CHAPTER 5 – HYDROLOGIC ANALYSIS AND DESIGN

Chapter Organization

5.1 INTRODUCTION

The purpose of this chapter is to provide the tools for estimating peak flow rates and volumes for sizing conveyance, treatment, and flow control facilities. Treatment facilities are designed to remove pollutants contained in stormwater runoff. Flow control facilities are necessary to mitigate potential adverse impacts on downstream/down-gradient properties due to the increase in stormwater runoff caused by land development.

Stormwater runoff from any proposed land development to any point of discharge downstream shall not exceed that of the pre-development condition, unless an exception is granted by the local jurisdiction.

Stormwater runoff from a developed site shall leave the site in the same manner and at the same location as in the pre-developed condition. Flow may not be concentrated onto downstream properties where sheet flow previously existed. Drainage shall not be diverted from a proposed development and released downstream at points not receiving stormwater runoff prior to the proposed development.

Non-standard systems shall be evaluated individually by the local jurisdiction and shall require a GSC report, a downstream analysis, and any additional information deemed necessary by the local jurisdiction.

All engineering work shall be performed by, or under the direction of, a qualified Engineer.

5.2 HYDROLOGIC ANALYSIS METHODS

The following methods shall be used for the design of flow control and conveyance systems:

- The National Resource Conservation Service (NRCS) Curve Number Method[1] or the Santa Barbara Urban Hydrograph (SBUH) Method can be used to estimate peak flow rates and volumes;
- The Level Pool Routing Method can be used to route hydrographs;
- The Rational Method can be used to estimate peak runoff rates;
- The Modified Rational Method (Bowstring Method) can be used to estimate peak flow rates and detention volumes;
- The Water Budget Method can be used to size evaporation facilities; and,
- Other hydrologic analysis methods appropriate to the site conditions and approved by the local jurisdiction.

[1] The NRCS Curve Number method is also referred to as the SCS Curve Number Method and the SCS Unit Hydrograph, as the NRCS was formerly called the Soil Conservation Service.

Note that regardless of the methodology used, if utilizing a given method yields a runoff volume or rate that is incongruent with the physical site characteristics and stormwater runoff patterns, the Engineer will be required to provide support for why the results should be accepted by the local jurisdiction. The local jurisdiction shall reserve the ability to limit discharge rates and volumes into any publicly owned facilities.

5.3 CURVE NUMBER METHOD

Single event hydrograph methods such as the NRCS Curve Number Method and the SBUH method can be used to develop hydrographs to estimate the peak flow rate and volumes for specific design storms. These methods can also be used with flow routing techniques to size detention facilities.

This section presents a general description of the NRCS Curve Number Method. For additional information refer to the NRCS National Engineering Handbook. Modeling with these methods is generally conducted using commercially available computer software packages.

5.3.1 NRCS CURVE NUMBER METHOD THEORY

In general, the rainfall-runoff equation of the NRSC Curve Number Method relates a land area’s runoff depth (precipitation excess) to the precipitation it receives and to its natural storage capacity. The amount of runoff from a given watershed is solved with the following equations. The NRCS curve number equation is shown below in Equation 5-1, and the NRCS rainfall excess equation is shown below in Equation 5-2:

$$S = \frac{1000}{CN} - 10 \tag{5-1}$$

$$Q = \frac{\left(P - 0.2S\right)^2}{\left(P + 0.8S\right)} \tag{5-2}$$

$$Q = 0 \quad for \;\; P < 0.2S$$

Where:

S	=	maximum storage volume of water on and within the soil (in);
CN	=	curve number (dimensionless).
Q	=	runoff depth (in); multiply by drainage area to determine runoff volume
P	=	precipitation (in); and
0.2S	=	initial abstraction; the fractional amount estimated as intercepted, evaporated and/or absorbed by the soil (in).

The NRCS Curve Number Method has the following limitations:

- When the calculated depth of runoff is less than 0.5 inch, another method shall be used, as approved by the local jurisdiction;
- When (P-0.2S) is a negative number, another method shall be used, as approved by the local jurisdiction;
- When the weighted curve number is less than 40, another method shall be used, as approved by the local jurisdiction;
- For additional limitations, see NRCS publication 210-VI-TR-55, Second Edition, June 1986; and,
- Local jurisdictions reserve the ability to limit discharge to public facilities.

Note that regardless of the methodology used, if utilizing a given method yields a runoff volume or rate that is incongruent with the physical site characteristics, the Engineer will be required to provide support for why the results should be accepted.

5.3.2 DESIGN STEPS

The following steps are based on the assumption that the Engineer uses a software package that utilizes the NRCS Curve Number or the SBUH method for hydrologic computations and the level pool method for reservoir routing (see Section 5.4). If hand calculations are proposed, the Engineer can consult currently available technical publications on hydrograph routing for additional information. Additional calculation details are provided in sections 5.3.3 through 5.3.8.

1. Determine the pre-developed and post-developed drainage basin boundaries and identify permeable and impervious areas per Section 5.3.3;
2. Determine the hydrologic soil group classification(s) per Section 5.3.4 and correlate to the drainage basin boundaries;
3. Identify the appropriate land use(s) within the delineated basins and select CN values for each of the pre-developed and post-developed basins per Section 5.3.5;
4. Determine the time of concentration per Section 5.3.6 for both pre-developed and post-developed conditions;
5. Determine the precipitation Section 5.3.7 and Appendix 5A) for the required design storms specified in Chapter 2 and input into software program;
6. Select the appropriate storm type in the software program or enter the hyetograph as necessary (Section 5.3.8). For Central Oregon, use the NRCS Type I, 24-hour Storm for all calculations;
7. Set the routing and hydrograph time increments in the computer software program to six-minutes or less;

8. Compute peak flow rates and volumes for the pre-developed basins and determine the allowable release rates per the design criteria specified in Chapter 2;
9. Compute peak flow rates and volumes for the post-developed basins, assuming no flow control (retention/detention/infiltration) facilities have been installed to mitigate flows;
10. Compute the surface area or volume at incremental stages (heights) of the drainage facility, beginning at the bottom of the anticipated drainage facility to an elevation at least 1 foot above the overflow;
11. Input the elevation and storage volume relationship into the software program;
12. For infiltration facilities, determine soil infiltration rate in accordance with Chapter 4;
13. Input the geometry of the anticipated outflow structures (i.e. weirs, orifices, etc.) into the software program;
14. Create basin links for combining and/or routing basin hydrographs to the proposed facility. Links may have routing elements, such as pipes or channels;
15. Using the hydrographs of the post-developed basins, combine and route the hydrographs to the drainage facility and route the inflow hydrograph through the facility; and,
16. Verify that the release from the site does not exceed the allowable release rate (or volume, when required), as determined in step 8. Modify the pond geometry and outflow structure input data if the results indicate that the allowable thresholds are exceeded.

5.3.3 BASIN AREAS

The basin modeling (drainage areas and assumptions) needs to reflect the actual runoff behavior as closely as feasible. The impervious and permeable areas must be estimated from best available plans, topography, or aerial photography, and verified by field reconnaissance.

5.3.4 HYDROLOGIC SOIL GROUP CLASSIFICATION

The NRCS has classified over 4,000 soil types into the following four soils groups listed below. Refer to the most recent NRCS maps for the hydrologic soil group classification for soils common to Central Oregon. The NRCS provides an interactive online soils mapping tool at http://websoilsurvey.nrcs.usda.gov/.

Group A soils have high infiltration rates, even when thoroughly wetted, and consist chiefly of deep, well-to-excessively drained sands or gravels. These soils have a high rate of water transmission and low runoff potential.

Group B soils have moderate infiltration rates when thoroughly wetted, and consist chiefly of moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission and moderately low runoff potential.

Group C soils have slow infiltration rates when thoroughly wetted, and consist chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine textures. These soils have a slow rate of transmission and moderately high runoff potential.

Group D soils have very slow infiltration rates when thoroughly wetted, and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a hardpan or clay layer at or near the surface, and shallow soils over nearly impervious materials. These soils have a very slow rate of transmission and high runoff potential.

5.3.5 CURVE NUMBERS

Curve Numbers (CNs) indicate the runoff potential of a watershed. The higher the CN value, the higher the potential for runoff. The CN takes into consideration the hydrologic soil group, land use, and cover.

Weighting CNs

Connected impervious areas can include driveways and adjacent sidewalks discharging directly into the drainage system without first traversing an area of permeable ground. Connected impervious areas shall not be weighted with permeable areas.

Unconnected impervious areas are defined as those that discharge over a permeable area as sheet flow, such as a tennis court in the middle of a lawn or runoff from roofs flowing over lawn. Unconnected impervious areas can be weighted with permeable areas.

Basin configurations shall be consistent with surface runoff patterns. For example, the roof and lawn areas of residential neighborhoods can be combined and considered one basin when the roof runoff travels through the lawn before getting to the streets. The driveway and street areas should be combined, as they are typically hydraulically connected and should be considered a separate basin. The impervious and permeable hydrographs shall then be linked with or without a routing element, such as a pipe or a channel.

In most cases, if permeable areas within the same basin have CN values that differ by more than 20 points, separate hydrographs shall be generated for each and the hydrographs shall be combined.

Table 5-1 lists CNs values for agricultural, suburban, and urban land use classifications. See NRCS publication 210-VI-TR-55 for additional CN values. For an example of weighting CNs and addressing both connected and unconnected impervious areas refer to Appendix 5D.

TABLE 5-1
RUNOFF CURVE NUMBERS
ANTECEDENT RUNOFF CONDITION (ARC) II

Cover Type And Hydrologic Condition *Hydrologic Soil Group:*	*A*	*B*	*C*	*D*
Open Space (lawns, parks, golf courses, cemeteries, landscaping, etc.): [1]				
Poor condition (grass cover <50% of the area)	68	79	86	89
Fair condition (grass cover on 50% to 75% of the area)	49	69	79	84
Good condition (grass cover on >75% of the area)	39	61	74	80
Impervious Areas:				
Open water bodies: lakes, wetlands, ponds, etc.	100	100	100	100
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)	98	98	98	98
Streets and Roads:				
Paved: curbs and storm sewers (excluding right-of-way)	98	98	98	98
Paved: open ditches/swales (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
Porous Pavers and Permeable Interlocking Concrete (assume 85% impervious and 15% fair condition lawn):	91	94	95	96
Urban Districts:				
Commercial and Business (average 85% impervious)	89	92	94	95
Industrial (average 72% impervious)	81	88	91	93
Residential Districts By Average Lot Size:				
1/8 acre or less or townhouses (average 65% impervious)	77	85	90	92
1/4 acre (average 38% impervious)	61	75	83	87
1/3 acre (average 30 % impervious)	57	72	81	86
1/2 acre (average 25% impervious)	54	70	80	85
1 acre (average 20% impervious)	51	68	79	84
2 acres (average 12% impervious)	46	65	77	82
Newly graded areas (pervious areas only, no vegetation)	77	86	91	94
Farmsteads – buildings, lanes, driveways, and surrounding lots	59	74	82	86
Pasture, Grassland, or Range-Continuous Forage for Grazing:				
Poor condition (ground cover <50% or heavily grazed with no mulch)	68	79	86	89
Fair condition (ground cover 50% to 75% and not heavily grazed)	49	69	79	84
Good condition (ground cover >75% and lightly or only occasionally grazed)	39	61	74	80
Meadow (continuous grass, protected from grazing and generally mowed for hay)	30	58	71	78
Cultivated Agricultural Lands:				
Row Crops (good) e.g. corn, sugar beets, soy beans	64	75	82	85
Small Grain (good) e.g. wheat, barley, flax	60	72	80	84
Brush-Weed-Grass Mixture (with brush the major element):				
Poor (<50% ground cover)	48	67	77	83
Fair (50% to 75% ground cover)	35	56	70	77
Good (>75% ground cover)[2]	30	48	65	73
Woods:				
Poor (Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning)	45	66	77	83
Fair (Woods are grazed but not burned, and some forest litter covers the soil)	36	60	73	79
Good (Woods are protected from grazing, and litter and brush adequately cover the soil)	30	55	70	77

TABLE 5-1 (CONTINUED)

Cover Type And Hydrologic Condition	*Hydrologic Soil Group: A*	*B*	*C*	*D*
Herbaceous (mixture of grass, weeds, and low-growing brush, with brush the minor element)[4]:				
Poor (<30% ground cover)		80	87	93
Fair (30% to 70% ground cover)		71	81	89
Good (>70% ground cover)		62	74	85
Pinyon-Juniper (pinyon, juniper, or both; grass understory)[4]:				
Poor (<30% ground cover)		75	85	89
Fair (30% to 70% ground cover)		58	73	80
Good (>70% ground cover)		41	61	71
Sagebrush With Grass Understory[4]:				
Poor (<30% ground cover)		67	80	85
Fair (30% to 70% ground cover)		51	63	70
Good (>70% ground cover)		35	47	55

[1] Composite CNs may be computed for other combinations of open space cover type.
[2] Actual curve number is less than 30; use CN = 30 for runoff computations.
[3] CNs shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CNs for woods and pasture.
[4] Curve numbers have not been developed for group A soils.

Antecedent Runoff Condition – Curve Number Adjustment

The moisture condition in a soil prior to a storm event is referred to as the antecedent runoff condition (ARC). The NRCS developed three antecedent runoff conditions:

- ARC I (Dry Condition): soils are dry but surface cracks are not evident.
- ARC II (Average Condition): soils are not dry or saturated. The CN values listed in Table 5-1 are applicable under this condition and do not account for snowmelt or runoff on frozen ground conditions.
- ARC III (Wet Condition): soils are saturated or near saturation due to heavy rainfall or light rainfall and low temperatures within the last 5 days.

The design of detention or infiltration ponds shall be based on ARC II. When ARC III applies, such as when designing evaporation facilities or modeling the winter months (Section 5.7.4), Table 5-2 shall be used to adjust the CN values.

TABLE 5-2
ANTECEDENT RUNOFF CONDITION (ARC)

CN ARC II	CN ARC I	CN ARC III		**CN ARC II**	CN ARC I	CN ARC III
100	100	100		**76**	58	89
99	97	100		**75**	57	88
98	94	99		**74**	55	88
97	91	99		**73**	54	87
96	89	99		**72**	53	86
95	87	98		**71**	52	86
94	85	98		**70**	51	85
93	83	98		**69**	50	84
92	81	97		**68**	48	84
91	80	97		**67**	47	83
90	78	96		**66**	46	82
89	76	96		**65**	45	82
88	75	95		**64**	44	81
87	73	95		**63**	43	80
86	72	94		**62**	42	79
85	70	94		**61**	41	78
84	68	93		**60**	40	78
83	67	93		**59**	39	78
82	66	92		**58**	38	76
81	64	92		**57**	37	75
80	63	91		**56**	36	75
79	62	91		**55**	35	74
78	60	90		**54**	34	73
77	59	89		**50**	31	70

Curve Number Conversions for different ARC are for the case of I_a = 0.2 S. Source NRSC-National Engineering Handbook

5.3.6 TIME OF CONCENTRATION

Time of concentration is affected by the way stormwater moves through a watershed. Stormwater can move in the form of sheet flow, shallow concentrated flow, open channel flow, or some combination of these. The type of flow should be verified by field inspection.

The time of concentration for rainfall shall be computed for all overland flow, ditches, channels, gutters, culverts, and pipe systems. When using the NRCS Curve Number or SBUH methods, the time of concentration for the various surfaces and conveyances shall be computed using the procedures presented in this section, these procedures are based on the methods described in NRCS publication 210-VI-TR-55.

Travel time (T_t) is the time it takes stormwater runoff to travel from one location to another in a watershed. Time of concentration (T_c) is the time for stormwater runoff to travel from the hydraulically most distant point to the point of discharge of a watershed. T_c is computed by adding all the travel times for consecutive components of the drainage conveyance system as given by the following equation:

$$T_c = T_{t1} + T_{t2} + \ldots T_{tn} \quad (5\text{-}3)$$

Where: T_c = time of concentration (min); (minimum 5 minutes)

n = number of flow segments; and,

T_t = travel time (min) is the ratio of flow length to flow velocity given by:

$$T_t = \frac{L}{60V} \quad (5\text{-}4)$$

where: L = flow length (ft);

V = average velocity (ft/s); and,

60 = conversion factor (seconds to minutes).

T_c influences the shape and peak of the runoff hydrograph. Urbanization usually decreases T_c, thereby increasing the peak discharge. But T_c can be increased as a result of ponding behind small or inadequate drainage systems, including storm drain inlets and road culverts, or reduction of land slope through grading. Note: the minimum T_c for any runoff calculations should be 5 minutes.

Sheet Flow

Sheet flow is flow over plane surfaces and shall not be used over distances exceeding 300 feet. Use Manning's kinematic solution to directly compute T_t:

$$T_t = \frac{0.42(n_s L)^{0.8}}{(P_2)^{0.5}(S_o)^{0.4}} \quad (5\text{-}5)$$

Where: T_t = travel time (min);

n_s = Manning's effective roughness coefficient for sheet flow (use Table 5-3);

L = flow length (ft);

P_2 = 2-year, 24-hour rainfall (in), (use Appendix 5A); and,

S_o = slope of hydraulic grade line (land slope, ft/ft).

The friction value (n_s) is used to calculate sheet flow. The friction value is Manning's effective roughness coefficient modified to take into consideration the effect of raindrop impact; drag over the plane surface; obstacles such as litter, crop ridges, and rocks; and erosion and transportation of sediment. The n_s values are for very shallow flow depths of about 0.1 foot and are only used for travel lengths up to 300 feet. Table 5-3 gives Manning's n_s values for sheet flow for various surface conditions.

Shallow Concentrated Flow

After 300 feet, sheet flow is assumed to have developed into shallow concentrated flow. The average velocity is calculated using equation 5-6, and the travel time (T_t) for the shallow concentrated flow segment can be computed using equation 5-4.

Velocity Equation

A commonly used method of computing average velocity of flow, once it has measurable depth, is the following equation:

$$V = k\sqrt{S_o} \qquad (5\text{-}6)$$

Where: V = velocity (ft/s);

k = k_s or k_c, time of concentration velocity factor (ft/s); and,

S_o = slope of flow path (ft/ft).

Table 5-3 provides "k" for various land covers and channel characteristics with assumptions made for hydraulic radius. For flow situations not addressed in Table 5-3, calculate "k" using the following rearrangement of Manning's equation:

$$k = \frac{1.49R^{2/3}}{n} \qquad (5\text{-}7)$$

Where: R = hydraulic radius; and,

n = Manning's roughness coefficient for open channel flow (Tables 5-3 or 5-4).

Open Channel Flow

Open channels are assumed to exist where channels are visible on aerial photographs, where streams appear on United States Geological Survey (USGS) quadrangle sheets, or where topographic information indicates the presence of a channel. The k_c values from Table 5-3 used in equation 5-6 or water surface profile information can be used to estimate average flow velocity. Average flow velocity is usually determined for bank-full conditions. After average velocity is computed the travel time (T_t) for the channel segment can be computed using equation 5-4. Note: for flow conditions not addressed in Table 5-3, k_c can be calculated using equation 5-7.

TABLE 5-3
FRICTION VALUES (*n* and *k*)
FOR COMPUTING TIME OF CONCENTRATION

SHEET FLOW *	n_S
Bare sand	0.010
Smooth surfaces (concrete, asphalt, gravel, or bare hard soil)	0.011
Asphalt and gravel	0.012
Fallow fields of loose soil surface (no vegetal residue)	0.05
Cultivated soil with crop residue (slope < 0.20 ft/ft)	0.06
Cultivated soil with crop residue (slope > 0.20 ft/ft)	0.17
Short prairie grass and lawns	0.15
Dense grass	0.24
Bermuda grass	0.41
Range, natural	0.13
Woods or forest, poor cover	0.40
Woods or forest, good cover	0.80
SHALLOW, CONCENTRATED FLOW	k_s
Forest with heavy ground litter and meadows (n = 0.10)	3
Brushy ground with some trees (n =0.06)	5
Fallow or minimum tillage cultivation (n = 0.04)	8
High grass (n = 0.035)	9
Short grass, pasture and lawns (n = 0.030)	11
Newly-bare ground (n = 0.025)	13
Paved and gravel areas (n = 0.012)	27
CHANNEL FLOW (INTERMITTENT, R = 0.2)	k_c
Forested swale with heavy ground litter (n=0.10)	5
Forested drainage course/ravine with defined channel bed (n=0.050)	10
Rock-lined waterway (n=0.035)	15
Grassed waterway (n=0.030)	17
Earth-lined waterway (n=0.025)	20
CMP pipe (n=0.024)	21
Concrete pipe (n=0.012)	42
Other waterways and pipes	0.508/n
CHANNEL FLOW (CONTINUOUS STREAM, R =0.4)	k_c
Meandering stream with some pools (n=0.040)	20
Rock-lined stream (n=0.035)	23
Grassed stream (n=0.030)	27
Other streams, man-made channels and pipe	0.807/n

*These values were determined specifically for overland (sheet) flow conditions and are not appropriate for conventional open channel flow calculations.

Source: WSDOT Hydraulics Manual, March 2004; Engman (1983) and the Florida Department of Transportation Drainage Manual (1986).

TABLE 5-4
SUGGESTED VALUES OF THE MANNING'S ROUGHNESS COEFFICIENT "*n*" FOR CHANNEL FLOW

TYPE OF CHANNEL AND DESCRIPTION	"*n*"[1]
A. CONSTRUCTED CHANNELS	
a. Earth, straight and uniform	
1. Clean, recently completed	0.018
2. Gravel, uniform selection, clean	0.025
3. With short grass, few weeds	0.027
b. Earth, winding and sluggish	
1. No vegetation	0.025
2. Grass, some weeds	0.030
3. Dense weeds or aquatic plants in deep channels	0.035
4. Earth bottom and rubble sides	0.030
5. Stony bottom and weedy banks	0.035
6. Cobble bottom and clean sides	0.040
c. Rock lined	
1. Smooth and uniform	0.035
2. Jagged and irregular	0.040
d. Channels not maintained, weeds and brush uncut	
1. Dense weeds, high as flow depth	0.080
2. Clean bottom, brush on sides	0.050
3. Same, highest stage of flow	0.070
4. Dense brush, high stage	0.100
B. NATURAL STREAMS	
B-1 Minor Streams (top width at flood stage < 100ft.)	
a. Streams on plain	
1. Clean, straight, full stage, no rifts or deep pools	0.030
2. Same as above, but more stones and weeds	0.035
3. Clean, winding, some pools and shoals	0.040
4. Same as above, but some weeds	0.045
5. Same as 4, but more stones	0.050
6. Sluggish reaches, weedy deep pools	0.070
7. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.100
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages	
1. Bottom: gravel, cobbles and few boulders	0.040
2. Bottom: cobbles with large boulders	0.050
B-2 Flood Plains	
a. Pasture, no brush	
1. Short grass	0.030
2. High grass	0.035
b. Cultivated areas	
1. No crop	0.030
2. Mature row crops	0.035
3. Mature field crops	0.040
c. Brush	
1. Scattered brush, heavy weeds	0.050
2. Light brush and trees	0.060
3. Medium to dense brush	0.070
4. Heavy, dense brush	0.100
d. Trees	
1. Dense willows, straight	0.150
2. Cleared land with tree stumps, no sprouts	0.040
3. Same as above, but with heavy growth of sprouts	0.060
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.100
5. Same as above, but with flood stage reaching branches	0.120

[1]The "n" values presented in this table are the "Normal" values as presented in Chow (1959). For an extensive range and for additional values refer to Chow (1959)

5.3.7 PRECIPITATION MAPS

Precipitation isopluvial maps for Central Oregon are available from the *NOAA Atlas 2, Volume X.* The maps in Appendix 5A include isopluvials for the 2-, 10-, 25-, 50-, and 100-year 24 hour storm events. Table 5-5 lists the 24-hour storm rainfall depths for each of the major communities in Central Oregon. The values in this table are intended to be a guide only. Project proponents should verify the storm depth for their particular project site using the isopluvial maps in Appendix 5A.

TABLE 5-5
24-HOUR STORM DEPTHS FOR SELECTED AREAS
(INCHES)

AREA	6-MONTH[1]	2-YEAR	10-YEAR	25-YEAR	50-YEAR	100-YEAR
Bend	1.0	1.5	2.0	2.5	2.8	3.0
LaPine	1.1	1.6	2.25	2.6	2.9	3.0
Madras	0.8	1.2	1.8	2.1	2.3	2.6
Prineville	0.8	1.2	1.7	2.0	2.2	2.4
Redmond	0.7	1.0	1.5	1.8	2.0	2.2
Sisters	1.2	1.8	2.5	2.8	3.0	3.5

[1]Calculated as 2/3 of the 2-year, 24-Hour storm depth

Source: NOAA Atlas 2, Volume X

5.3.8 DESIGN STORM DISTRIBUTIONS

These methods require the selection of, or the input of, a rainfall distribution and the precipitation associated with a design storm. In Central Oregon, the NRCS Type I 24-hour storm distribution shall be used. This distribution simulates a high intensity peak and is used throughout most of the United States. The distribution is appropriate for both flow-based and volume-based treatment BMPs, as well as the sizing of retention/detention and infiltration facilities. The graphical representation and tabular values for the NRCS Type I hyetograph are in Appendix 5B. The NRCS Type I hyetograph is also a standard option in most software programs.

5.4 LEVEL POOL ROUTING METHOD

This section presents a general description of the methodology for routing a hydrograph through an existing retention/detention facility or closed depression, and for sizing a new retention/detention facility using hydrograph analysis. Many commercially available software packages include routines to perform these calculations.

The "level pool routing" technique presented here is one of the simplest and most commonly used hydrograph routing methods. This method is described in "Handbook of Applied Hydrology," Chow, Ven Te, 1964, and elsewhere, and is based upon the continuity equation:

Inflow - Outflow = Change in storage

$$\left[\frac{I_1 + I_2}{2} - \frac{O_1 + O_2}{2}\right] = \frac{\Delta S}{\Delta t} = S_2 - S_1 \qquad (5\text{-}8)$$

Where: I = inflow at time 1 and time 2;

O = outflow at time 1 and time 2;

S = storage at time 1 and time 2; and,

Δt = time interval, time 2 – time 1.

The time interval, Δt, must be consistent with the time interval used in developing the inflow hydrograph. The Δt variable can be eliminated by dividing it into the storage variables to obtain the following rearranged equation:

$$I_1 + I_2 + 2S_1 - O_1 = O_2 + 2S_2 \qquad (5\text{-}9)$$

If the time interval, Δt, is in minutes, the units of storage (S) are now [cubic feet/min] which can be converted to cfs by multiplying by 1 minute/60 seconds.

The terms on the left-hand side of the equation are known from the inflow hydrograph and from the storage and outflow values of the previous time step. The unknowns O_2 and S_2 can be solved interactively from the given stage-storage and stage-discharge curves.

The level pool routing method can be used to size a new storage facility by comparing the calculated peak outflow to the predeveloped runoff rate. An iterative process is typically used to adjust the facility storage volumes and control structure configuration until the design meets the outflow guidelines in Chapter 7.

5.5 RATIONAL METHOD

The rational method is used to predict peak flows for small undeveloped or developed drainage areas. The rational method can be used for the design of conveyance, flow control, and subsurface infiltration facilities. The greatest accuracy is obtained for areas smaller than 10 acres and for developed conditions with large impervious areas. In Central Oregon, the Rational Method is recommended for small projects (less than 25 acres) in urbanized areas. For larger basins, the Curve Number Method in Section 5.3 should be used whenever possible. The rational method peak flow rate is calculated using the following equation:

$$Q_P = CIA \tag{5-10}$$

Where: Q_P = peak flow rate (cfs);

C = runoff coefficient (dimensionless units);

I = rainfall intensity (in/hr), Section 0; and,

A = drainage area (acres).

Calculation details are provided in the Section 5.5.1 through 5.5.3. An example runoff calculation using the Rational Method is included as steps 1-4 in the Bowstring Method example in Appendix 5E.

5.5.1 RUNOFF COEFFICIENTS

Table 5-6 provides runoff coefficients for the 10-year storm frequency. Less frequent, higher intensity storms require the use of higher coefficients because infiltration and other losses have a proportionally smaller effect on runoff. When designing for a 25-, 50-, or 100-year frequency, runoff coefficients should be increased by 10 percent, 20 percent, and 25 percent respectively. Runoff coefficients shall not be increased above 0.95. Higher values may be appropriate for steeply sloped areas and/or longer return periods, because in these cases infiltration and other losses have a proportionally smaller effect on runoff.

TABLE 5-6
RUNOFF COEFFICIENTS FOR THE RATIONAL METHOD
10-YEAR RETURN FREQUENCY[1]

TYPE OF COVER	FLAT (<2%)	ROLLING (2% - 10%)	HILLY (>10%)
Pavement and Roofs	0.90	0.90	0.90
Earth Shoulders	0.50	0.50	0.50
Drives and Walks	0.75	0.80	0.85
Gravel Pavement	0.85	0.85	0.85
City Business Areas	0.80	0.85	0.85
Apartment Dwelling Areas	0.50	0.60	0.70
Light Residential: 1 to 3 units/acre	0.35	0.40	0.45
Normal Residential: 3 to 6 units/acre	0.50	0.55	0.60
Dense Residential: 6 to 15 units/acre	0.70	0.75	0.80
Lawns	0.17	0.22	0.35
Grass Shoulders	0.25	0.25	0.25
Side Slopes, Earth	0.60	0.60	0.60
Side Slopes, Turf	0.30	0.30	0.30
Median Areas, Turf	0.25	0.30	0.30
Cultivated Land, Clay and Loam	0.50	0.55	0.60
Cultivated Land, Sand and Gravel	0.25	0.30	0.35
Industrial Areas, Light	0.50	0.70	0.80
Industrial Areas, Heavy	0.60	0.80	0.90
Parks and Cemeteries	0.10	0.15	0.25
Playgrounds	0.20	0.25	0.30
Woodland and Forest	0.10	0.15	0.20
Meadow and Pasture Land	0.25	0.30	0.35
Unimproved Areas	0.10	0.20	0.30

Source: ODOT Hydraulics Manual, June 2006
[1]When desiging for the 25-, 50-, or 100-year storm events, increase the runoff coefficients by 10%, 20%, and 25% respectively. Coefficients should not exceed 0.95.

5.5.2 TIME OF CONCENTRATION

The travel time, the time required for flow to move through a flow segment, shall be computed for each flow segment. The flow path for each basin should be divided into segments representing different land cover and flow types (i.e. overland flow through grass vs. shallow gutter flow). The time of concentration is equal to the sum of the travel times for all flow segments. As with the Curve Number method, any overland flow segments should be limited to 300 feet in length.

The procedure described below was developed by the NRCS. It is sensitive to slope, type of ground cover, and the size of channel. The time of concentration can be calculated as follows:

$$T_t = \frac{L}{K\sqrt{S}} \tag{5-11}$$

$$T_c = T_{t1} + T_{t2} + \ldots + T_{tn} \tag{5-12}$$

Where: T_t = travel time of flow segment (min);

T_c = time of concentration (min);

L = length of segment (ft);

K = ground cover coefficient, Table 5-7 (ft/min);

S = slope of segment (ft/ft); and,

n = number of flow segments.

The time of concentration for any one basin shall not be less than 5 minutes. An example time of concentration calculation is provided in Step 2 of Appendix 5E.

For a few drainage areas, the time of concentration that produces the largest amount of runoff is less than the time of concentration for the entire basin. This can occur when two or more basins have dramatically different types of cover. The most common case would be a large paved area together with a long narrow strip of natural area. In this case, the Engineer shall check the runoff produced by the paved area alone to determine if this scenario would cause a greater peak runoff rate than the peak runoff rate produced when both land segments are contributing flow. The scenario that produces the greatest runoff shall be used, even if the entire basin is not contributing flow to this runoff.

TABLE 5-7
GROUND COVER COEFFICIENTS

TYPE OF COVER	K (ft/min)[1]
Forest With Heavy Ground Cover	150
Minimum Tillage Cultivation	280
Short Pasture Grass Or Lawn	420
Nearly Bare Ground	600
Small Roadside Ditch W/Grass	900
Paved Area	1,200
Gutter Flow:	
4 inches deep	1,500
6 inches deep	2,400
8 inches deep	3,100
Storm Sewers:	
12 inch diameter	3,000
18 inch diameter	3,900
24 inch diameter	4,700

TABLE 5-7 (CONTINUED)

Open Channel Flow (n = .040):	
12 inches deep	1,100
Narrow Channel (w/d =1):	
2 feet deep	1,800
4 feet deep	2,800
Open Channel Flow (n = .040):	
1 foot deep	2,000
Wide Channel (w/d =9):	
2 feet deep	3,100
4 feet deep	5,000

Source: WSDOT Hydraulics Manual, March 2004;
[1]Coefficients listed represents flow velocities equivalent to those in Figure 1 – *Shallow Concentrated Flow Velocities* in Appendix F of the ODOT Hydraulics Manual, Chapter 7

5.5.3 INTENSITY

Rainfall intensity is related to rainfall duration and the recurrence interval (or frequency) of the design storm. Rainfall Intensity-Duration-Recurrence/Frequency Interval (IDR/F) curves for areas in Central Oregon are reproduced in Appendix 5C. The curves are from two sources:

- For the Cities of Bend, Redmond, and Prineville, updated IDF curves were developed in 2008 by MGS Engineering Consultants in partnership with the Oregon Climate Service. The updated IDF curves are based on recent rainfall data and are specific to the three listed communities.
- For other areas of Central Oregon, the IDR curves in the ODOT Hydraulics Manual should be used. The IDR curves were developed in accordance with the method described in the *NOAA Atlas 2: Precipitation-Frequency Atlas of the Western United States, Volume X-Oregon*. Thirteen zones were established across the State of Oregon, and most projects in Central Oregon will fall within Zones 9, 10, or 13.

For each project, first determine the appropriate curve to use based on the project location and the IDR Curve Zone Map in Appendix 5C. Then calculate the appropriate rainfall intensity for each basin based on the time of concentration (T_c) calculated in Section 5.5.2 and the desired storm recurrence interval. Curves are provided for the 2-, 5-, 10-, 25-, 50-, and 100-year storm events.

5.6 BOWSTRING METHOD (MODIFIED RATIONAL METHOD)

The Bowstring Method is used to estimate storage volume requirements for a given design storm using a series of hydrographs for different storm durations (t). This method is based on the Rational Method runoff calculations outlined in Section 5.5. As with the Rational Method, the Bowstring Method is recommended for small projects (less than 25 acres) in urbanized areas. For larger basins, the Curve Number Method in Section 5.3 should be used whenever possible.

Depending on the relative magnitude of the time of concentration (T_c) and the storm duration, the shape of the hydrograph generated with this method varies from triangular to trapezoidal. The recession period (T_R) of the hydrograph is given by equation 5-13.

$$T_R = 1.67 T_P \qquad (5\text{-}13)$$

Where: $T_P = \mathrm{t}$ when $\mathrm{t} < \mathrm{T_c}$; or

$T_P = \mathrm{T_c}$ when $\mathrm{t} \geq \mathrm{T_c}$.

The volume (V) under the hydrograph at a given time (t) is given by:

$$V(\mathrm{t}) = 1.34 Q_P \mathrm{t} \quad \text{for} \quad \mathrm{t} \leq \mathrm{T_c} \quad \text{(triangular hydrograph)} \qquad (5\text{-}14)$$

$$V(\mathrm{t}) = Q_P \mathrm{t} + 0.34 Q_P \mathrm{T_C} \quad \text{for} \quad \mathrm{t} > \mathrm{T_c} \quad \text{(trapezoidal hydrograph)} \qquad (5\text{-}15)$$

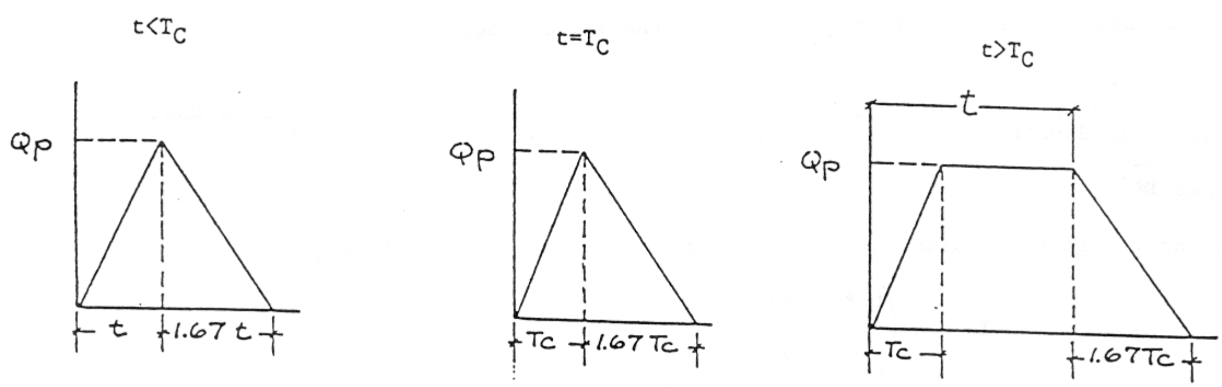

Figure 5-1 – Bowstring Method Hydrographs

With these equations, the base of the triangular hydrograph is equal to 2.67t. For the trapezoidal hydrograph, the time base is t + 1.67$\mathrm{T_c}$. The top width of the trapezoid is equal to t - $\mathrm{T_c}$. With this method, the hydrograph for each storm duration is overlaid with the outflow hydrograph. The outflow hydrograph is given by the following equation:

$$V_{OUT}(\mathrm{t}) = Q_{OUT}\,\mathrm{t} \qquad (5\text{-}16)$$

The critical storm duration is the storm duration that results in the maximum required detention storage.

5.6.1 DESIGN STEPS

For detention design using the Bowstring Method, the following procedure can be used:

1. Compute the peak flow rate (Q_P) for t = T_c using equation 5-10 for the pre-developed condition. If the project proposes to release runoff offsite, this is the maximum peak flow rate that shall be released.
2. Compute Q_P for t = T_c using equation 5-10 for the post-developed condition.
3. Compute intensities (I), peak flow rates (Q_P), and volumes (V) for various times (i.e. t = 5, 10, 25…minutes) using equations 5-10, 5-14, 5-15, and 5-16.
4. Determine the allowable release rate (Q_{OUT}), which is limited to either the pre-developed peak flow rate or the allowable infiltration rate through drywells as determined by Section 4.3.2.
5. Calculate the outflow volume (V_{OUT}) using equation 5-16.
6. The required storage is obtained as the maximum difference between inflow and outflow volumes by either graphical or tabular methods. The tabular method is illustrated in the example given in Appendix 5E.

5.7 WATER BUDGET METHOD

A water budget analysis is required for the design of an evaporative pond. The analysis utilizes average monthly precipitation and pan evaporation values to estimate the net stormwater runoff volume increase during a two year cycle. The water budget analysis is conducted for a two-year cycle to account for seasonal variations in precipitation, pan evaporation and antecedent runoff conditions and to verify that equilibrium is reached.

Equilibrium is reached when the analysis confirms that the required pond size does not increase in the second year of the cycle.

5.7.1 WATER BUDGET METHODOLOGY

The water budget analysis is performed utilizing the following relationships:

$$V_{STORAGE}(x) = V_{IN}(x) - V_{OUT}(x) + V_{STORAGE}(x-1) \quad (5\text{-}17)$$

$$V_{POND} = \max[V_{STORAGE}(x)] \quad (5\text{-}18)$$

Where: x = any given month;

V_{IN} = water volume entering the evaporative pond in a given month. Stormwater runoff volume is calculated using the NRCS runoff equations 5-1 and 5-2;

V_{OUT} = stormwater volume leaving the evaporative pond in a given month (i.e. pan evaporation, surface release);

$V_{STORAGE}$ = storage volume necessary for a given month; and,

V_{POND} = storage volume necessary to reach equilibrium in a 2-year cycle.

The analysis is repeated until the maximum storage volume in the second year is equal or less than the maximum storage volume in the first year.

The cycle shall start in October, the month that yields the greatest net storage volume for the year.

Water loss through evaporation from overland surface areas is not considered in the water budget due to the wide variation in evaporation rates that occur over these types of surfaces. Depressional storage is the only reduction that can be considered in this analysis. This reduction may be considered if closed depressions are present on site in the pre-developed condition and are proposed to remain as an existing topographical feature, set aside for drainage purposes. Vegetal and minor topographical abstraction and interception are already accounted for in the NRCS curve numbers.

Depending on the site conditions and proposed pond design, evaporative systems shall be designed using the Outflow or Full Containment method design criteria.

Outflow Method

The Outflow Method is used to size evaporation facilities that store the excess stormwater runoff volume (after evaporation losses) created when new development occurs. Reference Figures 7-3 and 7-4 for schematics of how this design is implemented.

The water budget analysis needs to demonstrate that the volume of runoff leaving the site, over the 2-year cycle, is below or equal to the pre-developed volume for the cycle. In addition, if the facility has a surface release, the rate of release from the facility shall meet the detention design criteria (Section 7.3.2). If site conditions permit, the pre-developed volume should be infiltrated when a defined release point is not present onsite. The evaporative system shall have a containment volume separate from the detention system to provide attenuation of peak flows during the storm events. A minimum factor of safety of 1.2 shall be applied to the evaporative volume, normally by increasing the depth of the facility.

If the evaporative system is designed in combination with a surface discharge, then equations 5-17 through 5-20 shall be used:

$$V_{ALL} \leq V_{PRE} \qquad (5\text{-}19)$$

$$Q_{ALL} \leq Q_{PRE} \qquad (5\text{-}20)$$

Where: V_{ALL} = the total volume released from the site in two year cycle (not including pan evaporation or infiltration);

V_{PRE} = the total pre-developed volume of runoff for two year cycle;

Q_{PRE} = the pre-developed rate for the contributing basin; and,

Q_{ALL} = the release rate from the facility.

This analysis is run on a 2 year cycle to determine the maximum required storage volume.

Full Containment Method

The Full Containment Method is used to size evaporation facilities that store the total post-developed runoff volume (less evaporative losses) or full containment evaporative systems. The Full Containment Method is used when the project site does not have a defined discharge point or when site conditions are not conductive to infiltration of the pre-developed volume. A minimum of one (1) foot of freeboard shall be added to the calculated storage depth.

The facility shall be sized to store the volume per equations 5-17, 5-18, and 5-21:

$$V_{STORAGE}(o) = V_{100} + V_{IN}(o) - V_{OUT}(o) \qquad (5\text{-}21)$$

Where: o = first month of the two year cycle; and,

V_{100} = the volume of stormwater runoff resulting from a 100 year, 24-hour storm event.

The analysis is run on a 2 year cycle to determine the maximum required storage volume.

The facility shall be sized with a dead storage that is at least as large as equivalent to the 100-year storm, 24-hour storm event. A full containment evaporative pond is required when there is no discharge point or site conditions prohibit the use of infiltration. These conditions may include little infiltrative capacity in the soil, existing high groundwater, or potential for adverse impacts to adjacent or downstream/down-gradient properties from additional stormwater being injected into the subsurface.

5.7.2 DESIGN STEPS

The following steps outline how to utilize the spreadsheets referenced in Appendix 5F – Outflow Method and Appendix 5G – Full Containment Method. Note that all shaded cells require that a value be input by the designer; all other cells have set equations.

1. Determine the drainage basin boundaries that contribute to the evaporative pond and the land surface characteristics (i.e. grass, pavement, roof area, sidewalk, woods, etc.) for the established drainage basin(s) for the post-developed

conditions. For the Outflow Method, these parameters need to be determined also for the pre-developed conditions;

2. Determine the ARC II CN values for the permeable and impervious surfaces using Table 5-1 and weight the CN values per Section 5.3.5.
3. Determine the associated ARC III CN values per Table 5-2. Input the ARC II and ARC III CN values into the spreadsheet;
4. Input the impervious basin and total basin size, in acres, into the spreadsheet;
5. Input the mean annual precipitation, monthly precipitation, and monthly pan evaporation data, in inches, per Section 5.7.5 and Tables 5-9 and 5-10. For Full Containment Method enter the 100-year precipitation from Appendix 5A.
6. Input the proposed pond sideslopes into the spreadsheet;
7. Input an assumed pond depth, for the Outflow Method only, based upon depth to limiting layer or desired depth. Pond depth is calculated automatically for the Full Containment Method based upon the necessary surface area (projected from pond bottom area) and the required volume necessary to store/evaporate;
8. Enter an assumed pond bottom area (typically 5 to 10 percent of the total basin area or 10 to 25 percent of the contributing impervious area) and input that value, in square feet, into the pond bottom area cell of the spreadsheet;
9. The pond bottom perimeter is calculated as a square for simplicity; should the actual perimeter be known (or general shape), this can be inserted in place of the calculated field; however, each time the pond bottom is changed during the iterative process, the pond bottom perimeter needs to be adjusted; and,

   [*Note that the proper pan coefficient factors need to be used. It is estimated that the lake evaporation is approximately 77 percent of pan evaporation in the Central Oregon area*]

10. Iterate the pond bottom area (up or down) until:
    - The "Amount Spilled" is less than or equal to the "Total Annual Pre-Developed Volume" for the Outflow Method.
    - The month in which the "Total Volume Stored" in Pond (STORAGE column) shows a decrease from year one to year two of the water budget cycle for the Full Containment Method.
11. Note that for Outflow Method, these steps only satisfy the requirement to control volume to the pre-developed condition. In order to satisfy the requirement to control flow rates to the pre-developed condition, Chapter 7 must be utilized to design the detention portion of the drainage facility.

5.7.3 CURVE NUMBER ADJUSTMENT

The antecedent runoff conditions (ARC) need to be considered during the months of the year when the ground may be saturated or frozen. The following should be noted when choosing CN values:

- For impervious surfaces such as roads, sidewalks and driveways, the ARC II CN is typically 98, and the correlating ARC III CN is 99. From December through February, the assumption is that if the CN of 98 goes up to 99 during the wet months, it will not revert to 98 during frozen ground conditions; and,
- During December through February, the CN for permeable surfaces is 95 regardless of the ARC II or III CNs; this is meant to approximate runoff from permeable surfaces during snowpack buildup and snowmelt.

The CNs shall be adjusted as indicated in Table 5-8 and Table 5-2 (ARC conversion table).

TABLE 5-8
CURVE NUMBER ADJUSTMENT FOR ANTECEDENT RUNOFF CONDITION

MONTH	ANTECEDENT RUNOFF CONDITION (ARC)	CURVE NUMBER
April through October	Normal (ARC = II)	See Table 5-2
November and March	Wet (ARC = III)	See Table 5-2
December, January & February	n/a	99 impervious 95 permeable

5.7.4 AVERAGE PRECIPITATION AND EVAPORATION

Average annual precipitation data have been obtained from the Oregon Climate Service (OCS). Data for cities in Central Oregon are listed below. For outlying areas, choose the nearest city listed in the table or consult the Annual Precipitation Map published by the OCS.

Bend: Average Annual Precipitation = 11.7 inches

Burns: Average Annual Precipitation = 10.6 inches

LaPine: Average Annual Precipitation = 17.0 inches (estimated)

Madras: Average Annual Precipitation = 10.3 inches

Metolius: Average Annual Precipitation = 10.3 inches

Prineville: Average Annual Precipitation = 10.5 inches

Redmond: Average Annual Precipitation = 8.0 inches

Sisters: Average Annual Precipitation = 14.2 inches

The average monthly precipitation rates and pan evaporation rates have been obtained from the OCS and the Western Region Climate Center (WRCC). Data for cities in Central Oregon is found in Tables 5-9 and 5-10 below. For outlying areas, choose the nearest city listed in the table.

TABLE 5-9
AVERAGE MONTHLY PRECIPITATION

AREA	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT
Bend	0.62	1.46	1.78	1.73	1.13	0.92	0.70	0.90	0.75	0.62	0.60	0.49
Madras	0.76	1.39	1.21	1.26	0.93	0.89	0.83	0.95	0.58	0.53	0.48	0.46
Prineville	0.76	1.30	1.20	1.14	1.00	0.95	0.80	1.06	0.84	0.58	0.45	0.41
Redmond	0.55	0.99	0.85	1.20	0.70	0.86	0.57	0.58	0.60	0.26	0.71	0.34
Sisters	0.98	2.14	2.15	2.32	1.72	1.17	0.89	0.79	0.60	0.45	0.50	0.48

Source: Oregon Climate Service, Climate Zone Summary

TABLE 5-10
PAN EVAPORATION VALUES

AREA	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT
Bend	2.27[1]	0.81[1]	0.45[1]	0.54[1]	0.98[1]	2.01[1]	4..25	6.14	6.69	8.66	7.91	5.42
Madras	3.16	1.70	0.53[1]	0.63[1]	1.14[1]	2.35[1]	4.72	7.12	8.66	10.23	9.17	6.21

Source: Western Region Climate Center

[1]No evaporation measurements were available for the winter months. Values calculated based on ratios to Spokane Regional Stormwater Manual.

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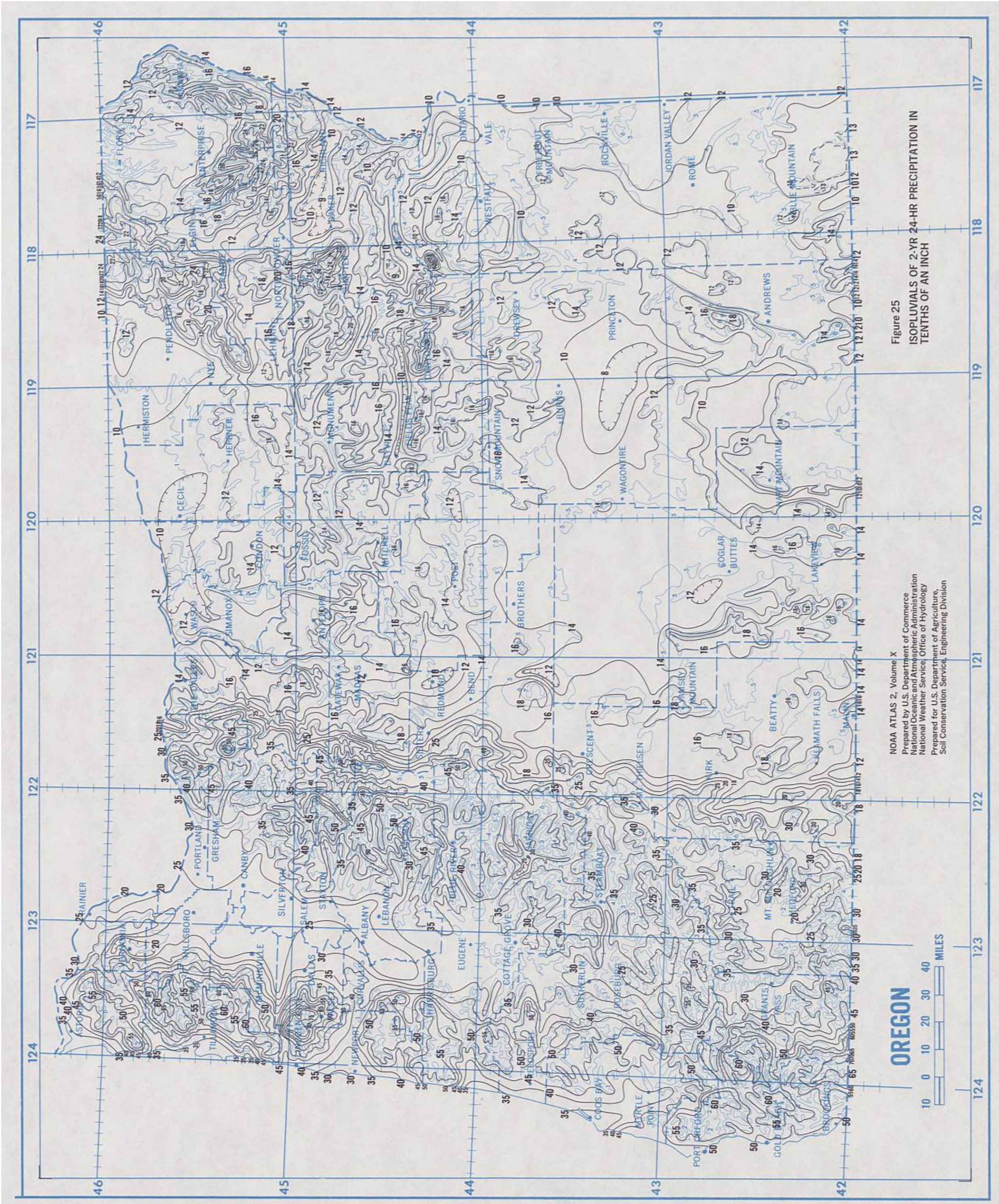
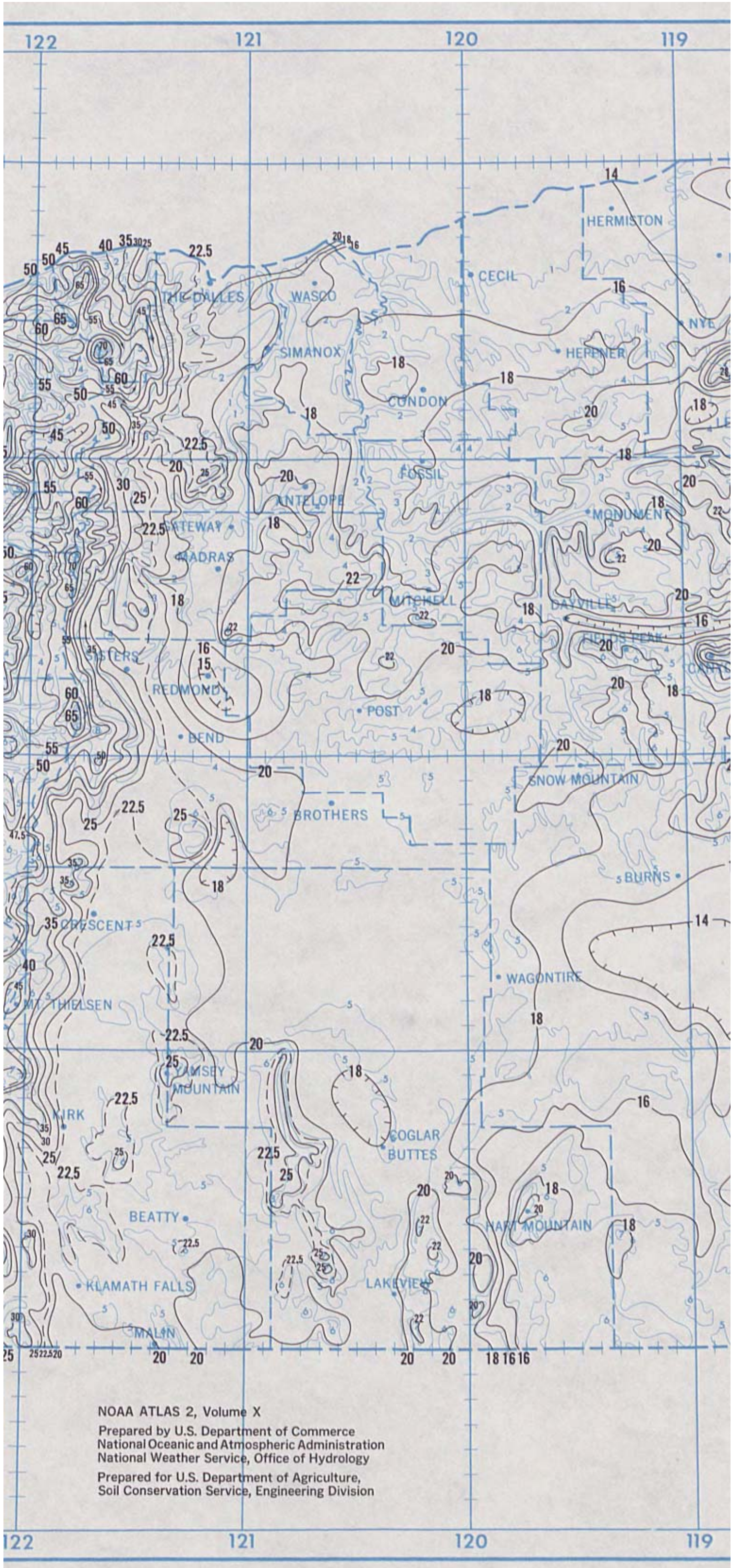
APPENDIX 5A – PRECIPITATION MAPS

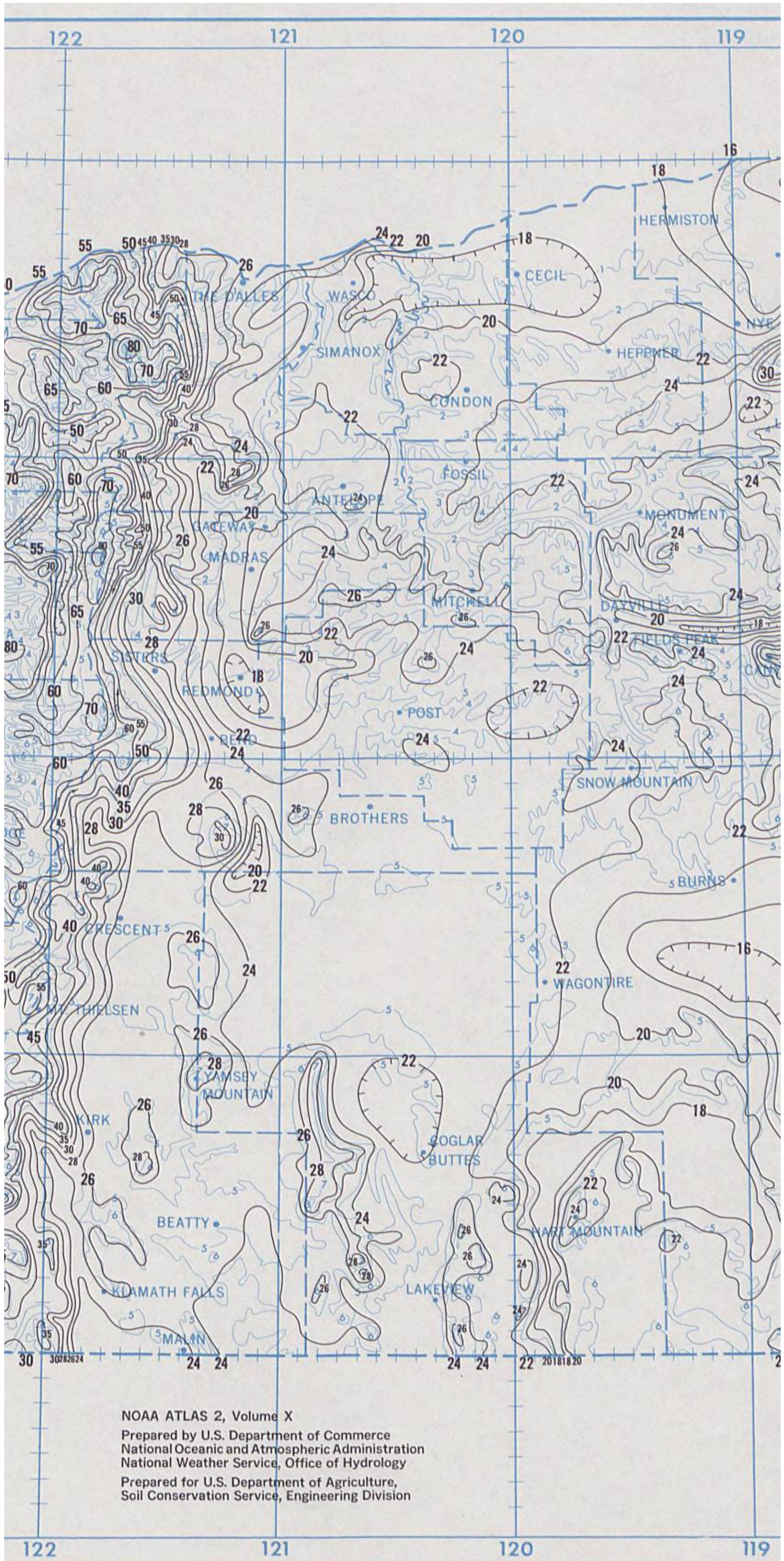
(Note: Table 5-5 includes 24-hour storm depths for selected areas, as interpreted from these isopluvial maps.)



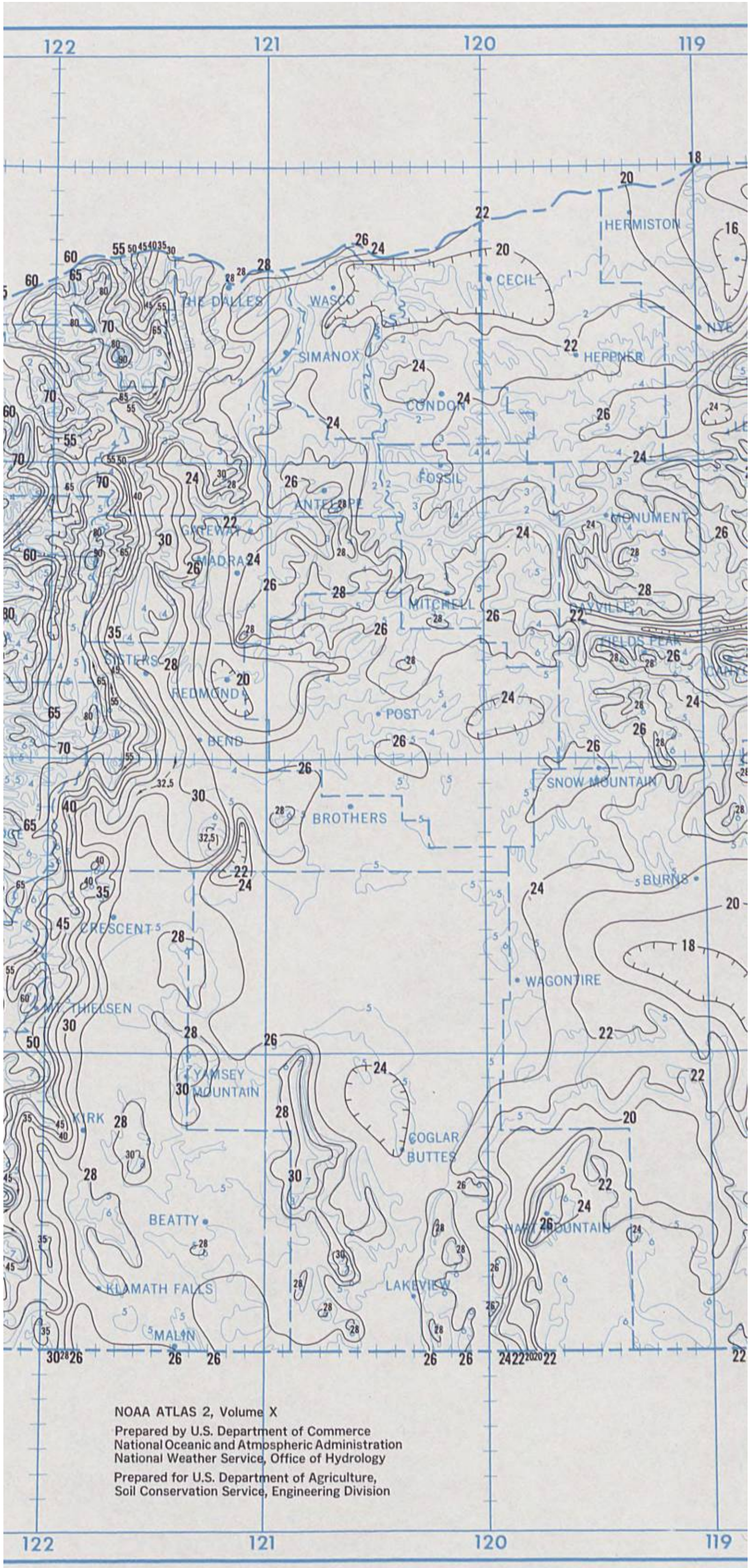
2-year, 24-hour Isopluvial Map



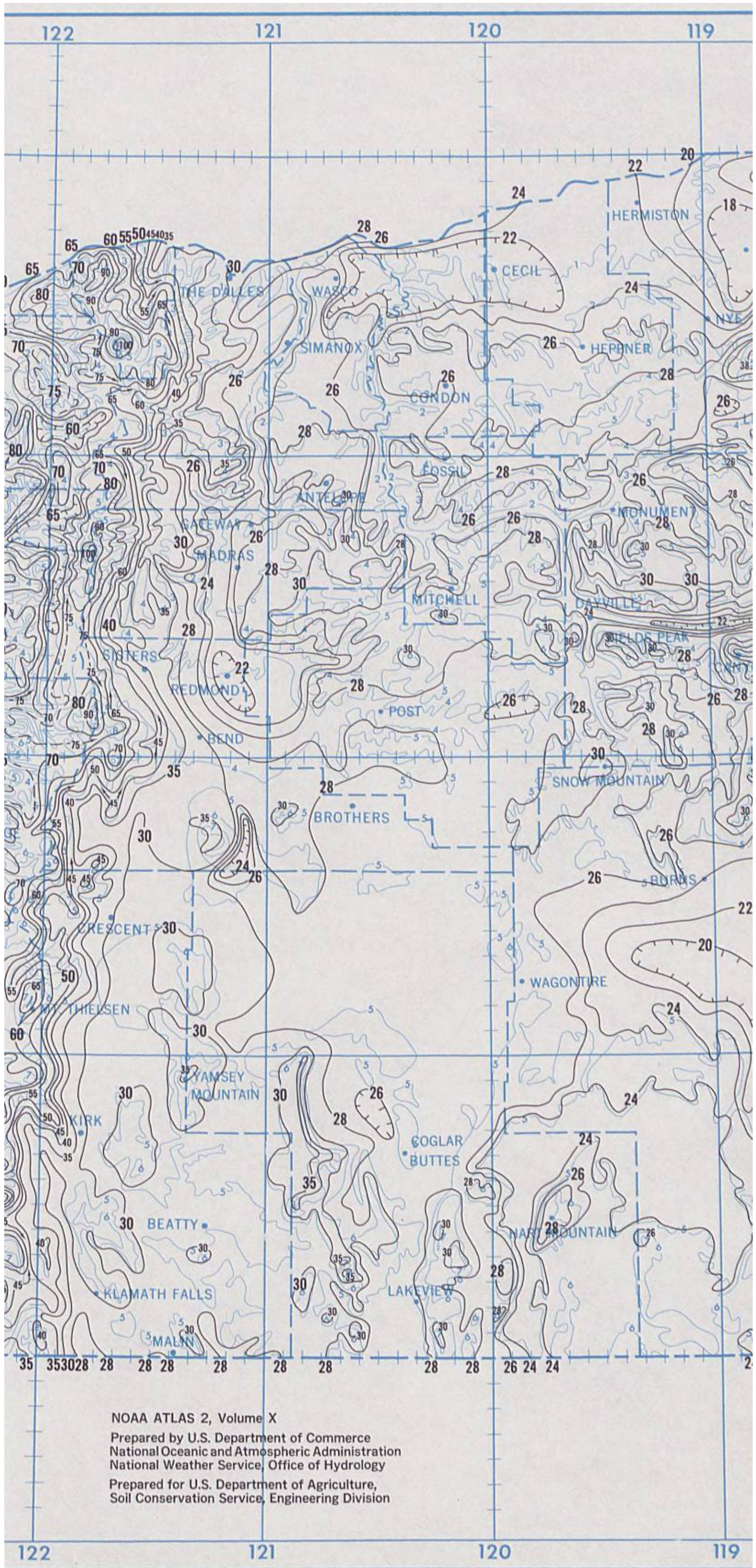
10-year, 24-hour Isopluvial Map



25-year, 24-hour Isopluvial Map



50-year, 24-hour Isopluvial Map



100-year, 24-hour Isopluvial Map

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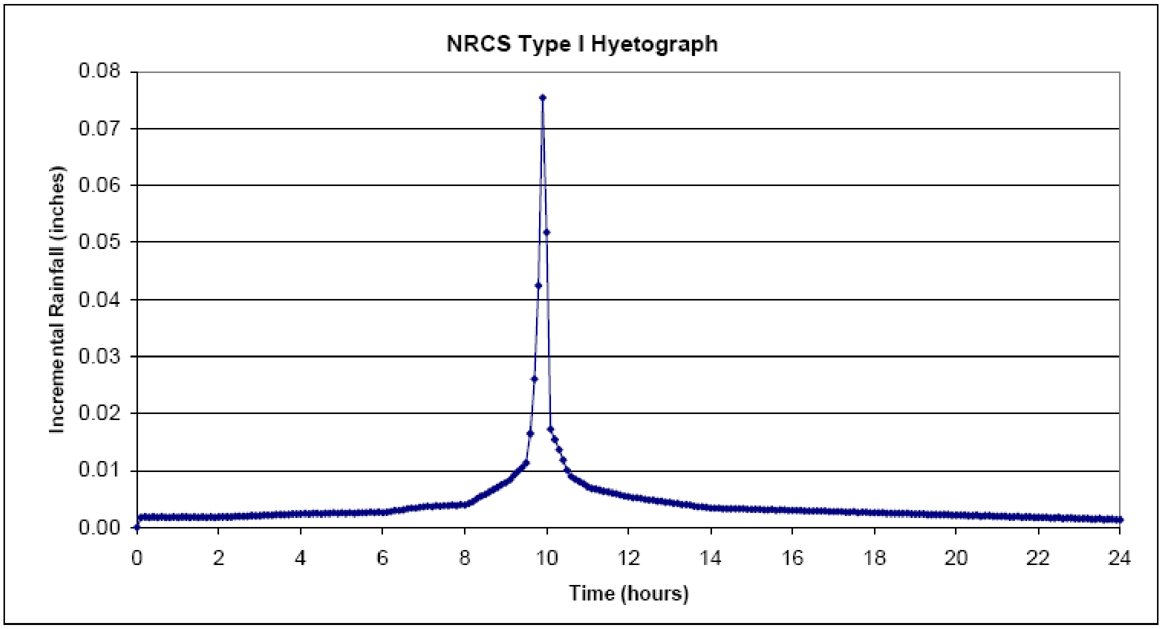
APPENDIX 5B – NRCS TYPE I HYETOGRAPH



Time (0.1 Hours)	Incremental Rainfall	Cumulative Rainfall
0.0	0.0000	0.0000
0.1	0.0017	0.0017
0.2	0.0018	0.0035
0.3	0.0017	0.0052
0.4	0.0018	0.0070
0.5	0.0017	0.0087
0.6	0.0018	0.0105
0.7	0.0017	0.0122
0.8	0.0017	0.0139
0.9	0.0018	0.0157
1.0	0.0017	0.0174
1.1	0.0018	0.0192
1.2	0.0018	0.0210
1.3	0.0017	0.0227
1.4	0.0018	0.0245
1.5	0.0017	0.0262
1.6	0.0018	0.0280
1.7	0.0017	0.0297
1.8	0.0018	0.0315
1.9	0.0017	0.0332
2.0	0.0018	0.0350
2.1	0.0018	0.0368
2.2	0.0018	0.0386
2.3	0.0018	0.0404
2.4	0.0019	0.0423
2.5	0.0019	0.0442
2.6	0.0019	0.0461
2.7	0.0019	0.0480
2.8	0.0020	0.0500
2.9	0.0020	0.0520
3.0	0.0020	0.0540

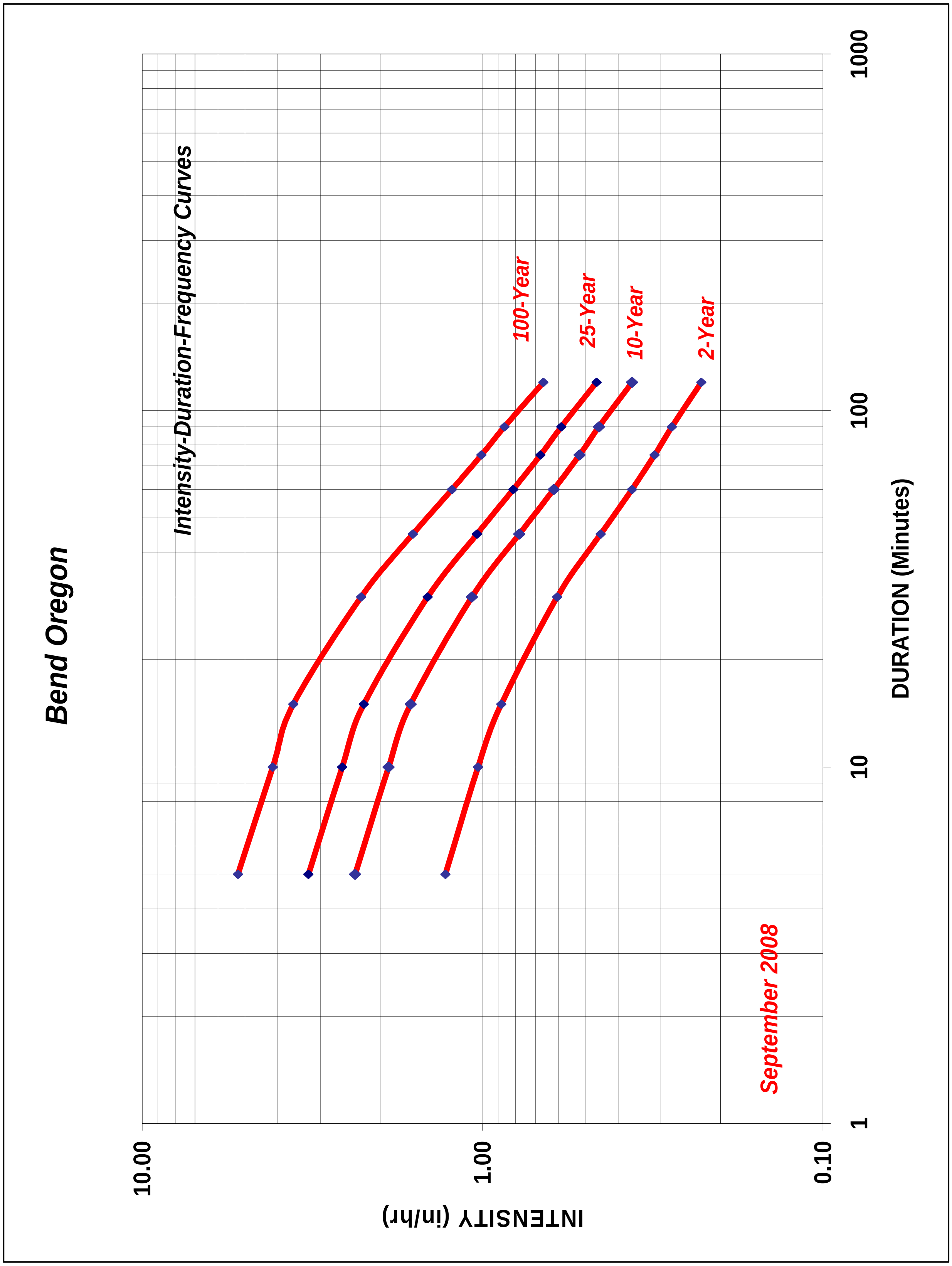
Time (0.1 Hours)	Incremental Rainfall	Cumulative Rainfall
3.1	0.0021	0.0561
3.2	0.0021	0.0582
3.3	0.0021	0.0603
3.4	0.0022	0.0625
3.5	0.0022	0.0647
3.6	0.0022	0.0669
3.7	0.0022	0.0691
3.8	0.0023	0.0714
3.9	0.0023	0.0737
4.0	0.0023	0.0760
4.1	0.0024	0.0784
4.2	0.0023	0.0807
4.3	0.0024	0.0831
4.4	0.0024	0.0855
4.5	0.0023	0.0878
4.6	0.0024	0.0902
4.7	0.0024	0.0926
4.8	0.0025	0.0951
4.9	0.0024	0.0975
5.0	0.0025	0.1000
5.1	0.0024	0.1024
5.2	0.0025	0.1049
5.3	0.0024	0.1073
5.4	0.0025	0.1098
5.5	0.0025	0.1123
5.6	0.0025	0.1148
5.7	0.0026	0.1174
5.8	0.0025	0.1199
5.9	0.0026	0.1225
6.0	0.0025	0.1250
6.1	0.0026	0.1276

Time (0.1 Hours)	Incremental Rainfall	Cumulative Rainfall
6.2	0.0027	0.1303
6.3	0.0029	0.1332
6.4	0.0029	0.1361
6.5	0.0030	0.1391
6.6	0.0032	0.1423
6.7	0.0033	0.1456
6.8	0.0033	0.1489
6.9	0.0035	0.1524
7.0	0.0036	0.1560
7.1	0.0037	0.1597
7.2	0.0036	0.1633
7.3	0.0038	0.1671
7.4	0.0037	0.1708
7.5	0.0038	0.1746
7.6	0.0038	0.1784
7.7	0.0039	0.1823
7.8	0.0038	0.1861
7.9	0.0040	0.1901
8.0	0.0039	0.1940
8.1	0.0042	0.1982
8.2	0.0045	0.2027
8.3	0.0050	0.2077
8.4	0.0055	0.2132
8.5	0.0058	0.2190
8.6	0.0062	0.2252
8.7	0.0066	0.2318
8.8	0.0070	0.2388
8.9	0.0074	0.2462
9.0	0.0078	0.2540
9.1	0.0083	0.2623
9.2	0.0091	0.2714

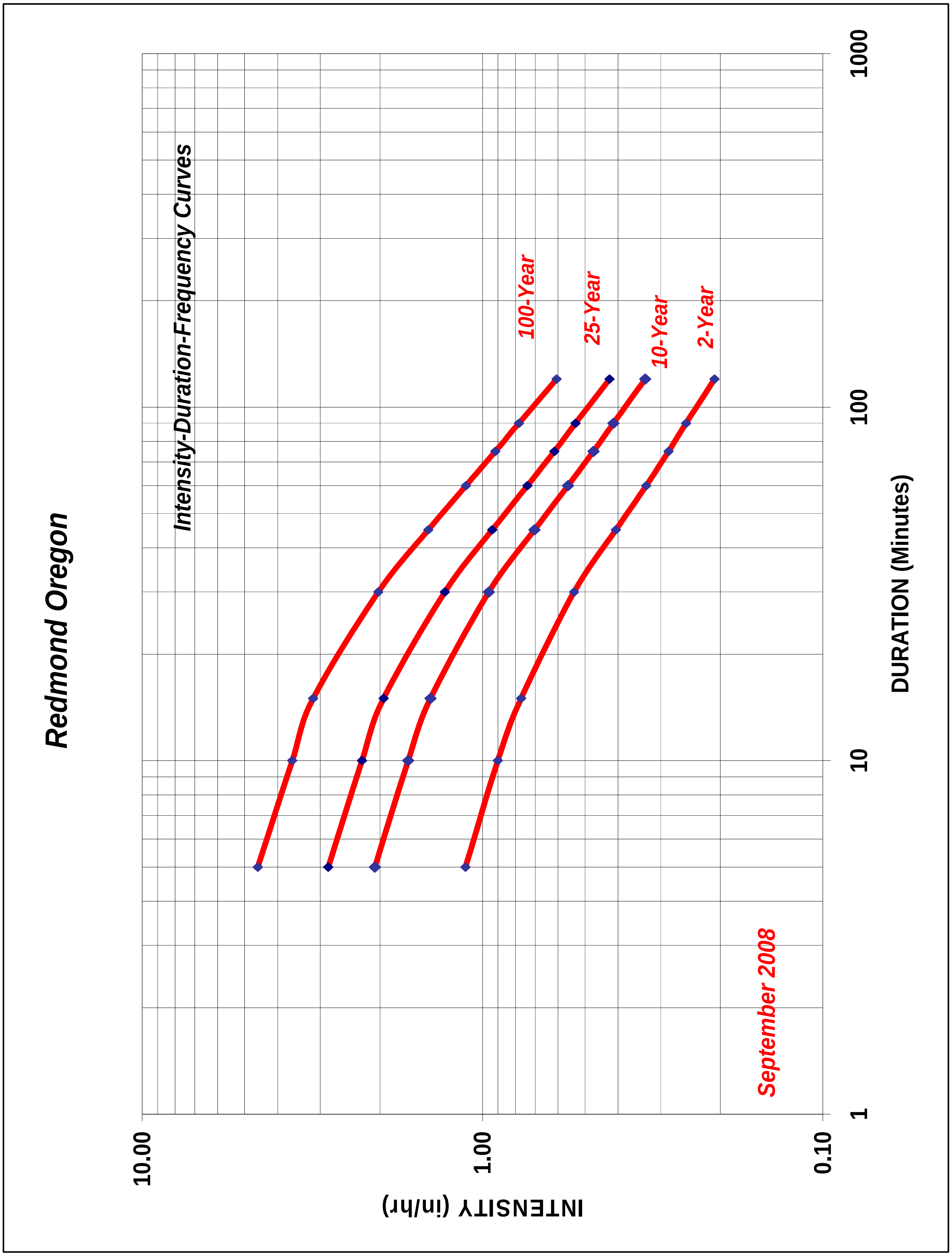
Time (0.1 Hours)	Incremental Rainfall	Cumulative Rainfall
9.3	0.0098	0.2812
9.4	0.0105	0.2917
9.5	0.0113	0.3030
9.6	0.0164	0.3194
9.7	0.0260	0.3454
9.8	0.0424	0.3878
9.9	0.0754	0.4632
10.0	0.0518	0.5150
10.1	0.0172	0.5322
10.2	0.0154	0.5476
10.3	0.0136	0.5612
10.4	0.0118	0.5730
10.5	0.0100	0.5830
10.6	0.0089	0.5919
10.7	0.0084	0.6003
10.8	0.0080	0.6083
10.9	0.0076	0.6159
11.0	0.0071	0.6230
11.1	0.0068	0.6298
11.2	0.0067	0.6365
11.3	0.0065	0.6430
11.4	0.0063	0.6493
11.5	0.0062	0.6555
11.6	0.0060	0.6615
11.7	0.0059	0.6674
11.8	0.0057	0.6731
11.9	0.0055	0.6786
12.0	0.0054	0.6840
12.1	0.0052	0.6892
12.2	0.0052	0.6944
12.3	0.0051	0.6995
12.4	0.0049	0.7044
12.5	0.0048	0.7092
12.6	0.0048	0.7140
12.7	0.0046	0.7186
12.8	0.0046	0.7232
12.9	0.0044	0.7276
13.0	0.0044	0.7320
13.1	0.0042	0.7362
13.2	0.0042	0.7404
13.3	0.0040	0.7444
13.4	0.0040	0.7484
13.5	0.0039	0.7523
13.6	0.0037	0.7560
13.7	0.0036	0.7596
13.8	0.0036	0.7632
13.9	0.0035	0.7667
14.0	0.0033	0.7700
14.1	0.0033	0.7733
14.2	0.0033	0.7766
14.3	0.0032	0.7798
14.4	0.0032	0.7830
14.5	0.0032	0.7862
14.6	0.0032	0.7894
14.7	0.0032	0.7926
14.8	0.0032	0.7958
14.9	0.0031	0.7989
15.0	0.0031	0.8020
15.1	0.0031	0.8051
15.2	0.0031	0.8082
15.3	0.0030	0.8112
15.4	0.0030	0.8142
15.5	0.0031	0.8173
15.6	0.0029	0.8202
15.7	0.0030	0.8232
15.8	0.0030	0.8262
15.9	0.0029	0.8291
16.0	0.0029	0.8320
16.1	0.0029	0.8349
16.2	0.0029	0.8378
16.3	0.0028	0.8406
16.4	0.0028	0.8434
16.5	0.0028	0.8462
16.6	0.0028	0.8490
16.7	0.0028	0.8518
16.8	0.0028	0.8546
16.9	0.0027	0.8573
17.0	0.0027	0.8600
17.1	0.0027	0.8627
17.2	0.0027	0.8654
17.3	0.0026	0.8680
17.4	0.0026	0.8706
17.5	0.0027	0.8733
17.6	0.0025	0.8758
17.7	0.0026	0.8784
17.8	0.0026	0.8810
17.9	0.0025	0.8835
18.0	0.0025	0.8860
18.1	0.0025	0.8885
18.2	0.0025	0.8910
18.3	0.0024	0.8934
18.4	0.0024	0.8958
18.5	0.0024	0.8982
18.6	0.0024	0.9006
18.7	0.0024	0.9030
18.8	0.0024	0.9054
18.9	0.0023	0.9077
19.0	0.0023	0.9100
19.1	0.0023	0.9123
19.2	0.0023	0.9146
19.3	0.0022	0.9168
19.4	0.0022	0.9190
19.5	0.0022	0.9212
19.6	0.0022	0.9234
19.7	0.0022	0.9256
19.8	0.0022	0.9278
19.9	0.0021	0.9299
20.0	0.0021	0.9320
20.1	0.0021	0.9341
20.2	0.0021	0.9362
20.3	0.0020	0.9382
20.4	0.0020	0.9402
20.5	0.0021	0.9423
20.6	0.0019	0.9442
20.7	0.0020	0.9462
20.8	0.0020	0.9482
20.9	0.0019	0.9501
21.0	0.0019	0.9520
21.1	0.0019	0.9539
21.2	0.0019	0.9558
21.3	0.0018	0.9576
21.4	0.0018	0.9594
21.5	0.0019	0.9613
21.6	0.0017	0.9630
21.7	0.0018	0.9648
21.8	0.0018	0.9666
21.9	0.0017	0.9683
22.0	0.0017	0.9700
22.1	0.0017	0.9717
22.2	0.0017	0.9734
22.3	0.0016	0.9750
22.4	0.0016	0.9766
22.5	0.0017	0.9783
22.6	0.0015	0.9798
22.7	0.0016	0.9814
22.8	0.0016	0.9830
22.9	0.0015	0.9845
23.0	0.0015	0.9860
23.1	0.0015	0.9875
23.2	0.0015	0.9890
23.3	0.0014	0.9904
23.4	0.0014	0.9918
23.5	0.0015	0.9933
23.6	0.0013	0.9946
23.7	0.0014	0.9960
23.8	0.0014	0.9974
23.9	0.0013	0.9987
24.0	0.0013	1.0000

APPENDIX 5C – INTENSITY-DURATION-RECURRENCE INTERVAL CURVES

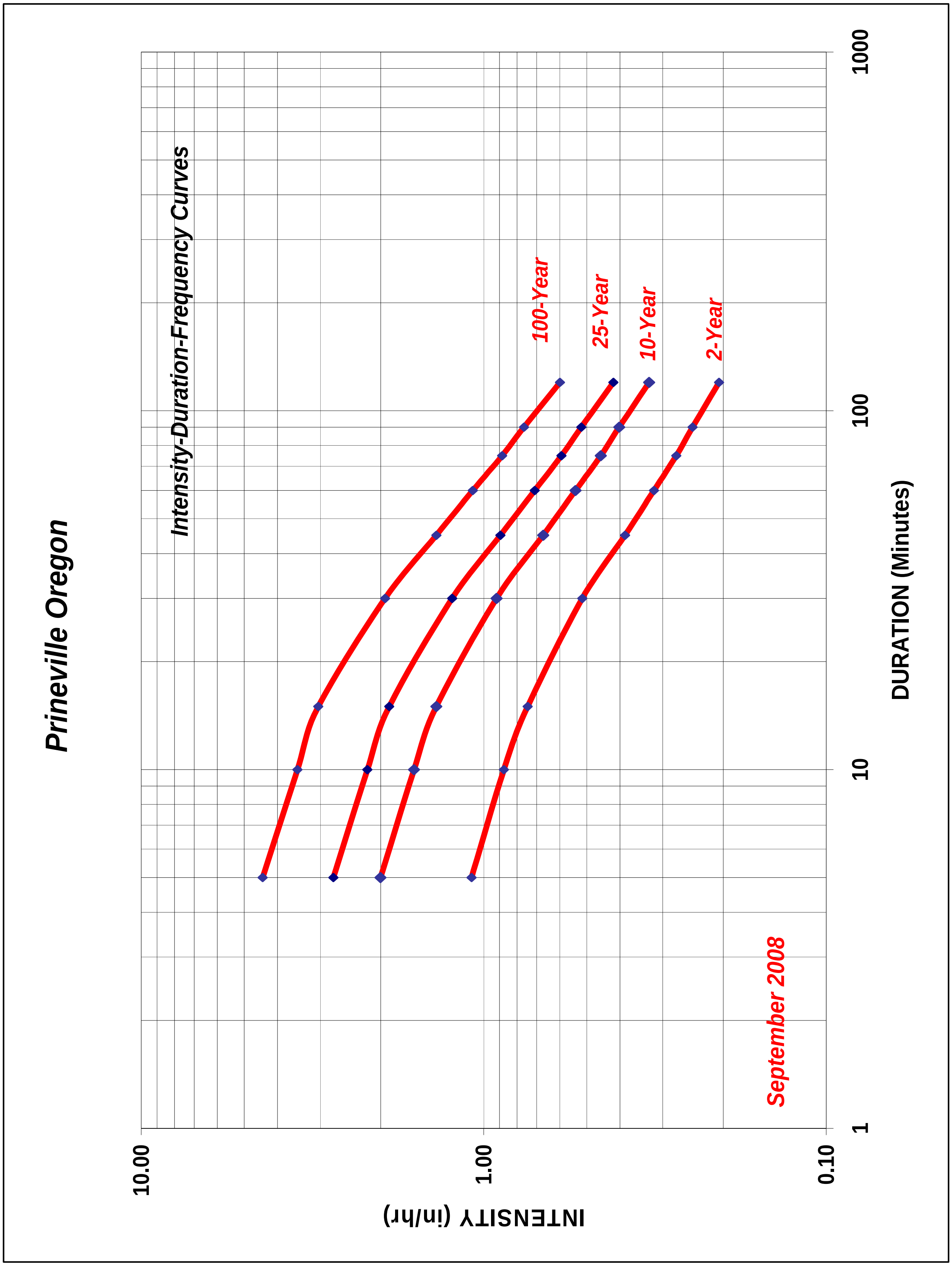
For the Cities of Bend, Redmond, and Prineville use the city-specific IDF curves developed by MGS Engineering Consultants on the following three pages. For all other areas of Central Oregon, use the IDR curves from the ODOT Hydraulics Manual, Chapter 7, Appendix A. Utilize the enclosed map to determine the zone in which a project is located. If the project lies within two zones or is on or near a dividing line, the designer must use engineering judgment to select the appropriate IDR curve.



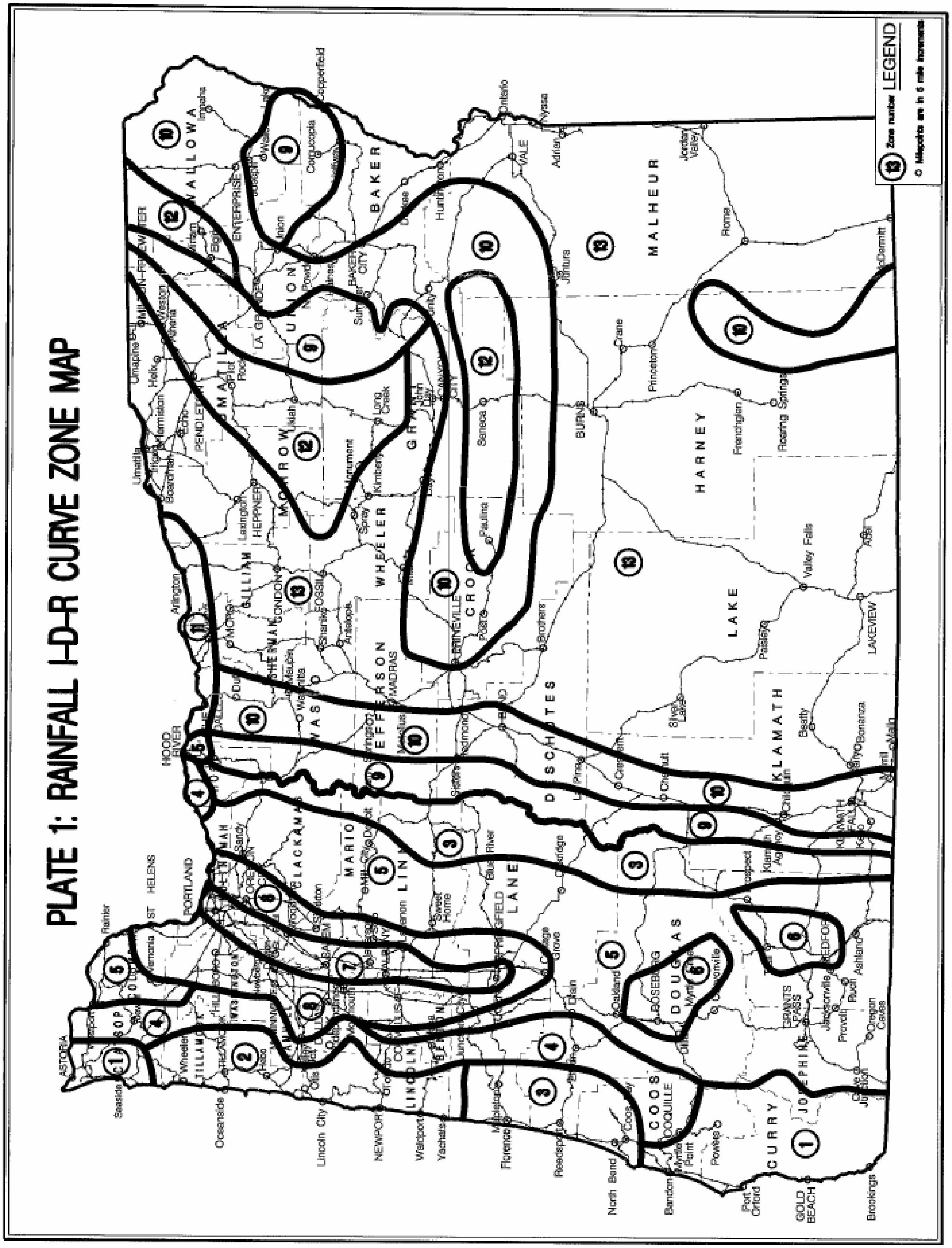
Source: MGS Engineering Consultants



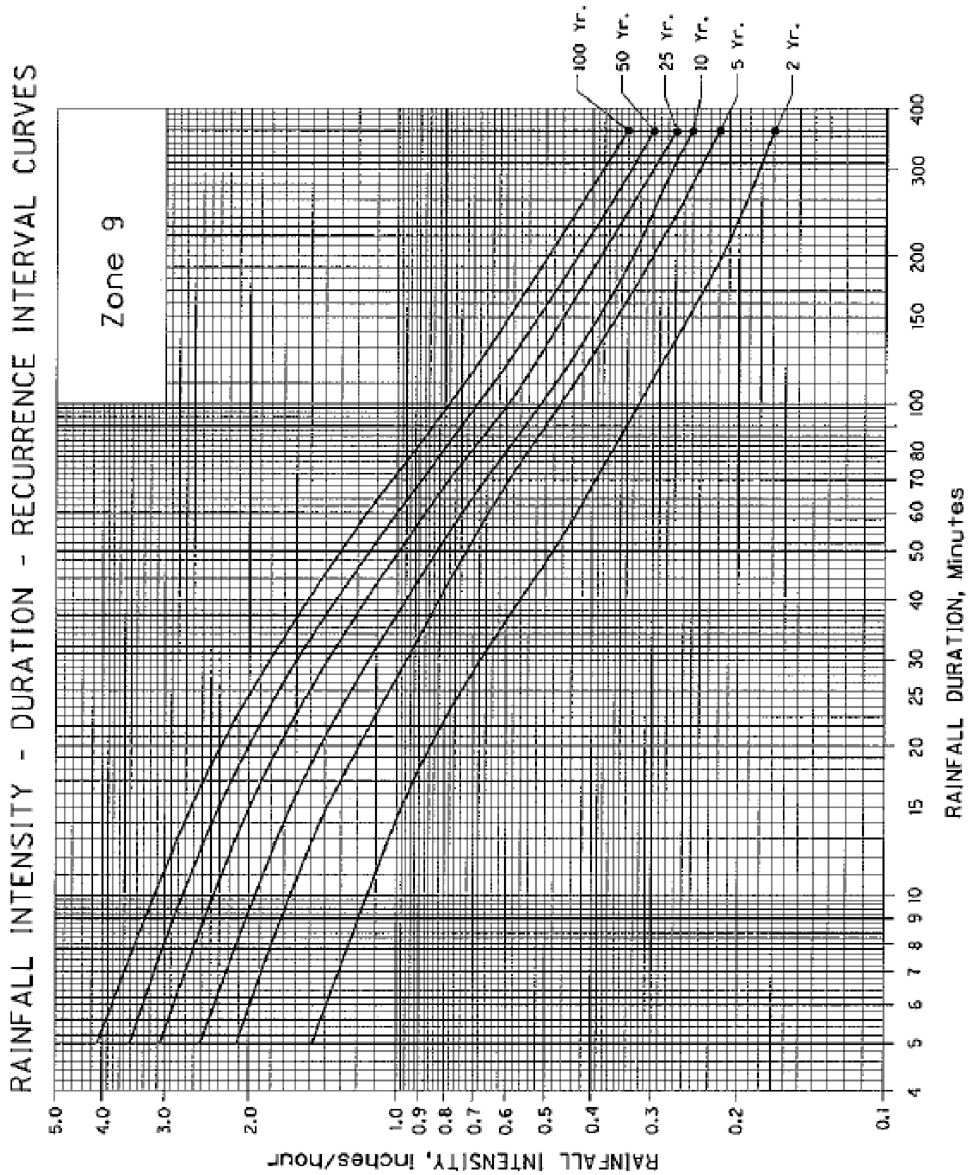
Source: MGS Engineering Consultants



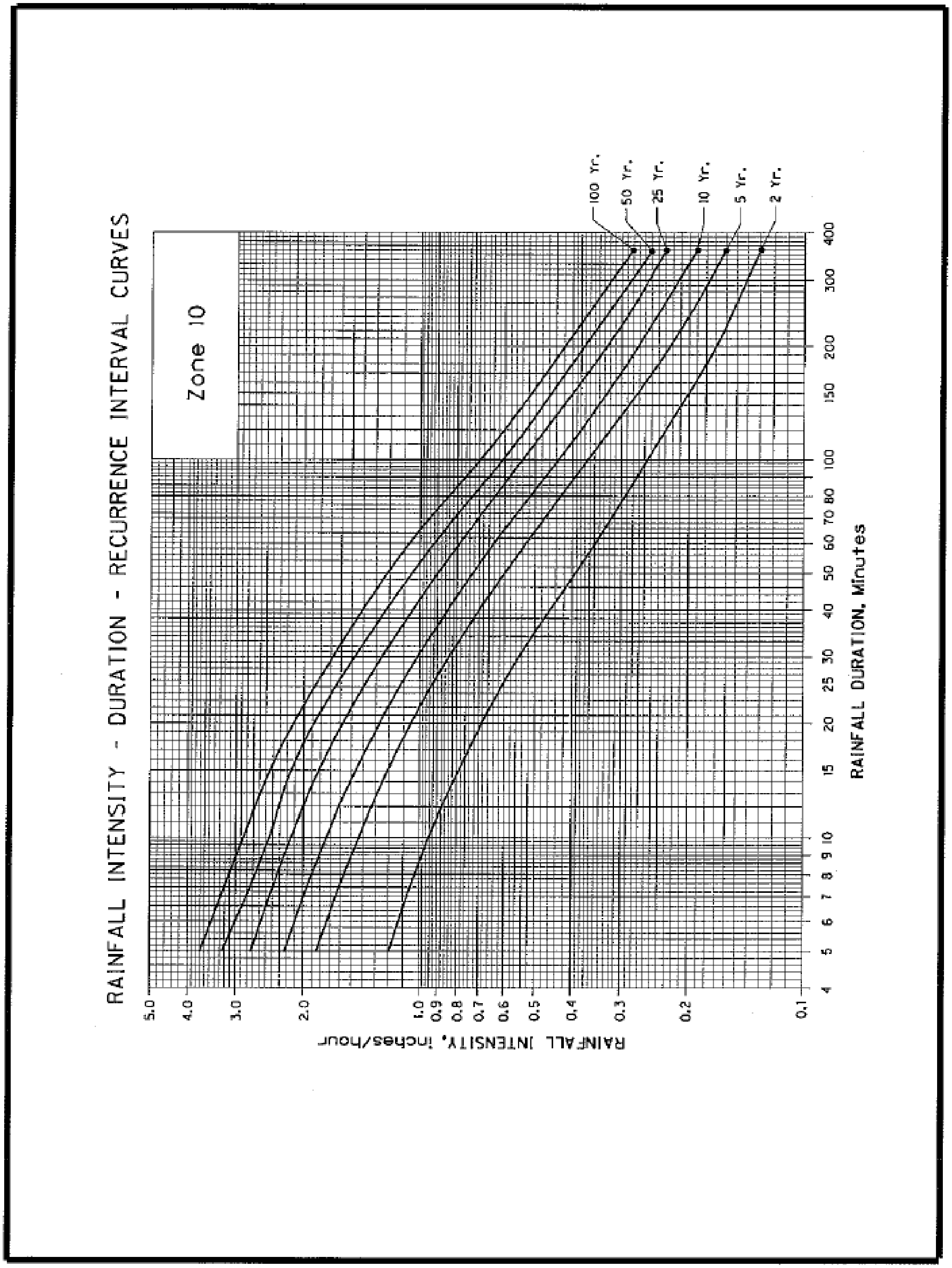
Source: MGS Engineering Consultants



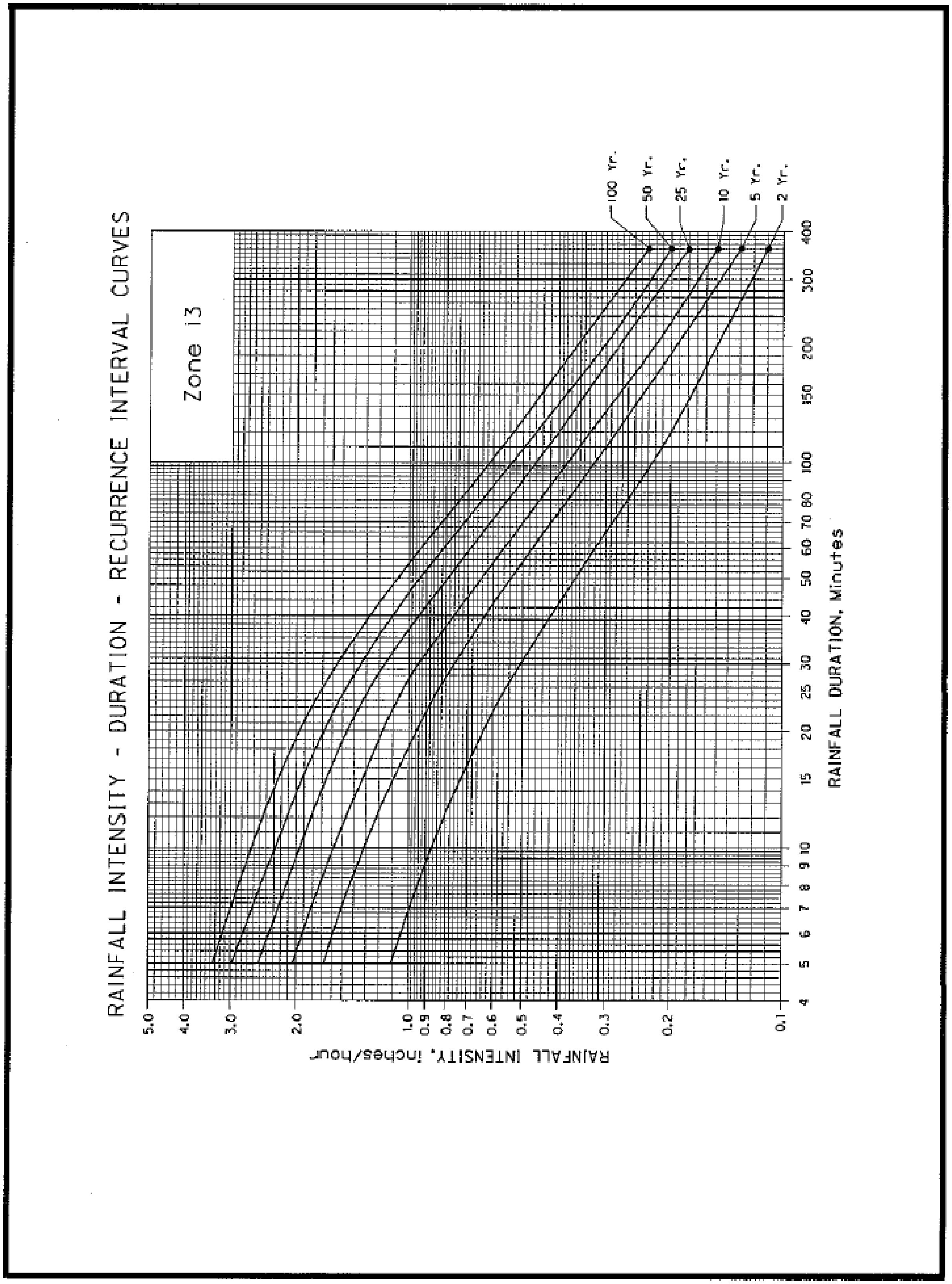
Source: ODOT Hydraulics Manual



Source: ODOT Hydraulics Manual



Source: ODOT Hydraulics Manual



Source: ODOT Hydraulics Manual

APPENDIX 5D – EXAMPLE CALCULATION – WEIGHTING CNs

GIVEN

- The existing site is approximately 10-acres, consisting of Type B soils. Existing surface vegetative conditions include short grass and weeds.
- Post developed site conditions consist of:
  - 38 – 10,000 square foot lots;
  - 1,500 sq ft homes with 500 sq ft driveways;
  - 1.3 acres of road impervious areas; and,
  - No sidewalks are proposed.

CALCULATIONS

1. Find the CNs for the lawn areas and the roofs, driveways, and streets.

   From Table 5-1:

   CN = 61 permeable areas – lawns (good condition) – Type B soils

   CN = 98 impervious areas – streets, driveways, and roofs

2. Calculate the CN for the impervious basin. The connected impervious areas are the driveways and the streets. No weighting is required because the CNs for the impervious areas are the same.

   Total driveway area: (38 driveways)*(500 sq ft/driveway) = 19,000 sq ft = 0.44 ac

   Total connected impervious area: 1.3 ac (roads) + 0.44 ac (driveways) = 1.74 ac

   CN FOR THE IMPERVIOUS BASIN = 98

3. Calculate the CN for the permeable basin. Although the roof area is impervious, it can be weighted with the lawn area because the two are considered homogeneous; (i.e. the roofs drain onto landscaped areas and are not hydraulically connected to the roads or driveways.)

   Total roof area: (38 houses)*(1500 sq ft/roof) = 57,000 sq ft = 1.31 ac

   Total lawn area: Total site – total impervious area = 10 ac – 1.74 ac – 1.31 ac = 6.95 ac

   Total permeable basin: 1.31 ac + 6.95 ac = 8.26 ac

   Weighted CN for permeable basin: $\frac{6.95(61)+1.31(98)}{8.26} = 66.87 \approx 67$

   CN FOR THE PERMEABLE BASIN = 67

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APPENDIX 5E – EXAMPLE CALCULATION – BOWSTRING METHOD

GIVEN

- The existing site is approximately 5-acres, consisting of sandy soils. Existing surface vegetative conditions include short grass and weeds. The project lies within I-D-R Curve Zone 10.
- Post developed site conditions consist of:
  - 20 – 10,000 square foot lots;
  - 1,500 sq ft homes with 500 sq ft driveways;
  - 0.50 acres of road impervious area; and,
  - Topographic relief ranges 2 to 5 %.
- When the site is developed, the longest time of concentration will consist of:
  - 100 feet of overland flow @ 1 percent;
  - 300 feet of gutter flow @ 1 percent; and,
  - 300 feet of pipe flow @ 2 percent.
- The proponent proposes a pond with drywells for stormwater runoff disposal.
- Field tests were conducted at the proposed location of the drywells. The test pit method estimated that the drywell outflow rate is 1 cfs. (accounting for the safety factor).

CALCULATIONS

4. Determine the weighted Runoff Coefficient (C) for the post-developed condition:

   From Table 5-5:

   C = 0.22 permeable areas – lawns (sandy soils, rolling terrain)

   C = 0.90 impervious areas – streets, driveways, and sidewalks

   Total roof area: 20*(1,500 sq. ft) = 30,000 sq. ft. = 0.69 ac

   Total driveway area: 20*(500 sq. ft) = 10,000 sq. ft. = 0.23 ac

   Total impervious area: 0.69 (roofs) + 0.23 (driveways) + 0.5 (roads) = 1.42 ac

   Total permeable area: 5 – 1.42 ac = 3.58 ac

   Weighted C: $\frac{3.58(0.15) + 1.42(0.90)}{5} = 0.41$

5. Determine the time of concentration (T_C).

   Length (L): Measured from site plan

   Ground Cover Coefficient (K): Table 5-6

   Flow Segment Travel Time (T_t): $T_t = \frac{L}{K\sqrt{S}}$ Equation (5-11)

FLOW SEGMENT	LENGTH (ft)	SLOPE (ft/ft)	K (ft/min)	T_t (min)
Overland flow	200	0.02	420	3.37
Gutter flow	300	0.02	1500	1.41
Pipe flow	300	0.01	3000	1.00
Total Time of Concentration, *Tc*				5.78 (MIN)

6. Determine the intensity using the Zone 10 I-D-R Curve.

   For a 25-year storm (design event for drywells) and a *Tc* of 5.78 minutes:

   I = 2.60 in/hr

7. Determine the peak flow rate t = T_c using equation 5-10.

   $$Q_P = CIA = 0.41 * 2.60\text{in/hr} * 5\text{acres} = 5.33\text{cfs}$$

8. Compute the volume for t = T_c using equation 5-14.

   $$V(\text{t}) = 1.34 Q_P \text{t} = 1.34 * 5.33\text{cfs} * 5.78\text{min} * 60\text{sec/min} = 2477\text{cf}$$

9. Determine the allowable release rate (Q_{OUT}).

   Q_{OUT} = 1.0cfs

   The outflow rate of a drywell as determined based on the field test and safety factor

10. Compute the outflow volume (V_{OUT}) for t = T_c using equation 5-16.

   $$V_{OUT} = Q_{OUT}\text{t} = 1.0\text{cfs} * 5.78\text{min} * 60\text{sec/min} = 346.8\text{cf}$$

11. Compute intensities (I), peak flow rates (Q_P), and inflow and outflow volumes (V, V_{OUT}) for various times (i.e. t = 5, 10, 25…minutes) using equations 5-10, 5-14, 5-15, 5-16, and 5-17. This is simply done in a spreadsheet program (see attached).

12. The required pond storage is obtained as the maximum difference between inflow and outflow volumes. In this example, the required storage is 3143 cubic feet.

BOWSTRING METHOD

DETENTION BASIN DESIGN WITH DRYWELL OUTFLOW
25-YEAR DESIGN STORM

PROJECT:	PROJECT NAME
PROJECT NO:	PROJECT NUMBER
BASIN:	**BASIN NAME**
DESIGNER:	DESIGNER NAME
DATE:	DATE

Area, A	5.00	ac
Time of Conc., T_c	5.78	min
Weighted C	0.41	
Number of Drywells	1	
Outflow (cfs), Q_{out}	1.00	cfs

#1 Time, t (min.)	#2 Time, t (sec.) (#1*60)	#3 Intensity, I (in./hr.)	#4 Q_p (cfs) (C*#3*A)	#5 V in (cu. ft.)	#6 V out (cu. ft.) (Q_{out}*#2)	#7 Storage (cu. ft.) (#5-#6)
5.78	346.80	2.60	5.33	2477	346.8	2130
5	300	2.73	5.60	2250	300	1950
10	600	2.15	4.41	3164	600	2564
15	900	1.80	3.69	3756	900	2856
20	1200	1.60	3.28	4323	1200	3123
25	1500	1.40	2.87	4643	1500	3143
30	1800	1.25	2.56	4915	1800	3115
35	2100	1.15	2.36	5229	2100	3129
40	2400	1.05	2.15	5420	2400	3020
45	2700	0.96	1.97	5546	2700	2846
50	3000	0.90	1.85	5753	3000	2753
55	3300	0.84	1.72	5886	3300	2586
60	3600	0.78	1.60	5945	3600	2345
65	3900	0.74	1.52	6095	3900	2195
70	4200	0.70	1.44	6196	4200	1996
75	4500	0.67	1.37	6343	4500	1843
80	4800	0.64	1.31	6452	4800	1652
85	5100	0.61	1.25	6525	5100	1425
90	5400	0.58	1.19	6561	5400	1161
95	5700	0.56	1.15	6679	5700	979
100	6000	0.54	1.11	6773	6000	773

DRYWELL REQUIREMENTS - 25 YEAR DESIGN STORM

Maximum storage required by Bowstring Method:	3143	cu. ft.	
Storage Provided:	**3300**	**cu. ft.**	OK!

Notes:
Shaded cells should be entered by the designer. All other cells are calculated.
I values shown are for 25-year design storm in Zone 10. For other zones or other design events, update the I values

Figure 5E-1 Bowstring Method Spreadsheet Example

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APPENDIX 5F – EXAMPLE CALCULATION – EVAPORATION (OUTFLOW METHOD)

GIVEN

- The project is located near the City of Madras.
- Pre-Developed Site Conditions
  - Pinyon-Juniper combination, Type B soil, fair condition CN = 58
- Post Developed Site Conditions
  - Impervious basin CN = 98, 1.75 ac
  - Pervious basin CN = 67 (includes roofs and lawns)
  - Total basin area = 8.00 ac (includes ponds and open space)

CALCULATIONS

13. Determine the associated ARC III CN values per Table 5-2. Input the ARC II and ARC III CN values into the spreadsheet.

ARC II CN	*ARC III CN*
58	76
67	83
98	99

14. Input the impervious basin and total basin size, in acres, into the spreadsheet;

    Total impervious area (streets, driveways, sidewalks) = 1.75 ac

    Total permeable area (lawns and roofs) = 6.25 ac

    Total basin area (includes pond areas and open areas) = 8.0 ac

15. Input the pond bottom area in square feet, assume 10 percent of the total developed area;

    Pond Bottom Area: assume 20,000 square feet

    The pond bottom perimeter is calculated as a square for simplicity. Should the actual perimeter be known (or general shape), this can be inserted in place of the calculated field (Note that each time the pond bottom is changed during the iterative process, the pond bottom perimeter needs to be adjusted.)

16. Input the mean annual precipitation, in inches.

    Mean annual precipitation = 10.3 inches (Section 5.3.4.5)

17. Input the monthly precipitation and monthly evaporation (in inches) for Madras from Tables 5-9 and 5-10.

18. Input the proposed pond sideslopes and pond depth into the spreadsheet.

    Use: 3:1 for side slopes; and,

    1.5 feet for maximum surface water elevation

19. Adjust the pond bottom area up and down until the *Amount Spilled* is less than or equal to the *Total Annual Pre-Developed Volume* for the Outflow method. In this example, the Total Annual Pre-Developed Volume is 66,200 cubic feet. The assumed pond bottom area (20,000 square feet) results in a larger pond than is required. The bottom area has been reduced until the *Amount Spilled* is closer to the *Total Annual Pre-Developed Volume*.

    RESULTS OF THE EVAPORATIVE CELL

    The pond bottom area required is 13,000 sq. ft

    The depth of the evaporative cell is 1.5*1.2 (Factor of Safety) = 1.8 feet

    This is the size of the first cell of a separated system, or the lower cell for a combined system.

20. Begin sizing the detention cell facility by determining the peak flow rates for the pre-developed basin and post-developed basins using the design steps outlined in Section 5.3.2 for the 2 and 25-year, 24-hour storm.

    If sizing a separated system (two separate cells), the detention cell is sized per the steps outlined in Section 5.3.2 and placed downstream of the evaporative cell. The overflow from the evaporative cell is placed at or above the required evaporative depth of 1.8 feet.

    If sizing a combined system (one cell), the upper cell is placed on top of the lower cell. Thus, the detention cell "bottom" and outflow structure has to be placed at or above the maximum surface water elevation of the evaporative system (including the factor of safety). The detention cell is designed per the criteria specified in Chapter 7, including freeboard requirements.

Project :	Name of Project
Job No.:	number
Date:	DATE
Designer:	designer
Pond Bottom Area:	13,000 sq. ft.
Pond Bottom Perimeter:	456 ft
Pond Side Slopes:	3 : 1
Assumed Pond Depth:	1.5 ft
Assumed Pond Volume:	21,039 c.f.

OUTFLOW METHOD
Evaporative / Detention
Combination Pond

	ARC II Normal	ARC III Nov., Mar.	- - Dec.-Feb.
Pre-Dev. (Impervious) CN:	98	99	99
Pre-Dev. (Permeable) CN:	58	76	95
Post-Dev. (Impervious) CN:	98	99	99
Post-Dev. (Permeable) CN:	67	83	95
Pre-Dev.(Impervious) S:	0.20	0.10	0.10
Pre-Dev.(Permeable) S:	7.24	3.16	0.53
Post-Dev.(Impervious) S:	0.20	0.10	0.10
Post-Dev.(Permeable) S:	4.93	2.05	0.53

	Pre-dev	Post-dev	
Impervious Basin Size:	0.10	1.75	acres
Impervious Pond Size:	0.00	0.30	acres
Pervious Basin Size:	7.90	5.95	acres
Total Site:	8.00	8.00	acres

Project Location: Near Madras
Mean Annual Precipitation 10.3
Enter monthly precip and evap data into shaded cells below

Month	Precip. "P" (in)	Runoff Depth (in) $(P-0.2S)^2/(P+0.8S)$ pre-dev Imp	pre-dev Perm	post-dev Imp	post-dev Perm	Runoff Volume (cu ft) Depth * Area pre-dev Imp	pre-dev Perm	pre-dev TOTAL	Runoff Volume (cft) Depth * Area post-dev Imp	post-dev Perm	post-dev TOTAL	NET Increase in Volume (cft) post-pre	Pan Evap. (in.)	Evap Volume Out (cft) 23% Adj.	Total Volume to Handle (cft)	Current Volume in Pond (cft)	Pond Depth (ft)	Spill Volume to Detention < PRE (cft)
																	0.0	
Oct.	0.76	0.56	0.00	0.56	0.00	203	0	203	4,166	0	4,166	3,962	3.16	2,636	1,530	1,530	0.1	0
Nov.	1.39	1.28	0.15	1.28	0.32	463	4,212	4,675	9,486	6,856	16,342	11,667	1.70	1,434	16,437	16,437	1.2	0
Dec.	1.21	1.10	0.75	1.10	0.75	398	21,458	21,856	8,155	16,165	24,320	2,464	0.53	497	40,261	21,039	1.5	19,222
Jan.	1.25	1.14	0.78	1.14	0.78	413	22,488	22,901	8,450	16,942	25,392	2,492	0.63	608	45,823	21,039	1.5	24,784
Feb.	0.93	0.82	0.50	0.82	0.50	297	14,438	14,735	6,089	10,877	16,966	2,231	1.14	1,101	36,904	21,039	1.5	15,865
Mar.	0.89	0.78	0.02	0.78	0.09	283	561	843	5,795	1,972	7,766	6,923	2.35	2,270	26,536	21,039	1.5	5,496
Apr.	0.83	0.63	0.00	0.63	0.00	228	0	228	4,663	0	4,663	4,435	4.72	4,559	21,143	21,039	1.5	104
May	0.95	0.74	0.00	0.74	0.00	270	0	270	5,521	0	5,521	5,252	7.12	6,877	19,684	19,684	1.4	0
June	0.58	0.39	0.00	0.39	0.00	142	0	142	2,908	0	2,908	2,766	8.66	8,291	14,301	14,301	1.0	0
July	0.53	0.35	0.00	0.35	0.00	125	0	125	2,567	0	2,567	2,441	10.23	9,449	7,419	7,419	0.5	0
Aug.	0.48	0.30	0.00	0.30	0.00	109	0	109	2,230	0	2,230	2,121	9.17	8,075	1,573	1,573	0.1	0
Sept.	0.46	0.28	0.00	0.28	0.00	102	0	102	2,096	0	2,096	1,994	6.21	5,241	0	0	0.0	0
Oct.	0.76	0.56	0.00	0.56	0.00	203	0	203	4,166	0	4,166	3,962	3.16	2,636	1,530	1,530	0.1	0
Nov.	1.39	1.28	0.15	1.28	0.32	463	4,212	4,675	9,486	6,856	16,342	11,667	1.70	1,434	16,437	16,437	1.2	0
Dec.	1.21	1.10	0.75	1.10	0.75	398	21,458	21,856	8,155	16,165	24,320	2,464	0.53	497	40,261	21,039	1.5	19,222
Jan.	1.25	1.14	0.78	1.14	0.78	413	22,488	22,901	8,450	16,942	25,392	2,492	0.63	608	45,823	21,039	1.5	24,784
Feb.	0.93	0.82	0.50	0.82	0.50	297	14,438	14,735	6,089	10,877	16,966	2,231	1.14	1,101	36,904	21,039	1.5	15,865
Mar.	0.89	0.78	0.02	0.78	0.09	283	561	843	5,795	1,972	7,766	6,923	2.35	2,270	26,536	21,039	1.5	5,496
Apr.	0.83	0.63	0.00	0.63	0.00	228	0	228	4,663	0	4,663	4,435	4.72	4,559	21,143	21,039	1.5	104
May	0.95	0.74	0.00	0.74	0.00	270	0	270	5,521	0	5,521	5,252	7.12	6,877	19,684	19,684	1.4	0
June	0.58	0.39	0.00	0.39	0.00	142	0	142	2,908	0	2,908	2,766	8.66	8,291	14,301	14,301	1.0	0
July	0.53	0.35	0.00	0.35	0.00	125	0	125	2,567	0	2,567	2,441	10.23	9,449	7,419	7,419	0.5	0
Aug.	0.48	0.30	0.00	0.30	0.00	109	0	109	2,230	0	2,230	2,121	9.17	8,075	1,573	1,573	0.1	0
Sept.	0.46	0.28	0.00	0.28	0.00	102	0	102	2,096	0	2,096	1,994	6.21	5,241	0	0	0.0	0
Oct.	0.76	0.56	0.00	0.56	0.00	203	0	203	4,166	0	4,166	3,962	3.16	2,636	1,530	1,530	0.1	0

Total Annual Predeveloped Volume 66,189 total annual post 114,937 Amount Spilled 65,470 Okay

10.26 Check Mean Annual Precip

Figure 5F-1 Evaporative Pond Spreadsheet Example (Outflow Method)

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APPENDIX 5G – EXAMPLE CALCULATION – EVAPORATION (FULL CONTAINMENT METHOD)

GIVEN

- The project is located near Madras
- Pre-Developed Site Conditions
  - Pinyon-Juniper combination, Type B soil, fair condition CN = 58
- Post Developed Site Conditions
  - Impervious basin CN = 98, 1.75 ac
  - Pervious basin CN = 67 (includes roofs and lawns), 6.25 ac
  - Pond Area CN = 98
  - Total basin area = 8.00 acres (includes ponds and open space)

CALCULATIONS

21. Determine the associated ARC III CN values per Table 5-2. Input the ARC II and ARC III CN values into the spreadsheet.

ARC II CN	*ARC III CN*
58	76
67	83
98	99

22. Input the impervious basin and total basin size, in acres, into the spreadsheet;

    Total impervious area (streets, driveways, sidewalks) = 1.75 ac

    Total permeable area (lawns & roofs) = 6.25 ac

    Total basin area (includes pond areas & open areas) = 8.00 ac

23. Input the pond bottom area in square feet, assume 10 percent of the total area developed.

    Pond bottom area: Assume 35,000 square feet

    The pond bottom perimeter is calculated as a square for simplicity; should the actual perimeter be known (or general shape), this can be inserted in place of the calculated field. (Note that each time the pond bottom is changed during the iterative process, the pond bottom perimeter needs to be adjusted.)

24. Input the mean annual precipitation and the 100-year precipitation, in inches.

    100-year, 24-hour precipitation = 2.60 inches (Appendix 5A)

    Mean annual precipitation = 10.26 inches (Section 5.3.4.5)

25. Input the monthly precipitation and monthly evaporation (in inches) for Madras from Tables 5-9 and 5-10.
26. Input the proposed pond sideslopes into the spreadsheet.

    Use: 3:1 for side slopes

27. Adjust the pond bottom area up and down until the month with the largest *Total Volume Stored in Pond* in year two of the water budget cycle is lower that the largest month in year one.

RESULTS OF THE EVAPORATIVE CELL

For this example, the month with the largest volume requirements is March.

The pond bottom area required is 43,000 sq. ft

The depth of the evaporative cell is 3.25 feet + 1 foot freeboard = 4.25 feet

FULL CONTAINMENT METHOD
Evaporative Pond to Accommodate All Post-Developed Volume
(no infiltration allowed)

Project :	Name of Project		
Plat / BSP / Proj No:	number	Engineer:	designer
Date:	2/8/2007		
Pond Bottom Area:	34,000	sq. ft.	
Pond Bottom Perimeter:	738	ft	
Pond Side Slopes:	3	: 1	
Impervious Basin Size (Constant):	1.75	acres	
Impervious Basin Size (Pond Area):	0.78	acres	
Permeable Basin Size:	6.25	acres	
Off-Site Upstream Basin:	1.00	acres	
Total Contributing Area:	9.00	acres	
Project Location:	Near Madras		
Mean Annual Precipitation	10.3		
Enter monthly precip and evap data into shaded cells below			
100-Year, 24 Hour, Prec.:	2.60	in	

	AMC II Norm (Apr-Oct)	AMC III Nov and Mar	--- Dec-Feb
Impervious CN:	98	99	99
Permeable CN:	67	83	95
Off-Site CN:	58	76	95
Impervious S:	0.20	0.10	0.10
Permeable S:	4.93	2.05	0.53
Off-Site S:	7.24	3.16	0.53

					INFLOW					OUTFLOW		STORAGE	
Month	Precipitation (in)	Impervious Runoff from Precipitation (in)	Permeable Runoff from Precipitation (in)	Off-Site Runoff from Precipitation (in)	Impervious Total Runoff Volume (cu ft)	Permeable Total Runoff Volume (cu ft)	Off-Site Total Runoff Volume (cu ft)	NET Total Volume (Imp+Perm+OS) (cu ft)	Pan Evap. (in)	Total Evap. Volume Out (cft) 77% Adj.	Total Volume Stored In Pond (cu ft)	Approximate Pond Depth (ft)	Pond Capacity (%)
											31,393	0.9	23
Oct.	0.76	0.56	0.00	0.00	5,146	0	0	5,146	3.16	7,308	29,230	0.9	21
Nov.	1.39	1.28	0.32	0.15	11,719	7,200	533	19,452	1.70	3,916	44,765	1.3	32
Dec.	1.21	1.10	0.75	0.75	10,074	16,976	2,716	29,766	0.53	1,255	73,276	2.2	53
Jan.	1.25	1.14	0.78	0.78	10,439	17,791	2,847	31,077	0.63	1,567	102,786	3.0	74
Feb.	0.93	0.82	0.50	0.50	7,522	11,422	1,828	20,772	1.14	2,976	120,582	3.5	87
Mar.	**0.89**	**0.78**	**0.09**	**0.02**	**7,158**	**2,070**	**71**	**9,300**	**2.35**	**6,310**	**123,571**	**3.6**	**89**
Apr.	0.83	0.63	0.00	0.00	5,760	0	0	5,760	4.72	12,733	116,598	3.4	84
May	0.95	0.74	0.00	0.00	6,821	0	0	6,821	7.12	19,000	104,418	3.1	76
June	0.58	0.39	0.00	0.00	3,593	0	0	3,593	8.66	22,669	85,342	2.5	62
July	0.53	0.35	0.00	0.00	3,171	0	0	3,171	10.23	25,964	62,548	1.8	45
Aug.	0.48	0.30	0.00	0.00	2,754	0	0	2,754	9.17	22,401	42,902	1.3	31
Sept.	0.46	0.28	0.00	0.00	2,590	0	0	2,590	6.21	14,661	30,831	0.9	22
Oct.	0.76	0.56	0.00	0.00	5,146	0	0	5,146	3.16	7,301	28,676	0.8	21
Nov.	1.39	1.28	0.32	0.15	11,719	7,200	533	19,452	1.70	3,912	44,215	1.3	32
Dec.	1.21	1.10	0.75	0.75	10,074	16,976	2,716	29,766	0.53	1,254	72,727	2.1	53
Jan.	1.25	1.14	0.78	0.78	10,439	17,791	2,847	31,077	0.63	1,566	102,239	3.0	74
Feb.	0.93	0.82	0.50	0.50	7,522	11,422	1,828	20,772	1.14	2,974	120,037	3.5	87
Mar.	**0.89**	**0.78**	**0.09**	**0.02**	**7,158**	**2,070**	**71**	**9,300**	**2.35**	**6,305**	**123,031**	**3.6**	**89**
Apr.	0.83	0.63	0.00	0.00	5,760	0	0	5,760	4.72	12,722	116,069	3.4	84
May	0.95	0.74	0.00	0.00	6,821	0	0	6,821	7.12	18,984	103,905	3.1	75
June	0.58	0.39	0.00	0.00	3,593	0	0	3,593	8.66	22,651	84,847	2.5	61
July	0.53	0.35	0.00	0.00	3,171	0	0	3,171	10.23	25,943	62,075	1.8	45
Aug.	0.48	0.30	0.00	0.00	2,754	0	0	2,754	9.17	22,383	42,446	1.2	31
Sept.	0.46	0.28	0.00	0.00	2,590	0	0	2,590	6.21	14,649	30,387	0.9	22

Resulting Pond Volume:	123,571 cu ft
Resulting Pond Depth:	3.63 ft
Including 1' freeboard:	4.63 ft
Total Pond Capacity without freeboard:	138,185 cu ft

Figure 5G-1 Evaporative Pond Spreadsheet Example (Full Containment Method)

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