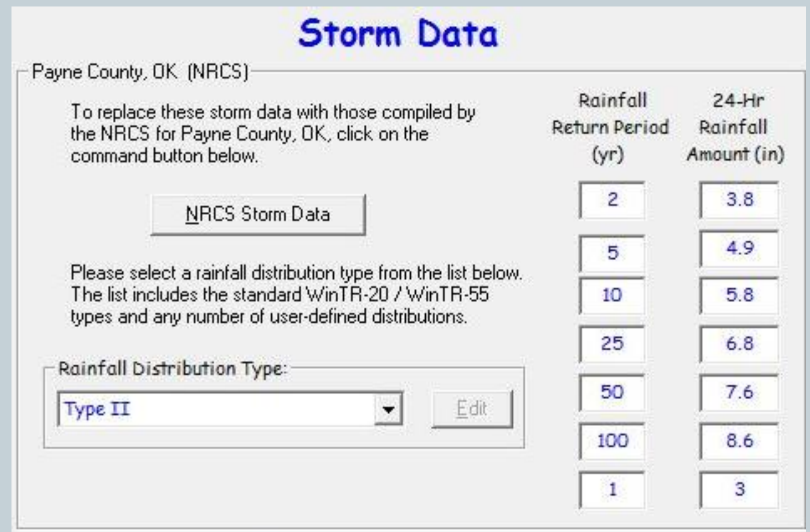
Soil texture results from Soil, Water, and Forage Analytical Laboratory at Oklahoma State University

Modeling Runoff

- Storm data for Payne county

Figure 6.10 ■ Geographic Boundaries of NRCS Rainfall Distributions

NRCS Rainfall map (Soil Conservation Service, 1986)



Modeling Runoff

- Curve Number
  - Land cover descriptions

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	.118	86
	Paved parking lots, roofs, driveways	C	.106	98
	Total Area / Weighted Curve Number		.22	92

$$CN = \frac{\sum A_i CN_i}{\sum A_i}$$

Modeling Runoff

- Time of Concentration
  - NRCS Method
  - WinTR-55 built in function
  - $t_c(hours) = \frac{L_{sc}}{V_{sc}}$

Sub-area Name: USDA-ARS W — Rename — Clear

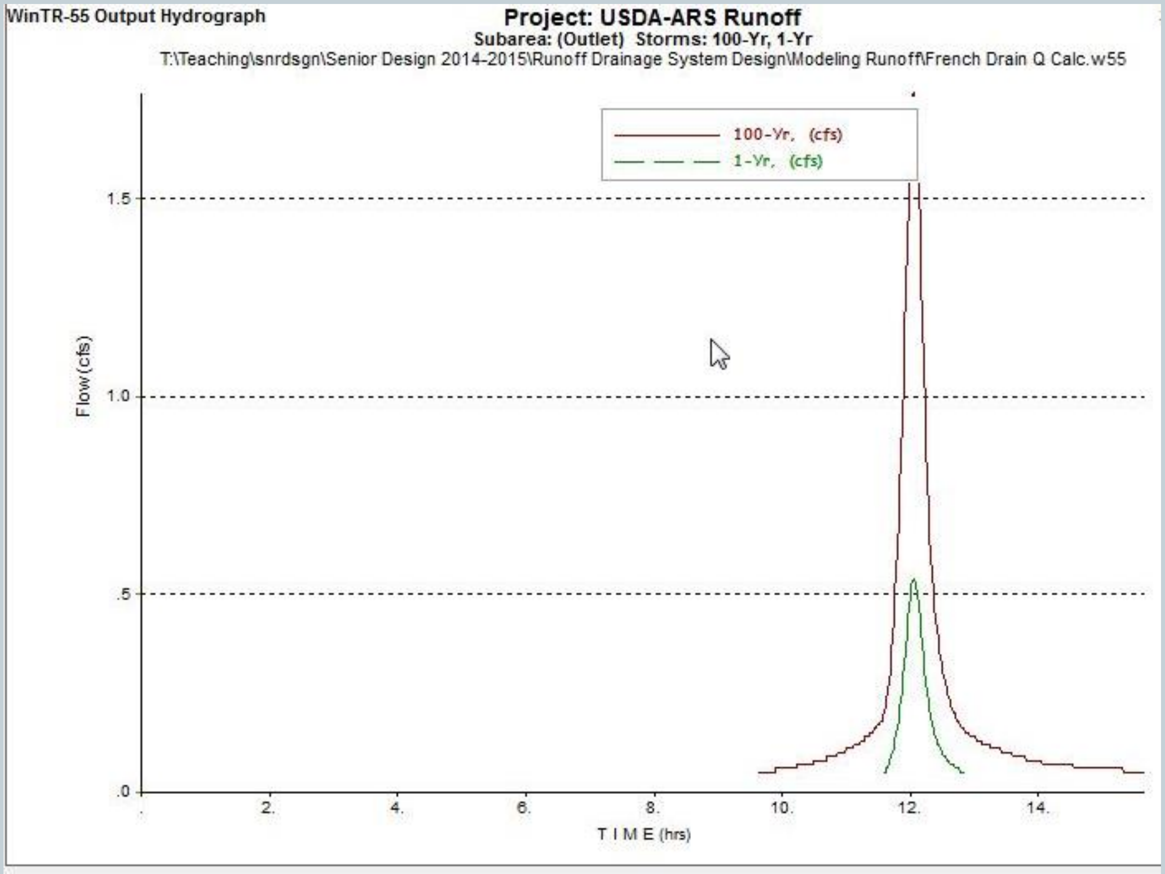
2-Year Rainfall (in): 3.8

Time of Concentration Details

Flow Type	Length (ft)	Slope (ft/ft)	Surface (Manning's n)	n	Area (ft²)	WP (ft)	Velocity (f/s)	Time (hr)
Sheet	100	0.0047	Grass-Range, Short (0.15)					0.267
Shallow Concentrated	113	0.0047	Unpaved					0.028
Shallow Concentrated								
Channel								
Channel								
Total	213						0.2006	0.295

Help — Cancel — Accept

Modeling Runoff



Modeling Runoff

- Q_p after development $\leq$ current Q_p
  - 1.65 cfs ≤ 1.77 cfs
- After development t_c $\geq$ current t_c
  - 0.315 hr ≥ 0.295 hr

Hydrograph Peak/Peak Time Table Close

Hanna

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 12.06	0.96 12.06	1.16 12.06	1.38 12.06	1.55 12.06	1.77 12.06	0.54 12.06
REACHES							
OUTLET	0.71	0.96	1.16	1.38	1.55	1.77	0.54

Hydrograph Peak/Peak Time Table Close

Hanna

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	0.58 12.07	0.82 12.07	1.02 12.06	1.25 12.06	1.42 12.07	1.65 12.06	0.40 12.07
REACHES							
OUTLET	0.58	0.82	1.02	1.25	1.42	1.65	0.40

Design Concepts and Ideas

- Rain storage tanks
- Gutter repair
- Addition of sod
- French Drain
  - Option: Vegetated channel down gradient of French Drain

Solutions

Design Solution 1

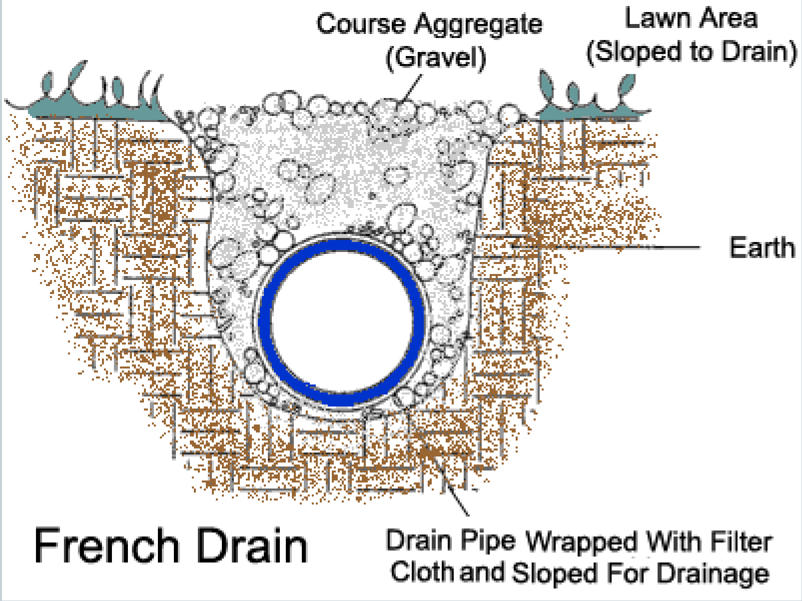
- French drain
- Gutter repair
- Fescue sod

Design Solution 2

- 600 Gallon Plastic Water Storage Tank
- Gutter repair
- Fescue sod (optional)

Design Solution 1: French Drain

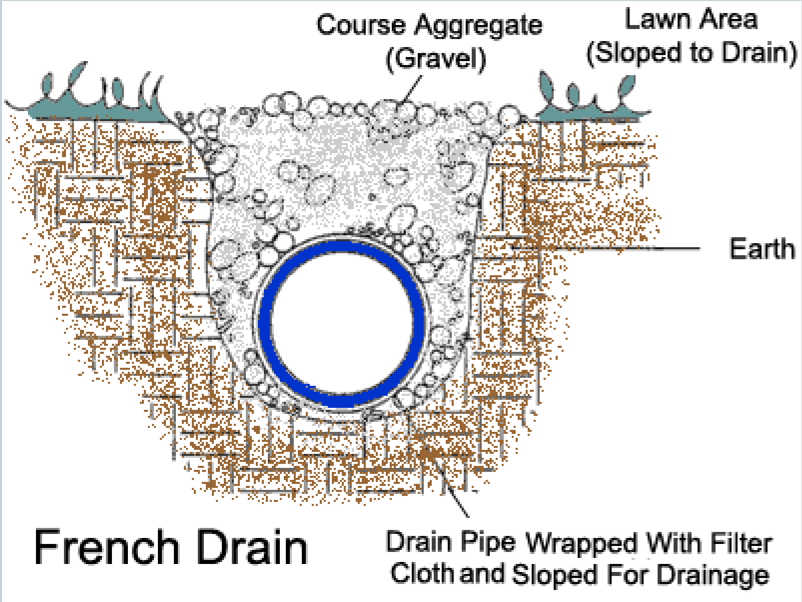
- French Drain Design
  - Permeable pipe
  - Drainage filter cloth
  - Buried with gravel or any course aggregate
- Maintenance Costs
  - Cleaning out debris



French Drain (Nusite Waterproofing, 2012)

Design Solution 1: French Drain

- Advantages
  - Simple design concept
  - Effectively transports flow
- Disadvantages
  - Gravel may be within eyesight
  - Removal of trees
    - Costly
  - Design will be bid out



French Drain (Nusite Waterproofing, 2012)

French Drain Location

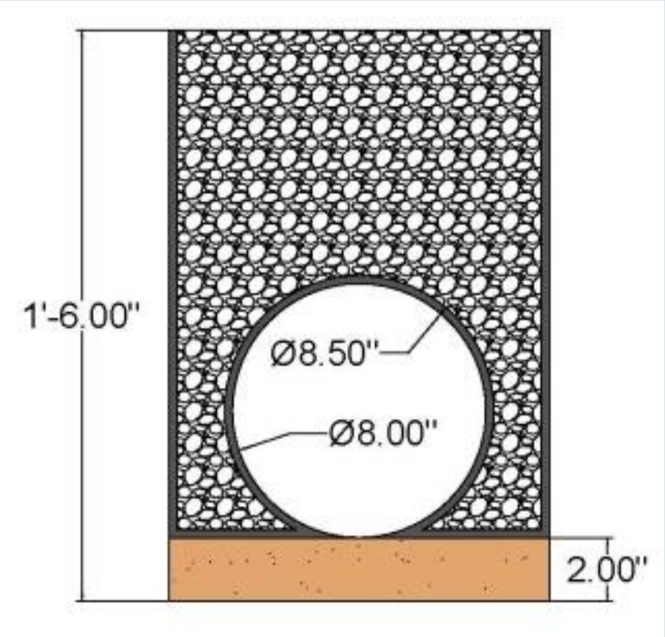
French Drain Pipe Calculations

- Manning's Equation
- $Q = \frac{1.486}{n} A R_h^{\frac{2}{3}} S_o^{\frac{1}{2}}$
- $Q_x = 0.0084 * X \ ft^2/s$
- $\int S_x dx = \int [\frac{n}{1.486} * \frac{Q_x}{A R_h^{2/3}} x]^2$
  - 8" diameter pipe
    - 1.5' drop in elevation over 210'

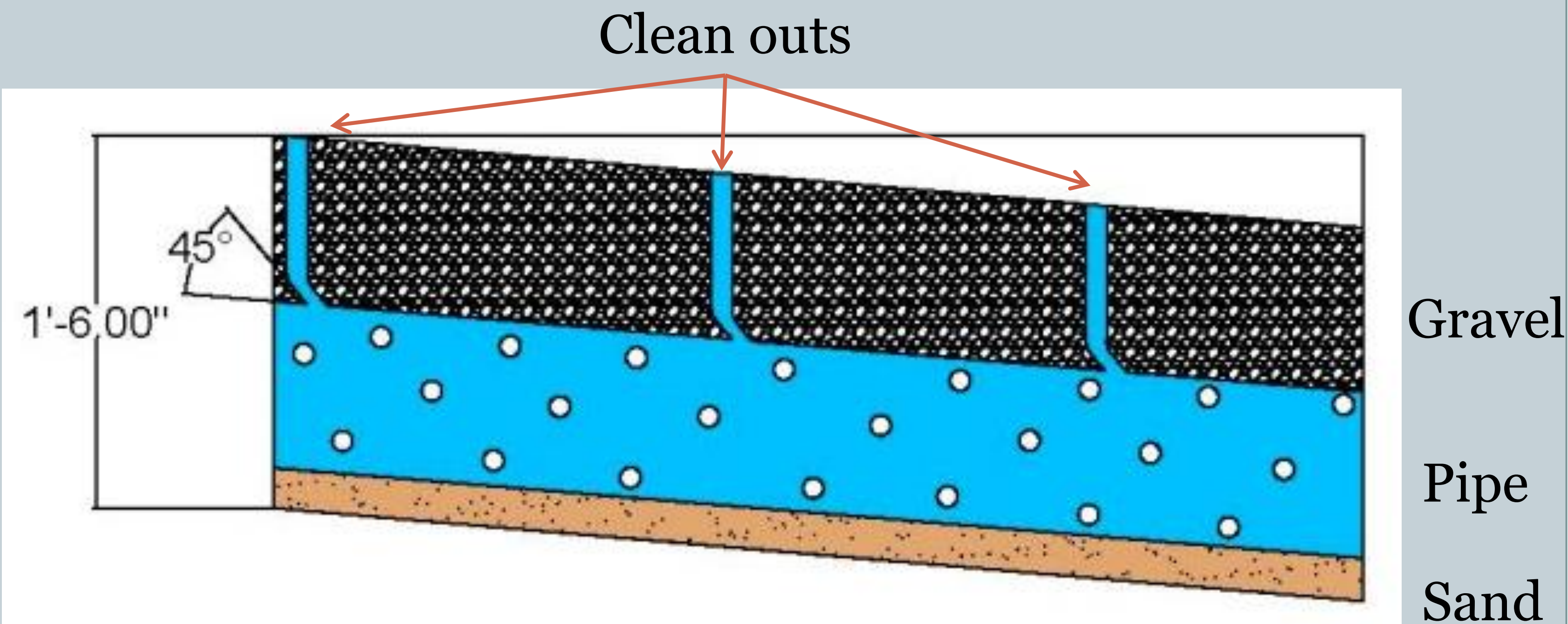
- Circular Pipe with Varying Flow
- Infiltration
  - Through gravel = 0.005 ft/s
  - Gravel k = 0.16 ft/s

Design Solution 2: French Drain

- Materials:
  - Course Sand
  - 8" Perforated PVC
  - Drainage Filter Fabric
  - 3/8" Pea Gravel
  - 8" 45º PVC Wye
  - 4" 45º PVC Elbow
  - 4" Cleanout Cap
- Trench Dimensions
  - 1.5’ x 1.0’



French Drain Specifications



*Length is not to scale

French Drain Cost Analysis

- Stillwater Sand and Gravel
  - Course Sand, Pea Gravel
  - $330
- Lowe's and Locke Supply Co.
  - Filter Fabric, PVC
  - $1,592.74
- Green Acres Sod Farm
  - Fescue Sod
  - $2,198.15
- Total Cost: $4,120.90
  - Does not include cost of labor

Watershed Area

Watershed Flow

Hydrograph Peak/Peak Time Table

Close

Hanna

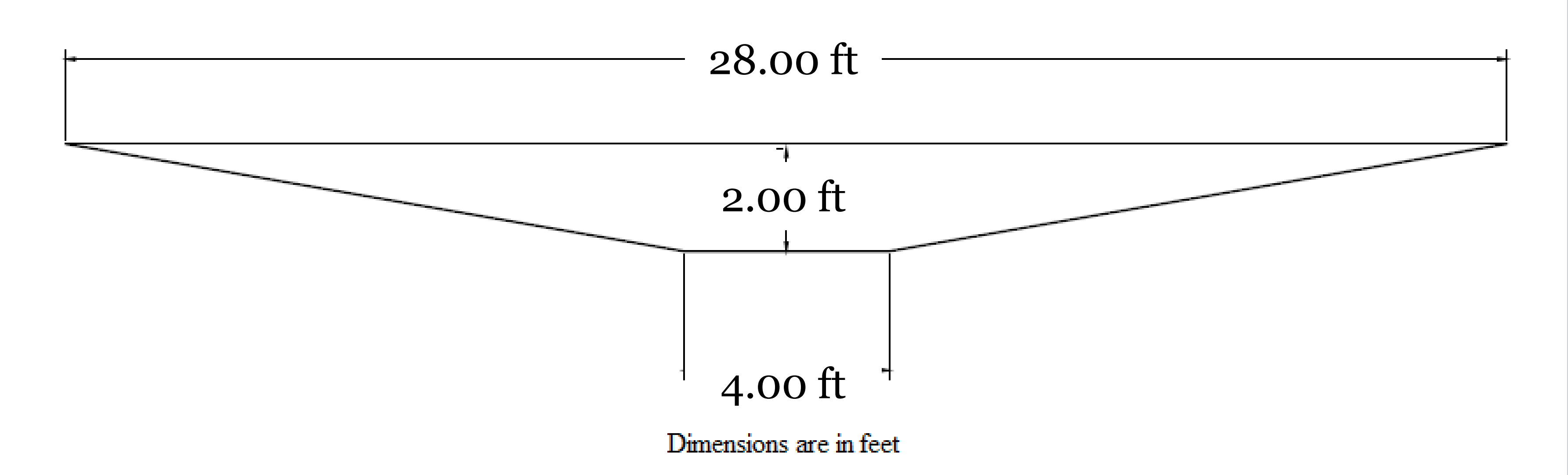
USDA-ARS Runoff
Peak Runoff
Payne County, Oklahoma

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	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

Vegetated Channel – not recommended

- Q = 11.97 cfs (entire watershed)
- Cover – Bermuda grass
- 10% slope of channel
- 6:1 side slope
- Easily erodible soil



Tree Removal

- Nate's Tree Service- Stillwater, OK
  - Remove a maximum of 9 trees to install French drain
  - Bradford Pear trees
  - Grind stumps and dispose
  - $4,625.00

Design Solution 2

- 600 Gallon Plastic Water Storage Tank
  - 4 storage tanks required
    - 2 per building
    - $438.99 each
  - Located on the edges of the buildings
  - Captures runoff from roof
    - 1.3 inch rainfall event

Design Solution 2

- Gutter Repair
  - Fix gutter leaks
  - Decreases ponding
  - Reseal the seams
- Able Seamless Guttering (Oklahoma City)
  - Cost estimate: $1600.00

Design Solution 2

- Fescue sod (optional)
  - Decreases runoff
- Green Acre Sod Farm (Oklahoma City)
  - $215/500 ft^2
  - 5,100 ft^2
  - Total Cost: $2,198.16

Design 1 Summary

Design 1: French Drain			
Component	**Cost**	**Advantages**	**Disadvantages**
Gutter Repair (Able Seamless Guttering)	$1600.00	• Effectively captures runoff • Transports runoff away from buildings, sustainable	• Bid out to construction company • Additional labor costs
French Drain	$4,120.90		
Tree Removal	$4625.00		
Total	**$10,346.70**		

Design 2 Summary

Design 2: Rain Storage Tanks + Gutter Repair			
Component	**Cost**	**Advantages**	**Disadvantages**
Rain tanks (4)	$1755.96 + shipping	• Simple • Cost effective • Minimizes runoff • Potential Green Points	• Possibility of ponding • Less aesthetically pleasing
Gutter Repair - Able Seamless Guttering	$1600.00		
Fescue Sod (optional)	$2198.16		
Total:	**$5,554.12**		

Acknowledgements

- Dr. Paul Weckler, Senior Design instructor
- Dr. Sherry Hunt and Linda Gronewaller, USDA-ARS
- Dr. Glenn Brown for advisement regarding the French Drain design
- Dr. Garey Fox for advisement regarding the WinTR-55 modeling software
- Dr. John Long , assistance during the surveying process
- Freshmen team (Tony Blackbear, Ty Fisher, Derek Hurst, and Bailey Poe) for helping us with the collection of soil samples and surveying
- Soil, Water, and Forage Analytical Laboratory for analyzing our soil samples
- Chuck Cassidy and OSU Physical Plant Services, and Mike Buchert and Long Range Facilities Planning

Questions?

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Runoff Drainage System Design

USDA-ARS

1301 N Western, Stillwater, OK, 74074

12/5/2014

Huling, Hanna

Short, Caroline

Spitler, Hannah

Contents

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 will be taken 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 fall semester, CH_2 Consulting will present the USDA-ARS with a topographic map of the site and soil sample results. This will allow CH_2 Consulting to communicate where more runoff is likely to occur because of increases in elevation, along with the type of grass to be planted at the site to promote infiltration based on the current soil properties. In the spring semester CH_2 Consulting's research, topographic map, soil sample results, and runoff-modeling results will be used to develop a runoff drainage system design to present to the USDA-ARS.

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.

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).

Paved Channel

As described by the Virginia DEQ (2014) a paved channel is a concrete channel typically of a trapezoidal, parabolic, or v-shape. Stormwater runoff travels into the channel, which is then directed to an outlet. Concrete channels can carry a higher flow (Virginia DEQ, 2014).

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. 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.

Pervious Piping

Pervious piping would be buried shallowly to transport runoff to an outlet. Three types of corrugated plastic pipes are available through Plastics Pipe Institute. The first type (C) has a corrugated exterior and interior surface, the second type (S) has a smooth interior and a corrugated exterior pipe wall, and the third type (D) has an "essentially smooth" interior surface connected to an "essentially smooth" outer wall. Corrugated perforated HDPE pipes have been used in hillside subsurface drainage systems (Plastics Pipe Institute, 2014).

When constructing a runoff drainage system design, appropriate piping and the water table need to be considered. HDPE corrugated pipe allows for a custom design, with headers and fittings, and a layout based upon the storage needs and environmental regulations such as maintaining a certain distance above groundwater. This is applicable to the USDA site because the groundwater table needs to be evaluated before the design of a runoff drainage system can be applied. HDPE piping is resistant to aggressive environments, therefore it will need to be determined if there are any chemicals in the soil on site that could damage the HDPE piping (Plastics Pipe Institute, 2014).

HDPE piping is generally installed at shallow depths (see Figure 2) to limit construction costs and prevent hitting groundwater. This allows for the road or cement walkways at the USDA site to be built above the piping system. Maintenance costs associated with HDPE piping include flushing out soil and debris that have entered the pipe. However, some HDPE contain a smooth interior making it easier to clean. Initial costs for implementing HDPE piping are low because they are designed at shallow depths and result in a long life of use (Plastics Pipe Institute, 2014).

Figure 2 Construction of HDPE piping (Plastics Pipe Institute, 2014)

Geotextiles

Geotextiles are mats or nets that can be installed at the surface or buried to promote vegetation growth, protect the soil, reduce the detachment and transport capacity of rainfall, and enhance soil water holding capacity. Alvarez-Mozes researched the effectiveness of two biological geotextiles (jute net and coir blanket), and a synthetic polyester geogrid were applied to steep slopes of 45^{o} and 60^{o} at a standard construction site (2014). Table 1 shows that the jute net had higher water holding capacity, mass, and tensile strength than the coir blanket.

Table 1 Main properties of tested geotextiles (Alvarez-Mozos, 2014)

Treatment	Roll Size (mxm)	Thickness (mm)	Mass per area (g m^{-2})	Open area (%)	Water holding capacity (mm)	Tensile strength (Kn m^{-1})
1 – Jute net	1.2 x 68.6	5	500	60	3.1	21
2- Coir blanket	2 x 33	8	271	7	.84	3
3- Geogrid	4.5 x 100	10	300	50	-	30
4 – Geogrid(B)	4.5 x 100	10	300	100	-	30

The jute net is biodegradable thus making its lifetime only last for 1-2 years. The coir blanket is usually made with a close fiber structure causing it to have a superior durability in comparison. The geogrid has a 3D traverse structure, is lightweight, and is made out of a strong material with low deformability making its durability exceed the biological geotextiles with a life of up to 20 years (Alvarez-Mozos 2014). It was found that the jute net and surface-laid geogrid produced the lowest soil loss rates (3.2 g m^{-2} and 2.1 g m^{-2}) at 45^o but at 60^o the soil loss rates were approximately the same as the control plot with no covering. Out of these two applications the surface-laid geogrid produced the lowest soil loss rates, but when buried it did not effectively control erosion in the upper soil layer (Alvarez-Mozos 2014).

With the installation of permeable pipes below the ground surface, geotextiles or a polyester geogrid can be applied to the surface or buried to help prevent soil loss. The durability of the geogrid is much longer than the geotextiles but it is less visually appealing and would cost more. Maintenance costs and requirements would be minimal for both the geotextiles and polyester geogrid.

Figure 3 Geotextile used in drainage applications (Lowes, 2014)

Rain Gardens

A rain garden is a garden featuring plants that are suitable for wet and dry conditions. Runoff directed (via pipes or channels) into the rain garden supports plant growth (Franti and Rodie, 2014.). The Wisconsin Department of Natural Resources advises rain gardens be built at least 10 feet away from a building structure to prevent water from seeping into the foundation (2014). Rain gardens should not be built where ponding occurs (Wisconsin Department of

Natural Resources, 2014). A site for rain gardens should also have a slope less than 12%. Clay soil may not be suitable for rain gardens due to low infiltration. Furthermore, rain gardens should be located in sunny areas (Franti and Rodie, 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.

Figure 4 illustrates an Oak Sedge, *Carex albicans*, which requires light shade-sun exposure. Tall fescue turfgrass is being considered as the grass of choice, due to its ability to grow in shady drought-tolerant conditions.

Figure 4 Oak Sedge - Carex albicans (Missouri Wildflower Nursery, 2014)

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 all 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 Concept 1: French Drain

- Implement a French drain to solve the runoff problem.
    - Details: Hire a construction company to implement a rectangular trench with a perforated pipe at the bottom of the channel and gravel surrounding the pipe. Typically a French drain is about 10-12 inches wide and has a depth of about 1.5 feet (Fairfax County, Virginia, 2013).
    - Materials: gravel, pervious pipe, construction equipment. Optional: landscape fabric, topsoil, sod
    - Advantage: Simple design concept, cost effective
    - Disadvantages: May require uprooting the trees in front of the building. 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.

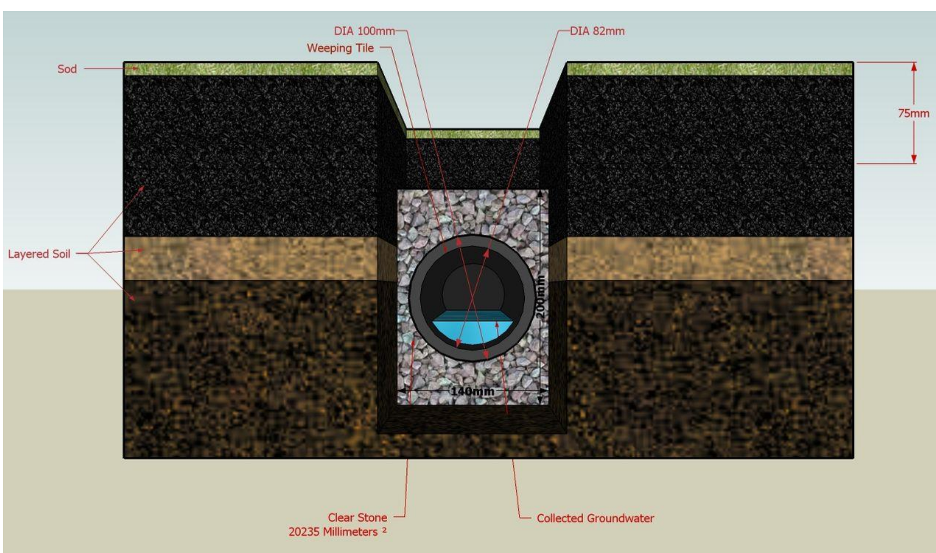


Figure 5 French Drain design (Wikipedia, 2014)

Design Concept 2: Underground Pervious Piping

- Design an underground pervious piping system to solve the runoff problem.
    - Hire a construction company to implement underground pervious piping system design. Plant sod or native Oklahoma plants on ground surface above the underground pervious piping system to promote infiltration to the pipes.
    - Materials: Pervious pipes, construction equipment, sod, Oklahoma native plants
    - Advantage: Would collect runoff underground causing the design to be aesthetically pleasing because of sod and Oklahoma native plants on the top layer with no drainage design eyesores
    - Disadvantage: Could require uprooting the trees in front of the building. If so we would plant new trees after uprooting the old trees

Design Concept 3: Grass-lined Channel

- Uses native grasses to reduce the stormwater velocity and promote stormwater infiltration; various shapes could be implemented – rectangular, trapezoidal, etc.
- Advantages: Relatively low cost; aesthetically pleasing
- Disadvantages: Requires construction equipment to implement channel characteristics; maintenance of mowing, removing sediment deposits
- 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, 9.81 m s^{-2} (Fox, 2014a).
- Design method and validation requirements described in *Design of Open Channels* (Fox, 2014a). In the design process, flow would be calculated using Manning's equation. $Q =$

$\frac{1}{n} A R_h^{\frac{2}{3}} S_o^{\frac{1}{2}}$, 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.

Figure 6 Grass-lined channel (Fairfax County, Virginia, 2014)

Design Concept 4: Concrete-lined channel

- Description: V-shaped, parabolic, or trapezoidal concrete channel that discharges into a natural channel
- Materials needed: Concrete and excavator
- Advantages: Efficient at carrying runoff and low maintenance (Virginia DEQ, 2014)
- Disadvantages: Flooding (Virginia DEQ, 2014), not aesthetically pleasing, expensive, and limited site space
- Velocity cannot exceed 2.1 m s^{-1} (Fox, 2014a)
- Froude number should be greater than 0.8 for non-reinforced linings (Fox, 2014a)
- Recommended minimum permissible velocity of 0.6 to 0.9 m s^{-1} (Fox, 2014a)

- Minimum freeboard requirement of 30 cm. Freeboard can be calculated using the following equation: $F = 0.55\sqrt{Cy}$, where F is the freeboard in meters, C is the freeboard coefficient and y is the normal depth in meters (Fox, 2014a)
- Design method and validation requirements described in *Design of Open Channels* (Fox, 2014a). $Q = \frac{1}{n} A R_h^{\frac{2}{3}} S_o^{\frac{1}{2}}$, 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

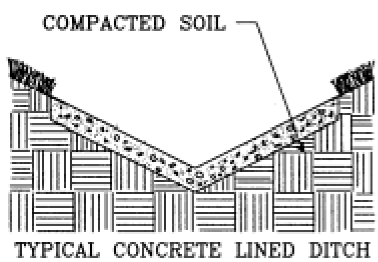


Figure 7 Concrete-lined channel (Virginia DEQ, 2014)

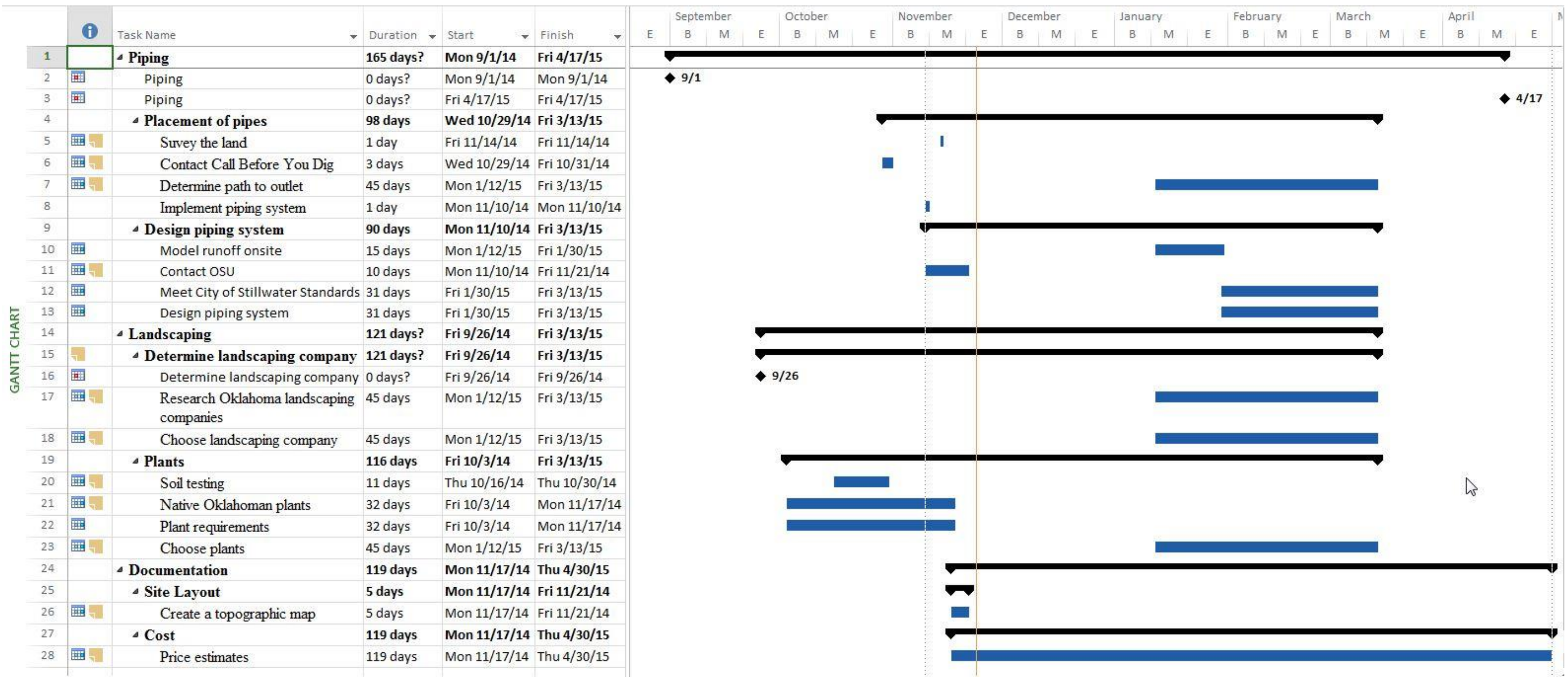
Project Schedule

Table 2 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**
Survey the land	1 day	Fri 11/14/14	Fri 11/14/14
Contact Call Before You Dig	3 days	Wed 10/29/14	Fri 10/31/14
Determine path to outlet	45 days	Mon 1/12/15	Fri 3/13/15
Implement piping system	1 day	Mon 11/10/14	Mon 11/10/14
Design piping system	**90 days**	**Mon 11/10/14**	**Fri 3/13/15**
Model runoff onsite	15 days	Mon 1/12/15	Fri 1/30/15
Contact OSU	10 days	Mon 11/10/14	Fri 11/21/14
Meet City of Stillwater Standards	31 days	Fri 1/30/15	Fri 3/13/15
Design piping system	31 days	Fri 1/30/15	Fri 3/13/15
Landscaping	**121 days?**	**Fri 9/26/14**	**Fri 3/13/15**
Determine landscaping company	**121 days?**	**Fri 9/26/14**	**Fri 3/13/15**
Determine landscaping company	0 days?	Fri 9/26/14	Fri 9/26/14
Research Oklahoma landscaping companies	45 days	Mon 1/12/15	Fri 3/13/15
Choose landscaping company	45 days	Mon 1/12/15	Fri 3/13/15
Plants	**116 days**	**Fri 10/3/14**	**Fri 3/13/15**
Soil testing	11 days	Thu 10/16/14	Thu 10/30/14
Native Oklahoman plants	32 days	Fri 10/3/14	Mon 11/17/14
Plant requirements	32 days	Fri 10/3/14	Mon 11/17/14
Choose plants	45 days	Mon 1/12/15	Fri 3/13/15
Documentation	**119 days**	**Mon 11/17/14**	**Thu 4/30/15**
Site Layout	**5 days**	**Mon 11/17/14**	**Fri 11/21/14**

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

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 8 Gantt chart from Microsoft Project 2013

Proposed Budget

Our current expenses are listed below:

Table 3 Current and future expenses

Quantity	Item	Cost
2	SWAFL - Soil Texture and Nutrient Analysis of Soil Samples	$40.00
	Estimated Future Expenses	$50.00

At this time, we do not know of any other future expenses to meet the requirements of designing a stormwater drainage plan. Cost estimates of our recommended solutions will be determined during the spring semester.

Preliminary Testing and Modeling

Design Constraints

Call Before You Dig was contacted to determine the location of any buried cables or gas lines. Near the buildings there was an Oklahoma Natural Gas buried gas line and an ATT/D buried cable near the Environmental Laboratory. There was also a City of Stillwater electrical utility line near the paved road.

Figure 9 Buried gas line and buried cable locations

Figure 10 City of Stillwater Electric Utility location

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 4 and Table 5.

Table 4 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 5 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

Surveying

As recommended by Dr. John Long in the Biosystems and Agricultural Engineering Department at Oklahoma State University, the Total Station system was used to survey the land in front of the warehouse and environmental laboratory in order to obtain a detailed topographic map. We assumed a Northing and Easting of 1000 ft and an initial elevation (Z) of 100 ft. We collected data points based on these assumptions. We used the Trimble Juno 3B handheld device to gather an estimated Nothing, Easting and initial elevation to convert our data points to actual elevation values. ArcGIS or AutoCAD will be used to create a topographic map with our data points.

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 (in), approximate area, slope, length, hydrologic soil group, land use details, and Manning's roughness coefficient for the watershed. Figure 11 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 12, Stillwater, Oklahoma is located in the white portion of the map therefore indicating a type II rainfall distribution.

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 13 shows the approximate area of the watershed outlined in orange. Figure 14 shows how sub areas of the watershed were used to calculate a weighted curve number (CN) for the different characteristics of the land, $CN = \sum \frac{A_i CN_i}{\sum A_i}$. Different sub areas were chosen based upon the land use details. The three different land use details are open space with good grass cover, open space with poor grass cover, and 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.

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 15 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, 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.

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 16 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 17 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.

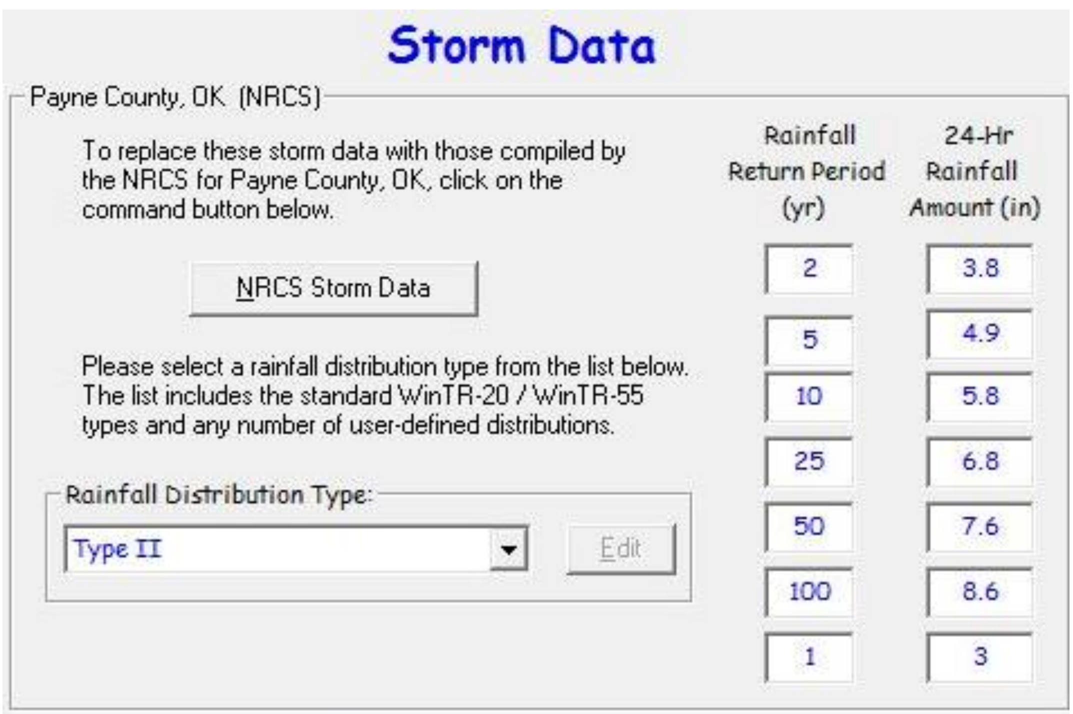


Figure 11 NRCS 24-Hour rainfall data for various rainfall return periods in Payne County, Oklahoma

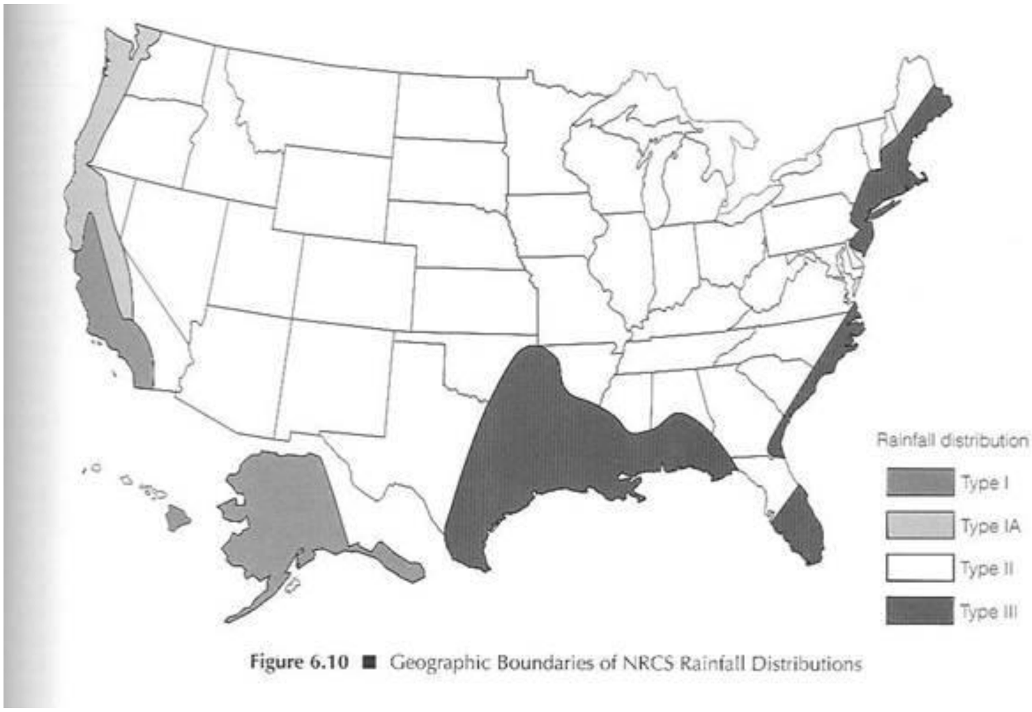
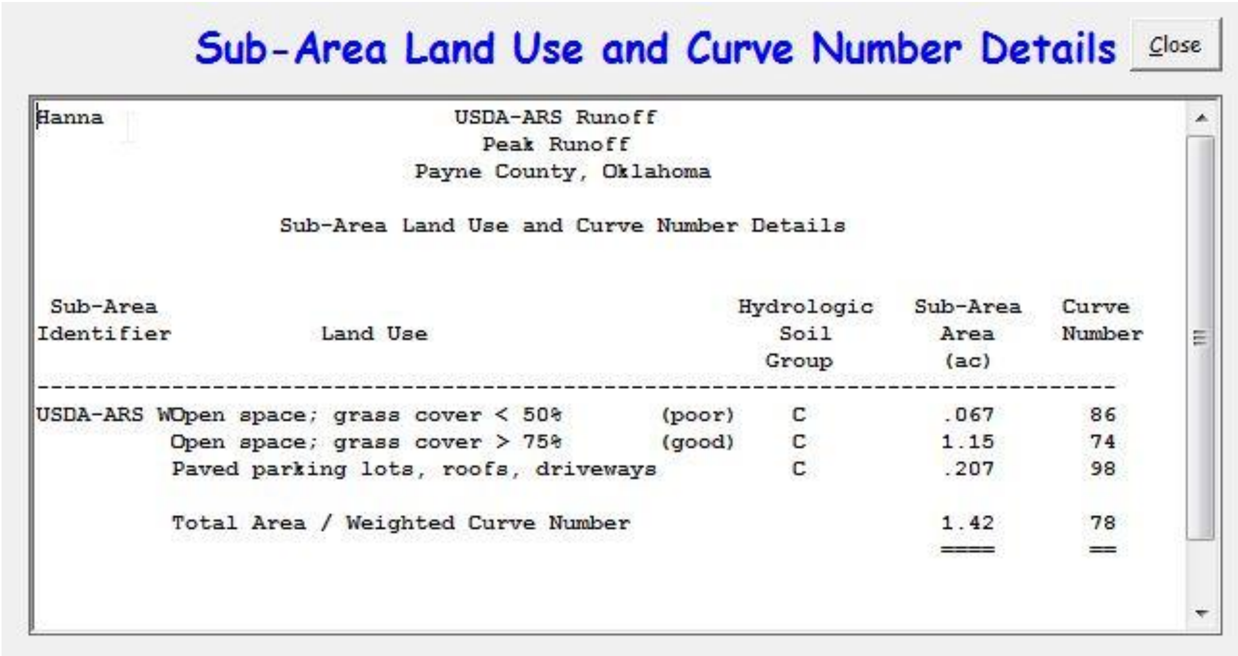


Figure 12 NRCS Rainfall distribution map of the United States of America

Figure 13 Area of Watershed

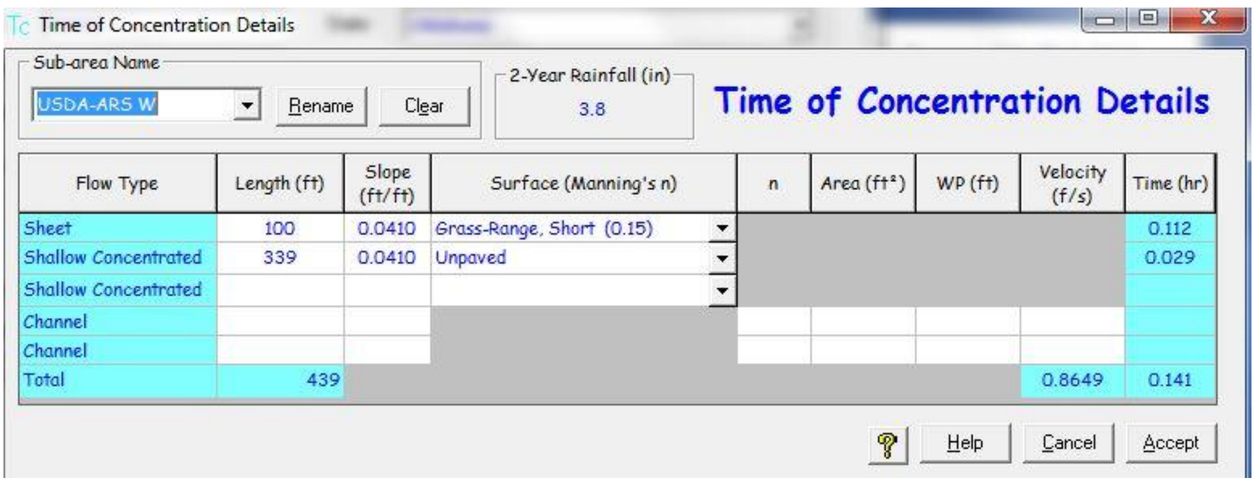

Sub-Area Land Use and Curve Number Details

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 14 Weighted curve number details produced in WinTR-55


Time of Concentration Details

Sub-area Name: USDA-ARS W

2-Year Rainfall (in): 3.8

Flow Type	Length (ft)	Slope (ft/ft)	Surface (Manning's n)	n	Area (ft²)	WP (ft)	Velocity (f/s)	Time (hr)
Sheet	100	0.0410	Grass-Range, Short (0.15)					0.112
Shallow Concentrated	339	0.0410	Unpaved					0.029
Shallow Concentrated								
Channel								
Channel								
Total	439						0.8649	0.141

Figure 15 Time of concentration details produced in WinTR-55

Hydrograph Peak/Peak Time Table

Close

Hanna

USDA-ARS Runoff
Peak Runoff
Payne County, Oklahoma

Hydrograph Peak/Peak Time Table

Sub-Area or Reach Identifier	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)
	Peak Flow and Peak Time (hr) by Rainfall Return Period						
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 16 Peak flow time table produced in WinTR-55

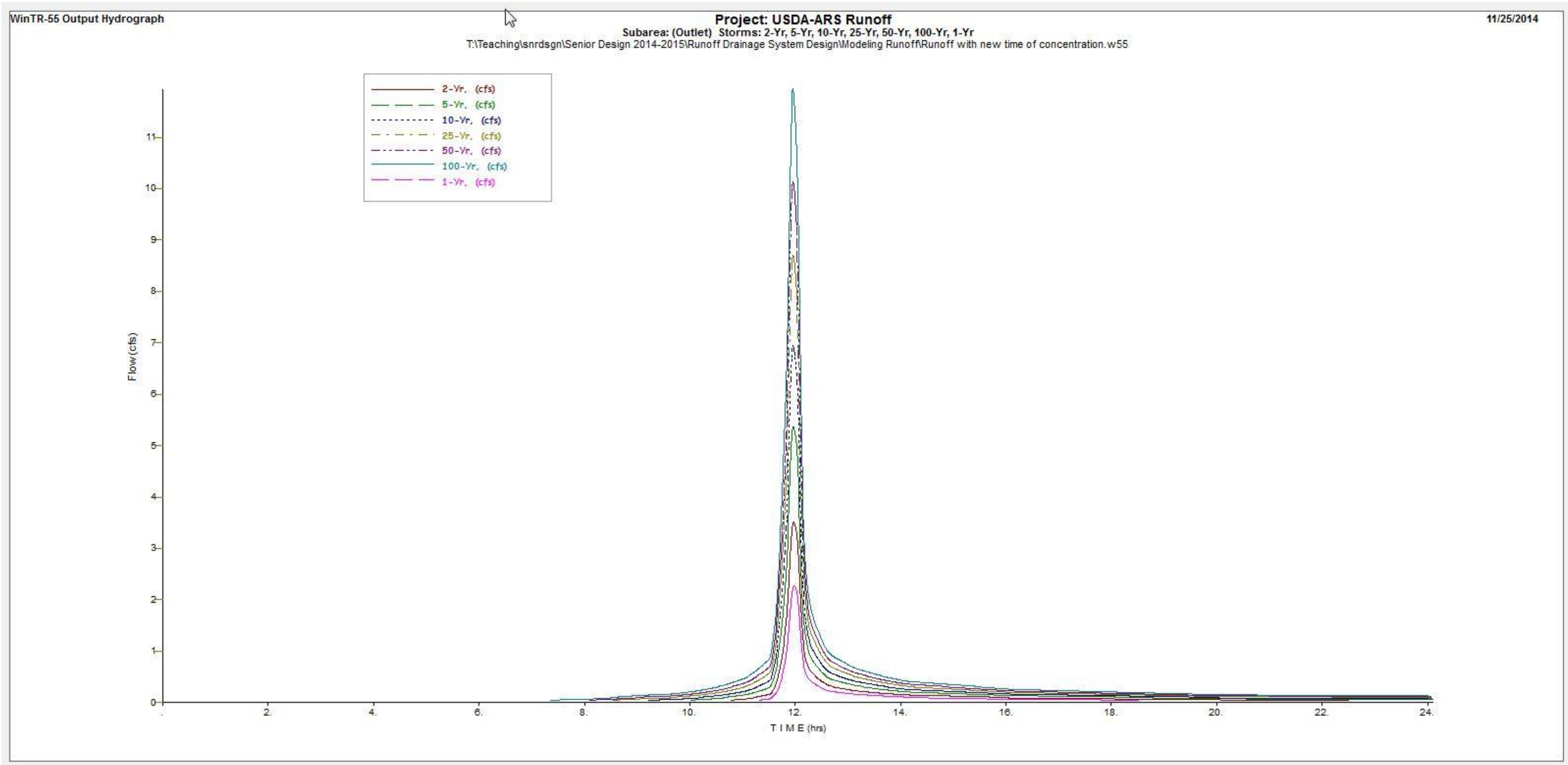


Figure 17 Peak flow hydrograph as produced in WinTR-55

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, 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, and Mike Buchert and Long Range Facilities Planning.

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Appendices

Design of Open Channels (BAE 4314 Lecture Notes from Dr. Garey Fox[a])

Rainfall/Runoff Analysis: Rainfall Excess and Peak Runoff (BAE 4314 Lecture Notes from Dr. Garey Fox[b])

CH2 Consulting

USDA-ARS Runoff Drainage System Design

HANNA HULING
CAROLINE SHORT
HANNAH SPITLER

Overview

- Introduction
- Problem Statement
- Possible Solutions
- Preliminary work

Client: USDA-ARS

- The United States Department of Agriculture Agricultural Research Service (USDA-ARS)
  - The largest agricultural research organization in the world
- Stillwater - 2 Research Units
  - Wheat, Peanut and Other Field Crops Research
  - Hydraulic Engineering Research Unit

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.

Site Location

- USDA-ARS Location:

  1301 N Western

  Stillwater, OK 74075
- South side of property: Warehouse and Environmental Laboratory buildings
- Nearby creek on SE corner of property

USDA-ARS site (Google Earth, 2014)

USDA-ARS Site

- The USDA-ARS rents the site from Oklahoma State University (OSU)
- OSU is the property owner
- Considered private property
- Meet City of Stillwater Standards for modifying private property and OSU requirements

Site Visit

Customer Requests

- Details
  - Solution should be aesthetically pleasing
  - Trees in front of the buildings can be removed if needed
  - The flow can be directed to a creek on the southeast portion of the property

Detailed Plans

- Soil Sampling
- Hydraulic Conductivity
- Surveying
- Storm information from NRCS USDA website
- Modelling runoff
  - WinTR-55
- The City of Stillwater Standards contains design standards for modifying private property in Stillwater, OK.

Possible Solutions

- Grass lined channel
- Paved channel
- French drain
- Underground pervious piping

Grass Lined Channel

- Shape
  - V-shaped
  - Trapezoidal
  - Parabolic
- Mild slope - 5:1
  - 6:1 or 7:1 is better
- Vegetation slows flow rate
- $Q = \frac{1}{n} A R_h^{\frac{2}{3}} S_o^{\frac{1}{2}} \quad (\frac{m}{s})$

Grass-lined channel (Fairfax County, Virginia, 2014)

Grass Lined Channel

- Design method and validation requirements described in *Design of Open Channels* by Dr. Garey Fox.
- Advantages
  - Cost effective
  - Aesthetically pleasing
- Disadvantages
  - Requires mowing
  - Sediment removal

Grass-lined channel (EPA, 2014)

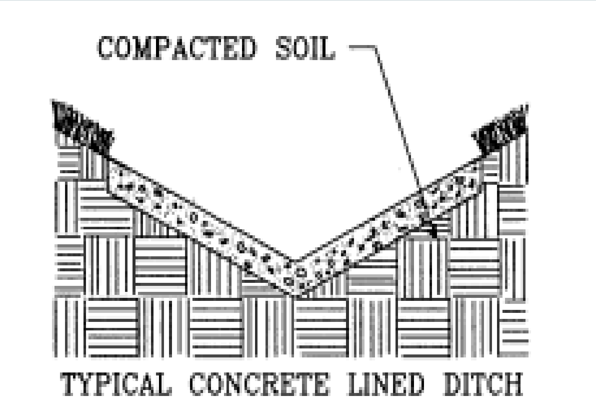
Paved Channel

- Shape
  - V-shaped
  - Trapezoidal
  - Parabolic
- Carries a higher flow than vegetated channels
- Velocity should not exceed 2.1 m/s
- $Q = \frac{1}{n} A R_h^{\frac{2}{3}} S_o^{\frac{1}{2}} \qquad (\frac{m}{s})$

Concrete channel (Geosynthetic Magazine, 2014)

Paved Channel

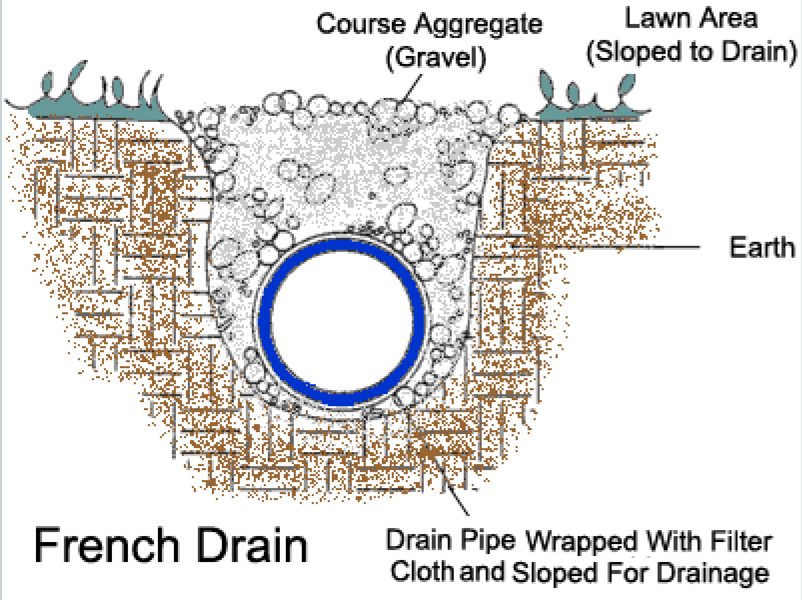
- Design method and validation requirements described in *Design of Open Channels* (Fox, 2014a)
- Advantages
  - Efficient at carrying runoff
  - Low maintenance
- Disadvantages
  - Expensive
  - Not visually appealing



Profile of a concrete channel (Virginia DEQ, 2014)

French Drain

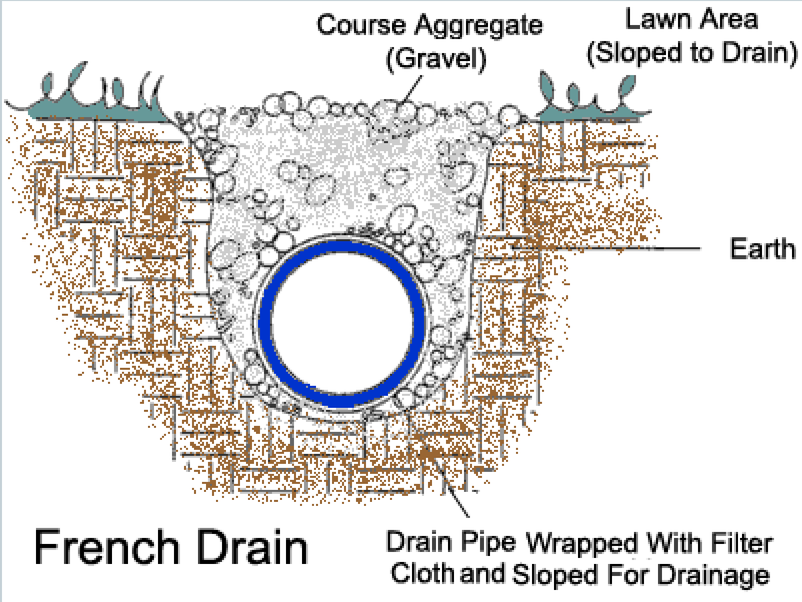
- Design
  - Permeable pipe
  - Filter cloth
  - Buried with gravel or any course aggregate
- Improve foundation of building
- Maintenance Costs
  - Flushing out debris



French Drain (Nusite Waterproofing, 2012)

French Drain

- Advantages
  - Simple design concept
  - Cost effective
- Disadvantages
  - Removal of trees
  - Gravel may be within eyesight



French Drain (Nusite Waterproofing, 2012)

Underground pervious piping

- Corrugated HDPE plastic pipes
- Hillside subsurface drainage systems
- Maintenance Costs
  - Flushing debris out
  - Installed at shallow depths causing long life of use

Construction of HDPE piping at shallow depths limiting excavation cost (Plastics Pipe Institute, 2014)

Underground pervious piping

- Advantages
  - Structural Design
    - High cover and low cover applications
    - Supports and distributes live and dead load
  - Environmental
    - Chemical and corrosion resistant
  - Service life: 100 years

- Disadvantages
  - Possibility of removing trees
  - High excavation costs
  - Above ground
    - Thermal expansion
    - Weather resistance

Plants and Grasses

Tall Fescue turfgrass (UC Davis, 2014)

Oak Sedge, *Carex albicans* (Missouri Botanical Garden, 2014)

Oklahoma Native Plants

- Plants and Grasses
  - Rill erosion: removal of soil through small channels
  - Promote infiltration
  - Increase topsoil resistance

- Shaded plants
  - Light shade-sun exposure
    - Oak Sedge *Carex albicans*
- Drought-Tolerant
  - Grows in shade
    - Tall Fescue turfgrass

Soil Sampling

6 inches below the surface

20 random samples

Soil Sample Results

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

Soil texture results from Soil, Water, and Forage Analytical Laboratory at Oklahoma State University

Soil Sample Results

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

Soil nutrient results from Soil, Water, and Forage Analytical Laboratory at Oklahoma State University

Surveying

- Total Station System
  - Digital read-out
  - Data collected in November
- Create topographic map (in progress)
  - ARC-GIS
- General topographic map
  - Physical plant

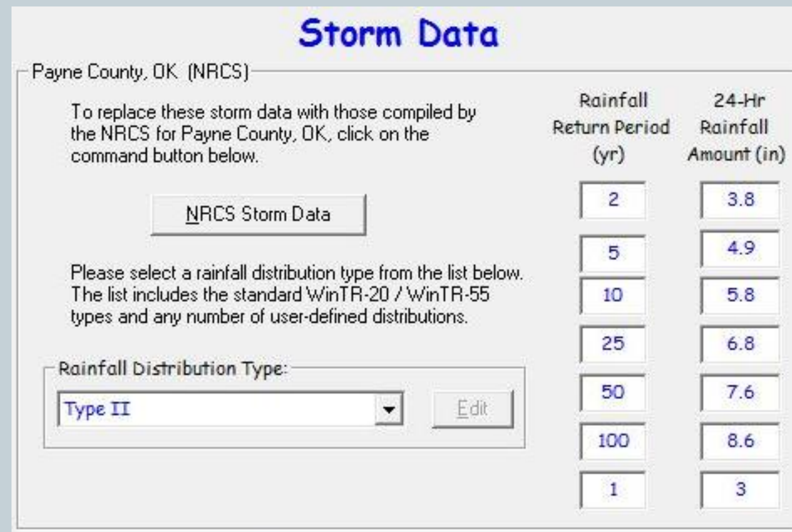
Topographic Map

Modeling Runoff

- Storm data for Payne county

Figure 6.10 ■ Geographic Boundaries of NRCS Rainfall Distributions

NRCS Rainfall map (Fox, 2014)



Modeling Runoff

- Watershed Area
  - Google Maps & Google Earth
  - Trimble Juno 3B handheld device

Modeling Runoff

- Curve Number
  - Land cover descriptions

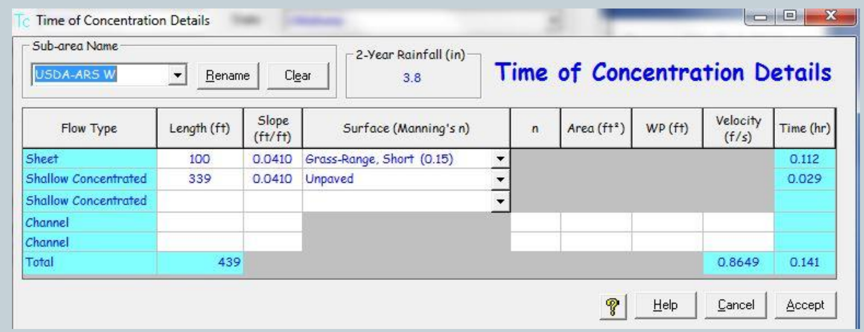
Sub-Area Land Use and Curve Number Details Close

```
Hanna                         USDA-ARS Runoff
                                Peak Runoff
                           Payne County, Oklahoma

                 Sub-Area Land Use and Curve Number Details


 Sub-Area                                          Hydrologic   Sub-Area   Curve
Identifier           Land Use                          Soil        Area     Number
                                                      Group       (ac)
--------------------------------------------------------------------------------
USDA-ARS WOpen 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
                                                                   ====       ==
```

$$CN = \frac{\sum A_i CN_i}{\sum A_i}$$

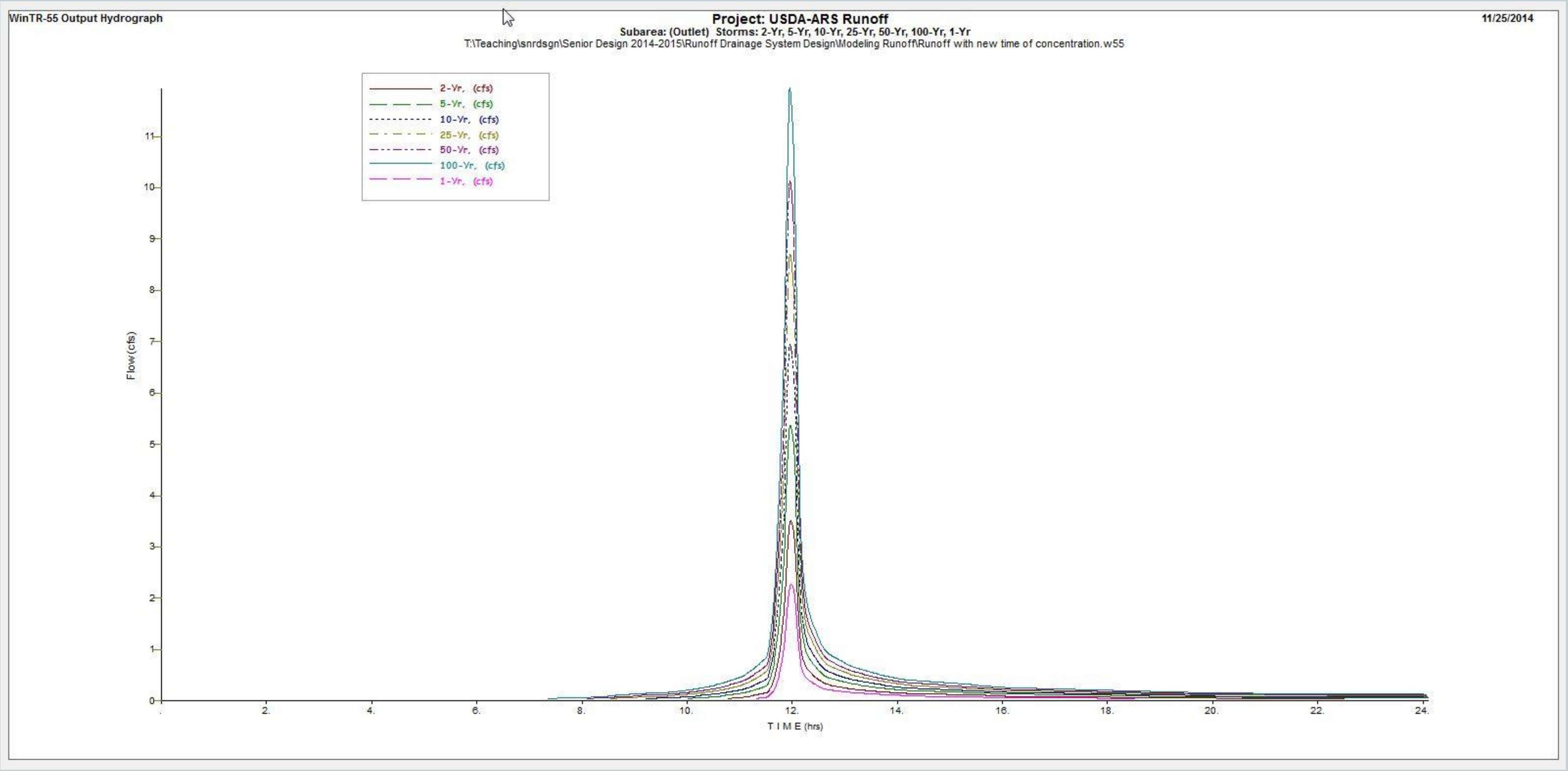
Modeling Runoff

- Time of Concentration
  - NRCS Method
  - WinTR-55 built in function
  - $t_c(hours) = \frac{L_{sc}}{V_{sc}}$



Flow Type	Length (ft)	Slope (ft/ft)	Surface (Manning's n)	n	Area (ft²)	WP (ft)	Velocity (f/s)	Time (hr)
Sheet	100	0.0410	Grass-Range, Short (0.15)					0.112
Shallow Concentrated	339	0.0410	Unpaved					0.029
Shallow Concentrated								
Channel								
Channel								
Total	439						0.8649	0.141

Modeling Runoff



Design Specifications

- Analyze 1 to 100-year, 24-hour rainfall event
  - Current Q_p
- Peak flow (Q_p) after development ≤ current Q_p
- Cannot construct on a regulatory flood plain
- Detention basin
  - Control Q_p
  - Increased t_c

Call Before You Dig

- ATT/D buried cable
- Oklahoma Natural Gas buried gas line
- City of Stillwater electric utilities

Future Plans

- Design recommended solutions
- Peak flow (Q_p) after development $\leq$ current Q_p
- Determine after development Q_p
- Hydrologic Routing
  - Storage Indication Curve

Future Plans

- Determine options for buried cables and gas lines
- Develop a proposed budget for recommended solutions
- Hydraulic Conductivity
  - Ksat testing machine
  - Undisturbed soil core sample

Acknowledgements

- Dr. Paul Weckler, Senior Design instructor
- Dr. Sherry Hunt and Linda Gronewaller, USDA-ARS
- Dr. John Long , assistance during the surveying process
- Dr. Garey Fox for advisement regarding the WinTR-55 modeling software
- Freshmen team (Tony Blackbear, Ty Fisher, Derek Hurst, and Bailey Poe) for helping us with the collection of soil samples and surveying
- Soil, Water, and Forage Analytical Laboratory for analyzing our soil samples
- Chuck Cassidy and OSU Physical Plant Services, and Mike Buchert and Long Range Facilities Planning

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Questions?