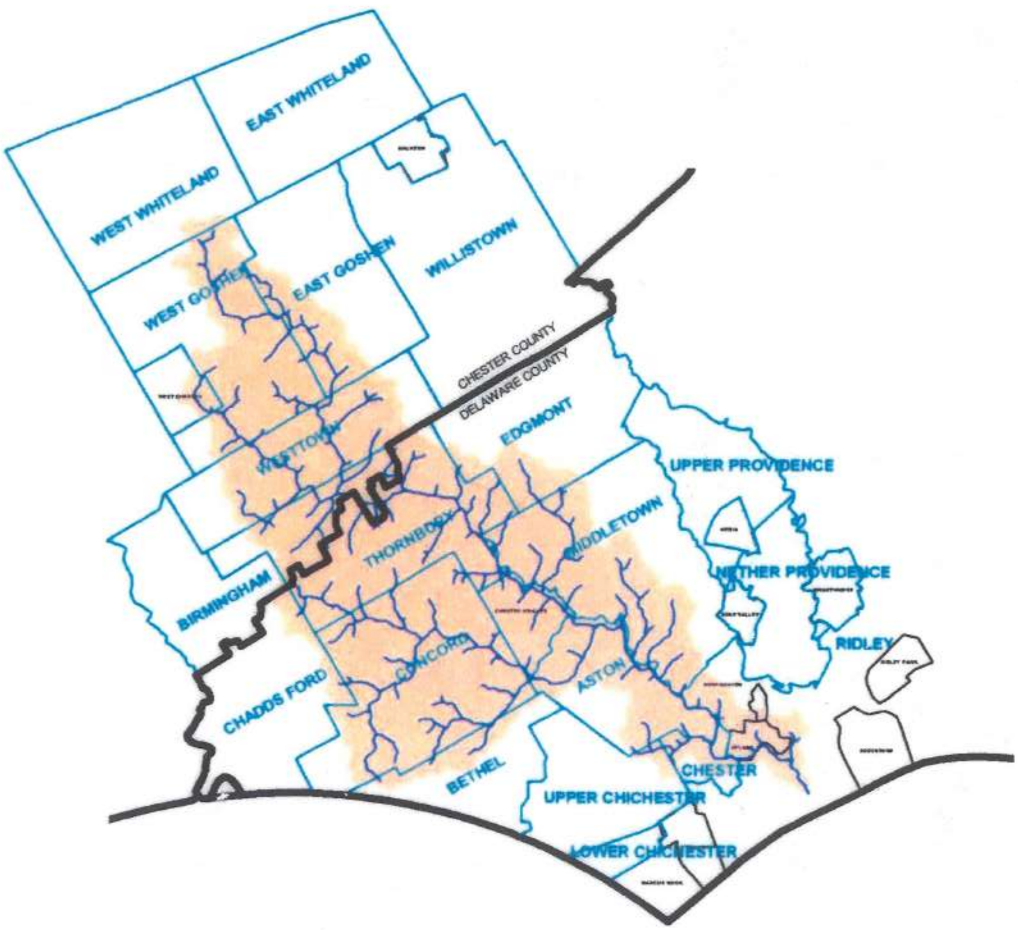
ACT 167
STORMWATER MANAGEMENT PLAN
CHESTER CREEK WATERSHED

VOLUME II
WATERSHED MODELING REPORT



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JUNE 2002

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CHESTER CREEK WATERSHED

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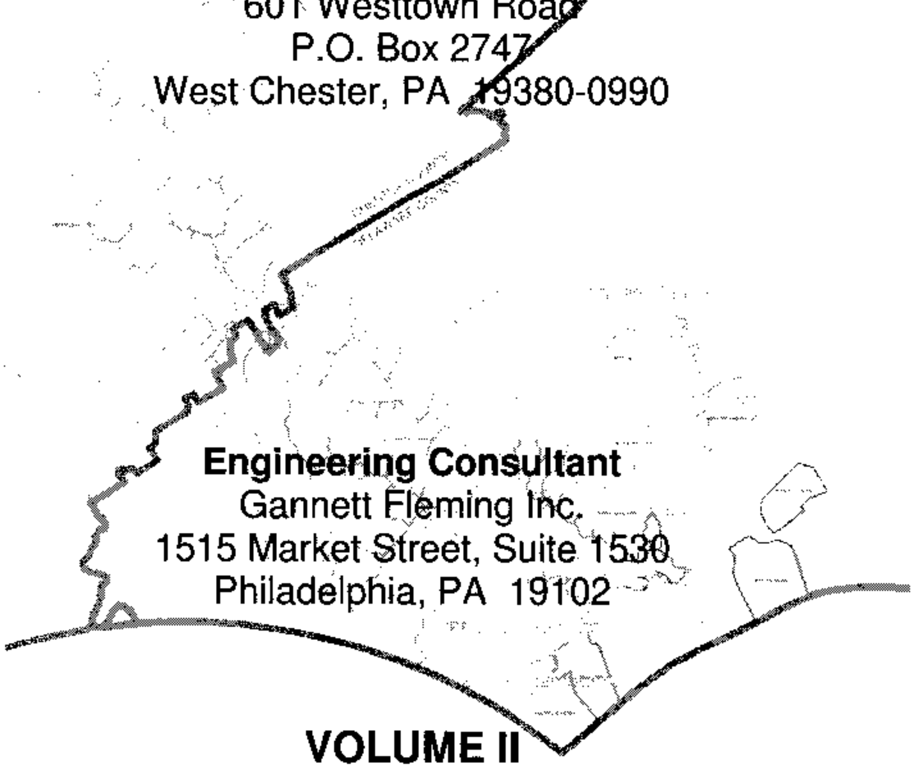

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VOLUME II
WATERSHED MODELING REPORT

JUNE 2002

CHESTER CREEK ACT 167 STUDY

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I. INTRODUCTION AND PURPOSE OF REPORT

Predicting the rate and amount of water that runs off the land surface and into streams is an inexact science. There are a multitude of factors that affect how much of the rainfall will be absorbed by the ground, intercepted and held by plants, or retained in shallow depressions to eventually infiltrate or evaporate. There are numerous methods for estimating runoff characteristics, some of which provide only an estimate of the peak rate of runoff while others also approximate the volume and distribution of runoff over time. The two best known methods for runoff prediction are the Rational Formula and the Runoff Curve Number (RCN) approach. These two methods, as well as an overall description of watershed modeling techniques, are found in **Attachment 1**, Storm Runoff and Streamflow Modeling, located at the end of this watershed modeling report. This attachment also includes a discussion of the rationale for the selection of the specific models used in the Chester Creek Stormwater Management Plan.

The purpose of this watershed modeling report is to summarize the data compiled and the results of the modeling performed during preparation of the Chester Creek Stormwater Management Plan.

II. MODEL EVALUATION AND SELECTION

The Soil Conservation Service's (SCS) (now NRCS) TR-20 model was selected to simulate runoff hydrographs and to route the flows through the stream channels for the watershed. However, due to the size and complexity of the watershed, we investigated using a geographic information system (GIS)-based approach to streamline the TR-20 model construction.

Brigham Young University's Environmental Modeling Research Laboratory created a comprehensive GIS-based hydrologic modeling environment called WMS, Watershed Modeling System. WMS uses GIS-based coverages to construct databases for hydrologic models and provides a graphical user interface for the HEC-1, TR-20, TR-55, Rational Method, LA County's F0601, and National Flood Frequency Program (NFF) models. The inherent flexibility with using GIS and the numerous models supported by WMS were major factors in the selection of WMS for the project.

The County of Lancaster, Pennsylvania, County Engineer's Office created a program, STREMTUL, that incorporates TR-20 and the Penn State Runoff Model (PSRM). The program was designed specifically for the determination of release rates using TR-20 input files and PSRM for the calculation of release rates according to the Act 167 guidelines. STREMTUL was used to calculate release rates for this study.

III. MODELING DATA

The TR-20 model requires two types of data: information regarding the land surface used to develop runoff hydrographs and information describing the channel characteristics used to route hydrographs downstream. The following paragraphs describe the source of the information used in developing the modeling database.

A. Watershed Subareas

The Chester Creek watershed was divided into 123 modeling subareas as shown on **Plate 1**. The locations of the subarea discharge points were selected based on two criteria: they occurred at major tributary points along the stream or at the location of key road or railroad crossings. Once the downstream discharge points were selected, the boundaries of the subwatersheds were delineated based on topography. Using this approach to develop subwatershed boundaries provides a convenient tree-like structure for the channel routing process. **Table 1** provides the areas of the individual subwatersheds.

B. Soils

There are approximately 26 different soil series within the watershed boundaries. The primary soils are the Glenelg series, which cover approximately 42% of the Chester Creek watershed. Another 9% of the watershed consists of the Glenville series. The remaining watershed is interspersed with numerous other soil series classifications. A complete breakdown of the individual soil series located within the watershed can be found in **Appendix A**.

TABLE 1 SUBWATERSHED AREAS					
TR-20 Subbasin ID	Area Sq. Mi.	TR-20 Subbasin ID	Area Sq. Mi.	TR-20 Subbasin ID	Area Sq. Mi.
1	0.66	42	0.70	83	0.99
2	0.24	43	0.49	84	0.64
3	0.62	44	0.70	85	0.86
4	0.27	45	0.62	86	0.39
5	0.88	46	0.76	87	0.71
6	0.52	47	0.25	88	0.17
7	0.52	48	0.70	89	0.54
8	0.22	49	0.20	90	0.36
9	0.22	50	0.41	91	1.02
10	0.63	51	1.03	92	0.53
11	0.62	52	0.66	93	0.55
12	0.65	53	0.08	94	0.19
13	0.33	54	0.53	95	0.71
14	0.64	55	0.19	96	0.27
15	0.68	56	0.54	97	0.65
16	0.67	57	0.27	98	0.31
17	0.33	58	0.66	99	0.83
18	0.41	59	0.81	100	0.49
19	0.19	60	0.04	101	0.99
20	0.62	61	0.51	102	0.26
21	0.01	62	0.51	103	0.83
22	0.86	63	0.49	104	0.37
23	0.54	64	0.63	105	0.21
24	0.34	65	0.94	106	0.64
25	1.20	66	0.77	107	0.50
26	0.57	67	0.46	108	0.06
27	0.22	68	0.15	109	0.47
28	0.63	69	0.44	110	0.10
29	0.47	70	0.55	111	0.68
30	0.09	71	0.28	112	0.25
31	1.05	72	1.01	113	0.94
32	0.41	73	0.13	114	0.32
33	1.14	74	0.67	115	0.51
34	0.15	75	0.98	116	0.75
35	0.30	76	0.43	117	0.27
36	0.46	77	0.72	118	0.44
37	1.06	78	0.10	119	0.71
38	0.06	79	0.79	120	0.41
39	0.14	80	0.57	121	0.44
40	0.91	81	0.01	122	1.05
41	0.40	82	1.00	123	0.99

Source: Gannett Fleming, 2001

The Glenelg-Manor-Chester association is the largest soil association in Chester and Delaware Counties and is found in all areas of the watershed. Glenelg soils are typically found in upland areas on level to steep slopes. They are typically well drained and moderately deep. Glenelg soils are generally formed from weathered granite, gneiss, and mica schist.

Made land is defined as areas where the soil has been moved and removed or added and mixed to provide a suitable surface for development. These areas have a high degree of variability within the soils and may consist of clean fill or construction fill. Made land is scattered throughout the watershed in developed areas and makes up about 7% of the watershed.

The hydrologic soil type is a classification applied by SCS in its soils mapping documents published for each county. The hydrologic soil type relates to the infiltration and saturation characteristics of the soils. **Plate 2** shows the hydrologic soil types found in the Chester Creek watershed, and **Table 2** describes the general characteristics of the four hydrologic soil types.

TABLE 2
HYDROLOGIC SOIL TYPE CHARACTERISTICS

HYDROLOGIC SOIL TYPE	SOIL CHARACTERISTICS
A	Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively well drained sands or gravels. These soils have low runoff potential and a high rate of water transmission.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
D	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission and high runoff potential.

Source: *National Engineering Handbook, Section 4, Hydrology*, Soil Conservation Service, 1972

C. Land Use

Existing land use in the watershed includes all major types: residential, commercial, industrial, institutional, agricultural, and forestry. Existing land use was defined based on mapping provided by the Delaware County Planning Department (DCPD) and the Chester County Planning Commission (CCPC).

Plate 3 shows the breakdown of the watershed by the major land use categories, and **Table 3** provides a summary of the acreages associated with each land use. The watershed is generally located southwest and west of Philadelphia, Pennsylvania. As such, the watershed is dominated by suburban and urban areas with a mixture of wooded land interspersed along the streams and rivers. Agricultural land is also interspersed throughout the watershed. There are no dominant geographical features that limit, define, or divide the existing land use. Overall, towns and township development, agricultural lands, and wooded areas are intermixed throughout the watershed similar to a patchwork quilt. However, since the Chester Creek watershed is located in close proximity to Philadelphia, the watershed is dominated by suburban housing.

The predominant land use within the Chester Creek watershed is medium- and low-density residential, while the second largest land use is wooded. Combined, residential land use covers over 41% of the total watershed. Agricultural and wooded land uses account for another 41% of the total watershed. The remaining 18% of the watershed is a combination of commercial, industrial, institutional, and other land uses.

Future land development was based on the current municipal zoning maps for the watershed within Chester and Delaware Counties. However, due to the extent of the present development and the urban/suburban nature of the watershed, the majority of future land development will be restricted to the wooded and agricultural land or infilling and redevelopment in urban areas. All other areas of the watershed are presently developed and will not be altered significantly by future development that will impact the rainfall-runoff characteristics of the watershed. Therefore, the future development conditions were limited to the wooded and agricultural areas within the watershed as illustrated on the map in **Plate 4.**

TABLE 3 SUMMARY OF LAND USE ACREAGE			
LAND USE CATEGORY	**PERCENTAGE**	**ACRES**	**SQ MI**
AGRICULTURE/PASTURE	11.57	4849.2	7.6
COMMERCIAL	3.99	1670.7	2.6
HIGH-DENSITY RESIDENTIAL	2.77	1159.1	1.8
INDUSTRIAL	1.96	823.2	1.3
INSTITUTIONAL	2.38	995.6	1.6
LOW-DENSITY RESIDENTIAL	13.68	5732.7	9.0
MEDIUM-DENSITY RESIDENTIAL	23.35	9783.9	15.3
MILITARY	0.01	4.7	0.0
MINING/QUARRY	0.46	192.3	0.3
OPEN SPACE	2.40	1004.4	1.6
RECREATION	2.30	962.1	1.5
TRANSPORTATION	2.64	1105.2	1.7
UTILITY	0.98	410.4	0.6
WATER	0.77	3225.	0.5
WOODED	30.76	12889.4	20.1
TOTALS	**100.00**	**41905.3**	**65.5**

Source: Gannett Fleming, 2001

Under the future development conditions, the municipal zoning maps indicate that the watershed will continue to develop as a predominantly medium- to low-density residential area with commercial, industrial, and high-density residential areas intermixed. The nature of the future development in the existing wooded and agricultural areas will continue to be low- and medium-density housing. As a by-product of this development, small commercial and industrial areas will develop in support of this growth, primarily providing service type goods and industries. Approximately 80% of the future growth will be low- and medium-density residential housing and the remaining 20% a mix of commercial, industrial, institutional, open space, manufacturing, and mixed use.

D. Runoff Curve Number

The TR-20 model uses a modeling parameter called RCN to estimate the volume of rainfall that runs off the subwatershed area versus the amount that is assumed to infiltrate or be trapped in surface depressions. The RCN is an empirical coefficient derived from two physical characteristics of the subwatershed: the hydrologic soil type and the land cover. NRCS has published RCN values for various combinations of soil and land cover. **Table 4** is a listing of RCN values compiled from *Urban Hydrology for Small Watersheds* published by NRCS.

TABLE 4
RUNOFF CURVE NUMBER CLASSIFICATION

Land Use		**Runoff Curve Number for Hydrologic Soil Group**			
		A	**B**	**C**	**D**
Open Space:	Poor Condition	68	79	86	89
	Fair Condition	49	69	79	84
	Good Condition	39	61	74	80
Impervious Areas:	Paved Parking Lots, Roofs, Driveways	98	98	98	98
	Paved Streets and Roads	98	98	98	98
	Gravel Streets and Roads	76	85	89	91
Urban Districts:	Commercial and Business	89	92	94	95
	Industrial	81	88	91	93
Residential Districts:	1/8 Acre Lots or less (townhouses)	77	85	90	92
	1/4 Acre Lots	61	75	83	87
	1/3 Acre Lots	57	72	81	86
	1/2 Acre Lots	54	70	80	85
	1 Acre Lots	51	68	79	84
	2 Acre Lots or Larger	46	65	77	82
Fallow Land:	Bare Soil	77	86	91	94
	Crop Residue Cover	74	83	88	90
Row Crops:	Straight Row	67	78	85	89
	Contoured	65	75	82	86
	Contoured and Terraced	62	71	78	81
Small Grain:	Straight Row (Good Condition)	63	75	83	87
	Contoured (Good Condition)	61	73	81	84
	Contoured and Terraced (Good Condition.)	59	70	78	81
Pasture:	For Grazing – Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
	For Hay	30	58	71	78
Brush:	Poor: < 50% ground cover	48	67	77	83
	Fair: 50 to 75 % ground cover	35	56	70	77
	Good: > 75% ground cover	30	48	65	73
Woods:	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77

Source: *Urban Hydrology for Small Watersheds*, NRCS

The RCN values were developed for the 123 subbasins based on a combined weighted average of land use and underlying soil type. **Appendix B** lists the RCN for hydrologic soil groups for each land use category. The average overall RCN value for the Chester Creek watershed is 74. RCN values were also developed for the future conditions model. As previously mentioned, future development will only occur in wooded and agricultural areas. All other areas are developed and have an RCN value assigned based on the type of existing land use. Future development is also assumed to continue with the same historical development patterns presently established.

Using these assumptions, the future conditions were modeled by increasing the existing RCN in areas of the watershed that are currently wooded or under agricultural use. The RCN values for all agricultural and wooded areas were increased to the existing average watershed RCN of 74. Designated open space was not assumed to develop under the future condition. Weighted curve numbers for all of the subareas within the watershed were recomputed based on the change in RCN value in wooded and agricultural areas. The minimum RCN value of 74 was determined to represent the weighted curve number for the suburban growth that will occur throughout the watershed over the next 10 to 20 years. This accounts for the predominant residential growth with intermixed commercial and industrial areas expected to occur within the watershed. **Table 5** summarizes the existing and projected RCN values for the Chester Creek watershed. **Appendices C and D** provide additional information on the TR-20 subbasin characteristics for existing and projected development conditions, respectively.

E. Time of Concentration

A modeling parameter that strongly affects the shape of the runoff hydrograph and the timing and value of the peak discharge from the subwatershed is the time of concentration (T_C). The T_C is, in effect, the time it takes for a raindrop to move following the longest path (in terms of time) in the subwatershed to the discharge point. Since the T_C represents the longest path in time, it may not be the longest path in terms of total length due to varying land cover and slope conditions. NRCS has developed a methodology and worksheet for calculating T_C that involves defining different flow regimes (sheet flow, shallow channel flow, and channel flow) based on land cover, slopes, and lengths. WMS used the three-dimensional topographic coverage for the watershed to determine the

TABLE 5 EXISTING AND PROJECTED RUNOFF CURVE NUMBERS								
TR-20 Subbasin ID	**Existing NRCS CN**	**Proposed NRCS CN**	**TR-20 Subbasin ID**	**Existing NRCS CN**	**Proposed NRCS CN**	**TR-20 Subbasin ID**	**Existing NRCS CN**	**Proposed NRCS CN**
1	75.8	77.0	**42**	66.4	73.7	**83**	74.3	78.1
2	82.8	84.1	**43**	68.5	72.7	**84**	73.9	75.7
3	77.4	78.7	**44**	74.7	76.3	**85**	67.9	74.6
4	80.0	83.2	**45**	66.0	71.5	**86**	69.9	72.3
5	81.0	81.9	**46**	72.2	73.1	**87**	71.1	75.4
6	78.1	78.8	**47**	68.1	74.2	**88**	77.2	77.5
7	86.0	86.0	**48**	70.4	75.0	**89**	71.3	74.7
8	78.2	79.5	**49**	82.0	83.4	**90**	76.2	76.4
9	80.4	80.4	**50**	75.5	76.4	**91**	71.6	75.5
10	81.5	81.6	**51**	63.4	64.1	**92**	78.1	78.1
11	72.7	74.0	**52**	57.3	58.6	**93**	73.8	76.1
12	77.3	77.3	**53**	82.4	83.5	**94**	68.8	70.3
13	82.7	82.7	**54**	71.3	74.8	**95**	74.6	74.8
14	76.1	78.7	**55**	71.7	74.4	**96**	80.3	81.4
15	76.5	76.5	**56**	76.8	76.8	**97**	70.6	72.9
16	75.9	76.6	**57**	82.8	82.8	**98**	70.5	74.8
17	72.9	74.6	**58**	76.8	76.8	**99**	69.7	74.2
18	76.2	76.6	**59**	71.9	71.9	**100**	74.7	79.8
19	73.8	74.5	**60**	94.0	94.0	**101**	74.2	77.6
20	73.6	76.4	**61**	69.9	72.4	**102**	75.9	78.5
21	79.5	80.5	**62**	74.4	77.8	**103**	73.2	77.8
22	74.8	76.2	**63**	68.7	72.3	**104**	84.1	84.3
23	74.3	75.7	**64**	70.1	76.3	**105**	84.0	86.4
24	75.9	76.7	**65**	76.0	76.0	**106**	74.6	76.8
25	88.7	88.7	**66**	73.1	76.7	**107**	72.0	75.5
26	84.7	84.7	**67**	70.0	76.7	**108**	70.7	74.6
27	85.0	85.6	**68**	63.7	77.3	**109**	73.2	78.2
28	81.9	82.0	**69**	75.1	77.9	**110**	64.7	68.7
29	74.8	76.7	**70**	72.8	75.9	**111**	72.5	73.5
30	71.9	74.6	**71**	71.9	75.4	**112**	68.8	72.8
31	73.8	73.9	**72**	70.1	74.0	**113**	71.7	75.6
32	79.3	80.4	**73**	71.9	73.5	**114**	69.1	74.8
33	75.0	76.2	**74**	78.1	79.8	**115**	76.8	77.4
34	72.2	75.9	**75**	72.1	77.0	**116**	73.7	77.4
35	75.0	76.3	**76**	74.0	74.9	**117**	79.9	81.3
36	71.8	73.3	**77**	70.1	73.6	**118**	80.6	81.0
37	68.8	72.3	**78**	58.0	75.8	**119**	77.3	79.9
38	68.6	73.5	**79**	71.2	76.2	**120**	76.8	79.1
39	62.8	71.3	**80**	73.1	75.8	**121**	73.7	77.4
40	66.7	73.6	**81**	73.0	76.0	**122**	77.5	79.2
41	65.9	72.9	**82**	74.0	77.0	**123**	85.5	85.9

Source: Gannett Fleming, 2001

T_c based on the NRCS methodology. **Table 6** summarizes these values for all of the subbasins modeled. The T_c values were not adjusted for future development.

F. Channel Length and Slope

Channel lengths and slopes were obtained from contour data representing Chester and Delaware Counties. The channels were broken into modeling reaches of similar slope. Then the length and average slope of the channel reaches between section points were determined from the contours. The TR-20 model is based on the assumption that the channel length and slope coded in the model database represent the channel reach that is downstream from the section.

G. Channel Cross-Sections and Capacity

Channel cross-sections were estimated based on field measurements taken at bridge locations during the obstruction inventory program, pictures at the bridge locations, and topographic maps of the watershed. Based on this information, the stream channels within the banks were assumed to be generally trapezoidal with steep side slopes (1H:1V). The overbank floodplain was assumed to slope outward at a constant positive slope. The heights of the streambank and channel bottom width were estimated at bridge locations throughout the watershed. From these estimated channel dimensions, generalized stream cross-sections were developed. The generalized stream cross-sections were assumed to apply for different stream reach lengths within the watershed where similar slope and cross-section characteristics were encountered. A total of 83 cross-sections were used in the TR-20 model. These locations are shown on **Plate 1.**

The flow capacity for each section was estimated using Haestad Method's FlowMaster computer program. This program uses channel geometry and Manning's coefficient and develops a stage-discharge curve based on Manning's equation. A Manning's coefficient was estimated based on the photographs taken during the field reconnaissance. Summaries from the FlowMaster program are included in **Appendix E.**

TABLE 6
TIME OF CONCENTRATION FOR ALL SUBAREAS

TR-20 Subbasin ID	Tc Hours	TR-20 Subbasin ID	Tc Hours	TR-20 Subbasin ID	Tc Hours
1	0.46	**42**	0.50	**83**	0.52
2	0.39	**43**	0.34	**84**	0.44
3	0.45	**44**	0.56	**85**	0.49
4	0.35	**45**	0.26	**86**	0.35
5	0.64	**46**	0.41	**87**	0.36
6	0.48	**47**	0.27	**88**	0.19
7	0.49	**48**	0.39	**89**	0.34
8	0.36	**49**	0.51	**90**	0.30
9	0.42	**50**	0.78	**91**	0.52
10	0.58	**51**	1.34	**92**	1.34
11	0.45	**52**	1.12	**93**	1.41
12	0.43	**53**	0.46	**94**	0.24
13	0.38	**54**	0.31	**95**	0.46
14	1.20	**55**	0.26	**96**	0.86
15	0.41	**56**	0.86	**97**	0.39
16	0.39	**57**	0.64	**98**	0.28
17	0.38	**58**	1.06	**99**	0.57
18	0.33	**59**	0.99	**100**	0.35
19	0.30	**60**	0.27	**101**	1.20
20	0.41	**61**	0.84	**102**	0.60
21	0.18	**62**	0.92	**103**	1.17
22	0.48	**63**	0.87	**104**	0.71
23	0.45	**64**	1.23	**105**	0.59
24	0.43	**65**	1.27	**106**	0.95
25	1.06	**66**	1.28	**107**	1.33
26	0.63	**67**	1.03	**108**	0.42
27	0.36	**68**	0.75	**109**	0.98
28	0.52	**69**	1.01	**110**	0.61
29	0.35	**70**	0.37	**111**	1.38
30	0.18	**71**	0.36	**112**	1.03
31	0.53	**72**	0.51	**113**	1.31
32	0.38	**73**	0.27	**114**	1.08
33	0.50	**74**	0.50	**115**	1.00
34	0.28	**75**	0.58	**116**	1.66
35	0.34	**76**	0.40	**117**	1.38
36	0.30	**77**	0.46	**118**	1.18
37	0.50	**78**	0.16	**119**	1.94
38	0.27	**79**	0.77	**120**	1.37
39	0.25	**80**	0.67	**121**	1.19
40	0.50	**81**	0.11	**122**	1.84
41	0.37	**82**	0.53	**123**	2.42

Source: Gannett Fleming, 2001

H. Road Crossings (Bridges and Culverts)

Road crossings can have a significant impact on the flow characteristics of streams. Quite often roads can act as dams, restricting the flow of water through the bridge or culvert opening and storing excess flow upstream of the roadway embankment. These storage areas will reduce flood flows during some storm events. For this study, the physical dimensions of all of the road crossings in the watershed were obtained through field measurement. Then a preliminary evaluation was performed to determine the relative effect the structure would have during a storm event. Only major stream crossings over main stem river reaches were considered for inclusion in the model. For this study, it was determined that none of the major crossings represented a significant restriction to flood flows, and, therefore, no stream crossings were modeled as a detention basin in the TR-20 model.

I. Reservoirs, Detention Ponds, and Storm Sewers

A review of Pennsylvania Department of Environmental Protection (DEP) records revealed that a total of 14 regulated reservoirs are located within the Chester Creek watershed. **Appendix F** provides a summary of the reservoir characteristics. Of the 14 total dams, 4 have been breached, and 7 are run-of-river structures with no flood storage. The final three dams (Brinton Lake, Milltown Dam, and Township Line Dam) were evaluated for inclusion in the TR-20 model. Brinton Lake Dam is a small dam, 5 feet in height, and located on an unnamed tributary to Chester Creek. The dam has a small drainage area with little storage and was determined to have an insignificant impact on the overall results. Milltown Dam and Township Line Dam are significant structures. Phase I inspection reports for both dams were reviewed as an informational source for this study. They indicated that the dams are operated as a water supply for local residents. The operating normal water level is the spillway crest in both cases, and the spillway is sized to pass over the 100-year flood event. Given this information, under the flood conditions modeled for this study, the dams will pass the flood flows without attenuation. Therefore, none of the regulated dams were modeled as part of this study.

Information regarding unregulated dams and regional detention ponds or other ponds was not available for this study, and, therefore, no dams, ponds, or detention basins were incorporated into the TR-20 analysis.

IV. RAINFALL STATISTICS

Historical rainfall data was analyzed for this study. A list of the precipitation gauging stations within and surrounding the Chester Creek watershed are listed in **Appendix G**. A total of 20 gauging stations listing daily precipitation are located in or around the watershed. The three closest gauges, Chadds Ford, Marcus Hook, and West Chester, representing 40 years of record, were selected for further evaluation. A frequency analysis was performed on each gauge and compared with the PennDOT Storm Intensity-Duration-Frequency Charts (May 1986). The results of this analysis show that the PennDOT rainfall volumes were slightly larger during most storm events. The Marcus Hook gauge had higher precipitation volumes for the 50- and 100-year storms, but the gauge is located outside of the watershed and may not be a good indicator of the overall precipitation characteristics. We decided that, overall, the statistical rainfall volumes from the PennDOT Storm Intensity-Duration-Frequency Charts best represent the entire watershed area for all storm events. The Chester Creek watershed is located in Rainfall Region 2. The rainfall volumes for a 24-hour storm event were determined to be as shown in **Table 7.** Further rainfall data can be found in **Appendix G.**

TABLE 7 RAINFALL VOLUMES						
Return Frequency (Years)	2	5	10	25	50	100
Rainfall Volume (Inches)	3.40	4.10	5.00	6.00	7.20	8.50

Source: PennDOT Storm Intensity-Duration-Frequency Charts – Rainfall Region 2

V. MODEL CALIBRATION

There is a streamflow recording station on Chester Creek near the City of Chester (Gauge #01477000) which has been operated by the U.S. Geological Survey since 1931. The flow records were obtained and a flood frequency analysis performed on the peak values for the period of 1932-1989. Peak flood flow data for this gauge was only available until 1989, and, thus, for this study the frequency analysis only covers the period of record from 1932 through 1989. **Table 8** shows the results of the frequency analysis for the gauge data.

The average daily flow during the recording period was 91 cubic feet per second (cfs), and the greatest instantaneous peak flow recorded was 21,000 cfs on September 13, 1971. Stream gauge information and the flood frequency analysis for Chester Creek are presented in **Appendix H**.

TABLE 8 FLOOD FREQUENCY RESULTS	
Frequency in Yrs.	**Flow in CFS**
2	2,720
5	5,120
10	6,740
25	9,940
50	12,800
100	21,000

Source: USGS Gauge #01477000 (1932-1989)

The Chester Creek gauge was used for calibration of the TR-20 existing conditions model. However, the model outlet and the gauge location are not at the same location. The TR-20 outlet point is located at the confluence of Chester Creek and the Delaware River. The gauge is located approximately 3 miles upstream from the confluence. Therefore, an areal adjustment was used to translate the gauge flows downstream to the outlet point. The adjusted flood frequency data was used to calibrate the TR-20 existing conditions model. Further information on the area adjustment used is located in **Appendix H**.

The initial TR-20 model was run using the Antecedent Moisture Condition (AMC) 2 moisture conditions, and the peak flows were orders of magnitude higher (approximately 166% larger) than those recorded at the gauging station. In order to reduce these flows, the model was adjusted using the NRCS AMC 1 condition. The AMC 1 condition assumes dry conditions (less than 0.5 inch of rain occurring in the previous five days) and has the lowest potential for runoff. After adjusting the model, the peak flows were within approximately 3% to 55% of the gauge data. See **Table 9** for calibration results. The results showed relatively good agreement with the gauged data, and no further adjustment was made to the model.

TABLE 9 CALIBRATION RESULTS					
Adjusted			TR-20 RESULTS AT OUTLET POINT		
Flood Frequency (YRS)	PDT-IDT Precipitation (IN)	Gauge Discharge* (CFS)	Existing Conditions Model		Future Conditions Model 1 (CFS)
			AMC 1 (CFS)	Difference (%)	
2-YR	3.4	2,900	1,242	-57	1,691
5-YR	4.1	5,500	2,538	-54	3,279
10-YR	5.0	7,200	5,039	-30	6,273
25-YR	6.0	10,600	8,426	-21	10,216
50-YR	7.2	13,600	13,817	2	16,527
100-YR	8.5	22,400	21,049	-6	24,486

* Adjusted to compensate for area difference
Source: Gannett Fleming, 2001

VI. MODELING RESULTS

Model runs were made for each return frequency storm. The full model output is too voluminous to include in this report. However, the summary tables from each model run, existing and proposed, are provided in **Appendix I**. **Table 10** provides a summary of the existing and future flows located at key points throughout the watershed.

VII. COMPARISON OF RESULTS

Future growth conditions were modeled in TR-20 and compared to the existing conditions model. As noted previously, the future model had increased RCN values in only agricultural and wooded areas. The discussion of the results is based on percentages of flow, and more specifically, the percentage of increase in flow from the existing to future conditions. Therefore, it should be noted that a 1% increase during larger flows will be greater than a 1% increase during a smaller flow.

The results show that during the future conditions, increases in flow at the outlet will range from 42% to 17%, depending on the flood modeled. There will be approximately a 42% increase for the 2-year

TABLE 10
SUBAREA RELEASE RATE SUMMARY

SUBAREA ID	EXISTING FLOW (CFS)	FUTURE FLOW CONTROLLED (CFS)	DESIGNATED RELEASE RATE	SUBAREA ID	EXISTING FLOW (CFS)	FUTURE FLOW CONTROLLED (CFS)	DESIGNATED RELEASE RATE
1	546	309	0.50	**41**	9,418	8,346	0.50
2	344	172	0.50	**42**	9,906	8,964	0.75
3	1,382	794	0.50	**43**	289	160	0.50
4	1,456	974	0.50	**44**	552	276	0.50
5	731	798	1.00	**45**	9,904	9,163	0.75
6	1,546	1,404	1.00	**46**	590	620	1.00
7	636	636	1.00	**47**	169	85	0.50
8	1,086	898	0.50	**48**	608	337	0.50
9	272	272	1.00	**49**	10,348	9,767	0.50
10	2,187	2,013	1.00	**50**	10,408	9,848	1.00
11	2,442	2,243	0.50	**51**	196	211	1.00
12	2,155	2,076	1.00	**52**	10,649	10,056	0.50
13	2,191	2,128	1.00	**53**	104	104	1.00
14	360	180	0.50	**54**	452	226	0.50
15	638	638	1.00	**55**	600	314	0.50
16	2,709	2,595	1.00	**56**	11,003	10,534	1.00
17	278	139	0.50	**57**	10,961	10,541	1.00
18	459	471	1.00	**58**	409	409	1.00
19	499	517	1.00	**59**	11,412	10,934	1.00
20	984	777	0.50	**60**	12,478	11,699	1.00
21	3,136	3,106	0.50	**61**	224	117	0.50
22	3,652	3,475	0.50	**62**	495	248	0.50
23	392	236	0.50	**63**	189	99	0.50
24	4,249	3,776	1.00	**64**	809	484	0.50
25	1,300	1,300	1.00	**65**	507	507	1.00
26	1,852	1,852	1.00	**66**	339	339	1.00
27	1,984	1,988	1.00	**67**	12,819	12,133	0.50
28	753	758	1.00	**68**	12,781	12,149	1.00
29	2,590	2,637	0.50	**69**	260	260	1.00
30	2,534	2,590	0.50	**70**	468	234	0.50
31	786	788	1.00	**71**	575	356	0.50
32	392	257	0.50	**72**	1,172	669	0.50
33	1,310	746	0.50	**73**	120	60	0.50
34	4,271	3,777	0.50	**74**	1,828	1,055	0.50
35	4,427	3,926	0.75	**75**	3,174	1,915	0.50
36	296	204	0.50	**76**	343	379	1.00
37	5,213	4,428	0.50	**77**	465	233	0.50
38	9,332	8,143	0.75	**78**	21	11	0.50
39	9,356	8,187	0.75	**79**	408	204	0.50
40	403	202	0.50	**80**	761	384	0.50

TABLE 10
SUBAREA RELEASE RATE SUMMARY (CONT'D.)

SUBAREA ID	EXISTING FLOW (CFS)	FUTURE FLOW CONTROLLED (CFS)	DESIGNATED RELEASE RATE	SUBAREA ID	EXISTING FLOW (CFS)	FUTURE FLOW CONTROLLED (CFS)	DESIGNATED RELEASE RATE
81	742	389	0.50	**103**	389	389	1.00
82	754	377	0.50	**104**	403	408	1.00
83	1,859	1,153	0.50	**105**	623	518	0.50
84	2,014	1,416	0.50	**106**	927	678	0.50
85	4,949	3,342	0.50	**107**	20,064	101	0.50
86	4,804	3,482	0.50	**108**	42	42	1.00
87	556	278	0.50	**109**	20,177	19,375	0.50
88	4,937	3,793	1.00	**110**	33	33	1.00
89	440	220	0.50	**111**	266	139	0.50
90	4,780	4,053	1.00	**112**	20,266	19,498	0.50
91	677	339	0.50	**113**	378	378	1.00
92	307	307	1.00	**114**	20,318	19,694	0.50
93	545	426	0.50	**115**	20,267	19,722	1.00
94	147	74	0.50	**116**	295	295	1.00
95	877	872	1.00	**117**	172	86	0.50
96	224	112	0.50	**118**	459	386	1.00
97	1,404	1,218	0.50	**119**	763	544	0.50
98	1,441	1,306	0.50	**120**	20,822	20,319	0.50
99	6,337	5,679	0.50	**121**	20,687	20,294	1.00
100	6,305	5,890	0.50	**122**	20,677	20,409	1.00
101	19,455	18,496	0.75	**123**	21,048	20,748	1.00
102	19,388	48,505	1.00				

Source: Gannett Fleming, 2001

storm event, a 30% increase during the 5-year storm event, a 26% increase during the 10-year storm event, a 21% increase during the 25-year event, a 20% increase during the 50-year flood, and a 17% increase during the 100-year event. The largest increase in flow at the outlet occurred during the 2- through 10-year precipitation events.

In each individual subbasin, the increase in flow during future conditions is highly variable, depending upon the precipitation event and subbasin modeled. In approximately 10% (13) of the subbasins, the future and existing conditions remained the same, and, therefore, there was zero increase in these basins. However, during the 2-, 5-, 10-, 25-, 50-, and 100-year precipitation events, the average increase in runoff for the individual subbasins was 101%, 119%, 116%, 78%, 47%, and 28%, respectively. The actual flow values for each subbasin are summarized by precipitation event for the existing and future conditions models in **Appendix I.** **Table 10** shows a summary of the TR-20 model output at key sections throughout the watershed.

Based on the anticipated increases in flow in the future, release rates were developed for the 123 subbasins in the Chester Creek watershed using the STREMTUL computer program. Release rates were developed for 84 points within the watershed, corresponding to the TR-20 stream cross-sections. In certain instances, more than one subbasin has the potential to drain to the same release rate outlet point. In these cases where multiple subareas drain to a common release rate point, the release rate will be the same for all of the subareas draining to that commonly defined outlet point.

STREMTUL calculates release rates using the PSRM methodology from an existing and future conditions TR-20 input file. If there are no changes in the RCN value or T_C , STREMTUL will not determine a release rate. For all other basins a release rate is determined. In STREMTUL, a release rate is calculated without regard to magnitude and may be unrealistic since the analysis does not account for attenuation of a flood peak as it travels downstream. Due to the wide variation in the magnitude of the release rates calculated in STREMTUL, three release rates were designated for the purposes of this study, 50%, 75%, and 100%. A minimum release rate of 50% was chosen as the lowest allowable rate based on prior experience and DEP acceptance.

Release rates, as calculated by STREMTUL, below the minimum 50% release rate and up to 63% were put into the 50% release rate category. Calculated release rates between 63% and 88% were lumped into the 75% category. Finally, all basins where release rates were not set in STREMTUL or where release rates were above 88% are categorized in the 100% release rate group. **Plate 5** provides a graphical illustration of which basins belong to each of the release rate categories. The release rates calculated in STREMTUL and the adjusted release rates are summarized in tabular form in **Table 10.**

APPENDIX A:
SUMMARY OF SOILS COVERAGE

NRCS SOIL SUMMARY FOR CHESTER CREEK WATERSHED

SOIL NAME/TYPE	AREA SQUARE MILES	AREA ACRES	PERCENT COVERAGE
BELTSVILLE	0.50	317.85	0.76
BRANDYWINE	1.38	882.07	2.11
BUTLERTOWN	0.34	215.49	0.52
CALVERT	0.01	4.84	0.01
CHESTER	2.12	1,353.98	3.25
CHEWACLA	0.84	538.94	1.29
CHROME	0.27	174.74	0.42
CONESTOGA	0.02	11.77	0.03
CONGAREE	0.12	75.65	0.18
CONOWINGO	0.13	82.78	0.20
EDGEMONT	0.01	4.03	0.01
GLENELG	27.05	17,313.51	41.51
GLENVILLE	5.65	3,615.03	8.67
MADE LAND	4.49	2,872.65	6.89
MANOR	3.56	2,281.50	5.47
MELVIN	0.40	256.03	0.61
MONTALTO	0.01	4.38	0.01
NESHAMINY	3.93	2,512.37	6.02
OTHELLO	0.13	81.52	0.20
QUARRY	0.15	99.15	0.24
SASSAFRASS	0.08	49.64	0.12
UDORTHENTS	4.09	2,619.15	6.28
URBAN LAND	4.58	2,928.44	7.02
WATCHUNG	0.01	4.97	0.01
WATER	0.27	170.65	0.41
WEHADKEE	2.92	1,867.30	4.48
WOODSTOWN	0.02	12.56	0.03
WORSHAM	2.12	1,359.79	3.26
TOTALS =	65.17	41,710.77	100

APPENDIX B:
LAND USE AND RCN FOR HYDROLOGIC SOIL GROUPS

Gannett Fleming

SUBJECT	Chester Creek ACT 167 Study	SHEET NO.	1	OF	1
	Runoff Curve Numbers for Hydrologic Soil Types	JOB NO	35054		
BY	KAS	DATE	Oct-00	CHKD. BY	DATE

LAND USE DESCRIPTION	RUNOFF CURVE NUMBER FOR HYDROLOGIC SOIL GROUP			
	A	B	C	D
Agricultural/Pasture	49	69	79	84
Commercial	89	92	94	95
High-density Residential	77	85	90	92
Industrial	81	88	91	93
Institutional	89	92	94	95
Low-density Residential	54	70	80	85
Medium-density Residential	61	75	83	87
Military	89	92	94	98
Mining/Quarry	36	36	36	36
Open Space	49	69	79	84
Recreation	49	69	79	84
Transportation	98	98	98	98
Utility	81	88	91	93
Water	98	98	98	98
Wooded	36	60	73	79

APPENDIX C:
EXISTING TR-20 SUBBASIN CHARACTERISTICS

TR-20 Subbasin ID	Area Sq. Mi.	SCS CN	Tc Hours
1	0.66	76.0	0.46
2	0.24	82.8	0.39
3	0.62	77.8	0.45
4	0.27	80.4	0.35
5	0.88	80.5	0.64
6	0.52	78.1	0.48
7	0.52	85.8	0.49
8	0.22	78.2	0.36
9	0.22	80.1	0.42
10	0.63	81.5	0.58
11	0.62	72.7	0.45
12	0.65	77.3	0.43
13	0.33	82.7	0.38
14	0.64	76.1	1.20
15	0.68	76.5	0.41
16	0.67	75.9	0.39
17	0.33	72.9	0.38
18	0.41	76.2	0.33
19	0.19	75.0	0.30
20	0.62	73.7	0.41
21	0.01	79.5	0.18
22	0.86	74.7	0.48
23	0.54	74.0	0.45
24	0.34	75.9	0.43
25	1.20	88.5	1.06
26	0.57	84.3	0.63
27	0.22	84.6	0.36
28	0.63	81.4	0.52
29	0.47	74.8	0.35
30	0.09	71.9	0.18
31	1.05	73.7	0.53
32	0.41	78.9	0.38
33	1.14	74.1	0.50
34	0.15	71.9	0.28
35	0.30	75.0	0.34
36	0.46	71.2	0.30
37	1.06	68.5	0.50
38	0.06	68.6	0.27
39	0.14	61.9	0.25
40	0.91	66.7	0.50
41	0.40	66.0	0.37
42	0.70	66.1	0.50
43	0.49	68.1	0.34
44	0.70	73.6	0.56
45	0.62	64.8	0.26
46	0.76	71.3	0.41
47	0.25	68.3	0.27
48	0.70	70.0	0.39
49	0.20	69.9	0.51
50	0.41	73.6	0.78
51	1.03	64.1	1.34
52	0.66	60.8	1.12
53	0.08	73.6	0.46
54	0.53	71.1	0.31
55	0.19	71.7	0.26
56	0.54	70.6	0.86
57	0.27	74.6	0.64
58	0.66	68.2	1.06
59	0.81	70.6	0.99
60	0.04	72.2	0.27
61	0.51	69.9	0.84

TR-20 Subbasin ID	Area Sq. Mi.	SCS CN	Tc Hours
62	0.51	74.0	0.92
63	0.49	68.7	0.87
64	0.63	70.1	1.23
65	0.94	75.8	1.27
66	0.77	71.3	1.28
67	0.46	70.0	1.03
68	0.15	63.7	0.75
69	0.44	75.1	1.01
70	0.55	72.5	0.37
71	0.28	71.9	0.36
72	1.01	70.1	0.51
73	0.13	71.9	0.27
74	0.67	78.1	0.50
75	0.98	72.1	0.58
76	0.43	74.0	0.40
77	0.72	70.1	0.46
78	0.1	58.0	0.16
79	0.79	71.2	0.77
80	0.57	73.1	0.67
81	0.01	73.0	0.11
82	1.00	74.0	0.53
83	0.99	74.3	0.52
84	0.64	73.9	0.44
85	0.86	67.9	0.49
86	0.39	69.9	0.35
87	0.71	71.1	0.36
88	0.17	77.2	0.19
89	0.54	71.3	0.34
90	0.36	76.2	0.30
91	1.02	71.6	0.52
92	0.53	78.1	1.34
93	0.55	73.8	1.41
94	0.19	68.8	0.24
95	0.71	74.6	0.46
96	0.27	80.3	0.86
97	0.65	70.6	0.39
98	0.31	70.5	0.28
99	0.83	69.7	0.57
100	0.49	74.2	0.35
101	0.99	74.2	1.20
102	0.26	75.9	0.60
103	0.83	73.2	1.17
104	0.37	84.1	0.71
105	0.21	84.0	0.59
106	0.64	74.6	0.95
107	0.50	72.0	1.33
108	0.06	70.7	0.42
109	0.47	73.2	0.98
110	0.10	64.7	0.61
111	0.68	72.6	1.38
112	0.25	68.8	1.03
113	0.94	71.7	1.31
114	0.32	69.1	1.08
115	0.51	76.8	1.00
116	0.75	73.7	1.66
117	0.27	79.8	1.38
118	0.44	80.6	1.18
119	0.71	77.3	1.94
120	0.41	76.8	1.37
121	0.44	73.7	1.19
122	1.05	77.5	1.84
123	0.99	85.4	2.42

APPENDIX D:
PROJECTED TR-20 SUBBASIN CHARACTERISTICS

TR-20 Subbasin ID	Area Sq. Mi.	SCS CN	Tc Hours
1	0.66	77.2	0.46
2	0.24	84.1	0.39
3	0.62	79.1	0.45
4	0.27	83.4	0.35
5	0.88	81.5	0.64
6	0.52	78.8	0.48
7	0.52	85.9	0.49
8	0.22	79.5	0.36
9	0.22	80.1	0.42
10	0.63	81.6	0.58
11	0.62	74.0	0.45
12	0.65	77.2	0.43
13	0.33	83.5	0.38
14	0.64	75.8	1.20
15	0.68	77.0	0.41
16	0.67	76.6	0.39
17	0.33	72.8	0.38
18	0.41	76.6	0.33
19	0.19	74.5	0.30
20	0.62	76.4	0.41
21	0.01	80.5	0.18
22	0.86	76.2	0.48
23	0.54	75.7	0.45
24	0.34	76.7	0.43
25	1.20	88.4	1.06
26	0.57	84.8	0.63
27	0.22	85.2	0.36
28	0.63	81.7	0.52
29	0.47	76.7	0.35
30	0.09	74.6	0.18
31	1.05	73.9	0.53
32	0.41	80.0	0.38
33	1.14	75.2	0.50
34	0.15	71.9	0.28
35	0.30	75.5	0.34
36	0.46	72.7	0.30
37	1.06	72.0	0.50
38	0.06	73.5	0.27
39	0.14	71.3	0.25
40	0.91	73.6	0.50
41	0.40	72.9	0.37
42	0.70	73.4	0.50
43	0.49	72.8	0.34
44	0.70	76.3	0.56
45	0.62	71.5	0.26
46	0.76	73.3	0.41
47	0.25	74.2	0.27
48	0.70	75.0	0.39
49	0.20	83.4	0.51
50	0.41	76.4	0.78
51	1.03	64.2	1.34
52	0.66	58.8	1.12
53	0.08	81.3	0.46
54	0.53	74.8	0.31
55	0.19	74.4	0.26
56	0.54	76.5	0.86
57	0.27	78.7	0.64
58	0.66	74.1	1.06
59	0.81	71.7	0.99
60	0.04	83.2	0.27
61	0.51	72.4	0.84

TR-20 Subbasin ID	Area Sq. Mi.	SCS CN	Tc Hours
62	0.51	74.4	0.92
63	0.49	72.3	0.87
64	0.63	76.3	1.23
65	0.94	75.9	1.27
66	0.77	76.7	1.28
67	0.46	76.7	1.03
68	0.15	77.3	0.75
69	0.44	77.9	1.01
70	0.55	75.7	0.37
71	0.28	75.4	0.36
72	1.01	74.0	0.51
73	0.13	73.5	0.27
74	0.67	79.8	0.50
75	0.98	77.0	0.58
76	0.43	74.9	0.40
77	0.72	73.6	0.46
78	0.1	75.8	0.16
79	0.79	76.2	0.77
80	0.57	75.8	0.67
81	0.01	76.0	0.11
82	1.00	77.0	0.53
83	0.99	78.0	0.52
84	0.64	75.7	0.44
85	0.86	74.8	0.49
86	0.39	72.3	0.35
87	0.71	75.4	0.36
88	0.17	77.5	0.19
89	0.54	74.7	0.34
90	0.36	76.4	0.30
91	1.02	75.5	0.52
92	0.53	77.5	1.34
93	0.55	76.1	1.41
94	0.19	70.3	0.24
95	0.71	74.8	0.46
96	0.27	81.4	0.86
97	0.65	72.4	0.39
98	0.31	74.8	0.28
99	0.83	74.2	0.57
100	0.49	79.8	0.35
101	0.99	77.6	1.20
102	0.26	78.5	0.60
103	0.83	77.8	1.17
104	0.37	84.3	0.71
105	0.21	86.4	0.59
106	0.64	76.8	0.95
107	0.50	75.7	1.33
108	0.06	74.6	0.42
109	0.47	78.2	0.98
110	0.10	68.7	0.61
111	0.68	73.6	1.38
112	0.25	72.8	1.03
113	0.94	75.6	1.31
114	0.32	74.8	1.08
115	0.51	77.4	1.00
116	0.75	77.4	1.66
117	0.27	81.2	1.38
118	0.44	81.0	1.18
119	0.71	79.9	1.94
120	0.41	79.1	1.37
121	0.44	77.4	1.19
122	1.05	79.2	1.84
123	0.99	85.8	2.42

APPENDIX E:
WATERSHED CHANNEL CROSS-SECTIONS

Gannett Fleming

SUBJECT	Chester Creek ACT 167 Study					SHEET NO.	1	OF 1
Channel Routing Data						JOB NO.	35054	
BY	KAS	DATE	Oct-00	CHKD. BY		DATE		

PROBLEM: Need discharge rating curves for streams within Chester Creek watershed to perform channel routing within the TR-20 model.

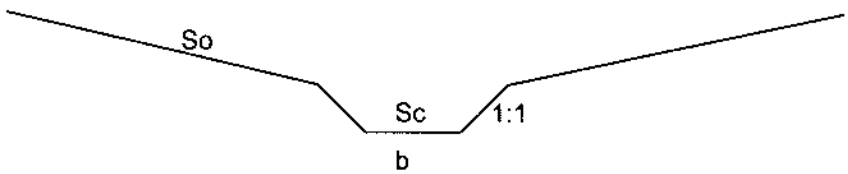
GIVEN:

1. Bridge measurements at numerous locations throughout watershed.
2. Pictures at measurement locations.
3. Maps and topography of watershed.

ASSUMPTIONS:

1. Stream channels are generally trapezoidal in shape.
2. Stream banks are steel (1:1 sideslopes).
3. Overbanks slope outward at a constant slope.

Generalized Stream Cross-Section



So = Average Overbank Slope } Estimated based on measurements
Sc = Average Channel Slope } from topographic map

h = Height of stream banks } Estimated from bridge measurements
b = Channel bottom width } and pictures of stream

SOLUTION:

1. Determine the dimensions of the stream channel (h and b) for all the tributaries modeled in TR-20 using the bridge measurements and pictures of the stream.

2. Calculate the overbank slopes and channel slopes for the streams from the topographic maps.

3. Develop generalized stream cross-sections for the streams within the watershed and the lengths over which the cross section will apply. The streams were subdivided into tributaries where certain generalized stream cross sections applied. Tributaries were further subdivided based on the slope of the channel.

4. Use FLOWMASTER to calculate the discharge and flow area for various water depths within each channel. "Real" elevation based on topography was not used in developing the channel cross section within the FLOWMASTER model. Elevation 100 was assumed to be the channel invert for all cross-sections.

SECTION NAME: Typical Section 1
TR-20 SECTION No.: 1, 13, 26, 49, 75, 79

CHANNEL CHARACTERISTICS:

Slope, S:	0.012
Bottom Width, b:	6
Streambank Height, h:	3
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	28	7
102	92	16
103	191	27
104	288	49
105	595	91
106	1,147	153
107		
108	3,210	337
109		
110	6,894	601
111		
112		
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 2
TR-20 SECTION No.: 14, 23

CHANNEL CHARACTERISTICS:

Slope, S:	0.0035
Bottom Width, b:	9
Streambank Height, h:	2
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	23	10
102	73	22
103		
104	303	88
105		
106	1,072	234
107		
108	2,613	460
109		
110	5,140	766
111		
112		
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 3

TR-20 SECTION No.: 11, 17, 18, 31, 44, 45, 54, 55

CHANNEL CHARACTERISTICS:

Slope, S:	0.01
Bottom Width, b:	11
Streambank Height, h:	3
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	47	12
102	149	26
103	298	42
104		
105	767	116
106		
107	2,225	270
108		
109	5,024	504
110		
111		
112		
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 4
TR-20 SECTION No.: 2, 3, 38, 43, 80

CHANNEL CHARACTERISTICS:

Slope, S:	0.014
Bottom Width, b:	16
Streambank Height, h:	4
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	80	17
102	254	36
103	503	57
104	823	80
105		
106	1,550	168
107		
108	3,604	336
109		
110	7,329	584
111		
112		
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 5

TR-20 SECTION No.: 62, 63, 71, 72

CHANNEL CHARACTERISTICS:

Slope, S:	0.01
Bottom Width, b:	18
Streambank Height, h:	4
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	76	19
102	241	40
103	477	63
104	778	88
105		
106	1,442	180
107		
108	3,251	352
109		
110	6,493	604
111		
112	11,501	936
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 6
TR-20 SECTION No.: 34, 42

CHANNEL CHARACTERISTICS:

Slope, S:	0.01
Bottom Width, b:	7
Streambank Height, h:	4
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	30	8
102	97	18
103	198	30
104	336	44
105		
106	755	114
107		
108	2,160	264
109		
110	4,887	494
111		
112		
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 7
TR-20 SECTION No.: 64

CHANNEL CHARACTERISTICS:

Slope, S:	0.04
Bottom Width, b:	8
Streambank Height, h:	2
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	67	9
102	219	20
103		
104	960	84
105		
106	3,494	228
107		
108		
109		
110		
111		
112		
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 8

TR-20 SECTION No.: 5, 6

CHANNEL CHARACTERISTICS:

Slope, S:	0.004
Bottom Width, b:	14
Streambank Height, h:	3
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	38	15
102	119	32
103	237	51
104		
105	575	131
106		
107	1,563	291
108		
109	3,418	531
110		
111		
112		
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 9
TR-20 SECTION No.: 19, 20, 21, 65, 66

CHANNEL CHARACTERISTICS:

Slope, S:	0.01
Bottom Width, b:	20
Streambank Height, h:	4
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	85	21
102	268	44
103	529	69
104	861	96
105		
106	1,575	192
107		
108	3,459	368
109		
110	6,795	624
111		
112		
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 10
TR-20 SECTION No.: 7, 8, 9, 16, 22

CHANNEL CHARACTERISTICS:

Slope, S:	0.004
Bottom Width, b:	20
Streambank Height, h:	4
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	54	21
102	170	44
103	335	69
104	544	96
105		
106	996	192
107		
108	2,188	368
109		
110	4,298	624
111		
112		
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 11
TR-20 SECTION No.: 50, 51, 52, 56

CHANNEL CHARACTERISTICS:

Slope, S:	0.015
Bottom Width, b:	22
Streambank Height, h:	5
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	114	23
102	361	48
103	711	75
104	1,156	104
105	1,690	135
106		
107	2,660	239
108		
109	5,195	423
110		
111	9,568	687
112		
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 12
TR-20 SECTION No.: 4, 24

CHANNEL CHARACTERISTICS:

Slope, S:	0.01
Bottom Width, b:	29
Streambank Height, h:	5
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	123	30
102	388	62
103	763	96
104	1,236	132
105	1,801	170
106		
107	2,795	288
108		
109	5,142	486
110		
111	9,057	764
112		
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 13
TR-20 SECTION No.: 10, 28, 29, 57, 58, 59, 60, 61

CHANNEL CHARACTERISTICS:

Slope, S:	0.003
Bottom Width, b:	32
Streambank Height, h:	4
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	75	33
102	235	68
103	461	105
104	746	144
105		
106	1,323	264
107		
108	2,605	464
109		
110	4,743	744
111		
112	7,911	1,104
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 14
TR-20 SECTION No.: 12, 15, 25, 27, 53

CHANNEL CHARACTERISTICS:

Slope, S:	0.01
Bottom Width, b:	41
Streambank Height, h:	5
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	174	42
102	549	86
103	1,078	132
104	1,742	180
105	2,531	230
106		
107	3,915	372
108		
109	6,754	594
110		
111	11,269	896
112		
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 15
TR-20 SECTION No.: 30, 32

CHANNEL CHARACTERISTICS:

Slope, S:	0.003
Bottom Width, b:	38
Streambank Height, h:	4
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	88	39
102	279	80
103	548	123
104	885	168
105		
106	1,563	300
107		
108	2,974	512
109		
110	5,270	804
111		
112	8,621	1,176
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 16
TR-20 SECTION No.: 33, 35, 36, 67, 68

CHANNEL CHARACTERISTICS:

Slope, S:	0.005
Bottom Width, b:	50
Streambank Height, h:	5
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	150	51
102	474	104
103	930	159
104	1,502	216
105	2,179	275
106		
107	3,383	435
108		
109	5,662	675
110		
111	9,178	995
112		
113		
114		
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 17

TR-20 SECTION No.: 37, 39, 40, 41, 46, 47, 48, 69, 70

CHANNEL CHARACTERISTICS:

Slope, S:	0.004
Bottom Width, b:	64
Streambank Height, h:	8
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	172	65
102	543	132
103	1,066	201
104	1,720	272
105	2,494	345
106	3,380	420
107	4,373	497
108	5,469	576
109		
110	6,971	776
111		
112	9,695	1,056
113		
114	13,691	1,416
115		
116		
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 18

TR-20 SECTION No.: 73, 74, 76, 77, 78, 81, 82

CHANNEL CHARACTERISTICS:

Slope, S:	0.002
Bottom Width, b:	80
Streambank Height, h:	8
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	152	81
102	481	164
103	943	249
104	1,521	336
105	2,205	425
106	2,989	516
107	3,862	609
108	4,826	704
109		
110	6,224	936
111		
112	8,521	1,248
113		
114	11,768	1,640
115		
116	16,064	2,112
117		
118		
119		
120		
130		

SECTION NAME: Typical Section 19
TR-20 SECTION No.: 83

CHANNEL CHARACTERISTICS:

Slope, S:	0.002
Bottom Width, b:	100
Streambank Height, h:	8
Side Slopes:	1:1

STAGE DISCHARGE DATA:

ELEVATION	DISCHARGE	FLOW AREA
100	0	0
101	190	101
102	601	204
103	1,179	309
104	1,903	416
105	2,757	525
106	3,734	636
107	4,827	749
108	6,029	864
109		
110	7,876	1,136
111		
112	10,660	1,488
113		
114	14,453	1,920
115		
116	19,354	2,432
117		
118		
119		
120		
130		

APPENDIX F:
REGULATED RESERVOIR DATA

DELAWARE RIVER BASIN
CHESTER CREEK WATERSHED
REGULATED RESERVOIR SUMMARY TABLE
MAJOR BASIN CODE – 90
SUB-BASIN CODE – 3

PERMIT NUMBER	COORDINATES LATITUDE	COORDINATES LONGITUDE	DRAINAGE AREA	SURFACE AREA	STORAGE VOLUME	DAM HEIGHT	DAM CODE NUMBER			NAME AND LOCATION
	DEG-MIN	DEG-MIN	SQUARE MILES	ACRES	MILLION GALLONS	FEET	TYPE	USE	CLASS	DAM OR RESERVOIR – STREAM – COUNTY - TOWNSHIP
15-29	39 57.1	75 32.9	6.4	13	-	7	2	2	4	WESTTOWN SCHOOL LAKE – E BRANCH CHESTER CREEK – CHESTER – WESTTOWN
15-30	39 57.0	75 32.6	1.1	14	10	13	1	1	4	UNNAMED – TRIB. TO EAST BRANCH CHESTER CREEK – CHESTER - WESTTOWN
15-146	39 58.9	75 32.7	6.6	12	22	21	1	1	3	MILLTOWN DAM – EAST BRANCH CHESTER CREEK – CHESTER – EAST GOSHEN
15-266	39 59.1	75 34.3	2.9	65	205	34	1	1	2	TOWNSHIP LINE DAM – EAST BRANCH CHESTER CREEK – CHESTER – W. GOSHEN
23-4	39 53.5	75 25.8	56	-	2	10	3	8	4	ROCKDALE DAM – CHESTER CREEK – DELAWARE – ASTON
23-5	39 53.6	75 26.6	36.6	4	-	10	6	8	4	COTTON MILL DAM – CHESTER CREEK – DELAWARE – MIDDLETOWN
23-6	39 53.0	75 26.8	18.5	-	-	12	6	8	4	PLANT NO. 3 – WEST BRANCH CHESTER CREEK – DELAWARE – ASTON
23-10	39 53.7	75 27.1	36.2	16	-	17	23	8	3	LENNI DAM – CHESTER CREEK – DELAWARE – ASTON
23-11	39 53.3	75 26.6	19	-	-	10	6	8	4	UNNAMED – WEST BRANCH CHESTER CREEK – DELAWARE – ASTON
23-12	39 52.5	75 27.4	18	-	-	20	6	8	3	LLEWELLEN MILL – WEST BRANCH CHESTER CREEK – DELAWARE – ASTON
23-17	39 53.2	75 30.6	5.1	-	-	6	6	8	4	CONCORD MILLS – WEST BRANCH CHESTER CREEK – DELAWARE – CONCORD
23-33	39 54.8	75 32.6	32.6	-	-	12	6	8	4	UNNAMED – EAST BRANCH CHESTER CREEK – DELAWARE - THORNBURY
23-70	39 54.5	75 28.9	17.1	9	5	5	23	2	4	BRINTON LAKE DAM – WEST CHESTER CREEK – DELAWARE – THORNBURY
23-87	39 51.6	75 31.6	1.4	-	-	10	12	1	4	UNNAMED – CONCORD CREEK – DELAWARE – CONCORD

NOTES:
1.) Highlighted rows signify that the dam has been breached.
2.) There are a total of 14 dams in the Chester Creek watershed. Of that total 4 have been breached and 7 are "run-of-river" dams with no flood storage.
3.) There are 3 remaining dams 15-146, 15-266, and 23-70 that were considered for modeling. 15-146 and 15-266 are large enough structures that a Phase I Inspection Report has been completed on the dams. The normal operating pool for these reservoirs is the spillway crest and the spillway is sufficient in size to pass the 100-year storm. Therefore, these 2 dams will not have an impact on the storms modeled for the ACT 167 Study. The other dam (23-70) is sufficiently small and located on a secondary tributary, such that it will have an insignificant impact on the model and was not included in the TR-20 model for this study.

Gannett Fleming

APPENDIX G:
WATERSHED RAINFALL DATA

Chester Creek
Precipitation Data

Station	ID #	County	Type	Begin Yr.	End Yr.	Total Yrs.
Chadds Ford	1342	Delaware	Daily	May-48	Dec-96	49
Coatesville 1 SW	1589	Chester	Daily	May-48	Nov-82	35
Coatesville W	1591	Chester	Daily	Mar-83	Dec-96	14
Conshohocken	1737	Montgomery	Daily	May-48	Dec-96	49
Devault 1 W	2116	Chester	Daily	Jun-51	Jan-88	38
Drexel University	6879	Philadelphia	Daily	Jul-48	May-78	31
Drexel University	2236	Philadelphia	Daily	Jun-78	Sep-85	8
Glenmoore	3321	Chester	Daily	Apr-59	Dec-96	38
Marcus Hook	5390	Delaware	Daily	May-48	Dec-96	49
Norristown	6370	Montgomery	Daily	May-48	Mar-87	40
Philadelphia Franklin	6884	Philadelphia	Daily	Aug-48	Sep-51	4
Philadelphia Franklin	6886	Philadelphia	Daily	Mar-94	Dec-96	3
Philadelphia WSFO	6888	Philadelphia	Daily	Jan-74	Sep-78	5
Philadelphia WSCMO A	6889	Philadelphia	Daily	May-48	Dec-96	49
Philadelphia City	6909	Philadelphia	Daily	May-48	May-63	12
Philadelphia Shawmon	6904	Philadelphia	Daily	Jan-26	Jun-57	32
Philadelphia Point B	6899	Philadelphia	Daily	May-48	Jun-63	16
Phoenixville 1 E	6927	Chester	Daily	May-48	Dec-96	49
West Chester 2 W	9465	Chester	Daily	May-82	Oct-82	1
West Chester 1 W	9464	Chester	Daily	May-48	Sep-91	44
Coatesville 1 SW	1589	Chester	Hourly	May-48	Dec-84	37
Glenmoore	3321	Chester	Hourly	Jan-71	Dec-95	25
Philadelphia	6889	Philadelphia	Hourly	Jan-00	Dec-95	96
Philadelphia	6899	Philadelphia	Hourly	May-48	Aug-63	16
Philadelphia	6909	Philadelphia	Hourly	May-48	Sep-57	10
Phoenixville 1 E	6927	Chester	Hourly	May-48	Dec-95	47

CHESTER CREEK WATERSHED
PRECIPITATION – FREQUENCY SUMMARY

RETURN PERIOD years	PDT-IDT[1] RAINFALL inches	CHADDS FORD[2] RAINFALL inches	MARCUS HOOK[2] RAINFALL inches	WEST CHESTER[2] RAINFALL inches	AVERAGE[3] RAINFALL inches
1	2.75	1.60	1.12	1.37	1.36
2	3.40	2.65	2.36	2.65	2.55
5	4.10	3.34	3.67	3.65	3.55
10	5.00	4.30	4.33	4.40	4.34
25	6.00	5.66	7.50	5.94	6.37
50	7.20	6.05	8.03	7.11	7.06
100	8.50				

NOTES:

1. Field Manual of Pennsylvania Department of Transportation, Storm Intensity-Duration-Frequency Charts, PDT-IDT, May 1986.
2. Based on a frequency analysis of daily data from the Chadds Ford, Marcus Hook, and West Chester gauging stations.
3. Average of the three gauging stations data.

APPENDIX H:
CHESTER CREEK STREAMFLOW RECORDS

PROBLEM: Calibrate the TR-20 Model

GIVEN:
1. TR-20 Model Constructed Using WMS from GIS Coverages.
2. 67 Years of Daily Streamflow Records for Chester Creek near Chester, PA.
3. PDT-IDT Storm Intensity-Duration-Frequency Charts for Pennsylvania.
4. Precipitation Gauge Data for Various Regional Gauges.

ASSUMPTIONS:
1. PDT-IDT Rainfall Values Best Represent Watershed Rainfall Frequency Storm Events.
2. Baseflow is Sufficiently Low and will not Significantly Effect the Results (Baseflow not Modeled in TR-20).

SOLUTION:
1. Run TR-20 Model and Compare to Frequency Analysis of Gauge Data near Outlet of Watershed.
2. Adjust Model as Necessary.

Calibration Results

			TR-20 RESULTS AT OUTLET POINT				
			Existing Conditions Model				**Future Conditions Model**
Flood Frequency (YRS)	PDT-IDT Precipitation (IN)	Gauge Discharge * (CFS)	AMC 2 (CFS)	Difference (%)	AMC 1 (CFS)	Difference (%)	Model 1 (CFS)
2-YR	3.4	2,900	-----	-----	1,292	-55	1,838
5-YR	4.1	5,500	-----	-----	2,691	-51	3,498
10-YR	5	7,200	-----	-----	5,169	-28	6,508
25-YR	6	10,600	-----	-----	8,687	-18	10,550
50-YR	7.2	13,600	-----	-----	14,052	3	16,895
100-YR	8.5	22,400	59,664	166	21,262	-5	24,949

* A frequency analysis was performed on the Chester Creek gauge near Chester, PA in order to determine the return periods for the flood flows used for calibration. The outlet point of the watershed and the gauge are not the same and therefore an area adjustment was used to translate the gauge flows to the watershed outlet point.

Originally the TR-20 Model assumed an AMC 2 condition; however, based on the extremely large runoff values at the watershed outlet the model was rerun using AMC 1. The existing TR-20 Model showed a difference of -55%, -51%, -28%, -18%, 3%, and -5% versus the gauged discharges for the 2-year thru 100-year precipitation events modeled. Based on the limited information for calibration of the model the results were accepted and no other adjustments were made to the model.

Future conditions within the watershed were based on zoning maps for Chester and Delaware Counties and were modeled in TR-20 by increasing the SCS Curve Number. The curve number was increased to 74, the average curve number for the watershed under the existing conditions, for all existing agricultural and wooded areas. The results are summarized in the table above. For further information on the future conditions model see the discussion on the Future Conditions SCS CN values.

USGS
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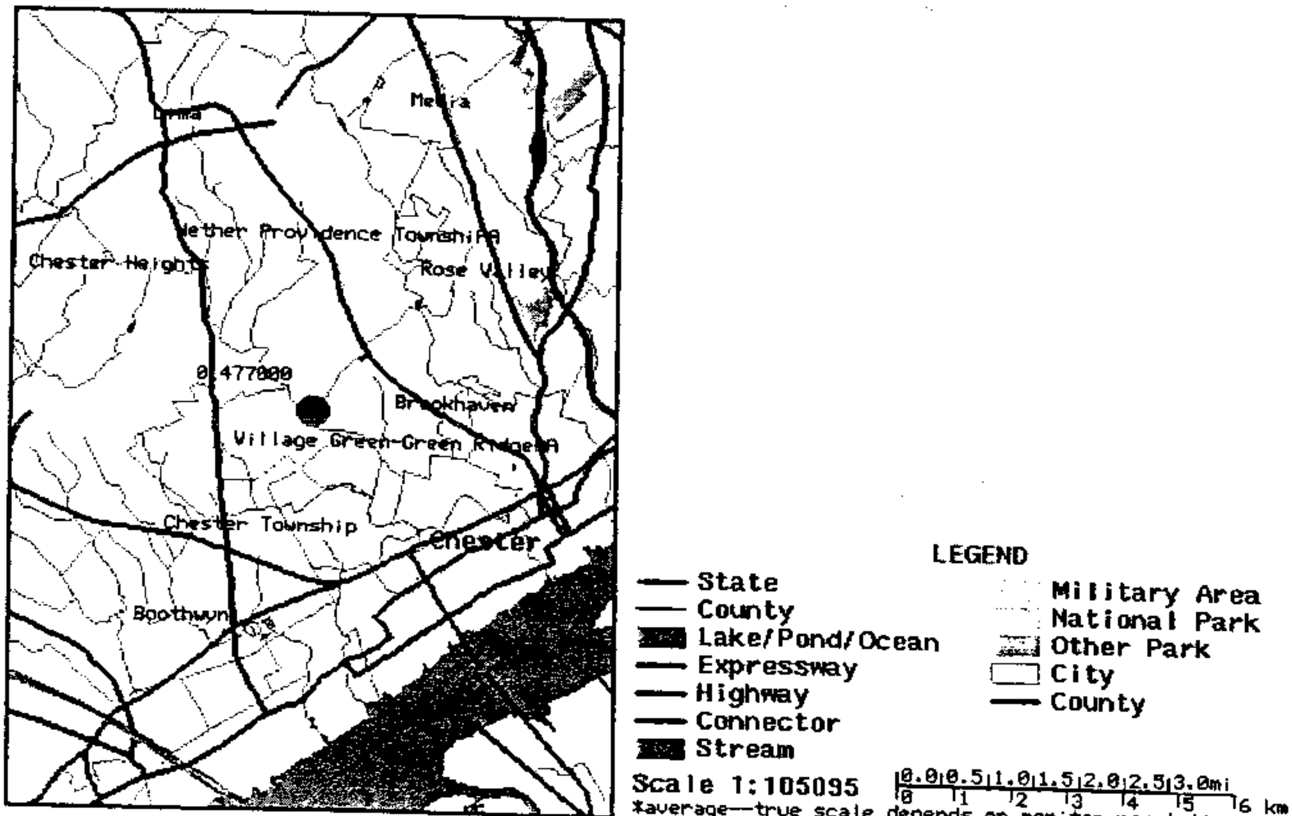
Map of region surrounding Chester Creek Near Chester, Pa

This map is provided by the US Census Tiger Mapping Server.

Another interface to this service is provided by USGS Mapping Information server.



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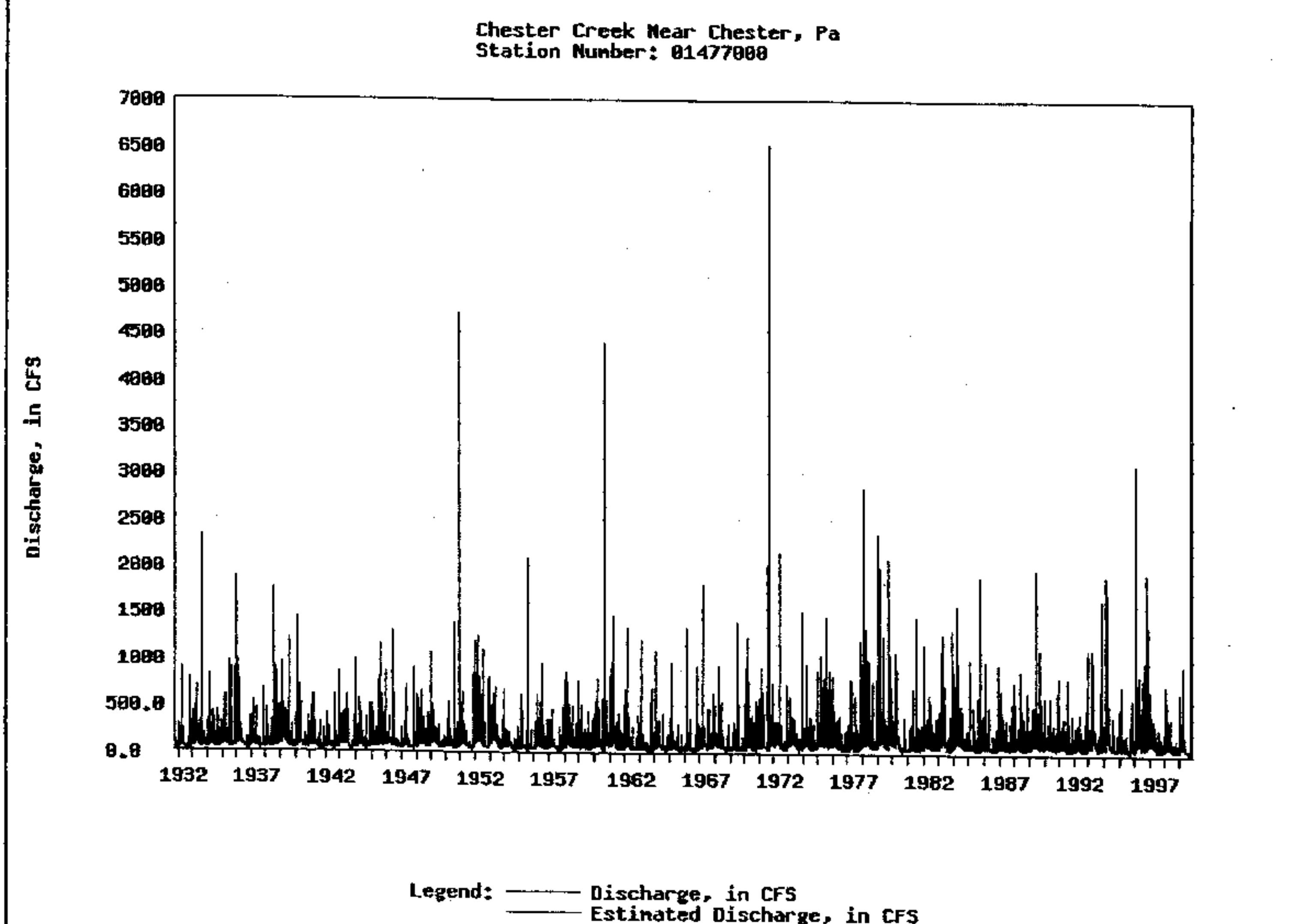
This page was created in real time by the NWIS-W package: (NWIS-W: 3.1 ; API: 3.01 ; nmdmap: 3.1)

Historical Streamflow Daily Values Graph for Chester Creek Near Chester, Pa (01477000)



Some stations have red data points. These represent days for which data were estimated, rather than recorded.

Force this graph to be redrawn | Why you might press this button

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Gannett Fleming

SUBJECT	Chester Creek ACT 167 Study			SHEET NO.	1	OF	1
Summary of Historical Flood Flows				JOB NO.	35054		
BY	KAS	DATE	Oct-00	CHKD. BY		DATE	

PROBLEM: 1. Calculate the 2-, 5-, 10-, 25-, 50- and 100-year flood flows for Chester Creek.

2. Gauge is not located at the watershed outlet modeled in TR-20.

GIVEN:

1. 67 years of streamflow data for the Chester Creek near Chester, PA.
2. Area at gauge = 61.1 sq. mi.
3. Area to outlet = 65.11 sq. mi.

ASSUMPTIONS:

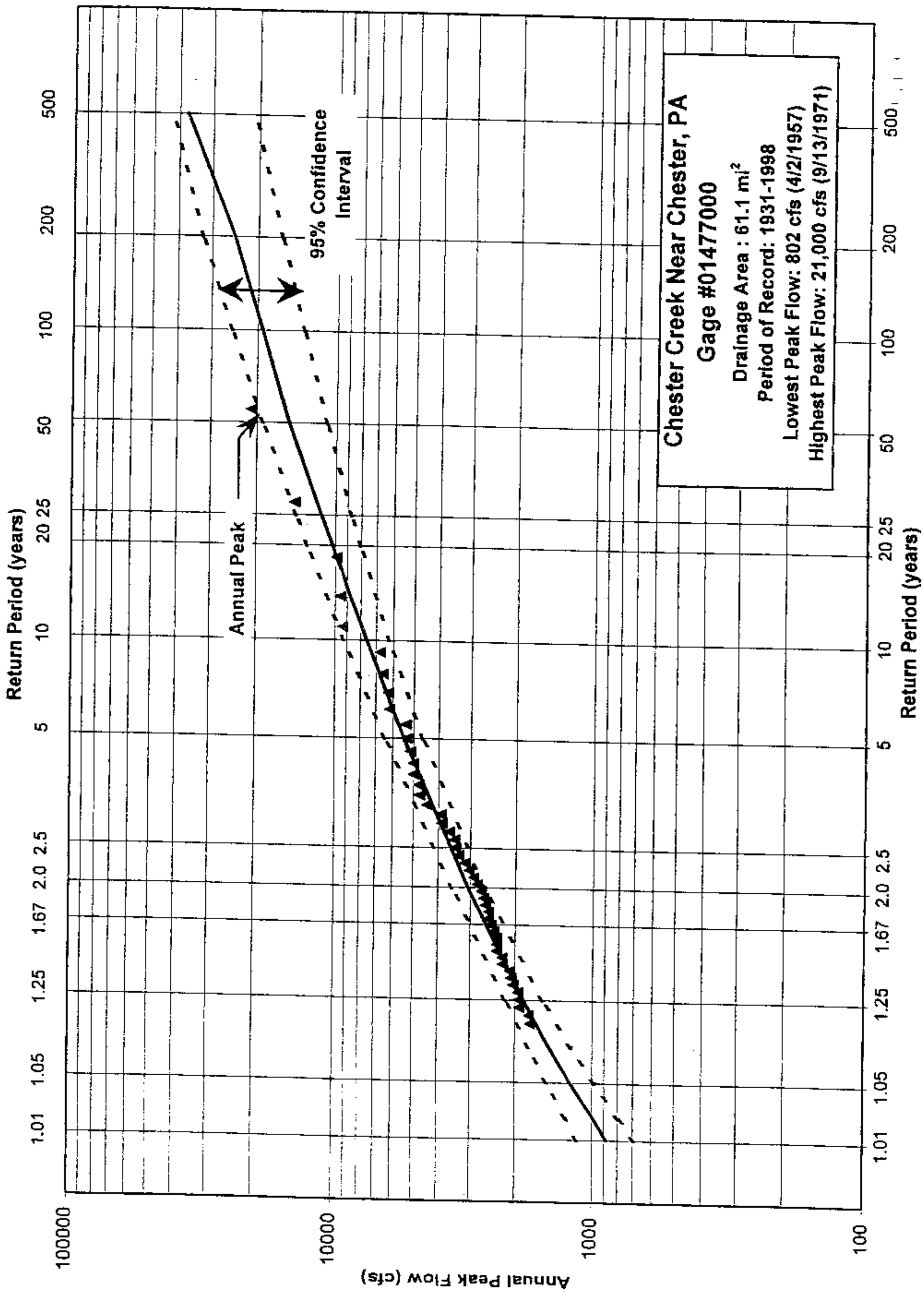
1. Q1/A1 = Q2/A2

SOLUTION:

1. Perform a frequency analysis on the flow records using the instantaneous peak values.
2. Use an area ratio to translate the gauge data to the watershed outlet.

SUMMARY

FLOOD FREQUENCY (YRS)	USGS GAUGE DATA (CFS)	AREA ADJUSTED FLOW DATA (CFS)
2-YR	2,720	2,899
5-YR	5,120	5,456
10-YR	6,740	7,182
25-YR	9,940	10,592
50-YR	12,800	13,640
100-YR	21,000	22,378


Chester Creek Near Chester, PA
Gage #01477000
Drainage Area : 61.1 mi²
Period of Record: 1931-1998
Lowest Peak Flow: 802 cfs (4/2/1957)
Highest Peak Flow: 21,000 cfs (9/13/1971)
95% Confidence Interval
Annual Peak
Return Period (years)
1.01 1.05 1.25 1.67 2.0 2.5 5 10 20 25 50 100 200 500
Annual Peak Flow (cfs)
100 1000 10000 100000

FFFREQ - Flood Flow Frequency Analysis version 2.0

Date: 10-04-2000
Station: CHESTER CREEK NEAR CHESTER, PA.
ID. No.: 01477000
Input File: chester.bin
Output File: chester.out
Historic Data File:
Deletion Option: 1
General Skew:
General Skew Weight: .302
Station Skew Weight:
High Outlier Threshold:
Low Outlier Threshold:
Confidence Interval: 95

Systematic or Recorded Data Date	Discharge (cfs)
03/28/1932	2100
08/23/1933	6250
03/05/1934	2480
09/04/1935	2920
01/09/1936	5000
02/22/1937	1350
07/23/1938	5120
08/19/1939	3630
03/15/1940	4770
02/07/1941	1350
08/13/1942	2360
12/30/1943	2360
04/24/1944	1480
08/01/1945	4440
06/02/1946	2660
05/01/1947	2240
11/12/1948	2420
12/30/1949	1940
08/03/1950	5000
11/25/1951	14400
07/09/1952	3920
01/24/1953	1730
12/14/1954	1630
08/18/1955	9380
07/21/1956	2620
04/02/1957	802
04/06/1958	1950
01/02/1959	2070
09/12/1960	9940
04/13/1961	2550
03/12/1962	2550
03/06/1963	1770
01/09/1964	3430
02/08/1965	2820
02/13/1966	2720
03/07/1967	4730

Systematic or Recorded Data Date	Discharge (cfs)
03/18/1968	1750
07/28/1969	9560
04/02/1970	3470
09/13/1971	21000
06/22/1972	6180
11/14/1973	1930
12/21/1974	3160
07/21/1975	3340
01/27/1976	1660
03/22/1977	2250
01/26/1978	5320
09/30/1979	6570
11/26/1980	2360
08/08/1981	5340
01/04/1982	2040
04/10/1983	3040
04/05/1984	3880
07/05/1989	6740

Number of systematic discharges= 54
Number of historic discharges= 0

Station: CHESTER CREEK NEAR CHESTER, PA.
ID. No.: 01477000

Ordered Data Date	Discharge (cfs)	Plotting Position
09/13/1971	21000	0.0182
11/25/1951	14400	0.0364
09/12/1960	9940	0.0545
07/28/1969	9560	0.0727
08/18/1955	9380	0.0909
07/05/1989	6740	0.1091
09/30/1979	6570	0.1273
08/23/1933	6250	0.1455
06/22/1972	6180	0.1636
08/08/1981	5340	0.1818
01/26/1978	5320	0.2000
07/23/1938	5120	0.2182
01/09/1936	5000	0.2364
08/03/1950	5000	0.2545
03/15/1940	4770	0.2727
03/07/1967	4730	0.2909
08/01/1945	4440	0.3091
07/09/1952	3920	0.3273
04/05/1984	3880	0.3455
08/19/1939	3630	0.3636
04/02/1970	3470	0.3818
01/09/1964	3430	0.4000
07/21/1975	3340	0.4182
12/21/1974	3160	0.4364
04/10/1983	3040	0.4545
09/04/1935	2920	0.4727
02/08/1965	2820	0.4909
02/13/1966	2720	0.5091
06/02/1946	2660	0.5273
07/21/1956	2620	0.5455
04/13/1961	2550	0.5636
03/12/1962	2550	0.5818
03/05/1934	2480	0.6000
11/12/1948	2420	0.6182
11/26/1980	2360	0.6364
12/30/1943	2360	0.6545
08/13/1942	2360	0.6727
03/22/1977	2250	0.6909
05/01/1947	2240	0.7091
03/28/1932	2100	0.7273
01/02/1959	2070	0.7455
01/04/1982	2040	0.7636
04/06/1958	1950	0.7818
12/30/1949	1940	0.8000
11/14/1973	1930	0.8182
03/06/1963	1770	0.8364
03/18/1968	1750	0.8545

Ordered Data Date	Discharge (cfs)	Plotting Position
01/24/1953	1730	0.8727
01/27/1976	1660	0.8909
12/14/1954	1630	0.9091
04/24/1944	1480	0.9273
02/22/1937	1350	0.9455
02/07/1941	1350	0.9636
04/02/1957	802	0.9818

Station: CHESTER CREEK NEAR CHESTER, PA.
ID. No.: 01477000
Unadjusted Frequency Curve of Raw Data

Frequency Curve Frequency	Frequency Curve Discharge (cfs)	Expected Probability Discharge (cfs)	Confidence Limits .05 limit (cfs)	Confidence Limits .95 limit (cfs)
0.9900	923	886	1150	695
0.9800	1040	991	1270	795
0.9500	1250	1220	1500	985
0.9000	1490	1470	1770	1210
0.8000	1880	1860	2190	1560
0.5000	3070	3070	3540	2650
0.2000	5390	5450	6450	4620
0.1000	7450	7620	9290	6240
0.0500	9890	10300	12900	8070
0.0400	10800	11400	14200	8710
0.0200	13800	15200	19000	10900
0.0100	17500	19200	25000	13400
0.0050	21900	24600	32500	16300
0.0020	29000	37500	45200	20800

Frequency Curve Statistics		Statistics Based On
Mean Logarithm	3.5086	0 Historic events
Standard Deviation	0.2751	0 High outliers above 0
Station Skew	0.7049	0 Low outliers below 0
Generalized Skew	0.0000	0 Missing or zero events
Station Skew Wgt.	0.1486	54 Systematic years
Generalized Skew Wgt	0.3020	54 Total period of years
Final Adopted Skew	0.4724	

Station: CHESTER CREEK NEAR CHESTER, PA.
ID. No.: 01477000

Ordered Data Date	Discharge (cfs)	Adjusted Plotting Position
09/13/1971	21000	0.0099
11/25/1951	14400	0.0241
09/12/1960	9940	0.0426
07/28/1969	9560	0.0611
08/18/1955	9380	0.0796
07/05/1989	6740	0.0981
09/30/1979	6570	0.1166
08/23/1933	6250	0.1351
06/22/1972	6180	0.1536
08/08/1981	5340	0.1721
01/26/1978	5320	0.1905
07/23/1938	5120	0.2090
08/03/1950	5000	0.2275
01/09/1936	5000	0.2460
03/15/1940	4770	0.2645
03/07/1967	4730	0.2830
08/01/1945	4440	0.3015
07/09/1952	3920	0.3200
04/05/1984	3880	0.3385
08/19/1939	3630	0.3570
04/02/1970	3470	0.3755
01/09/1964	3430	0.3940
07/21/1975	3340	0.4125
12/21/1974	3160	0.4310
04/10/1983	3040	0.4495
09/04/1935	2920	0.4680
02/08/1965	2820	0.4865
02/13/1966	2720	0.5050
06/02/1946	2660	0.5234
07/21/1956	2620	0.5419
03/12/1962	2550	0.5604
04/13/1961	2550	0.5789
03/05/1934	2480	0.5974
11/12/1948	2420	0.6159
08/13/1942	2360	0.6344
11/26/1980	2360	0.6529
12/30/1943	2360	0.6714
03/22/1977	2250	0.6899
05/01/1947	2240	0.7084
03/28/1932	2100	0.7269
01/02/1959	2070	0.7454
01/04/1982	2040	0.7639
04/06/1958	1950	0.7824
12/30/1949	1940	0.8009
11/14/1973	1930	0.8194
03/06/1963	1770	0.8378
03/18/1968	1750	0.8563

Ordered Data Date	Discharge (cfs)	Adjusted Plotting Position
01/24/1953	1730	0.8748
01/27/1976	1660	0.8933
12/14/1954	1630	0.9118
04/24/1944	1480	0.9303
02/07/1941	1350	0.9488
02/22/1937	1350	0.9673
04/02/1957	802	0.9858

Station: CHESTER CREEK NEAR CHESTER, PA.
ID. No.: 01477000

Frequency Curve Frequency	Frequency Curve Discharge (cfs)	Expected Probability Discharge (cfs)	Confidence Limits .05 limit (cfs)	Confidence Limits .95 limit (cfs)
0.9900	952	916	1170	725
0.9800	1060	1020	1300	825
0.9500	1270	1250	1520	1010
0.9000	1510	1490	1780	1230
0.8000	1890	1870	2190	1580
0.5000	3030	3030	3470	2630
0.2000	5190	5250	6170	4480
0.1000	7090	7240	8760	5980
0.0500	9300	9640	12000	7650
0.0400	10100	10700	13200	8230
0.0200	12800	14000	17400	10200
0.0100	16100	17500	22700	12400
0.0050	19900	22200	29100	15000
0.0020	26100	33300	39900	19000

Frequency Curve Statistics		Statistics Based On
Mean Logarithm	3.5015	0 Historic events
Standard Deviation	0.2642	1 High outliers above 19000
Station Skew	0.6021	0 Low outliers below 612
Generalized Skew	0.0000	0 Missing or zero events
Station Skew Wgt.	0.0860	54 Systematic years
Generalized Skew Wgt	0.3020	100 Total period of years
Final Adopted Skew	0.4686	

APPENDIX I:
TR-20 MODEL OUTPUT COMPARISON
CROSS-SECTIONS AND SUBBAREAS

Cross Section ID	2-Year		5-year		10-year		25-year		50-year		100-year	
	Existing Routed Q (cfs)	Future Routed Q (cfs)	Existing Routed Q (cfs)	Future Routed Q (cfs)	Existing Routed Q (cfs)	Future Routed Q (cfs)	Existing Routed Q (cfs)	Future Routed Q (cfs)	Existing Routed Q (cfs)	Future Routed Q (cfs)	Existing Routed Q (cfs)	Future Routed Q (cfs)
1	19	25	57	70	137	156	239	258	376	402	552	584
2	70	67	180	225	183	450	647	716	989	1,074	1,397	1,496
3	79	114	199	257	424	505	715	807	1,070	1,169	1,472	1,589
4	138	190	328	410	670	782	1,109	1238	1,642	1,783	2,241	2,394
5	100	102	167	169	260	262	359	361	482	484	629	633
6	257	322	536	638	1,061	1,202	1,702	1866	2,489	2,669	3,383	3,581
7	306	371	624	720	1,193	1,331	1,917	2080	2,846	3,029	3,908	4,113
8	312	380	644	743	1,234	1,378	1,998	2169	2,987	3,183	4,127	4,348
9	329	397	677	773	1,284	1,427	2,087	2258	3,130	3,326	4,348	4,573
10	327	391	673	764	1,235	1,364	2,000	2162	3,025	3,214	4,236	4,454
11	23	25	68	74	161	170	289	299	449	461	638	651
12	374	451	771	881	1,416	1,574	2,302	2501	3,489	3,724	4,906	5,184
13	17	18	51	54	130	134	227	231	348	354	517	525
14	26	38	83	116	224	281	418	487	669	756	1,006	1,111
15	399	483	824	944	1,515	1,692	2,466	2684	3,737	3,992	5,256	5,560
16	417	505	858	984	1,575	1,759	2,562	2788	3,879	4,144	5,455	5,571
17	9	14	24	39	69	98	145	184	256	304	381	432
18	320	328	493	502	740	749	1,036	1050	1,410	1,423	1,829	1,849
19	340	349	524	536	788	800	1,104	1122	1,504	1,521	1,957	1,983
20	395	411	627	651	998	1,030	1,386	1422	1,921	1,962	2,547	2,600
21	377	394	610	634	973	1,005	1,345	1383	1,870	1,916	2,493	2,550
22	18	22	45	52	95	106	165	179	262	280	384	405
23	37	51	102	132	242	305	483	557	816	907	1,221	1,332
24	431	463	757	808	1,324	1,411	1,930	2042	2,894	3,065	4,142	4,332
25	437	469	771	822	1,356	1,446	1,986	2102	3,007	3,171	4,296	4,491
26	6	7	12	17	42	54	104	125	200	218	285	313
27	439	484	198	872	1,449	1,598	2,204	2424	3,462	3,758	5,048	5,448
28	756	890	1,491	1,665	2,610	2,875	4,268	4601	6,614	7,155	9,684	10,371
29	756	891	1,490	1,696	2,611	2,881	4,272	4616	6,626	7,181	9,705	10,450
30	752	906	1,488	19	2,637	2,955	4,331	4731	6,691	7,381	9,856	10,772
31	4	7	8	1,757	21	62	64	141	152	257	271	390
32	762	939	1,516	1,757	2,709	3,077	4,463	4931	6,965	7,793	10,311	11,423
33	759	944	1,516	1,771	2,720	3,106	4,488	4980	6,990	7,835	10,356	11,475
34	10	22	20	73	70	194	189	366	377	581	601	855
35	776	983	1,567	1,843	2,806	3,234	4,632	5182	7,241	8,182	10,747	11,992
36	781	990	1,570	1,858	2,827	3,263	4,665	5229	7,286	8,251	10,799	12,077
37	780	990	1,574	1,862	2,852	3,287	4,731	5295	7,437	8,392	11,074	12,364
38	9	15	21	52	77	148	192	295	370	499	595	747
39	796	1,021	1,608	1,916	2,917	3,381	4,838	5446	7,624	8,646	11,359	12,735
40	795	1,022	1,609	1,922	2,928	3,400	4,860	5476	7,632	8,638	11,339	12,691
41	807	1,044	1,639	1,966	2,990	3,485	4,969	5623	7,835	8,906	11,670	13,122
42	5	7	11	16	30	44	70	93	137	168	224	263
43	4	7	9	15	22	40	53	85	111	156	189	254
44	13	21	29	55	80	129	171	242	312	399	485	588
45	24	43	51	101	128	238	282	434	510	699	799	1,053
46	845	1,108	1,727	2,091	3,170	3,732	5,290	6075	8,466	9,736	12,687	14,388
47	859	1,139	1,757	2,145	3,230	3,832	5,395	6243	8,659	10,031	12,993	14,818
48	856	1,140	1,755	2,149	3,231	3,842	5,400	6257	8,658	10,029	12,968	14,804
49	12	22	29	71	97	177	213	293	360	482	568	723
50	22	38	52	122	175	326	408	585	728	979	1,165	1,475
51	42	71	105	204	308	498	686	918	1,183	1,402	1,822	2,172
52	7	9	20	28	58	75	123	147	223	251	343	379
53	70	120	173	345	507	836	1,149	1589	2,039	2,643	3,168	3,829
54	18	39	43	107	129	240	272	425	491	679	761	987
55	18	37	41	98	118	225	257	407	472	660	742	968
56	53	98	121	256	335	577	700	1016	1,206	1,603	1,859	2,341
57	63	111	141	279	377	633	785	1092	1,308	1,714	2,014	2,513
58	137	247	314	653	889	1,526	1,913	2623	3,140	4,235	4,943	6,251
59	141	250	319	646	874	1,455	1,814	2520	3,035	4,093	4,798	6,064
60	152	271	343	680	912	1,491	1,854	2586	3,122	4,204	4,931	6,280
61	164	286	365	684	909	1,423	1,766	2479	3,017	4,052	4,774	6,077
62	25	32	61	74	131	152	231	260	373	409	545	588
63	41	48	93	108	194	220	340	374	570	606	877	921
64	18	22	37	43	68	76	108	118	162	173	224	236
65	58	70	133	157	286	323	533	590	928	1,005	1,404	1,494
66	61	76	139	168	300	347	559	633	968	1,063	1,441	1,554
67	240	399	537	919	1,274	1,868	2,395	3228	4,044	5,246	6,332	7,841
68	246	411	548	930	1,282	1,882	2,401	3227	4,033	5,226	6,297	7,802
69	1,104	1,588	2,350	3,028	4,486	5,753	7,819	9580	12,881	15,507	19,556	22,977
70	1,107	1,592	2,354	3,036	4,498	5,765	7,821	9570	12,862	15,474	19,514	22,911
71	71	87	129	150	216	241	324	353	462	496	623	662
72	69	92	143	178	268	317	439	500	668	741	927	1,002
73	1,162	1,668	2,454	3,165	4,675	5,995	8,109	9921	13,308	16,020	20,171	23,705
74	1,169	1,681	2,468	3,188	4,703	6,037	8,151	9983	13,380	16,118	20,281	23,845
75	10	11	21	24	51	58	101	111	178	191	267	281
76	1,176	1,689	2,485	3,213	4,746	6,071	8,199	10021	13,434	16,186	20,381	23,958
77	1,184	1,707	2,504	3,251	4,793	6,123	8,243	10080	13,485	16,264	20,455	24,075
78	1,189	1,712	2,514	3,265	4,817	6,133	8,256	10077	13,481	16,239	20,433	24,036
79	39	44	79	86	144	153	225	235	330	343	459	473
80	56	73	116	143	219	257	356	403	540	597	762	827
81	1,241	1,780	2,607	3,386	4,996	6,338	8,501	10364	13,841	16,680	20,986	24,678
82	1,240	1,779	2,605	3,392	5,001	6,329	8,477	10331	13,784	16,605	20,881	24,554
83	1,252	1,792	2,623	3,422	5,048	6,378	8,522	10371	13,812	16,625	20,906	24,566
84	1,292	1,838	2,691	3,498	5,169	6,508	8,687	10550	14,052	16,895	21,262	24,949

Gannett Fleming

TR-20 MODEL OUTPUT COMPARISON
SUMMARY TABLE
TR-20 CROSS SECTIONS

ATTACHMENT 1
STORM RUNOFF AND STREAMFLOW MODELING

ATTACHMENT 1
STORM RUNOFF AND STREAMFLOW MODELING

I. INTRODUCTION

Predicting the rate and amount of water that runs off the land surface and into streams is an inexact science. There are a multitude of factors that affect how much of the rainfall will be absorbed by the ground, intercepted and held by plants, or retained in shallow depressions to eventually infiltrate or evaporate. There are numerous methods for estimating runoff characteristics, some of which provide only an estimate of the peak rate of runoff while others also approximate the volume and distribution of runoff over time. The two best known methods for runoff prediction are the Rational Formula and the RCN approach.

II. RATIONAL FORMULA

The Rational Formula was originally developed to predict the peak discharge that could be expected from a rainfall of a specified intensity. The formula is:

$$Q = CIA$$

where Q is the peak discharge in cfs, C is a runoff coefficient depending on the drainage area characteristics, I is the rainfall intensity in inches per hour, and A is the drainage area in acres. The formula and the coefficients that have been developed are intended to be applied to small catchment areas (generally less than 100 acres). As shown in **Table 1**, values for the runoff coefficient have been developed by various researchers for combinations of land cover and soil conditions.

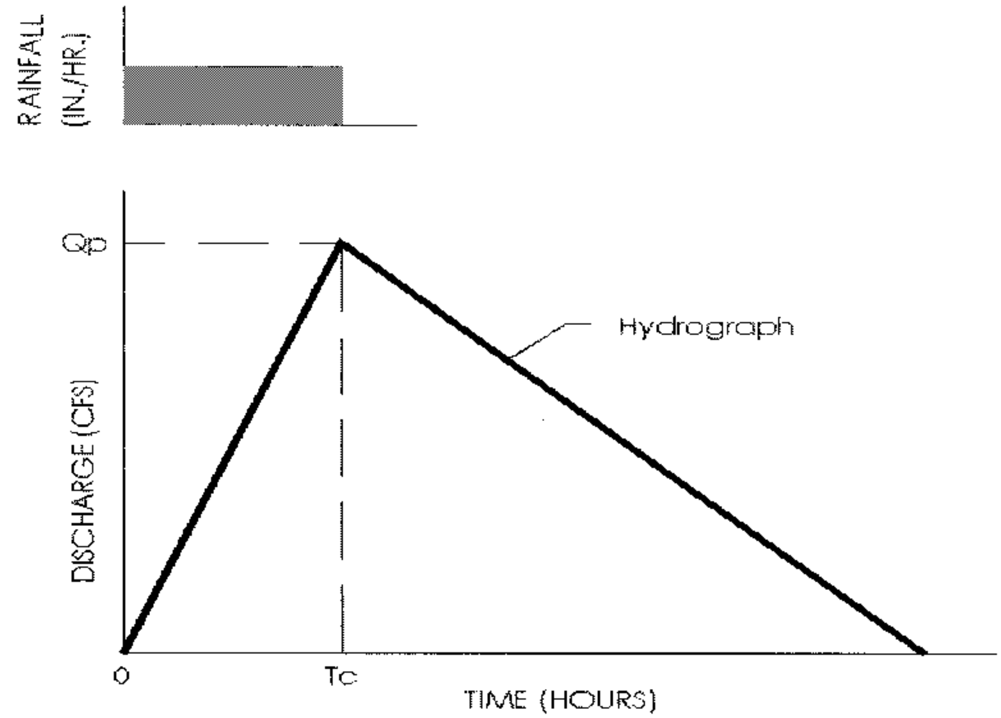
The rainfall intensity, I, has been developed by statistical analysis of long-term rainfall records and is documented in various U.S. Weather Bureau publications. The rainfall intensity is assumed to be constant in this application.

More recently, researchers have developed variations of the Rational Formula that resulted in the approximation of a hydrograph showing the distribution of runoff over time. The basis of this application is that the peak discharge occurs at the Tc for the drainage area. The T_C is, theoretically, the time that it takes runoff from the hydrologically furthest point of the drainage area to reach the discharge point. The applicability of this approach is limited to small, somewhat homogeneous drainage areas. The resulting hydrograph is triangular, as illustrated on **Plate 1.**

Table 1
Values of Runoff Coefficient, C

Drainage Area Characteristics	Runoff Coefficient, C
Lawns:	
Sandy soil, flat, 2% or less	0.05-0.10
Sandy soil, average, 2-7%	0.10-0.15
Sandy soil, steep, 7%+	0.15-0.20
Heavy soil, flat, 2% or less	0.13-0.17
Heavy soil, average, 2-7%	0.18-0.22
Heavy soil, steep, 7%+	0.25-0.35
Business:	
Downtown areas	0.70-0.95
Neighborhood areas	0.50-0.70
Residential:	
Single-family areas	0.30-0.50
Multi units, detached	0.40-0.60
Multi units, attached	0.60-0.75
Suburban	0.25-0.40
Apartment dwelling areas	0.50-0.70
Industrial:	
Light areas	0.50-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.20-0.35
Railroad yard areas	0.20-0.40
Unimproved areas	0.10-0.30
Streets:	
Asphaltic	0.70-0.95
Concrete	0.80-0.95
Brick	0.70-0.85
Drives and walks	0.75-0.85
Roofs	0.75-0.95

Source: *Handbook of Applied Hydrology* by Ven Te Chow, McGraw-Hill Book Co., 1964



SIMPLE HYDROGRAPH BASED ON RATIONAL FORMULA
PLATE 1

III. RUNOFF CURVE NUMBER APPROACH

The RCN approach was developed by the U.S. Department of Agriculture, SCS. This approach is based on the development of a unit hydrograph which assumes that discharge at any time is proportional to the volume of runoff and that factors affecting the shape of the hydrograph at any time are constant. The RCN methodology accounts for the initial moisture conditions of a watershed (i.e., how long since the last significant rainfall), different types of land cover and soils, and time-varying rainfall. The basic equations for estimating runoff are:

$$Q = (P - 0.2S)2 / (P + 0.8S)$$
$$S = (1000 / CN) - 10$$

where Q is the runoff volume (inches), P is the precipitation volume (inches), S is the potential maximum retention (inches), and CN is the runoff curve number.

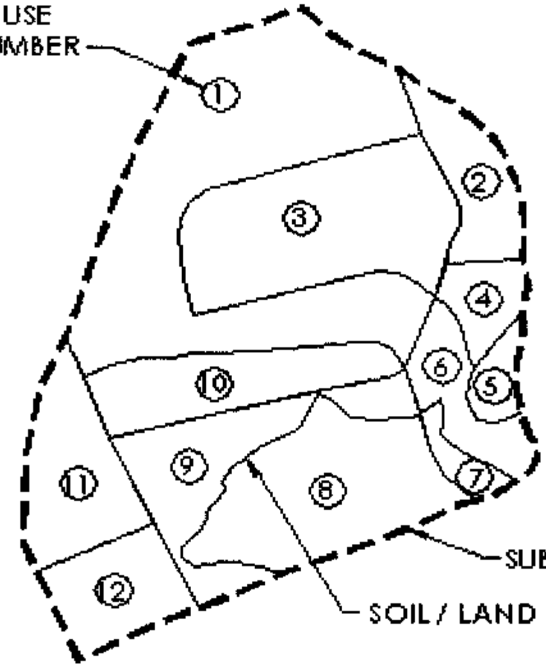
The most significant component of the methodology involves the definition of the RCN, which is based on the land cover and soils in a drainage area. The soils are classified based on their hydrologic characteristics into four groups as defined in **Table 2**. The RCN values are then defined based on soil and land cover combinations as illustrated in **Table 3**.

Table 2 Hydrologic Soil Groups	
Soil Group	**Definition**
A	Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands or gravels. These soils have a high rate of water transmission. Low runoff potential.
B	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.
C	Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.
D	Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.
U	The SCS uses this classification to denote soils that have been significantly disturbed by the urbanization process. There are no specific characteristics associated with this soil type; the modeler must use judgment in assigning hydrologic parameters to these soils.
Source: *National Engineering Handbook, Section 4, Hydrology*, Soil Conservation Service, 1972	

Table 3 Runoff Curve Numbers						
Cover Characteristics			Hydrologic Soil Group			
Land Use	Treatment	Hydrologic Condition	A	B	C	D
Fallow	---	---	77	86	91	94
Row crops	Straight row Contoured	Good Good	67 65	78 75	85 82	89 86
Small grain	Straight row	Good	63	75	83	87
Pasture	---	Good	39	61	74	80
Meadow		Good	30	58	71	78
Woods		Fair Good	36 25	60 55	73 70	79 77
Urban Areas	Low density (15% imp.) Medium density (25% imp.) High density (65% imp.)		70 72 74	76 78 80	83 85 87	86 88 90
Source: *National Engineering Handbook, Section 4, Hydrology*, Soil Conservation Service, 1972						

In application, watersheds are comprised of many small soil/cover areas. The modeler generally subdivides a watershed into smaller areas based on stream physiography and key points of interest and then averages the small soil/cover areas to derive an RCN for each subwatershed. The average RCN of a subwatershed is derived as illustrated in **Plate 2**.

SCS also developed equations that account for the movement of water through a watershed and for the varying rates of flow associated with overland (sheet), shallow channel, and stream flow conditions. The theory behind the RCN approach is documented in the SCS *National Engineering Handbook, Section 4, Hydrology* (1972). In this methodology, the T_C of a subwatershed has a significant impact on the peak rate of discharge. The T_C can be computed using a worksheet developed by SCS and presented in its publication *Urban Hydrology for Small Watersheds, TR-55*, June 1986. This methodology requires information regarding the surface cover, lengths of flow, and slopes.



SUBAREA NUMBER	SOIL TYPE	LAND USE	AREA (ACRES)	SUBAREA RCN	AREA x RCN PRODUCT
1	A	Open	43.57	39	1,699
2	A	Single Family	7.46	61	455
3	U	Single Family	22.43	78	1,750
4	D	Institutional	4.03	88	355
5	D	Single Family	2.56	86	220
6	A	Open	6.25	39	244
7	C	Open	2.05	74	152
8	C	Industrial	19.29	87	1,678
9	A	Industrial	13.06	74	966
10	A	Single Family	11.23	61	685
11	B	Open	11.05	61	674
12	B	Industrial	8.17	80	654
		TOTALS	151.15		9,532

$$\text{AVERAGE RCN} = \frac{9.532}{151.15} = 63.1$$

SUBWATERSHED RCN CALCULATION

PLATE 2

As the water flows over the surface of the ground and collects into stream channels, additional information is required to estimate the effect of channel flow. This includes a description of the cross-section of the channel, the channel slope, and the channel lining. If the flows exceed the capacity of the channel, then information regarding the floodplain (cross-section and material) must also be incorporated into the analysis.

IV. WATERSHED MODELS

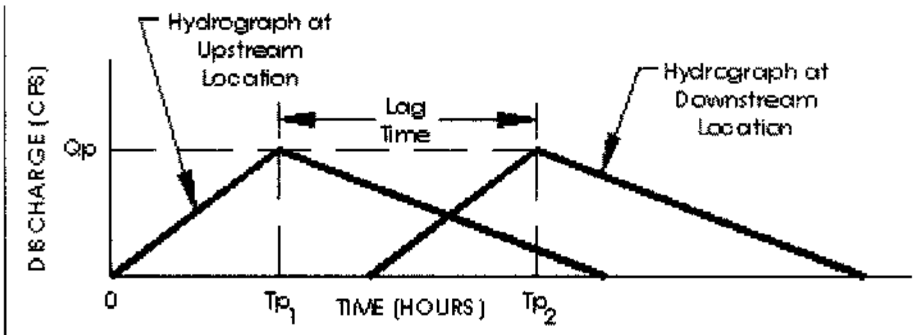
There are a great many watershed models that have been developed to simulate the rainfall/runoff and stream flow phenomena. Some of these models are very simplistic, while others go to great lengths to try to account for every possible source or loss of water in a watershed. Watershed models have also been developed for a variety of purposes including flood forecasting, water budget studies, and water quality studies. The Pennsylvania Act 167 watershed studies focus on the need to simulate runoff for individual storm events that can be statistically defined in terms of their probability of occurrence. For this reason, we have selected two models to utilize in this study: PSRM and SCS's TR-20 model. Both of these models base their runoff estimates on the RCN approach. However, they differ significantly in their approach to routing the flows overland and through the watershed. The following paragraphs describe these models and discuss their differences.

V. PENN STATE RUNOFF MODEL

PSRM was originally developed as an educational and research tool. However, as the model's capabilities expanded, it was recognized to be an easy-to-use, economical method of estimating runoff. Furthermore, it provided a unique relationship referred to as the release rate that was of interest to watershed planners.

The model evaluates the incremental volume of rain falling on a subarea over a short period of time, subtracts quantities that represent the "initial abstraction" and infiltration, and then routes the remaining "excess" rainfall over the subarea using a kinematic wave method. This incremental procedure continues until the end of the rain event. The required runoff and routing parameters include subarea size, RCN, initial abstraction (volume), average slope, and overland flow length. At the discharge end of the subarea, the runoff is assumed to enter a channel or pipe system.

PSRM utilizes a very simplistic approach to routing water through a channel or sewer system. The modeler provides estimates of the time of travel through the channel or sewer, and the runoff hydrograph is "lagged" for that time. That is, the incremental flow values are shifted in time by the "lag" amount as illustrated on **Plate 3**. Therefore, if a peak occurred at the upstream end of a system at 12:00 noon and the travel time to the downstream end of the system was one hour, the time of peak at the discharge end would be 1:00 p.m. The advantages of this approach are the simplicity of computation and the fact that it allows you to determine what portion of a discharge hydrograph is contributed by a particular upstream subarea. The disadvantage is that the methodology does not account for the attenuation of the peak that is caused by water being stored in the floodplain of streams.



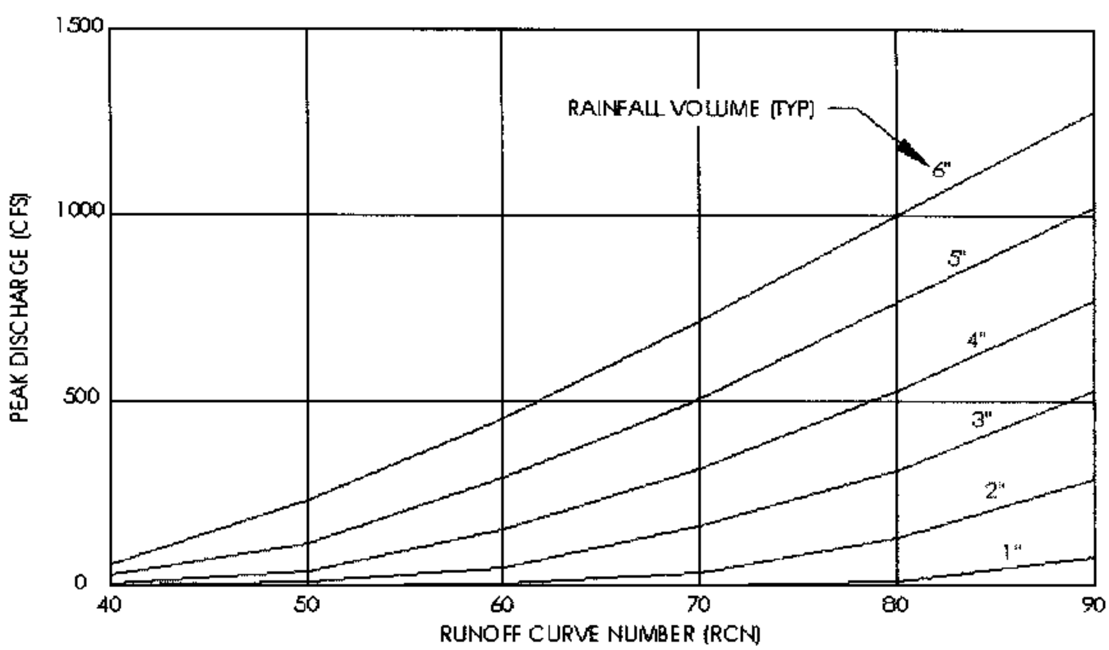
HYDROGRAPH LAGGING METHOD
PLATE 3

The release rate is a useful concept for watershed planning in that it provides some indication of where storage of runoff can be most beneficially implemented to reduce flooding potential. The release rate, as computed by PSRM, specifies the percentage of the pre-development peak flow that should be discharged after development takes place. The release rate varies throughout a watershed but generally ranges between 50% and 100%. The primary assumptions in this approach are that all areas must store increased runoff so that the peak discharge after development does not exceed the pre-development peak and that there is no channel storage or backwater conditions affecting the movement of water through a channel reach.

VI. SCS TR-20 MODEL

The SCS TR-20 model (and its simpler, hand-calculated approach, TR-55) determines the rate of runoff from a subarea based on a unit hydrograph approach. The standard unit hydrograph is modified for the subarea based on the RCN and T_C. The resulting unit hydrograph is then converted to an actual runoff hydrograph by applying the rainfall volume. Standard rainfall distribution curves are generally used, although the modeler can input custom distribution curves in the TR-20 model. **Plate 4** illustrates the effects of different rainfall volumes and RCNs with respect to the peak discharge rate and time.

As with PSRM, once the runoff for a subarea has been determined, it is assumed to flow through a channel system to the discharge end of the watershed. The TR-20 model routes the channel flow through the stream reaches using a technique called the Att-Kin Method, which accounts for channel storage and time-varying flows. Minor backwater conditions at road crossings (culverts and bridges) can be approximated by developing adjusted stage-discharge relationships for the channels. Severe backwater conditions can be modeled by assuming the presence of a detention basin at the backwater point.



PEAK DISCHARGE VERSUS RCN
PLATE 4

VII. DEFINITIONS

Convex Routing Method - a method of evaluating the flow of water through a stream reach. The methodology is applied in the SCS TR-20 model and involves multiplying the difference in the inflow and outflow rates for a given time period by a storage factor and using that result in computing the outflow for the next time step.

Hydrograph - a graphical representation of flow at a point in a stream that relates discharge rate (e.g., cfs or gallons per minute) versus time (e.g., hours or minutes).

Hydrologic Soil Type - a soils classification system developed by SCS to represent the infiltration/runoff characteristics of soils.

Initial Abstraction - the volume of water that is stored in depressions before infiltration and overland flow begin. The initial abstraction for paved areas is quite low and generally does not impact the runoff hydrograph; however, it can be a significant parameter in determining the volume and peak rate of runoff from pervious areas (e.g., lawns, fields, forest).

Kinematic Wave Routing - a method of evaluating the movement of a wave of water through a channel or pipe that incorporates changes in speed, depth, and flow rate caused by variations in the channel cross-section, slope, and material. This routing technique is based on the continuity equation that states that the inflow to a stream section minus the outflow should equal the change in storage within the section.

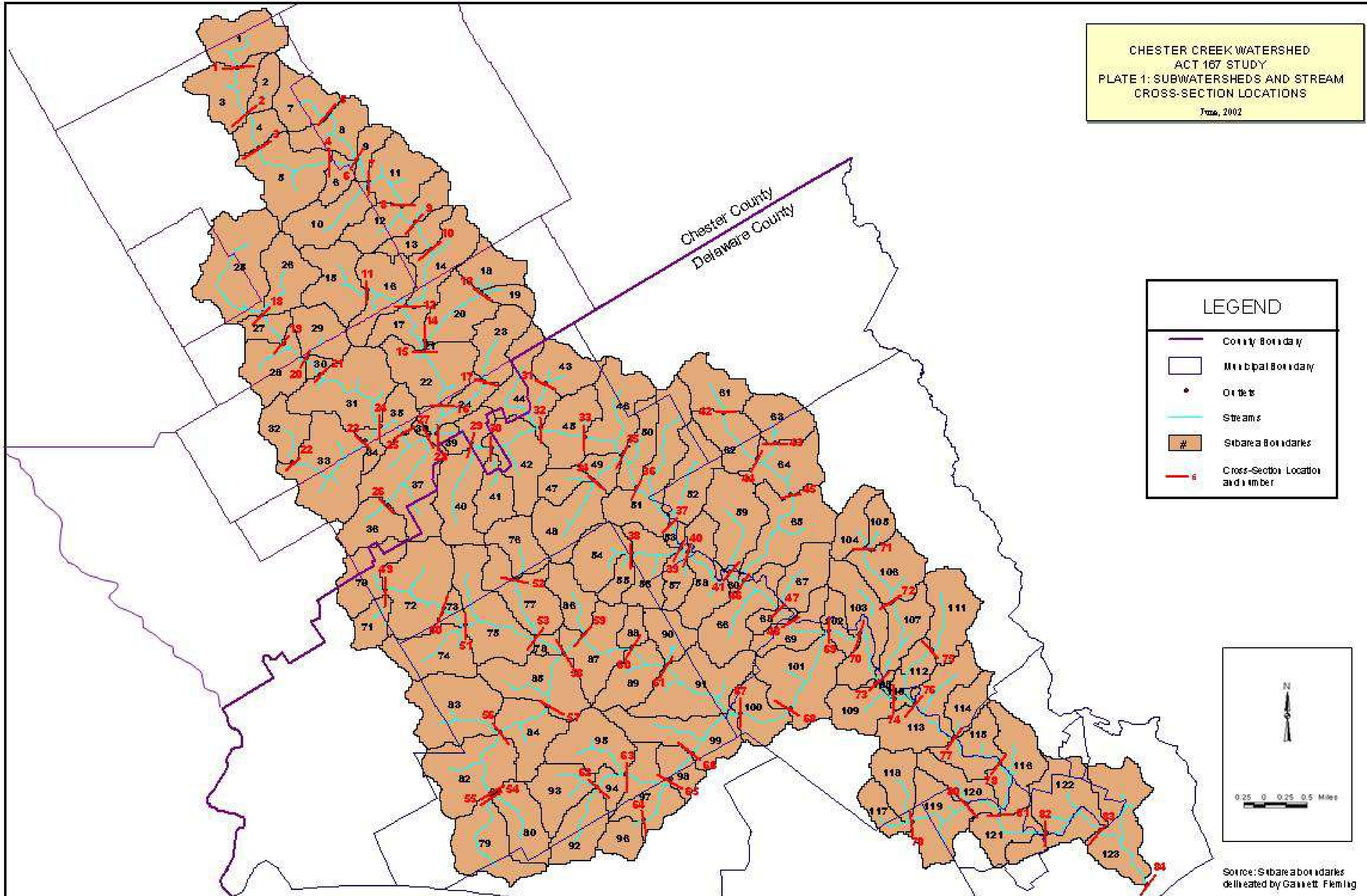
Release Rate - the percentage of the pre-development peak flow that should be discharged after development takes place.

Runoff Coefficient - a variable developed for the Rational Formula to represent the runoff potential of an area based on its soil and land cover characteristics.

Runoff Curve Number - a variable defined by SCS to represent the runoff potential of an area based on its soil and land cover characteristics. This variable is used in the SCS TR-20 and TR-55 methodologies.

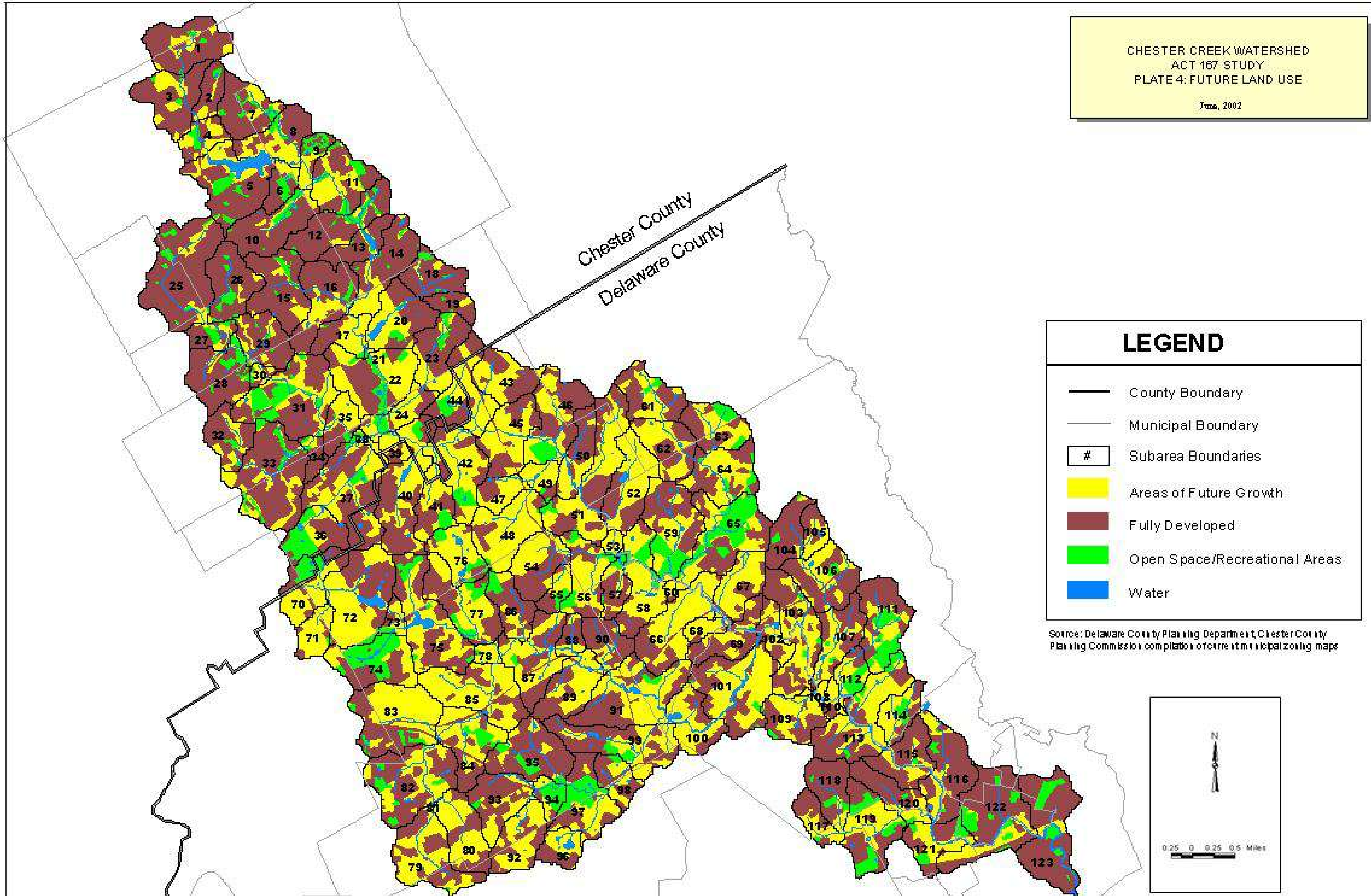
Time of Concentration - the time it takes water to move overland from the hydrologically furthest point of the area to the discharge point of the area.

Time of Travel - the time it takes water to move from an upstream to a downstream point in a channel or pipe under gravity or free flow (as opposed to pressure) conditions.


CHESTER CREEK WATERSHED
ACT 167 STUDY
PLATE 1: SUBWATERSHEDS AND STREAM CROSS-SECTION LOCATIONS
June, 2002
Chester County
Delaware County
LEGEND
County Boundary
Municipal Boundary
Outlets
Streams
Subarea Boundaries
Cross-Section Location and number
N
0.25 0 0.25 0.5 Miles
Source: Subarea boundaries delineated by Gannett Fleming

CHESTER CREEK WATERSHED
ACT 167 STUDY
PLATE 2: HYDROLOGIC SOILS GROUP
June, 2002
LEGEND
County Boundary
Municipal Boundary
Subarea Boundaries
Streams
Soil
A - High Infiltration Potential
B - Moderate Infiltration Potential
C - Slow Infiltration Potential
D - Poor Infiltration Potential
Source: USDA - NRCS Pennsylvania Map Compilation and Digitizing Center, 2001
Chester County
Delaware County
N
0.25 0 0.25 0.5 Miles


CHESTER CREEK WATERSHED
ACT 167 STUDY
PLATE 3: EXISTING LAND USE MAP
June, 2002
LEGEND
County Boundary
Municipal Boundary
#
Subarea Boundaries
Landuse
Agricultural
Commercial
High Density Residential
Industrial
Institutional
Low Density Residential
Medium Density Residential
Military
Mining
Open Space
Recreation
Transportation
Utility
Water
Wooded
West Whiteland
East Goshen
West Goshen
West Chester
Chester County
Delaware County
Edgmont
Westtown
Thornbury
Middletown
Birmingham
Chester Heights
Parkside
Chadds Ford
Aston
Brookhaven
Upland
Concord
Bethel
Upper Chichester
Chester Twp.
Chester City
N
0.25 0 0.25 0.5 Miles
Source: Delaware Valley Regional Planning Commission, 1995 as modified by Delaware County Planning Department and Chester County Planning Commission


CHESTER CREEK WATERSHED
ACT 167 STUDY
PLATE 4: FUTURE LAND USE
June, 2002
Chester County
Delaware County
LEGEND
County Boundary
Municipal Boundary
Subarea Boundaries
Areas of Future Growth
Fully Developed
Open Space/Recreational Areas
Water
Source: Delaware County Planning Department, Chester County Planning Commission compilation of current municipal zoning maps
N
0.25 0 0.25 0.5 Miles


CHESTER CREEK WATERSHED
ACT 167 STUDY
PLATE 5: RELEASE RATE MAP
June, 2002
LEGEND
County Boundary
Stream
Municipal Boundary
Release Rates
0.5
0.75
1
#
Subarea Boundaries
N
0.25 0 0.25 0.5 Miles
Note:
Map is for reference use only. The exact location of the stormwater management district boundaries as they apply to a given development site must be determined by mapping the boundaries using the two-foot topographic contours (or the most accurate data) required, provided as part of the drainage plan.
Chester County
Delaware County
West Whiteland
East Goshen
West Goshen
West Chester
Westtown
Thornbury
Thornbury
Edgmont
Middletown
Chester Heights
Concord
Chadds Ford
Aston
Bethel
Upper Chichester
Brookhaven
Upland
Chester Twp.
Chester City
Sources: Gannett Fleming