

April 18, 2017

City of Orem
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Dear Sam Kelly:

We are very grateful for the recent meeting in regards to the Soil Data Percolation App Development. We hope that our work on this project has met your expectations and will be a useful tool for designing and analyzing storm water systems. We are devoted to your satisfaction so please let us know if there is anything else we can do.

Please look over the final report enclosed and feel free to contact us regarding anything that you see fit to ask.

With warm regards,

SWL Engineers
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Enclosed

**SOIL DATA PERCOLATION APP DEVELOPMENT
CEEn-2016CPST-002**

By

**SWL Engineers
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A Final Report for the Capstone Project submitted to

**Sam Kelly
City of Orem**

**Department of Civil and Environmental Engineering
Brigham Young University**

April 18, 2016

Executive Summary

PROJECT TITLE: Soil Data Percolation App Development
PROJECT ID: CEEEn-2016CPST-004
PROJECT SPONSOR: Sam Kelly, City of Orem
TEAM NAME: SWL Engineers

The following report contains the final summary of the work requested for the soil data percolation application. The desired outcome of the spreadsheet application has been dissolved into individual tasks which have contributed to a user friendly interface. Each task has been organized in the spreadsheet for the design of various storm water detention systems using several different methods. The primary inputs of the application are storm type, watersheds with corresponding C values, available detention design area, soil type and ground water table. Additional inputs are system specific and are defined under each system's sheet. The systems available to choose from are Storm Chambers, Swales, Sumps, R-Tanks, and Detention Ponds. A few of the outputs of the application are the storage capacity of the system, dimensions of the system, and calculated percolation rates.

In regards to our recent discussion about percolation rates for Orem, UT, soil data was extracted from the United State Geological Survey (USGS) to examine the correlations between infiltration rates and soil types that were presented in the provided soil reports. These correlations between the provided soil reports, USGS soil data, and conservative percolation rates look great. Tabulated data in the application accounts for the percolation rates for the user determined soil types.

The soil data percolation application project has progressed on schedule and has been completed. The team has overcome many obstacles such as determining the best approach to the lack of percolation data for Orem, UT, bringing the team together by clarifying the scope of the project, lack of education and code for the differing storm systems, and learning how to predict the diminishing returns of sumps. The final application is a versatile and powerful approach to the initial problem provided by the City of Orem.

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Introduction

Currently, Orem City has a few applications that are used in the design process of sumps and other storm water detention systems. However, these applications are limited and do not take into consideration percolation, various storm water systems, or multiple storm events when detention systems are still releasing runoff from a previous storm. Another problem of the current applications is that they do not account for the buildup of sediment inside the detention system which can cause a diminishing return.



The Project completed by SWL Engineers for the City of Orem is the development of a spreadsheet application capable of comparing different storm water detention devices primarily R-Tanks, Sumps, Swales, Storm Chambers and Detention Ponds. The application takes into consideration percolation from the systems, the effect of multiple storm events as well as the diminishing returns of sump systems. The team consists of Alex Arndt as the project manager, Cameron Lusvardi as the application specialist, William Shelton as the ArcGIS specialist, and Jacob Wadman as the data analysis and technical writing specialist.

The project began in January of 2017. The City of Orem has provided the city IDF curve, available percolation data, and soil reports to the SWL Engineers for use in the project. The soil data was analyzed and compared with USGS soil data. The research on the various stormwater detention devices and equations was been completed in February. Application development began on February 6 and was completed April 10, 2017. The SWL Engineers delivered the final product as an Excel spreadsheet application on April 17, 2017 and gave a presentation in the presence of Sam Kelly.

This final project report includes a brief project description, project limitations, obstacles encountered, solutions provided, and comprehensive instructions/explanations of the varying steps of the application.

Project Description

The Project completed by SWL Engineers for the City of Orem is the development of a spreadsheet application capable of comparing different storm water detention devices primarily R-Tanks, Sumps, Swales, Storm Chambers and Detention Ponds. This was accomplished by using correlations between percolation rates and soil types, interpolating the city's Intensity Duration Frequency (IDF) curve, and collating the calculations into a spreadsheet capable of designing the various indicated storm water systems that meet the demands. The City of Orem provided the city IDF curve, current available percolation data, and soil reports to the SWL Engineers for use in the project. The soil data has been analyzed and compared with USGS soil data. The excel spreadsheet application built analyzes the efficiencies and capacities of storm water detention devices by referring to the user inputs.

The desired outcome of the spreadsheet application has been dissolved into individual tasks which contribute to a user friendly interface. Each task has been organized in the spreadsheet to create a simple interface and create ease in revisions by future users. The application was completed without the use of Visual Basic Code to permit the application to run on any operating system. The primary inputs of the application are storm type, watershed areas with corresponding C values, available detention design area, and soil profiles. Additional inputs are system specific and will be defined as they are explained in the body of the report under each system's sheet. The sheets available to choose from are named Storm Chamber, Swale, Sump, R-Tank, Detention Pond, Storm Data, Home, and Water Balance. The outputs of the application include the systems' capacities, system dimensions, and percolation rates. These outputs are displayed on the Water Balance Sheet along with each systems' design sheet.

The USGS data has been beneficial due to the correlations between the soil reports and soil data. A map has been included to aid the user in selecting the soil type which will determine the correct percolation rate based on researched relationships. The soil type input by the user is referenced in the application to help calculate the capacities derived from inputs like percolation rates for the various storm water detention devices in any location of the city.

Project Limitations

The results of this project are limited to areas along the gravel belt on the eastern side of the city and outside of well protection zones. It should be noted that other locations around the city which have clayey and/or silty soils will also have a severely decreased infiltration rate. This will limit the effectiveness of the percolation outflows in the detention design.

All coding for the application was programmed “in-cell” and no actions are performed by macros or visual basic. If Orem City wished to adjust the application to use VB code, a user with experience should make those alterations. We recommend that if any in cell calculations need to be made, a separate copy of the application should be created and saved.

Due to the lack of percolation data available, the soil percolation was estimated using hydraulic conductivity and hydraulic head for one of the options. As such, these values give conservative values for the percolation flow and are different depending on the detention system chosen. If the user decided to use the default values for the percolations rates, either the average rate or minimum rate is automatically chosen based on the tabulated data.

Obstacles and Provided Solutions

Upon receipt of the soil data from Orem City, each team member went through a group of reports to extract data pertinent to the project. From all of the reports received, only three percolation rates were found. Thus, the data necessary to compile a proposed database was absent. The solution proposed by SWL engineers was to allow the user to input a known percolation rate or use one from tabulated data. The absence of data made the creation of a percolation database unfeasible for a capstone project. With the variability of soil and rates even from the same soil, the method proposed was accepted by Orem City. To understand the layout of different types of soils for Orem City, a GIS map of soil types was developed and is shown in Figure 1.

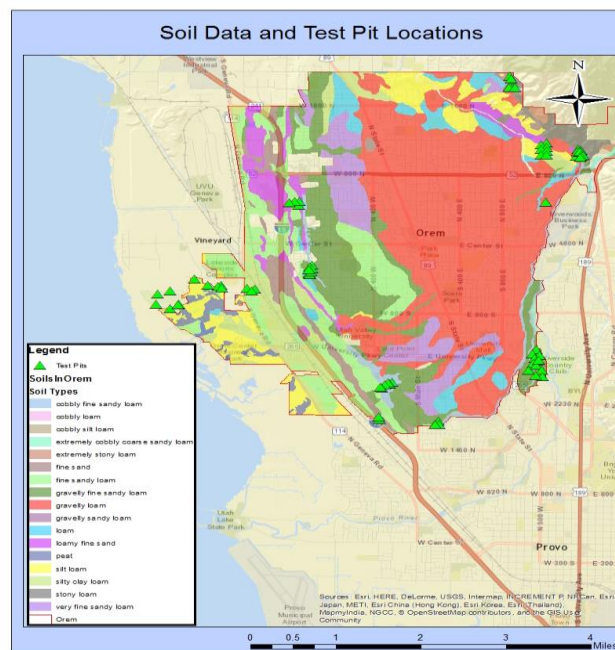


Figure 1: Map of Soils by Type within Orem City Limits

Percolation rates for the soil types shown in Figure 1 were found from varying sources. These rates are used in the application by default and can be seen on the Home Page.

During the research phase of the project, an absence of policy and design standards for the design of storm water detention systems created another obstacle. The lack of consistent policy regarding the design of the detention systems lead the team to instead investigate the preexisting design criteria and methodology already in place. This was done using the existing excel applications and city drawings as a guide. Addition criteria about the designs were clarified in a meeting with Orem City engineering department.

The inputs and outputs of the application also served as an obstacle. The goal of the spreadsheet was to assist in the design of storm water detention systems in a user-friendly manner. This requires a limited amount of inputs. Too many inputs may overwhelm the user. Additional equations were

needed to connect each aspect of the design. The inputs were limited as much as possible with the general inputs on the “Home Page” and system specific inputs on the individual design sheets

Lastly, another obstacle encountered was determining the design life and diminishing returns of the various systems. Over time, fines clog the coarse soil fill surrounding the system which lowers the percolation rate. The solution provided by SWL engineers is based on research by Siwiradene et al and Hatt et al. The clogging occurs due to particles with a diameter less than 6 micrometers that become caught at the barrier between the gravel fill and native soil. This creates a layer of low permeability that increases over time. An estimate of the fines reaching this part of the percolation system was obtained from hydrometer testing. The testing is summarized in the appendix of this report.

Application Description and Instructions for Use

The application is divided into 8 sheets that are summarized in the following table along with a brief description of the content.

Table 1: Application Sheet Designations and Descriptions

Home Page	General system inputs and supplementary descriptions.
Water Balance	Inputs and outputs for storm event(s).
R-Tank	Design sheet for R-Tank.
Storm Chamber	Design sheet for Storm Chamber.
Detention Pond	Design sheet for Detention Pond.
Swale	Design sheet for Swale.
Sump	Design sheet for Sump.
Storm Data	Precipitation data for the three different weather stations in Orem from NOAA.
Extra (Hidden)	Sheet containing calculations and references not needed on other sheets.

The Home Page is the sheet where all of the general inputs are set in order to determine the effectiveness of the design system chosen. The water balance sheet is where the outputs are summarized and special circumstances can be considered. The design sheets are where the system of interest can be manipulated to meet the storage demands based on the Water Balance Page. The Storm Data sheet is where the precipitation data is stored for use on the Water Balance Page based on the user inputs of the Home Page.

Home Page

The Home Page is where the user sets up the general inputs of the system. This sheet is divided up into four columns; the first column is the actual input column, the second column contains explanations for the different input sections and options, the third column contains tabulated data that is used in calculations along with the sources, and the fourth column shows an example of a completed input column.

Input column

Below in Figure 2 the Project description input is shown.

Project Description:			
Project Name:	R-Tank at Target Parking Lot		
Street Address:	57 N 82 E		
City, State:	Orem, Utah		
Zip Code:	84057		
Latitude:	40.2	Longitude:	-111.63
Date:	3/16/2017		

Figure 2: Project Description Input Box

The Project Description input section is for the user to enter the project information for their own reference. Information such as Project Name, Site Address, etc. are to be placed in this box. This description is shown on each Design Sheet for the user’s reference.

Figure 3 shows the Weather Station input section for retrieval of the proper precipitation data.

Weather Station:	
Station Name:	OLMSTEAD P H
Location:	Orem, Utah
Latitude:	40.3173
Longitude:	-111.6533
Elevation:	4820 [ft]

Figure 3: Weather Station Input Box

Precipitation data was downloaded from the NOAA database for three locations in Orem City. The user should refer to the map given in column 2 in order to choose a relatively close station for the site in question. The station is selected from the orange drop down at the top of the input box and the rest of the station information is automatically populated. By selecting the appropriate station, all of the station’s precipitation data is populated in tables on the Storm Data Sheet for use in calculations.

Figure 4 shows the Watershed Parameters input section. The user should consider each of the three options and engineering judgement should be used to choose the best option for the site-specific circumstances.

Watershed Parameters:					
Furthest Distance from Watershed Boundary to Drain				300	[ft]
Option 1: Rational Method			Active	No	
Cover Type	Area	C Values	Slope		
Landscaping:	0 [ac]	0.35	0.01	[ft/ft]	
Building:	2.078 [ac]	0.75	0.0001	[ft/ft]	
Hard Surface:	5.295 [ac]	0.90	0	[ft/ft]	
Total/Weighted C/Ave Slope		7.4 [ac]	0.86	0.0034 [ft/ft]	
Option 2: Rational Method			Active	Yes	
Cover Type	Area	C Values	Slope		
Downtown Business	1 [ac]	0.908	0.01	[ft/ft]	
Single Family Residential	2 [ac]	0.500	0.0001	[ft/ft]	
Lawns, Sandy Soil (2% Slope)	2 [ac]	0.094	1	[%]	
Asphalt or Concrete Pavement	5 [ac]	0.908	0.01	[ft/ft]	
EMPTY	0 [ac]	0.000		[ft/ft]	
EMPTY	0 [ac]	0.000		[ft/ft]	
EMPTY	0 [ac]	0.000		[ft/ft]	
Empty	0 [ac]	0.000		[ft/ft]	
Empty	0 [ac]	0.000		[ft/ft]	
Empty	0 [ac]	0.000		[ft/ft]	
Empty	0 [ac]	0.000		[ft/ft]	
Total/Weighted C/Ave Slope		10.0 [ac]	0.66325	0.0075 [ft/ft]	
Option 3: NRCS Method			Active	No	
Cover Types	Area	CN Value	Slope		
Commercial/Business District	3 [ac]	89	0.01	[ft/ft]	
Open Space (Lawn, Park w/ grass cover >70%)	2 [ac]	39	0.01	[ft/ft]	
Residential (1/4 ac avg lot size)	4 [ac]	61	1	[ft/ft]	
EMPTY	[ac]	0		[ft/ft]	
EMPTY	[ac]	0		[ft/ft]	
EMPTY	[ac]	0		[ft/ft]	
EMPTY	[ac]	0		[ft/ft]	
EMPTY	[ac]	0		[ft/ft]	
EMPTY	[ac]	0		[ft/ft]	
EMPTY	[ac]	0		[ft/ft]	
EMPTY	[ac]	0		[ft/ft]	
Total Area / Composite CN / Ave Slope		9.0 [ac]	65	0.3400 [ft/ft]	

Figure 4: Watershed Parameters Input Options

Under watershed parameters, the user may enter a distance from the watershed boundary to the location of the drain into the detention system. This will be used to calculate a time of concentration for the site. This value is mainly considered when analyzing peak inflows at the initial catch.

Above each option there is a cell labeled “Active” (circled in the figure) with a yellow cell beside it. The yellow cell provides the user with a drop down of the options “yes” or “no”. To select an option to be used, the corresponding yellow cell must be changed to “Yes” and the other two options must be set to “No” or else errors will arise in the design.

Option 1 uses a simplified version of the rational method where the coefficients of runoff are grouped into three average values for Landscaping, Building, and Hard surface. The total average coefficients, slopes and area are then calculated for use in design. These values determine the runoff flow and volume of the watershed.

Option 2 uses the rational method as well. However, it incorporates more precise calculations for the coefficients of runoff and slope. The different cover types are chosen from drop down menus and the coefficients of runoff are automatically calculated based on the table the third column. These values determine the runoff flow and volume of the watershed.

Option 3 uses the NRCS curve number method. The curve number method is generally more accurate for larger watersheds. The NRCS method takes into consideration surface infiltration and initial abstraction based on the predominate soil type at the surface. The user selects the cover type from the drop down menus and the curve numbers are automatically populated. The total area, composite curve number, and average slope are then calculated for use in the design. These values determine the runoff flow and volume of the watershed.

Figure 2 shows the Soil Description input section. The method of choosing the correct option from the two options shown below is the same as the previous input discussion about activating an option.

Soil Description:		
Depth to Ground Water Table:	50	[ft]
Soil Classification Type:	Sacramento County Code	
Predominant Soil Type at Surface:	Coarse Sand	
Hydrologic Soil Group:	A	
Option 1:	Active	Yes
Soil Classification Type:	SCS	
Predominant Soil Type at Depth of Storage System:	Sand	
Percolation Rate for Soil:	60	[in/hr]
Option 2:	Active	No
Soil Classification Type:	USCS	
Soil Profile Down to Depth	Depth	Hydraulic Conductivity
Poorly graded gravel, sandy gravel, with little or no fines	15 [ft]	999 [in/hr]
Medium sand, very well sorted	20 [ft]	999 [in/hr]
Well graded gravel, sandy gravel, with little or no fines	50 [ft]	999 [in/hr]
Well graded gravel, sandy gravel, with little or no fines	50 [ft]	999 [in/hr]
Well graded gravel, sandy gravel, with little or no fines	50 [ft]	999 [in/hr]
Well graded gravel, sandy gravel, with little or no fines	50 [ft]	999 [in/hr]
Well graded gravel, sandy gravel, with little or no fines	50 [ft]	999 [in/hr]
Well graded gravel, sandy gravel, with little or no fines	50 [ft]	999 [in/hr]
Well graded gravel, sandy gravel, with little or no fines	50 [ft]	999 [in/hr]
Well graded gravel, sandy gravel, with little or no fines	50 [ft]	999 [in/hr]
Well graded gravel, sandy gravel, with little or no fines	50 [ft]	999 [in/hr]
Well graded gravel, sandy gravel, with little or no fines	50 [ft]	999 [in/hr]

Figure 5: Soil Description Input Box

The water table depth is the first input cell for the Soil Description input section. A depth must be entered. If the exact depth is not known, then an estimate should be provided using experience and engineering judgment. This depth is important when choosing option 2 in the Soil Description section.

Next, the user must choose a predominant soil type at the surface of the site. This aids in computing the flows for the NRCS method in Option 3 of the Watershed Parameters input section. The user can select which classification type they want to use, then they must select the soil type and a hydrologic soil group number is assigned based on the tables in column 3 of the Home Page.

Option 1 is to be used when a percolation rate is known for the site at the depth of the system. The predominant soil type in the in-situ soil is chosen from the dropdown of the same label and the percolation rate is then input by the user into the bottom cell. If the user

decided to use a provided value from the tables in column 3 of the Home page then they can enter 999 for the percolation rate value.

Option 2 is to be used when a soil profile is known for the site. Here, the user inputs the soil profile at the site using a cumulative depth down to the layer boundaries. The first depth should begin at the bottom of the prospective storm system and the last depth should end at the water table. Note that this value may need to be changed based on dimensions entered on a design sheet. For example, if initially you set the first layer boundary to occur at 15 feet when actually the user specifies the sump to end at a 20 foot depth. The user then enters the respective hydraulic conductivity of each soil layer. If the actual hydraulic conductivities are not known, the user enters 999 which will prompt the application to use default values from the respective table in column 3. These hydraulic conductivities are used along with a calculated hydraulic head to determine percolation through the layered soil when this option is set to active.

Figure 6 shows the Allowable Release Rate input section. As with the previous options, the method for choosing the correct option depends on engineering judgement and ensuring that only the desired option is active.

Allowable Release Rate:	
Option 1:	Active Yes
Allowable Release Rate:	0 [cfs]
Option 2:	Active No
Pipe Material Type:	Concrete - Centrifugally Spun
Mannings Value (n):	0.013
Pipe Diameter:	18 [in]
Pipe Grade:	0.01 [ft/ft]
Maximum Possible Flow Rate:	10.504 [cfs]
Option 3:	Active No
Cd (discharge coefficient):	0.6
Head (measured to center of Orifice):	5 [ft]
Pipe Diameter:	24 [in]
Cross Sectional Orifice Area:	3.142 [ft^2]
Maximum Possible Flow Rate:	33.824 [cfs]

Figure 6: Allowable Release Rate Input Box

Option 1 prompts the user to enter a maximum allowable release rate in units of cubic feet per second to be used in the design.

Option 2 prompts the user to input the maximum permissible pipe size. This option uses manning’s equation to calculate the maximum flow rate using the material type, slope and diameter of the pipe.

Option 3 uses the orifice equation to determine the maximum flowrate from the parameters of hydraulic head, pipe diameter, and discharge coefficient. This hydraulic head may need to be changed based on the dimensions of the system specified on a Design Sheet.

Water Balance Page

Once the Home Page is completed with all of the appropriate inputs, the user should visit the Water Balance Page. The Water Balance Page is where the storage demands are calculated based on the inputs from the Home Page and the Percolation from the Design Sheets. In order to complete the design including percolation the following parameters must first be identified as shown in Figure 7.

System of Interest		R Tank		Select the system of Interest or NONE for preliminary design	
Calculated Percolation		Active		Yes	
Percolation Rate		0.948652249		[cfs]	
Allowable Release Rate:		0		[cfs]	
Storm of Interest		Select a storm event and input a storm duration of interest. If interested in just the maximum storage required for the particular storm event then simply insert 999 for the storm duration.			
Storm Duration		999		Hours	
Storm Event		10		Year Storm	
Input Value		Active		No	
Time of Concentration:		20		(min)	
Calculated Value		Active		Yes	
Time of Concentration:		4		(min)	
If you wish to observe the critical inflow (Qp) for inlet design then either input a value or use a calculated value for the time of concentration.					

Water Balance Table for Given Storm												
Duration		Rainfall			Surface			Percolation		Outflow (Release)		Storage
[days]	[min]	Depth [in]	Intensity [in/hr]	Volume [ft ³]	Runoff [cfs]	R Volume [ft ³]	Q Peak [cfs]	Q [cfs]	Q Volume [ft ³]	Q [cfs]	Q Volume [ft ³]	Volume [ft ³]
0.003	5	0.29	3.49	10527	23.15	6944	23.15	0.95	284.60	0	0	6660
0.007	10	0.44	2.65	15972	17.58	10546	17.58	0.95	569.19	0	0	9976
0.010	15	0.55	2.19	19965	14.53	13073	14.53	0.95	853.79	0	0	12219
0.021	30	0.74	1.48	26862	9.82	17669	9.82	0.95	1707.57	0	0	15961
0.042	60	0.91	0.91	33033	6.04	21728	6.04	0.95	3415.15	0	0	18313
0.083	120	1.06	0.53	38478	3.52	25310	3.52	0.95	6830.30	0	0	18479
0.125	180	1.18	0.39	42834	2.59	27936	2.59	0.95	10245.44	0	0	17691
0.250	360	1.45	0.24	52635	1.59	34383	1.59	0.95	20490.89	0	0	13892
0.500	720	1.85	0.15	67155	0.99	42979	0.99	0.95	40981.78	0	0	1997
1.000	1440	2.25	0.09	81675	0.60	51574	0.60	0.95	81963.55	0	0	0
2.000	2880	2.71	0.06	98373	0.40	68766	0.40	0.95	163927.11	0	0	0
3.000	4320	3.10	0.04	112530	0.27	68766	0.27	0.95	245890.66	0	0	0
4.000	5760	3.50	0.04	127050	0.27	91688	0.27	0.95	327854.22	0	0	0
7.000	10080	4.17	0.02	151371	0.13	80227	0.13	0.95	573744.88	0	0	0
10.000	14400	4.66	0.02	169158	0.13	114610	0.13	0.95	819635.54	0	0	0

Storage Required:	18479	[ft ³]
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Figure 7: Water Balance Parameters and Water Balance Table

First, the system of interest must be chosen from the drop down provided in the first input cell. This step is vital because based on the system of interest, a percolation rate will be populated from that specific system Design Sheet and used in the water balance. The Percolation rate can be turned "On/Off" using the active dropdown in the yellow box. The Allowable release rate from the Home Page is shown for reference. Then the storm of interest must be chosen. The duration of interest in hours needs to be input by the user or a

value of 999 should be used if the user wants all durations to be considered. If the user wants to determine the maximum storage required for a storm event, the number 999 should be used for the storm duration. The Storm recurrence interval in years should also be selected from the dropdown provided. At this point, the user may also input a time of concentration if desired or use the calculated time of concentration from the Home Page. Whichever is chosen the user must ensure that that option is selected as active and the other option as inactive with the “Yes/No” dropdowns.

The Water Balance sheet will then give the required storage for the system of interest as shown in Figure 7. Also included on the Water Balance Page is the option for considering a multiple storm event as shown below in Figure 8.

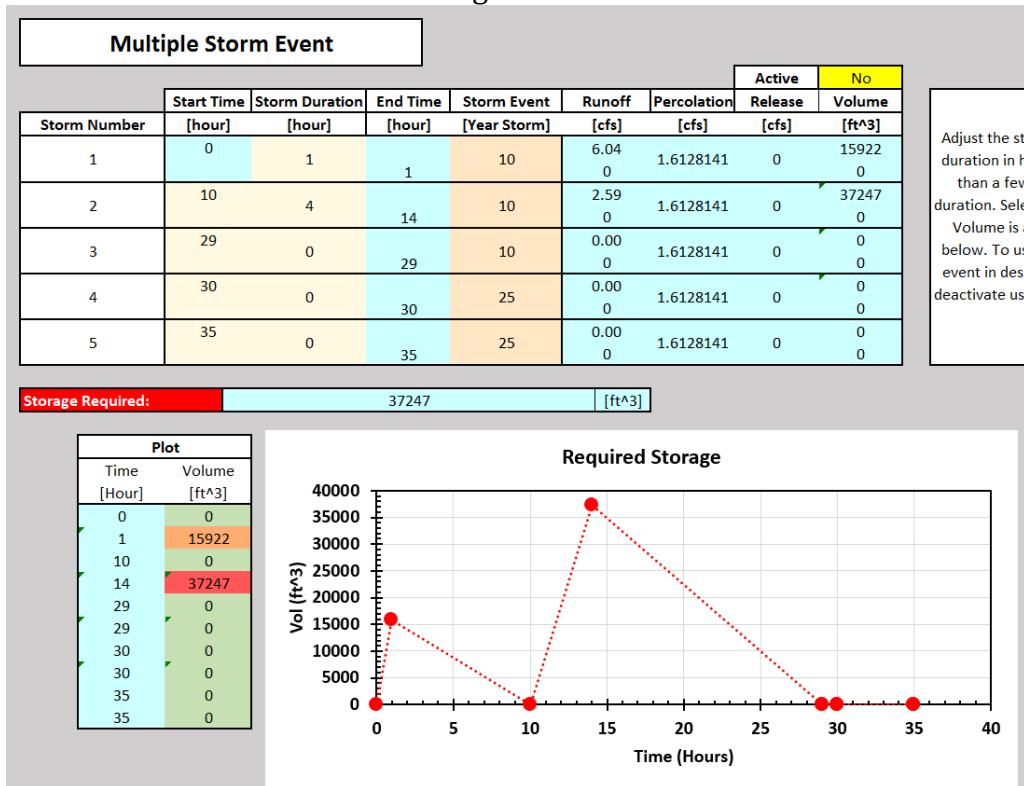


Figure 8: Table for Evaluating a Multiple Storm Event

For this portion of the application to be used in design the “Active” cell must be set to “Yes”. Then the user can specify a storm combination. The evaluator begins at a time zero. The Start Time column contains the start times of the user’s desired storms, the Storm Duration column is for the user to input the durations of each storm, and the recurrence interval of each storm is selected in Storm Event column. The application then shows the storage required and a plot of the required storage is displayed for visual reference. It is important to note that the line connecting the dots is not representative of the actual volume over time. The Dots show the actual volumes at the shown times in Figure 8.

Individual Design Sheets

Each Design Sheet is for the user to manipulate a system until the system’s design has a storage capacity greater than the demands from the Water Balance Page. The inputs for each sheet are the dimensions and parameters of the system. Based on the size of the system, the percolation area is adjusted which adjusts the storage required. The user can then iterate until an adequate design is found.

R-Tank

The design inputs for the R-Tank design sheet are shown in Figure 9 below.

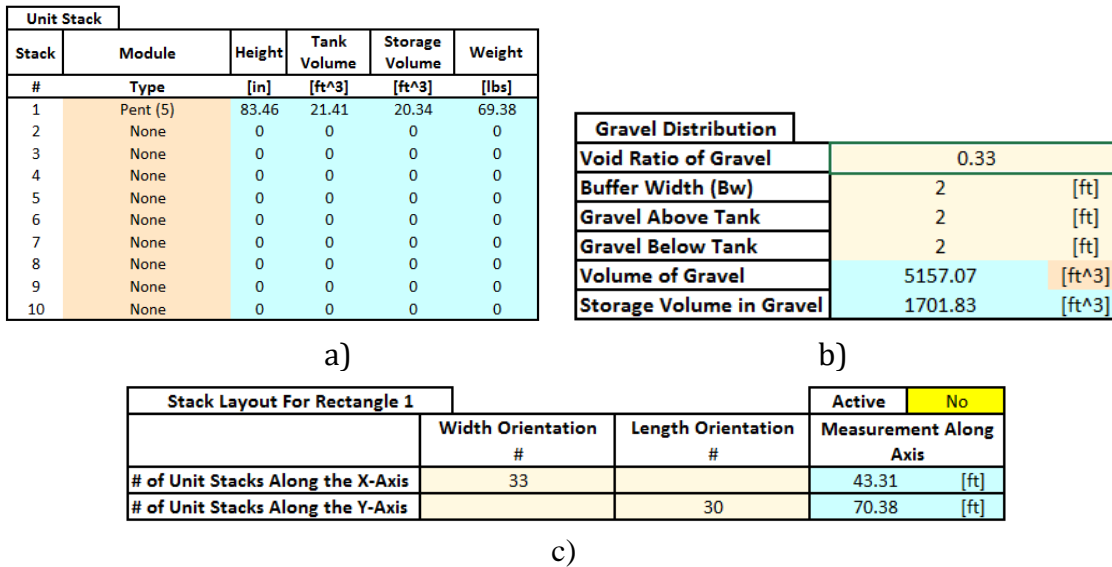


Figure 9: R-Tank Design Dimensions

In Figure 9-a, are the inputs for the stack configuration of the R-Tank modules. The configuration type is chosen from a drop down and various configurations can be combined in this table for use in the storage calculation. Figure 9-b shows the inputs for the gravel fill to be placed around the system. The buffer width is the width of gravel that is placed between the walls of the tank and the walls of the native soil. Figure 9-c shows part of the option of a non-rectangular R-Tank configuration. This option requires activation by the user by selecting “Yes” from the yellow dropdown. The user then divides the R-Tank system into a series of smaller rectangular configurations. Which are then used to calculate the system storage.

Storm Chamber

Figure 10 Below shows the inputs for the Storm Chamber design.

Layout Design			
Length Of Individual Chamber	$L_c =$	4.333333	[ft]
Length of Available Lot Area	$AL_L =$	100	[ft]
Width of Manifold	$W_m =$	5	[ft]
Width Of Buffer Area	$B_w =$	5	[ft]
Width Of Chamber	$W_c =$	8.333333	[ft]
Space Between Chambers	$W_s =$	1.33	[ft]
Width of Lot	$A_{LW} =$	60	[ft]
Width of Buffer Area	$B_w =$	5	[ft]
Calculated Footprint Area =		6000	[ft ²]
Minimum Required Footprint Area =		5423.5	[ft ²]
FOOTPRINT CHECK		OKAY	

Figure 10: Storm Chamber Design Inputs

The dimension inputs for the Storm Chamber sheet include, from top to bottom, colored in light orange, available area, manifold width, gravel buffer width, chamber spacing, and system width. The user also can choose from the different chambers provided in the tables on the sheet, along with the number of chambers and rows.

Detention Pond and Swales

Below in Figure 11 are the inputs for the detention pond (right) and for swales (left).

Rectangular Pond	Active	Yes
Width (w)	100	[ft]
Length (L)	100	[ft]
Depth (D)	2	[ft]
Area	10000	[ft ²]
Volume	20000	[ft ³]

Trapezoidal Pond	Active	No
Top Width (W)	5	[ft]
Bottom Width (A)	4	[ft]
Length (L)	15	[ft]
Depth (D)	3	[ft]
Area of Base	60	[ft ²]
Volume	202.5	[ft ³]

Other Pond	Active	No
Area of Base	245	[ft ²]
Depth of Pond	2	[ft]
Volume	3005	[ft ³]

Inputs		
Q=	23.15	[cfs]
f=	60	[in/hr]
n=	0.012	
Z=	1	
S=	0.05	[ft/ft]
B=	10	[ft]

a) b)
 Figure 11: Detention Pond and Swale Inputs

For the design of the Detention Pond in Figure 11 a) one of the options must be chosen by the user and then the proper dimensions need to be provided. The options are: A rectangular pond where the volume is calculated as a rectangular prism, Trapezoidal Pond where the area is calculated as a trapezoidal prism, and Other Pond where the base area must be known by the user but doesn't need to be a regular shape.

Swales are very similar to detention ponds in that they usually have a trapezoidal cross-sectional area. The inputs however require a manning roughness coefficient (n), a side slope (Z), a flow slope (S), and a bottom width (B). The length of the swale recommended is shown instead of a storage capacity.

Sumps

Figure 12 shows the inputs for the Sump design sheet.

Sump Dimensions		
Inner Diameter (D):	5	[ft]
Thickness of Shell (t):	1	[in]
Height of Sump (H):	30	[ft]
Depth From Surface to Bottom	30	[ft]
# Lateral Holes per Level (m):	15	
# of Levels of Holes (Δd):	15	
Base Area of Sump:	19.6	[ft ²]
Volume of Sump:	589.0	[ft ³]

Gravel Distribution		
Void Ratio of Gravel	0.33	
Buffer Width (Bw)	3	[ft]
Gravel Below Sump	3	[ft]
Volume of Gravel	2561.64	[ft ³]
Storage Volume in Gravel	845.34	[ft ³]

Design Parameters		
Design Life:	20	[yrs]
% Reduction:	92.2	[%]
Total % Reduction	19.5	[%]

Use Diminished Rates?	Yes
-----------------------	-----

Option 1		
Rate for System Surface Area	Active	Yes
Percolation Rate	0.5273	[cfs]
Diminished Percolation Rate	0.1030	[cfs]

Option 2		
Rate for Sump Excluding Gravel	Active	No
Percolation Rate	0.0299	[cfs]
Diminished Percolation Rate	0.0058	[cfs]

Number of Sumps	2
-----------------	---

Figure 12: Inputs for Sump Design

First, the user needs to define the dimensions of the sump. The dimensions are: diameter, height, shell thickness, and the depth from the surface to the bottom of the system. Then the user defines the gravel void ratio and the width of the gravel buffer. Next the design life of the system must be chosen. A value of 20 years is already programmed into the application but can be changed by the user to suite their design needs. The design life is used to calculate the diminishing returns over time calculated from the research done by Siwiradene et al and Hatt et al. A summary of these calculations can be seen in the appendix of this report. To calculate the percolation of the system either option 1 or 2 must be chosen. Option 1 uses the percolation area at the base of the gravel and part of the sidewalls of the gravel. Option 2 focuses only on the percolation area of the base of the sump and the holes drilled into the shell of the sump. Above these options the user specifies whether or not to use the diminished percolation rates for the design. To use more than 1 sump, the user enters a number into the number of sumps cell.

Outputs

Each design sheet lists its outputs as shown in Figure 13.

Storage Capacity of System	21842	[ft ³]	Volume Required Based off Water Balance	12719	[ft ³]	Does your system meet the demands?	YES
----------------------------	-------	--------------------	---	-------	--------------------	------------------------------------	-----

Storm Chamber Selected on Water Balance Page

Figure 13: Design Sheet Output Configuration

The design sheet will calculate the storage capacity of the system according to the inputs of the user and then compare that volume to the required design storage from the Water Balance sheet. It is then indicated whether the design is adequate. The user then returns to the top of the sheet and alters their inputs until a satisfactory design is found. Under the

“Volume Required Based off Water Balance” a reminder is shown for which system of interest is chosen on the Water Balance sheet since percolation is dependent upon the system of interest selected on that page.

Summary

The report contains the final design of the requested soil data percolation application. The desired outcome of the spreadsheet application was dissolved into individual tasks. Each task has been organized in the spreadsheet. The primary inputs of the application are storm type, areas with corresponding C values or CN numbers, permissible outflow, storm type and duration, available detention design area, soil type and ground water table. Additional inputs are system design specific and are defined under each system's design sheet. The systems available to choose from are Storm Chambers, Swales, Sumps, R-Tanks, and Detention Ponds.

Percolation rates are set as inputs for the user to specify or can be estimated using Hydraulic Conductivity. The diminishing returns has been solved using research by Siwiradene et al and Hatt et al.. These diminishing returns were found to be approximately 7-8% loss to the percolation rate per year.

The spreadsheet can be used to design using various methods that can be specified by the user. There is some iteration required by the user before a final design can be found. The soil data percolation application project progressed on schedule. The team has overcome many obstacles such as determining the best approach to the lack of percolation data for Orem, UT, bringing the team together by clarifying the scope of the project, lack of education and code for storm system design, and learning how to predict the design life for the indicated stormwater systems.

It should be noted that the project is submitted as is and should be checked and approved by a Licensed engineer before being used in Design.

Appendix

Hydrometer and Diminishing Returns

Introduction

A hydrometer analysis was completed in order to estimate the diminished returns of the stormwater infiltration systems. The calculation of the diminishing factor was completed following the research of Siriwardene et al and Hatt et al. The clogging of the gravel fill around a given stormwater infiltration system is due to the fines caught in the stormwater runoff. Siriwardene et al noticed that the clogging was due primarily to the fines with a diameter of less than six micrometers. Thus, a hydrometer was done on a sample of street sweepings from Orem public works to obtain the amount of fines in the stormwater runoff entering the systems.

Experiment

The hydrometer analysis was done in the BYU soils lab located in the Clyde Building. The sample of sweepings was first dried and then sent through the sieve to separate out the coarse material and the large organics. The material from the pan, 200 sieve, and 100 sieve were measured and collected. These three sizes were mixed and a 50.4 g sample was collected and soaked in a 4% solution of sodium hexametaphosphate (NaPO_3) overnight. The sample was then mixed and added to water until 1010 ml of solution was obtained. The readings were then taken at increasing intervals over the course of the next 24 hours. Specifically 15sec, 30sec, 1min, 2min, 5min, 10min, 15min, 30min, 60min, 120min, 180min, 360min, 600 min, and 1440 min. The Measurements were then correction and the percent finer was calculated.

The data and results of the hydrometer analysis can be seen in Table 1 below. The table shows the original hydrometer readings, time when the reading was taken as well as all of the corrections and calculated values.

Table 2: Hydrometer Readings, Corrections, and Results

Time/date of reading		Elapsed time, t (min)	Temp. (°C)	Actual hydrometer reading, R_a	Corrected hydrometer reading, R_c	Percent finer, P (%)	Meniscus corrected hydrometer reading	Hydrometer effective depth, L (cm)	L/t (cm/min)	Correction value, K	Soil particle diameter, D (mm)
3/29/2017	2:31 PM	0.25	24.6	15.0	14.80	29.13	14.00	14.00	56.016	0.012745	0.0954
3/29/2017	2:31 PM	0.5	24.6	12.0	11.80	23.22	11.00	14.50	28.992	0.012745	0.0686
3/29/2017	2:32 PM	1	24.6	10.5	10.30	20.27	9.50	14.74	14.742	0.012745	0.0489
3/29/2017	2:33 PM	2	24.6	10.5	10.30	20.27	9.50	14.74	7.371	0.012745	0.0346
3/29/2017	2:36 PM	5	24.5	9.0	8.78	17.27	8.00	14.99	2.998	0.012759	0.0221
3/29/2017	2:41 PM	10	24.4	8.5	8.25	16.24	7.50	15.07	1.507	0.012773	0.0157
3/29/2017	2:46 PM	15	24.1	8.1	7.78	15.30	7.10	15.14	1.009	0.012815	0.0129
3/29/2017	3:01 PM	30	23.8	8.2	7.80	15.35	7.20	15.12	0.504	0.01286	0.0091
3/29/2017	3:31 PM	60	23.2	7.9	7.35	14.47	6.90	15.17	0.253	0.012952	0.0065
3/29/2017	4:31 PM	120	22.6	7.1	6.40	12.60	6.10	15.30	0.127	0.013043	0.0047
3/29/2017	5:31 PM	180	22.0	7.0	6.15	12.10	6.00	15.32	0.085	0.013134	0.0038
3/29/2017	8:31 PM	360	21.4	7.0	6.00	11.81	6.00	15.32	0.043	0.013229	0.0027
3/30/2017	12:31 AM	600	21.4	7.0	6.00	11.81	6.00	15.32	0.026	0.013229	0.0021
3/30/2017	2:00 PM	1440	21.1	7.0	5.93	11.66	6.00	15.32	0.011	0.013275	0.0014

The diameter of interest was 0.006mm. The percent finer by weight was calculated by interpolation the between the points for 0.0065mm and 0.0047mm and was found to be 13.87% for the particle diameter of interest.

Diminishing Returns Calculation

The diminishing returns was calculated using the equation develop by Siriwardene et al shown below.

$$Q_{out\&} = \frac{100a}{(a + Mass_{<6}^b)}$$

Where a and b are constants found by Siriwardene et al to be $a=1.68 \times 10^{13}$ and $b=6.03$ for use in stormwater infiltration systems. From the research of Hatt et al it was found that only about half of these fines migrate all the way to the soil boundary to form the clogging layer. To obtain the mass required for the calculation the average sedimentation rate of the sumps given my Orem City was used. This value was 1 ft per year. Using the standard sump diameter given in the detail drawings a mass was found for one year. The calculation was $0.5 * 13.87\% * 1ft * \pi * (5ft)^2 * 0.25 * 2.7 * 62.4lb/ft^3$. This gave the weight of fines accumulated over the course of one year, which was then converted into grams and used in the equation above. This gave a $Q_{out\%}$ of 92.2% per year or a 7.8% loss per year. This was then added to the application and applied to the design life to find the total loss over the lifetime of the system.

This estimate of loss is based on very small sample size. For greater accuracy it is recommended that Orem City perform several more hydrometer analyses on their street sweepings in order to find a more precise value.

Team Credentials

Alex Arndt



Project Manager

BS in Civil Engineering, BYU
Geotechnical Engineering experience with Gerhart Cole INC.

Cameron Lusvardi



Excel Specialist

Team Lead

Liaison between the Team and the Sponsor

Task Lead

App Development, R-tank Research

Relevant Coursework

CEEn 270 Computational methods

Relevant Work Experience

Teaching Assistant for CEEEn 270 Computational methods
Managerial experience with TRACO Manufacturing
Research Assistant for Dr. Kyle Rollins

William Shelton



ArcGIS Specialist

Task Lead

GIS mapping, Dog-house Research

Relevant Coursework

CEEn 414 Engineering Applications of GIS
CEEn 270 Computational methods

Relevant Work Experience

Experience with water facilities
Engineer in Training with Redwood Engineering
Research Assistant

Jacob Wadman



Data Analyst and Technical Writer

Task Lead

Data Analysis, Report Building, Sump Research

Relevant Coursework

ENGL 316 Technical Writing
CEEn 270 Computational methods

Norman Jones, Ph.D.

Project Faculty Advisor

Professor for Seepage and Groundwater Modeling

References

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