Section 5

Hydrological Analysis

5.1 Storm Frequency

An essential part of storm water analysis is selection of the design storm or storm frequency that will be used. Selection of the design storm includes economic and statistical relations. The frequency chosen for a storm depends upon such factors as the existing drainage system, the nature of the contributing areas, and the cost of storm drainage improvements.

The design storm is the total amount of rainfall that will occur over a period of time based on the statistical evaluation of precipitation records. Typical intervals for storm frequencies are 2, 5, 10, 25, 50, and 100 years. A 25-year storm can be expected to occur once within a 25-year period. The 25-year storm could occur any year during a 25-year time span, although each year it only has a 4 percent chance of occurring. The 25-year storm could conceivably occur for several years, or even twice in a given year, even though, statistically, it would not be probable.

Economic factors are considered when selecting the design storm in the engineering analysis. For instance, a drainage system sized for the 100-year storm will result in a larger, more costly drainage system than for a more frequent storm. Conversely, a drainage system designed for the frequent storm, though less costly, may not prevent property flooding, damage to public facilities, and the potential loss of life. Costs of improvements must be compared to the potential risks.

Selection of the storm frequency for this analysis is based on individual basins and projects. Based on the State of Oregon Department of Transportation Hydraulics Manual, a 50-year recurrent storm should be utilized for facilities draining through state highways and a 25-year storm can be used for smaller city streets. In cases where roadway overtopping is a problem, the 100-year storm, may be used.

Design storm precipitation totals for the City of Coos Bay are shown below.

TABLE 5.1.1
DESIGN STORM RAINFALL TOTALS AND ANALYSIS AREAS

DESIGN STORM FREQUENCY	RAINFALL TOTAL	REQUIRED FOR DRAINAGE BASINS
25 year storm	5.5 inches	City Streets and Neighborhoods
50 year storm	6.0 inches	Major City Streets

5.2 Channelization

As storm water flows downstream, it travels in some type of channel, for example, ditch, culvert, natural creek, and pipes. A common mathematical formula used to characterize the hydraulic behavior of these conduits is the Manning's Equation, which is generally expressed as:

$$Q=(1.49/n)*A*R^{2/3}*S^{1/2}$$

Where:
Q=Channel Flow (cfs)
A=Cross-Sectional Area (sf)
R=Hydraulic Radius=A/P (ft)
P=Wetted Perimeter (ft)
S=Channel Slope (ft/ft)
n=Manning's Roughness Coefficient

Channels vary widely in their hydraulic performance. The roughness coefficient, n, is used to describe the texture of the channel in terms of the material of construction. Materials differ in surface friction. If a channel is made up of a rough surface, there is more friction as the water flows through the channel and more energy is used to overcome that friction. The result is lower water velocities and therefore lower flows. Table 5.2 lists some commonly used Manning's "n" values for different pipe and channel surfaces.

TABLE 5.2.1
TYPICAL MANNING'S ROUGHNESS COEFFICIENTS

SURFACE OR MATERIAL	MANNING'S "n"
Finished Concrete	0.012
Unfinished Concrete	0.014
Plastic Pipe	0.009
Brick	0.016
Cast Iron	0.015
Concrete Pipe	0.015
Bare Earth	0.022
Corrugated Metal Flumes	0.025
Corrugated Metal Pipe	0.026
Rubble	0.030
Earth with Stones and Weeds	0.035

5.3 Analysis Method

The term "storm water" typically refers to rainfall runoff, snowmelt runoff, and surface runoff and drainage. Effective storm water management includes the accurate sizing of storm water conveyance systems; specifically, culverts, catch basins, detention/retention ponds, and storm drainage pipelines. Sizing for conveyance systems is generally estimated by using instantaneous peak runoff from a storm of specified frequency.

There are numerous methods for estimating peak runoff. For purposes of this study, the Rational Method and the Soil Conservation Service Runoff Method (TR-20 model) are used to estimate peak runoff values.

While the Rational Method is in common use for engineering analysis of drainage basins, its use is most applicable for analyzing areas with simple drainage systems. For this study, an alternate analysis tool, the SCS Method was used for developed areas with complex drainage system.

The following sections describe the methods in the analysis.

Rational Method

The Rational Method is based upon the concept of mass balance and relates rainfall intensity to runoff intensity. The Rational Method incorporates the use of the rational formula, which is generally expressed as:

$$Q_p = CIA$$

Where:
Q_p = peak discharge (cfs)
C = runoff coefficient (dimensionless)
I = rainfall intensity (in/hr)
A = watershed area (ac)

Once values for runoff coefficient, rainfall intensity, and watershed area have been determined, peak discharge (Q_p) values for drainage basins in the area are calculated. Each of the parameters in the formula is described below.

Runoff Coefficients
Values for C, the runoff coefficient, are readily available in most hydrology or engineering handbooks. Some common C values are listed in Table 5.3.1.

TABLE 5.3.1
COMMON RUNOFF COEFFICIENTS

AREA DESCRIPTION	RUNOFF COEFFICIENT
Downtown Business	0.70 to 0.95
Neighborhood	0.50 to 0.70
Single Family (Residential)	0.30 to 0.50
Detached Multi-units (Residential)	0.40 to 0.60
Attached Multi-units (Residential)	0.60 to 0.75
Light Industrial	0.50 to 0.80
Parks, Cemeteries	0.10 to 0.25
Unimproved	0.10 to 0.30

Rainfall Intensity

Rainfall intensity (I) is the intensity (inches per hour) of rainfall for a given design storm at a given time in the storm. Intensity is typically determined from Rainfall Intensity, Duration, Frequency (IDF) curves. IDF curves are used to determine rainfall intensity associated a specific storm frequency. The IDF curves for Coos Bay are provided in Appendix A.

Time of Concentration

Rainfall duration in a drainage basin is computed by determining the time of concentration for that drainage basin. Time of concentration (t_c) is defined as the longest travel time it takes a particle of water to reach a discharge point in a watershed. While traveling towards a discharge point, a water particle may experience sheet flow, shallow concentrated flow, open channel flow, or a combination of these. Once the drainage route and surfaces have been identified, Manning's equation is used to calculate the travel time of a water particle through a drainage basin.

$$T_c = \frac{L}{.6} \quad where \quad L = \frac{l^{.8}\,(s+1)^{.7}}{1900\ Y^{.5}}$$

$$and \quad S = \frac{1000}{CN} - 10$$

T_c = Time of concentration [hours]
L = Lag time [hours]
l = Hydraulic length of watershed [feet]
Y = Average land slope [percent]
S = Potential maximum retention [inches]
CN = Weighed Curve Number

Area
The final variable in the rational formula is the watershed area (A). Watershed area is determined from topographic maps of the area.

Soil Conservation Service Method

The SCS method, commonly referred to as SCS TR-20, is a more sophisticated storm water analysis tool than the Rational Method. Rather than simply determining the peak discharge, TR-20 utilizes a synthetic rainfall distribution to generate a hydrograph showing the runoff peak and volume. This method provides a more accurate assessment of the runoff volume because it sums the total volume discharged from the basin, rather than just the peak discharge.

The SCS method is based on combining unit hydrographs resulting from bursts of rainfall that vary in magnitude, but occur in a predictable pattern. This pattern is defined by SCS as a rainfall distribution curve. Though variations in the storm intensity are synthetic, runoff generated from the storm is based on local characteristics, such as; regional rainfall totals, soil permeability classifications, intensity of development, drainage slopes, area of impact, and even the time lag created by conveyance of flows through the drainage elements.

The benefits of the SCS method is that areas within a basin, called subbasins, can be simultaneously modeled with other subbasins by combining hydrographs using excess runoff and time to peak runoff. This process allows for a more accurate prediction of the peak discharge and calculation of the total runoff volume.

In comparison, the simplicity of the Rational Method requires the results to be more conservative than the SCS Method. Consequently, using the more complex method smaller pipe may be used if sufficient detail of the basin is available. A brief description of the fundamentals of the SCS method is provided below.

Synthetic storm distribution
The basis of the TR-20 Method is the “synthetic storm." This storm is based on SCS research that suggests the intensity of rainfall within a storm occurs in a predictable pattern. The SCS has applied this to the entire continental United States and developed rainfall mass distributions for four geographic locations. Storms occurring in Coos Bay and most of the Pacific Northwest have been classified as type 1A storms. Type 1A storms represent the Pacific maritime climate with wet winters and dry summers. Rainfall gradually increases until about 10 hour point and then gradually decreases. The NRCS storm type distribution is illustrated in Figure 5.3.1. The rainfall distribution hydrograph for a Type 1A 24-hour storm is illustrated in Figure 5.3.2.

FIGURE 5.3.1
NRCS RAINFALL DISTRIBUTIONS

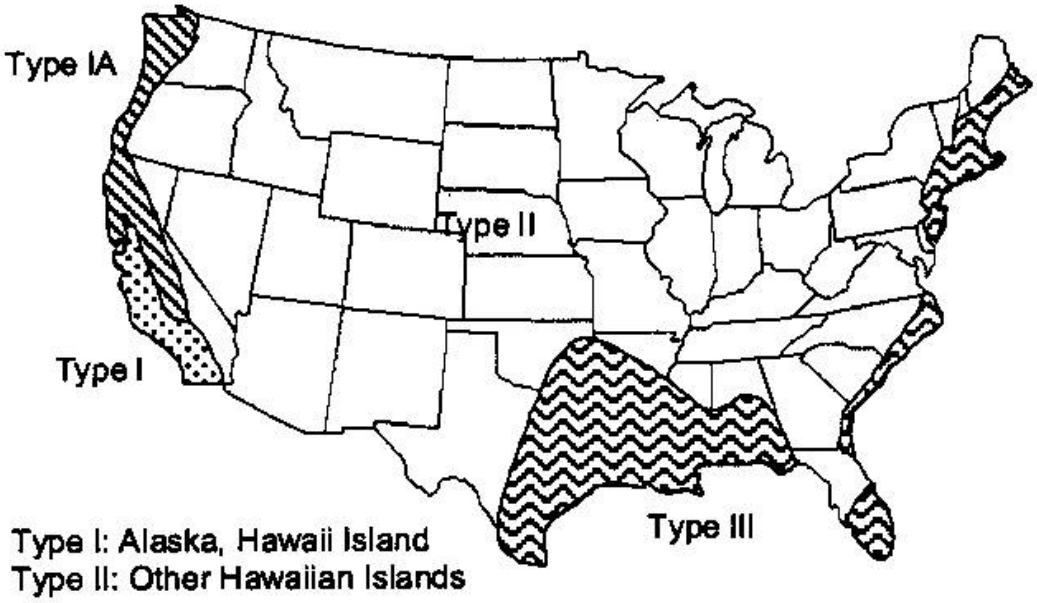
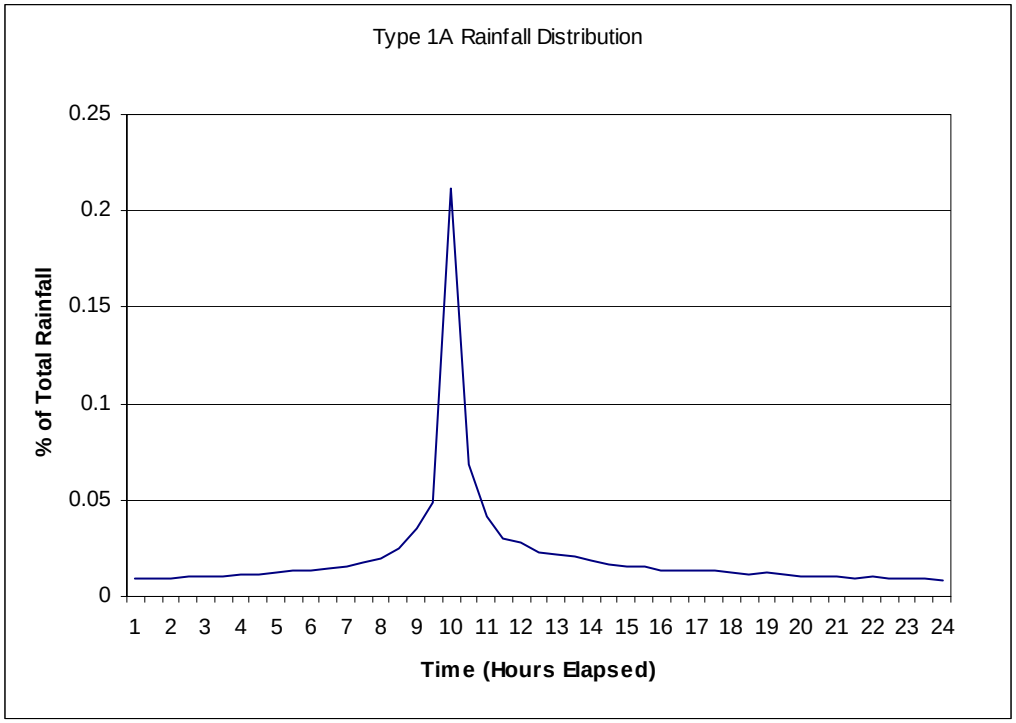


FIGURE 5.3.2
RAINFALL DISTRIBUTION FOR A TYPE 1A 24-HOUR STORM



Soil classification

The type of soil and ground cover occurring within a basin are used in the SCS Method. This information determines the amount of rainfall retained on the surface and the excess rainfall generating runoff. Soil and ground covers are classified by curve numbers (CN) similar to the coefficient of runoff, C, used with the Rational Method. Typical CN values used for the City of Coos Bay are provided below in Table 5.3.2. Since most of the soil within the City is classified as well draining, curve numbers for soil groups B and C were utilized in the analysis of the city's drainage system. A few soils were modeled at type D. Existing fill was modeled at type B.

TABLE 5.3.2
TYPICAL CN VALUES

GROUND COVER CHARACTERISTICS		CURVE NUMBER FOR SOIL GROUP			
Ground Cover Type and Condition	Percent Impervious	A well drained	B moderate	C poor	D very poor
Streets, Roads, Parking Lots	100	98	98	98	98
Urban Commercial Districts	85	89	92	94	95
Residential: 1/8 acre or less	65	77	85	90	92
Residential: 1/4 acre	38	61	75	83	87
Residential: 1/3 acre	30	57	72	81	86
Residential: > acre	25	54	70	80	85
Wooded: No Forest Litter	Poor	45	66	77	83
Wooded: Some Forest Litter	Fair	36	60	73	79
Wooded: Heavily Forested	Good	30	55	70	77

Rainfall

Storm rainfall is determined from the design frequency or design storm as previously mentioned. Total rainfall for the design storm used in Coos Bay is based on the National Oceanic and Atmospheric Administration (NOAA) Precipitation Maps for the Western United States. NOAA precipitation maps for Oregon are provided in Appendix B.

Time of concentration

As in the Rational Method, the time of concentration is an important parameter in the SCS Method. Unlike the Rational Method, the SCS utilizes t_c to determine the time to peak discharge rather than the time of peak rainfall.

Time to Peak

The Time to Peak, T_p, is the amount of time to the peak discharge. The time to peak is calculated with the unit hydrograph and time of concentration. The time to peak is not equal to the time of concentration.

Peak Runoff

The peak runoff is the peak amount of runoff discharged during a rainfall event. The peak runoff is calculated with the SCS method, and varies greatly with the slope and land use of the area in the drainage area. The peak flow is usually in cubic feet per second, and is used to size structures associated with the storm drain system.

$$Q = \frac{(P - .2S)^2}{P + .8S} \quad (Q = 0 \ \ if \ \ P < .2S)$$

$$where \quad S = \frac{1000}{CN} - 10$$

Q = Precipitation excess (runoff) [inches]
P = Cumulative precipitation [inches]
S = Potential maximum retention [inches]
CN = SCS Curve Number[1]

Unit Hydrograph

Runoff generated from a storm can be described by a hydrograph. A hydrograph is a predicted discharge wave that, similar to a bell curve, starts slowly then increases with time to a peak before decreasing to its pre-storm levels.

A unit hydrograph is a dimensionless hydrograph, hypothetically generated by one inch of excess precipitation resulting from a uniformly distributed storm of uniform duration over a uniform area. The peak discharge (the y ordinate) and the time of peak discharge (the x axis) for the unit hydrograph is plotted as fractions of the peak and time to peak runoff, respectively. This standardized hydrograph is used to generate site-specific hydrographs by combining rainfall and time to the unit values. The calculation, called runoff generation, is performed as described below.

Runoff Generation

In order to dimension the unit hydrograph and generate runoff according to TR-20 predictions, rainfall is assumed to fall on an area in a “burst." The burst of rain is assumed to flow downstream where it is collected and discharged from the area over an extended time interval.

The duration of the discharge is extended because not all of the rainfall reaches the discharge at the same time. Some of the flow is retained because of soil characteristics; some is delayed because of distance and velocity of travel.

At the same time that the water from farthest point of the basin reaches the discharge point, the lower areas of drainage are also contributing to the flow. The sum creates the peak discharge, which is shown on the y-axis of the hydrograph. The time of the peak is similarly based on the time of travel and plotted as the x-axis. Both the discharge and time of travel are utilized to dimension the unit hydrograph.

Once dimensioned, the unit hydrograph provides the runoff from one interval of the storm's duration. To predict the impact from an entire storm, it is necessary to generate and sum hydrographs for each storm interval. Each new hydrograph generated is based on the mass of rainfall occurring at that particular time, as predicted by the SCS synthetic rainfall distribution curve. As each burst of rainfall generates a new runoff hydrograph, it is added to the preceding hydrograph with its axis displaced by the time between bursts. Once the entire storm is summed, a single hydrograph results. This hydrograph depicts the runoff prediction for that subbasin.

Hydrograph routing.
Within each basin, there are often several subbasins, each generating a runoff hydrograph. In order to observe the effects of a storm on an entire basin, it is necessary to route each subbasin hydrograph throughout the system. Since each hydrograph is based on the time of concentration, it is possible to add each subbasin hydrograph at its discharge point. The process is repeated until all of the hydrographs have been routed through the entire basin and summed at the point of discharge. This process is called hydrograph routing.

Computer Model

The storm drain analysis was done using HydroCad™, WaterCad, and XP-SWMM 2000, packaged computer applications. Consequently, a large level of detail was applied to establish runoff characteristics. In addition to calculating the peak discharge, the SCS method can also calculate the total quantity of water produced from the storm. This information is useful to determine the extent of downstream flooding or the size ponds to contain and release runoff without creating significant increases in the quantity of discharged water. Data sheets from the computer model are included in Appendix D.