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UNIVERSITY HONORS PROGRAM

SENIOR PROJECT - APPROVAL

Name: PRESTON BREEDING

College: ENGINEERING Department: CIVIL AND ENVIRONMENTAL

Faculty Mentor: DR. JAMES SMOOT

PROJECT TITLE: THE EFFECTS OF LOGGING ON THE HYDROLOGIC PROPERTIES OF SMALL WATERSHEDS

I have reviewed this completed senior honors thesis with this student and certify that it is a project commensurate with honors level undergraduate research in this field.

Signed: James L. Smoot, Professor, Faculty Mentor

Date: 12/13/00

Comments (Optional):

The Effects of Logging on the Hydrologic Properties of Small Watersheds

By Preston E. Breeding
Senior Project, University Honors Program
The University of Tennessee, Knoxville

As a sawmill owner and operator I often contemplate the environmental consequences of my actions in the forest. As an engineering student I try to apply the concepts I learn in school to my activities in the woodshed. The study of hydrology has given me a wonderful opportunity to examine the effects of my actions and the actions of others on the watersheds in which we work. The removal of trees for sale and processing is essential to our survival economically; however, the exodus of wood from a watershed could result in our demise environmentally. It is with these thoughts in mind that I use my engineering skills and my forestry knowledge to examine a question that has plagued me for some time: Does the harvesting of trees increase surface runoff in small watersheds in southwestern Virginia? The following project addresses this issue and interrelated issues.

-Preston Breeding

Abstract

When man enters a watershed and tinkers with the perfectly balanced system that has been formed over hundreds and often thousands of years, changes are going to take place. Society today recognizes these changes that man makes to his surroundings and weighs the costs and benefits of doing so. When loggers remove trees from a woodshed, these changes are never more prominent. Forestry officials and environmentalists have succeeded throughout the past two decades in improving logging practices in an effort to make the necessary benefits of the timbering industry outweigh or equal the costs of removing trees from forests. One consequence of logging may have been overlooked in the efforts to reduce erosion and improve water quality: an increase in the amount of water exiting the watershed via surface runoff. Through utilization of hydrology software packages, the research presented in this paper illustrates a pattern of increased runoff depths and peak flows experienced by small watersheds where logging has taken place. The most significant increases occur during small storms when virtually no runoff was present before logging took place. This evidence is increasingly important when combined with the fact that most rainfall received by a watershed over the course of a year is in the form of small storms. One possible solution to this problem is the construction of detention ponds at or near the outlet of the watershed by loggers who already are using the necessary equipment to complete the job. Whether detention ponds, improved logging methods, or a reduction in tree harvesting is the answer, this paper is evidence a problem exists and more research on the topic is needed.

Table of Contents

Index of Tables and Figures

Introduction

Social Implications

Wood has been and will continue to be a cornerstone of the construction and furniture business in America. From the lumberjacks of the seventeenth and eighteenth centuries to the pulpwood plant workers of today, the timber industry has employed many men. The products fashioned by these men, such as paper, furniture, and framing lumber, affect every single citizen of the United States each and every day. It is for this reason alone that the logging industry will remain a staple in the American economy. In many rural areas such as southwestern Virginia, timber harvesting is the sole means of income for many families. For all of the good that logging and wood processing facilities do, there is the inherent ecological consequences of the timbering process itself that society must deal with as a result of the continued use of these products. It is no secret, especially to environmentalists, that logging produces many ill effects in the environment and teeters with the delicate balance between man and nature. In addition to the elimination of wildlife habitats, the removal of trees from the landscape also increases the amount of water falling on the soil and decreases the quantity of water used by root systems. In areas where a high percentage of a watershed is being logged at once, the small effects of each logging operation could culminate into large-scale problems for all inhabitants downstream. The combination of loggers largely uneducated about the ecological effects of their vocation and forestry departments chiefly concerned with reforestation and erosion has resulted in little effort to curb newly generated runoff into streams and has the potential to create many hydrologic hazards downstream for all who use or live near the water.

Hydrologic Background

When precipitation occurs in a watershed, the water either results in runoff or is lost to interception, depression storage, infiltration, or evaporation. Any decreases or increases in these losses directly affect the amount of runoff experienced by the watershed. Logging affects the determining characteristics of all of the discussed losses. The term initial abstraction refers to the water intercepted by vegetation and stored in surface depressions, collectively. These parameters will be discussed in the hydrologic background individually, but the term initial abstraction will be used to describe them from this point forward.

Interception is the wetting of surfaces in the watershed that must become saturated before runoff begins. The surface areas of all of the leaves on trees standing in the watershed provide a large area for interception to occur. Once these trees are removed, all of the interception volume proceeds to the forest floor. This flow must be soaked up by the ground or removed via surface runoff.

Depression storage is greatly affected by cover and slope of terrain. In the mountainous region of southwest Virginia, steep slopes in most areas provide little depression storage. After bulldozers and skidders make roads along the hills, depression storage will be reduced due to the smoothing of the ground. On slopes such as those found in the region, the depression storage is minimal, even before any type of disturbance takes place in the watershed.

Another precipitation loss that reduces runoff is infiltration. Infiltration is the amount of water leaving the surface and entering the ground. Some of this water travels underground and then exits the slope as runoff. This quantity is extremely hard to determine. However, it is logical to assume that if more water enters the soil due to less interception and less water is demanded by the root system since the trees have been harvested, more water would exit the slope. Due to the difficulties faced in measuring this amount, it was also neglected for this study. It is worth noting that any change in the runoff would have most likely been an increase.

Evaporation is generally neglected in the analysis of a watershed and its runoff. As with the infiltration discussion, it would seem logical to conclude that the amount of water evaporated would decrease, thus increasing surface runoff. This deduction is supported by the decrease in surface area on which the water was evaporated in the undisturbed watershed. The decrease can once again be contributed to the reduction in leaves from the harvest of trees.

Two other important characteristics of the watershed had to be identified before an analysis could proceed. The time of concentration is a function of the watershed's ability to handle excess surface runoff. The time of concentration is defined as the amount of time it takes for the entire watershed to contribute to the runoff. In other words, it is the amount of time required for surface runoff to travel from the most remote area of the watershed to the outlet point. This time has the potential to be greatly altered by surface reshaping. Removal of trees, compounded by a reduction in obstacles along the forest floor decreases the time of concentration. This translates to peak flows for runoff being attained in shorter periods of time and longer durations of high flow – both of which are adverse effects on the communities downstream from the watershed.

The other characteristic of the watershed that was identified was the soil type or types present. Hydrologic Soil Groupings (HSG) would logically have a dramatic effect on the amount of water absorbed by the ground versus the amount of runoff passing over the ground. Clayey soils and sandy soils will display very different properties when water is introduced to them. Without entering into a discussion of soil mechanics and the permeability of soils, the soil types in this analysis will range from HSG A to HSG D. This range corresponds to a range of soils composed of well-drained sandy soils, HSG A, to poorly drained clayey soils, HSG D. These effects should be rather obvious when presented in tabular form.

Timbering Background

In addition to the hydrologic properties of the watershed, the method of timbering must also be considered. There are many different strategies to remove timber from a particular woodshed. "Clear-cutting" is the most devastating to the behavior of the watershed. In the clear-cutting method, all trees are removed from the woodshed. This leaves a barren landscape that is susceptible to erosion and, consequently, to runoff. Clear-cutting in a small watershed can have catastrophic effects on the hydrologic behavior of the environment. The Department of Forestry seems quite concerned about erosion but generally does not address the issue of runoff. Erosion and sediment removal are major issues in forestry; however, for this study of hydrology, runoff will be the focus.

Timber harvesting is risky business physically and fiscally. Loggers are trained and certified in safety procedures for falling trees and removing logs from the woodshed. Most loggers also have well trained eyes which, from across a ridge, can easily distinguish between a veneer and a three-sided red oak. However, few appreciate the changes they make with each cut of their chainsaw. This analysis hopes to outline those changes and offer solutions that can be implemented by loggers in the field.

Scope and Objectives

This project is intended to examine the possibility of excess surface runoff generated from logging activities in small watersheds. The hydrologic characteristics of the watershed to be examined were closely monitored to see how they varied when logging was simulated and how they subsequently affected the flows at the watershed outlet. The method of investigation included the utilization of the TR-55 and SMADA computer programs. TR-55 has been a popular computer tool for hydrologists for many years and SMADA is becoming increasingly popular as its features become more widely recognized. These two programs are also the hydrology programs available to the students at the University of Tennessee. In addition to the analysis of the watershed for hydrologic variances, a comparison between the two software packages will also be made. The differences in the two programs will be scrutinized and investigated as a possible source of error in the calculation of runoff from rural watersheds.

This investigation attempts to compare the different methods of logging and their impacts on watershed hydrology. Due to the limited scope of the project, many assumptions and good engineering judgments had to be made. Whenever possible, specialists in the field of hydrology were consulted when assumptions were to be made.

The objective of this study is to show a pattern of runoff increases for small watersheds and determine how they vary with different rain events. Furthermore, the significance of these runoff increases will be examined in relation to the current policies of local forestry offices. Finally, if significant increases are found to be present in the watershed, solutions to curb the excess runoff, as well as a plan to further study the possible problem will be offered.

Methods

Data Collection

For this analysis, a small watershed, typical of those found in rural southwestern Virginia was fabricated. The watershed has been described as hydrologically accurately as possible. In order to limit the data to a reasonable amount for an investigation of this magnitude, the watershed was limited to 150 acres and is located in the Appendix. This is not an unreasonable size and is often found nestled away in the mountains of Virginia.

The area can be subdivided into smaller, more detailed sections. Approximately 90 acres of the watershed is heavily wooded and will be logged. This is the area of interest in this study. The parameters describing this subarea were varied to study the effects on runoff. The remaining 60 acres remained fixed in size and condition: a meadow consisting of 20 acres of grassland conditions; 20 acres of wooded area comprised mostly of small brush; and 20 acres of rocky terrain, sparsely vegetated. These areas were hydrologically described as accurately as possible; however, the characteristics assigned to these areas were not as important as their consistency from the pre-logged state to the post-logged state. A TR-55 output identifies the parameters used to describe these subareas and the effects of each on the watershed's runoff.

The characteristics of the woodshed, the area to be logged, are vital to the analysis. In order to predict the most accurate portrayal of this watershed's behavior, three conditions of the environment were examined. First, the woodshed was intact; no logging activities had taken place. Secondly, the woodshed was examined at a state that reflects a recent "select-cutting" method of timber harvesting. The third case was representative of clear-cutting techniques.

Initially, the woodshed was assumed to be dense and steep, both distinct features of the southwestern Virginia landscape. For case 1 analysis, the woods were classified as being of hydrologically good conditions. For case 2, the woods were classified as a woods-grass combination in poor condition. Finally, for case 3, the woodshed was classified as newly formed grassland in poor condition. The drainage slopes and distances for the woodshed were not varied from case to case.

The drainage conditions of the watershed itself are representative of many small watersheds in southwest Virginia. Small watersheds are often drained by streams of no more than 3-5 ft. in width that may be 6 in. deep. They are typically rough and tumble down significant slopes. An attempt to accurately represent these conditions was made during the input of data into the TR-55 program.

Software Packages

The watershed was examined using the TR-55 and SMADA hydrology programs. These programs are both used in the field of hydrology today and were sufficient to determine the possibility of a runoff problem. TR-55 was used to determine times of concentration, curve numbers, runoff depths, and runoff peak flows. TR-55 allows the user to examine each subarea within the watershed. This was very useful in determining the curve number for each subarea and consequently the composite curve number for the watershed. 2, 5, 10, 25, 50, and 100-yr storm events were simulated. The rainfall corresponding to these storm magnitudes was determined from the TR-55 manual, which can be found on-line. The storm intensities are presented in the following table.

Storm (yr)	2	5	10	25	50	100
Rainfall (in)	2.8	3.6	4.0	4.7	5.3	5.7

SMADA was also used to compute the runoff and peak flows for the same rain events; however, SMADA does not allow the user to input data for subareas within a watershed. For the SMADA analyses, a composite curve number was calculated for the entire watershed from the TR-55 data. These values were found using an area-weighted method. The time of concentration used in the SMADA analysis was also determined in the TR-55 program. This value was used for Case 1 analysis only, the pre-logging condition. For Case 2 and Case 3, a time of concentration was estimated, consistent with the changes taking place in the watershed's hydrology. The Case 1 value was calculated in TR-55 to be 1.14 hours, converted to 68.4 minutes used in SMADA. For Case 2, the time of concentration was estimated to reduce to approximately 60 minutes and for Case 3 a reduction to 45 minutes. These values were discussed with professionals and thought to be a reasonable assumption of the changes taking place within the watershed.

Another difference in the software packages was the value used for initial abstraction. TR-55 uses a default value of 20% for the initial abstraction. This value is preset and the user is not allowed to change the value as conditions change within the watershed.

SMADA, on the other hand, allows the user to input the value of initial abstraction to be used. Some texts have suggested values for initial abstraction to be as high as 30% for densely wooded areas. It is also been suggested that engineers in areas such as Florida often use values as high as 30% to accommodate for the dense vegetation. In this study, the value was not adjusted upward for dense vegetation. Instead, for Case 2 and Case 3 calculations, the value of initial abstraction were decreased to represent the reduction of vegetation and interception area. Again, SMADA only allows inputs for the entire watershed, not subareas. Since only the area to be logged was adjusted from the default 20%, a weighted average was calculated. For Case 2, an initial abstraction of 15% was used and for Case 3, the value was further reduced to 10%. These values are estimates of the effects of logging on the initial abstraction of the watershed. Once the weighted average was calculated, the values input into SMADA for Case 2 and Case 3 were 17% and 14%, respectively. Again, the default value for the pre-logged wooded subarea possibly could have been adjusted upward and justified based on common engineering practices. The rest of the watershed fell comfortably into the average value of 20%.

TR-55 also allows the user to select the type of soil present within each subarea of the watershed. This selection factors into the curve number calculation, which also translated to the SMADA analysis through the weighted-average calculation. An analysis was performed in each program, for each storm frequency previously discussed, for soil types HSG A – HSG D.

Approach

Since the main focus of this study was to determine the excess runoff generated in this watershed, tables of runoff values were calculated for each rain event to be examined. The values were also grouped by soil type and scenario presented in the introduction, i.e. Case 1, 2, and 3. Both runoff depths and peak flow values were examined for increases. The increases observed under each analysis were reported as percent increases.

The runoff depth gives the reader a better understanding of the amount of rainfall that actually exits the watershed as runoff; although, measurement of the peak flow leaving the watershed is a more common form of monitoring the hydrologic performance of the watershed. Data was presented in identical formats where possible for both the TR-55 and SMADA analyses. The differences in the two programs were not enormous, but reporting both shows the variations that are present.

Results

TR-55

The results of the TR-55 investigation produced runoff depths and peak flows for each subarea within the watershed. The data was output from TR-55 in a one-page printout that has the hydrologic descriptions for each subarea, the curve number, soil type, runoff depth, and corresponding peak flow. This raw data was reformatted to better understand the effects of soil type and logging method. Table A shows the runoff increases in inches for various storms and soil types. Table B shows the increases in peak flows from the watershed outlet. TR-55 gives runoff and peak flows for each subarea within the watershed and this more detailed data can be found in Tables E – J. These tables show the runoff for each subarea and are listed for each soil type and case. The data is grouped in tables based on the storm used in the simulation.

The percent increases in runoff and flows have been summarized in a series of graphical plots that help to illustrate a possible pattern of significance. Figure 1 is a summary of the percent increases for all scenarios and soil types. Figures 2 – 5 show percent increase for soil types HSG A – D, respectively. Figure 6 is a three-dimensional look at the general pattern of increases in runoff for various storms under different hydrologic situations, i.e. Case 1, 2, and 3. A complete analysis of the 2-yr storm data is included in the Appendix for review of procedure and validity.

SMADA

The results of the SMADA analysis are presented in Tables C and D. Tables C and D are in the same format as Tables A and B so that the outputs from TR-55 and SMADA can be compared. These tables verify the legitimacy of the TR-55 outputs and show deviations in the smaller storms where the initial abstraction issue is more significant. The results from the SMADA analyses show much larger increases in runoff and peak flows. Since SMADA only performs simulations for the entire watershed and does not break down runoff and peak flows for subareas, Tables E – J cannot be duplicated for the SMADA numbers. Table K shows composite curve number calculations and the tabulation of initial abstraction values used in SMADA.

The percent increases in runoff and flows have been summarized in a series of graphical plots that help to illustrate a possible pattern of significance. Figure 7 is a summary of the percent increases for all scenarios and soil types. Figures 8 – 11 show percent increase for soil types HSG A – D, respectively. Figure 12 is a three-dimensional look at the general pattern of increases in runoff for various storms under different hydrologic situations, i.e. Case 1, 2, and 3. As with the TR-55 investigation, data is included in the Appendix for review of procedure and validity. However, due to the large amount of data used in the SMADA analysis, 72 pages for an entire storm calculation, only the data for HSG A, 2-yr storm is included in the Appendix.

Table A
TR-55 Analysis

Summary of Runoff Increases From Various Storms for Different Soil Types

HSG - A												
Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	0.21		0.34		0.43		0.63		0.85		1.00	
2	0.22	4.8%	0.43	26.5%	0.56	30.2%	0.82	30.2%	1.08	27.1%	1.27	27.0%
3	0.52	147.6%	0.90	164.7%	1.12	160.5%	1.53	142.9%	1.92	125.9%	2.18	118.0%

HSG - B												
Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	0.43		0.77		0.98		1.36		1.73		1.99	
2	0.64	48.8%	1.09	41.6%	1.34	36.7%	1.83	34.6%	2.26	30.6%	2.57	29.1%
3	0.97	125.6%	1.53	98.7%	1.83	86.7%	2.40	76.5%	2.89	67.1%	3.23	62.3%

HSG - C												
Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	0.84		1.37		1.66		2.19		2.66		2.99	
2	1.03	22.6%	1.63	19.0%	1.94	16.9%	2.52	15.1%	3.03	13.9%	3.38	13.0%
3	1.37	63.1%	2.04	48.9%	2.39	44.0%	3.01	37.4%	3.56	33.8%	3.92	31.1%

HSG - D												
Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	1.13		1.75		2.07		2.66		3.19		3.54	
2	1.35	19.5%	2.01	14.9%	2.36	14.0%	2.98	12.0%	3.53	10.7%	3.90	10.2%
3	1.60	41.6%	2.32	32.6%	2.68	29.5%	3.33	25.2%	3.90	22.3%	4.28	20.9%

All Runoff values in inches.

Table B
TR-55 Analysis

Summary of Outlet Flow Increases From Various Storms for Different Soil Types

HSG - A												
Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	39		59		69		89		106		119	
2	39	0.0%	59	0.0%	69	0.0%	89	0.0%	106	0.0%	120	0.8%
3	40	2.6%	61	3.4%	73	5.8%	96	7.9%	117	10.4%	132	10.9%

HSG - B												
Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	49		78		95		126		152		172	
2	49	0.0%	80	2.6%	98	3.2%	132	4.8%	161	5.9%	182	5.8%
3	54	10.2%	88	12.8%	108	13.7%	143	13.5%	174	14.5%	196	14.0%

HSG - C												
Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	68		106		126		165		200		223	
2	71	4.4%	111	4.7%	132	4.8%	172	4.2%	208	4.0%	231	3.6%
3	77	13.2%	120	13.2%	140	11.1%	180	9.1%	215	7.5%	238	6.7%

HSG - D												
Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	84		127		151		190		227		251	
2	88	4.8%	133	4.7%	157	4.0%	196	3.2%	232	2.2%	256	2.0%
3	93	10.7%	138	8.7%	161	6.6%	200	5.3%	237	4.4%	261	4.0%

All Flow values in cubic feet per second, cfs.

Table C
SMADA Analysis

Summary of Runoff Increases From Various Storms for Different Soil Types

HSG - A												
Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	0.03		0.17		0.27		0.48		0.70		0.87	
2	0.16	433.3%	0.40	135.3%	0.55	103.7%	0.84	75.0%	1.14	62.9%	1.35	55.2%
3	0.56	1766.7%	0.98	476.5%	1.22	351.9%	1.67	247.9%	2.08	197.1%	2.37	172.4%

HSG - B												
Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	0.32		0.66		0.86		1.26		1.63		1.89	
2	0.67	109.4%	1.15	74.2%	1.42	65.1%	1.91	51.6%	2.36	44.8%	2.67	41.3%
3	1.06	231.3%	1.64	148.5%	1.95	126.7%	2.52	100.0%	3.03	85.9%	3.37	78.3%

HSG - C												
Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	0.85		1.31		1.60		2.13		2.60		2.93	
2	1.10	29.4%	1.71	30.5%	2.03	26.9%	2.61	22.5%	3.13	20.4%	3.48	18.8%
3	1.45	70.6%	2.12	61.8%	2.47	54.4%	3.10	45.5%	3.65	40.4%	4.02	37.2%

HSG - D												
Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	1.10		1.71		2.04		2.63		3.15		3.51	
2	1.40	27.3%	2.07	21.1%	2.42	18.6%	3.05	16.0%	3.60	14.3%	3.97	13.1%
3	1.64	49.1%	2.35	37.4%	2.72	33.3%	3.37	28.1%	3.93	24.8%	4.31	22.8%

All Runoff values in inches.

Table D
SMADA Analysis

Summary of Outlet Flow Increases From Various Storms for Different Soil Types

HSG - A

Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	0.54		3.62		6.75		14.84		24.26		31.75	
2	4.44	717.5%	14.49	299.8%	21.67	220.9%	37.23	150.9%	53.26	119.6%	65.25	105.5%
3	33.14	6002.4%	63.07	1640.7%	80.02	1084.9%	112.12	655.6%	141.67	484.0%	162.23	410.9%

HSG - B

Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	10.46		26.06		36.00		56.28		75.99		90.05	
2	32.95	215.1%	60.92	133.8%	76.54	112.6%	105.73	87.9%	132.23	74.0%	150.49	67.1%
3	71.58	584.5%	113.43	335.4%	135.71	277.0%	176.20	213.1%	212.05	179.0%	236.37	162.5%

HSG - C

Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	38.90		63.90		79.41		108.03		133.69		151.22	
2	60.65	55.9%	96.33	50.8%	115.20	45.1%	149.33	38.2%	179.39	34.2%	199.72	32.1%
3	100.83	159.2%	148.61	132.6%	173.23	118.1%	217.04	100.9%	255.04	90.8%	280.72	85.6%

HSG - D

Case	2-YR		5-YR		10-YR		25-YR		50-YR		100-YR	
1	54.68		87.73		105.14		136.49		164.28		183.07	
2	79.39	45.2%	118.58	35.2%	138.81	32.0%	174.81	28.1%	206.06	25.4%	227.02	24.0%
3	115.11	110.5%	164.78	87.8%	190.06	80.8%	234.94	72.1%	273.70	66.6%	299.59	63.6%

All Flow values in cubic feet per second, cfs.

Table E

Composite Curve Number and Initial Abstraction Calculations

Soil Type	Case	Subarea / Acreage				Composite Curve Number	I_a*	ΔI_a	Percent Decrease in Initial Abstraction
		Woods	Brush	Meadow	Rocky				
		90	20	20	20		inches	inches	
A	1	40	43	49	86	48	2.17	----	----
	2	48	43	49	86	53	1.51	0.66	30.41%
	3	68	43	49	86	65	0.75	1.42	65.44%
B	1	55	65	69	87	62	1.23	----	----
	2	67	65	69	87	70	0.73	0.50	40.65%
	3	79	65	69	87	77	0.42	0.81	65.85%
C	1	70	76	79	88	74	0.70	----	----
	2	77	76	79	88	79	0.45	0.25	35.71%
	3	86	76	79	88	84	0.27	0.43	61.43%
D	1	77	82	84	89	80	0.50	----	----
	2	83	82	84	89	84	0.32	0.18	36.00%
	3	89	82	84	89	87	0.21	0.29	58.00%

* Calculated using SMADA's watershed description analysis.

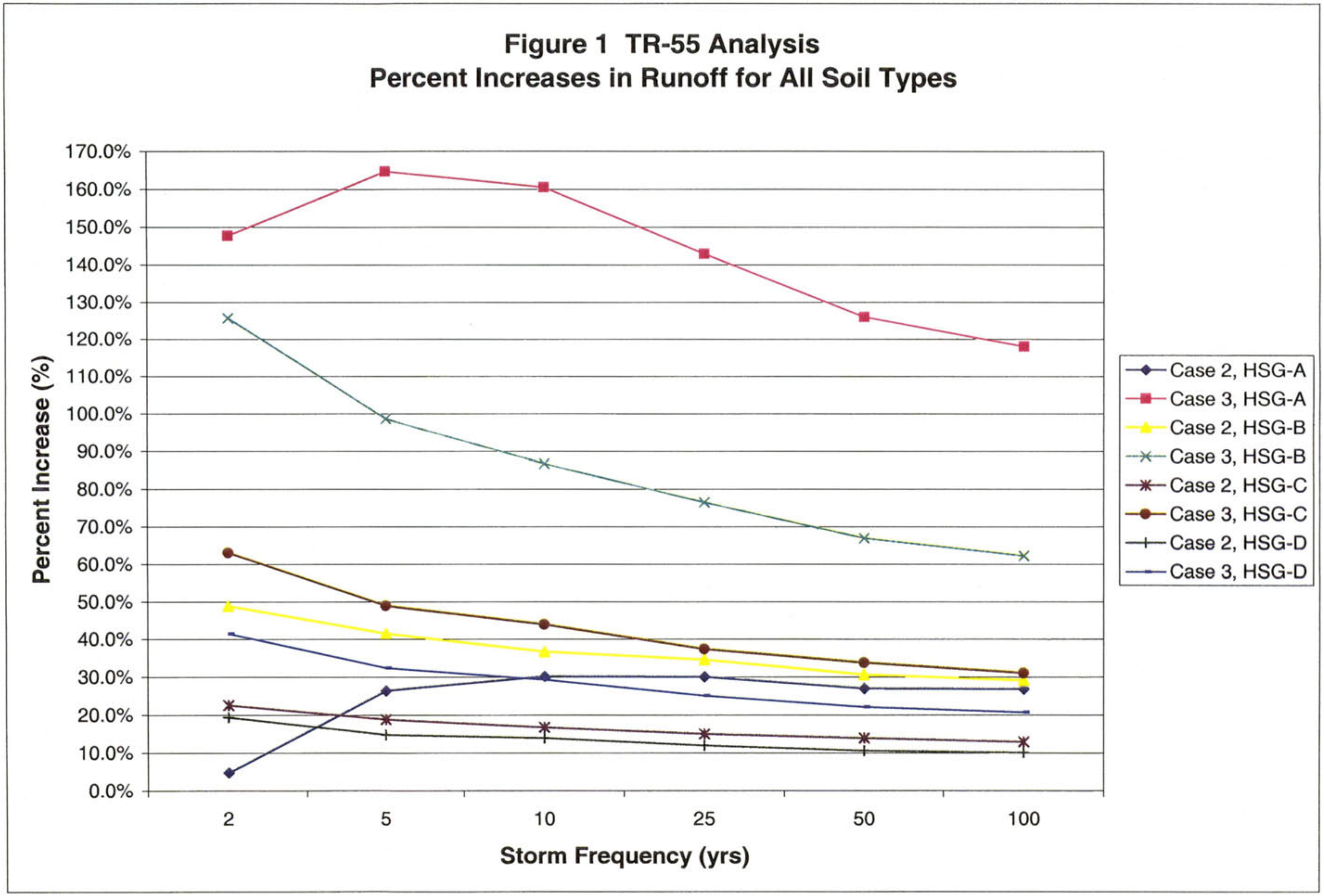


Figure 1 TR-55 Analysis
Percent Increases in Runoff for All Soil Types
170.0%
160.0%
150.0%
140.0%
130.0%
120.0%
110.0%
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Percent Increase (%)
2
5
10
25
50
100
Storm Frequency (yrs)
Case 2, HSG-A
Case 3, HSG-A
Case 2, HSG-B
Case 3, HSG-B
Case 2, HSG-C
Case 3, HSG-C
Case 2, HSG-D
Case 3, HSG-D

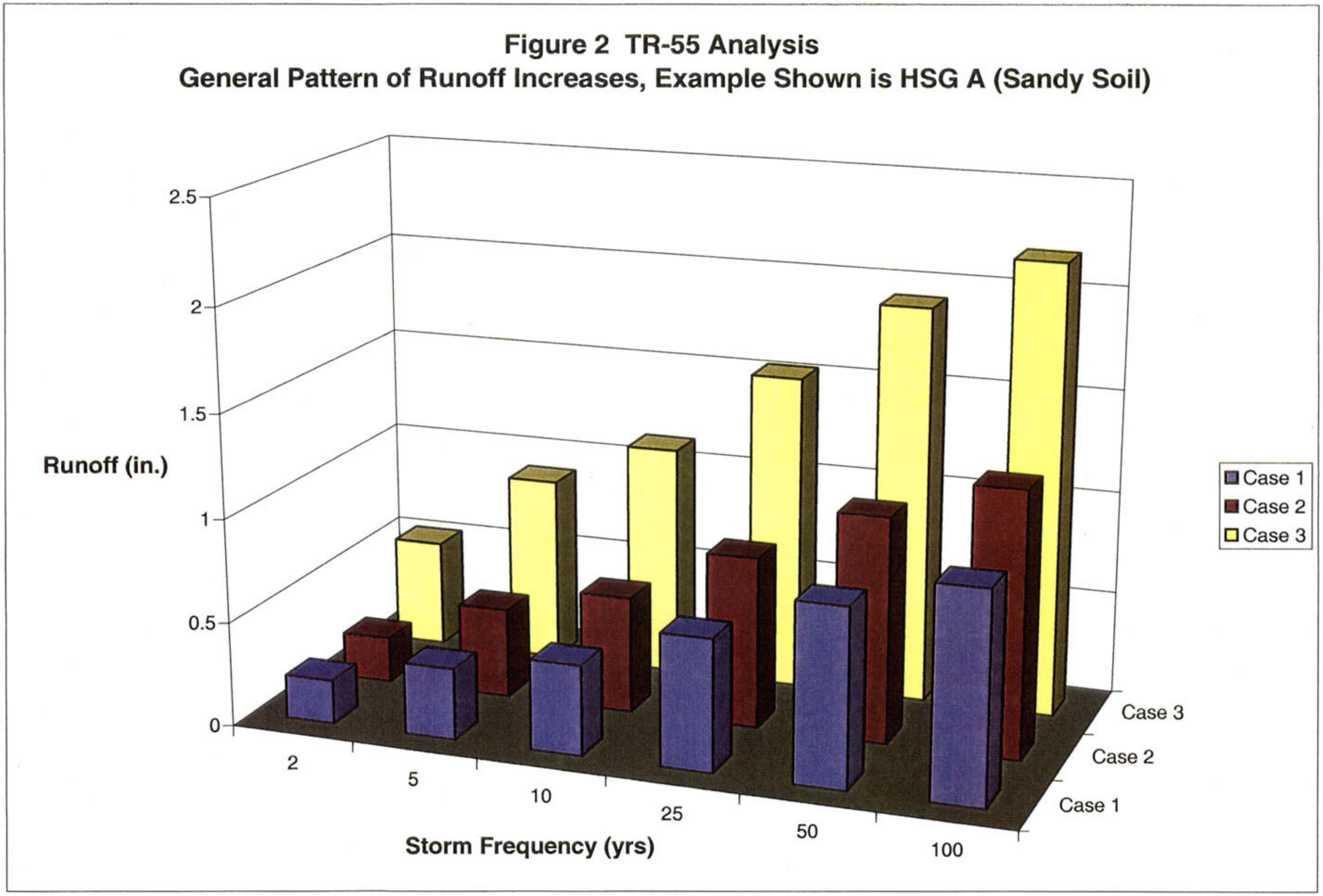


Figure 2 TR-55 Analysis
General Pattern of Runoff Increases, Example Shown is HSG A (Sandy Soil)
Runoff (in.)
2.5
2
1.5
1
0.5
0
2
5
10
25
50
100
Storm Frequency (yrs)
Case 3
Case 2
Case 1
Case 1
Case 2
Case 3

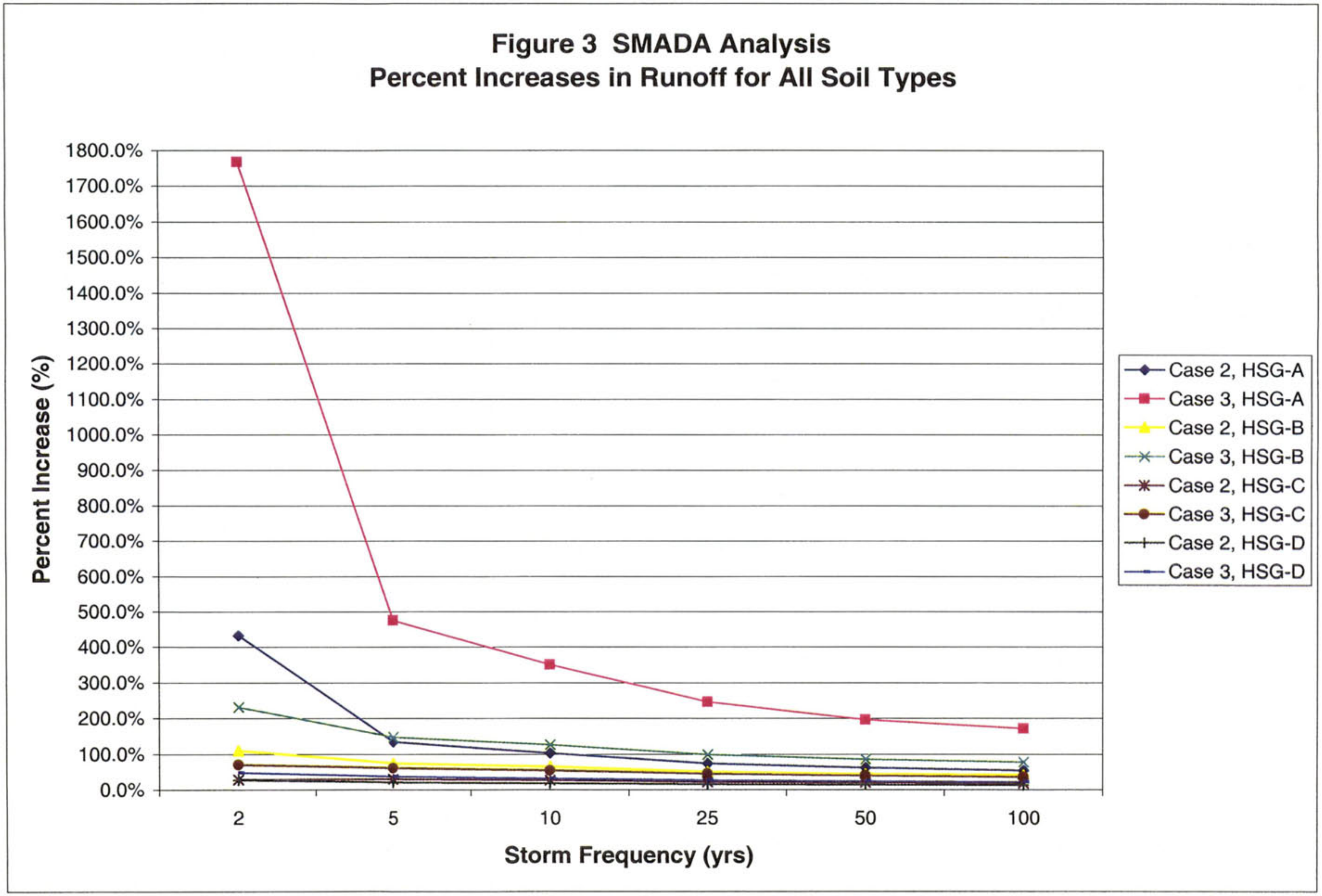
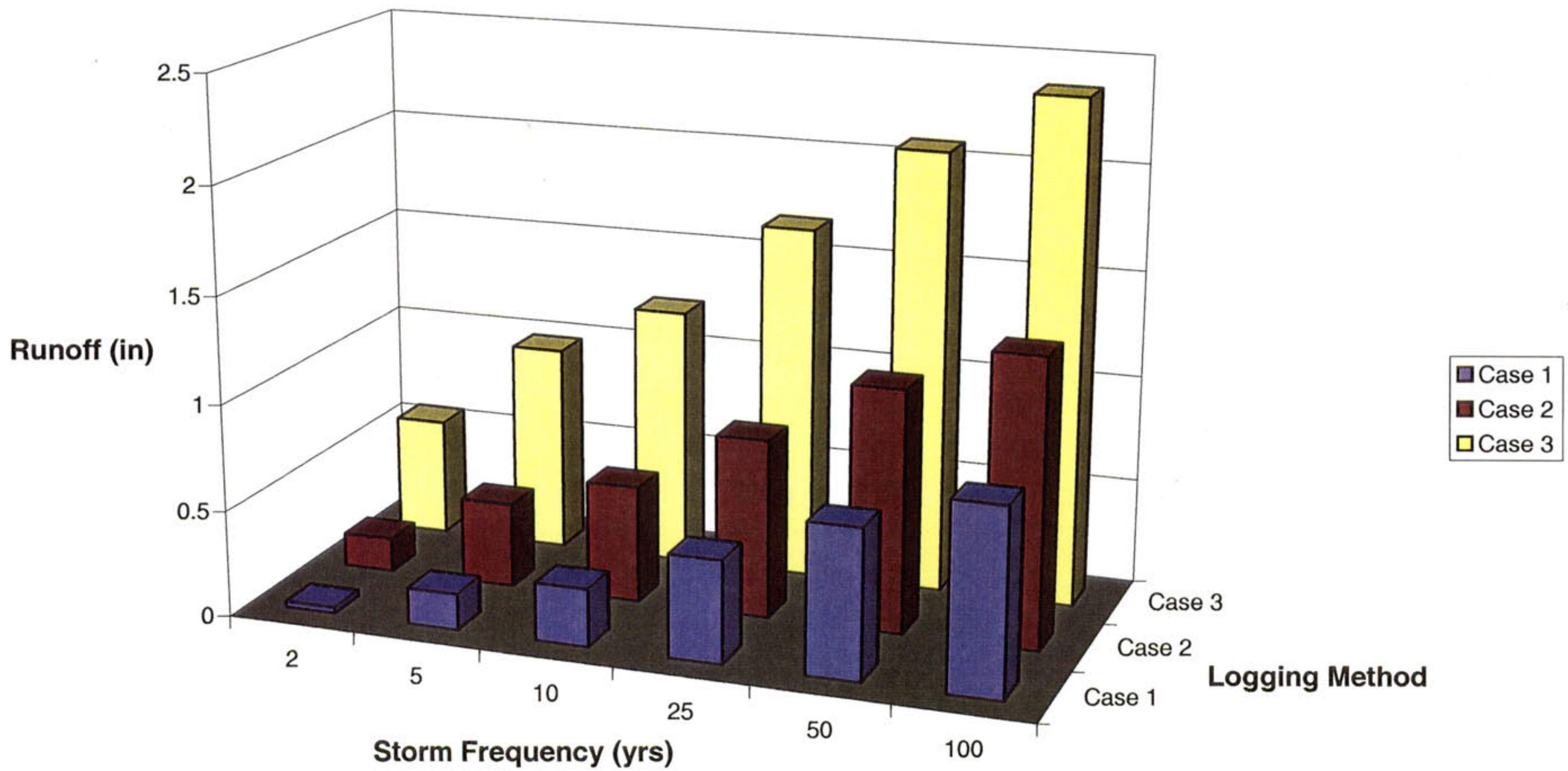


Figure 3 SMADA Analysis
Percent Increases in Runoff for All Soil Types
Percent Increase (%)
1800.0%
1700.0%
1600.0%
1500.0%
1400.0%
1300.0%
1200.0%
1100.0%
1000.0%
900.0%
800.0%
700.0%
600.0%
500.0%
400.0%
300.0%
200.0%
100.0%
0.0%
2
5
10
25
50
100
Storm Frequency (yrs)
Case 2, HSG-A
Case 3, HSG-A
Case 2, HSG-B
Case 3, HSG-B
Case 2, HSG-C
Case 3, HSG-C
Case 2, HSG-D
Case 3, HSG-D

Figure 4 SMADA Analysis
General Pattern of Runoff Increases, Example Shown is HSG A (Sandy Soil)



Discussion

The data presented in the results section shows increases in all instances where logging was simulated in the watershed. The area that was logged saw substantial increases in both runoff and peak flows. The larger increases occurred in the smaller storms, which was expected. In larger storms there is significant runoff even when no logging has taken place; therefore, when logging does take place and large runoff values are recorded, the change is not as large. The plots of percent increases for the TR-55 data show a general trend of the largest increases occurring in either the 2 or 5-yr rain event.

The SMADA analyses showed much larger values of runoff and peak flow increases than did the TR-55 outputs. These simulations were performed using curve numbers and an initial time of concentration determined by TR-55. The differences in the programs were much larger for the sandy soils than the clayey soils. This is most likely due to a reduction in the initial abstraction of the watershed as logging takes place. This effect was compensated for in the SMADA analysis.

As seen in the Figures 7 – 11, the largest percent increase occurred in the 2-yr storm event in all instances but one (HSG C, Case 2). These figures solidify the results of similar plots constructed from the TR-55 data (Figures 1-5).

Conclusions

The data presented in this project clearly show that logging activities affect a watershed's hydrologic properties and increase surface runoff and peak flows exiting the watershed. The data also points to a general trend in both the TR-55 analyses and the SMADA analyses toward a more significant increase in the smaller storms. Increases were seen for all storms in all scenarios for all soil types. This overwhelming response to the hydrologic changes in the watershed points directly toward the logging activities as detrimental toward the watershed.

The sandy soils, HSG A, showed much higher increases in runoff and peak flows. This result is similar to that of small increases in larger storms. The clayey soils saw more runoff for smaller storms than the sandy soils. Because there was already a large amount of runoff present during bigger storms, the percent increases were not as large. For example, a sandy soil in a 2-yr storm produced little to no runoff, 0.03" in the SMADA analysis. After logging had been simulated, the runoff increased slightly, 0.56" in the SMADA analysis. One-half an inch runoff will not flood Smalltown, USA, but the changes produced a 1700% increase in runoff. This number is large but not as alarming as the value indicates.

One very important aspect to realize in conjunction with the previous conclusion is that most rainfall events in a watershed are very small events. Since the majority of the storms seen by a watershed are small, increases in runoff due to logging are going to be seen very regularly. After small storms, which produce no runoff in most areas, water will be exiting a watershed that has been recently logged.

Another crucial consideration is that in many instances, there will be simultaneous logging operations within a larger watershed and all may contribute to small increases in flow from their respective watersheds. These flows from several small watersheds can produce a situation that results in unexpected downstream flooding from storms that previously created no overflow. In many rural areas such as southwestern Virginia, there is little to no means for investigating these possibilities and no current provisions to prohibit these problems from arising.

Another conclusion can be drawn from the investigation of the two computer programs. The TR-55 program seems to be more applicable for urban settings and is hampered by an inability to modify the initial abstraction values. SMADA, on the other hand, allows the user to handle more rural situations and set the initial abstraction value, but fails to produce flows for various subareas within a watershed. This made a full comparison of the two programs impossible, but did shed some light on the applications of both software packages in instances where logging activities are to be investigated.

Finally, the facts that most increases occur in smaller storms (2 and 5 yr in this study) combined with the largest portion of rainfall occurring as smaller storms create more concern for runoff in areas that have been logged. The post-logging conditions generally do not worsen from the state they are left in when loggers exit the woodshed. After a period of a few years there is considerable regrowth of trees and vegetation. Once a new root system is established and more leaves are created for interception, the possibility of runoff problems decreases. It is not fair to suggest that a watershed that has been logged is likely to be subjected to a 6" rainfall event, i.e. a 100 yr storm. The consequences of a large storm can be catastrophic even for watersheds that have not been logged. The statistics do suggest that a storm of 2.8" to 3.6" in magnitude will occur in the watershed in the two to five year period following logging. These are the very storms that produced the greatest increases in runoff and peak flows for the watershed studied for this project. It is for this reason, if no other, that further investigation of this possible problem is needed.

Recommendations

Corrective Measures

In many cases, loggers own or rent equipment such as bulldozers or skidders with large blades. Since the equipment is already present on the job, construction of detention ponds to attenuate peak flows would be a feasible solution to the problem. Once the trees are removed from the watershed, little can be done to reduce the actual runoff that comes from the watershed. Even though the amount of water leaving the watershed would be greater, the peak flows at which that water exits could be reduced to match current watershed performance. This corrective measure could reduce downstream flooding and high velocity flows over the watershed itself.

Forestry Department Benefits

The construction of detention ponds at watershed outlets would correct the problem identified in this paper while contributing to the correction of problems currently addressed by Forestry Department officials: erosion and water quality. The reduction in flows and consequently the reduction in overland velocities could greatly decrease erosion of freshly exposed soils. The detention pond would also allow sediment to settle out of the storm water. Thus, construction of detention ponds could reduce erosion and improve water quality while curbing excessive peak flows exiting the watershed.

Proposals for Further Study

It is clear from the data reported in this project that there is a high probability that a problem exists in watersheds where logging has taken place. Collection of field data and analysis of that data is warranted. Collection of data from watersheds that are being logged or have just been logged could verify or disprove the problems suggested by this study.

Furthermore, a historical investigation could also be conducted. In watersheds where several logging operations have taken place over a short period of time, flows in downstream rivers could be researched. USGS data is available via the internet and gaging stations are found on many local streams in southwestern Virginia. If flows were increased over these periods or the time periods that followed shortly thereafter, a more detailed investigation would be justified.

References

Fetter, C.W.. Applied Hydrology. Prentice Hall, New Jersey: 1994.

Virginia Department of Forestry. *Water Quality.* Internet search. http://state.vipnet.org/dof/wq/waterq.htm.

Wanielista, Martin, Robert Kersten, and Ron Eaglin. Hydrology: Water Quantity and Quality Control. John Wiley and Sons, New York: 1997.

Appendix A

Additional Tables and Figures

Table F
TR-55 Analysis

Summary of Runoff Increases From a 2-Year Storm for Different Environmental Conditions and Soil Types

Case 1 - Pre-Logging Conditions HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	40	0
Brush	20	43	0
Meadow	20	49	0.05
Rocky	20	86	1.49
Total Runoff Generated			0.21
Peak Flow at Outlet (cfs)			39

Case 1 - Pre-Logging Conditions HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	55	0.14
Brush	20	65	0.42
Meadow	20	69	0.57
Rocky	20	87	1.57
Total Runoff Generated			0.43
Peak Flow at Outlet (cfs)			49

Case 1 - Pre-Logging Conditions HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	70	0.61
Brush	20	76	0.88
Meadow	20	79	1.04
Rocky	20	88	1.64
Total Runoff Generated			0.84
Peak Flow at Outlet (cfs)			68

Case 1 - Pre-Logging Conditions HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	77	0.93
Brush	20	82	1.22
Meadow	20	84	1.35
Rocky	20	89	1.72
Total Runoff Generated			1.13
Peak Flow at Outlet (cfs)			84

Case 2 - Select Cut Conditions HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	48	0.03
Brush	20	43	0
Meadow	20	49	0.05
Rocky	20	86	1.49
Total Runoff Generated			0.22
Peak Flow at Outlet (cfs)			39

Case 2 - Select Cut Conditions HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	67	0.49
Brush	20	65	0.42
Meadow	20	69	0.57
Rocky	20	87	1.57
Total Runoff Generated			0.64
Peak Flow at Outlet (cfs)			49

Case 2 - Select Cut Conditions HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	77	0.93
Brush	20	76	0.88
Meadow	20	79	1.04
Rocky	20	88	1.64
Total Runoff Generated			1.03
Peak Flow at Outlet (cfs)			71

Case 2 - Select Cut Conditions HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	83	1.29
Brush	20	82	1.22
Meadow	20	84	1.35
Rocky	20	89	1.72
Total Runoff Generated			1.35
Peak Flow at Outlet (cfs)			88

Case 3 - Clear Cut Conditions HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	68	0.53
Brush	20	43	0
Meadow	20	49	0.05
Rocky	20	86	1.49
Total Runoff Generated			0.52
Peak Flow at Outlet (cfs)			40

Case 3 - Clear Cut Conditions HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	79	1.04
Brush	20	65	0.42
Meadow	20	69	0.57
Rocky	20	87	1.57
Total Runoff Generated			0.97
Peak Flow at Outlet (cfs)			54

Case 3 - Clear Cut Conditions HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	86	1.49
Brush	20	76	0.88
Meadow	20	79	1.04
Rocky	20	88	1.64
Total Runoff Generated			1.37
Peak Flow at Outlet (cfs)			77

Case 3 - Clear Cut Conditions HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	89	1.72
Brush	20	82	1.22
Meadow	20	84	1.35
Rocky	20	89	1.72
Total Runoff Generated			1.60
Peak Flow at Outlet (cfs)			93

Table G
TR-55 Analysis

Summary of Runoff Increases From a 5-Year Storm for Different Environmental Conditions and Soil Types

Case 1 - Pre-Logging Conditions			
HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	40	0.02
Brush	20	43	0.06
Meadow	20	49	0.19
Rocky	20	86	2.19
Total Runoff Generated			0.34
Peak Flow at Outlet (cfs)			59

Case 1 - Pre-Logging Conditions			
HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	55	0.38
Brush	20	65	0.81
Meadow	20	69	1.01
Rocky	20	87	2.27
Total Runoff Generated			0.77
Peak Flow at Outlet (cfs)			78

Case 1 - Pre-Logging Conditions			
HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	70	1.07
Brush	20	76	1.44
Meadow	20	79	1.64
Rocky	20	88	2.36
Total Runoff Generated			1.37
Peak Flow at Outlet (cfs)			106

Case 1 - Pre-Logging Conditions			
HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	77	1.51
Brush	20	82	1.87
Meadow	20	84	2.02
Rocky	20	89	2.45
Total Runoff Generated			1.75
Peak Flow at Outlet (cfs)			127

Case 2 - Select Cut Conditions			
HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	48	0.17
Brush	20	43	0.06
Meadow	20	49	0.19
Rocky	20	86	2.19
Total Runoff Generated			0.43
Peak Flow at Outlet (cfs)			59

Case 2 - Select Cut Conditions			
HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	67	0.91
Brush	20	65	0.81
Meadow	20	69	1.01
Rocky	20	87	2.27
Total Runoff Generated			1.09
Peak Flow at Outlet (cfs)			78

Case 2 - Select Cut Conditions			
HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	77	1.51
Brush	20	76	1.44
Meadow	20	79	1.64
Rocky	20	88	2.36
Total Runoff Generated			1.63
Peak Flow at Outlet (cfs)			111

Case 2 - Select Cut Conditions			
HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	83	1.94
Brush	20	82	1.87
Meadow	20	84	2.02
Rocky	20	89	2.45
Total Runoff Generated			2.01
Peak Flow at Outlet (cfs)			133

Case 3 - Clear Cut Conditions			
HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	68	0.96
Brush	20	43	0.06
Meadow	20	49	0.19
Rocky	20	86	2.19
Total Runoff Generated			0.90
Peak Flow at Outlet (cfs)			61

Case 3 - Clear Cut Conditions			
HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	79	1.64
Brush	20	65	0.81
Meadow	20	69	1.01
Rocky	20	87	2.27
Total Runoff Generated			1.53
Peak Flow at Outlet (cfs)			80

Case 3 - Clear Cut Conditions			
HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	86	2.19
Brush	20	76	1.44
Meadow	20	79	1.64
Rocky	20	88	2.36
Total Runoff Generated			2.04
Peak Flow at Outlet (cfs)			120

Case 3 - Clear Cut Conditions			
HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	89	2.45
Brush	20	82	1.87
Meadow	20	84	2.02
Rocky	20	89	2.45
Total Runoff Generated			2.32
Peak Flow at Outlet (cfs)			138

Table H
TR-55 Analysis

Summary of Runoff Increases From a 10-Year Storm for Different Environmental Conditions and Soil Types

Case 1 - Pre-Logging Conditions			
HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	40	0.06
Brush	20	43	0.12
Meadow	20	49	0.30
Rocky	20	86	2.55
Total Runoff Generated			0.43
Peak Flow at Outlet (cfs)			69

Case 1 - Pre-Logging Conditions			
HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	55	0.53
Brush	20	65	1.03
Meadow	20	69	1.27
Rocky	20	87	2.64
Total Runoff Generated			0.98
Peak Flow at Outlet (cfs)			95

Case 1 - Pre-Logging Conditions			
HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	70	1.33
Brush	20	76	1.74
Meadow	20	79	1.96
Rocky	20	88	2.73
Total Runoff Generated			1.66
Peak Flow at Outlet (cfs)			126

Case 1 - Pre-Logging Conditions			
HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	77	1.81
Brush	20	82	2.20
Meadow	20	84	2.37
Rocky	20	89	2.82
Total Runoff Generated			2.07
Peak Flow at Outlet (cfs)			151

Case 2 - Select Cut Conditions			
HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	48	0.27
Brush	20	43	0.12
Meadow	20	49	0.30
Rocky	20	86	2.55
Total Runoff Generated			0.56
Peak Flow at Outlet (cfs)			69

Case 2 - Select Cut Conditions			
HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	67	1.14
Brush	20	65	1.03
Meadow	20	69	1.27
Rocky	20	87	2.64
Total Runoff Generated			1.34
Peak Flow at Outlet (cfs)			98

Case 2 - Select Cut Conditions			
HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	77	1.81
Brush	20	76	1.74
Meadow	20	79	1.96
Rocky	20	88	2.73
Total Runoff Generated			1.94
Peak Flow at Outlet (cfs)			132

Case 2 - Select Cut Conditions			
HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	83	2.29
Brush	20	82	2.20
Meadow	20	84	2.37
Rocky	20	89	2.82
Total Runoff Generated			2.36
Peak Flow at Outlet (cfs)			157

Case 3 - Clear Cut Conditions			
HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	68	1.20
Brush	20	43	0.12
Meadow	20	49	0.30
Rocky	20	86	2.55
Total Runoff Generated			1.12
Peak Flow at Outlet (cfs)			73

Case 3 - Clear Cut Conditions			
HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	79	1.96
Brush	20	65	1.03
Meadow	20	69	1.27
Rocky	20	87	2.64
Total Runoff Generated			1.83
Peak Flow at Outlet (cfs)			108

Case 3 - Clear Cut Conditions			
HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	86	2.55
Brush	20	76	1.74
Meadow	20	79	1.96
Rocky	20	88	2.73
Total Runoff Generated			2.39
Peak Flow at Outlet (cfs)			140

Case 3 - Clear Cut Conditions			
HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	89	2.82
Brush	20	82	2.20
Meadow	20	84	2.37
Rocky	20	89	2.82
Total Runoff Generated			2.68
Peak Flow at Outlet (cfs)			161

Table I
TR-55 Analysis

Summary of Runoff Increases From a 25-Year Storm for Different Environmental Conditions and Soil Types

Case 1 - Pre-Logging Conditions			
HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	40	0.17
Brush	20	43	0.27
Meadow	20	49	0.53
Rocky	20	86	3.19
Total Runoff Generated			0.63
Peak Flow at Outlet (cfs)			89

Case 1 - Pre-Logging Conditions			
HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	55	0.83
Brush	20	65	1.46
Meadow	20	69	1.74
Rocky	20	87	3.29
Total Runoff Generated			1.36
Peak Flow at Outlet (cfs)			126

Case 1 - Pre-Logging Conditions			
HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	70	1.82
Brush	20	76	2.29
Meadow	20	79	2.55
Rocky	20	88	3.38
Total Runoff Generated			2.19
Peak Flow at Outlet (cfs)			165

Case 1 - Pre-Logging Conditions			
HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	77	2.37
Brush	20	82	2.81
Meadow	20	84	3.00
Rocky	20	89	3.49
Total Runoff Generated			2.66
Peak Flow at Outlet (cfs)			190

Case 2 - Select Cut Conditions			
HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	48	0.48
Brush	20	43	0.27
Meadow	20	49	0.53
Rocky	20	86	3.19
Total Runoff Generated			0.82
Peak Flow at Outlet (cfs)			89

Case 2 - Select Cut Conditions			
HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	67	1.60
Brush	20	65	1.46
Meadow	20	69	1.74
Rocky	20	87	3.29
Total Runoff Generated			1.83
Peak Flow at Outlet (cfs)			132

Case 2 - Select Cut Conditions			
HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	77	2.37
Brush	20	76	2.29
Meadow	20	79	2.55
Rocky	20	88	3.38
Total Runoff Generated			2.52
Peak Flow at Outlet (cfs)			172

Case 2 - Select Cut Conditions			
HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	83	2.90
Brush	20	82	2.81
Meadow	20	84	3.00
Rocky	20	89	3.49
Total Runoff Generated			2.98
Peak Flow at Outlet (cfs)			196

Case 3 - Clear Cut Conditions			
HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	68	1.67
Brush	20	43	0.27
Meadow	20	49	0.53
Rocky	20	86	3.19
Total Runoff Generated			1.53
Peak Flow at Outlet (cfs)			96

Case 3 - Clear Cut Conditions			
HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	79	2.55
Brush	20	65	1.46
Meadow	20	69	1.74
Rocky	20	87	3.29
Total Runoff Generated			2.40
Peak Flow at Outlet (cfs)			143

Case 3 - Clear Cut Conditions			
HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	86	3.19
Brush	20	76	2.29
Meadow	20	79	2.55
Rocky	20	88	3.38
Total Runoff Generated			3.01
Peak Flow at Outlet (cfs)			180

Case 3 - Clear Cut Conditions			
HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	89	3.49
Brush	20	82	2.81
Meadow	20	84	3.00
Rocky	20	89	3.49
Total Runoff Generated			3.33
Peak Flow at Outlet (cfs)			200

Table J
TR-55 Analysis

Summary of Runoff Increases From a 50-Year Storm for Different Environmental Conditions and Soil Types

Case 1 - Pre-Logging Conditions			
HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	40	0.31
Brush	20	43	0.44
Meadow	20	49	0.76
Rocky	20	86	3.75
Total Runoff Generated			0.85
Peak Flow at Outlet (cfs)			106

Case 1 - Pre-Logging Conditions			
HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	55	1.13
Brush	20	65	1.86
Meadow	20	69	2.18
Rocky	20	87	3.85
Total Runoff Generated			1.73
Peak Flow at Outlet (cfs)			152

Case 1 - Pre-Logging Conditions			
HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	70	2.26
Brush	20	76	2.78
Meadow	20	79	3.06
Rocky	20	88	3.95
Total Runoff Generated			2.66
Peak Flow at Outlet (cfs)			200

Case 1 - Pre-Logging Conditions			
HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	77	2.88
Brush	20	82	3.35
Meadow	20	84	3.55
Rocky	20	89	4.06
Total Runoff Generated			3.19
Peak Flow at Outlet (cfs)			227

Case 2 - Select Cut Conditions			
HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	48	0.70
Brush	20	43	0.44
Meadow	20	49	0.76
Rocky	20	86	3.75
Total Runoff Generated			1.08
Peak Flow at Outlet (cfs)			106

Case 2 - Select Cut Conditions			
HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	67	2.01
Brush	20	65	1.86
Meadow	20	69	2.18
Rocky	20	87	3.85
Total Runoff Generated			2.26
Peak Flow at Outlet (cfs)			161

Case 2 - Select Cut Conditions			
HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	77	2.88
Brush	20	76	2.78
Meadow	20	79	3.06
Rocky	20	88	3.95
Total Runoff Generated			3.03
Peak Flow at Outlet (cfs)			208

Case 2 - Select Cut Conditions			
HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	83	3.45
Brush	20	82	3.35
Meadow	20	84	3.55
Rocky	20	89	4.06
Total Runoff Generated			3.53
Peak Flow at Outlet (cfs)			232

Case 3 - Clear Cut Conditions			
HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	68	2.10
Brush	20	43	0.44
Meadow	20	49	0.76
Rocky	20	86	3.75
Total Runoff Generated			1.92
Peak Flow at Outlet (cfs)			117

Case 3 - Clear Cut Conditions			
HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	79	3.06
Brush	20	65	1.86
Meadow	20	69	2.18
Rocky	20	87	3.85
Total Runoff Generated			2.89
Peak Flow at Outlet (cfs)			174

Case 3 - Clear Cut Conditions			
HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	86	3.75
Brush	20	76	2.78
Meadow	20	79	3.06
Rocky	20	88	3.95
Total Runoff Generated			3.56
Peak Flow at Outlet (cfs)			215

Case 3 - Clear Cut Conditions			
HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	89	4.06
Brush	20	82	3.35
Meadow	20	84	3.55
Rocky	20	89	4.06
Total Runoff Generated			3.90
Peak Flow at Outlet (cfs)			237

Table K
TR-55 Analysis

Summary of Runoff Increases From a 100-Year Storm for Different Environmental Conditions and Soil Types

Case 1 - Pre-Logging Conditions HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	40	0.41
Brush	20	43	0.57
Meadow	20	49	0.93
Rocky	20	86	4.12
Total Runoff Generated			1.00
Peak Flow at Outlet (cfs)			119

Case 1 - Pre-Logging Conditions HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	55	1.35
Brush	20	65	2.14
Meadow	20	69	2.48
Rocky	20	87	4.23
Total Runoff Generated			1.99
Peak Flow at Outlet (cfs)			172

Case 1 - Pre-Logging Conditions HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	70	2.57
Brush	20	76	3.12
Meadow	20	79	3.41
Rocky	20	88	4.34
Total Runoff Generated			2.99
Peak Flow at Outlet (cfs)			223

Case 1 - Pre-Logging Conditions HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	77	3.22
Brush	20	82	3.71
Meadow	20	84	3.92
Rocky	20	89	4.45
Total Runoff Generated			3.54
Peak Flow at Outlet (cfs)			251

Case 2 - Select Cut Conditions HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	48	0.87
Brush	20	43	0.57
Meadow	20	49	0.93
Rocky	20	86	4.12
Total Runoff Generated			1.27
Peak Flow at Outlet (cfs)			120

Case 2 - Select Cut Conditions HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	67	2.31
Brush	20	65	2.14
Meadow	20	69	2.48
Rocky	20	87	4.23
Total Runoff Generated			2.57
Peak Flow at Outlet (cfs)			182

Case 2 - Select Cut Conditions HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	77	3.22
Brush	20	76	3.12
Meadow	20	79	3.41
Rocky	20	88	4.34
Total Runoff Generated			3.38
Peak Flow at Outlet (cfs)			231

Case 2 - Select Cut Conditions HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	83	3.81
Brush	20	82	3.71
Meadow	20	84	3.92
Rocky	20	89	4.45
Total Runoff Generated			3.90
Peak Flow at Outlet (cfs)			256

Case 3 - Clear Cut Conditions HSG - A			
Subarea	Acres	CN	Runoff
Woods	90	68	2.39
Brush	20	43	0.57
Meadow	20	49	0.93
Rocky	20	86	4.12
Total Runoff Generated			2.18
Peak Flow at Outlet (cfs)			132

Case 3 - Clear Cut Conditions HSG - B			
Subarea	Acres	CN	Runoff
Woods	90	79	3.41
Brush	20	65	2.14
Meadow	20	69	2.48
Rocky	20	87	4.23
Total Runoff Generated			3.23
Peak Flow at Outlet (cfs)			196

Case 3 - Clear Cut Conditions HSG - C			
Subarea	Acres	CN	Runoff
Woods	90	86	4.12
Brush	20	76	3.12
Meadow	20	79	3.41
Rocky	20	88	4.34
Total Runoff Generated			3.92
Peak Flow at Outlet (cfs)			238

Case 3 - Clear Cut Conditions HSG - D			
Subarea	Acres	CN	Runoff
Woods	90	89	4.45
Brush	20	82	3.71
Meadow	20	84	3.92
Rocky	20	89	4.45
Total Runoff Generated			4.28
Peak Flow at Outlet (cfs)			261

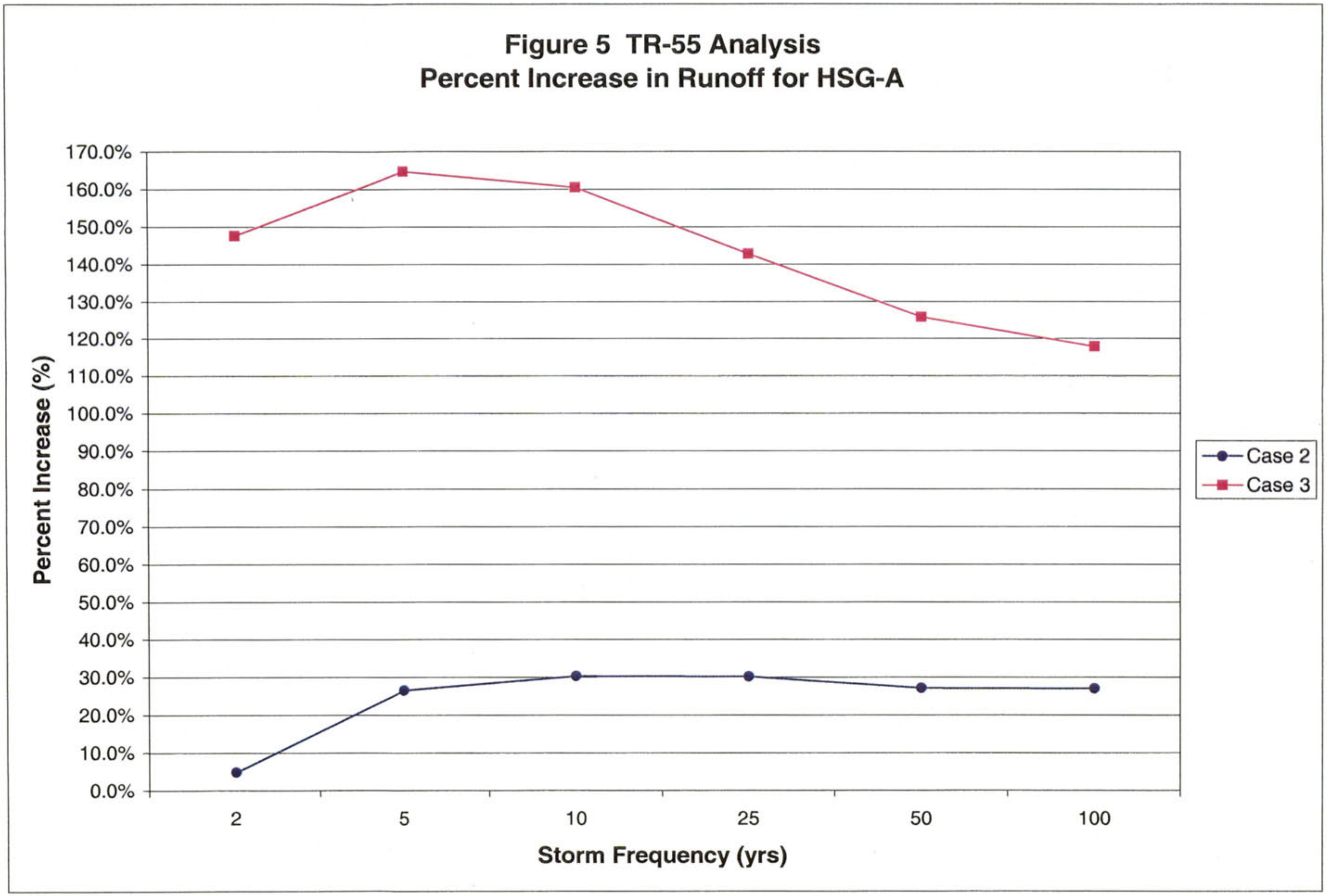


Figure 5 TR-55 Analysis
Percent Increase in Runoff for HSG-A
170.0%
160.0%
150.0%
140.0%
130.0%
120.0%
110.0%
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Percent Increase (%)
2
5
10
25
50
100
Storm Frequency (yrs)
Case 2
Case 3

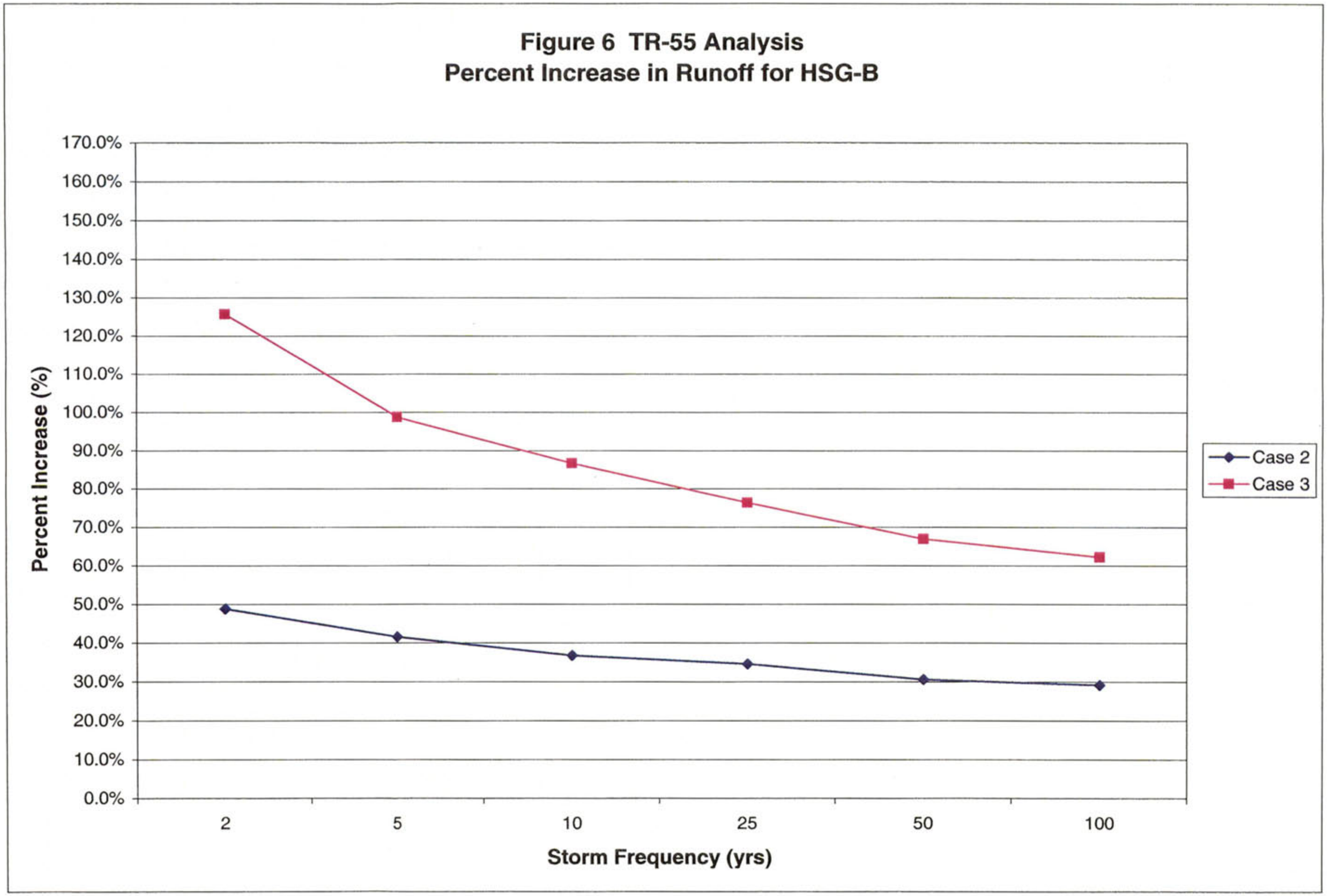


Figure 6 TR-55 Analysis
Percent Increase in Runoff for HSG-B
Percent Increase (%)
170.0%
160.0%
150.0%
140.0%
130.0%
120.0%
110.0%
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
2
5
10
25
50
100
Storm Frequency (yrs)
Case 2
Case 3

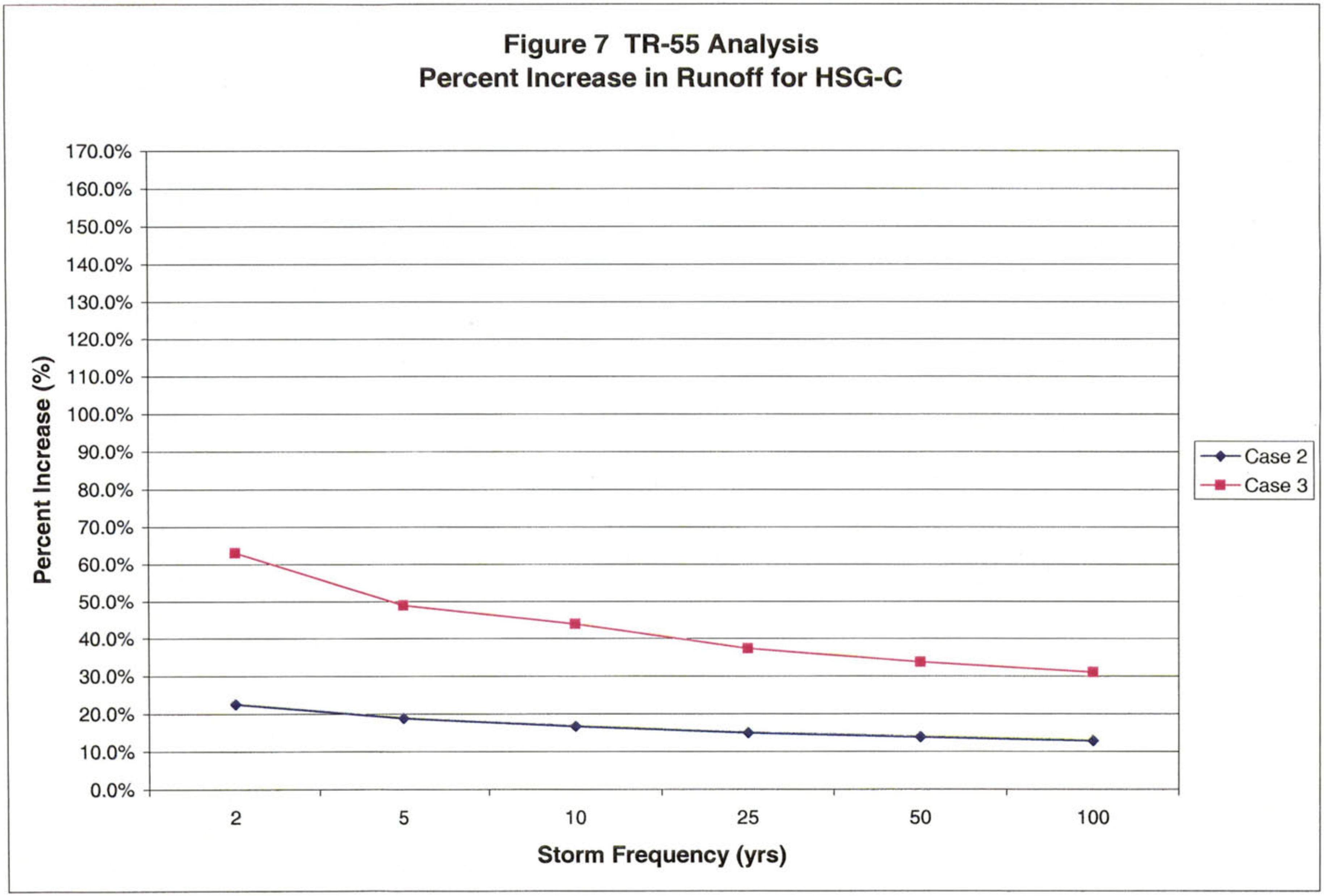


Figure 7 TR-55 Analysis
Percent Increase in Runoff for HSG-C
Percent Increase (%)
170.0%
160.0%
150.0%
140.0%
130.0%
120.0%
110.0%
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
2
5
10
25
50
100
Storm Frequency (yrs)
Case 2
Case 3

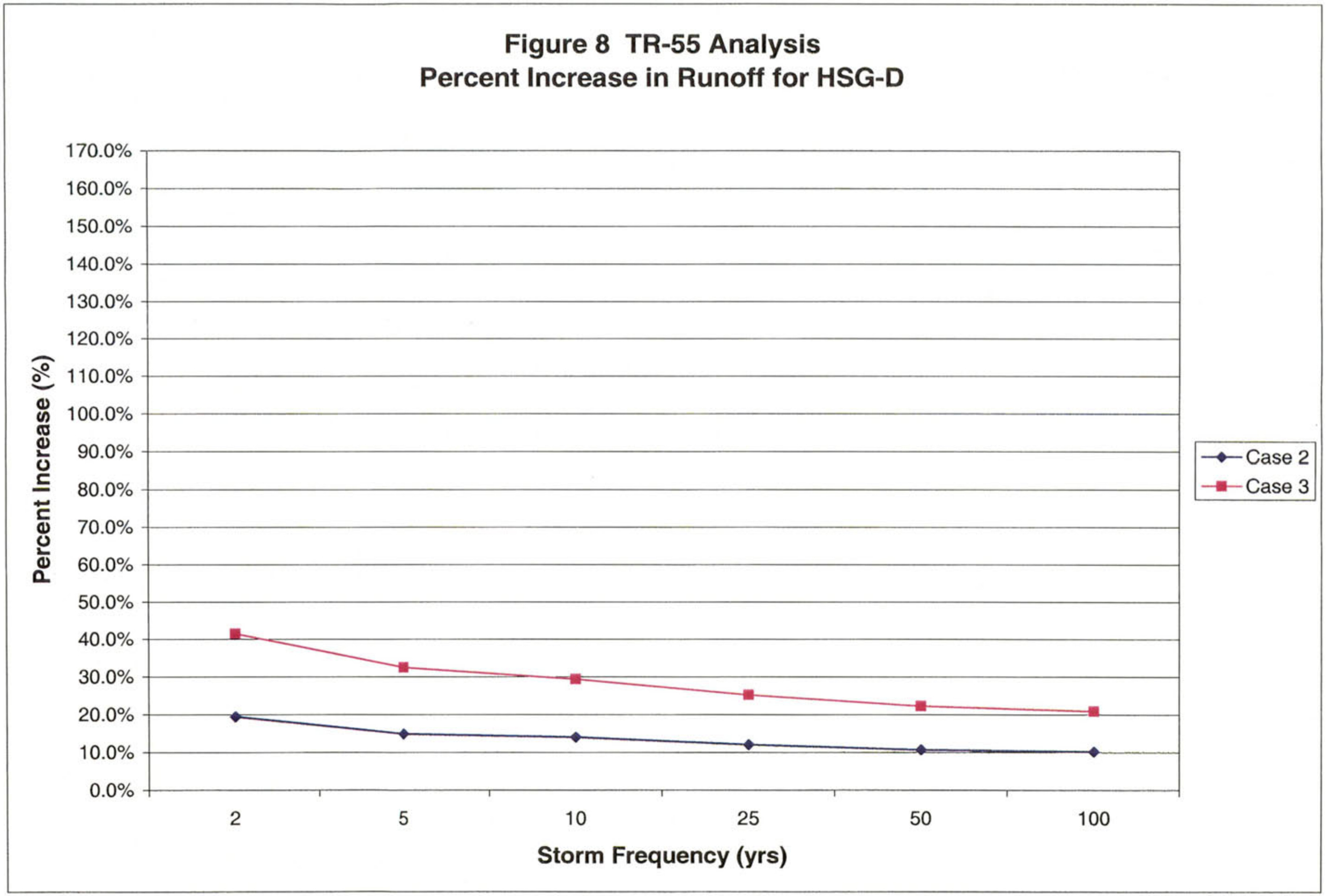


Figure 8 TR-55 Analysis
Percent Increase in Runoff for HSG-D
170.0%
160.0%
150.0%
140.0%
130.0%
120.0%
110.0%
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Percent Increase (%)
2
5
10
25
50
100
Storm Frequency (yrs)
Case 2
Case 3

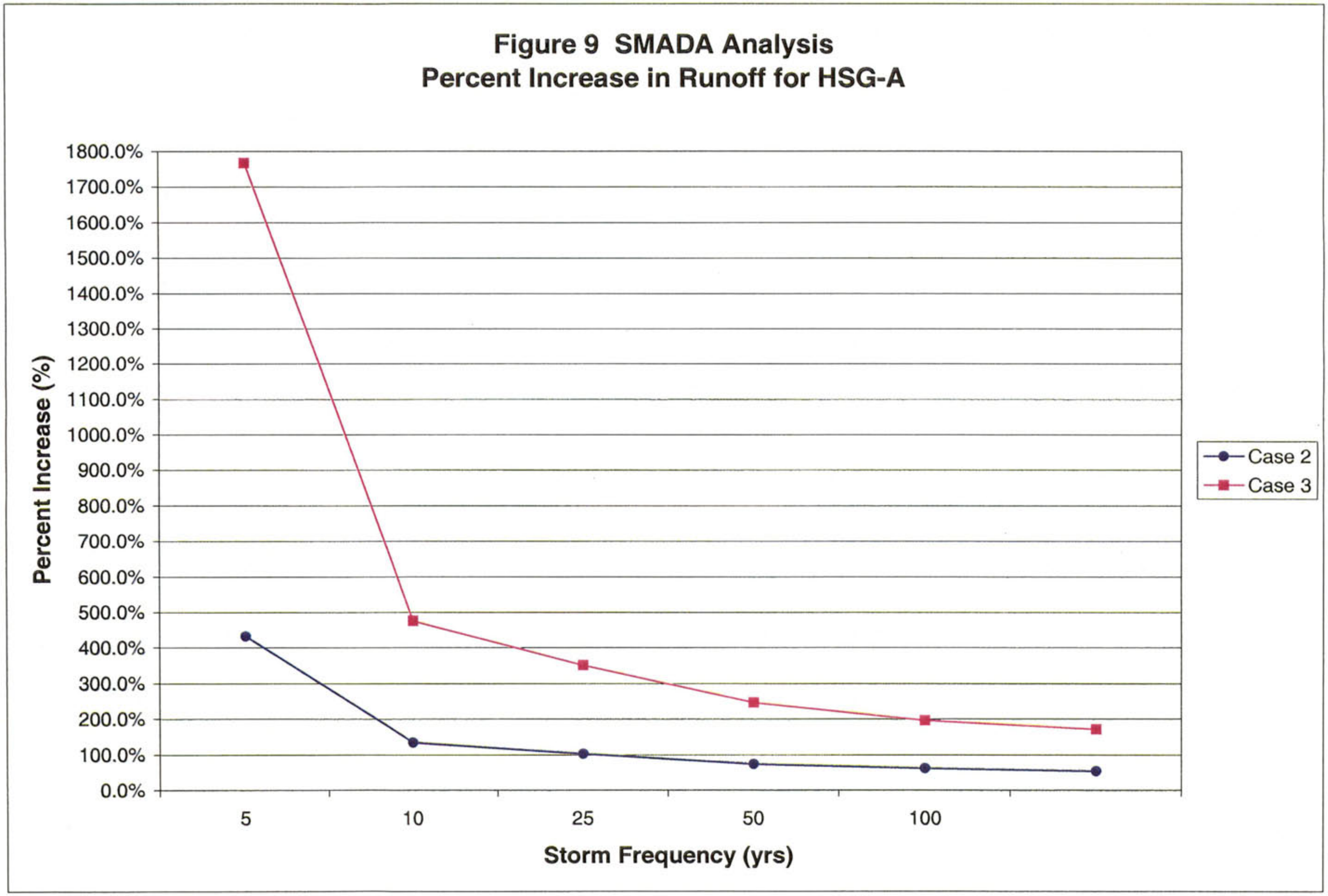


Figure 9 SMADA Analysis
Percent Increase in Runoff for HSG-A
1800.0%
1700.0%
1600.0%
1500.0%
1400.0%
1300.0%
1200.0%
1100.0%
1000.0%
900.0%
800.0%
700.0%
600.0%
500.0%
400.0%
300.0%
200.0%
100.0%
0.0%
Percent Increase (%)
5
10
25
50
100
Storm Frequency (yrs)
Case 2
Case 3

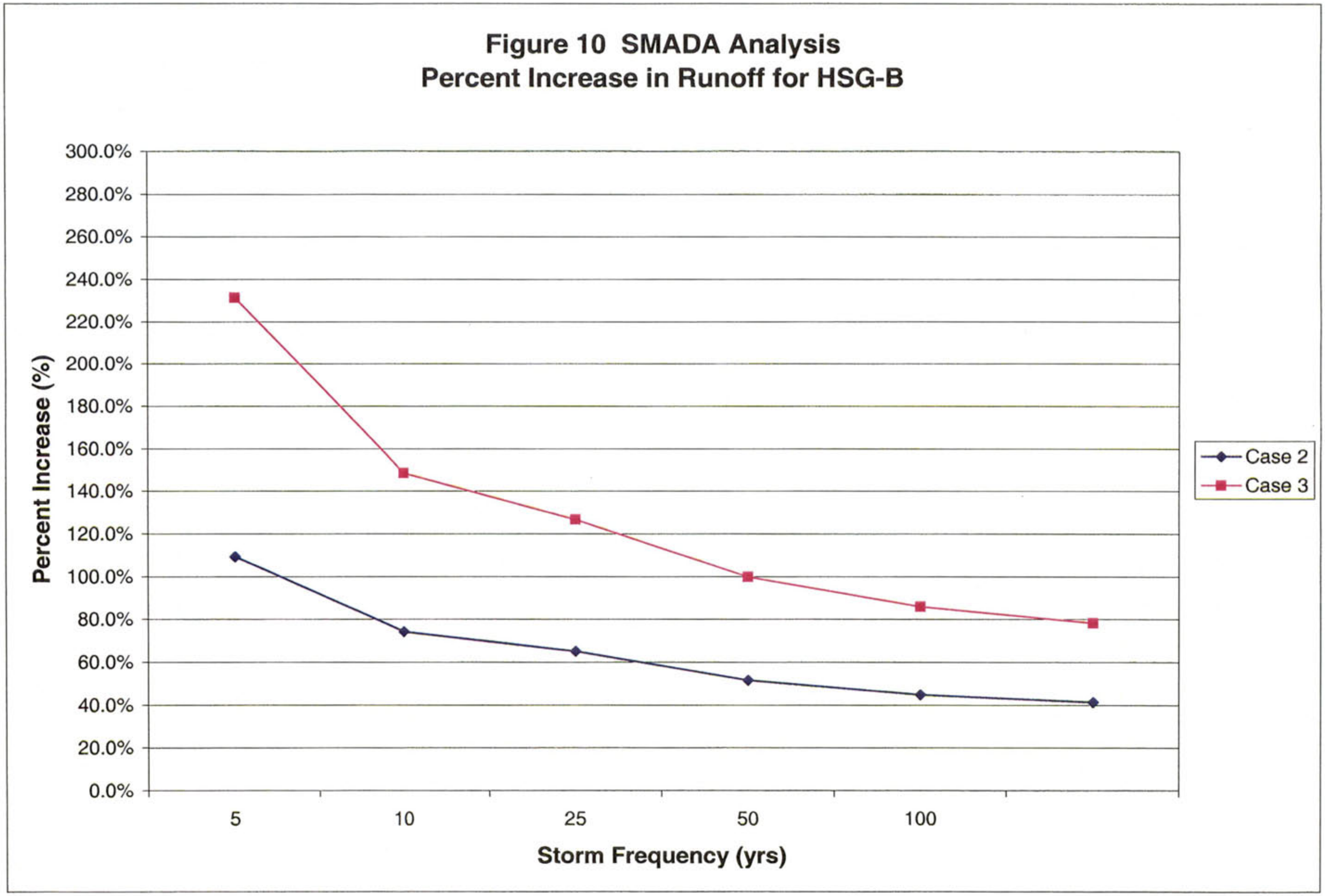


Figure 10 SMADA Analysis
Percent Increase in Runoff for HSG-B
300.0%
280.0%
260.0%
240.0%
220.0%
200.0%
180.0%
160.0%
140.0%
120.0%
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
Percent Increase (%)
5
10
25
50
100
Storm Frequency (yrs)
Case 2
Case 3

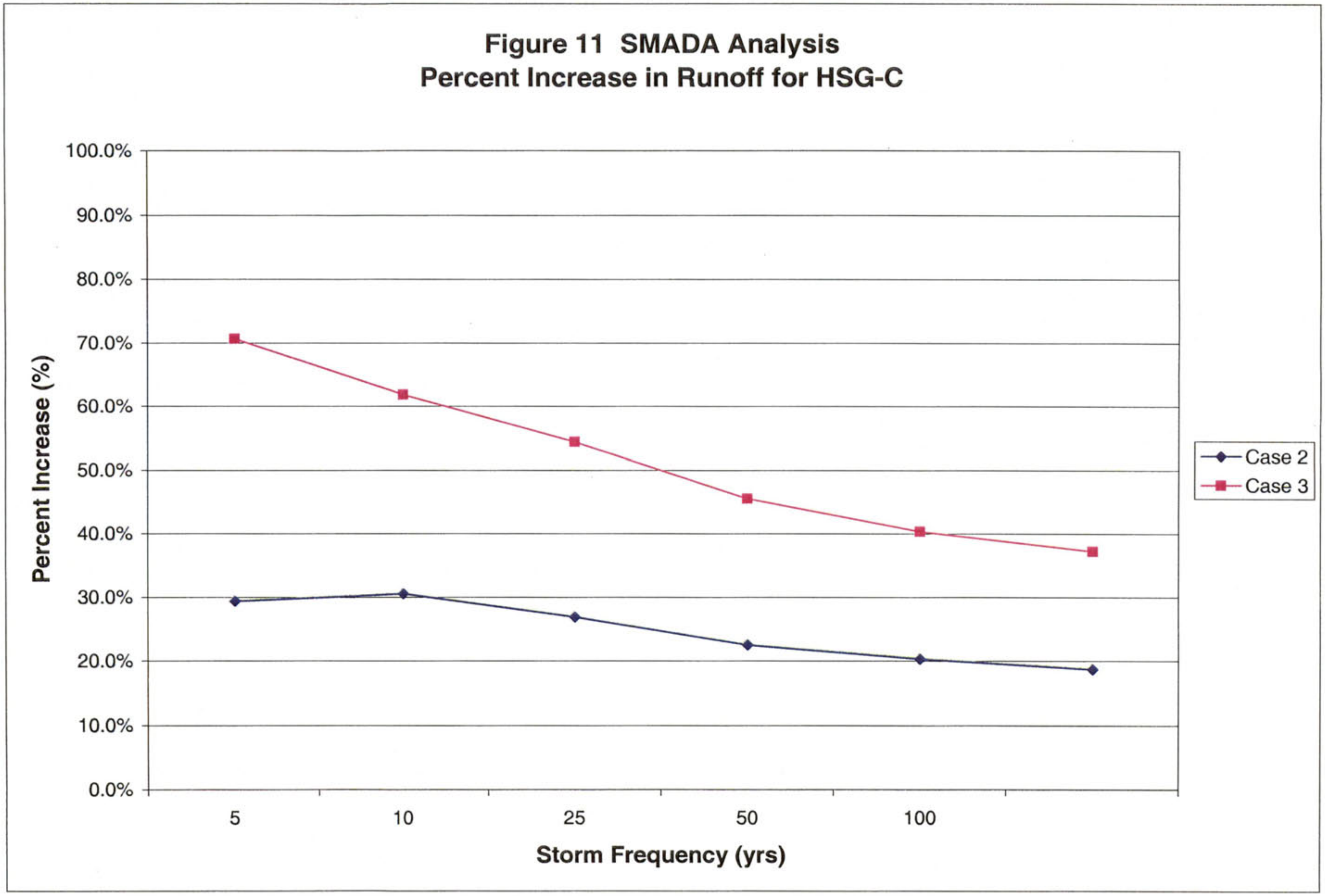


Figure 11 SMADA Analysis
Percent Increase in Runoff for HSG-C
100.0%
90.0%
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Percent Increase (%)
5
10
25
50
100
Storm Frequency (yrs)
Case 2
Case 3

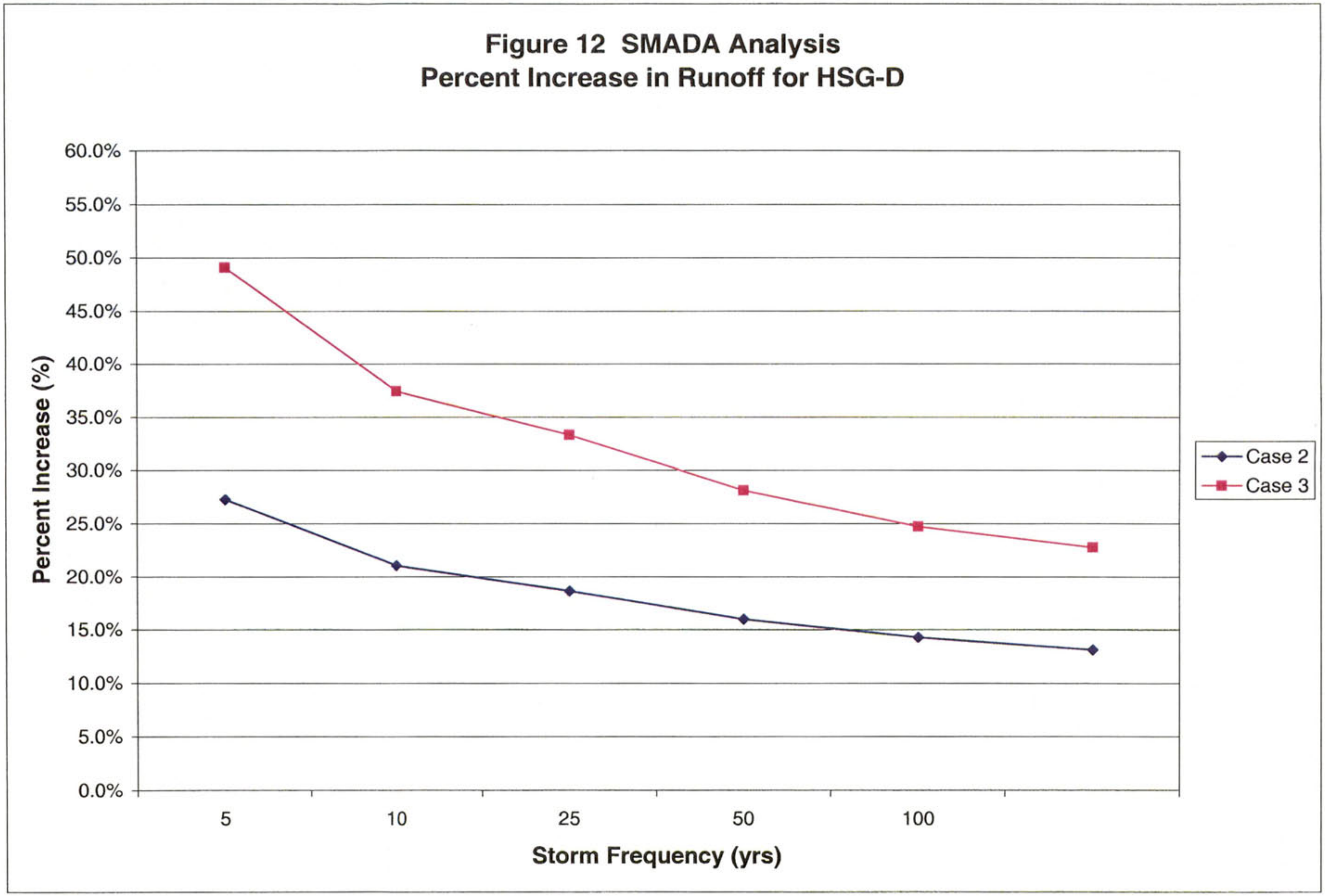


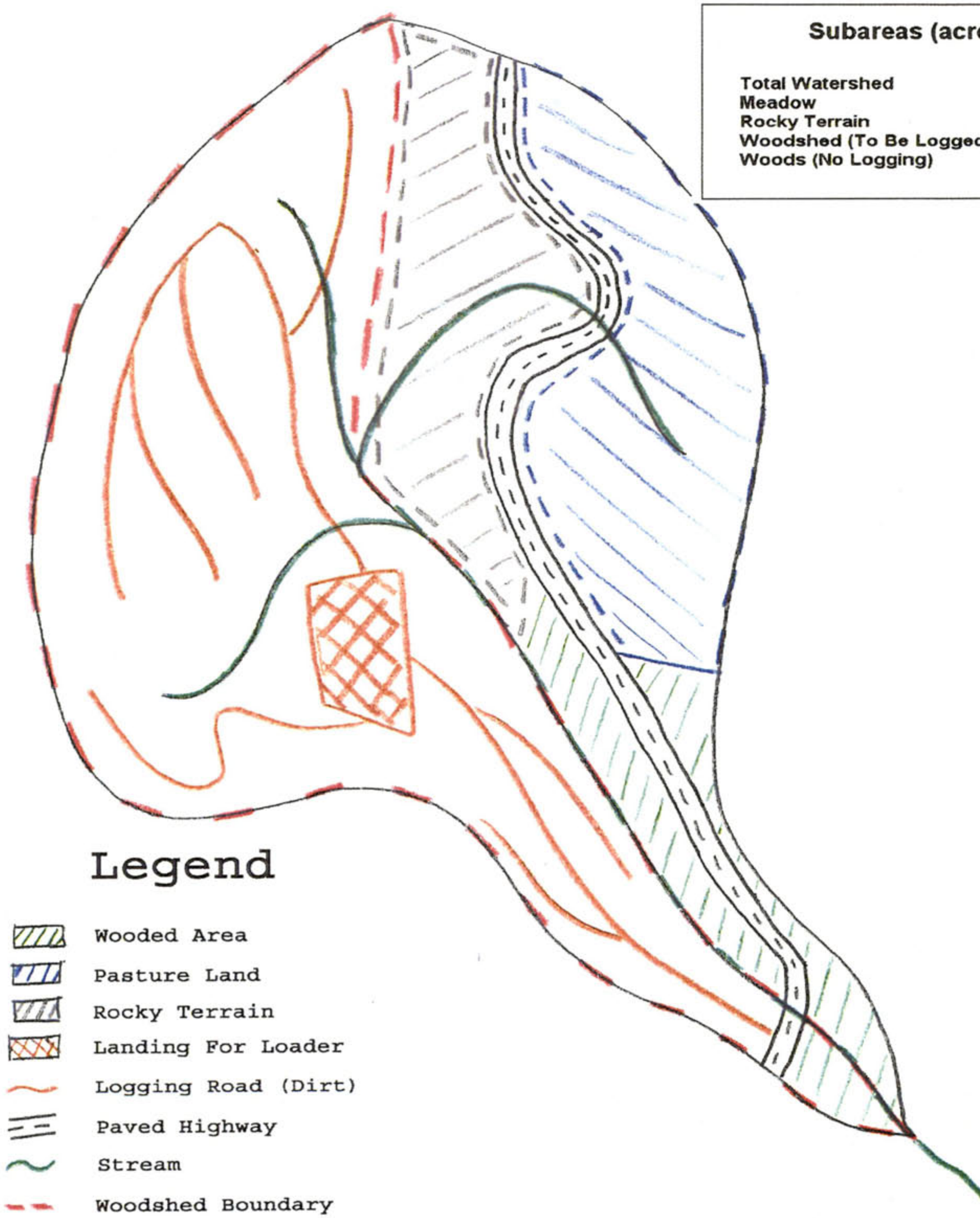
Figure 12 SMADA Analysis
Percent Increase in Runoff for HSG-D
60.0%
55.0%
50.0%
45.0%
40.0%
35.0%
30.0%
25.0%
20.0%
15.0%
10.0%
5.0%
0.0%
Percent Increase (%)
5
10
25
50
100
Storm Frequency (yrs)
Case 2
Case 3

Appendix B

Sketch of Watershed

Subareas (acres)

Total Watershed	150
Meadow	20
Rocky Terrain	20
Woodshed (To Be Logged)	90
Woods (No Logging)	20



Appendix C

TR-55 Storm Intensity Maps

Figure B-3 2-year, 24-hr rainfall

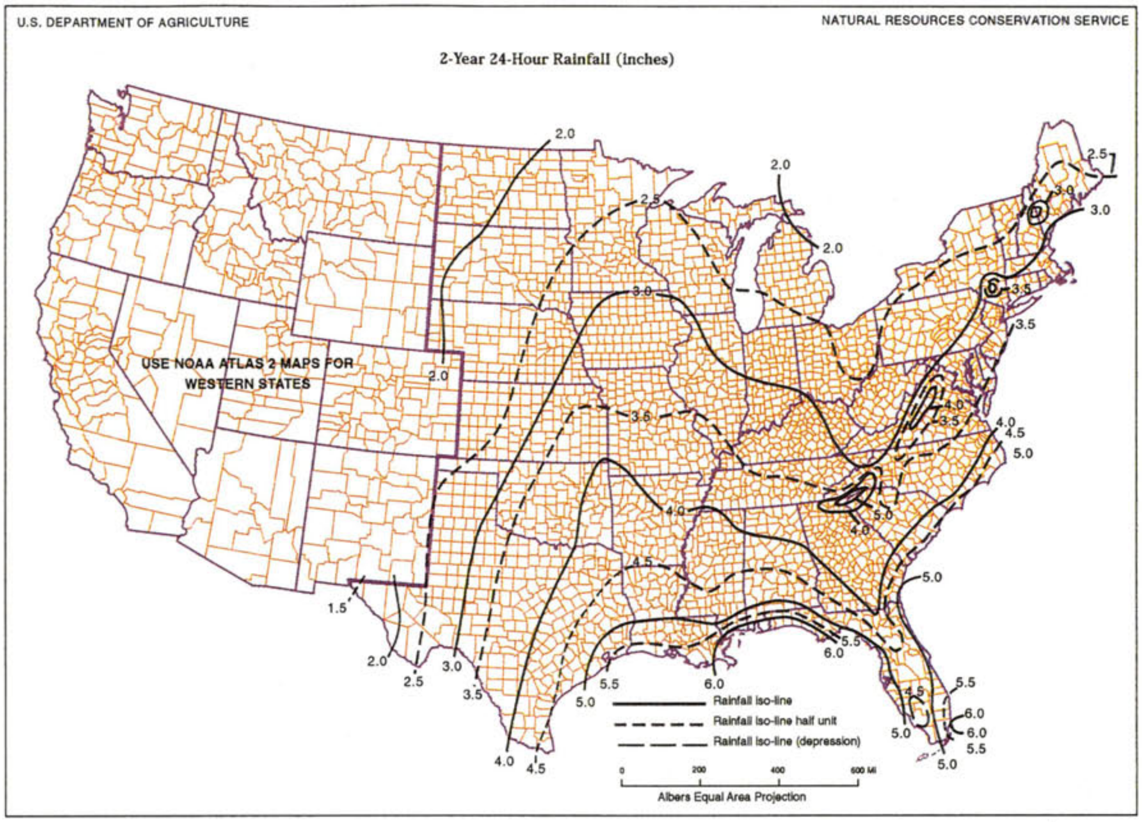


Figure B-4 5-year, 24-hour rainfall

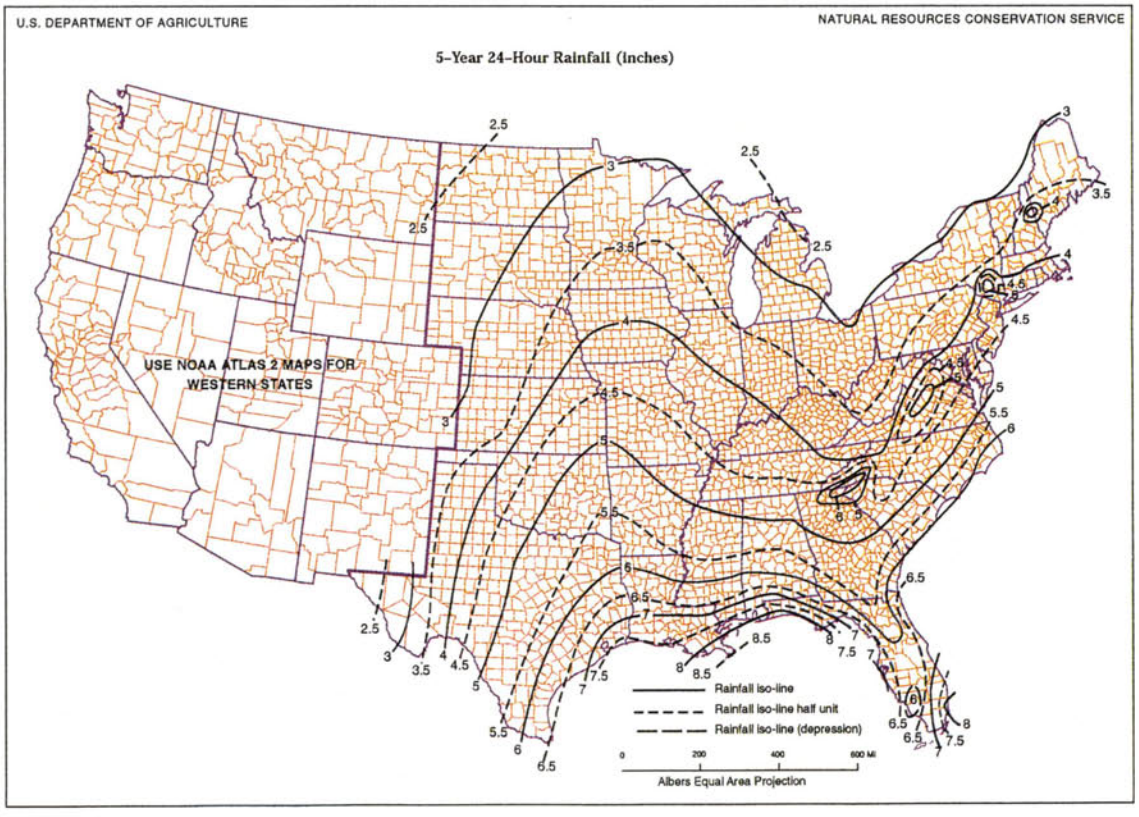


Figure B-5 10-year, 24-hour rainfall

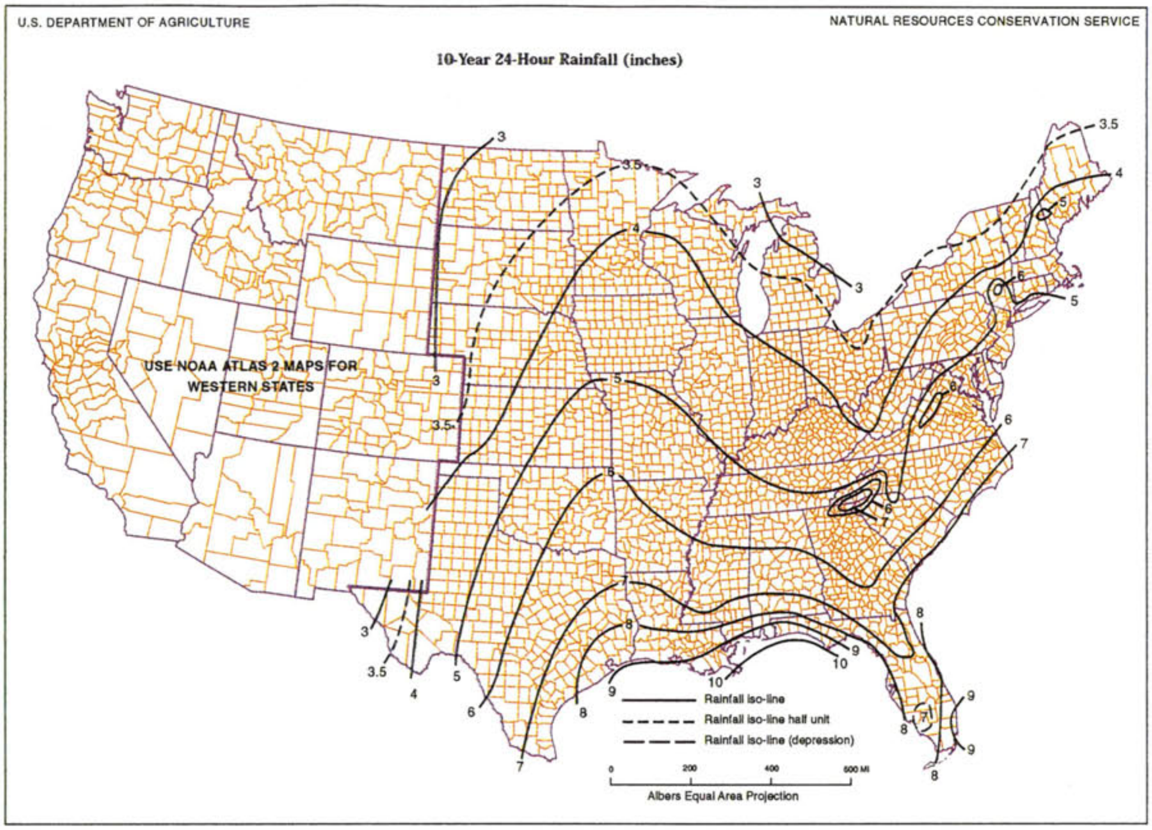


Figure B-6 25-year, 24-hour rainfall

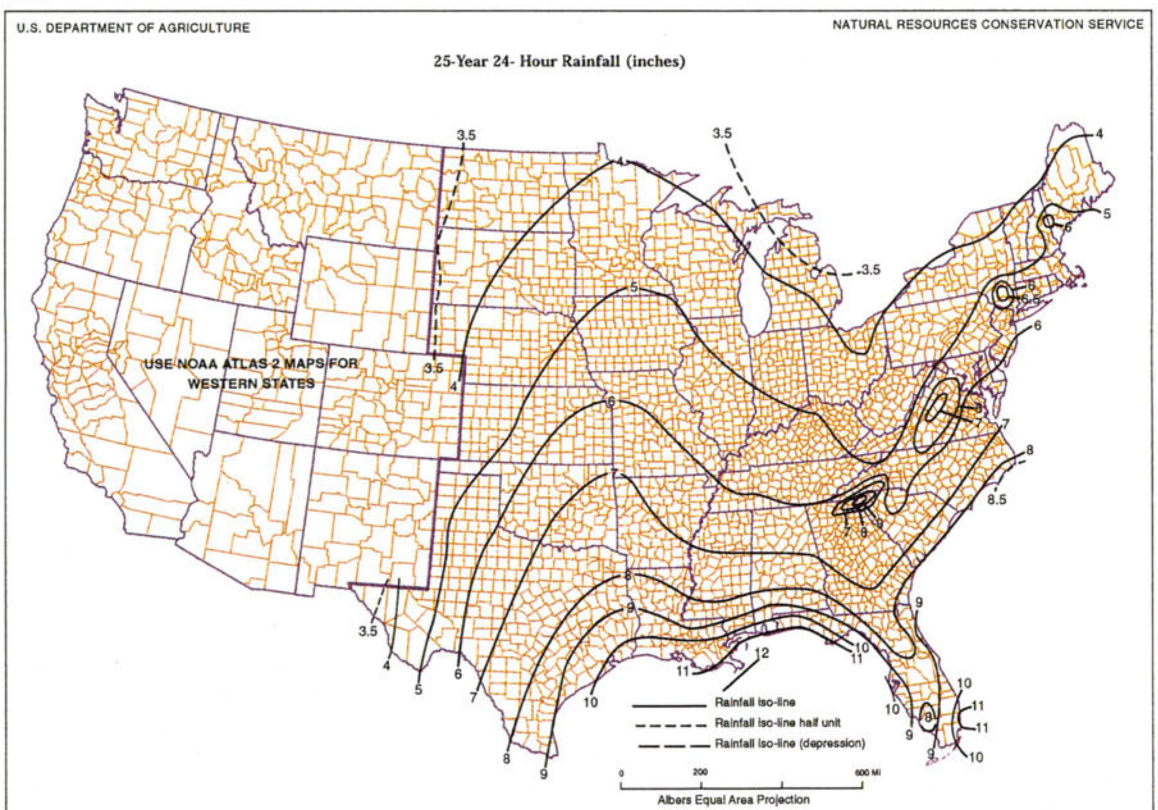


Figure B-7 50-year, 24-hour rainfall

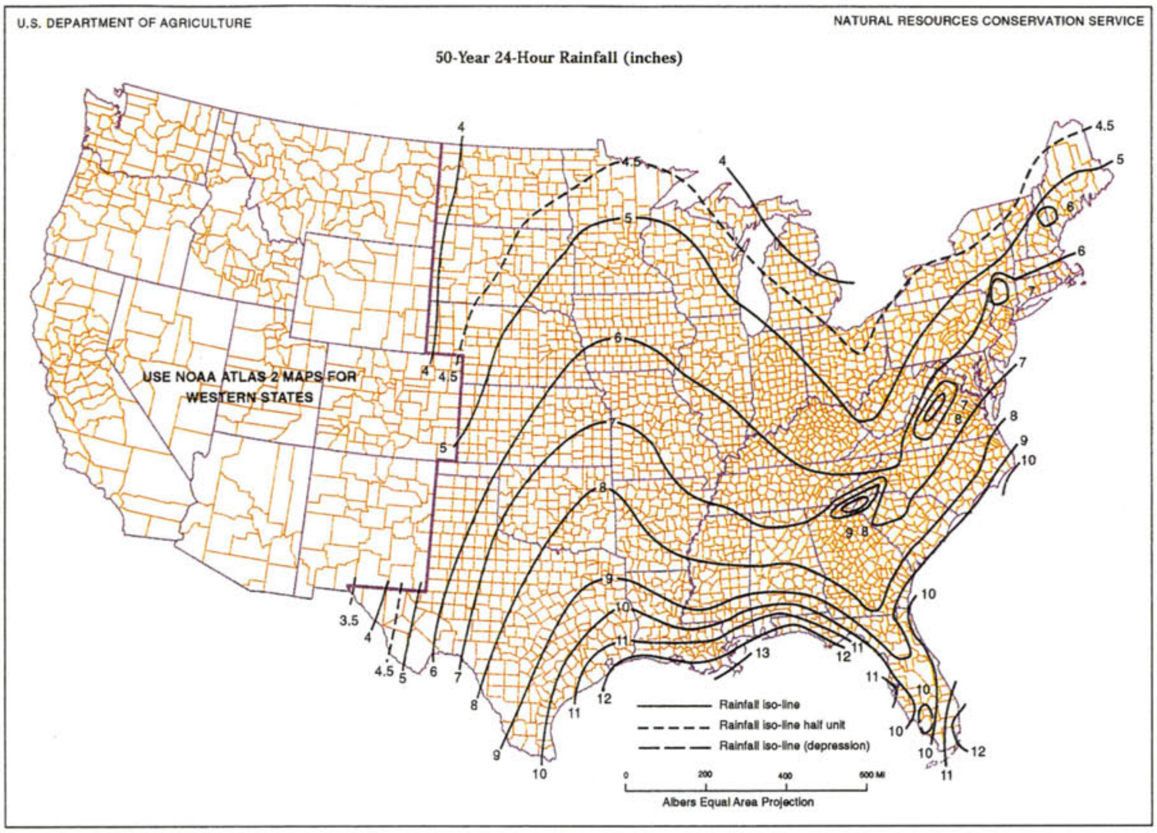
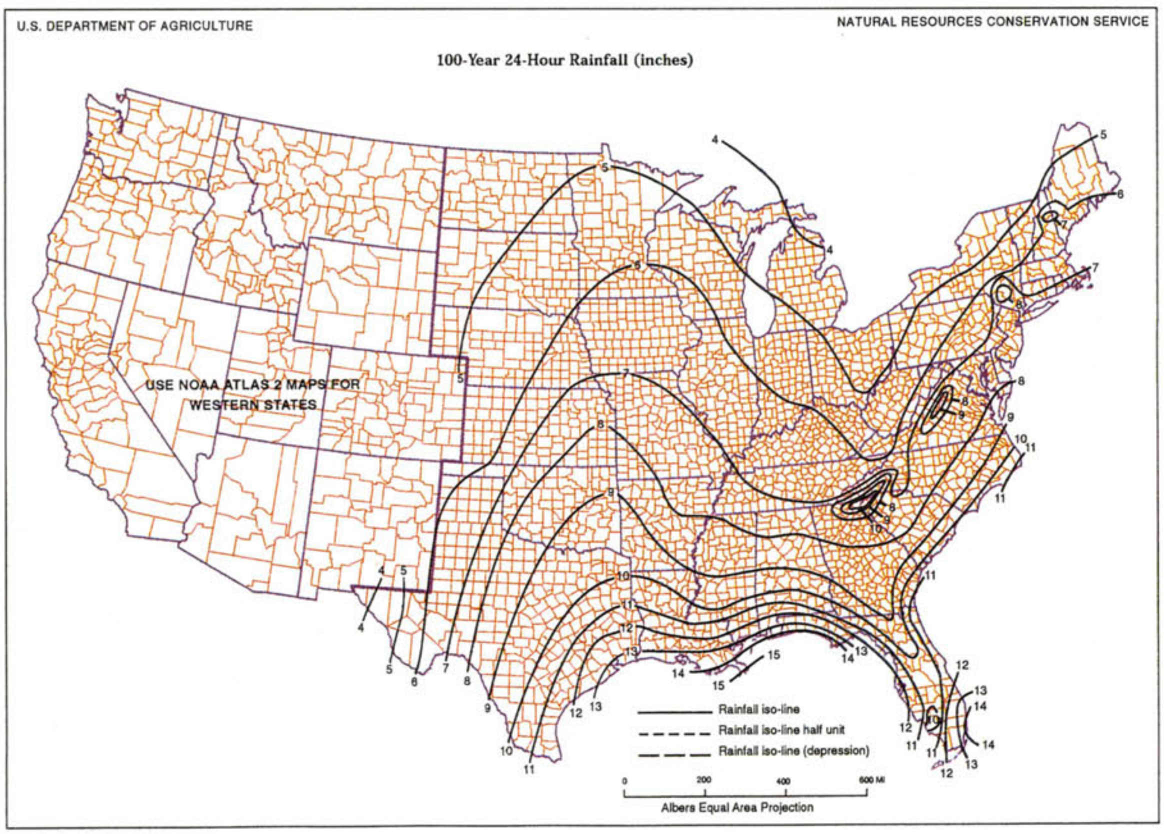


Figure B-8 100-year, 24-hour rainfall



Appendix D

Virginia Department of Forestry Literature

Water Quality

BMP Guide

Rain Gardens

Riparian Forest Buffers

Watershed Management

Wetland Values

Water Quality Law, Chapter 11, 10.1-1181.1

Water Quality Monitoring

Fairfax Water Quality Guide

Watershed Management

The key to maintaining good forest watershed conditions lies in proper management of the forest floor. Even when disturbed, forest litter effectively reduces soil movement and excessive surface runoff. With time, more water will soak into the soil as organic matter blends into the surface soil. Of course, the forest floor must be protected from additional disturbances to accomplish these improvements.

Timber harvesting at periodic intervals, using systems compatible with site, soil, slope and stream characteristics, permits timber production and watershed protection to continue in harmony. Logging truck roads and skid trails are among the leading contributors to watershed deterioration. Skidding can cause deep ruts and seriously compact the soils. Skid trails should be designated and "logger choice" skidding should not be allowed.

Pre-Harvest Plan
Advance planning of the logging operation can prevent much of this erosion. Roads should be located on ridges, not in or near stream beds. Locate roads just to one side of the ridge line to improve drainage. When roads traverse the hillside, they should follow the contour and roll with the grade to avoid excessive cut and fillslopes. Road grades of 3 to 5 percent are desirable; however, sustained grades of 6 to 8 percent are acceptable when following Best Management Practices. An occasional short pitch of up to 15 percent can be tolerated if proper road drainage is built into the road, to avoid erosion.

Use dips frequently to break long grades. Construct cross-drains as needed and out slope road beds. Locate the roads far enough from water courses to provide an effective forested filter strip, 50 feet minimum. Keep trucks, tractors, skidders, and logs away from drainage channels. When logging is over, smooth out ruts and holes to prevent channeling runoff, install cross-drains and clean culverts (if used), and cultivate or rip and seed the abandoned roads with grass/legume seed mixture, including some preferred by wildlife species.

Skidding should be uphill on designated skid trails. Winching logs to this trail will minimize the number of skid trails, lower restoration costs and restrict land area that will be subject to reduced growth potential. Roadway and culvert drainage should be dispersed and slowed to retard runoff and encourage vegetation/forest floor filtering. Stabilize the streambank or channel by planting trees and fostering a vigorous, healthy timber stand.

Recommended distance between water bars on skid roads and truck roads.
Grade Distance between Waterbars
percent - feet
2 - - - 250
5 - - - 135
10 - - - 80
15 - - - 60
20 - - - 45
25 - - - 40
30 - - - 35
40 - - - 30

For many years timber harvesting was associated with the deterioration of forestland and streams. Research and experience have shown that the mere cutting of trees is not the cause of erosion damage in the forest.

Forest Roads and Trails
It is important to plan road systems that can provide permanent and efficient access throughout the woodland without damaging the watershed value of the forest.

The following checklist can control erosion on roads:
1. Avoid logging during wet seasons or periods.
2. Keep skid trails on grades of less than 15%.
3. Keep roads on slopes less than 10%.
4. Use approved stream crossings, bridges and/or culverts.
5. Do not leave slash or tops in streams.
6. Provide for proper drainage of skid trails and roads:
a. Outslope roads where feasible
b. Vary the grade
c. Use waterbars or dips, culverts, drainage dips, and diversions.
d. Divert water into protected areas.
e. Create sediment traps below water bars or dips outlets.
7. Gravel roads where needed.
8. Seed roads, skid trails and log decks.

Maintenance
To prevent four-wheel drive vehicle traffic during wet weather, access to roads and trails needs to be controlled by gates or other methods.

Areas used as logging decks make excellent wildlife patches. The problem with these areas are soil compaction and pH (the measure of the acidity or alkalinity of the soil). All forested areas which are cleared should be limed and fertilized. The amount of lime and fertilizer needed can be determined by a soil test. You may want to consider developing some of these decks into small orchards for wildlife.

Logging and farm roads should be maintained for proper access and erosion control. Where these roads pass through recently harvested areas you may wish to widen the path to ten to twenty feet on each side.

These areas can be seeded with lespedeza or other wildlife food and periodically mowed or disced for maintenance. Every 400 to 500 feet you may wish to leave the natural vegetation. This will create strips which wildlife are more likely to utilize.

Fire lines which were constructed may be kept open by mowing every other year. If mowed, please follow the instructions in the wildlife section included with your management plan. If desired these areas may be disced and seeded with something which will be beneficial to wildlife, such as lespedeza, clover or small grain. These paths will also provide access, as walking paths, for yourself and other visitors to the property.

Wetland Values

Wetlands are found all across the state. Wetlands include marshes, bogs, and swamps, and may include other areas which are only flooded or saturated for fairly short periods of time. Nontidal wetlands are identified on the ground by the presence of wetland hydrology, wetland soils, and wetland vegetation. Many of these wetlands are forested.

Flood Control Flood water flows naturally into stream and river channels as it drains off the land. When surface water moves through wetlands adjacent to water courses, flood flows are temporarily retained by dense stands of vegetation in wetlands and slowly released downstream.

Water Supply
Wetlands may also provide a domestic or commercial supply of water. Flood waters may flow from wetland into a ground water aquifer and recharge it. For example, a five-square-mile bog in Wisconsin controls the groundwater supply for a 165- square-mile area.

Sediment and Erosion Control
Wetlands also help maintain water quality by controlling erosion and sedimentation. Vegetative cover over the soil will absorb most of the shock from the impact of the water, so it is less likely to loosen soil. Sediment carried by runoff will tend to be trapped in wetlands and held by ground vegetation. In shallow waters, submerged aquatic vegetation acts as a filter, as sediment clings to plants instead of floating in the water. Aquatic plants also reduce water velocity, so additional sediment tends to sink to the bottom instead of floating freely. Shoreline vegetation decreases the force of wave action and reduces erosion in tidal areas. **Nutrient Retention and Removal**
Wetlands also function to remove nutrients such as nitrogen and phosphorus from the environment. The nutrients are absorbed by wetland plants for their own growth so they become less available for algae. Otherwise, algae blooms in open water may dominate the system so that little oxygen is available for other aquatic life. It is important to remember that wetlands are efficient nutrient removers to a certain point. The algae blooms in the Chesapeake Bay result from nutrient overload to the system to such an extent that wetlands and aquatic plants cannot remove all of them.

Pollution Control
Wetlands are useful for filtering pollutants and treating sewage. Heavy metals are accumulated in wetland soils rather than plants or water which may be consumed by humans or wildlife.

Riparian Forest

Wildlife Values
Wooded buffer zones along streams, rivers, and the Bay can be classified as riparian forests. Riparian forests differ from upland forests in their hydrology, plant community, soils, and topography. These features determine the potential abundance of animal populations.

The riparian forest supports a greater diversity of wildlife than nearly all non-aquatic areas or upland forests. The reason for this is because of the numerous habitat features found in these areas. Forested riparian corridors function as connectors between isolated blocks of forested habitat. Riparian forests are often surrounded by low-quality wildlife habitats and therefore support higher densities and diversities of migratory birds. In agricultural areas where extensive forests are not present, riparian forests provide critical habitat and may be the only edge cover available.

Trees and shrubs are required for roosting or foraging by most riparian birds. Mammals depend on the vegetation for food and shelter. The increased humidity of riparian forests makes them important habitat for amphibians, snakes, and turtles. Snags are used as den sites by cavity nesters. Root systems of woody vegetation not only help stabilize banks, but supply cover for fish and aquatic insects. Forest litter is the basis of food in the stream ecosystem, being utilized by insects that are in turn prey for fish.

Water Quality
Recent studies have shown that riparian forests as narrow as 50 feet in width can completely remove excess nitrogen as it moves from farm fields through the forests to the adjacent stream. These forested areas also filter sediments and phosphorus, thereby acting as buffers to nutrient inputs to streams. Nutrient retention by a 100-foot forest adjacent to agricultural land is estimated at 80% for phosphorus and 89% for nitrogen. The retention varies depending on width of forest, slope, and other factors.

Tree roots help stabilize streambanks by holding soil in place. Riparian forests also lower flow velocities, causing sediment to settle out. The most important role of the riparian forest is the uptake and long-term storage of nutrients in its woody material.

A major concern to the aquatic environment is the increased nutrients entering a watercourse during and after a harvest operation. Nitrate-Nitrogen is the most common nutrient increased in the stream directly following a harvest; however, the slight increase will again convert to its geological rate in three years. As with sediment, leaving a buffer of 50 feet plus 4 feet for every 1% increase in slope will alleviate a nutrient problem.

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Appendix E

Sample Outputs from TR-55 and SMADA

Project : CE 395 Term Paper User: PEB Date:
unty : Buchanan State: VA Checked: ____ Date: ________
Subtitle: Excess Surface Runoff Generated From Logging in Small Watersheds

Total watershed area: 0.328 sq mi Rainfall type: II Frequency: 2 years

	Subareas			
	Woods	Brush	Meadow	Rocky
Area(sq mi)	0.14	0.03	0.03	0.13
Rainfall(in)	2.8	2.8	2.8	2.8
Curve number	40	43	49	86
Runoff(in)	0.00	0.00	0.05	1.49
Tc (hrs)	1.14	0.06	0.28	0.07
(Used)	1.25	0.10	0.30	0.10
TimeToOutlet	0.00	0.00	0.21	0.16
(Used)	0.00	0.00	0.20	0.10
Ia/P	1.07	0.95	0.74	0.12
(Used)	0.50	0.50	0.50	0.12

Time (hr)	Total Flow	Subarea Contribution to Total Flow (cfs) Woods	Brush	Meadow	Rocky
11.0	4	0P	0P	0P	4
11.3	5	0	0	0	5
11.6	7	0	0	0	7
11.9	23	0	0	0	23
12.0	47	0	0	0	47
12.1	95	0	0	0	95
.2	157P	0	0	0	157P
12.3	129	0	0	0	129
12.4	70	0	0	0	70
12.5	42	0	0	0	42
12.6	30	0	0	0	30
12.7	23	0	0	0	23
12.8	19	0	0	0	19
13.0	14	0	0	0	14
13.2	12	0	0	0	12
13.4	11	0	0	0	11
13.6	10	0	0	0	10
13.8	9	0	0	0	9
14.0	8	0	0	0	8
14.3	7	0	0	0	7
14.6	6	0	0	0	6
15.0	6	0	0	0	6
15.5	5	0	0	0	5
16.0	5	0	0	0	5
16.5	4	0	0	0	4
17.0	4	0	0	0	4
17.5	4	0	0	0	4
18.0	4	0	0	0	4
.0	3	0	0	0	3
20.0	3	0	0	0	3
22.0	2	0	0	0	2
26.0	0	0	0	0	0

TABULAR HYDROGRAPH METHOD Version 2.00

Project : CE 395 Term Paper User: PEB Date:
unty : Buchanan State: VA Checked: ____ Date: ________
Subtitle: Excess Surface Runoff Generated From Logging in Small Watersheds

Total watershed area: 0.235 sq mi Rainfall type: II Frequency: 2 years

	Subareas			
	Woods	Brush	Meadow	Rocky
Area(sq mi)	0.14	0.03	0.03	0.03
Rainfall(in)	2.8	2.8	2.8	2.8
Curve number	48	43	49	86
Runoff(in)	0.03	0.00	0.05	1.49
Tc (hrs)	1.14	0.06	0.28	0.07
(Used)	1.25	0.10	0.30	0.10
TimeToOutlet	0.00	0.00	0.21	0.16
(Used)	0.00	0.00	0.20	0.10
Ia/P	0.77	0.95	0.74	0.12
(Used)	0.50	0.50	0.50	0.12

Time (hr)	Total Flow	Subarea Contribution to Total Flow (cfs) Woods	Brush	Meadow	Rocky
11.0	1	0	0P	0P	1
11.3	1	0	0	0	1
11.6	2	0	0	0	2
11.9	6	0	0	0	6
12.0	12	0	0	0	12
12.1	24	0	0	0	24
.2	39P	0	0	0	39P
12.3	32	0	0	0	32
12.4	18	0	0	0	18
12.5	10	0	0	0	10
12.6	7	0	0	0	7
12.7	6	0	0	0	6
12.8	5	0	0	0	5
13.0	5	1P	0	0	4
13.2	4	1	0	0	3
13.4	4	1	0	0	3
13.6	3	1	0	0	2
13.8	3	1	0	0	2
14.0	3	1	0	0	2
14.3	2	0	0	0	2
14.6	2	0	0	0	2
15.0	1	0	0	0	1
15.5	1	0	0	0	1
16.0	1	0	0	0	1
16.5	1	0	0	0	1
17.0	1	0	0	0	1
17.5	1	0	0	0	1
18.0	1	0	0	0	1
.0	1	0	0	0	1
20.0	1	0	0	0	1
22.0	1	0	0	0	1
26.0	0	0	0	0	0

TABULAR HYDROGRAPH METHOD Version 2.00

Project : CE 395 Term Paper User: PEB Date:
unty : Buchanan State: VA Checked: ____ Date: ________
ubtitle: Excess Surface Runoff Generated From Logging in Small Watersheds

Total watershed area: 0.235 sq mi Rainfall type: II Frequency: 2 years

	Subareas			
	Woods	Brush	Meadow	Rocky
Area(sq mi)	0.14	0.03	0.03	0.03
Rainfall(in)	2.8	2.8	2.8	2.8
Curve number	68	43	49	86
Runoff(in)	0.53	0.00	0.05	1.49
Tc (hrs)	1.14	0.06	0.28	0.07
(Used)	1.25	0.10	0.30	0.10
TimeToOutlet	0.00	0.00	0.21	0.16
(Used)	0.00	0.00	0.20	0.10
Ia/P	0.34	0.95	0.74	0.12
(Used)	0.34	0.50	0.50	0.12

Time	Total	Subarea Contribution to Total Flow (cfs)			
(hr)	Flow	Woods	Brush	Meadow	Rocky
11.0	1	0	0P	0P	1
11.3	1	0	0	0	1
11.6	2	0	0	0	2
11.9	6	0	0	0	6
12.0	12	0	0	0	12
.1	24	0	0	0	24
.2	40P	1	0	0	39P
12.3	34	2	0	0	32
12.4	21	3	0	0	18
12.5	16	6	0	0	10
12.6	15	8	0	0	7
12.7	17	11	0	0	6
12.8	19	14	0	0	5
13.0	21	17P	0	0	4
13.2	19	16	0	0	3
13.4	17	14	0	0	3
13.6	14	12	0	0	2
13.8	12	10	0	0	2
14.0	10	8	0	0	2
14.3	9	7	0	0	2
14.6	8	6	0	0	2
15.0	6	5	0	0	1
15.5	5	4	0	0	1
16.0	4	3	0	0	1
16.5	4	3	0	0	1
17.0	4	3	0	0	1
17.5	4	3	0	0	1
18.0	3	2	0	0	1
.0	3	2	0	0	1
20.0	3	2	0	0	1
22.0	3	2	0	0	1
26.0	0	0	0	0	0

Project : CE 395 Term Paper User: PEB Date:
unty : Buchanan State: VA Checked: ____ Date: ________
ubtitle: Excess Surface Runoff Generated From Logging in Small Watersheds

Total watershed area: 0.235 sq mi Rainfall type: II Frequency: 02 years

	Subareas			
	Woods	Brush	Meadow	Rocky
Area(sq mi)	0.14	0.03	0.03	0.03
Rainfall(in)	2.8	2.8	2.8	2.8
Curve number	55	65	69	87
Runoff(in)	0.14	0.42	0.57	1.57
Tc (hrs)	1.14	0.06	0.28	0.07
(Used)	1.25	0.10	0.30	0.10
TimeToOutlet	0.00	0.00	0.21	0.16
(Used)	0.00	0.00	0.20	0.10
Ia/P	0.58	0.38	0.32	0.11
(Used)	0.50	0.38	0.32	0.11

Time (hr)	Total Flow	Subarea Contribution to Total Flow (cfs) Woods	Brush	Meadow	Rocky
11.0	1	0	0	0	1
11.3	1	0	0	0	1
11.6	2	0	0	0	2
11.9	7	0	1	0	6
12.0	18	0	5	0	13
..1	36	0	10P	1	25
.2	49P	0	6	2	41P
12.3	42	0	3	5	34
12.4	28	0	2	8P	18
12.5	22	1	2	8	11
12.6	18	1	2	7	8
12.7	13	1	1	5	6
12.8	12	2	1	4	5
13.0	11	3P	1	3	4
13.2	9	3	1	2	3
13.4	9	3	1	2	3
13.6	7	3	1	1	2
13.8	6	2	1	1	2
14.0	6	2	1	1	2
14.3	6	2	1	1	2
14.6	6	2	1	1	2
15.0	4	1	1	1	1
15.5	4	1	1	1	1
16.0	4	1	1	1	1
16.5	3	1	0	1	1
17.0	3	1	0	1	1
17.5	3	1	0	1	1
18.0	3	1	0	1	1
.0	2	1	0	0	1
20.0	2	1	0	0	1
22.0	2	1	0	0	1
26.0	0	0	0	0	0

TABULAR HYDROGRAPH METHOD Version 2.00

Project : CE 395 Term Paper User: PEB Date:
unty : Buchanan State: VA Checked: ____ Date: ________
Subtitle: Excess Surface Runoff Generated From Logging in Small Watersheds

Total watershed area: 0.235 sq mi Rainfall type: II Frequency: 2 years

	Subareas			
	Woods	Brush	Meadow	Rocky
Area(sq mi)	0.14	0.03	0.03	0.03
Rainfall(in)	2.8	2.8	2.8	2.8
Curve number	67	65	69	87
Runoff(in)	0.49	0.42	0.57	1.57
Tc (hrs)	1.14	0.06	0.28	0.07
(Used)	1.25	0.10	0.30	0.10
TimeToOutlet	0.00	0.00	0.21	0.16
(Used)	0.00	0.00	0.20	0.10
Ia/P	0.35	0.38	0.32	0.11

Time	Total	Subarea Contribution to Total Flow (cfs)			
(hr)	Flow	Woods	Brush	Meadow	Rocky
11.0	1	0	0	0	1
11.3	1	0	0	0	1
11.6	2	0	0	0	2
11.9	7	0	1	0	6
12.0	18	0	5	0	13
12.1	36	0	10P	1	25
[illegible].2	49P	0	6	2	41P
[illegible].3	43	1	3	5	34
12.4	31	3	2	8P	18
12.5	26	5	2	8	11
12.6	24	7	2	7	8
12.7	22	10	1	5	6
12.8	22	12	1	4	5
13.0	23	15P	1	3	4
13.2	20	14	1	2	3
13.4	19	13	1	2	3
13.6	15	11	1	1	2
13.8	13	9	1	1	2
14.0	12	8	1	1	2
14.3	10	6	1	1	2
14.6	9	5	1	1	2
15.0	7	4	1	1	1
15.5	7	4	1	1	1
16.0	6	3	1	1	1
16.5	5	3	0	1	1
17.0	5	3	0	1	1
17.5	4	2	0	1	1
18.0	4	2	0	1	1
19.0	3	2	0	0	1
[illegible].0	3	2	0	0	1
22.0	2	1	0	0	1
26.0	0	0	0	0	0

P - Peak Flow

TABULAR HYDROGRAPH METHOD Version 2.00

Project : CE 395 Term Paper User: PEB Date:
unty : Buchanan State: VA Checked: ____ Date: ________
Subtitle: Excess Surface Runoff Generated From Logging in Small Watersheds

Total watershed area: 0.235 sq mi Rainfall type: II Frequency: 2 years

	------------------------- Subareas -------------------------			
	Woods	Brush	Meadow	Rocky
Area(sq mi)	0.14	0.03	0.03	0.03
Rainfall(in)	2.8	2.8	2.8	2.8
Curve number	79	65	69	87
Runoff(in)	1.04	0.42	0.57	1.57
Tc (hrs)	1.14	0.06	0.28	0.07
(Used)	1.25	0.10	0.30	0.10
TimeToOutlet	0.00	0.00	0.21	0.16
(Used)	0.00	0.00	0.20	0.10
Ia/P	0.19	0.38	0.32	0.11

Time	Total	------------- Subarea Contribution to Total Flow (cfs) ------------			
(hr)	Flow	Woods	Brush	Meadow	Rocky
11.0	2	1	0	0	1
11.3	2	1	0	0	1
11.6	3	1	0	0	2
11.9	9	2	1	0	6
12.0	20	2	5	0	13
12.1	39	3	10P	1	25
12.2	54P	5	6	2	41P
.3	50	8	3	5	34
12.4	41	13	2	8P	18
12.5	40	19	2	8	11
12.6	43	26	2	7	8
12.7	44	32	1	5	6
12.8	47	37	1	4	5
13.0	50	42P	1	3	4
13.2	43	37	1	2	3
13.4	36	30	1	2	3
13.6	28	24	1	1	2
13.8	23	19	1	1	2
14.0	20	16	1	1	2
14.3	16	12	1	1	2
14.6	14	10	1	1	2
15.0	11	8	1	1	1
15.5	9	6	1	1	1
16.0	8	5	1	1	1
16.5	7	5	0	1	1
17.0	6	4	0	1	1
17.5	6	4	0	1	1
18.0	6	4	0	1	1
19.0	4	3	0	0	1
.0	4	3	0	0	1
22.0	3	2	0	0	1
26.0	0	0	0	0	0

P - Peak Flow

Project : CE 395 Term Paper User: PEB Date:
unty : Buchanan State: VA Checked: ____ Date: ________
Subtitle: Excess Surface Runoff Generated From Logging in Small Watersheds

Total watershed area: 0.235 sq mi Rainfall type: II Frequency: 02 years

	Subareas			
	Woods	Brush	Meadow	Rocky
Area(sq mi)	0.14	0.03	0.03	0.03
Rainfall(in)	2.8	2.8	2.8	2.8
Curve number	70	76	79	88
Runoff(in)	0.61	0.88	1.04	1.64
Tc (hrs)	1.14	0.06	0.28	0.07
(Used)	1.25	0.10	0.30	0.10
TimeToOutlet	0.00	0.00	0.21	0.16
(Used)	0.00	0.00	0.20	0.10
Ia/P	0.31	0.23	0.19	0.10
(Used)	0.31	0.23	0.19	0.10

Time (hr)	Total Flow	Subarea Contribution to Total Flow (cfs) Woods	Brush	Meadow	Rocky
11.0	1	0	0	0	1
11.3	1	0	0	0	1
11.6	4	0	1	1	2
11.9	14	0	6	1	7
12.0	32	0	16	2	14
12.1	57	0	27P	3	27
.2	68P	1	16	7	44P
12.3	57	2	6	13	36
12.4	45	4	5	17P	19
12.5	40	7	4	17	12
12.6	35	11	3	13	8
12.7	34	15	3	10	6
12.8	32	17	2	8	5
13.0	32	21P	2	5	4
13.2	28	20	2	3	3
13.4	25	17	2	3	3
13.6	21	14	2	2	3
13.8	17	12	1	2	2
14.0	15	10	1	2	2
14.3	13	8	1	2	2
14.6	10	6	1	1	2
15.0	9	5	1	1	2
15.5	7	4	1	1	1
16.0	7	4	1	1	1
16.5	6	3	1	1	1
17.0	6	3	1	1	1
17.5	6	3	1	1	1
18.0	6	3	1	1	1
.0	5	2	1	1	1
20.0	4	2	0	1	1
22.0	3	2	0	0	1
26.0	0	0	0	0	0

Project : CE 395 Term Paper User: PEB Date:
unty : Buchanan State: VA Checked: ____ Date: ________
Subtitle: Excess Surface Runoff Generated From Logging in Small Watersheds

Total watershed area: 0.235 sq mi Rainfall type: II Frequency: 2 years

	Subareas			
	Woods	Brush	Meadow	Rocky
Area(sq mi)	0.14	0.03	0.03	0.03
Rainfall(in)	2.8	2.8	2.8	2.8
Curve number	77	76	79	88
Runoff(in)	0.93	0.88	1.04	1.64
Tc (hrs)	1.14	0.06	0.28	0.07
(Used)	1.25	0.10	0.30	0.10
TimeToOutlet	0.00	0.00	0.21	0.16
(Used)	0.00	0.00	0.20	0.10
Ia/P	0.21	0.23	0.19	0.10
(Used)	0.21	0.23	0.19	0.10

Time	Total	Subarea Contribution to Total Flow (cfs)			
(hr)	Flow	Woods	Brush	Meadow	Rocky
11.0	2	1	0	0	1
11.3	2	1	0	0	1
11.6	5	1	1	1	2
11.9	15	1	6	1	7
12.0	34	2	16	2	14
.1	59	2	27P	3	27
.2	71P	4	16	7	44P
12.3	61	6	6	13	36
12.4	51	10	5	17P	19
12.5	49	16	4	17	12
12.6	46	22	3	13	8
12.7	47	28	3	10	6
12.8	47	32	2	8	5
13.0	48	37P	2	5	4
13.2	41	33	2	3	3
13.4	35	27	2	3	3
13.6	29	22	2	2	3
13.8	22	17	1	2	2
14.0	19	14	1	2	2
14.3	16	11	1	2	2
14.6	13	9	1	1	2
15.0	11	7	1	1	2
15.5	9	6	1	1	1
16.0	8	5	1	1	1
16.5	7	4	1	1	1
17.0	7	4	1	1	1
17.5	7	4	1	1	1
18.0	6	3	1	1	1
.0	6	3	1	1	1
20.0	5	3	0	1	1
22.0	3	2	0	0	1
26.0	0	0	0	0	0

Project : CE 395 Term Paper User: PEB Date:
unty : Buchanan State: VA Checked: ____ Date: ________
Subtitle: Excess Surface Runoff Generated From Logging in Small Watersheds

Total watershed area: 0.235 sq mi Rainfall type: II Frequency: 2 years

	Woods	Brush	Meadow	Rocky
Area(sq mi)	0.14	0.03	0.03	0.03
Rainfall(in)	2.8	2.8	2.8	2.8
Curve number	86	76	79	88
Runoff(in)	1.49	0.88	1.04	1.64
Tc (hrs)	1.14	0.06	0.28	0.07
(Used)	1.25	0.10	0.30	0.10
TimeToOutlet	0.00	0.00	0.21	0.16
(Used)	0.00	0.00	0.20	0.10
Ia/P	0.12	0.23	0.19	0.10
(Used)	0.12	0.23	0.19	0.10

Time (hr)	Total Flow	Woods	Brush	Meadow	Rocky
11.0	3	2	0	0	1
11.3	4	3	0	0	1
11.6	8	4	1	1	2
11.9	19	5	6	1	7
12.0	38	6	16	2	14
.1	64	7	27P	3	27
.2	77P	10	16	7	44P
12.3	71	16	6	13	36
12.4	65	24	5	17P	19
12.5	66	33	4	17	12
12.6	67	43	3	13	8
12.7	71	52	3	10	6
12.8	73	58	2	8	5
13.0	75	64P	2	5	4
13.2	63	55	2	3	3
13.4	52	44	2	3	3
13.6	41	34	2	2	3
13.8	32	27	1	2	2
14.0	27	22	1	2	2
14.3	22	17	1	2	2
14.6	17	13	1	1	2
15.0	14	10	1	1	2
15.5	11	8	1	1	1
16.0	10	7	1	1	1
16.5	9	6	1	1	1
17.0	8	5	1	1	1
17.5	8	5	1	1	1
18.0	7	4	1	1	1
.0	7	4	1	1	1
20.0	6	4	0	1	1
22.0	4	3	0	0	1
26.0	0	0	0	0	0

Subarea Contribution to Total Flow (cfs)

TABULAR HYDROGRAPH METHOD Version 2.00

Project : CE 395 Term Paper User: PEB Date:
County : Buchanan State: VA Checked: ____ Date: ________
Subtitle: Excess Surface Runoff Generated From Logging in Small Watersheds

Total watershed area: 0.235 sq mi Rainfall type: II Frequency: 2 years

	Subareas			
	Woods	Brush	Meadow	Rocky
Area(sq mi)	0.14	0.03	0.03	0.03
Rainfall(in)	2.8	2.8	2.8	2.8
Curve number	77	82	84	89
Runoff(in)	0.93	1.22	1.35	1.72
Tc (hrs)	1.14	0.06	0.28	0.07
(Used)	1.25	0.10	0.30	0.10
TimeToOutlet	0.00	0.00	0.21	0.16
(Used)	0.00	0.00	0.20	0.10
Ia/P	0.21	0.16	0.14	0.09
(Used)	0.21	0.16	0.14	0.10

Time	Total	Subarea Contribution to Total Flow (cfs)			
(hr)	Flow	Woods	Brush	Meadow	Rocky
11.0	4	1	1	1	1
11.3	5	1	1	1	2
11.6	5	1	1	1	2
11.9	21	1	11	2	7
12.0	43	2	24	3	14
.1	74	2	38P	6	28
12.2	84P	4	23	11	46P
12.3	71	6	8	19	38
12.4	60	10	6	24P	20
12.5	55	16	5	22	12
12.6	52	22	4	18	8
12.7	52	28	4	13	7
12.8	50	32	3	10	5
13.0	50	37P	3	6	4
13.2	42	33	2	4	3
13.4	35	27	2	3	3
13.6	30	22	2	3	3
13.8	23	17	2	2	2
14.0	20	14	2	2	2
14.3	16	11	1	2	2
14.6	14	9	1	2	2
15.0	11	7	1	1	2
15.5	9	6	1	1	1
16.0	8	5	1	1	1
16.5	7	4	1	1	1
17.0	7	4	1	1	1
17.5	7	4	1	1	1
18.0	6	3	1	1	1
.0	6	3	1	1	1
20.0	6	3	1	1	1
22.0	5	2	1	1	1
26.0	0	0	0	0	0

Project : CE 395 Term Paper User: PEB Date:
County : Buchanan State: VA Checked: ____ Date: ________
Subtitle: Excess Surface Runoff Generated From Logging in Small Watersheds

Total watershed area: 0.235 sq mi Rainfall type: II Frequency: 2 years

	Subareas			
	Woods	Brush	Meadow	Rocky
Area(sq mi)	0.14	0.03	0.03	0.03
Rainfall(in)	2.8	2.8	2.8	2.8
Curve number	83	82	84	89
Runoff(in)	1.29	1.22	1.35	1.72
Tc (hrs)	1.14	0.06	0.28	0.07
(Used)	1.25	0.10	0.30	0.10
TimeToOutlet	0.00	0.00	0.21	0.16
(Used)	0.00	0.00	0.20	0.10
Ia/P	0.15	0.16	0.14	0.09
(Used)	0.15	0.16	0.14	0.10

Time	Total	Subarea Contribution to Total Flow (cfs)			
(hr)	Flow	Woods	Brush	Meadow	Rocky
11.0	4	1	1	1	1
11.3	6	2	1	1	2
11.6	7	3	1	1	2
11.9	23	3	11	2	7
12.0	45	4	24	3	14
12.1	77	5	38P	6	28
12.2	88P	8	23	11	46P
12.3	77	12	8	19	38
12.4	68	18	6	24P	20
12.5	65	26	5	22	12
12.6	65	35	4	18	8
12.7	67	43	4	13	7
12.8	66	48	3	10	5
13.0	67	54P	3	6	4
13.2	56	47	2	4	3
13.4	46	38	2	3	3
13.6	38	30	2	3	3
13.8	30	24	2	2	2
14.0	25	19	2	2	2
14.3	20	15	1	2	2
14.6	17	12	1	2	2
15.0	13	9	1	1	2
15.5	10	7	1	1	1
16.0	9	6	1	1	1
16.5	8	5	1	1	1
17.0	8	5	1	1	1
17.5	7	4	1	1	1
18.0	7	4	1	1	1
19.0	7	4	1	1	1
20.0	6	3	1	1	1
22.0	6	3	1	1	1
26.0	0	0	0	0	0

Project : CE 395 Term Paper User: PEB Date:
County : Buchanan State: VA Checked: ____ Date: ________
Subtitle: Excess Surface Runoff Generated From Logging in Small Watersheds

Total watershed area: 0.235 sq mi Rainfall type: II Frequency: 2 years

	Subareas			
	Woods	Brush	Meadow	Rocky
Area(sq mi)	0.14	0.03	0.03	0.03
Rainfall(in)	2.8	2.8	2.8	2.8
Curve number	89	82	84	89
Runoff(in)	1.72	1.22	1.35	1.72
Tc (hrs)	1.14	0.06	0.28	0.07
(Used)	1.25	0.10	0.30	0.10
TimeToOutlet	0.00	0.00	0.21	0.16
(Used)	0.00	0.00	0.20	0.10
Ia/P	0.09	0.16	0.14	0.09
(Used)	0.10	0.16	0.14	0.10

Time	Total	Subarea Contribution to Total Flow (cfs)			
(hr)	Flow	Woods	Brush	Meadow	Rocky
11.0	5	2	1	1	1
11.3	7	3	1	1	2
11.6	8	4	1	1	2
11.9	26	6	11	2	7
12.0	48	7	24	3	14
.1	81	9	38P	6	28
.2	93P	13	23	11	46P
12.3	85	20	8	19	38
12.4	79	29	6	24P	20
12.5	78	39	5	22	12
12.6	82	52	4	18	8
12.7	86	62	4	13	7
12.8	87	69	3	10	5
13.0	88	75P	3	6	4
13.2	73	64	2	4	3
13.4	59	51	2	3	3
13.6	47	39	2	3	3
13.8	37	31	2	2	2
14.0	31	25	2	2	2
14.3	24	19	1	2	2
14.6	20	15	1	2	2
15.0	15	11	1	1	2
15.5	12	9	1	1	1
16.0	10	7	1	1	1
16.5	10	7	1	1	1
17.0	9	6	1	1	1
17.5	8	5	1	1	1
18.0	8	5	1	1	1
.0	7	4	1	1	1
20.0	7	4	1	1	1
22.0	6	3	1	1	1
26.0	0	0	0	0	0

SMADA Analysis
2-YR Storm, HSG-A, Case 1
11/29/00

Time (hrs)	Rainfall (inches)	Infiltration (inches)	Excess (cfs)	Runoff (cfs)	Runoff (inches)
0.08	0.002	0.002	0	0	0.0000
0.17	0.002	0.002	0	0	0.0000
0.25	0.002	0.002	0	0	0.0000
0.33	0.003	0.003	0	0	0.0000
0.42	0.003	0.003	0	0	0.0000
0.5	0.003	0.003	0	0	0.0000
0.58	0.003	0.003	0	0	0.0000
0.67	0.003	0.003	0	0	0.0000
0.75	0.003	0.003	0	0	0.0000
0.83	0.003	0.003	0	0	0.0000
0.92	0.003	0.003	0	0	0.0000
1	0.003	0.003	0	0	0.0000
1.08	0.003	0.003	0	0	0.0000
1.17	0.003	0.003	0	0	0.0000
1.25	0.003	0.003	0	0	0.0000
1.33	0.003	0.003	0	0	0.0000
1.42	0.003	0.003	0	0	0.0000
1.5	0.003	0.003	0	0	0.0000
1.58	0.003	0.003	0	0	0.0000
1.67	0.003	0.003	0	0	0.0000
1.75	0.003	0.003	0	0	0.0000
1.83	0.003	0.003	0	0	0.0000
1.92	0.003	0.003	0	0	0.0000
2	0.003	0.003	0	0	0.0000
2.08	0.003	0.003	0	0	0.0000
2.17	0.003	0.003	0	0	0.0000
2.25	0.003	0.003	0	0	0.0000
2.33	0.003	0.003	0	0	0.0000
2.42	0.003	0.003	0	0	0.0000
2.5	0.003	0.003	0	0	0.0000
2.58	0.003	0.003	0	0	0.0000
2.67	0.003	0.003	0	0	0.0000
2.75	0.003	0.003	0	0	0.0000
2.83	0.003	0.003	0	0	0.0000
2.92	0.003	0.003	0	0	0.0000
3	0.003	0.003	0	0	0.0000
3.08	0.003	0.003	0	0	0.0000
3.17	0.003	0.003	0	0	0.0000
3.25	0.003	0.003	0	0	0.0000
3.33	0.003	0.003	0	0	0.0000
3.42	0.003	0.003	0	0	0.0000
3.5	0.003	0.003	0	0	0.0000
3.58	0.003	0.003	0	0	0.0000
3.67	0.003	0.003	0	0	0.0000
3.75	0.003	0.003	0	0	0.0000

3.83	0.004	0.004	0	0	0.0000
3.92	0.004	0.004	0	0	0.0000
4	0.004	0.004	0	0	0.0000
4.08	0.004	0.004	0	0	0.0000
4.17	0.004	0.004	0	0	0.0000
4.25	0.004	0.004	0	0	0.0000
4.33	0.004	0.004	0	0	0.0000
4.42	0.004	0.004	0	0	0.0000
4.5	0.004	0.004	0	0	0.0000
4.58	0.004	0.004	0	0	0.0000
4.67	0.004	0.004	0	0	0.0000
4.75	0.004	0.004	0	0	0.0000
4.83	0.004	0.004	0	0	0.0000
4.92	0.004	0.004	0	0	0.0000
5	0.004	0.004	0	0	0.0000
5.08	0.004	0.004	0	0	0.0000
5.17	0.004	0.004	0	0	0.0000
5.25	0.004	0.004	0	0	0.0000
5.33	0.004	0.004	0	0	0.0000
5.42	0.004	0.004	0	0	0.0000
5.5	0.004	0.004	0	0	0.0000
5.58	0.004	0.004	0	0	0.0000
5.67	0.004	0.004	0	0	0.0000
5.75	0.004	0.004	0	0	0.0000
5.83	0.004	0.004	0	0	0.0000
5.92	0.004	0.004	0	0	0.0000
6	0.004	0.004	0	0	0.0000
6.08	0.005	0.005	0	0	0.0000
6.17	0.005	0.005	0	0	0.0000
6.25	0.005	0.005	0	0	0.0000
6.33	0.005	0.005	0	0	0.0000
6.42	0.005	0.005	0	0	0.0000
6.5	0.005	0.005	0	0	0.0000
6.58	0.005	0.005	0	0	0.0000
6.67	0.005	0.005	0	0	0.0000
6.75	0.005	0.005	0	0	0.0000
6.83	0.005	0.005	0	0	0.0000
6.92	0.005	0.005	0	0	0.0000
7	0.005	0.005	0	0	0.0000
7.08	0.005	0.005	0	0	0.0000
7.17	0.005	0.005	0	0	0.0000
7.25	0.005	0.005	0	0	0.0000
7.33	0.005	0.005	0	0	0.0000
7.42	0.005	0.005	0	0	0.0000
7.5	0.005	0.005	0	0	0.0000
7.58	0.005	0.005	0	0	0.0000
7.67	0.005	0.005	0	0	0.0000
7.75	0.005	0.005	0	0	0.0000
7.83	0.005	0.005	0	0	0.0000
7.92	0.005	0.005	0	0	0.0000
8	0.005	0.005	0	0	0.0000

8.08	0.006	0.006	0	0	0.0000
8.17	0.006	0.006	0	0	0.0000
8.25	0.006	0.006	0	0	0.0000
8.33	0.007	0.007	0	0	0.0000
8.42	0.007	0.007	0	0	0.0000
8.5	0.007	0.007	0	0.00	0.0000
8.58	0.007	0.007	0	0	0.0000
8.67	0.007	0.007	0	0	0.0000
8.75	0.007	0.007	0	0	0.0000
8.83	0.007	0.007	0	0	0.0000
8.92	0.007	0.007	0	0	0.0000
9	0.007	0.007	0	0	0.0000
9.08	0.007	0.007	0	0	0.0000
9.17	0.007	0.007	0	0	0.0000
9.25	0.007	0.007	0	0	0.0000
9.33	0.007	0.007	0	0	0.0000
9.42	0.007	0.007	0	0	0.0000
9.5	0.007	0.007	0	0	0.0000
9.58	0.008	0.008	0	0	0.0000
9.67	0.008	0.008	0	0	0.0000
9.75	0.008	0.008	0	0	0.0000
9.83	0.008	0.008	0	0	0.0000
9.92	0.008	0.008	0	0	0.0000
10	0.008	0.008	0	0	0.0000
10.08	0.009	0.009	0	0	0.0000
10.17	0.009	0.009	0	0	0.0000
10.25	0.009	0.009	0	0	0.0000
10.33	0.011	0.011	0	0	0.0000
10.42	0.011	0.011	0	0	0.0000
10.5	0.011	0.011	0	0	0.0000
10.58	0.014	0.014	0	0	0.0000
10.67	0.014	0.014	0	0	0.0000
10.75	0.014	0.014	0	0	0.0000
10.83	0.017	0.017	0	0	0.0000
10.92	0.017	0.017	0	0	0.0000
11	0.017	0.017	0	0	0.0000
11.08	0.02	0.02	0	0	0.0000
11.17	0.02	0.02	0	0	0.0000
11.25	0.02	0.02	0	0	0.0000
11.33	0.024	0.024	0	0	0.0000
11.42	0.024	0.024	0	0	0.0000
11.5	0.024	0.024	0	0	0.0000
11.58	0.097	0.097	0	0	0.0000
11.67	0.097	0.097	0	0	0.0000
11.75	0.097	0.097	0	0	0.0000
11.83	0.258	0.258	0	0	0.0000
11.92	0.258	0.258	0	0	0.0000
12	0.258	0.258	0	0	0.0000
12.08	0.041	0.041	0	0	0.0000
12.17	0.041	0.041	0	0	0.0000
12.25	0.041	0.041	0	0	0.0000

12.33	0.026	0.026	0	0	0.0000
12.42	0.026	0.026	0	0	0.0000
12.5	0.026	0.026	0	0	0.0000
12.58	0.021	0.021	0	0	0.0000
12.67	0.021	0.021	0	0	0.0000
12.75	0.021	0.021	0	0	0.0000
12.83	0.017	0.017	0	0	0.0000
12.92	0.017	0.017	0	0	0.0000
13	0.017	0.017	0.006	0	0.0000
13.08	0.014	0.014	0.061	0	0.0000
13.17	0.014	0.014	0.127	0.001	0.0000
13.25	0.014	0.014	0.192	0.003	0.0000
13.33	0.012	0.012	0.219	0.005	0.0000
13.42	0.012	0.012	0.267	0.009	0.0000
13.5	0.012	0.012	0.315	0.013	0.0000
13.58	0.01	0.01	0.305	0.019	0.0000
13.67	0.01	0.01	0.339	0.027	0.0000
13.75	0.01	0.01	0.373	0.035	0.0000
13.83	0.009	0.009	0.369	0.046	0.0000
13.92	0.009	0.009	0.397	0.058	0.0000
14	0.009	0.009	0.425	0.071	0.0000
14.08	0.008	0.008	0.407	0.087	0.0000
14.17	0.008	0.008	0.429	0.103	0.0001
14.25	0.008	0.008	0.452	0.121	0.0001
14.33	0.007	0.007	0.421	0.14	0.0001
14.42	0.007	0.007	0.439	0.16	0.0001
14.5	0.007	0.007	0.456	0.179	0.0001
14.58	0.007	0.006	0.414	0.199	0.0001
14.67	0.007	0.006	0.427	0.218	0.0001
14.75	0.007	0.006	0.441	0.237	0.0001
14.83	0.007	0.006	0.454	0.255	0.0001
14.92	0.007	0.006	0.468	0.273	0.0002
15	0.007	0.006	0.481	0.291	0.0002
15.08	0.007	0.006	0.495	0.308	0.0002
15.17	0.007	0.006	0.508	0.324	0.0002
15.25	0.007	0.006	0.522	0.339	0.0002
15.33	0.006	0.005	0.458	0.354	0.0002
15.42	0.006	0.005	0.467	0.368	0.0002
15.5	0.006	0.005	0.477	0.381	0.0002
15.58	0.006	0.005	0.487	0.393	0.0002
15.67	0.006	0.005	0.497	0.404	0.0002
15.75	0.006	0.005	0.506	0.414	0.0002
15.83	0.006	0.005	0.516	0.424	0.0002
15.92	0.006	0.005	0.526	0.433	0.0002
16	0.006	0.005	0.536	0.442	0.0002
16.08	0.006	0.005	0.545	0.449	0.0002
16.17	0.006	0.005	0.555	0.456	0.0003
16.25	0.006	0.005	0.565	0.462	0.0003
16.33	0.006	0.005	0.574	0.468	0.0003
16.42	0.006	0.005	0.584	0.474	0.0003
16.5	0.006	0.005	0.593	0.479	0.0003

16.58	0.005	0.004	0.502	0.485	0.0003
16.67	0.005	0.004	0.509	0.49	0.0003
16.75	0.005	0.004	0.515	0.495	0.0003
16.83	0.005	0.004	0.522	0.499	0.0003
16.92	0.005	0.004	0.528	0.504	0.0003
17	0.005	0.004	0.535	0.508	0.0003
17.08	0.005	0.004	0.542	0.512	0.0003
17.17	0.005	0.004	0.548	0.516	0.0003
17.25	0.005	0.004	0.555	0.52	0.0003
17.33	0.005	0.004	0.561	0.523	0.0003
17.42	0.005	0.004	0.568	0.526	0.0003
17.5	0.005	0.004	0.575	0.528	0.0003
17.58	0.005	0.004	0.581	0.531	0.0003
17.67	0.005	0.004	0.588	0.533	0.0003
17.75	0.005	0.004	0.594	0.535	0.0003
17.83	0.004	0.003	0.48	0.537	0.0003
17.92	0.004	0.003	0.484	0.538	0.0003
18	0.004	0.003	0.488	0.54	0.0003
18.08	0.004	0.003	0.493	0.541	0.0003
18.17	0.004	0.003	0.497	0.542	0.0003
18.25	0.004	0.003	0.501	0.542	0.0003
18.33	0.004	0.003	0.505	0.543	0.0003
18.42	0.004	0.003	0.509	0.543	0.0003
18.5	0.004	0.003	0.513	0.542	0.0003
18.58	0.004	0.003	0.518	0.541	0.0003
18.67	0.004	0.003	0.522	0.54	0.0003
18.75	0.004	0.003	0.526	0.538	0.0003
18.83	0.004	0.003	0.53	0.536	0.0003
18.92	0.004	0.003	0.534	0.533	0.0003
19	0.004	0.003	0.538	0.531	0.0003
19.08	0.004	0.003	0.542	0.53	0.0003
19.17	0.004	0.003	0.546	0.528	0.0003
19.25	0.004	0.003	0.551	0.527	0.0003
19.33	0.004	0.003	0.555	0.527	0.0003
19.42	0.004	0.003	0.559	0.527	0.0003
19.5	0.004	0.003	0.563	0.527	0.0003
19.58	0.004	0.003	0.567	0.527	0.0003
19.67	0.004	0.003	0.571	0.528	0.0003
19.75	0.004	0.003	0.575	0.529	0.0003
19.83	0.003	0.003	0.434	0.53	0.0003
19.92	0.003	0.003	0.436	0.53	0.0003
20	0.003	0.003	0.439	0.53	0.0003
20.08	0.003	0.003	0.441	0.53	0.0003
20.17	0.003	0.003	0.443	0.529	0.0003
20.25	0.003	0.003	0.446	0.528	0.0003
20.33	0.003	0.003	0.448	0.526	0.0003
20.42	0.003	0.003	0.45	0.524	0.0003
20.5	0.003	0.003	0.452	0.522	0.0003
20.58	0.003	0.003	0.455	0.519	0.0003
20.67	0.003	0.003	0.457	0.516	0.0003
20.75	0.003	0.003	0.459	0.512	0.0003

20.83	0.003	0.003	0.461	0.508	0.0003
20.92	0.003	0.003	0.464	0.504	0.0003
21	0.003	0.003	0.466	0.5	0.0003
21.08	0.003	0.003	0.468	0.496	0.0003
21.17	0.003	0.003	0.471	0.492	0.0003
21.25	0.003	0.003	0.473	0.489	0.0003
21.33	0.003	0.003	0.475	0.486	0.0003
21.42	0.003	0.003	0.477	0.483	0.0003
21.5	0.003	0.003	0.48	0.48	0.0003
21.58	0.003	0.003	0.482	0.478	0.0003
21.67	0.003	0.003	0.484	0.476	0.0003
21.75	0.003	0.003	0.486	0.474	0.0003
21.83	0.003	0.003	0.489	0.473	0.0003
21.92	0.003	0.003	0.491	0.472	0.0003
22	0.003	0.003	0.493	0.471	0.0003
22.08	0.003	0.003	0.495	0.47	0.0003
22.17	0.003	0.003	0.498	0.47	0.0003
22.25	0.003	0.003	0.5	0.47	0.0003
22.33	0.003	0.003	0.502	0.471	0.0003
22.42	0.003	0.003	0.504	0.472	0.0003
22.5	0.003	0.003	0.507	0.473	0.0003
22.58	0.003	0.003	0.509	0.474	0.0003
22.67	0.003	0.003	0.511	0.476	0.0003
22.75	0.003	0.003	0.513	0.478	0.0003
22.83	0.003	0.003	0.516	0.48	0.0003
22.92	0.003	0.003	0.518	0.482	0.0003
23	0.003	0.003	0.52	0.485	0.0003
23.08	0.003	0.003	0.522	0.487	0.0003
23.17	0.003	0.003	0.525	0.489	0.0003
23.25	0.003	0.003	0.527	0.492	0.0003
23.33	0.003	0.003	0.529	0.494	0.0003
23.42	0.003	0.003	0.531	0.496	0.0003
23.5	0.003	0.003	0.533	0.498	0.0003
23.58	0.003	0.003	0.536	0.501	0.0003
23.67	0.003	0.003	0.538	0.503	0.0003
23.75	0.003	0.003	0.54	0.505	0.0003
23.83	0.002	0.002	0.361	0.507	0.0003
23.92	0.002	0.002	0.362	0.507	0.0003
24	0.002	0.002	0.363	0.507	0.0003
24.08	0	0	0	0.505	0.0003
24.17	0	0	0	0.501	0.0003
24.25	0	0	0	0.494	0.0003
24.33	0	0	0	0.485	0.0003
24.42	0	0	0	0.474	0.0003
24.5	0	0	0	0.461	0.0003
24.58	0	0	0	0.446	0.0002
24.67	0	0	0	0.428	0.0002
24.75	0	0	0	0.408	0.0002
24.83	0	0	0	0.385	0.0002
24.92	0	0	0	0.361	0.0002
25	0	0	0	0.336	0.0002

25.08	0	0	0	0.309	0.0002
25.17	0	0	0	0.282	0.0002
25.25	0	0	0	0.256	0.0001
25.33	0	0	0	0.232	0.0001
25.42	0	0	0	0.208	0.0001
25.5	0	0	0	0.186	0.0001
25.58	0	0	0	0.165	0.0001
25.67	0	0	0	0.146	0.0001
25.75	0	0	0	0.127	0.0001
25.83	0	0	0	0.11	0.0001
25.92	0	0	0	0.094	0.0001
26	0	0	0	0.079	0.0000
26.08	0	0	0	0.066	0.0000
26.17	0	0	0	0.054	0.0000
26.25	0	0	0	0.043	0.0000
26.33	0	0	0	0.033	0.0000
26.42	0	0	0	0.025	0.0000
26.5	0	0	0	0.018	0.0000
26.58	0	0	0	0.012	0.0000
26.67	0	0	0	0.007	0.0000
26.75	0	0	0	0.004	0.0000
26.83	0	0	0	0.002	0.0000
				63.47	0.03

SMADA Analysis
2-YR Storm, HSG-A, Case 2
11/29/00

Time (hrs)	Rainfall (inches)	nfiltratio (inches)	Excess (cfs)	Runoff (cfs)	Runoff (inches)
0.08	0.002	0.002	0	0	0.0000
0.17	0.002	0.002	0	0	0.0000
0.25	0.002	0.002	0	0	0.0000
0.33	0.003	0.003	0	0	0.0000
0.42	0.003	0.003	0	0	0.0000
0.5	0.003	0.003	0	0	0.0000
0.58	0.003	0.003	0	0	0.0000
0.67	0.003	0.003	0	0	0.0000
0.75	0.003	0.003	0	0	0.0000
0.83	0.003	0.003	0	0	0.0000
0.92	0.003	0.003	0	0	0.0000
1	0.003	0.003	0	0	0.0000
1.08	0.003	0.003	0	0	0.0000
1.17	0.003	0.003	0	0	0.0000
1.25	0.003	0.003	0	0	0.0000
1.33	0.003	0.003	0	0	0.0000
1.42	0.003	0.003	0	0	0.0000
1.5	0.003	0.003	0	0	0.0000
1.58	0.003	0.003	0	0	0.0000
1.67	0.003	0.003	0	0	0.0000
1.75	0.003	0.003	0	0	0.0000
1.83	0.003	0.003	0	0	0.0000
1.92	0.003	0.003	0	0	0.0000
2	0.003	0.003	0	0	0.0000
2.08	0.003	0.003	0	0	0.0000
2.17	0.003	0.003	0	0	0.0000
2.25	0.003	0.003	0	0	0.0000
2.33	0.003	0.003	0	0	0.0000
2.42	0.003	0.003	0	0	0.0000
2.5	0.003	0.003	0	0	0.0000
2.58	0.003	0.003	0	0	0.0000
2.67	0.003	0.003	0	0	0.0000
2.75	0.003	0.003	0	0	0.0000
2.83	0.003	0.003	0	0	0.0000
2.92	0.003	0.003	0	0	0.0000
3	0.003	0.003	0	0	0.0000
3.08	0.003	0.003	0	0	0.0000
3.17	0.003	0.003	0	0	0.0000
3.25	0.003	0.003	0	0	0.0000
3.33	0.003	0.003	0	0	0.0000
3.42	0.003	0.003	0	0	0.0000
3.5	0.003	0.003	0	0	0.0000
3.58	0.003	0.003	0	0	0.0000
3.67	0.003	0.003	0	0	0.0000
3.75	0.003	0.003	0	0	0.0000

3.83	0.004	0.004	0	0	0.0000
3.92	0.004	0.004	0	0	0.0000
4	0.004	0.004	0	0	0.0000
4.08	0.004	0.004	0	0	0.0000
4.17	0.004	0.004	0	0	0.0000
4.25	0.004	0.004	0	0	0.0000
4.33	0.004	0.004	0	0	0.0000
4.42	0.004	0.004	0	0	0.0000
4.5	0.004	0.004	0	0	0.0000
4.58	0.004	0.004	0	0	0.0000
4.67	0.004	0.004	0	0	0.0000
4.75	0.004	0.004	0	0	0.0000
4.83	0.004	0.004	0	0	0.0000
4.92	0.004	0.004	0	0	0.0000
5	0.004	0.004	0	0	0.0000
5.08	0.004	0.004	0	0	0.0000
5.17	0.004	0.004	0	0	0.0000
5.25	0.004	0.004	0	0	0.0000
5.33	0.004	0.004	0	0	0.0000
5.42	0.004	0.004	0	0	0.0000
5.5	0.004	0.004	0	0	0.0000
5.58	0.004	0.004	0	0	0.0000
5.67	0.004	0.004	0	0	0.0000
5.75	0.004	0.004	0	0	0.0000
5.83	0.004	0.004	0	0	0.0000
5.92	0.004	0.004	0	0	0.0000
6	0.004	0.004	0	0	0.0000
6.08	0.005	0.005	0	0	0.0000
6.17	0.005	0.005	0	0	0.0000
6.25	0.005	0.005	0	0	0.0000
6.33	0.005	0.005	0	0	0.0000
6.42	0.005	0.005	0	0	0.0000
6.5	0.005	0.005	0	0	0.0000
6.58	0.005	0.005	0	0	0.0000
6.67	0.005	0.005	0	0	0.0000
6.75	0.005	0.005	0	0	0.0000
6.83	0.005	0.005	0	0	0.0000
6.92	0.005	0.005	0	0	0.0000
7	0.005	0.005	0	0	0.0000
7.08	0.005	0.005	0	0	0.0000
7.17	0.005	0.005	0	0	0.0000
7.25	0.005	0.005	0	0	0.0000
7.33	0.005	0.005	0	0	0.0000
7.42	0.005	0.005	0	0	0.0000
7.5	0.005	0.005	0	0	0.0000
7.58	0.005	0.005	0	0	0.0000
7.67	0.005	0.005	0	0	0.0000
7.75	0.005	0.005	0	0	0.0000
7.83	0.005	0.005	0	0	0.0000
7.92	0.005	0.005	0	0	0.0000
8	0.005	0.005	0	0	0.0000

8.08	0.006	0.006	0	0	0.0000
8.17	0.006	0.006	0	0	0.0000
8.25	0.006	0.006	0	0	0.0000
8.33	0.007	0.007	0	0	0.0000
8.42	0.007	0.007	0	0	0.0000
8.5	0.007	0.007	0	0	0.0000
8.58	0.007	0.007	0	0	0.0000
8.67	0.007	0.007	0	0	0.0000
8.75	0.007	0.007	0	0	0.0000
8.83	0.007	0.007	0	0	0.0000
8.92	0.007	0.007	0	0	0.0000
9	0.007	0.007	0	0	0.0000
9.08	0.007	0.007	0	0	0.0000
9.17	0.007	0.007	0	0	0.0000
9.25	0.007	0.007	0	0	0.0000
9.33	0.007	0.007	0	0	0.0000
9.42	0.007	0.007	0	0	0.0000
9.5	0.007	0.007	0	0	0.0000
9.58	0.008	0.008	0	0	0.0000
9.67	0.008	0.008	0	0	0.0000
9.75	0.008	0.008	0	0	0.0000
9.83	0.008	0.008	0	0	0.0000
9.92	0.008	0.008	0	0	0.0000
10	0.008	0.008	0	0	0.0000
10.08	0.009	0.009	0	0	0.0000
10.17	0.009	0.009	0	0	0.0000
10.25	0.009	0.009	0	0	0.0000
10.33	0.011	0.011	0	0	0.0000
10.42	0.011	0.011	0	0	0.0000
10.5	0.011	0.011	0	0	0.0000
10.58	0.014	0.014	0	0	0.0000
10.67	0.014	0.014	0	0	0.0000
10.75	0.014	0.014	0	0	0.0000
10.83	0.017	0.017	0	0	0.0000
10.92	0.017	0.017	0	0	0.0000
11	0.017	0.017	0	0	0.0000
11.08	0.02	0.02	0	0	0.0000
11.17	0.02	0.02	0	0	0.0000
11.25	0.02	0.02	0	0	0.0000
11.33	0.024	0.024	0	0	0.0000
11.42	0.024	0.024	0	0	0.0000
11.5	0.024	0.024	0	0	0.0000
11.58	0.097	0.097	0	0	0.0000
11.67	0.097	0.097	0	0	0.0000
11.75	0.097	0.097	0	0	0.0000
11.83	0.258	0.258	0	0	0.0000
11.92	0.258	0.257	1.686	0.009	0.0000
12	0.258	0.245	22.271	0.134	0.0001
12.08	0.041	0.038	5.84	0.289	0.0002
12.17	0.041	0.038	6.446	0.477	0.0003
12.25	0.041	0.037	7.045	0.703	0.0004

12.33	0.026	0.023	4.791	0.953	0.0005
12.42	0.026	0.023	5.028	1.23	0.0007
12.5	0.026	0.023	5.264	1.534	0.0008
12.58	0.021	0.019	4.498	1.861	0.0010
12.67	0.021	0.019	4.655	2.213	0.0012
12.75	0.021	0.019	4.81	2.589	0.0014
12.83	0.017	0.015	3.872	2.986	0.0016
12.92	0.017	0.015	3.966	3.389	0.0019
13	0.017	0.015	4.059	3.628	0.0020
13.08	0.014	0.012	3.454	3.837	0.0021
13.17	0.014	0.012	3.518	4.01	0.0022
13.25	0.014	0.012	3.582	4.143	0.0023
13.33	0.012	0.01	3.156	4.252	0.0023
13.42	0.012	0.01	3.204	4.336	0.0024
13.5	0.012	0.01	3.251	4.394	0.0024
13.58	0.01	0.009	2.788	4.428	0.0024
13.67	0.01	0.009	2.822	4.439	0.0024
13.75	0.01	0.009	2.855	4.424	0.0024
13.83	0.009	0.008	2.625	4.39	0.0024
13.92	0.009	0.008	2.653	4.338	0.0024
14	0.009	0.008	2.68	4.265	0.0023
14.08	0.008	0.007	2.436	4.176	0.0023
14.17	0.008	0.007	2.458	4.071	0.0022
14.25	0.008	0.007	2.48	3.949	0.0022
14.33	0.007	0.006	2.223	3.812	0.0021
14.42	0.007	0.006	2.24	3.661	0.0020
14.5	0.007	0.006	2.258	3.494	0.0019
14.58	0.007	0.005	1.99	3.319	0.0018
14.67	0.007	0.005	2.003	3.2	0.0018
14.75	0.007	0.005	2.016	3.087	0.0017
14.83	0.007	0.005	2.029	2.982	0.0016
14.92	0.007	0.005	2.043	2.888	0.0016
15	0.007	0.005	2.056	2.797	0.0015
15.08	0.007	0.005	2.069	2.713	0.0015
15.17	0.007	0.005	2.082	2.635	0.0015
15.25	0.007	0.005	2.095	2.562	0.0014
15.33	0.006	0.005	1.806	2.494	0.0014
15.42	0.006	0.005	1.816	2.431	0.0013
15.5	0.006	0.005	1.825	2.372	0.0013
15.58	0.006	0.005	1.835	2.318	0.0013
15.67	0.006	0.005	1.844	2.27	0.0013
15.75	0.006	0.005	1.854	2.225	0.0012
15.83	0.006	0.005	1.863	2.184	0.0012
15.92	0.006	0.005	1.873	2.147	0.0012
16	0.006	0.005	1.882	2.112	0.0012
16.08	0.006	0.005	1.891	2.08	0.0011
16.17	0.006	0.005	1.901	2.051	0.0011
16.25	0.006	0.005	1.91	2.023	0.0011
16.33	0.006	0.005	1.92	1.999	0.0011
16.42	0.006	0.005	1.929	1.979	0.0011
16.5	0.006	0.005	1.938	1.962	0.0011

16.58	0.005	0.004	1.622	1.946	0.0011
16.67	0.005	0.004	1.629	1.931	0.0011
16.75	0.005	0.004	1.635	1.918	0.0011
16.83	0.005	0.004	1.642	1.905	0.0010
16.92	0.005	0.004	1.648	1.893	0.0010
17	0.005	0.004	1.655	1.88	0.0010
17.08	0.005	0.004	1.661	1.868	0.0010
17.17	0.005	0.004	1.668	1.855	0.0010
17.25	0.005	0.004	1.674	1.842	0.0010
17.33	0.005	0.004	1.68	1.827	0.0010
17.42	0.005	0.004	1.687	1.812	0.0010
17.5	0.005	0.004	1.693	1.795	0.0010
17.58	0.005	0.004	1.699	1.781	0.0010
17.67	0.005	0.004	1.706	1.768	0.0010
17.75	0.005	0.004	1.712	1.756	0.0010
17.83	0.004	0.003	1.374	1.745	0.0010
17.92	0.004	0.003	1.378	1.734	0.0010
18	0.004	0.003	1.383	1.721	0.0009
18.08	0.004	0.003	1.387	1.708	0.0009
18.17	0.004	0.003	1.391	1.694	0.0009
18.25	0.004	0.003	1.395	1.679	0.0009
18.33	0.004	0.003	1.399	1.663	0.0009
18.42	0.004	0.003	1.403	1.646	0.0009
18.5	0.004	0.003	1.407	1.628	0.0009
18.58	0.004	0.003	1.411	1.609	0.0009
18.67	0.004	0.003	1.415	1.589	0.0009
18.75	0.004	0.003	1.419	1.568	0.0009
18.83	0.004	0.003	1.423	1.549	0.0009
18.92	0.004	0.003	1.427	1.532	0.0008
19	0.004	0.003	1.431	1.517	0.0008
19.08	0.004	0.003	1.435	1.504	0.0008
19.17	0.004	0.003	1.439	1.493	0.0008
19.25	0.004	0.003	1.443	1.482	0.0008
19.33	0.004	0.003	1.447	1.473	0.0008
19.42	0.004	0.003	1.451	1.465	0.0008
19.5	0.004	0.003	1.455	1.458	0.0008
19.58	0.004	0.003	1.459	1.451	0.0008
19.67	0.004	0.003	1.463	1.446	0.0008
19.75	0.004	0.003	1.467	1.442	0.0008
19.83	0.003	0.002	1.103	1.436	0.0008
19.92	0.003	0.002	1.105	1.43	0.0008
20	0.003	0.002	1.107	1.423	0.0008
20.08	0.003	0.002	1.109	1.415	0.0008
20.17	0.003	0.002	1.111	1.406	0.0008
20.25	0.003	0.002	1.114	1.397	0.0008
20.33	0.003	0.002	1.116	1.386	0.0008
20.42	0.003	0.002	1.118	1.374	0.0008
20.5	0.003	0.002	1.12	1.361	0.0007
20.58	0.003	0.002	1.122	1.345	0.0007
20.67	0.003	0.002	1.125	1.327	0.0007
20.75	0.003	0.002	1.127	1.308	0.0007

20.83	0.003	0.002	1.129	1.289	0.0007
20.92	0.003	0.002	1.131	1.272	0.0007
21	0.003	0.002	1.133	1.255	0.0007
21.08	0.003	0.002	1.136	1.24	0.0007
21.17	0.003	0.002	1.138	1.225	0.0007
21.25	0.003	0.002	1.14	1.212	0.0007
21.33	0.003	0.002	1.142	1.2	0.0007
21.42	0.003	0.002	1.144	1.189	0.0007
21.5	0.003	0.002	1.147	1.179	0.0006
21.58	0.003	0.002	1.149	1.17	0.0006
21.67	0.003	0.002	1.151	1.162	0.0006
21.75	0.003	0.002	1.153	1.155	0.0006
21.83	0.003	0.002	1.155	1.149	0.0006
21.92	0.003	0.002	1.157	1.145	0.0006
22	0.003	0.002	1.16	1.141	0.0006
22.08	0.003	0.002	1.162	1.139	0.0006
22.17	0.003	0.002	1.164	1.138	0.0006
22.25	0.003	0.002	1.166	1.137	0.0006
22.33	0.003	0.002	1.168	1.139	0.0006
22.42	0.003	0.002	1.17	1.141	0.0006
22.5	0.003	0.002	1.173	1.143	0.0006
22.58	0.003	0.002	1.175	1.145	0.0006
22.67	0.003	0.002	1.177	1.147	0.0006
22.75	0.003	0.002	1.179	1.149	0.0006
22.83	0.003	0.002	1.181	1.152	0.0006
22.92	0.003	0.002	1.183	1.154	0.0006
23	0.003	0.002	1.186	1.156	0.0006
23.08	0.003	0.002	1.188	1.158	0.0006
23.17	0.003	0.002	1.19	1.16	0.0006
23.25	0.003	0.002	1.192	1.163	0.0006
23.33	0.003	0.002	1.194	1.165	0.0006
23.42	0.003	0.002	1.196	1.167	0.0006
23.5	0.003	0.002	1.199	1.169	0.0006
23.58	0.003	0.002	1.201	1.171	0.0006
23.67	0.003	0.002	1.203	1.173	0.0006
23.75	0.003	0.002	1.205	1.176	0.0006
23.83	0.002	0.001	0.804	1.176	0.0006
23.92	0.002	0.001	0.805	1.174	0.0006
24	0.002	0.001	0.806	1.169	0.0006
24.08	0	0	0	1.159	0.0006
24.17	0	0	0	1.142	0.0006
24.25	0	0	0	1.119	0.0006
24.33	0	0	0	1.089	0.0006
24.42	0	0	0	1.054	0.0006
24.5	0	0	0	1.011	0.0006
24.58	0	0	0	0.963	0.0005
24.67	0	0	0	0.908	0.0005
24.75	0	0	0	0.846	0.0005
24.83	0	0	0	0.782	0.0004
24.92	0	0	0	0.714	0.0004
25	0	0	0	0.644	0.0004

25.08	0	0	0	0.577	0.0003
25.17	0	0	0	0.513	0.0003
25.25	0	0	0	0.454	0.0003
25.33	0	0	0	0.398	0.0002
25.42	0	0	0	0.345	0.0002
25.5	0	0	0	0.297	0.0002
25.58	0	0	0	0.252	0.0001
25.67	0	0	0	0.211	0.0001
25.75	0	0	0	0.173	0.0001
25.83	0	0	0	0.139	0.0001
25.92	0	0	0	0.109	0.0001
26	0	0	0	0.083	0.0000
26.08	0	0	0	0.06	0.0000
26.17	0	0	0	0.042	0.0000
26.25	0	0	0	0.027	0.0000
26.33	0	0	0	0.015	0.0000
26.42	0	0	0	0.025	0.0000
26.5	0	0	0	0.018	0.0000
26.58	0	0	0	0.012	0.0000
26.67	0	0	0	0.007	0.0000
26.75	0	0	0	0.004	0.0000
26.83	0	0	0	0.002	0.0000
					0.16

SMADA Analysis
2-YR Storm, HSG-A, Case 3
11/29/00

Time (hrs)	Rainfall (inches)	nfiltratio (inches)	Excess (cfs)	Runoff (cfs)	Runoff (inches)
0.08	0.002	0.002	0	0	0.0000
0.17	0.002	0.002	0	0	0.0000
0.25	0.002	0.002	0	0	0.0000
0.33	0.003	0.003	0	0	0.0000
0.42	0.003	0.003	0	0	0.0000
0.5	0.003	0.003	0	0	0.0000
0.58	0.003	0.003	0	0	0.0000
0.67	0.003	0.003	0	0	0.0000
0.75	0.003	0.003	0	0	0.0000
0.83	0.003	0.003	0	0	0.0000
0.92	0.003	0.003	0	0	0.0000
1	0.003	0.003	0	0	0.0000
1.08	0.003	0.003	0	0	0.0000
1.17	0.003	0.003	0	0	0.0000
1.25	0.003	0.003	0	0	0.0000
1.33	0.003	0.003	0	0	0.0000
1.42	0.003	0.003	0	0	0.0000
1.5	0.003	0.003	0	0	0.0000
1.58	0.003	0.003	0	0	0.0000
1.67	0.003	0.003	0	0	0.0000
1.75	0.003	0.003	0	0	0.0000
1.83	0.003	0.003	0	0	0.0000
1.92	0.003	0.003	0	0	0.0000
2	0.003	0.003	0	0	0.0000
2.08	0.003	0.003	0	0	0.0000
2.17	0.003	0.003	0	0	0.0000
2.25	0.003	0.003	0	0	0.0000
2.33	0.003	0.003	0	0	0.0000
2.42	0.003	0.003	0	0	0.0000
2.5	0.003	0.003	0	0	0.0000
2.58	0.003	0.003	0	0	0.0000
2.67	0.003	0.003	0	0	0.0000
2.75	0.003	0.003	0	0	0.0000
2.83	0.003	0.003	0	0	0.0000
2.92	0.003	0.003	0	0	0.0000
3	0.003	0.003	0	0	0.0000
3.08	0.003	0.003	0	0	0.0000
3.17	0.003	0.003	0	0	0.0000
3.25	0.003	0.003	0	0	0.0000
3.33	0.003	0.003	0	0	0.0000
3.42	0.003	0.003	0	0	0.0000
3.5	0.003	0.003	0	0	0.0000
3.58	0.003	0.003	0	0	0.0000
3.67	0.003	0.003	0	0	0.0000
3.75	0.003	0.003	0	0	0.0000

3.83	0.004	0.004	0	0	0.0000
3.92	0.004	0.004	0	0	0.0000
4	0.004	0.004	0	0	0.0000
4.08	0.004	0.004	0	0	0.0000
4.17	0.004	0.004	0	0	0.0000
4.25	0.004	0.004	0	0	0.0000
4.33	0.004	0.004	0	0	0.0000
4.42	0.004	0.004	0	0	0.0000
4.5	0.004	0.004	0	0	0.0000
4.58	0.004	0.004	0	0	0.0000
4.67	0.004	0.004	0	0	0.0000
4.75	0.004	0.004	0	0	0.0000
4.83	0.004	0.004	0	0	0.0000
4.92	0.004	0.004	0	0	0.0000
5	0.004	0.004	0	0	0.0000
5.08	0.004	0.004	0	0	0.0000
5.17	0.004	0.004	0	0	0.0000
5.25	0.004	0.004	0	0	0.0000
5.33	0.004	0.004	0	0	0.0000
5.42	0.004	0.004	0	0	0.0000
5.5	0.004	0.004	0	0	0.0000
5.58	0.004	0.004	0	0	0.0000
5.67	0.004	0.004	0	0	0.0000
5.75	0.004	0.004	0	0	0.0000
5.83	0.004	0.004	0	0	0.0000
5.92	0.004	0.004	0	0	0.0000
6	0.004	0.004	0	0	0.0000
6.08	0.005	0.005	0	0	0.0000
6.17	0.005	0.005	0	0	0.0000
6.25	0.005	0.005	0	0	0.0000
6.33	0.005	0.005	0	0	0.0000
6.42	0.005	0.005	0	0	0.0000
6.5	0.005	0.005	0	0	0.0000
6.58	0.005	0.005	0	0	0.0000
6.67	0.005	0.005	0	0	0.0000
6.75	0.005	0.005	0	0	0.0000
6.83	0.005	0.005	0	0	0.0000
6.92	0.005	0.005	0	0	0.0000
7	0.005	0.005	0	0	0.0000
7.08	0.005	0.005	0	0	0.0000
7.17	0.005	0.005	0	0	0.0000
7.25	0.005	0.005	0	0	0.0000
7.33	0.005	0.005	0	0	0.0000
7.42	0.005	0.005	0	0	0.0000
7.5	0.005	0.005	0	0	0.0000
7.58	0.005	0.005	0	0	0.0000
7.67	0.005	0.005	0	0	0.0000
7.75	0.005	0.005	0	0	0.0000
7.83	0.005	0.005	0	0	0.0000
7.92	0.005	0.005	0	0	0.0000
8	0.005	0.005	0	0	0.0000

8.08	0.006	0.006	0	0	0.0000
8.17	0.006	0.006	0	0	0.0000
8.25	0.006	0.006	0	0	0.0000
8.33	0.007	0.007	0	0	0.0000
8.42	0.007	0.007	0	0	0.0000
8.5	0.007	0.007	0	0	0.0000
8.58	0.007	0.007	0	0	0.0000
8.67	0.007	0.007	0	0	0.0000
8.75	0.007	0.007	0	0	0.0000
8.83	0.007	0.007	0	0	0.0000
8.92	0.007	0.007	0	0	0.0000
9	0.007	0.007	0	0	0.0000
9.08	0.007	0.007	0	0	0.0000
9.17	0.007	0.007	0	0	0.0000
9.25	0.007	0.007	0	0	0.0000
9.33	0.007	0.007	0	0	0.0000
9.42	0.007	0.007	0	0	0.0000
9.5	0.007	0.007	0	0	0.0000
9.58	0.008	0.008	0	0	0.0000
9.67	0.008	0.008	0	0	0.0000
9.75	0.008	0.008	0	0	0.0000
9.83	0.008	0.008	0	0	0.0000
9.92	0.008	0.008	0	0	0.0000
10	0.008	0.008	0	0	0.0000
10.08	0.009	0.009	0	0	0.0000
10.17	0.009	0.009	0	0	0.0000
10.25	0.009	0.009	0	0	0.0000
10.33	0.011	0.011	0	0	0.0000
10.42	0.011	0.011	0	0	0.0000
10.5	0.011	0.011	0	0	0.0000
10.58	0.014	0.014	0	0	0.0000
10.67	0.014	0.014	0	0	0.0000
10.75	0.014	0.014	0	0	0.0000
10.83	0.017	0.017	0	0	0.0000
10.92	0.017	0.017	0	0	0.0000
11	0.017	0.017	0	0	0.0000
11.08	0.02	0.02	0	0	0.0000
11.17	0.02	0.02	0	0	0.0000
11.25	0.02	0.02	0	0	0.0000
11.33	0.024	0.024	0	0	0.0000
11.42	0.024	0.024	0.069	0.001	0.0000
11.5	0.024	0.024	0.429	0.005	0.0000
11.58	0.097	0.094	5.548	0.061	0.0000
11.67	0.097	0.091	11.443	0.223	0.0001
11.75	0.097	0.088	17.037	0.543	0.0003
11.83	0.258	0.219	70.287	1.513	0.0008
11.92	0.258	0.201	103.129	3.438	0.0019
12	0.258	0.185	132.057	6.585	0.0036
12.08	0.041	0.028	23.498	9.95	0.0055
12.17	0.041	0.028	24.136	13.537	0.0075
12.25	0.041	0.027	24.762	17.347	0.0096

12.33	0.026	0.017	16.078	21.224	0.0117
12.42	0.026	0.017	16.324	25.082	0.0138
12.5	0,026	0.017	16.567	28.842	0.0159
12.58	0.021	0.014	13.789	31.688	0.0175
12.67	0.021	0.014	13.949	33.136	0.0183
12.75	0.021	0.014	14.108	32.759	0.0180
12.83	0.017	0.011	11.151	32.138	0.0177
12.92	0.017	0.011	11.246	31.263	0.0172
13	0.017	0.011	11.342	30.126	0.0166
13.08	0.014	0.009	9.523	28.84	0.0159
13.17	0.014	0.009	9.588	27.4	0.0151
13.25	0.014	0.009	9.653	25.805	0.0142
13.33	0.012	0.007	8.418	24.083	0.0133
13.42	0.012	0.007	8.466	22.234	0.0123
13.5	0.012	0.007	8.514	20.256	0.0112
13.58	0.01	0.006	7.241	18.212	0.0100
13.67	0.01	0.006	7.275	16.131	0.0089
13.75	0.01	0.006	7.309	14.045	0.0077
13.83	0.009	0.006	6.673	12.267	0.0068
13.92	0.009	0.006	6.701	10.981	0.0061
14	0.009	0.006	6.729	10.347	0.0057
14.08	0.008	0.005	6.079	9.778	0.0054
14.17	0.008	0.005	6.101	9.275	0.0051
14.25	0.008	0.005	6.123	8.839	0.0049
14.33	0.007	0.004	5.461	8.437	0.0046
14.42	0.007	0.004	5.479	8.068	0.0044
14.5	0.007	0.004	5.496	7.733	0.0043
14.58	0.007	0.004	4.823	7.421	0.0041
14.67	0.007	0.004	4.836	7.132	0.0039
14.75	0.007	0.004	4.849	6.867	0.0038
14.83	0.007	0.004	4.862	6.619	0.0036
14.92	0.007	0.004	4.875	6.387	0.0035
15	0.007	0.004	4.888	6.174	0.0034
15.08	0.007	0.004	4.901	5.977	0.0033
15.17	0.007	0.004	4.914	5.799	0.0032
15.25	0.007	0.004	4.927	5.638	0.0031
15.33	0.006	0.003	4.233	5.492	0.0030
15.42	0.006	0.003	4.243	5.36	0.0030
15.5	0.006	0.003	4.252	5.243	0.0029
15.58	0.006	0.003	4.262	5.134	0.0028
15.67	0.006	0.003	4.271	5.033	0.0028
15.75	0.006	0.003	4.28	4.939	0.0027
15.83	0.006	0.003	4.289	4.85	0.0027
15.92	0.006	0.003	4.299	4.765	0.0026
16	0.006	0.003	4.308	4.684	0.0026
16.08	0.006	0.003	4.317	4.614	0.0025
16.17	0.006	0.003	4.326	4.555	0.0025
16.25	0.006	0.003	4.336	4.508	0.0025
16.33	0.006	0.003	4.345	4.467	0.0025
16.42	0.006	0.003	4.354	4.435	0.0024
16.5	0.006	0.003	4.363	4.41	0.0024

16.58	0.005	0.003	3.643	4.382	0.0024
16.67	0.005	0.003	3.649	4.35	0.0024
16.75	0.005	0.003	3.655	4.316	0.0024
16.83	0.005	0.003	3.662	4.279	0.0024
16.92	0.005	0.003	3.668	4.239	0.0023
17	0.005	0.003	3.674	4.195	0.0023
17.08	0.005	0.003	3.681	4.149	0.0023
17.17	0.005	0.003	3.687	4.099	0.0023
17.25	0.005	0.003	3.693	4.047	0.0022
17.33	0.005	0.003	3.699	3.998	0.0022
17.42	0.005	0.003	3.705	3.953	0.0022
17.5	0.005	0.003	3.712	3.912	0.0022
17.58	0.005	0.003	3.718	3.875	0.0021
17.67	0.005	0.003	3.724	3.841	0.0021
17.75	0.005	0.003	3.73	3.812	0.0021
17.83	0.004	0.002	2.988	3.779	0.0021
17.92	0.004	0.002	2.992	3.744	0.0021
18	0.004	0.002	2.996	3.705	0.0020
18.08	0.004	0.002	3	3.664	0.0020
18.17	0.004	0.002	3.004	3.619	0.0020
18.25	0.004	0.002	3.008	3.571	0.0020
18.33	0.004	0.002	3.012	3.52	0.0019
18.42	0.004	0.002	3.016	3.467	0.0019
18.5	0.004	0.002	3.02	3.41	0.0019
18.58	0.004	0.002	3.024	3.357	0.0018
18.67	0.004	0.002	3.027	3.308	0.0018
18.75	0.004	0.002	3.031	3.263	0.0018
18.83	0.004	0.002	3.035	3.222	0.0018
18.92	0.004	0.002	3.039	3.185	0.0018
19	0.004	0.002	3.043	3.152	0.0017
19.08	0.004	0.002	3.047	3.123	0.0017
19.17	0.004	0.002	3.05	3.098	0.0017
19.25	0.004	0.002	3.054	3.078	0.0017
19.33	0.004	0.002	3.058	3.061	0.0017
19.42	0.004	0.002	3.062	3.048	0.0017
19.5	0.004	0.002	3.066	3.04	0.0017
19.58	0.004	0.002	3.07	3.035	0.0017
19.67	0.004	0.002	3.073	3.035	0.0017
19.75	0.004	0.002	3.077	3.039	0.0017
19.83	0.003	0.002	2.31	3.036	0.0017
19.92	0.003	0.002	2.312	3.025	0.0017
20	0.003	0.002	2.314	3.008	0.0017
20.08	0.003	0.002	2.317	2.983	0.0016
20.17	0.003	0.002	2.319	2.951	0.0016
20.25	0.003	0.002	2.321	2.911	0.0016
20.33	0.003	0.002	2.323	2.865	0.0016
20.42	0.003	0.002	2.325	2.811	0.0015
20.5	0.003	0.002	2.327	2.75	0.0015
20.58	0.003	0.002	2.329	2.694	0.0015
20.67	0.003	0.002	2.331	2.641	0.0015
20.75	0.003	0.002	2.334	2.592	0.0014

20.83	0.003	0.002	2.336	2.548	0.0014
20.92	0.003	0.002	2.338	2.508	0.0014
21	0.003	0.002	2.34	2.472	0.0014
21.08	0.003	0.002	2.342	2.44	0.0013
21.17	0.003	0.002	2.344	2.412	0.0013
21.25	0.003	0.002	2.346	2.389	0.0013
21.33	0.003	0.002	2.348	2.37	0.0013
21.42	0.003	0.002	2.35	2.355	0.0013
21.5	0.003	0.002	2.352	2.344	0.0013
21.58	0.003	0.002	2.354	2.338	0.0013
21.67	0.003	0.002	2.357	2.336	0.0013
21.75	0.003	0.002	2.359	2.338	0.0013
21.83	0.003	0.001	2.361	2.34	0.0013
21.92	0.003	0.001	2.363	2.342	0.0013
22	0.003	0.001	2.365	2.344	0.0013
22.08	0.003	0.001	2.367	2.346	0.0013
22.17	0.003	0.001	2.369	2.348	0.0013
22.25	0.003	0.001	2.371	2.35	0.0013
22.33	0.003	0.001	2.373	2.352	0.0013
22.42	0.003	0.001	2.375	2.354	0.0013
22.5	0.003	0.001	2.377	2.356	0.0013
22.58	0.003	0.001	2.379	2.359	0.0013
22.67	0.003	0.001	2.381	2.361	0.0013
22.75	0.003	0.001	2.383	2.363	0.0013
22.83	0.003	0.001	2.385	2.365	0.0013
22.92	0.003	0.001	2.387	2.367	0.0013
23	0.003	0.001	2.389	2.369	0.0013
23.08	0.003	0.001	2.391	2.371	0.0013
23.17	0.003	0.001	2.393	2.373	0.0013
23.25	0.003	0.001	2.395	2.375	0.0013
23.33	0.003	0.001	2.398	2.377	0.0013
23.42	0.003	0.001	2.4	2.379	0.0013
23.5	0.003	0.001	2.402	2.381	0.0013
23.58	0.003	0.001	2.404	2.383	0.0013
23.67	0.003	0.001	2.406	2.385	0.0013
23.75	0.003	0.001	2.408	2.387	0.0013
23.83	0.002	0.001	1.606	2.382	0.0013
23.92	0.002	0.001	1.607	2.369	0.0013
24	0.002	0.001	1.608	2.349	0.0013
24.08	0	0	0	2.306	0.0013
24.17	0	0	0	2.241	0.0012
24.25	0	0	0	2.154	0.0012
24.33	0	0	0	2.044	0.0011
24.42	0	0	0	1.911	0.0011
24.5	0	0	0	1.757	0.0010
24.58	0	0	0	1.591	0.0009
24.67	0	0	0	1.415	0.0008
24.75	0	0	0	1.229	0.0007
24.83	0	0	0	1.056	0.0006
24.92	0	0	0	0.896	0.0005
25	0	0	0	0.749	0.0004

25.08	0	0	0	0.615	0.0003
25.17	0	0	0	0.495	0.0003
25.25	0	0	0	0.388	0.0002
25.33	0	0	0	0.295	0.0002
25.42	0	0	0	0.214	0.0001
					0.56