APPENDIX E – USGS NATIONWIDE URBAN REGRESSION EQUATIONS

1.0 Introduction

These nationwide regression equations are described in detail in the 1983 USGS Water-Supply Paper 2207 "Flood Characteristics of Urban Watersheds in the United States" by V.B. Sauer et al. They can be used to estimate peak discharges from urban watersheds.

The results of these urban regression equations should not be directly compared to the results of corresponding rural regression equations to determine the increased runoff caused by urbanization. To determine effects on discharge due to urbanization, it is recommended that both the undeveloped and developed watersheds be analyzed with the urban regression equations and the results of these two analyses be compared. This method is shown in the example.

Two versions of the USGS urban regression equations are presented. One version uses three input parameters. The first parameter is the drainage area, the second parameter accounts for alterations to the natural drainage system through use of a basin development factor, and the third parameter accounts for regional variations in runoff by use of an equivalent rural peak runoff rate. These three parameter equations are suitable for most applications.

The second version of the urban regression equations uses seven input parameters. Three of the parameters are the same as those listed for the three-parameter equations. The other four parameters are the slope of the main drainage channel, the rainfall intensity, the basin storage, and the percent of the basin area that is impervious.

The seven-parameter equations are recommended for calculating flows from urban drainages with significant basin storage. Basin storage is defined as the drainage area covered by lakes, reservoirs, ponds, swamps, and wetlands.

2.0 Equations

The equations and definitions of the equation variables are presented in Table 1. The equations are expected to produce results within the standard errors of regression in Table 1 if the input variables are within the ranges in the following list. Use of input values outside of these ranges may produce excessive errors in the discharge predictions.

- Drainage Area (A) for the urban basin should be between 0.2 and 100 square miles.
- The Main Channel Slope (SL) should not be less than 3.0 feet per mile or greater than 70 feet per mile (seven parameter equations, only). The maximum value of slope for use in equations is 70 feet per mile, although numerous watersheds used in the study (Sauer et al) had SL values up to 500 feet per mile.
- The 2-year - 2-hour Rainfall Intensity (RI2) should not be less than 0.2 inches or greater than 2.8 inches (seven parameter equations, only).
- The Basin Storage (ST) should not be more than 11 percent of the drainage area (seven parameter equations, only).
- The Basin Development Factor (BDF) should not be less than 0 or more than 12.
- The Impervious Surface Area (IA) should not be less than 3 percent or greater than 50 percent of the drainage area (seven parameter equation, only).
- The Drainage Area (A) and all other variables used to determine flows from the equivalent rural drainage basin must be within the ranges of values applicable to those equations.

3.0 Procedure

The analysis procedure is as follows:

Step 1 - Verify the input variables are within the acceptable ranges for both the rural and urban regression equations.

Step 2 - Use the USGS regression equations from **Chapter 7** Appendices B, C, or D to estimate the peak discharge from the equivalent rural drainage basin (RQ_T).

Step 3 - Determine the input variables SL, RI2, ST, and IA using the guidelines in Table 1. This step is needed when using the seven-parameter equations, only.

Step 4 - Determine basin development factor (BDF), as follows:

a. The first step is to divide the basin into upper, middle, and lower thirds on a drainage map. Each third should contain about one-third of the contributing drainage area. If two or more branches of a stream are in the same third, the stream sections should have approximately the same length. The stream lengths in different thirds, however, can be different. This is shown in Figure 1. As shown in the figure, the stream lengths in the lower thirds are different than lengths in the middle thirds, and stream lengths in the middle thirds are different than stream lengths in the upper thirds. The boundaries between the thirds can be drawn by eye. Precise definition of the divisions is not necessary because the divisions have little effect on the final value of the BDF.

b. The second step is to evaluate and assign a code to the aspects of each third of the drainage area. The aspects are often determined by aerial photographs and verified by field inspection. Coding guidelines are as follows:

- **Channel Improvements -** If channel improvements such as straightening, enlarging, deepening, and clearing are prevalent for the main drainage channels and principal tributaries (those that drain directly into the main channels), then a code of One (1) is assigned. To be considered prevalent, at least 50 percent of the main drainage channels and principal tributaries must be improved to some degree over natural conditions. If channel improvements are not prevalent, then a code of Zero (0) is assigned.

- **Channel Linings -** If more than 50 percent of the length of the main drainage and principal tributaries have been lined with an impervious material, such as concrete, then a code of One (1) is assigned to this aspect. If less than 50 percent of these channels are lined, then a code of Zero (0) is assigned. The presence of channel linings is a good indication that channel improvements have been performed and signifies a more highly developed drainage system. As a result, if the channel lining aspect is One the channel improvement aspect is usually also One.

- **Storm Drains -** Storm drains are enclosed drainage structures (usually pipes) frequently used on the secondary tributaries which receive drainage directly from streets or parking lots. Many of these drains empty into open channels. In some basins, however, they empty into channels enclosed as box or pipe culverts. When more than 50 percent of the secondary tributaries within a sub-basin consist of storm drains, a code of One (1) is assigned to this aspect; if less than 50 percent, then a code of Zero (0). Note that if 50 percent or more of the main drainage channels and principal tributaries are enclosed, the aspects of channel improvements and channel linings would also be assigned a code of One.

- **Curb and Gutter -** If more than 50 percent of a sub-basin is urbanized, and if more than 50 percent of the streets and highways in the sub-basin are constructed with curbs and gutters, then a code of One (1) should be assigned to this aspect. Otherwise, it would receive a code of Zero (0). Urbanized land is defined as the area covered by industrial, residential, or commercial development. Drainage from curb and gutter streets often empties into storm drains. As a result, if the curb and gutter aspect is One the storm drains aspect is frequently also One.

Table 1: USGS Nationwide Regression Equations for Urban Conditions

a) Three Parameter Equations

Peak Discharge Equations	Standard Error of Regression in Percent
$UQ_2 = 13.2A^{0.21}\ (13 - BDF)^{-0.43}\ RQ_2^{0.73}$	± 43
$UQ_5 = 10.6A^{0.17}\ (13 - BDF)^{-0.39}\ RQ_5^{0.78}$	± 40
$UQ_{10} = 9.51A^{0.16}\ (13 - BDF)^{-0.36}\ RQ_{10}^{0.79}$	± 41
$UQ_{25} = 8.68A^{0.15}\ (13 - BDF)^{-0.34}\ RQ_{25}^{0.80}$	± 43
$UQ_{50} = 8.04A^{0.15}\ (13 - BDF)^{-0.32}\ RQ_{50}^{0.81}$	± 44
$UQ_{100} = 7.70A^{0.15}\ (13 - BDF)^{-0.32}\ RQ_{100}^{0.82}$	± 46
$UQ_{500} = 7.47A^{0.16}\ (13 - BDF)^{-0.30}\ RQ_{500}^{0.82}$	± 52

b) Seven Parameter Equations

Peak Discharge Equations	Standard Error of Regression in Percent
$UQ_2 = 2.35A^{0.41}\ SL^{0.17}\ (RI2 + 3)^{2.04}\ (ST + 8)^{-0.65}\ (13 - BDF)^{-0.32}\ IA^{0.15}\ RQ_2^{0.47}$	± 38
$UQ_5 = 2.70A^{0.35}\ SL^{0.16}\ (RI2 + 3)^{1.86}\ (ST + 8)^{-0.59}\ (13 - BDF)^{-0.31}\ IA^{0.11}\ RQ_5^{0.54}$	± 37
$UQ_{10} = 2.99A^{0.32}\ SL^{0.15}\ (RI2 + 3)^{1.75}\ (ST + 8)^{-0.57}\ (13 - BDF)^{-0.30}\ IA^{0.09}\ RQ_{10}^{0.58}$	± 38
$UQ_{25} = 2.78A^{0.31}\ SL^{0.15}\ (RI2 + 3)^{1.76}\ (ST + 8)^{-0.55}\ (13 - BDF)^{-0.29}\ IA^{0.07}\ RQ_{25}^{0.60}$	± 40
$UQ_{50} = 2.67A^{0.29}\ SL^{0.15}\ (RI2 + 3)^{1.74}\ (ST + 8)^{-0.53}\ (13 - BDF)^{-0.28}\ IA^{0.06}\ RQ_{50}^{0.62}$	± 42
$UQ_{100} = 2.50A^{0.29}\ SL^{0.15}\ (RI2 + 3)^{1.76}\ (ST + 8)^{-0.52}\ (13 - BDF)^{-0.28}\ IA^{0.06}\ RQ_{100}^{0.63}$	± 44
$UQ_{500} = 2.27A^{0.29}\ SL^{0.16}\ (RI2 + 3)^{1.86}\ (ST + 8)^{-0.54}\ (13 - BDF)^{-0.27}\ IA^{0.05}\ RQ_{500}^{0.63}$	± 49

Table 1, Contd. USGS Nationwide Regression Equations for Urban Conditions

General form of equations:

3-parameter: $UQ_T = C\ A^{b1}\ (13 - BDF)^{b2}\ RQ_T^{b3}$

7-parameter: $UQ_T = C\ A^{b1}\ SL^{b2}\ (RI2 + 3)^{b3}\ (ST + 8)^{b4}\ (13 - BDF)^{b5}\ IA^{b6}\ RQ_T^{b7}$

Where:

UQ_T = peak discharge from urban drainage basin in cubic feet per second for recurrence interval T.

C = regression constant.

A = contributing drainage area in square miles.

SL = main channel slope in feet per mile, measured between points which are 10 percent and 85 percent of the main channel length upstream from the study site (for sites where SL is greater than 70 feet per mile, use SL = 70 feet per mile in the equations).

ST = basin storage, the percentage of the drainage basin occupied by lakes, reservoirs, swamps, and wetlands (channel storage of a temporary nature, resulting from detention ponds or ponding upstream from the roadway embankments, is not included in the computation of ST).

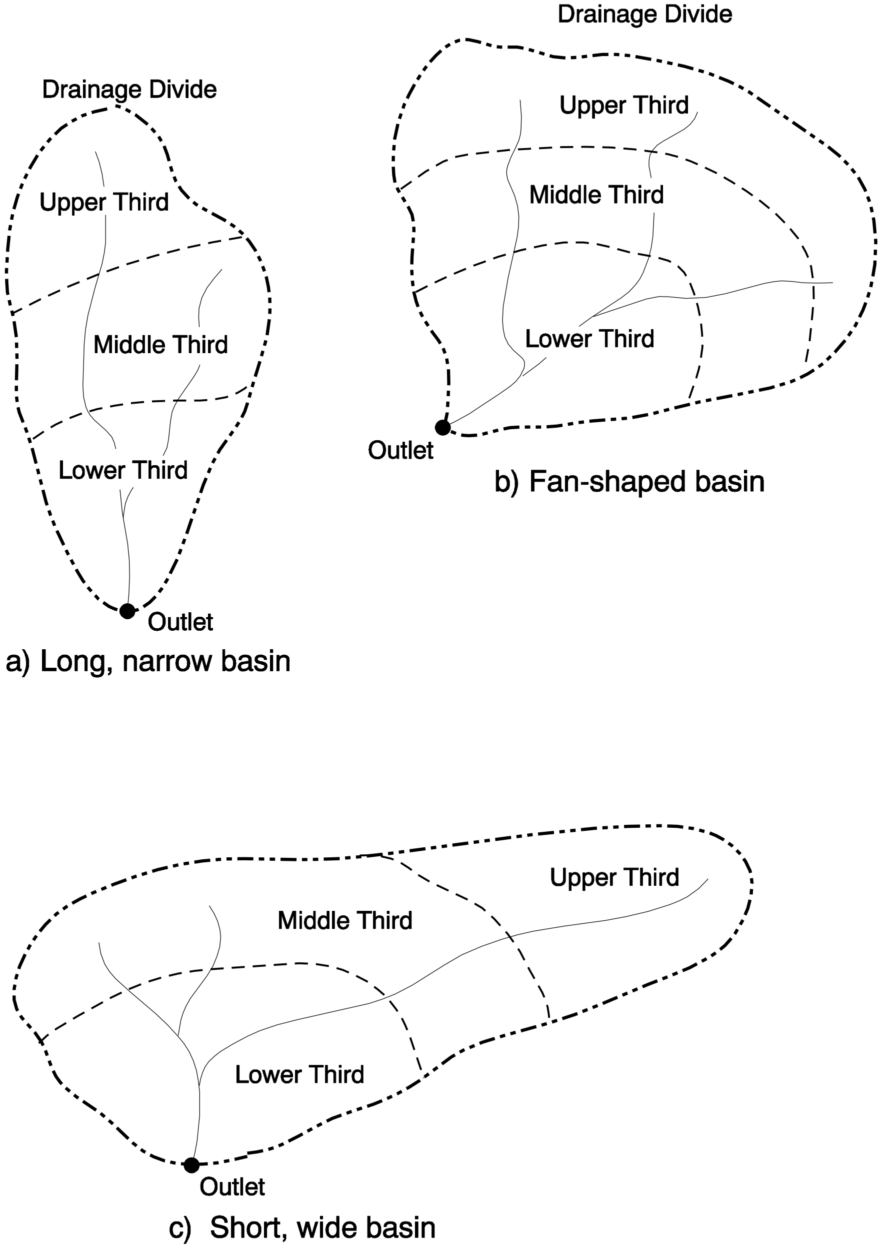
RI2 = rainfall intensity in inches for the 2-year - 2-hour occurrence. Use the 2-year - 120-minute intensity based on the appropriate Intensity-Duration-Recurrence Interval charts in Chapter 7 Appendix A.

BDF = basin development factor, an index of the prevalence of the drainage aspects of (a) storm drains, (b) channel improvements, (c) impervious channel linings, (d) curb and gutter streets, and (e) percent of the subarea that is urbanized. A value of zero for BDF indicates the above drainage aspects are not prevalent, but does not necessarily mean the basin is nonurban. A value of 12 indicates full development of the drainage aspects throughout the basin.

IA = percentage of the drainage basin area occupied by impervious surfaces such as houses, buildings, streets, and parking lots.

RQ_T = peak discharge from equivalent rural drainage basin in cubic feet per second for recurrence interval T.

b1, b2, b3, etc = regression exponents.



Schematic of typical drainage basin shapes and subdivision into basin thirds. The basin thirds should have approximately equal areas. The lengths of the various branches of the stream channel within each third should be approximately equal. The total length of stream channel within a third does not have to be the same as the channel length within any other third.

Figure 1 Basin Subdivision

c. The third step is to add the aspects. The sum of the twelve codes is the BDF. The maximum value for a drainage basin is Twelve (12), and the minimum value is Zero (0). A Zero rating does not necessarily mean that the basin is unaffected by urbanization. A basin can be partially urbanized with some improvement of principal and secondary tributaries, and still have an assigned BDF of Zero. Likewise, a rating of Twelve does not necessarily mean the drainage basin is fully developed.

Step 4 - Enter the data calculated in the preceding steps into the regression equations listed in Table 1 and calculate the peak flows for the desired recurrence intervals.

4.0 Example Problem – USGS Urban Nationwide Regression Equations

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A zoning change from mixed residential/commercial to industrial development is planned for a portion of the Rosalie Creek drainage basin in Helensburg. Pre-development and post-development peak discharges are needed. The city is in the Willamette Region of western Oregon.

Step 1 - The USGS regression equations for rural western Oregon were used to estimate the peak flows from an equivalent rural drainage basin. The Drainage Area (A) is 0.62 square miles based on measurement of a USGS quadrangle map. The 2-year 24-hour precipitation intensity (I) is 3.0 inches from Chapter 7 Appendix H.

These input variables are within the ranges of characteristics applicable for the Willamette Region equations listed in Chapter 7 Appendix B, and the drainage basin has little or no streamflow regulation or diversion. In addition, if urbanization is disregarded, the basin is typical of the drainage areas used to develop the rural regression equations. As a result, RQ_T of the basin can be calculated by the rural regression equations, and the results are expected to be within the ranges of standard errors listed in the publications.

The area of the urban drainage basin is also within the recommended range of input values for the urban equations. Therefore, discharge estimates produced by the urban equations are expected to be within the ranges of standard errors listed in Table 1.

Step 2 - Peak flows for 2 through 100-year recurrence intervals were calculated using the Willamette Region rural equations. These discharges were plotted on logarithmic probability paper and the 500-year flow was determined by linear extrapolation. The peak flows are:

RQ_2 = 38 cubic feet per second (cfs)
RQ_5 = 56 cfs
RQ_{10} = 70 cfs
RQ_{25} = 90 cfs

RQ_{50} = 105 cfs
RQ_{100} = 122 cfs
RQ_{500} = 165 cfs

Step 3 - The basin was subdivided into thirds on a map. The aspects were rated as follows:

- Lower third: existing and future land use is swamp with bordering parkland, and no existing or future drainage improvements are planned.

  Channel Improvement Aspect = 0
  Channel Lining Aspect = 0
  Storm Drain Aspect = 0
  Curb and Gutter Aspect = 0

- Middle third: existing use is light residential and commercial. Although over 50 percent of the area is urbanized, the drainage system is relatively undeveloped. There are curbs and gutters on many short side streets. Runoff from these gutters enters the ditches alongside the main roads. There are no storm drains. The future industrial area will have a fully developed drainage system including curbs, gutters, storm drains, channel improvements, and channel linings. Only the main stem of the creek will be left in a natural state.

  Channel Improvement Aspect = 0 (Existing) or 1 (Future)
  Channel Lining Aspect = 0 (Existing) or 1 (Future)
  Storm Drain Aspect = 0 (Existing) or 1 (Future)
  Curb and Gutter Aspect = 1 (Existing and Future)

- Upper third: existing and expected land use is residential. Most of the side streets have curbs and gutters that drain into roadside ditches alongside the main roads. There are no storm drains. The main stem of the creek and most principal tributaries are in a natural condition. No future improvements are planned.

  Channel Improvement Aspect = 0
  Channel Lining Aspect = 0
  Storm Drain Aspect = 0
  Curb and Gutter Aspect = 1

The basin development factor (BDF) is calculated by adding the aspects, as follows:

$$BDF_{Existing} = 0 + 0 + 0 + 0 + 0 + 0 + 0 + 1 + 0 + 0 + 0 + 1 = 2$$
$$BDF_{Future} = 0 + 0 + 0 + 0 + 1 + 1 + 1 + 1 + 0 + 0 + 0 + 1 = 5$$

Step 4 - The peak discharges were calculated for the existing basin as follows:

$UQ_2 = (13.2)\ (0.62^{0.21})\ (13 - 2)^{-0.43}\ (38^{0.73}) = 61$ cubic feet per second (cfs)
$UQ_5 = (10.6)\ (0.62^{0.17})\ (13 - 2)^{-0.39}\ (56^{0.78}) = 89$ cfs
$UQ_{10} = (9.51)\ (0.62^{0.16})\ (13 - 2)^{-0.36}\ (70^{0.79}) = 110$ cfs
$UQ_{25} = (8.68)\ (0.62^{0.15})\ (13 - 2)^{-0.34}\ (90^{0.80}) = 130$ cfs
$UQ_{50} = (8.04)\ (0.62^{0.15})\ (13 - 2)^{-0.32}\ (105^{0.81}) = 150$ cfs
$UQ_{100} = (7.70)\ (0.62^{0.15})\ (13 - 2)^{-0.32}\ (122^{0.82}) = 170$ cfs
$UQ_{500} = (7.47)\ (0.62^{0.16})\ (13 - 2)^{-0.30}\ (165^{0.82}) = 220$ cfs

The peak discharges for the developed basin were also calculated:

$UQ_2 = (13.2)\ (0.62^{0.21})\ (13 - 5)^{-0.43}\ (38^{0.73}) = 69$ cfs
$UQ_5 = (10.6)\ (0.62^{0.17})\ (13 - 5)^{-0.39}\ (56^{0.78}) = 100$ cfs
$UQ_{10} = (9.51)\ (0.62^{0.16})\ (13 - 5)^{-0.36}\ (70^{0.79}) = 120$ cfs
$UQ_{25} = (8.68)\ (0.62^{0.15})\ (13 - 5)^{-0.34}\ (90^{0.80}) = 150$ cfs
$UQ_{50} = (8.04)\ (0.62^{0.15})\ (13 - 5)^{-0.32}\ (105^{0.81}) = 170$ cfs
$UQ_{100} = (7.70)\ (0.62^{0.15})\ (13 - 5)^{-0.32}\ (122^{0.82}) = 190$ cfs
$UQ_{500} = (7.47)\ (0.62^{0.16})\ (13 - 5)^{-0.30}\ (165^{0.82}) = 240$ cfs

The peak flow versus recurrence interval curves before and after the anticipated development are shown in Figure 2. The changes in land use increase the peak discharges. This increase ranges from 8 cubic feet per second for the 2-year flood to 20 cubic feet per second for the 500-year flood.

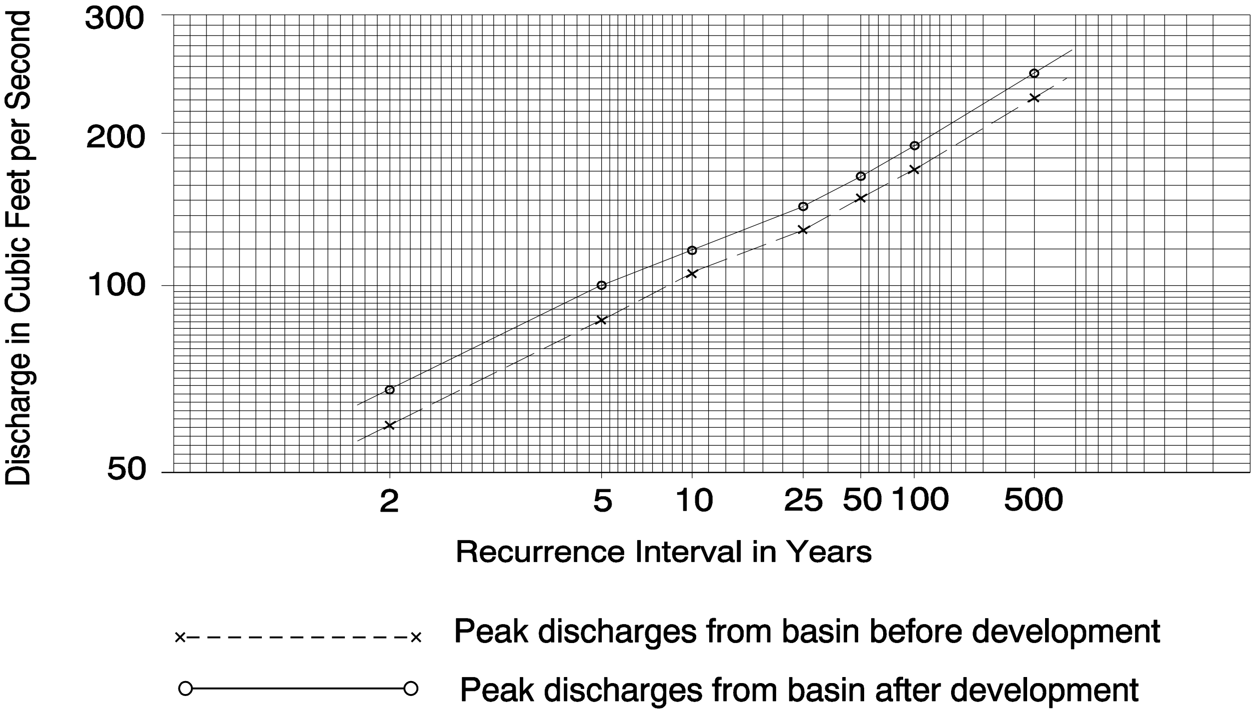

Figure 2 Discharges from Rosalie Creek Urban Drainage Basin