BULL RUN WATERSHED
STORMWATER MANAGEMENT PLAN

SECTION IV
WATERSHED TECHNICAL ANALYSIS - MODELING

INTRODUCTION

The requirement for assessing the watershed wide impact of the implementation of stormwater runoff controls demands the use of computer hydrologic modeling techniques to estimate stormwater runoff rates under various conditions. Digital computer modeling refers to the use of sets of mathematical expressions (algorithms) to reproduce key behavioral aspects of the natural system. This section contains a discussion of the modeling approached used in the preparation of the Bull Run Watershed Stormwater Management Plan.

MODEL SELECTION

There are a number of hydrologic modeling techniques available for estimating stormwater runoff based upon ground cover and precipitation conditions. The Penn State Runoff Model (PSRM) was selected for use in the Bull Run Watershed. PSRM was selected for use in this watershed for a number of reasons, including:

1. PSRM offers the ability to analyze the timing of flow combinations originating from various locations throughout a watershed. This capability is particularly important in the evaluation of the effects of various stormwater control techniques throughout a watershed.

2. PSRM offers flexible data input and output modes.

3. PSRM is accepted for use throughout Pennsylvania for the preparation of watershed stormwater management plans under Act 167.

DATA COLLECTION AND PREPARATORY ANALYSIS

OVERVIEW

Input data requirements for PSRM include the following parameters:

1. Watershed Representation Data

    A. Tributary Area (Subbasin) Physical Features

        1. tributary land areas
        2. land slopes
        3. overland flow lengths

    B. Tributary Area (Subbasin) Hydrologic Features

1. composite runoff curve numbers
2. percentage imperviousness
3. initial abstraction estimates

C. Drainage (Reach) System Features

1. conveyance system (streams and conduits) capacities
2. roughness coefficients
3. conveyance system travel times
4. characteristics of flow detention facilities

D. Rainfall Inputs

1. rainfall volumes
2. rainfall distribution

A discussion of the general methods used to develop the necessary input data set for the Bull Run watershed follows.

SUBBASIN PHYSICAL FEATURES

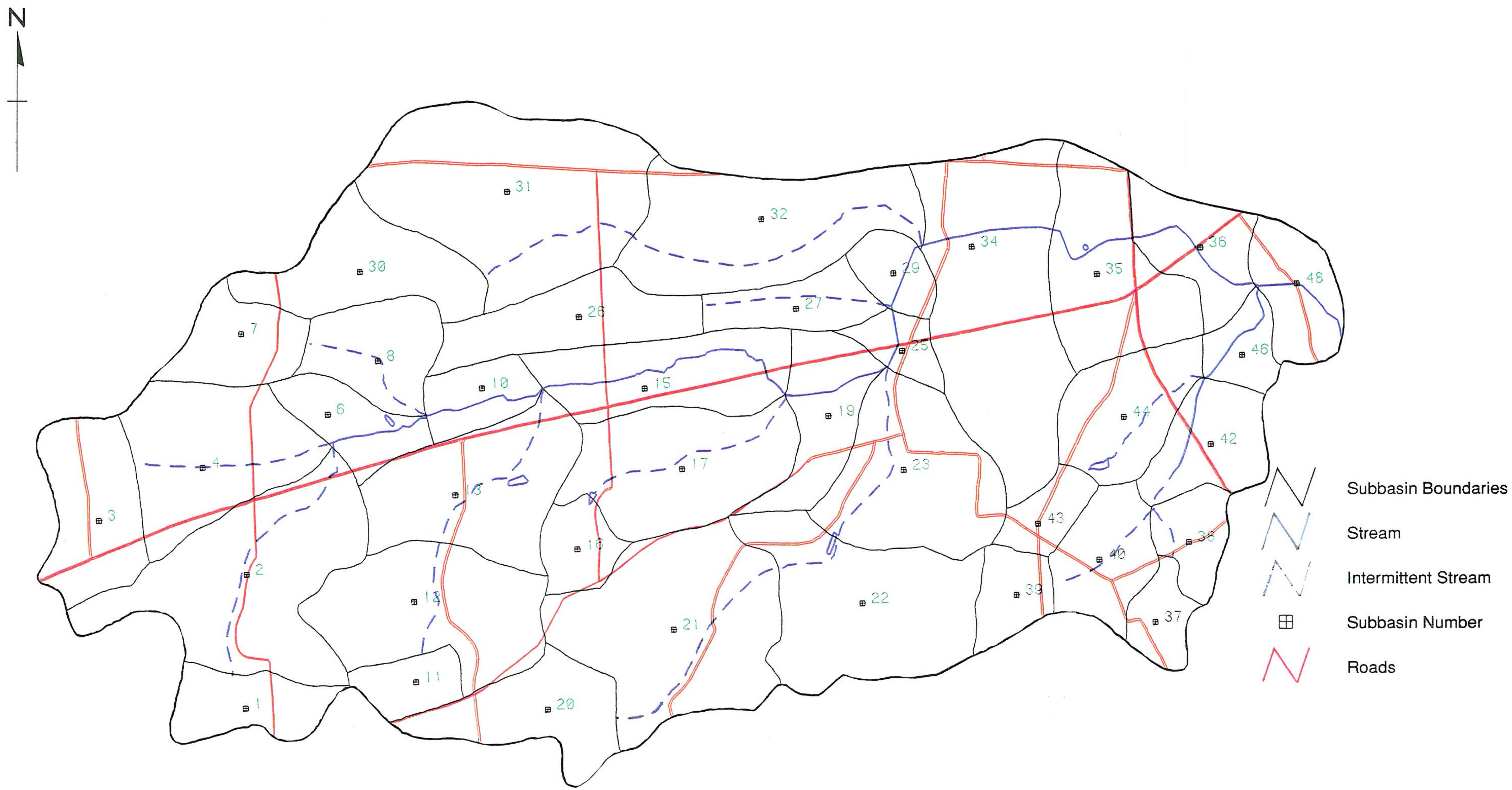
PSRM develops runoff hydrographs for individual portions (subbasins) of a watershed which are then routed and combined in a manner corresponding to the network of streams that link the subbasins. Consequently, the initial task in the development of the modeling data base was the delineation of subbasins within the watershed.

Subbasin boundaries were defined so as to as closely as practical produce hydrologically homogeneous areas as well as to adequately model hydrologically significant features such as tributaries and significant obstructions. A total of 38 subbasins were delineated. Delineated subbasin boundaries are illustrated in Plate IV-1.

United States Geological Survey (U.S.G.S.) 7.5 minute quadrangle topographic mapping supplemented with field investigations of obstructions was used as the basis for defining subwatersheds and subbasins. The subbasin boundaries were delineated on the U.S.G.S. base and digitized to facilitate subsequent analysis. Once digitized, the subbasin areas were calculated. The subbasins average 141.5 acres in size.

Stream locations were digitized and added to the data base. Representative overland flow widths for each subbasin were calculated based upon an analysis of the digitized stream locations and subbasin boundaries.

Digital Elevation Model (DEM) data obtained from U.S.G.S. served as the source of digital terrain data used to produce slope summaries for each subbasin. Slope in percent and aspect in degrees were calculated from the raw elevation data and were used to determine representative ground slopes for each of the subbasins.



GeoSpatial Solutions

Scale 0 1 2 Mile

11/91

Union County, Pennsylvania
Bull Run Watershed

Subbasins and Hydrography

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Plate IV-1

SUBBASIN HYDROLOGIC CHARACTERISTICS

The principal subbasin specific hydrologic characteristics of interest in this analysis are the composite Soil Conservation Service (S.C.S.) runoff curve number and percentage of impervious area for each subbasin. Percent of impervious area is defined as the percentage of the total subbasin area covered by surfaces which are essentially impermeable to water. The runoff curve number is a indication of the amount of surface runoff which may be expected to be produced as a result of a storm event. This runoff potential is influenced by land cover and soil conditions. The determination of impervious percentages and curve numbers required the classification of land cover and soil types.

Land Cover / Land Use Classification

Transparencies from the National Aerial Photography Program (NAPP) were the basis of the land use and land cover information.

Impervious Area Statistics

Impervious area statistics for each subbasin were estimated based upon the land cover and land use through the relationships of impervious area components of various land use / land cover classes developed and published by the U.S. Soil Conservation Service.

Soils Group Classifications

The spatial distribution of soils (aggregated by S.C.S. hydrologic soil groups) was defined through the use of S.C.S. soils maps and reports for Union County. The various soil types were aggregated into the appropriate hydrologic soil groups based upon S.C.S. procedures. The hydrologic soil group polygons were transferred from the S.C.S. plates to stable-base mylar, registered to the U.S.G.S. base and digitized. This procedure produced the data set used to create the hydrologic soil group map presented previously in Section III.

Calculation of Runoff Curve Numbers

The factors that determine runoff curve numbers (CN) are the hydrologic soil group and land cover type and condition. The S.C.S. has developed and published tables which provide runoff curve numbers for each intersection of hydrologic soil group and land cover type. Information extracted from the S.C.S. literature was used to assemble the CN matrix of land use / land cover characteristics versus hydrologic soil group displayed in Table IV-1.

Geographic Information system (GIS) methods were used to digitally combine the land use / land cover and hydrologic soil group themes to yield a set of associations between surface type and soils units. These associations were referenced to the S.C.S. information to attach the appropriate runoff curve number. Further processing within the GIS determined composite runoff curve numbers for each of the subbasins in the watershed.

TABLE IV-1
LAND COVER / HYDROLOGIC SOIL GROUP
CURVE NUMBER MATRIX

Land Use / Land Cover	HSG A	HSG B	HSG C	HSG D
High Density Residential	69	80	87	90
Medium Density Residential	56	71	81	86
Low Density Residential	49	66	78	83
Commercial	89	92	94	95
Industrial	81	88	91	93
Open Space (Parks)	39	61	74	80
Schools	56	71	81	86
Wooded	30	55	70	77
Brush	30	48	65	73
Meadow	30	58	71	78
Agricultural	64	75	83	87
Farmstead	59	74	82	86
Open Water	100	100	100	100
Disturbed	77	86	91	94

Modeling Subbasin Data File Production

All of the subbasin information necessary for PSRM modeling was represented in the GIS system as digitized themes. Once these data were resident in the GIS, the necessary analyses were performed to develop the required PSRM input data set. This data set is common to all subwatersheds and subbasins in the watershed and is keyed to assigned subbasin identification numbers. The version of PSRM used in this modeling effort has the capability of reading the appropriate individual subbasin characteristics data directly from the common subbasin data file.

STREAM REACH HYDRAULIC CHARACTERISTICS

Important input data requirements of the PSRM are estimates of the times of travel in each of the modeled stream reaches and the bankfull capacity of each reach.

Travel Time Estimates

Travel time is calculated as the length of the reach divided by the average velocity. Stream reaches were defined in conjunction with the delineation of watershed subbasins as described previously. The length of each reach was determined by direct measurement from the U.S.G.S. maps. Stream reach velocity estimates were based upon cross section information available from Flood Insurance Studies (FIS) completed within the watershed. This data was used in conjunction with empirical relationships between stream cross section measurements, discharge and mean velocity to produce velocity estimates for stream reaches for which no FIS information is available. Velocities for improved (i.e. channelized) stream reaches and major storm sewers and long culverts were calculated based upon reported and/or field measured dimensional and slope information.

Estimated velocities were divided by measured lengths to produce estimates of times of travel for each stream reach for input into PSRM.

Bankfull Capacity Estimates

The estimation of bankfull capacities in the natural stream reaches in the Bull Run watershed was performed based upon information reported in the literature which essentially states that bankfull capacities in natural streams approximate the 2-year return frequency flood discharge rate (Leopold, 1953; Brush, 1961; Harvey, 1969; and Brown, 1979). The estimates of the 2-year flood for each stream reach were developed using Leopold's Equations presented in the U.S.G.S. publication Hydrology of Area 2, Eastern Coal Province, Pennsylvania and New York. Discharges calculated using this procedure were used as initial bankfull capacity estimates for stream reaches.

Modeling Stream Reach Data File Production

The stream reach data required for PSRM modeling of the watershed was compiled into a single reach data file. This input file contains stream time of travel and capacity data keyed to each of the identified reaches modeled during this planning effort.

RAINFALL CHARACTERISTICS

Rainfall Intensity-Duration-Frequency

Rainfall depth-duration-frequency (DDF) values for the Bull Run watershed are summarized in Table IV-2.

This data was calculated using the charts describing rainfall intensity-duration-frequency (IDF) data presented in the Pennsylvania Department of Transportation IDF Field Manual. This document divides the state of Pennsylvania into five regions of relatively uniform rainfall patterns. Intensity-duration-frequency and depth-duration-frequency (DDF) relationships for each of the five regions are presented in the form of design charts. The Bull Run watershed lies in Region 3.

TABLE IV-2
RAINFALL DEPTH, DURATION AND FREQUENCY DATA

Return Period (Years)	Storm Duration (Hours) 3	6	12	24
2	1.51	1.80	2.15	2.59
5	1.80	2.16	2.60	3.12
10	2.16	2.64	3.16	3.72
25	2.48	3.06	3.75	4.56
50	2.92	3.60	4.38	5.28
100	3.28	4.08	5.02	6.12

Rainfall Distribution

The distribution of rainfall within the overall storm event is relevant to the modeling effort. The S.C.S. has developed synthetic rainfall distribution patterns which include maximum rainfall intensities for the selected design frequency arranged in a sequence that is critical for producing peak runoff. SCS has developed four synthetic distributions from available National Weather Service data. The SCS Type II distribution represents design storm conditions appropriate for the Bull Run watershed.

Other candidate storm distribution patterns for application in the Bull Run watershed are the composite rainfall distribution and historic average patterns. The composite rainfall distribution attempts to represent conditions critical to peak runoff rates while the historical average pattern represents actual local average rainfall distribution patterns. The historical pattern for the Bull Run watershed was produced through an analysis of rainfall records for the 1976 to 1990 period as measured at the National Climatic Data Center (NCDC) rainfall gaging station at Selinsgrove.

Since the SCS Type II storm distribution is supported by significant research activity, it is widely used in stormwater runoff calculations throughout the area and its use is incorporated directly in the frequently employed SCS stormwater runoff computational procedures it was selected for use in the Bull Run watershed model. Rainfall hyetographs for various durations and return frequencies constructed using the SCS Type II storm distributions are presented in Figures IV-1 through IV-4.

MODEL CALIBRATION / VERIFICATION

As was discussed in Section III, there are no continuously recording stream gages in operation in the Bull Run watershed. Unsuccessful attempts were made to gather simultaneous rainfall and streamflow information sufficient to calibrate / verify the model against observed, event specific data gathered within the watershed.

In order to assess the reasonableness of the model output, the model was evaluated against Bull Run flood frequency / discharge estimates provided in the following publication:

- Flood Insurance Study, Township of East Buffalo, Pennsylvania, Union County, Federal Emergency Management Agency, March 15, 1984.

The discharges in the above publication were computed using the regional flood-frequency method developed by the Corps of Engineers. The skew coefficient was modified to correspond more closely to the flood-frquency curve computed by the Soil Conservation Service. The discharges were then adjusted for effects of urbanization where appropriate.

Figure IV-1
Bull Run SCS Type II Storm Distributions

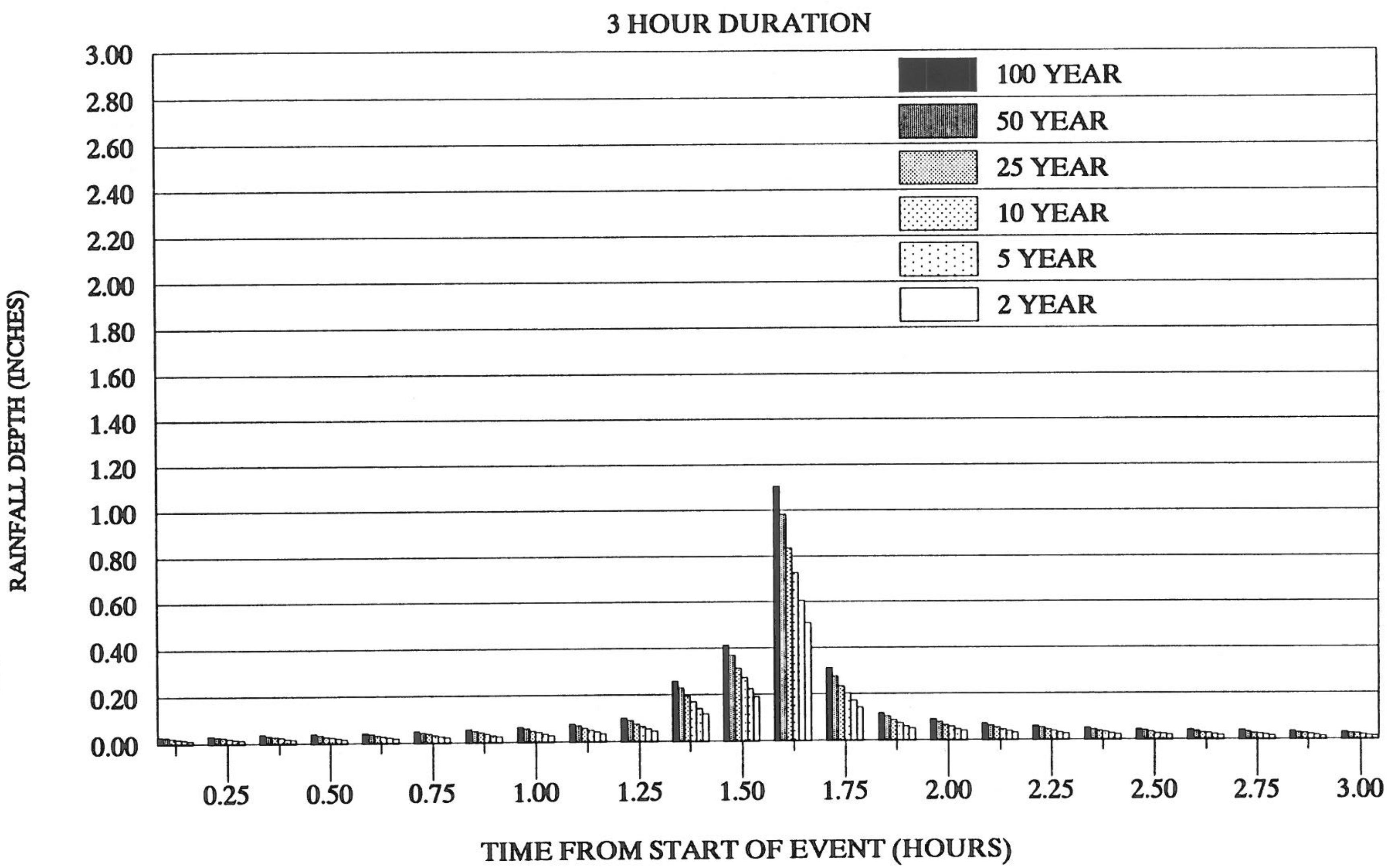

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Figure IV-2

Bull Run SCS Type II Storm Distributions

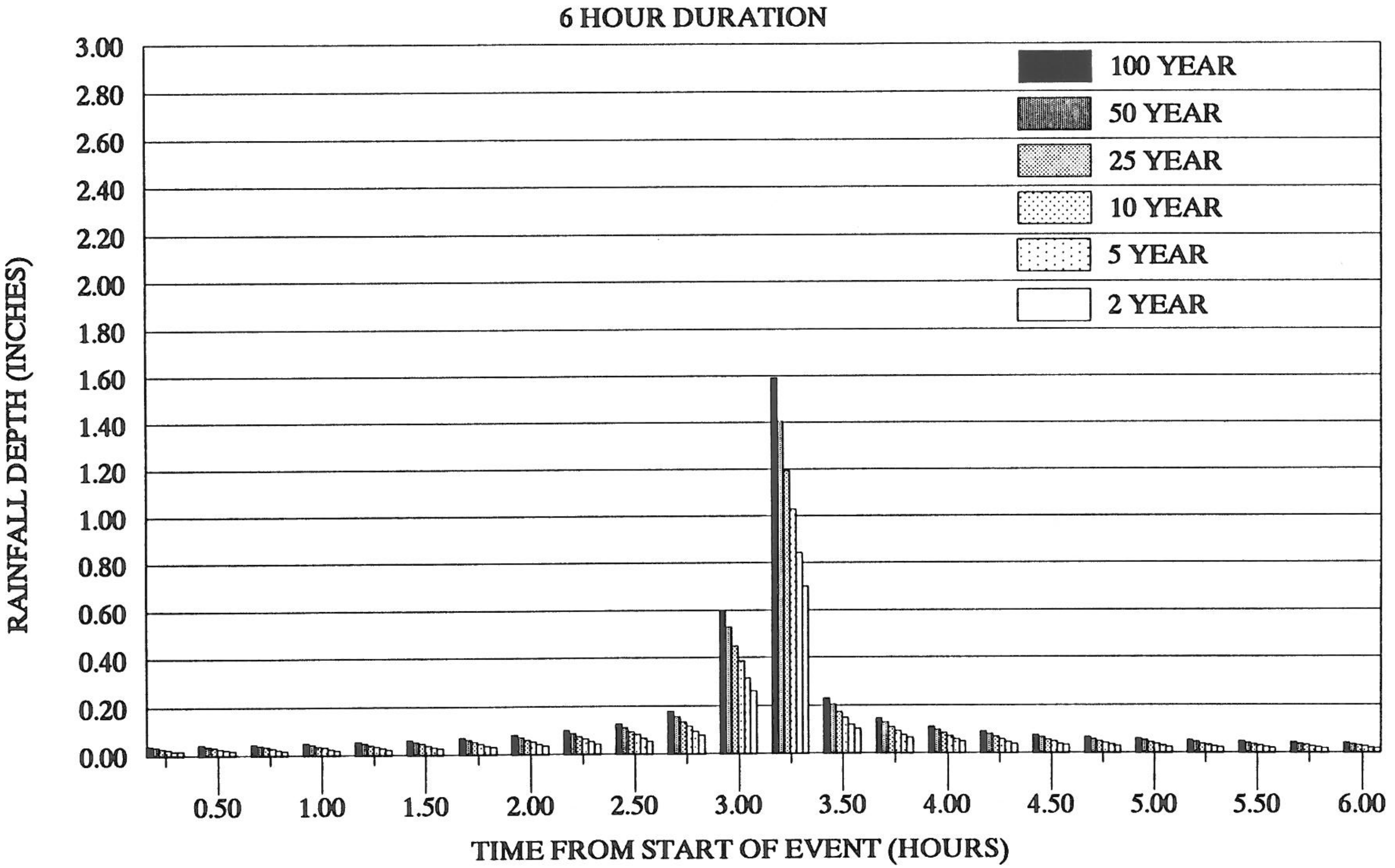

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Figure IV-3
Bull Run SCS Type II Storm Distributions

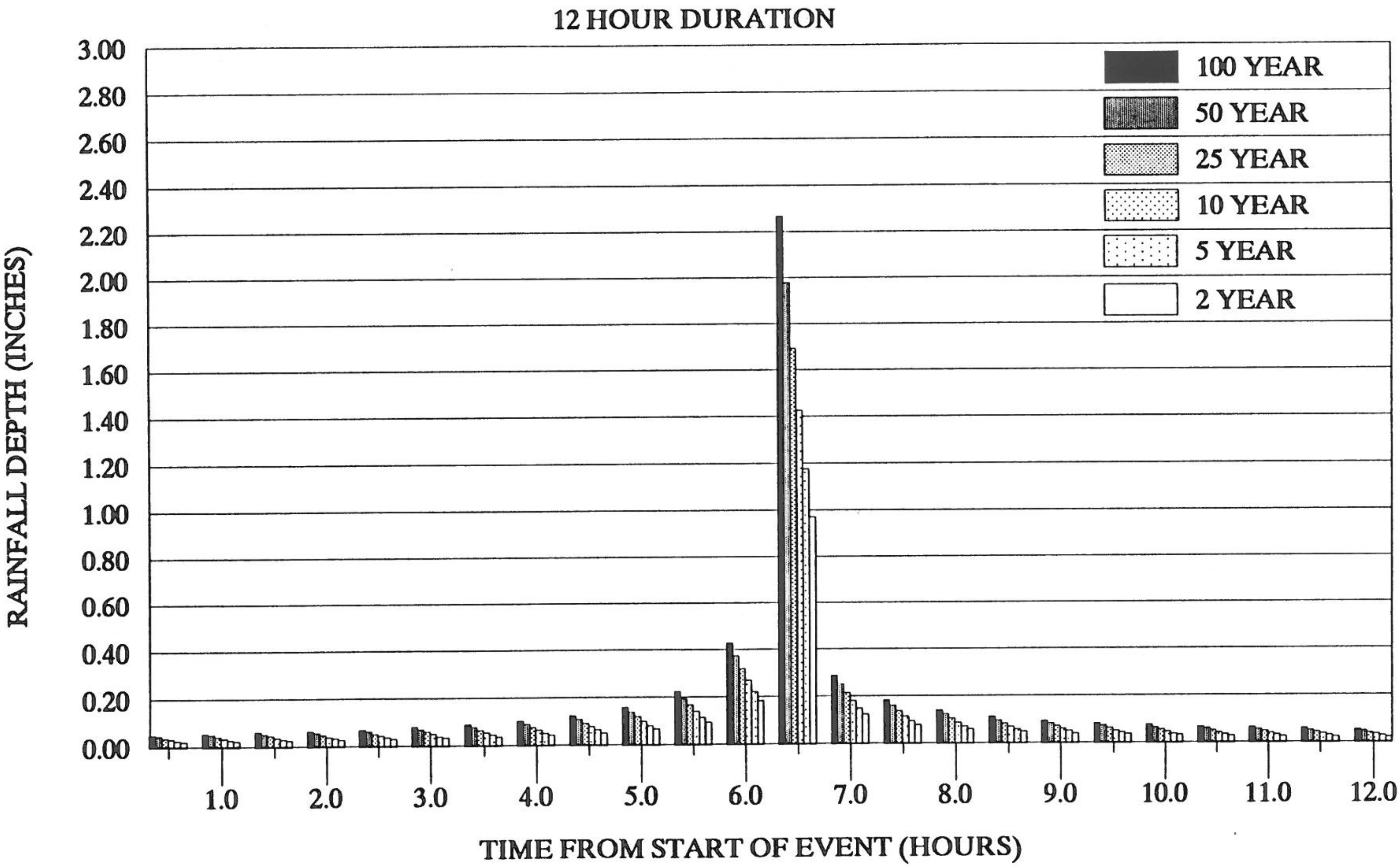

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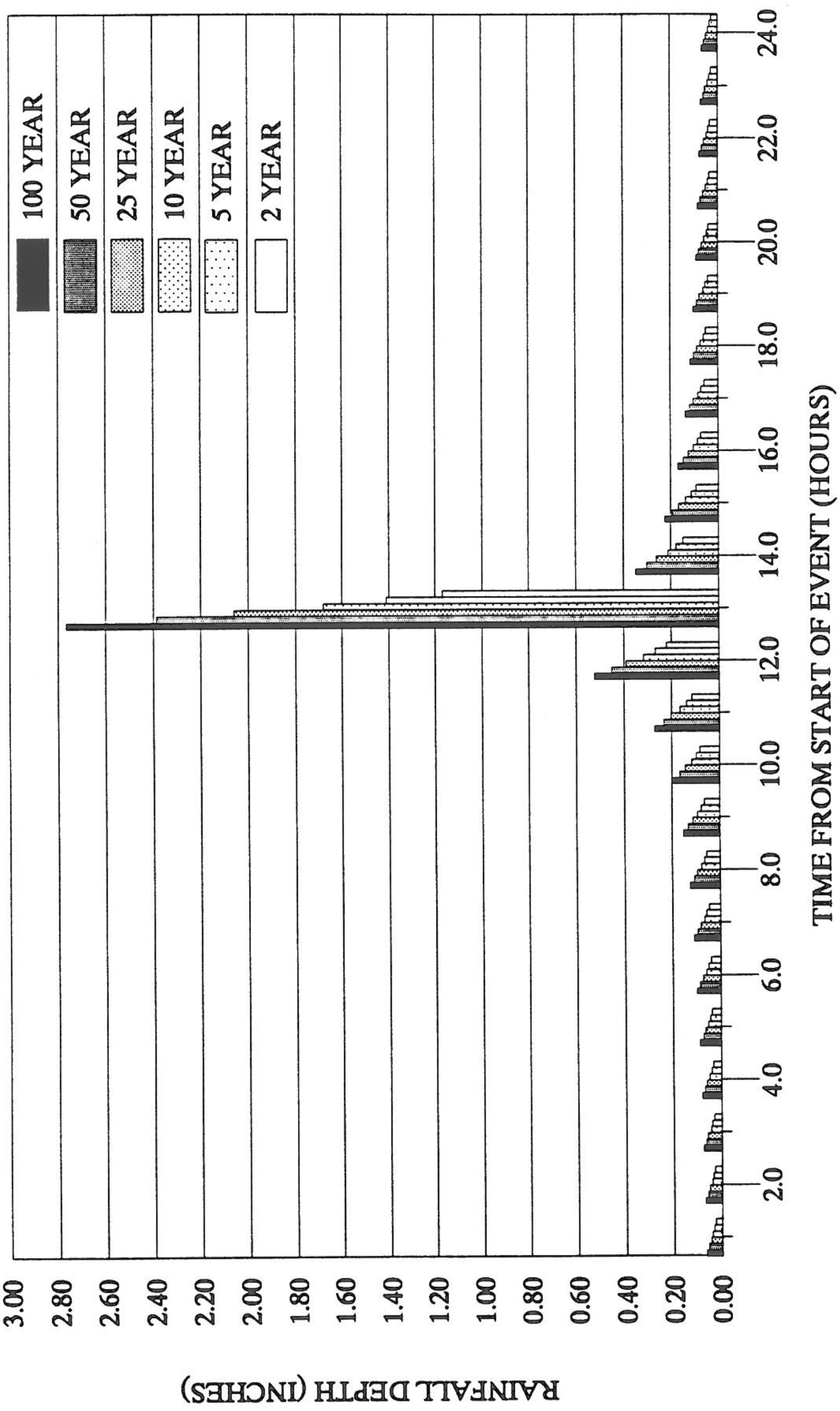
Figure IV-4

Bull Run SCS Type II Storm Distributions

24 HOUR DURATION



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Flood peaks were estimated using this method for events ranging in frequency from 2 to 100 years. The subwatersheds were then modeled using PSRM using rainfall events with the same return frequencies (i.e. 2 , 5, 10, 25, 50 and 100 year storms). Four storm durations (3, 6, 12 and 24 hour storms) were modeled, creating a family of flood frequency curves for each of the watersheds. The rainfall events were distributed in accordance with the S.C.S. Type II Distribution.

The model output representing peak discharges from Bull Run at its mouth is compared to the Flood Insurance Study (FIS) estimates in Figure IV-5 and Table IV-3. As this chart indicates, the FIS estimates approximate the 12 and 24 hour storm duration model estimates. This comparison verifies that the model reasonably approximates the actual conditions.

Table IV–3
Comparison of Discharge / Frequency Estimates
Bull Run at Mouth

Return Frequency (Years)	Estimated Discharge (cfs)				
	3 – Hour Duration	6 – Hour Duration	12 – Hour Duration	24 – Hour Duration	FIS Estimates
2	356	518	626	673	
5	499	710	869	994	
10	661	1,040	1,330	1,331	1,250
25	837	1,429	1,781	1,874	
50	1,102	1,905	2,330	2,337	2,400
100	1,336	2,339	2,894	2,934	3,200

MODEL RESULTS

EXISTING CONDITIONS

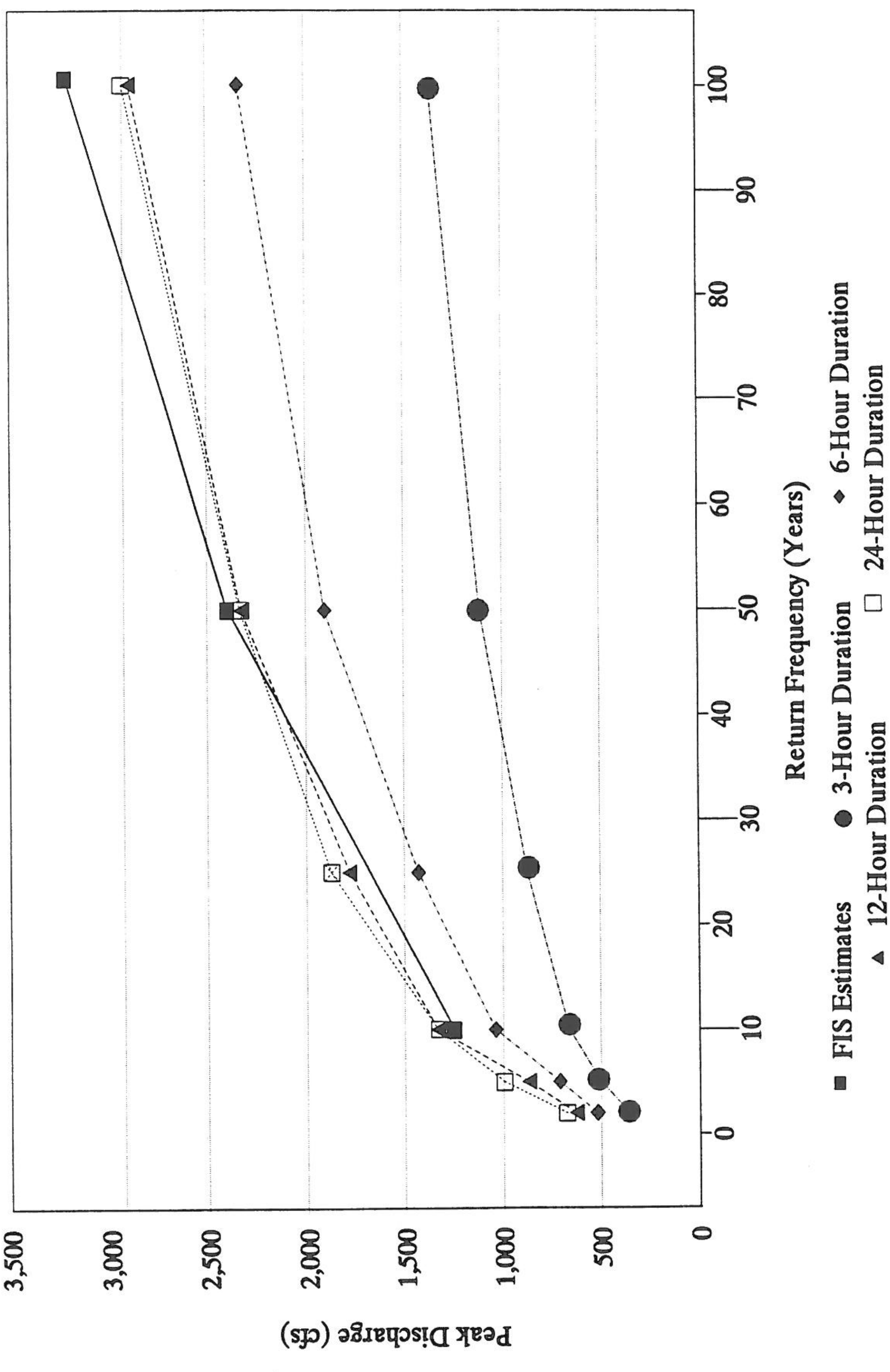
Runoff and streamflow rates were estimated under current conditions using the PSRM for each of the subwatersheds selected for detailed modeling. The model was run for 2 , 5, 10, 25, 50 and 100 return frequency volumes associated with 3, 6, 12 and 24 hour duration storm events. In all, model output was developed for 24 storm conditions for each of the 38 subbasins included in the modeling program. The results of this modeling effort are summarized in Appendix B, Table B-1.

In reviewing the model results, the reader's attention is redirected to the previous discussion concerning the observed variance between the rainfall - runoff model peak discharge estimates presented herein and estimates derived by others by applying statistical analysis techniques to measured flood peaks. It is important to recognize that the streamflow estimates developed as part of this plan have been developed by modeling the runoff produced by rainfall volumes with a range of return frequencies distributed according to the SCS Type II Distribution. Since this distribution is designed to maximize runoff from any given rainfall volume, this procedure produces conservatively high runoff rate estimates suitable for the design of local controls. The estimates presented herein should not be used in the design of regional flood control facilities or flood plain management projects. Estimates based upon flood frequency analyses of local gauged watersheds are more appropriate for these purposes.

FUTURE CONDITIONS

The PSRM was used to estimate runoff and streamflow rates under projected future development conditions. This was accomplished by revising the S.C.S. runoff curve number and percent impervious estimates in the model subbasin database to reflect the projected future land use / land cover characteristics as presented in Section III. The model was then run under these conditions to produce estimates of future runoff and streamflow rates for the 24 hour, 100 year return frequency storm. Model output for each of the modeled subbasins is provided in Appendix B, Table B-1. Please note that in Table B-1, columns headed "Peak Runoff" list the peak rate of surface water runoff estimated for each subbasin. Columns headed "Peak Discharge" list the estimated peak rate of discharge from the stream segment leaving each subbasin.

Figure IV-5
Comparison of Discharge / Frequency Estimates
Bull Run at Mouth



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BULL RUN WATERSHED
STORMWATER MANAGEMENT PLAN

SECTION V

DEVELOPMENT OF WATERSHED TECHNICAL STANDARDS AND CRITERIA

INTRODUCTION

As was discussed previously in Section I, the basic standard for stormwater management as established by Act 167 is that those involved in activities which can generate additional stormwater runoff, increase its velocity, or change the direction of its flow must be responsible for controlling and managing the runoff so that these changes will not cause harm to other persons or property throughout the watershed. This mandate requires comprehensive stormwater planning at a watershed level and the development of standards and criteria for managing stormwater to prevent adverse impacts, both at a particular site and anywhere downstream where the potential for harm can reasonably be identified.

Specifically, the primary prerequisite for effective stormwater management in the watershed is the development of standards which specify allowable stormwater discharges from land development activities. Standards must also be developed which address issues associated with the control of velocity, direction and quality, if appropriate. The standards must be accompanied by associated criteria which for the basis for the design and assessment of activities instituted to comply with those standards.

CONTROL STORM CHARACTERISTICS CRITERIA

A key element in the development of this stormwater management study is the definition of the characteristics of the rainfall events against which the developed control standards must be applied. Specifically, the rainfall events which the stormwater control measures must adequately handle need to be defined. The objective of the analyses discussed in the following paragraphs was to describe characteristics of storm events which will serve as the basis for the evaluation and design of effective control measures in the Bull Run watershed.

The critical rainfall event characteristics are as follows:

1. An identified duration or length of the particular rainfall event.

2. An identified rainfall intensity or distribution or pattern of precipitation falling over the duration of the event.

3. An identified frequency of occurrence or the expected time interval between occurrences of the given precipitation event.

4. An identified volume or total amount of rainfall that can be expected for the particular event.

STORM DISTRIBUTION

The selection of the appropriate distribution of rainfall within the overall storm event was discussed in Section IV. For the reasons specified therein, the Soil Conservation Service (SCS) Type II rainfall distribution was selected for application to the development of control standards and the design of actions to be taken to satisfy those standards.

STORM DURATION

Storm duration refers to the length of time over which the specified amount of precipitation falls. This factor is of concern because rainfall duration has a direct effect upon the resulting runoff volume and peak rate of discharge. The length of the rainfall period contributing to the peak runoff rate is related to the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest (time of concentration). In general, largest peak discharges result when the storm duration roughly equals the time of concentration in the watershed.

In small, urban watersheds the critical storm duration may be measured in minutes, while in large watersheds or basins the time of concentration may be measured in days. In the Bull Run watershed, the appropriate storm duration for use in the development and application of control standards was selected using the hydrologic model. The PSRM was used to estimated peak discharge rates throughout the watershed for the 2, 5, 10, 25, 50 and 100 year return frequency storms of the following candidate durations: 3 hour, 6 hour, 12 hour and 24 hours. The model runs produced estimates of the peak discharges at 38 points throughout the watershed for each of the four candidate durations. The 24 hour duration storm produced the highest peak discharges for all return frequencies, almost uniformly. These results support the selection of 24 hours as the design storm duration for use in watershed management.

A supporting consideration in the selection of the storm duration for use in the Bull Run watershed is the fact that the popular Soil Conservation Service Technical Release 55 Urban Hydrology for Small Watersheds procedure for estimating runoff and peak discharges is based upon a 24-hour storm duration. This procedure is extensively used within the region and nationally in the production of stormwater control plans for proposed land development. Adoption of a storm duration criteria other than 24 hours would effectively preclude the use of this most popular computational procedure.

For the reasons discussed above, 24 hours has been selected as the appropriate storm duration criteria for application throughout the watershed. It is recognized that the use of shorter durations will be appropriate and permissible in the design of stormwater collection facilities. However, the selection and application of controls to the discharge of runoff from developing sites will be based upon the 24-hour storm duration criteria.

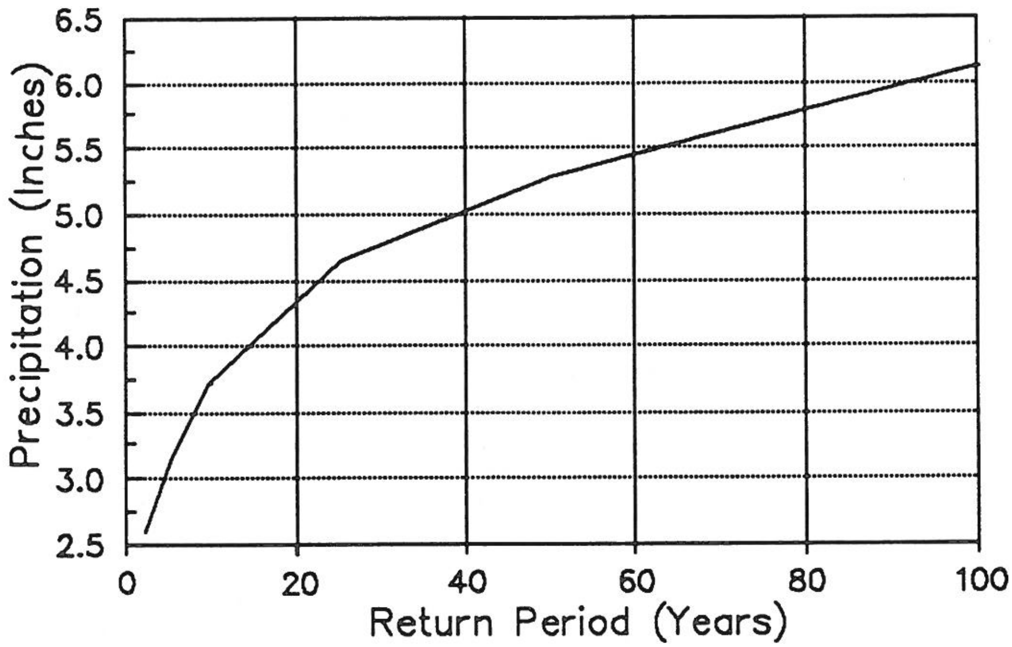
STORM RETURN FREQUENCIES AND PRECIPITATION VOLUMES

General

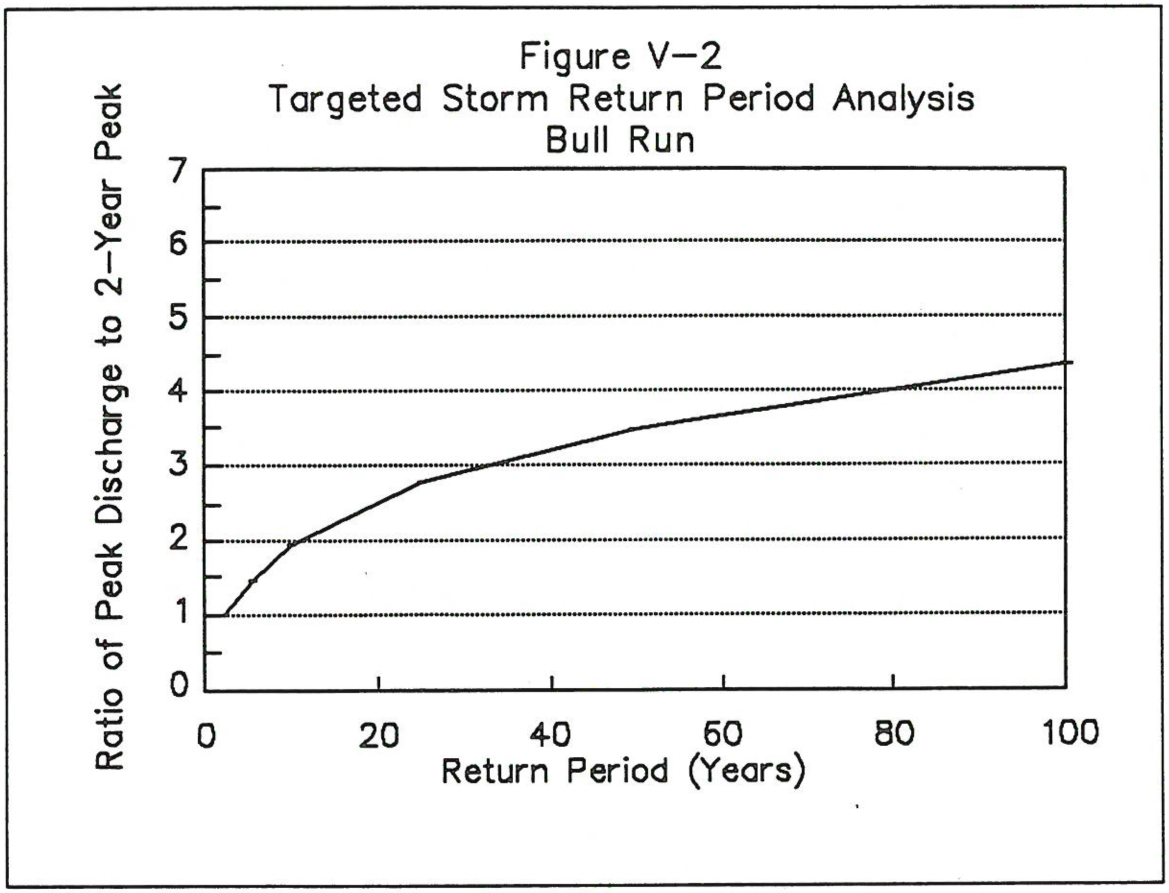
Storm return frequency refers to the average interval in years over which a storm event of a given precipitation volume can be expected to recur. For example, reference to a "10-year" storm with an associated 3.72 inch 24 hour duration storm volume indicates that a storm producing 3.72 inches of rainfall over a 24 hour period on the average can be expected to occur approximately every ten years. Another way to consider this storm is that, on the average, a storm producing 3.72 inches of rainfall over a 24 hour period has approximately a ten (10) percent chance of occurring in any given year. Storm duration and volumes for return frequencies ranging from 2-years to 100-years were presented previously in Section IV of this report (Table IV-2). This data for the 24-hour duration is presented graphically below in Figure V-1.

Figure V – 1

24 Hour Storm Return Frequency Curve



As is indicated in Figure V-1, precipitation amounts increase with increasing return periods reflecting the obvious fact that the larger the rainfall event the more infrequent the occurrence. As one would expect, larger rainfall amounts produce larger stream discharges. This is illustrated in Figure V-2 for the mouth of Bull Run. The estimates of stream discharges reflected in Figure V-2 were produced using the Penn State Runoff Model developed for the Bull Run watershed.



The Pennsylvania Department of Environmental Resources "Storm Water Management Guidelines" describe design frequencies as the peak rates of discharge for which the components of drainage systems are designed. Reoccurrence intervals used for design typically range from 2 to 100 years. Individual drainage system components are generally assigned design storm frequencies based upon an evaluation of such factors as the size of the area drained and the potential for damage produced as a result of inadequate drainage as characterized by the size of the affected area and the nature and characteristics of land use in the affected area (i.e., residential, commercial, industrial uses). Components of the initial drainage system such as storm sewers and inlet structures generally are designed for relatively high frequency events ranging upwards to 10-year storms. Major drainage system components are generally designed for less frequent, larger storms such as the 25-year and 50-year events. Flood protection projects typically are designed to accommodate conditions produced by the 100-year storm events.

Design frequency criteria for the construction of conveyance facilities such as storm sewers, pipes, culverts, bridge openings and spillways are contained in a number of regulations and design manuals, including: regulations produced relative to the Pennsylvania Dam Safety and Encroachments Act, the Pennsylvania Flood Plain Management Act; Pennsylvania Department of Transportation design criteria; Pennsylvania Soil and Erosion Control Manual; and the Water Pollution Control Federation Manual of Practice No. 9: Design and Construction of Sanitary and Storm Sewers. These references provide ample guidance under the law and standard engineering practice to permit local municipalities to establish local requirements for traditional stormwater facilities design commensurate with local conditions. There are, however, no state level criteria for stormwater discharges as they relate to total discharge volumes and rates from new land development. Moreover, unlike the generally site specific conduit construction criteria, site runoff criteria must be established based upon watershed wide considerations. Consequently, this watershed plan presents specific criteria relative to storm frequencies to be used in controlling total stormwater discharge volumes and rates from new site development.

Upper and Lower Storm Frequency Criteria Limits

For this study the design storm frequency criteria were selected to respond to watershed conditions and to meet the objective of Act 167 to minimize stormwater damage now and in the future. The following example serves to illustrate the design storm frequency criteria selection rationale. The following table contains pre-development and post-development peak rates of discharge for a hypothetical development.

Table V-1
Hypothetical Design Storm Discharge Rates

	Design Storm		
	2-Year	10-Year	100-Year
Pre-development	50 cfs	75 cfs	100 cfs
Post-development	100 cfs	150 cfs	200 cfs

Two conclusions may be drawn for the data presented in this table:

1. If the design storm frequency criteria require that only the 100-year event be used as a point of control, the post-development discharge for the 2- and 10-year storms will be greater than the pre-development rate and runoff from the development may cause downstream harm at the more frequent storm events.

2. If the criteria require that only the 2-year event be applied, damage may result from increased runoff during the less frequent storm conditions.

If the stormwater conveyance system from this hypothetical development site to the river were capable of accommodating flows generated under 100-year return frequency storm conditions, controlling discharges under simply a 100-year storm frequency criteria would be acceptable. However, information obtained from local municipal questionnaires and data produced through an analysis of existing obstruction capacities identified a number of locations where flooding occurs as frequently as once per year. The municipal questionnaires identified 15 locations within the watershed at which flooding occurs on average at least once per year

(Table III-4). Also, an analysis of the capacity of obstructions located throughout the watershed identified 25 structures with capacities less than the estimated 2 year annual flood in the vicinity (Appendix A, Table A-1). Consequently, the 2-year flood event has been selected as the lower limit design storm frequency criteria.

The 100-year frequency storm was selected for use in the watershed for the following several reasons.

1. The survey of obstructions identified 5 obstructions with capacities between the 50- and 100-year floods (Appendix A, Table A-1). A failure to control runoff under storms of these frequencies would exacerbate flooding conditions at these sites as well as those sites with even smaller capacities.

2. Control of the 100-year frequency runoff would serve to preserve the 100-year flood plain and floodway boundaries as defined in the flood insurance studies completed in the watershed. These boundaries provide the basis for on-going flood plain management in the area. Permitting increased runoff at the 100-year return frequency conditions would result in an expansion of the flood zones and substantially increase the potential for damage.

Intermediate Frequency Criteria

In setting the upper and lower limit for return frequency storms to be controlled, it is assumed that runoff produced from discharges occurring at all intermediate frequencies will also be controlled. In other words, the stormwater control facilities would regulate discharges such that the post-development discharges would match the pre-development discharges at the 3-year, 4-year, 5-year frequency storms and so on through the 100-year frequency event. It would clearly be impractical to design for such a multitude of conditions and cumbersome to review management plans produced on a yearly basis. Intermediate return frequency events were selected as reasonable points at which to verify that the runoff control system performance will generally parallel pre-development conditions between the 2- and 100-year limits. The selected check points and the manner in which they approximate modeled actual runoff rates at various return frequencies are illustrated in Figure V-3. This illustrates how the use of these intermediate points assures that the basis of the design of facilities (discharges at various frequencies) will closely track discharge rates occurring between the intermediate control points throughout the range to be controlled.

The following storm frequency check points have been selected for inclusion in the stormwater management criteria:

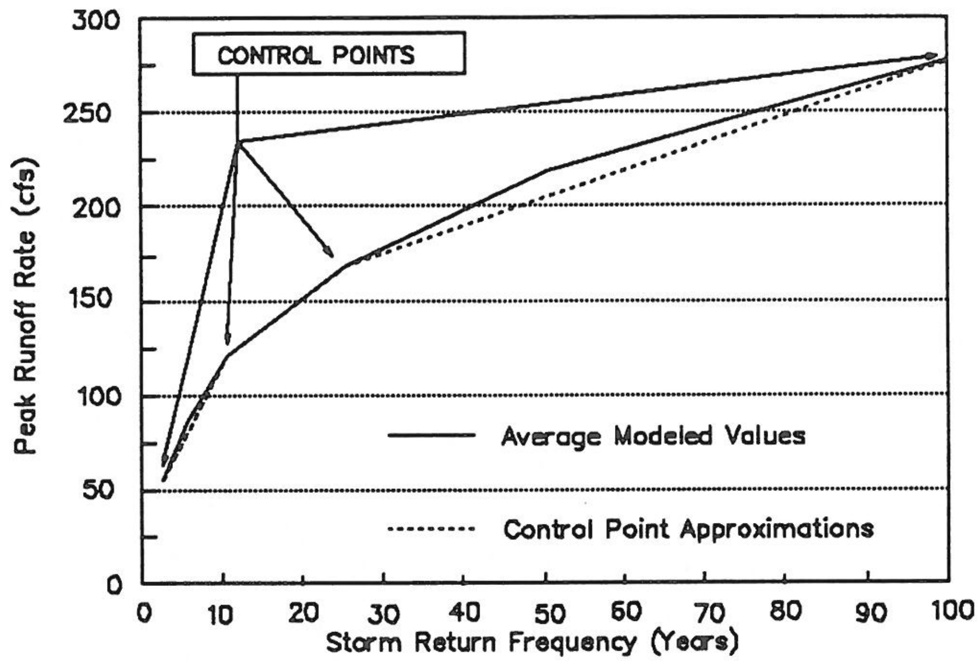
1. 2-year frequency storm;
2. 10-year frequency storm;
3. 25-year frequency storm; and
4. 100-year frequency storm.

The rationale for the selection of the upper and lower check points was described previously. The reasons for selecting the 10-year and 25-year frequency storm intermediate check points are as follows:

1. The use of these two intermediate points are effective in producing a curve of runoff rate verses storm return frequency which reasonably closely approximates the observed modeled relationship between the two variables (as illustrated in Figure V-4).

2. The 10-year and 25-year events are the most frequently referenced recommended design storm for a wide range of stormwater drainage facilities.

Figure V-3
Design Storm Control Points



Precipitation Volumes

Precipitation volumes to be used in the design and evaluation of stormwater control measures in the Bull Run watershed are presented in Table V-2.

TABLE V-2
PRECIPITATION VOLUMES

Return Period	Volume (Inches)
2 - Year	2.59
10 - Year	3.72
25 - Year	4.56
100 - Year	6.12

RUNOFF CONTROL STANDARDS

GENERAL APPROACH

The basis for the establishment of runoff control standards is contained in the Storm Water Management Act. The statement of legislative findings contained in the Act (Section 2 of the Act) presents the following findings:

"(1) Inadequate management of accelerated runoff of storm water resulting from development throughout a watershed increases flood flows and velocities, contributes to erosion and sedimentation, overtaxes the carrying capacity of streams and storm sewers, greatly increases the cost of public facilities to carry and control storm water, undermines flood plain management and flood control efforts in downstream communities, reduces ground water recharge, and threatens public health and safety.

(2) A comprehensive program of storm water management, including reasonable regulation of development and activities causing accelerated runoff, is fundamental to the public health, safety and welfare and the protection of the people of the Commonwealth, their resources and the environment."

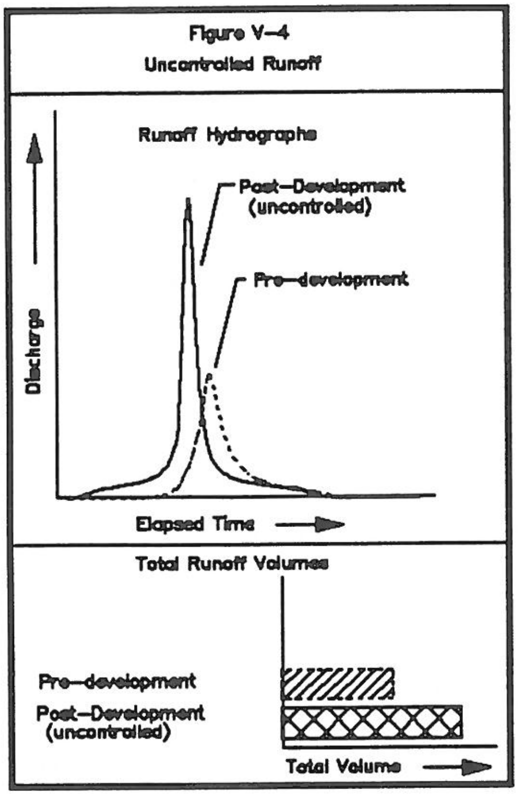
Section 3 of the Act defines the duty of persons engaged in the development of land as follows:

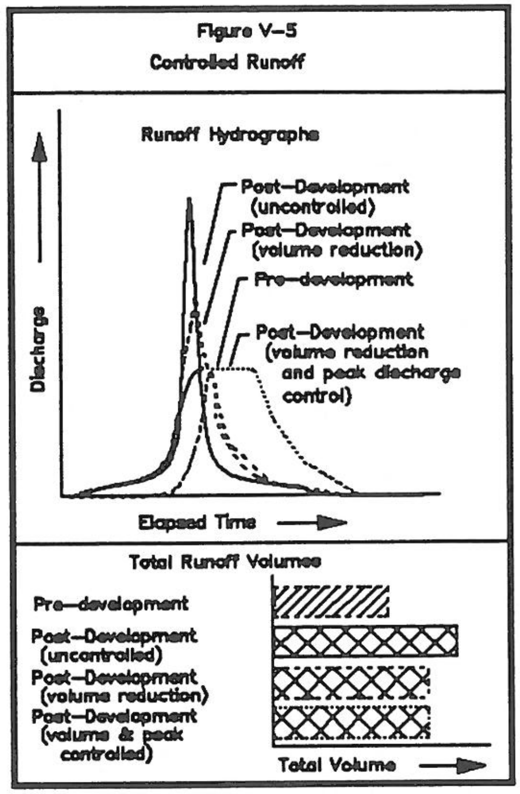
"Any landowner and any person engaged in the alteration or development of land which may affect storm water runoff characteristics shall implement such measures consistent with the provisions of the applicable storm water plan as are reasonably necessary to prevent injury to health, safety or other property. Such measures shall include such actions as are required:

(1) to assure that the maximum rate of storm water runoff is no greater after development than prior to development activities; or

(2) to manage the quantity, velocity and direction of resulting storm water runoff in a manner which otherwise adequately protects health and property from possible injury."

The most effective method means of satisfying the Act based upon the statements of legislative findings and definition of duty would be to control runoff from land development activities such that both the total volume and rate of runoff from new development are identical to that which occurred before development i.e., post-development runoff volume and rates identical to pre-development conditions. If this could be accomplished, stormwater runoff from the new development would not produce any effect on downstream flows, eliminating any concern relative to the creation of downstream damage potentials. Unfortunately, however, most land development activities involve the conversion of land use from a type which exhibits a relatively low runoff potential to a higher runoff potential type. This factor produces a typical effect upon runoff as illustrated in Figure V-4. As is indicated in Figure V-4, land development typically produces increases in both total runoff volumes and peak rates of discharge.





As is indicated in Figure V-5, measures can be taken to manage stormwater runoff by reducing the increase in total runoff volume and/or control peak rates of discharge. Techniques which may be used to minimize the increase in total runoff volume are described in Section VI of this report. These techniques generally consist of measures which minimize the extent of land cover changes from pervious to impervious areas and/or artificially induce infiltration to ground water. While these measures can be effective in reducing increases in runoff volumes, it is usually impractical to entirely avoid runoff volume increases attendant with most land development activities. Consequently, as indicated in Figure V-5, post-development hydrographs produced through the implementation of runoff volume reduction measures typically produce hydrographs with peak rates of discharge and total volumes falling between pre-development and uncontrolled post-development conditions.

Because it is impractical to entirely avoid increases in total runoff volume, the inevitability of some degree of runoff volume increases must be accepted and the primary emphasis of the stormwater control criteria must be placed upon the control of peak discharge rates. In order to minimize the potential for damage, the basic, <u>minimum</u> stormwater runoff control criteria to be applied in the watershed is that post-development peak discharges rates must not exceed pre-development peak discharge rates. Methods of controlling peak discharge rates from new development are presented in Section VI of this report. In general, they consist of measures which essentially retain and delay the controlled release of runoff so as not to exceed pre-development rates.

The typical results of the application of peak discharge control measures in addition to feasible runoff volume reduction provisions are illustrated in Figure V-5. As is indicated in Figure V-5, although the post-development total runoff volumes fall between pre-development and uncontrolled post-development volumes, the peak rate of discharge approximates the pre-development peak rate. This is accomplished by extending the time duration of time the peak rate of discharge occurs. Instead of an instantaneous peak as occurs in the pre-development condition, the peak discharge occurs over an extended period of time. This characteristic attenuation of peak discharge rates necessitates the development of additional standards designed to avoid the development of associated downstream problems. The derivation of these supplemental standards is discussed below.

RELEASE RATE PERCENTAGE CONCEPT

General Concept

It is through the development and application of release rate percentage based peak discharge standards that the stormwater management plan truly assumes a watershed wide status. The investigations which serve as the basis for the establishment of release rate percentage represent the principal means through which the watershed wide implications of control strategies are evaluated, considered and incorporated into specific control standards.

The general concepts behind the development and application of release rate percentage based stormwater management criteria are discussed below through the use of the hypothetical watershed illustrated in Figure V-6. Figure V-7 contains individual hydrographs for the total hydrograph for flows at the point of interest as well as the hydrographs for flows generated in each of the five (5) subbasins as they reach the point of interest.

As is illustrated in Figure V-7 and summarized in Table V-3, the peak discharge at the point of interest is sum of the discharges originating from each of the upstream subbasins as they coincidentally reach the point of interest.

The potential effects of land development occurring in Subbasin 3 upon the runoff hydrographs for Subbasin 3 and the entire hypothetical watershed are illustrated in Figures V-8 and V-9 and are tabulated in Table V-4. Figure V-9 illustrates the effects of the institution of stormwater controls which serve to limit post-development peak discharge rates to the pre-development discharge rate through flow detention. As is indicated by the hydrographs presented in Figure V-9, limiting the peak discharge in this manner would serve to extend the period over which the pre-development discharge occurs. The result of this flow attenuation is described by the data presented in Table V-4. Following development and the institution of the specified controls, Subbasin 3 would contribute 500 cfs to the watershed peak at the point of interest rather than the 400 cfs contributed in the pre-development state. This would produce a 100 cfs increase in the watershed peak despite the control of Subbasin 3 peak discharges to pre-development levels.

HYPOTHETICAL WATERSHED

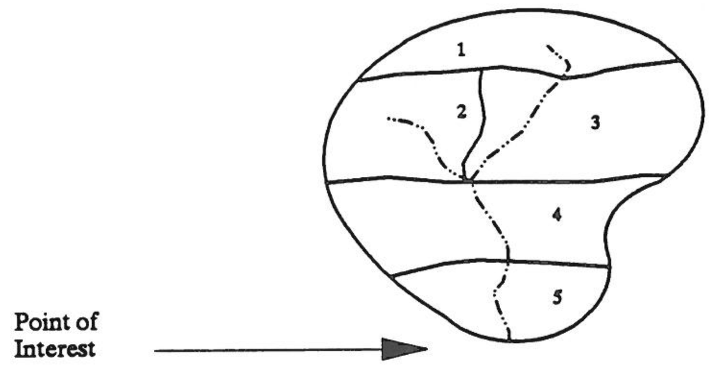


FIGURE V-6

SUBBASIN HYDROGRAPH

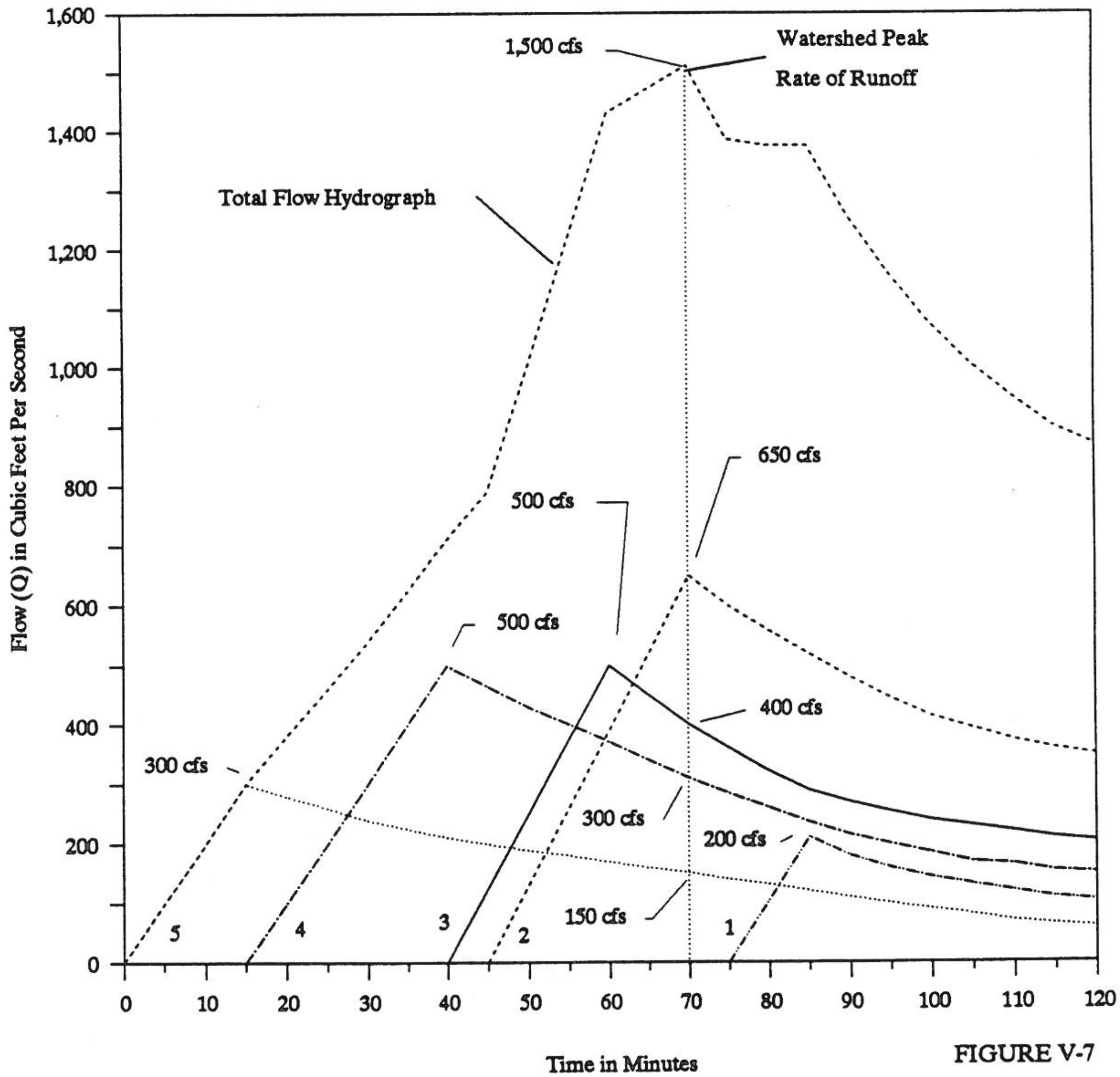


FIGURE V-7

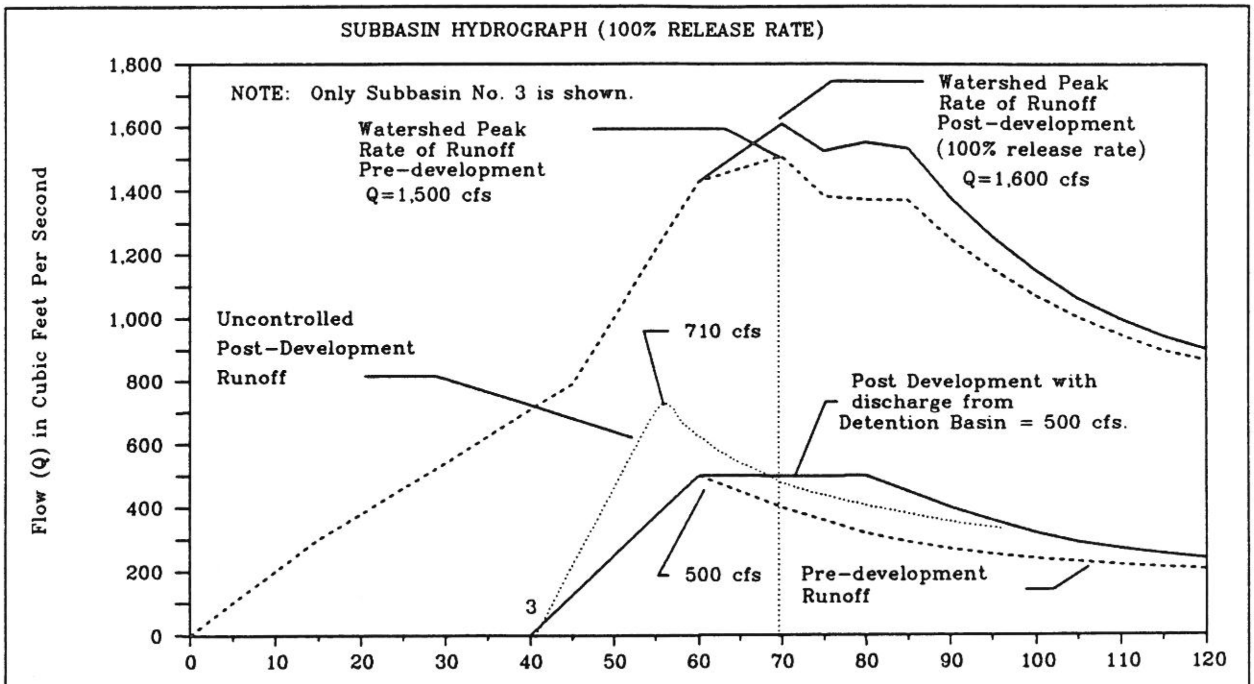


FIGURE V-8

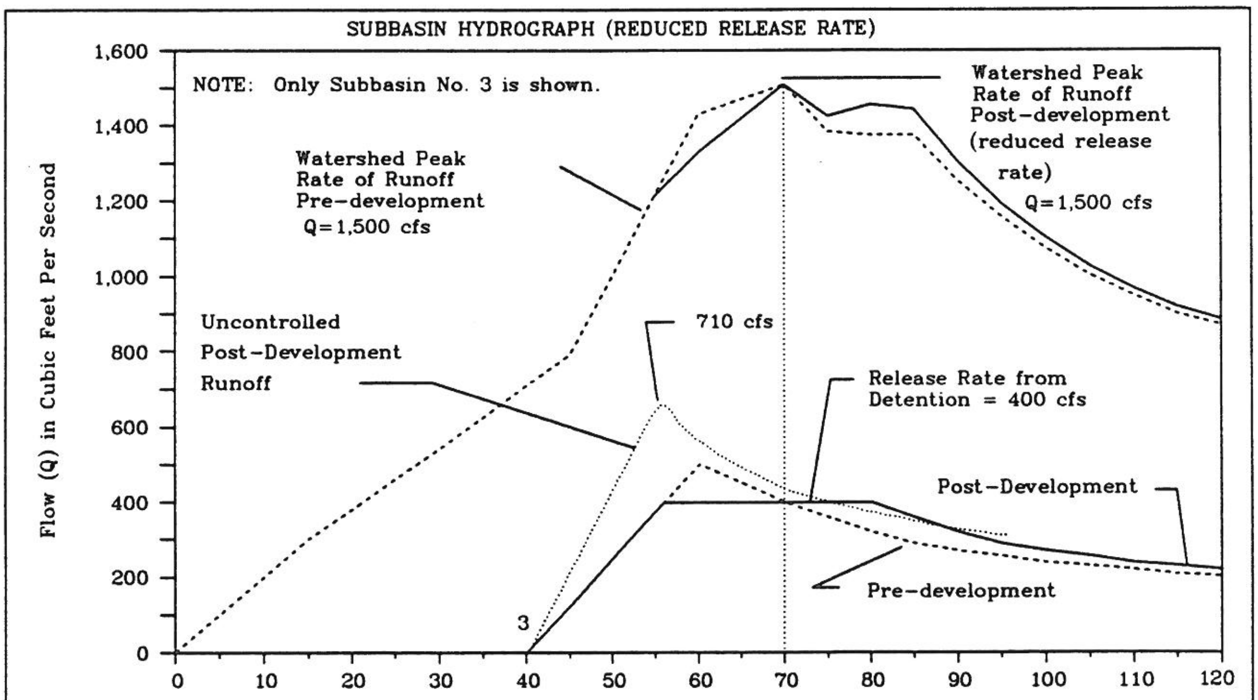


FIGURE V-9

Table V-3
Example Hydrograph Combination
Pre-Development Conditions

	Peak Discharge at Subbasin Mouth		Discharge at Point of Interest During Watershed Peak	
Subbasin Number	Time (Minutes)	Discharge (cfs)	Time (Minutes)	Discharge (cfs)
1	20	200	70	0
2	50	650	70	650
3	40	500	70	400
4	50	500	70	300
5	30	300	70	150
Total	----	----	----	1,500

Table V-4
Example Watershed Impacts
Flow Attenuation

	Peak Runoff	Contribution to Watershed Peak	Watershed Peak
Pre-development	500	400	1,500
Post-development (Uncontrolled)	710	490	1,590
Post-development (100% Release Rate)	500	500	1,600
Post-development (Reduced Release Rate)	400	400	1,500

This situation can be avoided if the post-development runoff rate is controlled so that the peak rate of runoff does not exceed the rate of flow contributed to the watershed peak.

The effects of controlling peak rates of runoff in the example situation are presented graphically in Figure V-10 and in tabular form in Table V-4. As is indicated, selection of the proper allowable post-development peak discharge rate in consideration of contribution to downstream flows can avoid unintentional increases in peak stream discharges as a consequence of efforts to limit runoff from the new development(s).

The methodology used to determine the allowable peak rate of post-development discharge in the previous example can be generalized as follows:

EQUATION 1	
	Pre-development Subbasin Peak Discharge Contribution to Watershed Peak
÷	<u>Pre-development Subbasin Peak Discharge</u>
=	Assigned Release Rate Percentage

EQUATION 2	
	Pre-development Subbasin Peak Discharge
X	<u>Assigned Release Rate Percentage</u>
=	Allowable Post-development Peak Discharge

The application of these two equations to the determination of appropriate post-development peak discharge rates defines the release rate percentage concept of stormwater management. This concept was developed to be fully responsive to the intent and requirements of Pennsylvania Act 167. The release rate percentage concept provides performance standards for storm drainage control in a watershed. The significance of this approach lies in the fact that the concept provides an effective tool for comprehensive watershed stormwater management.

Determination of Release Rate Percentages

The previous paragraphs introduced the release rate percentage concept using a simplified example. The following discussion presents the general strategy that was used to apply this concept in the Bull Run watershed.

The intent of the release rate percentage concept is to identify the general characteristics of subbasin interactions and combinations and define their relative impacts on total stream flows. This information is used to calculate the assigned release rate percentages as described previously.

The general approach employed in the Bull Run watershed was to establish release rate percentages for each subbasin by determining the peak rate of runoff from the subbasin and its contribution to peak discharges in downstream reaches. This was accomplished using the Penn State Runoff Model described in Section IV of this report. The specific steps in the approach are as follows:

1. Perform overall watershed modeling using the Penn State Runoff Model.

2. Identify the modeled flow contribution that a particular subbasin contributes to each of the modeled downstream reaches.

3. Calculate the release rate percentage for each subbasin at each downstream reach.

4. Assign a single release rate percentage for each subbasin which will adequately protect all downstream reaches.

Assigned Release Rate Percentages

Assigned release rate percentages for the Bull Run watershed are tabulated in Table V-6 and illustrated in Plate V-1. Please note that in both Table V-6 and Plate V-1, the 38 subbasins used in the modeling effort have been aggregated into twelve "Release Rate Percentage Areas". The twelve areas and their respective release rates are shown in Table V-5.

TABLE V-5
RELEASE RATE PERCENTAGES

Release Rate Area	Release Rate (Inches) Percentage
1	80%
2	50%
3	100%
4	100%
5	60%
6	60%
7	100%
8	70%
9	50%
10	60%
11	80%
12	90%

Application of the Assigned Release Rate Percentages

As indicated previously, the release rate percentage concept is a tool for watershed level stormwater management, developed to ensure that the application of runoff control plans for individual sites consider downstream stormwater runoff implications. As such, the release rate percentage functions as a performance standard; that is, it defines an end result which is to be attained. Under this approach, an individual developer can select and design those drainage control measures that are most appropriate to the site as long as the applicable release rate percentage for the subbasin is met. It is important to note that the assigned release rate percentages must be applied only to actions which control peak runoff through detention, retention or other methods which attenuate runoff discharges. Applica, ble stormwater control techniques are discussed in Section VI of this report.

To utilize the release rate for a particular site in one of the delineated release rate percentage areas, the developer should follow the following general sequence of actions.

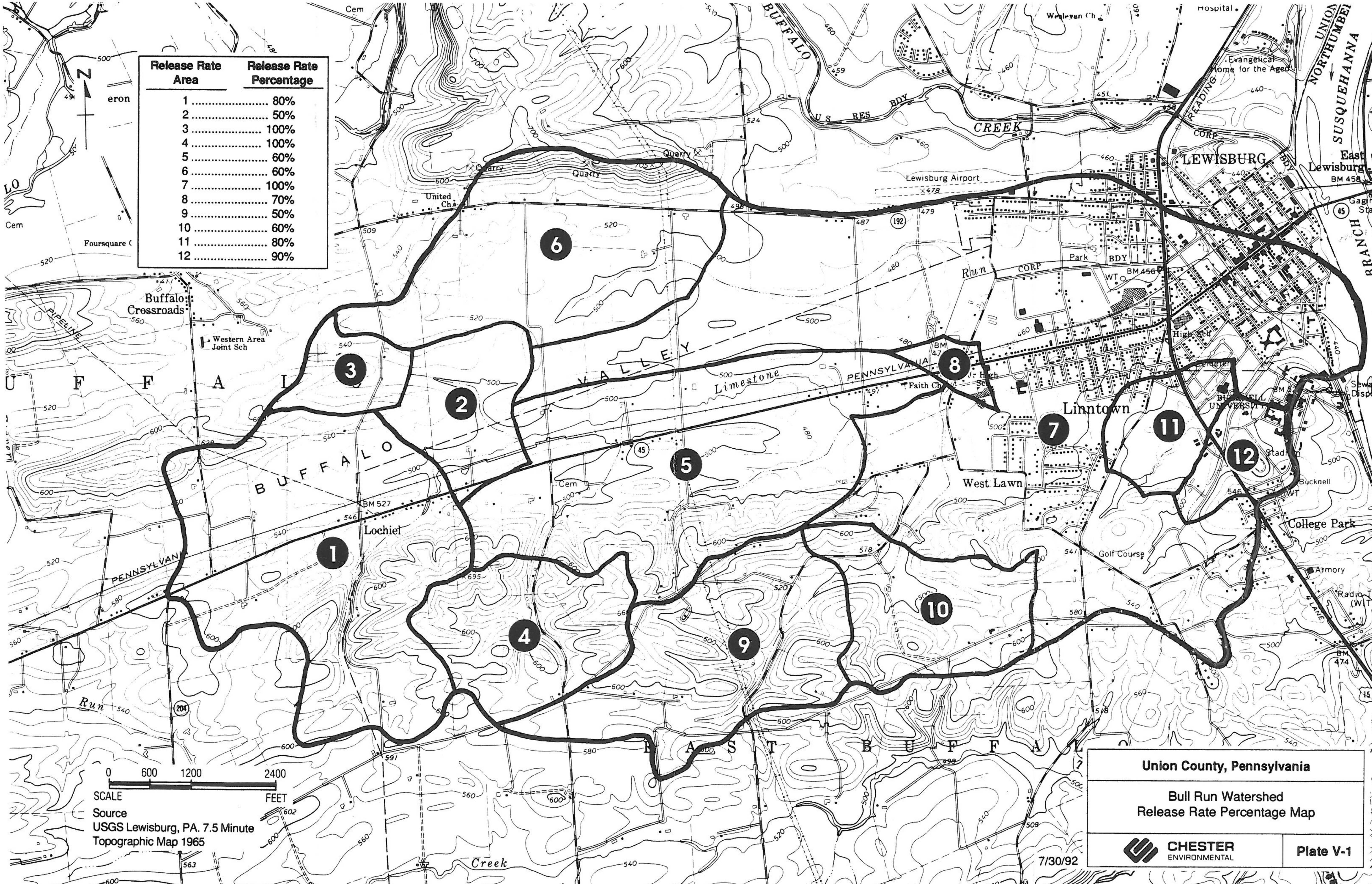
1. Compute the pre-development and post-development runoff for the specific site using an approved method for the 2, 10, 25 and 100 year storms, using no stormwater management techniques. If the post-development peak rate is less than or equal to the pre-development rate and time of peak of post and pre development rates are identical, the requirements of Act 167 and this plan have been met. If the post-development runoff rate exceeds the pre-development rate, proceed to Step 2.

2. Apply on-site stormwater management techniques to increase infiltration and reduce impervious surfaces. Recompute the post-development runoff rate for the 2, 10, 25 and 100 year storms; and if the resulting post-development rate is less than or equal to the pre-development rate, the requirements of this plan have been met. Otherwise, stormwater detention or retention will be required and the developer should proceed to Step 3.

3. Multiply the assigned release rate percentage for the area times the pre-development peak runoff rate to determine the allowable total peak runoff rate from the development. Design the necessary detention/retention facilities to meet the allowable peak runoff rate standard.

It should be noted that stormwater storage can be provided on or off site. The possibility for regional or off-site facilities is an option which can be considered as a means to more efficiently provide the needed facilities, in terms of both cost and land requirement considerations. In many areas, the best solution may be for several development sites to share a joint facility.

Municipalities may also benefit from this approach. They may maximize development in prime development areas by providing regional or distributed storage through the use of natural or artificial lakes, floodplains and steep sloped valleys which are unsuitable for development. However, where off site storage is to be used, the developer must ensure that no flooding or harm will be caused by



Union County, Pennsylvania

Bull Run Watershed
Release Rate Percentage Map

CHESTER ENVIRONMENTAL

Plate V-1

runoff between the new development and the off site storage area. This may require the protection of the stream channel or the construction of a storm sewer to convey runoff to the storage site.

The topic of regional storage is further discussed in Section VI of this report.

PERMISSIBLE RUNOFF COMPUTATION TECHNIQUES

GENERAL

A number of techniques and methods have been developed and are used to estimate rates and volumes of runoff from land. Runoff computation techniques permissible for use in developing runoff control plans pursuant to the requirements of this Plan have been identified. It is recommended that municipalities require land developers to limit the computation techniques employed to one or more of those listed. The list of permissible techniques includes a cross section of the most commonly used computation methods entailing a range of approaches, levels of effort and required access to computer facilities. The list affords developers the opportunity to select from a suite of techniques. At the same time, the number of techniques which the local reviewing engineer must be familiar with is kept to a manageable number. In addition, the use of inapplicable, unproven or inaccurate techniques is prohibited.

PERMISSIBLE RUNOFF COMPUTATION TECHNIQUES

The recommended permissible runoff computation techniques are as follows.

1. Soil Conservation Service Urban Hydrology Method (TR-55)
2. Soil Conservation Service Model (TR-20)
3. U. S. Army Corps of Engineers Flood Hydrograph Package (HEC-1)
4. Penn State Runoff Model
5. Modified Rational Method

Engineers involved in the preparation of stormwater control plans and reviewers of such plans should review the pertinent information relative to the use and applicability of each of these methods. It is important that the assumptions implicit and explicit in each of the techniques be understood and that the techniques are properly applied. Particular attention should be paid to the use of the Modified Rational Method. Experience in applying the Modified Rational Method and comparing the results to other stormwater detention facilities sizing techniques suggests that a significant under estimation of storage requirements may occur. Consequently, the Modified Rational Method should be used guardedly and generally restricted to preliminary sizing of detention facilities.

HYDROLOGICALLY SENSITIVE AREAS

As an aid to ongoing stormwater management in the watershed, efforts were made to identify subbasins within the Bull Run watershed which are particularly sensitive to the effects of land development activities. This was accomplished by evaluating the "hydrologic sensitivity" of each subbasin based upon the consideration of three (3) parameters descriptive of hydrological conditions in the subbasins.

The subbasins were ranked under each of the parameters or factors by assigning a scoring equivalent to the ranking (with increasing ranking or scoring indicative of increased hydrologic sensitivity). The rankings for each subbasin under each factor were totaled to produce an overall "hydrological sensitivity scoring" and the subbasins were ranked based upon this overall scoring. Roughly 25% of the subbasins with the highest overall ranking were assigned a "high" hydrologic sensitivity rating. Roughly 25% of the subbasins with the lowest overall ranking were assigned a "low" hydrologic sensitivity rating and the middle 50% of the subbasins were assigned a "moderate" rating.

The three parameters included in this analysis are as follows:

1. Slope: hydrologic sensitivity increases as representative land slope increases.

2. Current composite runoff curve number: since land development typically increases composite runoff curve numbers subbasins with currently low runoff will be most affected by development activities. Therefore, hydrologic sensitivity is inversely proportional to current composite runoff curve number.

3. Assigned release rate percentage: Hydrologic sensitivity is inversely proportional to assigned release rate percentage.

The results of the hydrologic sensitivity analysis and rating are presented in Table V-6. Note that the subbasin designations contained in Table V-6 refer to those displayed on Plate IV-1 introduced in Section IV of this report.

No special actions beyond the satisfaction of the various management criteria defined in this Plan necessarily need be applied in the "high" hydrologic sensitivity areas. Similarly, classification as a subbasin as a "low" hydrologic sensitivity area does not remove or reduce the required stormwater management requirements in force therein. Instead, the designation of a subbasin as a "high" hydrologic sensitivity area should alert developers and municipalities to take special care in the design of control plans and exercise special vigilance in the review of those plans. Future Plan updates should reevaluate these designations for changes in the conditions which affect hydrologic sensitivity.

TABLE V–6
HYDROLOGICALLY SENSITIVE AREAS

SUBBASIN	SLOPE	CN	RRATE	SLOPE RATING	CN RATING	RRATE RATING	COMPOSITE SCORE	HYDROLOGIC SENSITIVITY
1	0.056	83.1	80	2	1	3	6	LOW
2	0.102	80.5	80	6	2	3	11	MODERATE
3	0.093	78.9	80	5	3	3	11	MODERATE
4	0.084	82.7	80	5	1	3	9	MODERATE
6	0.079	83.6	50	4	1	6	11	MODERATE
7	0.086	83.0	100	5	1	1	7	MODERATE
8	0.070	83.0	50	3	1	6	10	MODERATE
10	0.093	82.3	60	5	1	5	11	MODERATE
11	0.055	82.3	100	2	1	1	4	LOW
12	0.105	81.0	100	6	2	1	9	MODERATE
13	0.097	81.6	60	6	1	5	12	HIGH
15	0.079	81.2	60	4	2	5	11	MODERATE
16	0.098	73.1	60	6	5	5	16	HIGH
17	0.096	81.1	60	6	2	5	13	HIGH
19	0.078	80.5	100	4	2	1	7	MODERATE
20	0.063	83.0	50	3	1	6	10	MODERATE
21	0.099	79.7	50	6	2	6	14	HIGH
22	0.092	79.0	60	5	3	5	13	HIGH
23	0.086	79.8	100	5	2	1	8	MODERATE
24	0.050	80.3	70	1	2	4	7	MODERATE
26	0.086	82.9	100	5	1	1	7	MODERATE
27	0.070	82.7	100	3	1	1	5	LOW
29	0.043	73.9	100	1	5	1	7	MODERATE
30	0.084	82.8	60	5	1	5	11	MODERATE
31	0.098	79.3	60	6	2	5	13	HIGH
32	0.064	78.9	100	3	3	1	7	MODERATE
34	0.047	78.7	100	1	3	1	5	LOW
35	0.050	83.7	100	1	1	1	3	LOW
36	0.046	83.1	100	1	1	1	3	LOW
37	0.080	74.1	100	4	5	1	10	MODERATE
38	0.084	79.8	100	5	2	1	8	MODERATE
39	0.059	79.6	100	2	2	1	5	LOW
40	0.064	75.4	100	3	4	1	8	MODERATE
42	0.084	74.6	90	5	5	2	12	HIGH
43	0.076	77.7	100	4	3	1	8	MODERATE
44	0.067	77.1	80	3	3	3	9	MODERATE
46	0.086	70.9	100	5	6	1	12	HIGH
47	0.071	70.2	100	3	6	1	10	MODERATE