Condition of Approval 38 and 39

Reclamation Plan Amendment Condition of Approval Boulder Removal

Water Quality Impact Analysis

Lehigh Permanente Quarry
Reclamation Plan Amendment Condition of Approval
Boulder Removal
Water Quality Impact Analysis
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Background

The Lehigh Permanente Quarry Reclamation Plan Amendment (RPA) of 2012 contains a Condition of Approval (COA) that requires an inventory of limestone boulders in the Permanente Creek watershed near the North Quarry. The inventory is intended to identify candidate limestone boulders that may contain selenium for removal. The removal is intended to remove a potential source of selenium to surface water. An inventory of the candidate boulders was prepared in August 2012 for the subject area (Bieber, 2012).

This analysis assesses the potential water quality impact of rainfall leaching selenium from the boulders in the inventory by comparing potential selenium leaching rates with water flow in the streambed. Data for the analysis are taken from the RPA documentation submitted to Santa Clara County or from other referenced documents.

Methodology

Project Area

The boulder project area is identified in Figure 1. The drainage area of Permanente Creek has been identified to contain 1,014 acres above the location of the limestone boulders from the inventory.

Boulder Selenium Leaching Potential

The aforementioned inventory of limestone boulders that could potentially leach selenium in the project area was considered to estimate the total amount (micrograms, ***u***g) of selenium that potentially could be leached from the outer surface of the boulders into stream flow in the area. The following equations were used to develop the leaching potential of each boulder:

(1) Surface area of boulder = π x r^2 x 4 = square feet
    a. r = radius
(2) Surface volume of bolder exposed to leaching = Area x 0.0.008 feet (0.1 inch) = cubic feet
(3) Mass of rock in exposed leaching area = Cubic feet X density (kg/ft^3) = kg of limestone
    a. Density of limestone = 74 kg/ft^3
(4) Potential selenium available for leaching in exposed surface area = concentration of selenium in limestone (mg/kg) x kg of limestone x 1000 = ***u***g of selenium potentially leached
    a. Selenium concentration in Permanente quarry limestone = 6.6 mg/kg (RPA, 2012, Attachment G Table 5.0)

The above analysis conservatively assumes that all selenium in the exposed surface layer of each boulder is leached in a 10-year 24-hour storm event. The analysis also assumes that the

area exposed to rainfall and thus leaching is 67% of the total surface area, i.e. the lower 33% of the boulder does not receive direct rainfall.

Using the above data, the total potential selenium leached from the 10-year 24-hour storm event was calculated and the results are provided in Table 1 below.

Table 1
Limestone Boulder Leaching Potential

Boulders	Diameter (feet)	Surface Area ft2	Effective Exposed Surface layer (ft3)	Effective Exposed Surface Layer Mass (kg)	Potential leaching Se (ug)
1	3	28.26	0.15	11.16	73,648
1	8	200.96	1.07	79.35	523,722
1	6	113.04	0.60	44.64	294,594
1	6	113.04	0.60	44.64	294,594
1	2	12.56	0.07	4.96	32,733
1	6	113.04	0.60	44.64	294,594
1	2	12.56	0.07	4.96	32,733
1	1.3	5.31	0.03	2.10	13,830
1	3.5	38.47	0.21	15.19	100,244
1	6	113.04	0.60	44.64	294,594
1	7	153.86	0.82	60.75	400,975
1	3.5	38.47	0.21	15.19	100,244
1	4	50.24	0.27	19.84	130,931
1	5	78.50	0.42	31.00	204,579
1	6	113.04	0.60	44.64	294,594
1	1.5	7.07	0.04	2.79	18,412
1	6	113.04	0.60	44.64	294,594
1	1	3.14	0.02	1.24	8,183
1	4	50.24	0.27	19.84	130,931
1	1	3.14	0.02	1.24	8,183
1	8	200.96	1.07	79.35	523,722
1	4	50.24	0.27	19.84	130,931
1	6	113.04	0.60	44.64	294,594
1	2	12.56	0.07	4.96	32,733
1	5	78.50	0.42	31.00	204,579
1	5	78.50	0.42	31.00	204,579
1	2.5	19.63	0.10	7.75	51,145
1	2	12.56	0.07	4.96	32,733
1	2	12.56	0.07	4.96	32,733
1	1	3.14	0.02	1.24	8,183
1	1.5	7.07	0.04	2.79	18,412

Boulders		Diameter (feet)	Surface Area ft2	Effective Exposed Surface layer (ft3)	Effective Exposed Surface Layer Mass (kg)	Potential leaching Se (ug)
	1	1.5	7.07	0.04	2.79	18,412
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	1	3.5	38.47	0.21	15.19	100,244
	1	2.5	19.63	0.10	7.75	51,145
	1	2	12.56	0.07	4.96	32,733
	1	4	50.24	0.27	19.84	130,931
	1	5	78.50	0.42	31.00	204,579
	1	2.5	19.63	0.10	7.75	51,145
	11	1.5	77.72	0.41	30.69	202,533
	1	2	12.56	0.07	4.96	32,733
	1	3	28.26	0.15	11.16	73,648
Total						6,044,820

Receiving Water Flow

The storm event that was used to estimate the leaching potential above is the 10-year 24-hour event reported as 4.98 inches (Geosyntec, 2011). This event was used to support the analysis that 100% of the selenium in the exposed surface layer of the boulders was leached.

The runoff of the Permanente Creek drainage area identified in Figure 1 was estimated using the United States Department of Agriculture Soil Conservation Service Runoff Curve Number approach. The equations for estimating runoff with this method are provided in Attachment A.

The specific data values used in these equations for this analysis include:

- Drainage area = 1014 acres
- Precipitation depths = 4.98 inches (10-year 24-hour) and 22.2 inches (annual average)
- Curve Number = 63 (Soil Group D, mountain brush, Fair hydrologic condition 30-70% ground cover)

Based on the runoff analysis, the 10-year-24-hour storm event generates 238,159,000 liters of runoff that passes the boulder location of the project.

The equations were used to estimate annual runoff equaling 1.83 billion liters.

Estimated Water Quality Impact Analysis

Using the results from the above analyses, the 10-year 24-hour event potentially leaches 6,044,820 micrograms of selenium which would be collected in 238,159,000 liters of runoff. This one-time event (assuming all selenium is leached in the exposed surface layer) generates a receiving water concentration of 0.025 micrograms/liter of selenium. The impact of leaching into the annual precipitation amount is too low to be stated with any confidence (<0.004 ug/l)

Discussion

The current applicable California water quality objective for chronic conditions (4-day average) is 5.0 micrograms/liter of selenium. The acute objective (1-hour average) is 20.0 micrograms/liter of selenium.

This analysis considers a one-time 24-hour event and comparison to the chronic objective is not directly applicable but provides a comparison point for relevancy. Comparison to the acute objective provides a similar point of relevancy, i.e. not directly applicable.

References

Bieber, David. 2012. Permanente Creek Limestone Boulder Survey Report. Geocon Project No. S9325-06-09. Geocon Consultants, Rancho Cordova, CA.

Geosyntec, 2011. Water Balance and Process Diagram Report Permanente Cement Plant. Geosyntec Project No. HR1204C. Geosyntec Consultants, Oakland, CA.

Reclamation Plan Amendment, 2012. Lehigh Southwest Cement Company Permanente Quarry. Submitted to Santa Clara County.

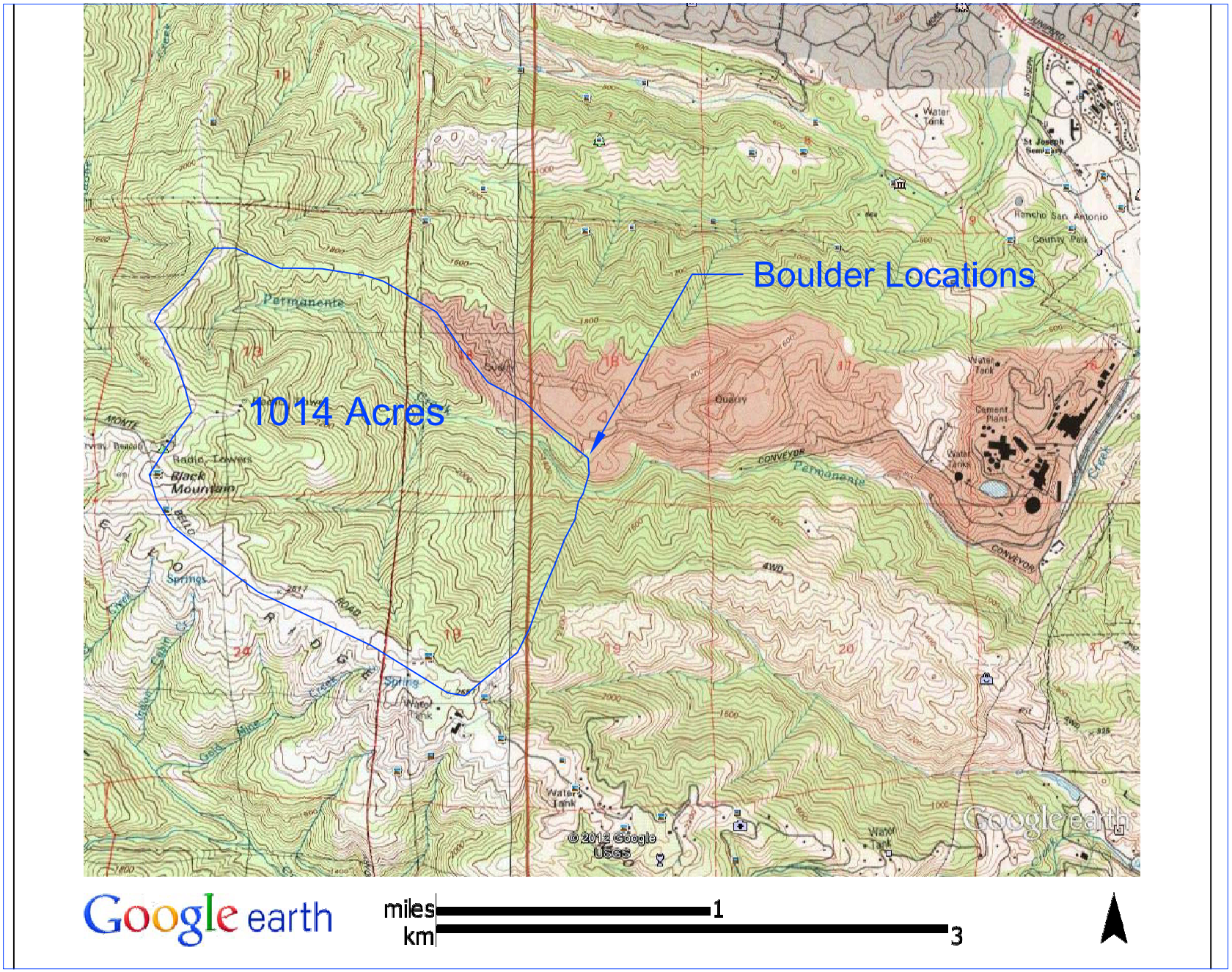

Figure 1

Permanente Creek Drainage Area
Above Boulder Locations

Attachment A

USDA SCS Runoff Curve Number

Runoff Estimation Approach

Section 7: NRCS Runoff Curve Number Methods

Anchor: #i1026683

Introduction

The department has adopted the following two specific runoff determination techniques developed by the U.S. Department of Agriculture and Natural Resources Conservation Service (NRCS), formerly known as the Soil Conservation Service (SCS):

- graphical peak discharge (TR 55) procedure
- NRCS dimensionless unit hydrograph.

The procedures presented here are derived from the NRCS National Engineering Handbook, Section 4 and Hydrology for Small Urban Watersheds, TR55.

Anchor: #i1026708

NRCS Runoff Curve Aspects

The techniques require basic data similar to that used in the Rational Method. However, the NRCS approach is more sophisticated in that it considers the following:

- time distribution of rainfall
- initial rainfall losses to interception and depression storage
- an infiltration rate that decreases during the course of a storm.

NRCS methods produce the direct runoff for a storm, either real or fabricated, by subtracting infiltration and other losses from the total rainfall using a method sometimes termed the Runoff Curve Number Method.

The primary input variables for the NRCS methods are as follows:

- drainage area size (A) in square miles (square kilometers)
- time of concentration (T_c) in hours
- weighted runoff curve number (RCN)
- rainfall distribution (NRCS Type II or III for Texas)
- total design rainfall (P) in inches (millimeters).

NRCS Rainfall-Runoff Equation. Equation 5-8 represents a relationship between accumulated rainfall and accumulated runoff. This was derived by NRCS from experimental plots for numerous soils and vegetative cover conditions. Data for land treatment measures, such as contouring and terracing, from experimental watersheds were included.

$$R = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Anchor: #i1000283

Equation 5-8.

where:

- *R* = accumulated direct runoff (in. or mm)
- *P* = accumulated rainfall (potential maximum runoff) (in. or mm)
- *Ia* = initial abstraction including surface storage, interception, and infiltration prior to runoff (in. or mm)
- *S* = potential maximum retention (in. or mm).

You may compute the potential maximum retention (S) using Equation 5-9:

$$S = z\left(\frac{100}{RCN} - 1\right)$$

Anchor: #i1000295

Equation 5-9.

where:

- *z=10 for* English measurement units, or 254 for metric
- *RCN* = runoff curve number described below.

Equation 5-9 is valid if S < (P-R). This equation was developed mainly for small watersheds from recorded storm data that included total rainfall amount in a calendar day but not its distribution with respect to time. Therefore, this method is appropriate for estimating direct runoff from 24-hour or one-day storm rainfall. Generally, I_a may be estimated as the following:

$$I_a = 0.2S$$

Equation 5-10.

Substituting this in Equation 5-8 gives:

$$R = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

Equation 5-11.

Anchor: #i1026851

Accumulated Rainfall (P)

For most highway drainage design purposes, you may abstract the accumulated rainfall from Technical Paper 40 (NWS, 1961) for a 24-hour duration storm for the relevant frequency. The data for 24-hour two, five, 10, 25, 50, and 100-year frequencies for Texas counties are presented in the 24-Hour Rainfall Depth versus Frequency Values for Texas Counties.

Anchor: #i1026863

Rainfall Distribution

Figure 5-9 shows two design dimensionless rainfall distributions for Texas: Type II and Type III. Figure 5-10 shows the areas in Texas to which these distribution types apply. The distribution represents the fraction of accumulated rainfall (not runoff) accrued with respect to time. The differences between Type II and Type III are minimal. Additional information is provided in the NRCS 24 Hour Rainfall Distributions subsection of Section 8.

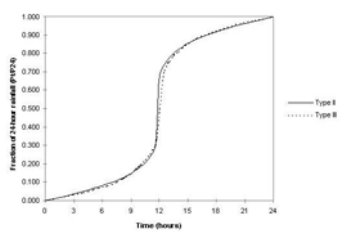

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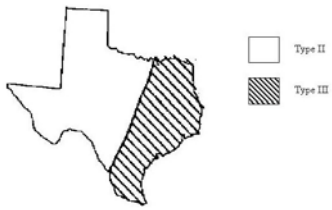
Figure 5-9. Soil Conservation Service 24-hour Rainfall Distributions - Adapted from TR55 (1986, pp. B-1)



Anchor: #i1000364

Figure 5-10. Rainfall Distribution Types in Texas

Anchor: #i1026893

Soil Groups

Soil properties influence the relationship between rainfall and runoff by affecting the rate of infiltration. NRCS divides soils into four hydrologic soil groups based on infiltration rates (Groups A-D). Remember to consider effects of urbanization on soil groups as well.

Group A. Group A soils have a low runoff potential due to high infiltration rates even when saturated (0.30 in/hr to 0.45 in/hr or 7.6 mm/hr to 11.4 mm/hr). These soils primarily consist of deep sands, deep loess, and aggregated silts.

Group B. Group B soils have a moderately low runoff potential due to moderate infiltration rates when saturated (0.15 in/hr to 0.30 in/hr or 3.8 mm/hr to 7.6 mm/hr). These soils primarily consist of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures (shallow loess, sandy loam).

Group C. Group C soils have a moderately high runoff potential due to slow infiltration rates (0.05 in/hr to 0.5 in/hr or 1.3 mm/hr to 3.8 mm/hr if saturated). These soils primarily consist of soils in which a layer near the surface impedes the downward movement of water or soils with moderately fine to fine texture such as clay loams, shallow sandy loams, soils low in organic content, and soils usually high in clay.

Group D. Group D soils have a high runoff potential due to very slow infiltration rates (less than 0.05 in./hr or 1.3 mm/hr if saturated). These soils primarily consist of clays with high swelling potential, soils with permanently high water tables, soils with a claypan or clay layer at or near the surface, shallow soils over nearly impervious parent material such as soils that swell significantly when wet or heavy plastic clays or certain saline soils.

Effects of Urbanization. Consider the effects of urbanization on the natural hydrologic soil group. If heavy equipment can be expected to compact the soil during construction or if grading will mix the surface and subsurface soils, you should make appropriate changes in the soil group selected.

Anchor: #i1026928

Runoff Curve Number (RCN)

Rainfall infiltration losses depend primarily on soil characteristics and land use (surface cover). The NRCS method uses a combination of soil conditions and land use to assign runoff factors known as runoff curve numbers. These represent the runoff potential of an area when the soil is not frozen. The higher the RCN, the higher the runoff potential. The following tables provide an extensive list of suggested runoff curve numbers. The RCN values assume medium antecedent moisture conditions (RCN II).

If necessary, adjust the RCN for wet or dry antecedent moisture conditions. Use a five-day

period as the minimum for estimating antecedent moisture conditions. Antecedent soil moisture conditions also vary during a storm; heavy rain falling on a dry soil can change the soil moisture condition from dry to average to wet during the storm period. Equation 5-12 adjusts values for expected dry soil conditions (RCN I). Use Equation 5-13 to accommodate wet soils (RCN III). For help determining which moisture condition applies, see the table titled Rainfall Groups for Antecedent Soil Moisture Conditions during Growing and Dormant Seasons.

$$RCN(I) = \frac{4.2RCN(II)}{10 - 0.058RCN(II)}$$

Anchor: #i1000405

Equation 5-12.

$$RCN(III) = \frac{23RCN(II)}{10 + 0.13RCN(II)}$$

Anchor: #i1000411

Equation 5-13.

Anchor: #i1010868Runoff Curve Numbers for Urban Areas					
Cover Type and Hydrologic Condition	**Average Percent Impervious Area**	**A**	**B**	**C**	**D**
Open space (lawns, parks, golf courses, cemeteries, etc.)					
• Poor condition (grass cover < 50%)		68	79	86	89
• Fair condition (grass cover 50% to 75%)		49	69	79	84
• Good condition (grass cover > 75%)		39	61	74	80
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					

• Paved; curbs and storm drains (excluding right-of-way)		98	98	98	98
• Paved; open ditches (including right-of-way)		83	89	92	93
• Gravel (including right-of-way)		76	85	89	91
• Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
• Natural desert landscaping (pervious areas only)		63	77	85	88
• Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
• Commercial and business	85	89	92	94	95
• Industrial	72	81	88	91	93
Residential districts by average lot size:					
• 1/8 acre or less (town houses)	65	77	85	90	92
• 1/4 acre	38	61	75	83	87
• 1/3 acre	30	57	72	81	86
• 1/2 acre	25	54	70	80	85
• 1 acre	20	51	68	79	84

• 2 acres	12	46	65	77	82
Developing urban areas:					
Newly graded areas (pervious areas only, no vegetation)		77	86	91	94
Notes: Values are for average runoff condition, and $I_a = 0.2S$. The average percent impervious area shown was used to develop the composite RCNs. Other assumptions are: impervious areas are directly connected to the drainage system, impervious areas have a RCN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition.					

Anchor: #i1011061Runoff Curve Numbers for Cultivated Agricultural Land1

Cover Type	**Treatment2**	**Hydrologic Condition3**	**A**	**B**	**C**	**D**
Fallow	Bare soil		77	86	91	94
	Crop residue	Poor	76	85	90	93
	cover (CR)	Good	74	83	88	90
Row Crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T + CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88

		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T + CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded	SR	Poor	66	77	85	89
or broadcast		Good	58	72	81	85
Legumes or C		Poor	64	75	83	85
Rotation		Good	55	69	78	83
Meadow	C&T	Poor	63	73	80	83
		Good	51	67	76	80

Notes: 1 Values are for average runoff condition, and $I_a = 0.2S$.

[2] Crop residue cover applies only if residue is on at least 5 percent of the surface throughout the year.

[3] Hydrologic condition is based on a combination of factors affecting infiltration and runoff: density and canopy of vegetative areas, amount of year-round cover, amount of grass or closed-seeded legumes in rotations, percent of residue cover on land surface (good > 20 percent), and degree of roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better infiltration and tend to decrease runoff.

Anchor: #i1011345Runoff Curve Numbers for Other Agricultural Lands

Cover Type	Hydrologic Condition	A	B	C	D
Pasture, grassland, or range-continuous forage for grazing	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow – continuous grass, protected from grazing and generally mowed for hay		30	58	71	78
Brush – brush-weed-grass mixture, with brush the major element	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30	48	65	73
Woods – grass combination (orchard or tree farm)	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77
Farmsteads – buildings, lanes, driveways, and surrounding lots		59	74	82	86

Notes: Values are for average runoff condition, and $I_a = 0.2S$.

Pasture: Poor is < 50% ground cover or heavily grazed with no mulch, Fair is 50% to 75% ground cover and not heavily grazed, and Good is >75% ground cover and lightly or only occasionally grazed.

Meadow: Poor is <50% ground cover, Fair is 50% to 75% ground cover, Good is >75% ground cover.

Woods/grass: RCNs shown were computed for areas with 50 percent grass (pasture) cover. Other combinations of conditions may be computed from RCNs for woods and pasture.

Woods: Poor is forest litter, small trees, and brush destroyed by heavy grazing or regular burning. Fair is woods grazed but not burned and with some forest litter covering the soil. Good is woods protected from grazing and with litter and brush adequately covering soil.

Anchor: #i1011405Runoff Curve Numbers for Arid and Semi Arid Rangelands					
Cover Type	**Hydrologic Condition**	**A**	**B**	**C**	**D**
Herbaceous—mixture of grass,	Poor		80	87	93
weeds, and low-growing brush,	Fair		71	81	89
with brush the minor element	Good		62	74	85
Oak-aspen—mountain brush	Poor		66	74	79
mixture of oak brush, aspen,	Fair		48	57	63
mountain mahogany, bitter brush,	Good		30	41	48
maple, and other brush					
Pinyon-juniper—pinyon, juniper,	Poor		75	85	89
or both; grass understory	Fair		58	73	80
	Good		41	61	71
Sagebrush with grass understory	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
saltbush, greasewood, creosote-	Poor	63	77	85	88
bush, blackbrush, bursage, palo	Fair	55	72	81	86
verde, mesquite, and cactus	Good	49	68	79	84

Notes. Values are for average runoff condition, and $I_a = 0.2S$.

Hydrologic Condition: Poor is <30% ground cover (litter, grass, and brush overstory), air is 30% to 70% ground cover, Good is >70% ground cover.

Curve numbers for Group A have been developed only for desert shrub.

Anchor: #i1011549Rainfall Groups for Antecedent Soil Moisture Conditions during Growing and Dormant Seasons			
Antecedent Condition	**Description**	**Growing Season**	**Dormant Season**

		5-Day Antecedent Rainfall	5-Day Antecedent Rainfall
Dry AMC I	An optimum condition of watershed soils, where soils are dry but not to the wilting point, and when satisfactory plowing or cultivation takes pace	Less than 1.4 in. or 35 mm	Less than 0.05 in. or 12 mm
Average AMC II	The average case for annual floods	1.4 in. to 2 in. or 35 to 53 mm	0.5 to 1 in. or 12 to 28 mm
Wet AMC III	When a heavy rainfall, or light rainfall and low temperatures, have occurred during the five days previous to a given storm	Over 2 in. or 53mm	Over 1 in. or 28 mm

Anchor: #i1026952

Graphical Peak Discharge (TR 55) Procedure

You can use this method of peak discharge determination for relatively homogeneous watersheds with a maximum time of concentration of 10 hours (600 minutes). In a similar fashion to the Rational Method, if soils and land use vary, you should subdivide the watershed. Precipitation records published in TP-40 and an assumed rainfall distribution are used to construct a synthetic storm. You should not use the method for runoff amounts of less than 1.5 in. (38 mm) and runoff curve numbers of less than 60. Additionally, the range of curve numbers should be small (say 20 percent) to reasonably conform to the assumption of homogeneity. A detailed description of this method appears in *Urban Hydrology for Small Watersheds* (TR-55). See References for information on obtaining this document. Use the following procedure to determine the graphic peak discharge:

1. Determine the drainage area (A) in square miles (square kilometers).
2. Determine the soil classification based on runoff potential (Type A, B, C, or D) as described in the Soil Groups paragraphs. One approach for a general classification is to determine the soil name and type from NRCS soil maps or reports.
3. Determine the antecedent soil moisture conditions (AMC).
4. Classify the hydrologic condition of the soil cover. Classify the hydrologic condition of the soil cover as good, fair, or poor. For more information, refer to the footnotes on the tables for Urban Areas tables, Cultivated Agricultural Land, Other Agricultural Lands, and Arid and Semi Arid Rangelands.
5. Determine the RCN for the AMC II soil classification. Determine the runoff curve number (RCN) for the particular soil classification for an AMC II. If appropriate, adjust for AMC I or AMC III using Equation 5-12 and Equation 5-13, respectively. If

necessary, determine a weighted value by dividing the sum of the products of the subarea sizes and RCNs by the total area. This process is similar to the weighting of runoff coefficients in the Rational Method. However, the runoff factors are not directly related.

6. Estimate the watershed time of concentration in hours (Tc).
7. Determine the potential maximum storage (S). Use Equation 5-9 to calculate the potential maximum storage.
8. Determine the initial abstraction (Ia). These are the losses that occur before runoff begins and include depression storage, interception, and infiltration. Use Equation 5-10 to calculate Ia. If Ia is greater than P, it is possible that the rainfall event would not produce runoff (which would be unusual for design frequencies). The abstraction equation may need modification, or an alternate means of estimating this value may be necessary, although no specific research has been performed to determine such adjustments.
9. Determine the rainfall distribution type based on the location of the watershed. Use Figure 5-10 to determine the rainfall distribution type based on the watershed location (Type II or Type III for Texas).
10. Determine the total rainfall (P) for watershed location. Based on the design frequency and the 24-Hour Rainfall Depth versus Frequency Values for Texas Counties to determine P for the watershed location.
11. Determine the accumulated direct runoff. Use Equation 5-11 to compute R. This value, when multiplied by the watershed area, will indicate the total volume of the rainfall that appears as runoff.
12. Determine the unit peak discharge. Refer to Equation 5-14 and the table that follows it with the relevant distribution type from step 10 to determine the unit peak discharge (q_u) using time of concentration (T_c) and the ratio I_a/P. If I_a/P is outside the bounds of the tables, use a more precise method that emulates the NRCS method, such as TR 20 or HEC-HMS.

$$q_u = \left(10^{C_0 - 3.36609}\right) \cdot \left(T_c^{\,C_1 + C_2 \log T_c}\right)$$

Anchor: #i1001761

Equation 5-14.

where:

- q_u = unit peak discharge (cfs/sq.mi./in. or $m^3/s/km^2/mm$)
- T_c = time of concentration (hours)

Anchor: #i1011573Coefficients for Equation 5-14

Rainfall Type	I_a/P	C_0	C_1	C_2
II	0.1	2.5532	-0.6151	-0.164
	0.3	2.4653	-0.6226	-0.1166

	0.35	2.419	-0.6159	-0.0882
	0.4	2.3641	-0.5986	-0.0562
	0.45	2.2924	-0.5701	-0.0228
	0.5	2.2028	-0.516	-0.0126
III	0.1	2.4732	-0.5185	-0.1708
	0.3	2.3963	-0.512	-0.1325
	0.35	2.3548	-0.4974	-0.1199
	0.4	2.3073	-0.4654	-0.1109
	0.45	2.2488	-0.4131	-0.1159
	0.5	2.1777	-0.368	-0.0953

13. Determine the pond adjustment factor (F). Use the following table to determine F. This adjustment is to account for pond or swamp areas within the watershed that do not interfere with the time of concentration flow path.

Anchor: #i1011661Ponding Adjustment Factor	
% Ponded/Swamp Area	**Factor (F)**
0	1
0.2	0.97
1	0.87
3	0.75
5	0.72
NOTE: This factor is not intended to replace a hydrograph routing technique where considerable detention storage is present (typically, with surface area of ponding in excess of 5 percent of the watershed area).	

14.

15. Compute the peak discharge (Q). Use Equation 5-15 to compute Q:

$$Q = q_u ARF$$

Anchor: #i1001967

Equation 5-15.

where:

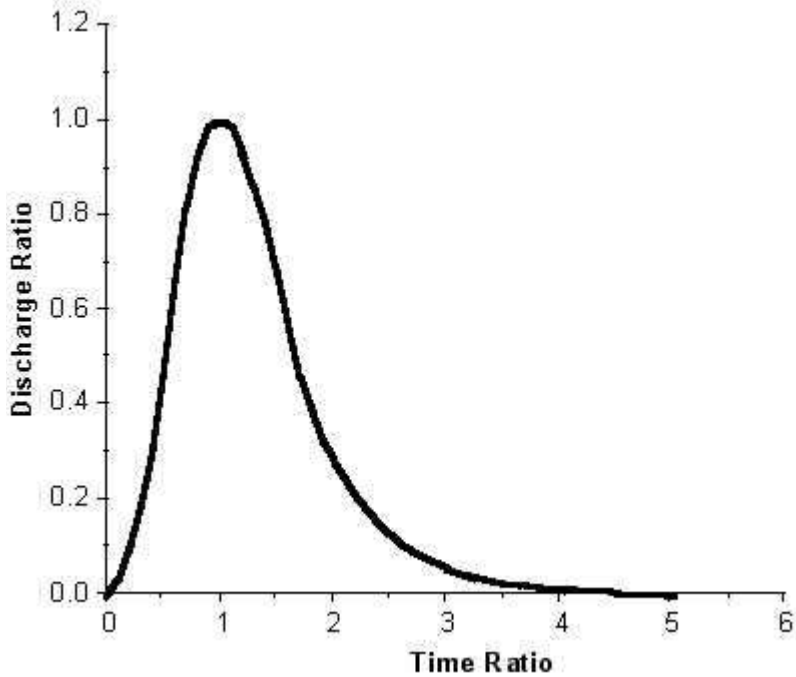
- Q = peak discharge (cfs or m^3/s)
- q_u = unit peak discharge (cfs/sq.mi./in. or $m^3/s/km^2/mm$) from step 12
- A = drainage area (sq.mi. or km^2) from step 1
- R = runoff volume (in. or mm) from step 11
- F = ponding factor from step 13

Anchor: #i1027119

NRCS Dimensionless Unit Hydrograph

In many instances for highway drainage design, peak discharge methods will suffice for runoff estimation. However, the estimation of runoff hydrographs may be necessary for situations such as detention pond design, reservoir routing, or channel routing, especially for larger areas and those in which watershed conditions cannot be considered homogeneous. Many hydrograph methods are available and not specifically excluded for use by the department. However, the NRCS Dimensionless Hydrograph Method is incorporated here due to its relative ease of use.

A unit hydrograph represents the time distribution of flow resulting from one in. (mm) of direct runoff occurring over the watershed in a specified time. You plot the NRCS dimensionless unit hydrograph in terms of the ratio of time over time to peak. A curvilinear dimensionless unit hydrograph is shown in Figure 5-11.



Anchor: #i1002003

Figure 5-11. NRCS Dimensionless Curvilinear Unit Hydrograph

For hand computations, a triangular hydrograph is reasonable, as shown in Figure 5-12.

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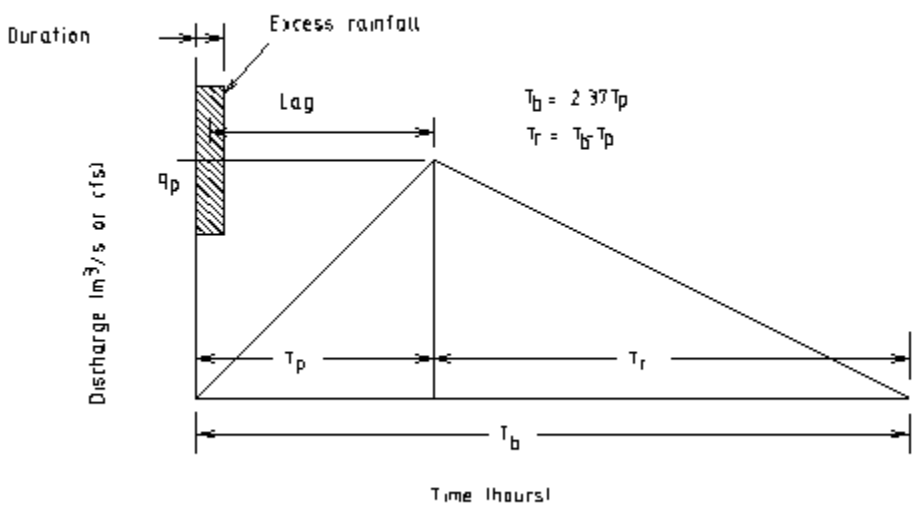

Figure 5-12. Triangular Unit Hydrograph

Triangular Hydrograph. The triangular hydrograph is a practical representation of excess runoff with one rise, one peak, and one recession. Its geometric makeup can be easily described mathematically, which makes it very useful in the processes of estimating discharge rates. NRCS developed Equation 5-16 to estimate the peak rate of discharge for an increment of runoff.

$$q_p = \frac{0.208Aq}{T_p}$$

Anchor: #i1002017

Equation 5-16.

where:

- q_p = peak rate of discharge (cfs or m^3/s)
- 0.208 = peak rate factor
- A = area (sq. mi. or km^2)
- q = storm runoff during time interval (in. or mm) = 1 in. or mm for unit hydrograph
- Tp = time to peak runoff (hours), which is estimated using Equation 5-17

$$T_p = \frac{d}{2} + 0.6\,T_c$$

Anchor: #i1002033

Equation 5-17.

where:

- TP = time of concentration (hours)
- d = duration of unit excess rainfall (hours)

Equation 5-18 provides an estimate of the duration of unit excess rainfall (d).

$$d = 0.133\,T_c$$

Anchor: #i1002043

Equation 5-18.

You can use Equation 5-16 to estimate the peak discharge for the unit hydrograph. You can then estimate the shape of the unit hydrograph derived with reference to Figure 5-9 or Figure 5-10. The peak rate factor of 0.208 is valid for the NRCS dimensionless unit hydrograph. Any change in the dimensionless unit hydrograph reflecting a change in the percent of volume under the rising side would cause a corresponding change in the shape factor associated with the triangular

hydrograph and, therefore, a change in the peak rate factor. This constant has been known to vary from about 0.258 in steep terrain to 0.129 in very flat, swampy country.

More detail on the NRCS dimensionless hydrograph method is provided in the NRCS National Engineering Handbook, Volume 4. See U.S. Department of Agriculture for information on obtaining this document.

Dimensionless Unit Hydrograph Characteristics. Dimensionless unit hydrograph characteristics vary with the size, shape, and slope of the tributary drainage area.

Lag Time and Peak Characteristics. The most significant characteristics affecting the dimensionless hydrograph shape are the basin lag and the peak discharge (q_p) for a given rainfall (see Figure 5-12). Basin lag is the time from the center of mass of rainfall excess to the hydrograph peak.

Steep slopes, compact shape, and an efficient drainage network tend to make lag time short and peaks high. Flat slopes, elongated shape, and an inefficient drainage network tend to make lag time long and peaks low.

Anchor: #i1027260

Flood Hydrograph Determination Procedure

The following procedure is for design discharges and assumes the area or subarea is reasonably homogeneous. That is, you have subdivided the watershed into homogeneous areas. The procedure only results in a hydrograph from the direct uncontrolled area. If you have subdivided the watershed, it might be necessary to perform hydrograph channel routing, storage routing, and hydrograph superposition to determine the hydrograph at the outlet of the watershed.

Use the following procedure for determining a flood hydrograph from a dimensionless unit hydrograph:

1. Determine the following parameters for each unit hydrograph: drainage area or subarea size, A, (sq. mi. or km^2), time of concentration (T_c--hrs), weighted runoff curve number (RCN), rainfall distribution type using Figure 5-10, and accumulated rainfall--P--(in. or mm) for design and check flood frequencies.
2. Determine the unit hydrograph variables: Determine the duration of excess rainfall (runoff) using Equation 5-18. For convenience, round d such that the actual duration of precipitation is a whole number times d. For example, if d is 0.332 hours for a 24 hour precipitation, then 24/0.332 = 72.29; use 72 in which case, d = 24/72 = 0.333 hours (20 min). Then calculate the time to peak of unit hydrograph (U.H.), T_p, using Equation 5-17. Then compute the peak runoff ordinate, q_p, for the unit hydrograph using Equation 5-16 and = 1 in. (1 mm). Finally, develop a table of the unit hydrograph ordinates using time step increments (d):
    - At each time n * d, where n is the time step, determine the time ratio (t/T_p):

$$\left(\frac{t}{T_p}\right) = \frac{nd}{T_p}$$

Equation 5-19.

- Use the dimensionless hydrograph (curvilinear as appears in Figure 5-11, or triangular as appears in Figure 5-12) to find the discharge ratio (q/Q_p) at this time ratio.
- Calculate the discharge at this time step using Equation 5-20.

$$q - q_p \left(\frac{q}{Q_p}\right)$$ Anchor: #i1002092

Equation 5-20.

- Repeat a, b, and c for each time step. The resulting table represents the runoff from 1.0 in. (1.0 mm) of rainfall excess occurring during a time of d hours.
- Use Equation 5-21 to check the volume under the resulting hydrograph. The result should be 1.0, reflecting the 1 in. (1 mm) of runoff from the entire drainage area. Rounding of the unit duration, d, and the likelihood that T_p will not be an integer multiple of d will often result in a volume slightly higher or lower than 1. If so, adjust all the ordinates proportionally until the resulting volume is 1.

$$\mathrm{VOL} = \frac{3.6\mathrm{d} \times \sum(\text{hydrograph ordinates})}{\mathrm{A}}$$ Anchor: #i1002103

Equation 5-21.

3. Develop a runoff (excess rainfall) table. Referring to Figure 5-9 or Figure 5-10, develop a table of accumulated rainfall, P, for the appropriate distribution type and use a time increment of d hours. Determine the fraction of total rainfall. Use Figure 5-9 to determine the fraction of total rainfall. Multiply the total rainfall by the 24-hour precipitation. Calculate the accumulated runoff (R). On the same table, calculate R, using the estimated RCN, and Equation 5-9 and Equation 5-11. If, for any time interval, $P - 0.2S < 0$, then $R = 0$. Calculate the incremental runoff for each time step. Make the calculation as the difference between the current accumulated runoff and the accumulated runoff from the previous time step.
4. Compute the hydrographs resulting from each increment of runoff. For each incremental runoff, multiply the ordinates of the unit hydrograph by the increment of runoff using the same time step, d. This will result in as many hydrographs as there are increments of runoff, each of which should be displaced by the duration time (d) from the previous

hydrograph.

5. At each time step, sum all the runoff values to yield the composite runoff hydrograph. This step is often termed convolution. The resulting hydrograph for the watershed or subarea may serve as an inflow hydrograph for channel or storage routing procedures.

Anchor: #i1027369

Complex Watersheds

For complex watersheds, subdivide the area, develop runoff hydrographs for each sub-area, and perform combinations of flood routing and channel routing.

If appraisal of the effect of storage is required, such as for detention pond design, you may apply the resulting hydrographs to flood-routing techniques such as appear in Section 9, Flood Hydrograph Routing Methods.

You may use other superposition or tabular methods for the convolution process. However, you are expected to use computer spreadsheets or programs for large computations, and the basic theory remains the same.