Stormwater Hydrology in a Developing Coastal Plain Watershed

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Abstract

Southern New Jersey is part of the Atlantic Coastal Plain, with generally flat topography and sandy soils. Hydrologic estimation techniques employed by state regulatory agencies typically rely on NRCS methods such as TR-55 and TR-20 with pre-defined runoff hydrographs. While these techniques work reasonably well in the steeper Piedmont regions of northern New Jersey, they typically over-predict runoff quantities in southern New Jersey by an order of magnitude. Several alternative unit hydrographs have been proposed for coastal plain regions, including the DelMarVa unit hydrograph, developed for the Delaware-Maryland-Virginia peninsula, and the Upper Maurice River unit hydrograph in southern New Jersey. To verify the applicability of these types of alternative approaches, a study has been conducted in support of developing Regional Stormwater Management Plans for several watersheds in the region.

Introduction

This paper presents the preliminary results of the hydrologic analysis of the Raccoon Creek Watershed in Gloucester County, New Jersey. The analysis focuses on appropriate techniques for assessing the hydrologic conditions of the watershed and an analysis of alternative modeling approaches. This work is associated with developing a Regional Stormwater Management Plan (RSMP) for this watershed. The RSMP will address water quantity and quality issues specific to the Raccoon Creek.

The Raccoon Creek Watershed retains many characteristics of a natural and healthy watershed. It has not been severely impacted by development and does not exhibit significant degraded areas with regard to stream erosion, water quality, riparian buffer width, floodplain management and wetlands quality. However, it must be noted that Gloucester County is one of the fastest growing counties in the Delaware Valley and as a result is experiencing extensive development pressure. To prevent degradation of the Raccoon Creek Watershed and to maintain the quality of the existing features, steps to minimize the impacts of urbanization on this watershed are vital.

Location and Description

Located in southern New Jersey, the Raccoon Creek flows from east to west in Gloucester County toward the Delaware River. The study area focuses on the upper portions of the Raccoon Creek, its streams and tributaries and all the lands draining to these streams to a point just below the confluence of the main stem and the south branch. The study area ends at the USGS stream gage 01477120 near Swedesboro, New Jersey. Nearly 63 linear miles of watercourse comprise the south branch, main stem and their various tributaries. Figure 1 depicts the location of the watershed.

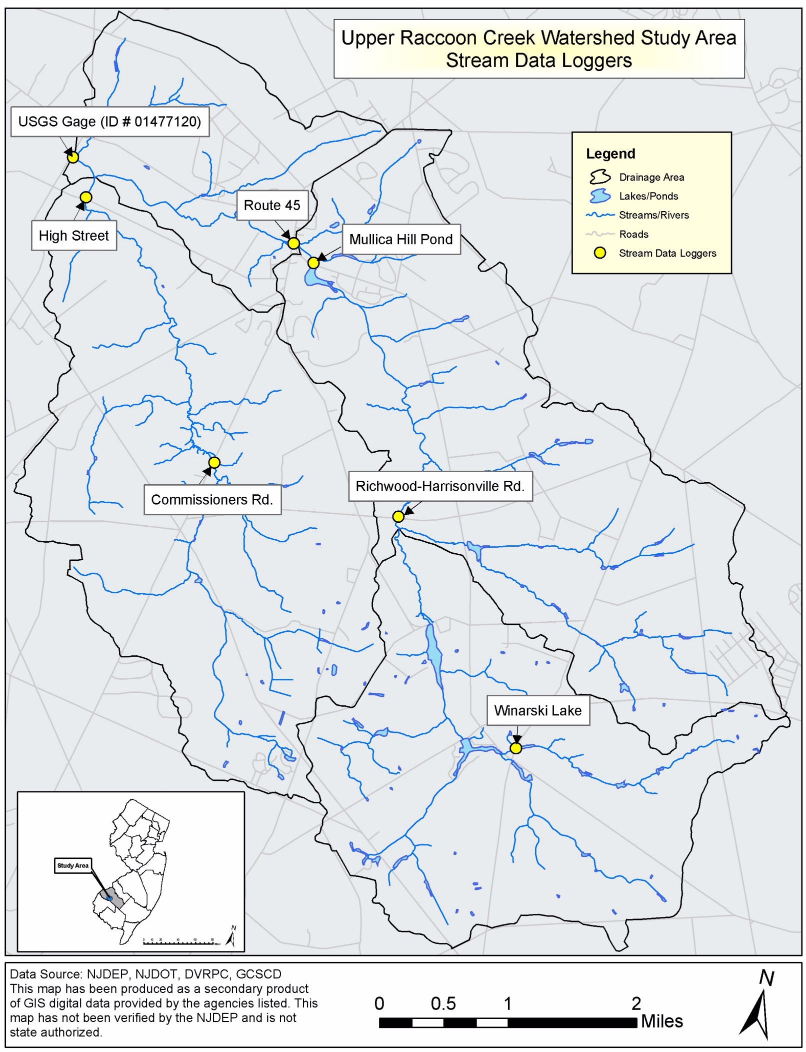

Figure 1: Raccoon Creek Watershed.

Land use is a mixture of agriculture and suburban development. A vast majority of the watershed remains undeveloped but is under severe development pressure with significant development having occurred over the past five years. Agriculture within the watershed consists mainly of small tree fruit, soybeans and vegetables, especially peaches, sweet corn and sweet potatoes. The limited forested areas within the watershed are restricted to unproductive (or wet) soils and as a buffer along the stream corridor.

The watershed has many small lakes and ponds. Most were constructed decades ago as mill or irrigation ponds. The major impoundments include Winarski Lake, Gilman Lake, Ewan Lake, Kincaid Lake and Mullica Hill Pond. These lakes and ponds serve as regional stormwater management facilities, leveling the watershed, providing storm flow storage and collecting sediment.

The entire study area can be classified as flat to gently rolling. The watershed ranges from 150 feet National Geodetic Vertical Datum (NGVD 1929) at the headwaters in Elk Township to a low of 10 feet at the terminal end of the study area. The south branch has a watershed slope of 22 feet/mile. The main stem is slightly flatter and averages 13 feet/mile as it flows from a high point of 140 feet.

Gloucester County is in the southwestern part of New Jersey and lies within the Coastal Plain physiographic province of New Jersey. All the soils have formed on unconsolidated beds of either sand or clay mixed with silt or gravel (SCS, 1962). These beds were laid down in a succession of ocean or river deposits and then tilted to the southeast. Glacial waters brought deposits of rounded quartzes gravel. During periods of low water, wind and water erosion reworked the original deposits. Climate and topography contributed significantly to the formation of the soils. More recently, human activities have begun to affect the soil, as large areas have been drained, stripped of topsoil, re-graded, filled, borrowed from and otherwise altered.

General Observations and Field Assessment

As part of the detailed assessment of the Raccoon Creek Watershed, various types of data were collected in the field. Point features were mapped with a Global Positioning Satellite (GPS) data collection system and assessed with a series of custom databases. This data will be used in the hydrologic analysis of the watershed and as part of the overall assessment of the watershed conditions. Data were collected on stream obstructions, stormwater outfalls, stormwater basins, and stream reaches.

Stream obstructions are primarily the bridges and culverts that cross the waterways, but other obstructions including significant debris jams were also located. In general, the size, shape and condition of each obstruction was recorded.

Stormwater outfalls include any structure constructed to discharge stormwater from a storm sewer system, a stormwater basin or other stormwater collection system to open water, wetland or open space. Information was collected on the size, shape and condition of the outfall as well as the discharge location and condition of the outfall area.

Stormwater basins where located and assessed through aerial interpretation, field inspections and from the district's records on new developments. A variety of information was collected at each basin and an assessment of the need for restoration or renovation was made.

Stream reaches were visually assessed in order to describe the overall conditions of each stream segment within the watershed. Stream reaches were delineated based on natural divisions, such as the confluence of two tributaries, and at every stream obstruction. Field crews evaluated the stream reaches, recorded the information on reach evaluation forms and created an extensive photographic record of the current conditions. Characteristic such as channel geometry, stream movement, bed material, bank erosion, and riparian buffer widths were noted during each assessment. A variety of conditions were assessed, each ranked with a numerical score.

Stream Flow Data

The US Geologic Survey has maintained and continuously operated a stream gaging station near Swedesboro, (Station ID 01477120) since 1966. This gage is located at the terminal end of the Raccoon Creek Watershed study area and provides a continuous record of discharge. A review of the gage data indicates the Raccoon Creek appears to respond quickly to rainfall. Figure 2 shows the daily mean discharges for the period January 2004 to January 2005. The quick response is somewhat surprising due to the current rural nature of the watershed and the presence of many lakes and ponds.

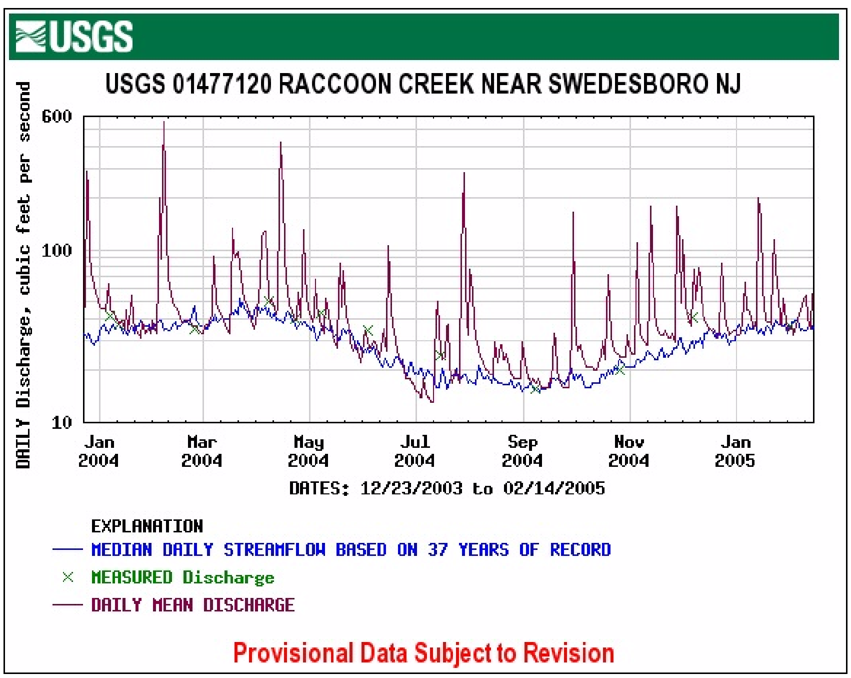

Figure 2: Daily mean discharge of the Raccoon Creek at USGS station 01477120.

To compliment the USGS data, rainfall data is being compiled from two local rain gages. Tipping bucket rain gages are included in weather stations maintained by the South Jersey Resource and Development Council (SJRCD). Two of these stations are located just outside of the watershed, one to the southeast and the other to the northwest. Rainfall data obtained from these sites is sufficiently accurate for use in compiling hydrologic event data for the Raccoon Watershed. Figure 3 shows the incremental rainfall from one of the gages and the response of the Raccoon Creek at the USGS gage during a recent storm event.

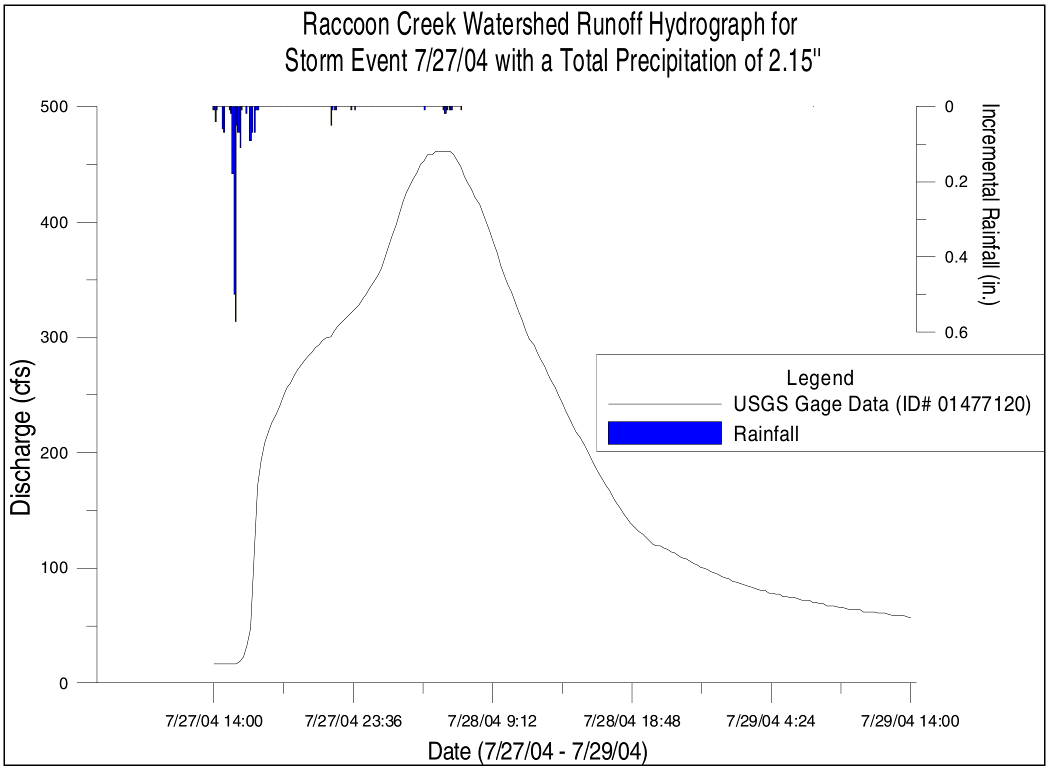

Figure 3: Response of Raccoon Creek during a recent rainfall event.

Despite the availability of the USGS gage data, a better understanding of the hydrologic response of the Raccoon Creek is desired as part of the regional planning process. To achieve this goal, project staff are monitoring stream stage at six sites within the watershed. The sites were chosen based on their location within the watershed in relation to specific elements of the developing hydrologic model, and are shown in Figure 1. At each of the sites, a staff gage and data logger with a pressure transducer has been installed to monitor stream depth and record water surface elevation. Four data loggers have been installed on the main stem and two on the south branch. Two of the loggers monitor the elevation of lakes above their spillways while the other four are located in standpipes at bridges crossing the streams. Frequent direct flow measurements are being made and rating tables are being developed at all of the monitoring locations. Figure 4 depicts the preliminary rating curve for the gage located at High Street, near the outlet of the south branch. Figure 5 compares the discharge as measured at the South Branch metering location with the USGS gage.

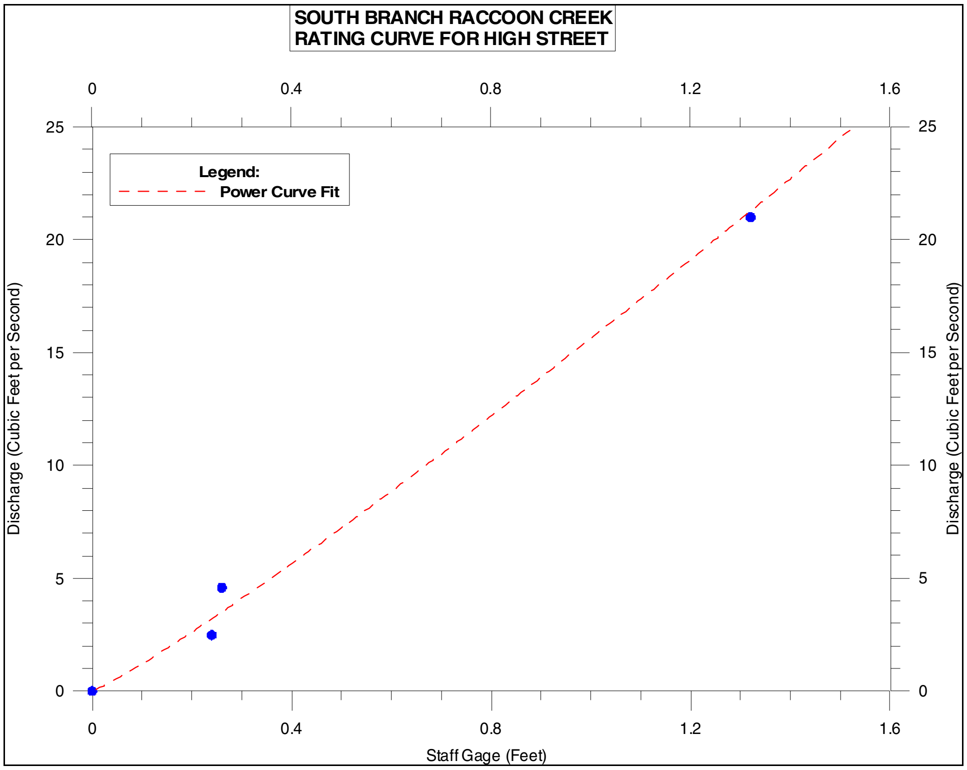

Figure 4: High Street stream gage preliminary rating curve.

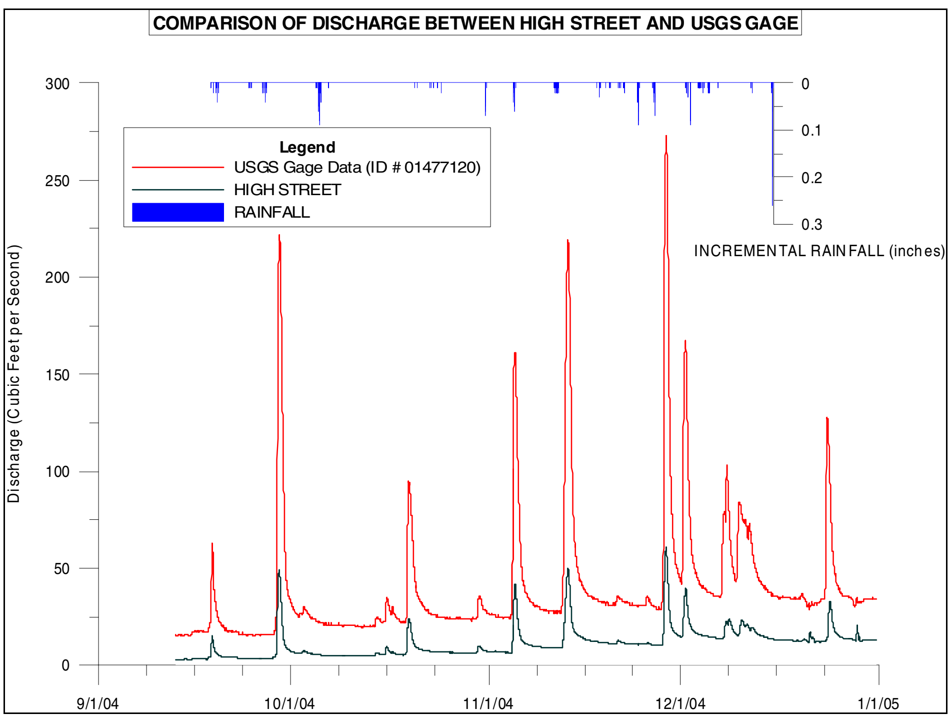

Figure 5: Comparison of discharge between High Street on the south branch of Raccoon Creek and the USGS gage on below the confluence with the main stem.

Introduction to Hydrologic Methods

Understanding the hydrologic and hydraulic processes in a watershed is critical for developing an RSMP. This is especially important in the Raccoon Creek Watershed, where the unique conditions (combination of terrain, soils and surface depression storage) and the rapid conversion of farmland to residential developments significantly impacts the hydrologic response.

The hydrologic analysis will utilize the HEC-HMS (Hydrologic Engineering Center–Hydrologic Modeling System) computer program. The HMS program, developed by the U. S. Army Corp of Engineers – Hydrologic Engineering Center includes a variety of methods to simulate the rainfall runoff processes for a watershed and provides peak flows and distribution hydrographs at all model element locations for a variety of design and actual storm events. To conform with the vast majority of stormwater reports prepared by engineers working in southern New Jersey and to be in compliance with the regulatory requirements of the NJDEP and local land use ordinances, the Natural Resource Conservation Service (NRCS) runoff methods were used. The NRCS runoff methods are defined in the NRCS National Engineering Handbook, Section 4 and Urban Hydrology for Small Watersheds, Technical Release 55 (NRCS, 1986). Currently the development of this model is in the initial stages. Figure 6 provides the HMS schematic of the proposed model.

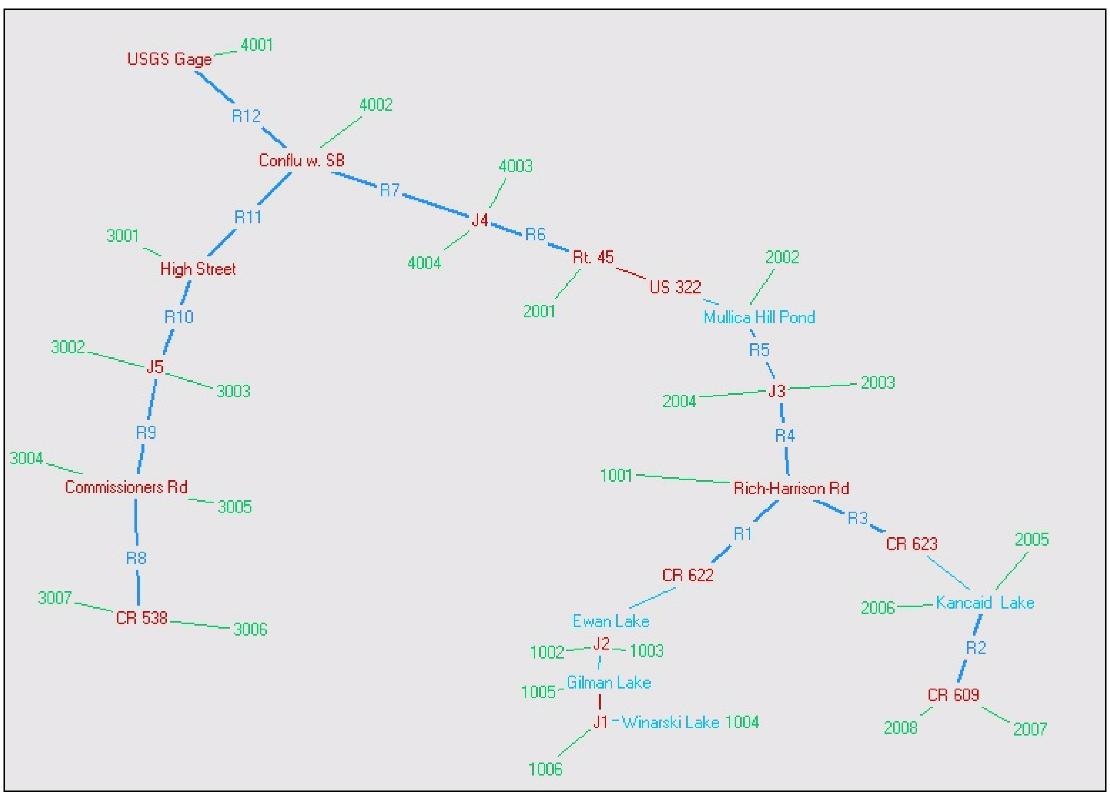

Figure 6: Raccoon Creek hydrologic model network schematic.

Modeling Goals

One of the goals of the regional planning process is to assess the effectiveness and determine alternatives to traditional modeling approaches. The Raccoon Creek Watershed is typical of many coastal plain watersheds where the conventional approach to stormwater analysis and design frequently fails to accurately predict runoff rates and volumes. This is suggested by staff from the Gloucester and Camden County Soil Conservation Districts, who while reviewing development plans frequently encounter pre-development hydrologic models predicting rates and volumes of runoff that exceed conditions observed in the field. These observations appear to contradict some of the basic assumptions used in the NRCS methodology, such as the overland flow travel time computation, the standard unit peak discharge factors and the effective drainage as defined by the primary watershed topography. If these assumptions in fact do not apply to the conditions present in this watershed, then using the NRCS methods "out of the box" is producing erroneous stormwater runoff values, which in turn are used to design and construct large and expensive stormwater management facilities.

Work previously conducted in the Maurice River Watershed (adjacent to the Raccoon Creek Watershed) in association with the preparation of the Upper Maurice River RSMP examined the impact of a variety of hydrologic parameters on watershed analysis (GCSCD, 2004). Although the topography and geology of the Raccoon Creek Watershed differs from the Maurice River Watershed, the proposed alternative approaches will be evaluated as part of the Raccoon Creek RSMP. The parameters to be evaluated include drainage area delineation, time of concentration parameters and unit hydrographs.

- *Drainage Area Delineation*

The traditional approach to determine a drainage area is to examine the topography, identify ridgelines above a point of interest and "connect the dots" of the highest elevation points, terminating at the drainage outlet. While this is certainly applicable to describe the maximum extent of a drainage area that captures all precipitation in a watershed, it may not accurately represent the portion of the watershed that actually contributes surface runoff. Observations by the authors appear to be consistent with research by Fennessey and others (Fennessey, undated), that the area contributing surface runoff is often smaller than the overall drainage area. Fennessey concludes, "surface runoff is generated by only a portion of the watershed and often occurs first or most commonly around streams or areas where the water table and soil depth quickly cause saturation. This is almost always true for non-extreme runoff events that cause nuisance flooding." The authors expect to evaluate the impact of this approach in the Raccoon Creek hydrologic models.

- *Time of Concentration*

In addition to the accurate determination of the contributing drainage area, determining the watershed time of concentration (t_c) likewise has proven to be an elusive target. The NRCS method of computing time of concentration (typically the method used by all designers throughout New Jersey) involves an attempt to mimic the perceived physical processes involved in water flowing over the land surface. This segmental method combines the travel time due to sheet flow, shallow concentrated flow and open channel flow. Often determining and delineating the various components of this flow path is at best subjective and will vary from designer to designer.

The subject of sheet flow is still further debated because in this approach, the model assumes an excess rainfall depth of 2 inches before surface flow begins. Because of the extreme ability of soils and forested areas in this watershed to capture and infiltrate rainfall, it is doubtful if there is enough excess rainfall during non-extreme events to result in surface flow, thereby negating a basic assumption of the NRCS method.

Investigations by Dewberry and Davis (Dewberry, 2003a) indicate that the segmental method is inadequate for determining time of concentration in this region. Further, the NRCS "lag" equation (used to predict time of concentration on a watershed scale) under-predicts the true t_c and time of peak flow as measured from a variety of USGS gaging station data. Dewberry's study concluded by stating that neither the segmental nor lag equations developed by NRCS can be relied upon to accurately determine watershed runoff timing in this region. Dewberry recommends the development of a regional equation (and offers a solution) and provides a variety of other suggestions to improve the accuracy and reproducibility in this calculation. Additional research will be necessary to develop suitable solutions. Time of concentration in the Raccoon Creek watershed will be calculated and measured using a variety of methods. Using the calibrated hydrologic model we expect to provide further evidence in support of revising the NRCS equations for the coastal plain.

- *Unit hydrographs*

A unit hydrograph is frequently used in runoff calculation methods to convert excess rainfall into runoff. The NRCS runoff methods transform rainfall to runoff with a dimensionless unit hydrograph (DUH). The dimensionless unit hydrograph as represented by the Peak Rate Factor (PRF) can vary significantly based on topographic conditions. Peak rate factors have been calculated in mountainous terrain as high as 600 and in low swampy terrain as low as 50. Traditionally employed hydrologic estimation techniques use an average peak rate factor of 484. The NRCS has encouraged the development of regional peak rate factors to better represent the conditions of differing physiographic provinces. The DelMarVa dimensionless unit hydrograph was developed in 1980 by the NRCS to reflect the conditions of the flat coastal plain conditions found in Delaware, Maryland and Virginia (NRCS, 1980). The peak rate factor for the DelMarVa DUH is 285. For the adjacent Maurice River watershed an even "milder" DUH was calculated by Dewberry (2003b) and is represented by the PRF of 214. It is important to note that these two hydrographs represent the same volume of runoff but with different distributions of flow over time. Figure 7 depicts a comparison of the standard NRCS, DelMarVa and the UMR dimensionless unit hydrographs.

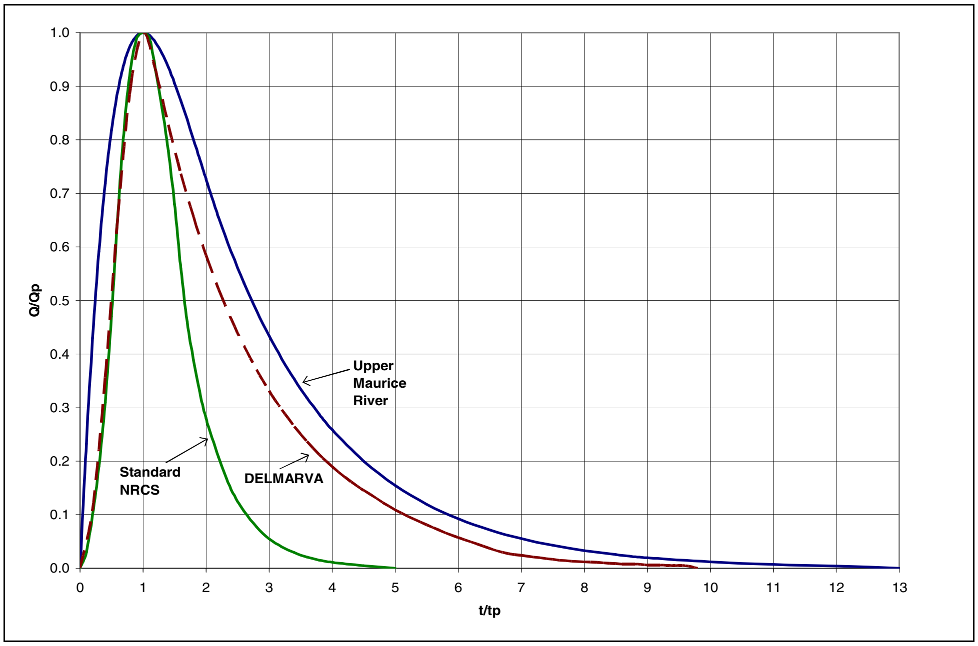

Figure 7: Comparison of the UMR, DelMarVa and Standard NRCS DUH.

It is notable that the majority of the hydrologic analysis for existing developments in Raccoon Creek Watershed were conducted using the methodologies of TR-20 and TR-55 (NRCS, 1986, 1992), which assumed the standard Dimensionless Unit Hydrograph represented by the unit PRF of 484. This may have resulted in many of the proposed developments overestimating existing conditions peak stormwater runoff rates. The result of which could be oversized and ineffective stormwater basins that provide little attenuation.

Conclusions

The development of a Regional Stormwater Management Plans affords the opportunity to review and revise traditional and accepted stormwater management techniques. Evaluating the surface runoff from a development site or any natural watershed requires careful consideration and evaluation by the design engineers. Through detailed watershed assessment, data collection and modeling, the authors expect to determine the best tools and strategies for managing stormwater in this watershed.

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