CHAPTER 5 – HYDROLOGIC ANALYSIS AND DESIGN

Chapter Organization

5.1 INTRODUCTION

This chapter provides the tools for estimating peak flow rates and volumes for sizing conveyance, treatment, and flow control facilities. Standard flow control facilities are detention and retention facilities, drywells, and evaporation ponds. Flow control facilities are necessary to mitigate potential adverse impacts on down-gradient properties due to the increase in stormwater runoff caused by land development.

Unless specifically accepted by the local jurisdiction, the peak rate and volume of stormwater runoff from any proposed land development to any natural or constructed point of discharge downstream shall not exceed the pre-development peak rate or volume of runoff. A down-gradient analysis demonstrating that there will be no expected adverse impacts on downgradient properties will be required (refer to Section 3.4.5 for down-gradient analysis criteria). Exceptions with regard to rate and volume control can be made for regional facilities planned by the local jurisdiction.

Stormwater runoff from a developed site shall leave the site in the same manner and location as in the pre-developed condition. Flow may not be concentrated onto down-gradient 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 geotechnical site characterization report, a down-gradient analysis, and any additional information deemed necessary by the local jurisdiction. Refer to Section 2.1.6 for variance procedures.

All engineering work for hydrologic analysis and design shall be performed by, or under the direction of, a professional engineer currently licensed in the State of Washington.

5.2 HYDROLOGIC ANALYSIS METHODS

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

- The Curve Number (CN) Method can be used to estimate peak flow rates and volumes; the most commonly used Curve Number Method in the Spokane Region is the Natural Resources Conservation Service Urban Hydrograph Method (NRCS Method); an acceptable but seldom-used alternative method is the Santa Barbara Urban Hydrograph Method;
- 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; and,
- The Water Budget Method can be used to size evaporation facilities.

5.3 CURVE NUMBER METHOD

5.3.1 INTRODUCTION

Single-event hydrograph methods based on the curve number equation can be used in combination with a routing technique to size detention facilities. These methods are used to develop hydrographs to estimate the peak flow rate and volumes for a specific design storm.

5.3.2 CURVE NUMBER METHOD THEORY

This section presents a general description of this methodology, for additional information refer to the *National Engineering Handbook* (1985). The amount of runoff from a site calculated using the Curve Number Method depends on the precipitation at the site and the natural storage capacity of the soil. The curve number equation and the NRCS rainfall excess equation are shown in Equations 5-1 and 5-2:

$$S = \frac{1000}{CN} - 10 \qquad (5\text{-}1)$$

Where: S = maximum storage volume of water on and within the soil (inches);

CN = curve number (dimensionless);

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad (5\text{-}2)$$

Q = 0 for P< 0.2S

Where: S = maximum storage volume of water on and within the soil (inches);

Q = runoff (inches);

P = precipitation (inches); and,

0.2S = initial abstraction; the fractional amount estimated as intercepted, evaporated and/or absorbed by the soil (inches).

5.3.3 LIMITATIONS

Another method approved by the local jurisdiction shall be used when:

- The calculated depth of runoff is less than 0.5 inch;
- The value (P-0.2S) is a negative number; or
- The weighted CN is less than 40.

For additional limitations, see the Soil Conservation Service's Technical Release No. 55 (Publication 210-VI-TR-55, Second Ed., June 1986).

Local jurisdictions reserve the authority to limit discharge to public facilities. Regardless of the methodology used, if a given method yields a runoff volume or rate that is inconsistent with the physical site characteristics, the engineer will be required to provide additional supporting documentation.

5.3.4 DESIGN STEPS

The following steps are based on the assumption that the engineer uses a software package that utilizes the Curve Number Method for hydrologic computations and the level pool method for reservoir routing (refer to Section 5.4). If hand calculations are proposed, the engineer can consult currently available technical publications for additional information.

1. Determine the pre-developed and post-developed drainage basin boundaries and identify pervious and impervious areas as described in the Basin Areas subsection below;
2. Determine the hydrologic soil group classifications, as described in the Hydrologic Soil Group Classification subsection below, and correlate to the drainage basin boundaries;
3. Identify the appropriate land uses within the delineated basins and select CN values for each of the pre-developed and post-developed basins, as described in the Curve Numbers subsection below;
4. Determine the time of concentration for both pre-developed and post-developed conditions, as described in the Time of Concentration subsection below;
5. 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;
6. Create basin links for combining and/or routing basin hydrographs to the proposed facility. Links may have routing elements, such as pipes or channels;
7. Determine the precipitation for the required design storms specified in Chapter 2. Precipitation maps for the design storms are provided in the Precipitation Maps subsection below;

8. Set the routing and hydrograph time increments in the computer software program to six-minutes or less;
9. Determine the required NRCS Storm Distribution, as described in the Design Storm Distribution subsection below, and select it in the software program;
10. Input the geometry of the anticipated outflow structures (i.e. weirs, orifices, etc.);
11. Input the elevation and storage volume relationship;
12. Compute peak rates and volumes for the pre-developed basins and determine the allowable release rates per the design criteria specified in Chapter 2;
13. Compute the hydrographs of the post-developed basins, combine and route the hydrographs to the drainage facility and route the inflow hydrograph through the facility;
14. Verify that the release from the site does not exceed the allowable release rate (or volume, when required), as determined in step 12. Modify the pond geometry and outflow structure input data if the results indicate that the allowable thresholds are exceeded.

Basin Areas

The basin modeling must reflect the actual runoff characteristics as closely as possible and be consistent with the assumptions within the model used. The impervious and pervious areas must be estimated from best available plans, topography, or aerial photography, and verified by field reconnaissance.

Hydrologic Soil Group Classification

The NRCS has classified over 4,000 soil types into the following four soils groups:

- 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 (greater than 0.30 inches/hour) 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 (0.15 to 0.30 inches/hour) 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 (0.05 to 0.15 inches/hour) 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 (0-0.05 inches/hour) and high runoff potential.

Refer to the current Spokane County NRCS maps for the hydrologic soil group classification for soils common to the Spokane Region.

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.

Table 5-1 lists CN values for agricultural, suburban and urban land use classifications. These values are for Antecedent Runoff Condition (ARC) II, which is defined below. See NRCS Publication 210-VI-TR-55 for additional CN values.

Weighting Curve Numbers: Basins often include areas with differing curve numbers based on their soils, land use and cover. Overall CNs for these basins are determined by weighting the CN for each area based on the size of the area. For an example of weighting CNs refer to Appendix 5A.

In most cases, if areas in 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. As an exception to this rule, separate hydrographs are not required for unconnected impervious areas. Unconnected impervious areas are defined as those that discharge over a pervious area in the form of 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 pervious areas.

Connected impervious areas shall not be weighted with pervious areas. Connected impervious areas can include driveways and sidewalks that are adjacent to (i.e. hydraulically connected to) a pollution generating impervious roadway and discharge directly into a drainage system without first traversing an area of pervious ground.

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 lawns before getting to the streets or drainage system. The driveway and adjacent sidewalk areas must be combined with the street areas, if they are hydraulically connected and would be considered a separate basin. The impervious and pervious hydrographs shall then be linked with or without a routing element, such as a pipe or a channel.

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).

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

Cover type and hydrologic condition	Group A Soils	Group B Soils	Group C Soils	Group D Soils
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
Porous pavers and permeable interlocking concrete (assumed as 85% impervious and 15% lawn):				
Fair lawn condition (weighted average CNs)	91	94	96	97
Gravel	76	85	89	91
Dirt	72	82	87	89
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
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
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 (<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 - grass combination (orchard or tree farm)[3]:				
Poor	57	73	82	86
Fair	43	65	76	82
Good	32	58	72	79
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
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
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.

For a more detailed and complete description of land use curve numbers refer to Chapter 2 of the Soil Conservation Service's Technical Release No. 55 (Publication 210-VI-TR-55, Second Ed., June 1986).

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, Table 5-2 shall be used to adjust the CN values.

TABLE 5-2
CURVE NUMBER BASED ON 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 initial abstraction (I_a) = 0.2 S. Initial abstraction represents all water losses before runoff begins (water retained in surface depressions, water intercepted by vegetation, evaporation, infiltration, etc.)

Source: U.S. Soil Conservation Service National Engineering Handbook Table 10.1.

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 Curve Number Method, 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 the Soil Conservation Service's Technical Release No. 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:

$$T_c = T_{t1} + T_{t2} + \ldots T_{tn} \tag{5-3}$$

Where: T_c = time of concentration (minutes);

n = number of flow segments; and,

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

$$T_t = \frac{L}{60V} \tag{5-4}$$

where: L = flow length (feet);

V = average velocity (feet/second); 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 facilities including storm drain inlets and road culverts, or reduction of land slope through grading. T_c shall not be less than 5 minutes.

<u>Sheet Flow:</u> Sheet flow is flow over plane surfaces and shall not be used over distances exceeding 100 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 (minutes);

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

L = flow length (feet);

P_2 = 2-year, 24-hour rainfall (inches), (use Figure 5-1);

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

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, depressions, 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 100 feet. Table 5-3 gives Manning's n_s values for sheet flow for various surface conditions.

Shallow Concentrated Flow: After 100 feet, sheet flow is assumed to have developed into shallow concentrated flow. The travel time (T_t) for the shallow concentrated flow segment can be computed using Equation 5-4. The average velocity for shallow concentrated flow is calculated using the following equation:

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

Where: V = velocity (feet/second);

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

S_o = slope of flow path (feet/foot).

Table 5-3 provides "k" for various land covers and channel characteristics with assumptions made for hydraulic radius using the following rearrangement of Manning's equation:

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

Where: R = hydraulic radius; and,

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

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

Sheet Flow[1]	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 feet/foot)	0.06
Cultivated soil with crop residue (slope > 0.20 feet/foot)	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
Corrugated metal 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

[1] These values were determined specifically for sheet flow conditions and are not appropriate for conventional open channel flow calculations.

Source: WSDOT Highway Runoff Manual (2004) Table 4B-5; Engman (1983); and the Florida Department of Transportation Drainage Manual (1986).

TABLE 5-4
SUGGESTED VALUES OF 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 < 100	
a. Streams on plain	
1. Clean, straight, full stage, no rifts or deep pools	0.030
2. Same as No. 1, but more stones and weeds	0.035
3. Clean, winding, some pools and shoals	0.040
4. Same as No. 3, but some weeds	0.045
5. Same as No. 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 Floodplains	
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 No. 2, 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)

Source: WSDOT Hyway Runoff Manual (2004) Table 4B-6; Engman (1983) and the Florida Department of Transportation Drainage Manual (1986).

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.

Precipitation Maps

The following isopluvial maps for the Spokane Region were generated with computer software by Spokane County from rain data collected from National Oceanic and Atmospheric Administration (NOAA) Atlas 2, Volume IX, 1973. The numbers shown on the isopluvial curves represent inches of precipitation.

Design Storm Distributions

These methods require the selection of, or the input of, a rainfall distribution and the precipitation associated with a design storm. The following storm distributions shall be used:

- The NRCS Type II 24-hour storm for sizing water quality treatment facilities; or,
- The NRCS Type IA 24-hour storm for sizing flow control facilities.

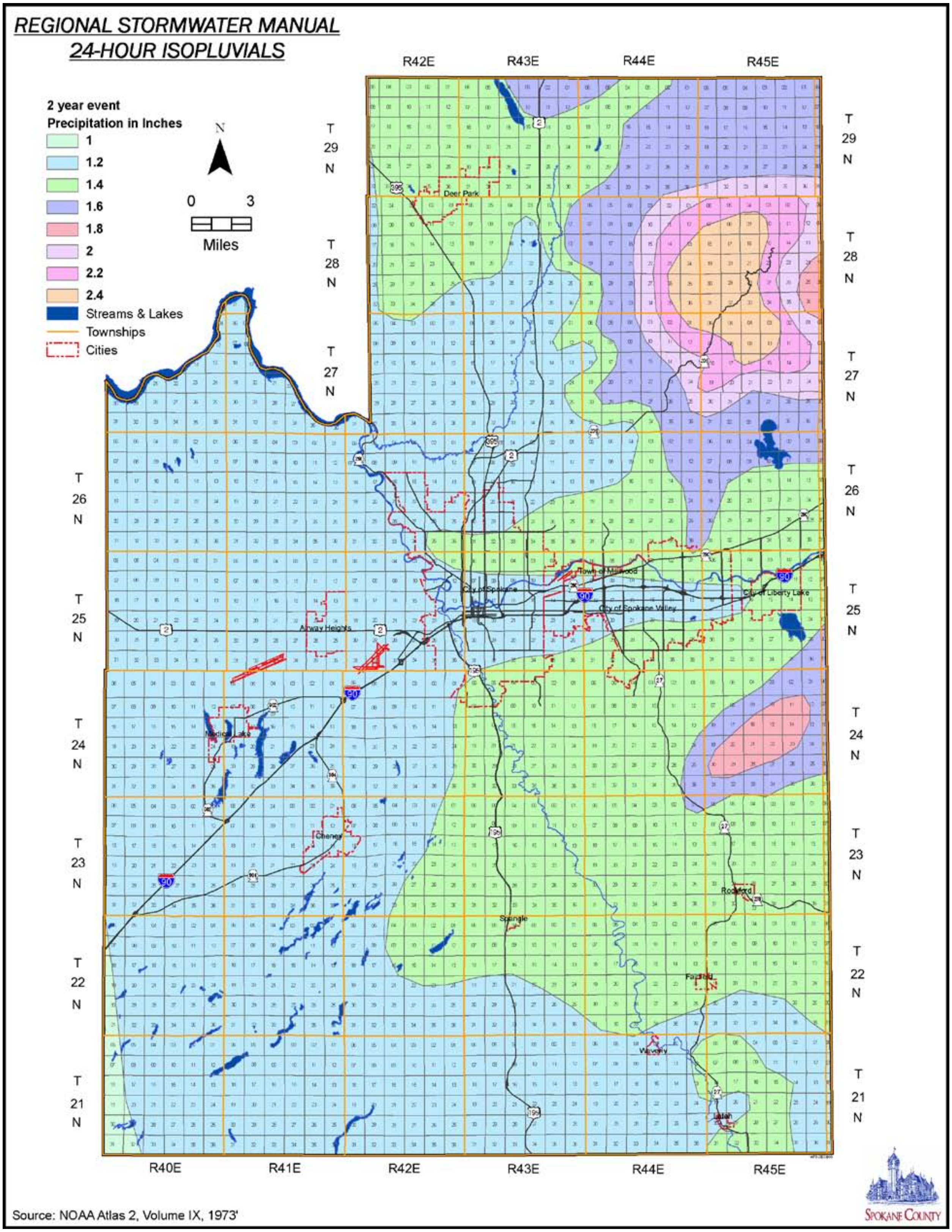

Figure 5-1 – 2-Year, 24-Hour Isopluvial Map

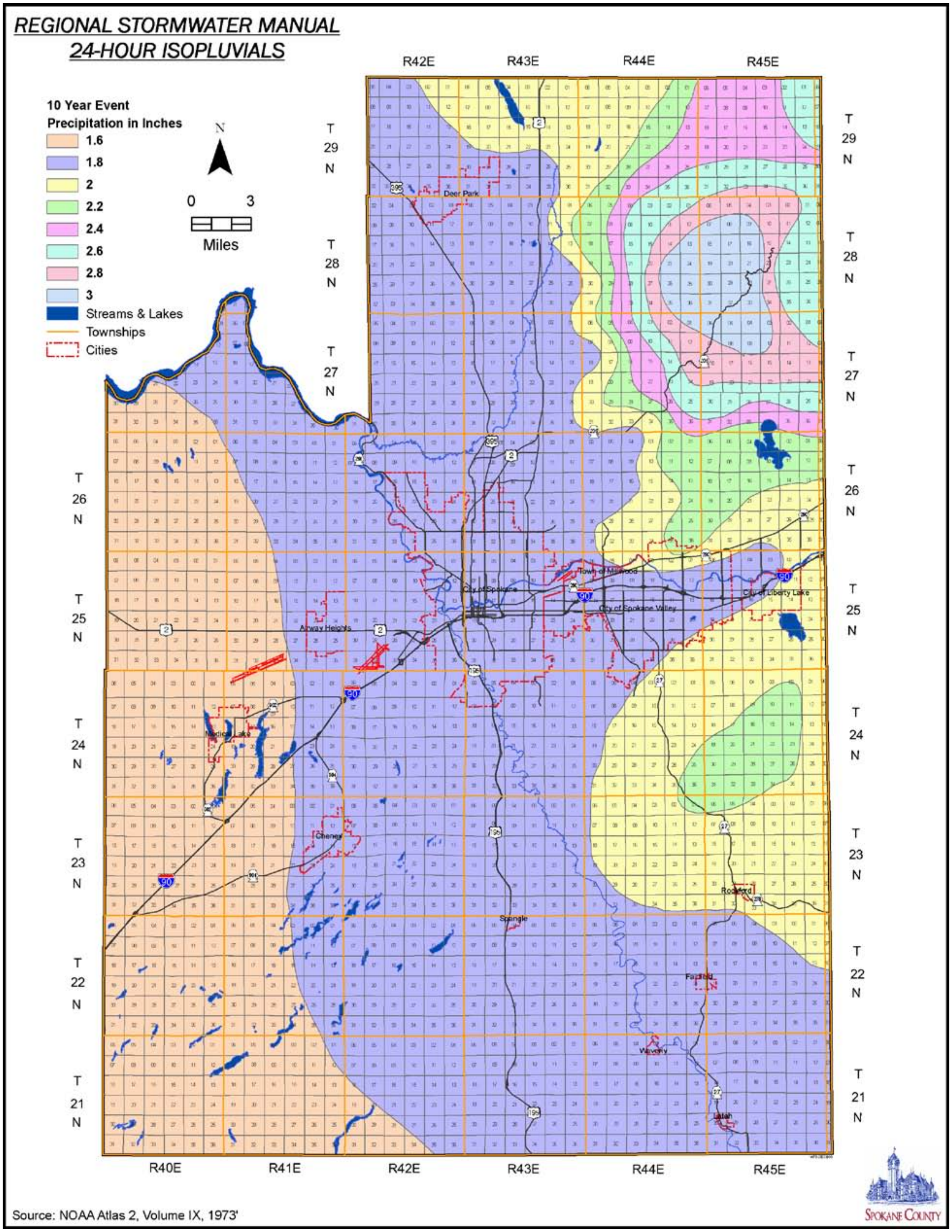

Figure 5-2 – 10-Year, 24-Hour Isopluvial Map

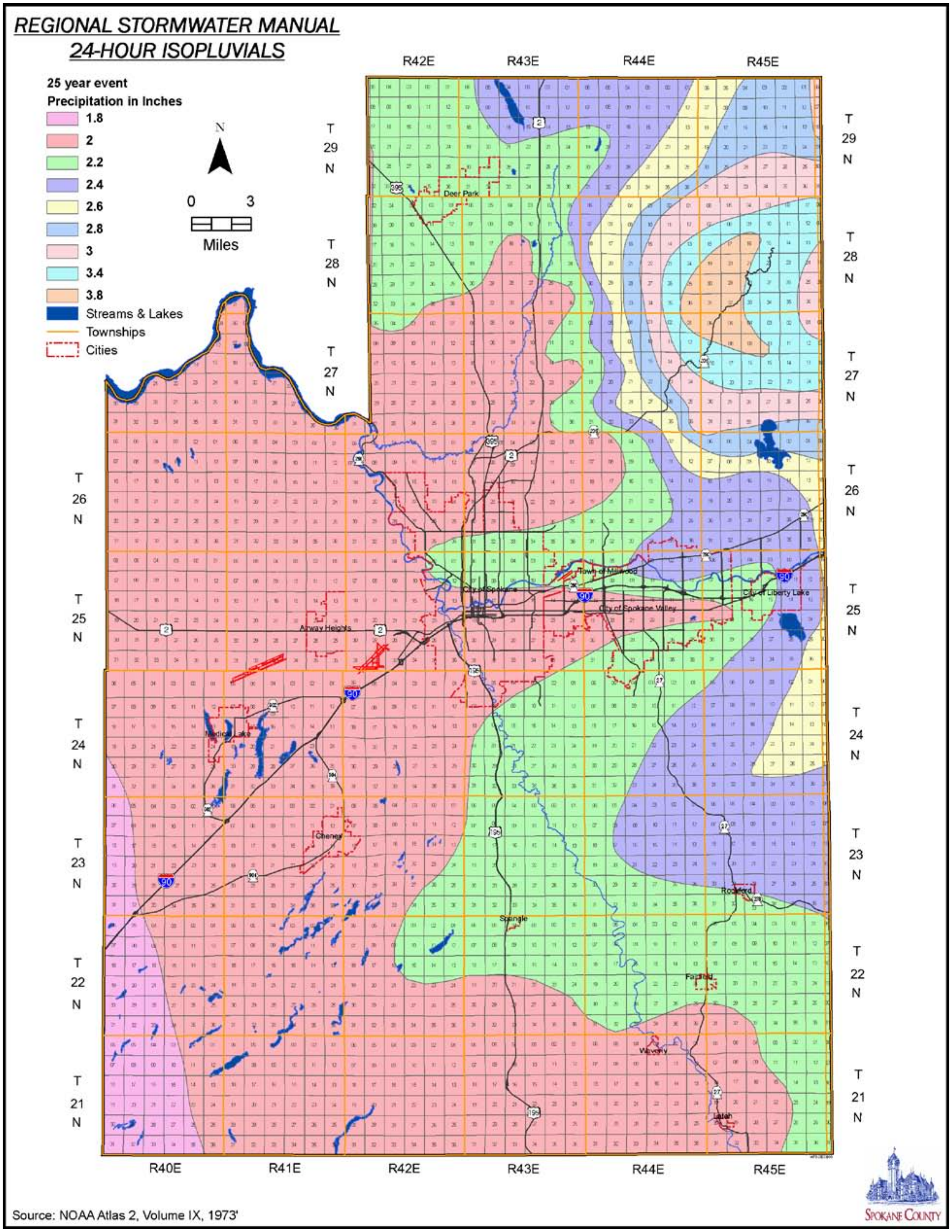

Figure 5-3 – 25-Year, 24-Hour Isopluvial Map

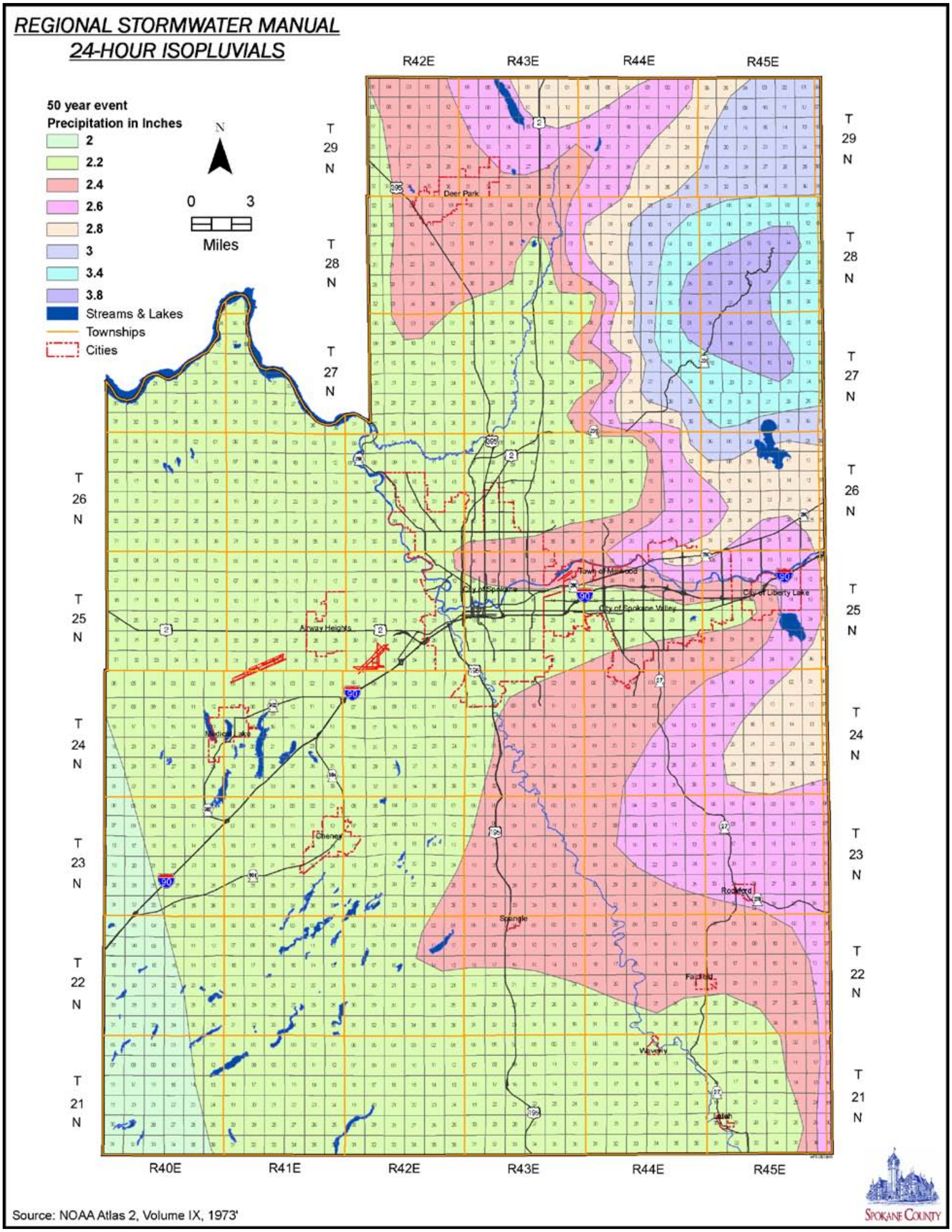

Figure 5-4 – 50-Year, 24-Hour Isopluvial Map

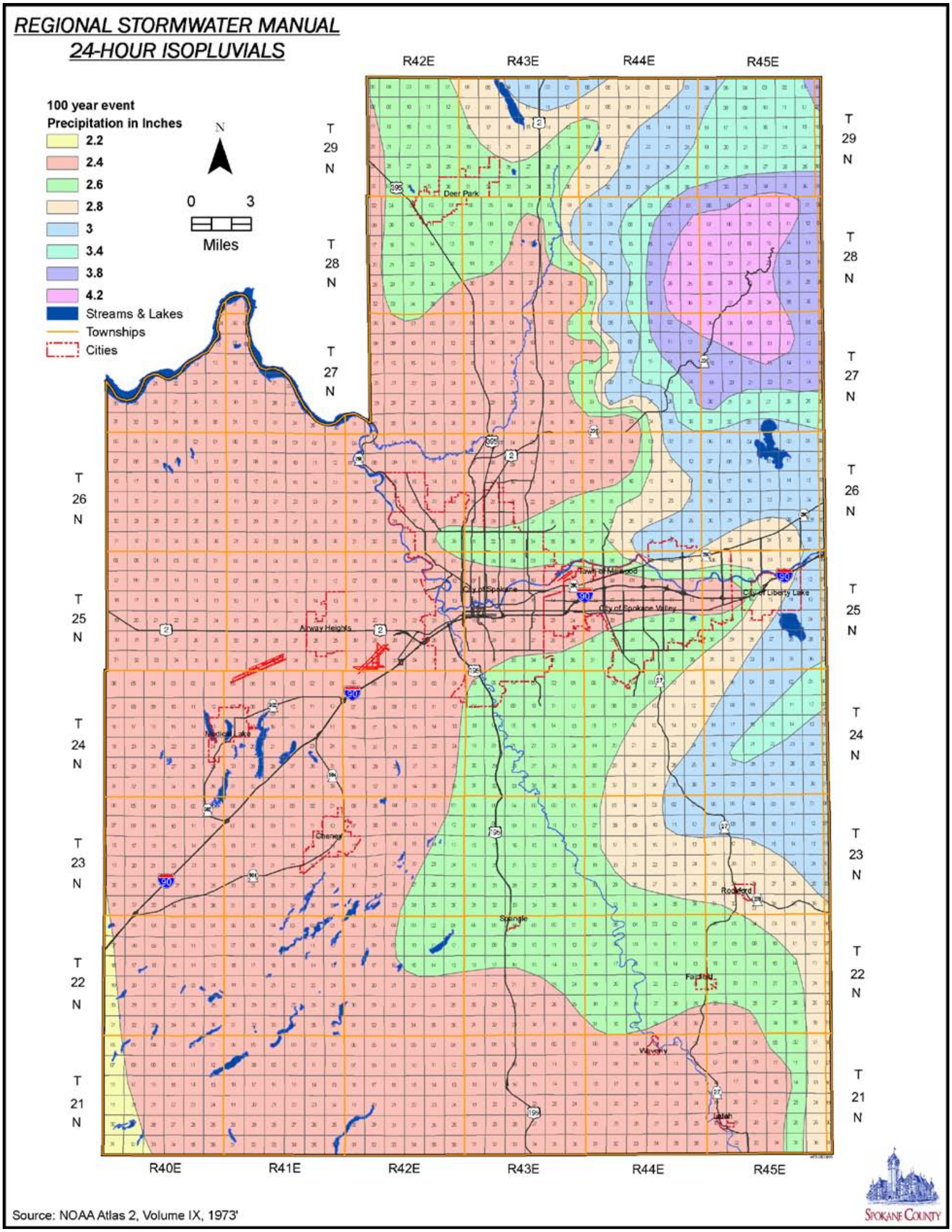

Figure 5-5 – 100-Year, 24-Hour Isopluvial Map

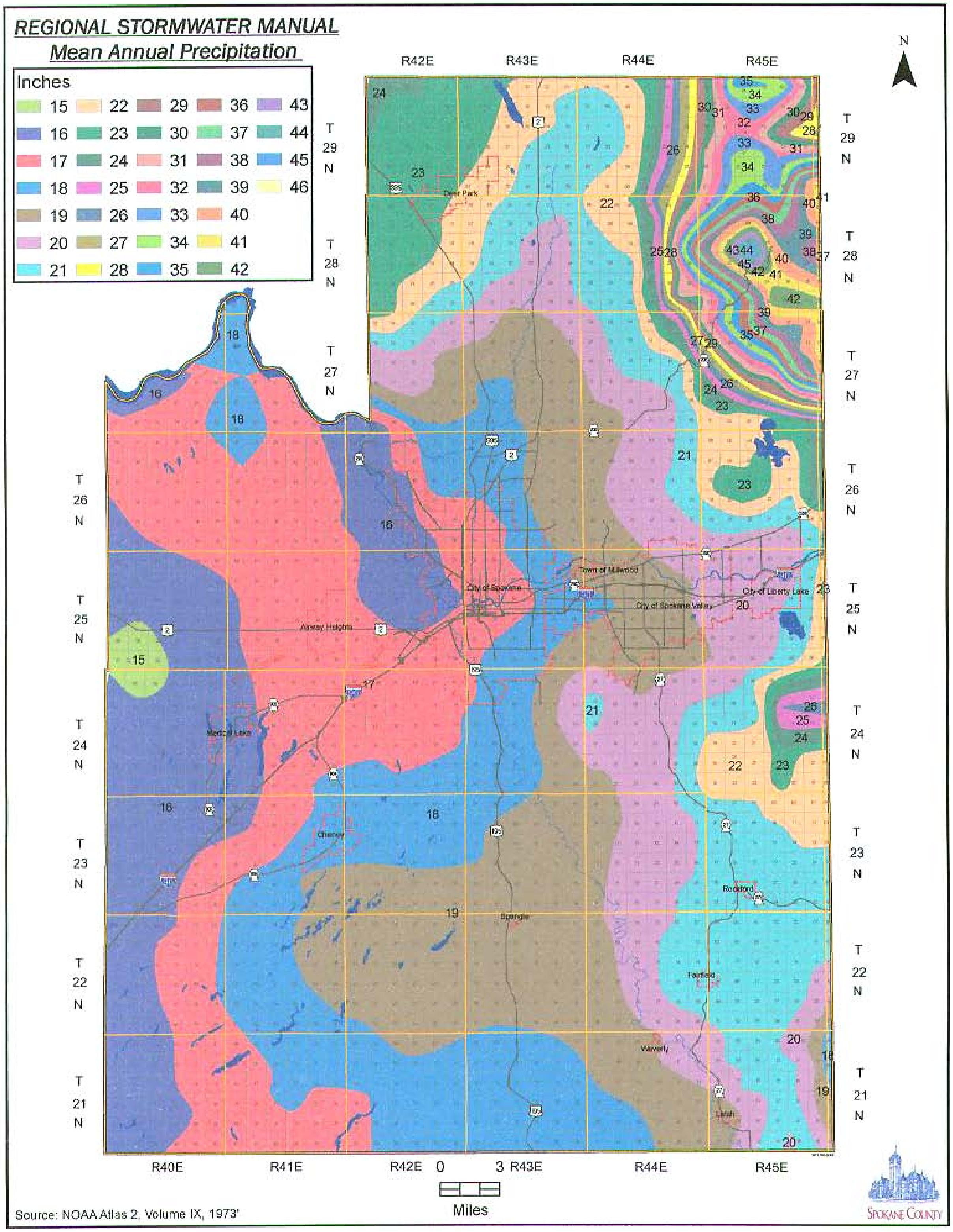

Figure 5-6 – Mean Annual Precipitation

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. 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 in cubic feet per minute, which can be converted to cubic feet per second 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 O2 and S2 can be solved interactively from the given stage-storage and stage-discharge curves.

5.5 RATIONAL METHOD

The rational method is used to predict peak flows for small 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 100 acres and for developed conditions with large impervious areas. The peak flow rate is calculated using the following equation:

$$Q_P = CIA \qquad (5\text{-}10)$$

Where: Q_P = peak flow rate (cfs);
C = runoff coefficient (dimensionless units);

I = rainfall intensity (inches/hour) (refer to Section 5.5.3); and,

A = drainage area (acres).

5.5.1 RUNOFF COEFFICIENTS

Table 5-5 provides runoff coefficients for the 10-year storm frequency. Steeply sloped areas and less frequent, higher intensity storms require the use of higher coefficients because infiltration and other losses have a proportionally smaller effect on runoff. Generally, runoff coefficients should be increased by 10% when designing for a 25-year frequency; by 20% for a 50-year frequency; and by 25% for a 100-year frequency. Runoff coefficients should not be increased above 0.95.

TABLE 5-5
RUNOFF COEFFICIENTS FOR THE RATIONAL METHOD
(10-YEAR RETURN FREQUENCY)

	Runoff Coefficient (C)		
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	0.90	0.90	0.90
Gravel Pavement	0.50	0.55	0.60
Lawns, Sandy Soil	0.10	0.15	0.20
Lawns, Heavy Soil	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
Woodland and Forest	0.10	0.15	0.20
Meadow and Pasture Land	0.25	0.30	0.35

Source: WSDOT Hydraulics Manual, March 2004

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 time of concentration is equal to the sum of the travel times for all flow segments. 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:

$$T_t = \frac{L}{K\sqrt{S}} \qquad (5\text{-}11)$$

$$T_c = T_{t1} + T_{t2} + \ldots + T_{tn} \qquad (5\text{-}12)$$

Where:
- T_t = travel time of flow segment (minutes);
- T_c = time of concentration (minutes);
- L = length of segment (feet);
- K = ground cover coefficient, Table 5-6 (feet/minute);
- S = slope of segment (feet/foot); and,
- n = number of flow segments.

The time of concentration shall not be less than 5 minutes. 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.

5.5.3 INTENSITY

The equation for calculating rainfall intensity is:

$$I = \frac{m}{T_C^n} \qquad (5\text{-}13)$$

Where:
- m = coefficient of rainfall intensity, Table 5-7;

n = coefficient of rainfall intensity, Table 5-7;

I = rainfall intensity (inches/hour); and,

T_c = time of concentration (minutes).

TABLE 5-6
GROUND COVER COEFFICIENTS

Type of Cover	K (feet/minute)
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
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

TABLE 5-7
INDEX TO RAINFALL COEFFICIENTS

2-year Event		10-year Event		25-year Event		50-year Event		100-year Event	
m	n	m	n	m	n	m	n	m	n
3.47	0.556	6.98	0.609	9.09	0.626	10.68	0.635	12.33	0.643

Source: WSDOT Hydraulics Manual, March 2004

The rainfall intensity (I) coefficients (m and n) have been determined for Spokane for the 2-, 10-, 25-, 50-, and 100-year storm events. These coefficients were developed from NOAA Atlas 2 and are shown in Table 5-7.

5.6 BOWSTRING METHOD (MODIFIED RATIONAL METHOD)

This method is used to estimate storage requirements for a given design storm using a series of hydrographs for different storm durations (t).

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 (see Figure 5-7).

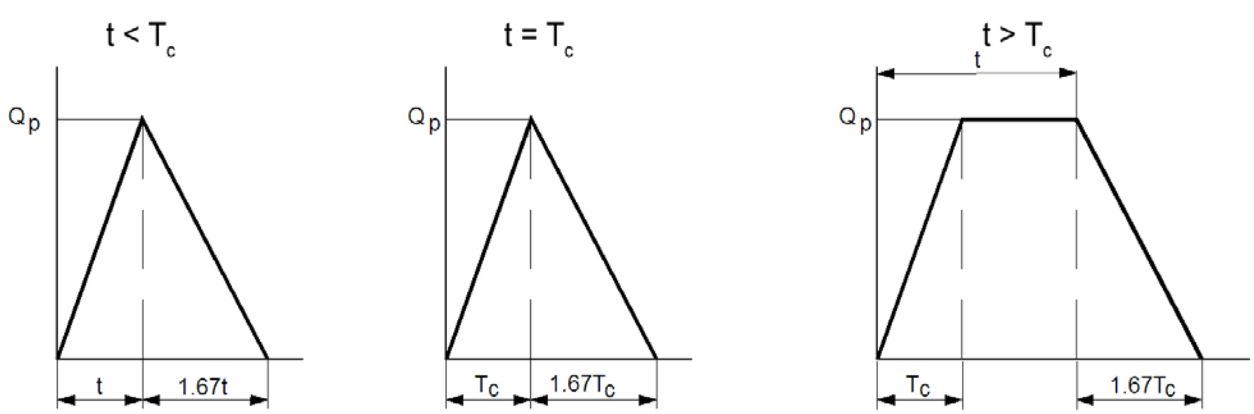

Figure 5-7 – Bowstring Method Hydrographs

The recession period (T_R) of the hydrograph is given by Equation 5-14.

$$T_R = 1.67T_P \tag{5-14}$$

Where: $T_P = T_c$, when $t \geq T_c$; or,

$T_P = t$, when $t < T_c$.

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

$$V(\mathrm{t}) = 1.34Q_P\mathrm{t} \text{ for } t \leq T_c \text{ (triangular hydrograph)} \tag{5-15}$$

$$V(\mathrm{t}) = Q_P\mathrm{t} + 0.34Q_P\mathrm{T_C} \text{ for } t > T_c \text{ (trapezoidal hydrograph)} \tag{5-16}$$

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

$$V_{OUT}(\mathrm{t}) = Q_{OUT}\mathrm{t} \tag{5-17}$$

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

5.6.1 DESIGN STEPS

Under certain circumstances as allowed by the local jurisdiction the Bowstring Method can be used for detention design with following procedure:

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 off site, 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 (e.g., t = 5, 10, 25…minutes) using Equations 5-10, 5-13, 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 4.3.1.
5. Calculate the outflow volume (V_{OUT}) using Equation 5-17.
6. The required storage is obtained as the maximum difference between inflow and outflow volumes by the tabular methods. The tabular method is illustrated in the example given in Appendix 5B.

Although credit is not given for infiltration through the pond bottom for ponds and swales, they shall comply with the criteria in Section 7.8.3.

5.7 WATER BUDGET METHOD

5.7.1 INTRODUCTION

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 precipitation values are adjusted to account for the changes in precipitation over the Spokane Region. 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.

5.7.2 METHODOLOGY

The water budget analysis is performed utilizing the following relationships:

$$V_{STORAGE}(x) = V_{IN}(x) - V_{OUT}(x) + V_{STORAGE}(x - 1) \quad (5\text{-}18)$$

$$V_{POND} = \max[V_{STORAGE}(x)] \quad (5\text{-}19)$$

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 to 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, evaporative systems shall be designed using the Preferred or Alternative method design criteria described below.

The Preferred Method

The Preferred Method is used to size evaporation facilities that store the increase in stormwater runoff volume (after evaporation losses). Refer to Figures 7-7 and 7-8 for schematics of how this design is implemented.

The water budget analysis must demonstrate that the volume of runoff leaving the site over a 2-year cycle is less than or equal to the pre-developed volume for the cycle. 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 could be infiltrated when a defined release point is not present on site.

If the evaporative system is designed in combination with a surface discharge, then Equations 5-18 through 5-21 shall be used:

$$V_{ALL} \leq V_{PRE} \quad (5\text{-}20)$$

$$Q_{ALL} \leq Q_{PRE} \quad (5\text{-}21)$$

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.

The Alternative Method

The Alternative Method is used to size evaporation facilities that store the total post-developed runoff volume (less evaporative losses) or full containment evaporative systems. The Alternative Method is used when the project site does not have a defined discharge point or when site conditions are not conducive to infiltration of the pre-developed volume.

The facility shall be sized to store the volume per Equations 5-18, 5-19, and 5-22:

$$V_{STORAGE}(o) = V_{IN}(o) - V_{OUT}(o) \quad (5\text{-}22)$$

Where: o = first month of the two year cycle.

The facility shall include a factor of safety on the maximum depth of 1.2. The extra capacity provides emergency storage in the event that above average total annual precipitation is experienced. 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 on adjacent or down-gradient properties from additional stormwater being injected into the subsurface.

5.7.3 DESIGN STEPS

The following steps outline how to use the spreadsheets that have been developed for this method (check with the local jurisdiction for the most current spreadsheets for a proposed project). Example calculations are presented in Appendices 5C and 5D.

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 post-developed conditions. These parameters also need to be determined for the pre-developed conditions when using the Preferred Method;
2. Determine the ARC II CN values for the pervious and impervious surfaces using Table 5-1 and weight the CN values per Section 5.3.4.
3. Determine the associated ARC III CN values per Table 5-2. Input the ARC II and ARC III CN values;
4. Input the impervious basin and total basin size, in acres;
5. Input the mean annual precipitation, in inches, per Figure 5-6;
6. Input the proposed pond side slopes;
7. Input an assumed pond depth, for the Preferred Method only, based upon depth to limiting layer or desired depth. Pond depth is calculated automatically for the Alternative Method based upon the necessary surface area (projected from pond bottom area) and the required volume necessary to store/evaporate;
8. Assume a value for the pond bottom 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,
10. Vary 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 Preferred Method; or,

- The month in which the "Total Volume Stored" in Pond (STORAGE column) shows a decrease from year one to year two for the Alternative Method.

11. Note that for the Preferred 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, Section 7.3 must be utilized to design the detention portion of the drainage facility.

5.7.4 CURVE NUMBER ADJUSTMENT

The antecedent runoff condition (ARC) needs to be considered during the months of the year when the ground may be saturated or frozen. The CNs shall be adjusted as indicated in Table 5-8 and Table 5-2.

TABLE 5-8
CURVE NUMBER ADJUSTMENT FOR
ANTECEDENT RUNOFF CONDITION (ARC)

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	95

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 pervious surfaces is 95 regardless of the ARC II or III CNs; this is meant to approximate runoff from pervious surfaces during snowpack buildup and snowmelt.

5.7.5 CLIMATOLOGICAL DATA

Average monthly precipitation rates were obtained from the Western Regional Climate Center (WRCC), based on records from January 1, 1890 to December 31, 2005. This information is found in Table 5-9 and is updated quarterly at the following website:

- http://www.wrcc.dri.edu/cgi-bin/cliRECtM.pl?waspok.

The monthly pan evaporation values were also obtained from the WRCC and are current for the period from 1889 through 2002. In Washington State many pan evaporation stations do not take readings during winter. A “0.00” total indicates that no measurement was taken. Some totals are computed from meteorological measurements using a form of the Penman equation. The rates in this table were obtained using this method according to the WRCC website: http:wrcc.dri.edu/htmlfiles/westevap.final.html.

TABLE 5-9
AVERAGE MONTHLY PRECIPITATION AND PAN EVAPORATION VALUES

Month / Data	Precipitation (in)	Pan Evaporation (in)
January	1.97	0.61
February	1.54	1.11
March	1.39	2.28
April	1.11	4.45
May	1.42	6.69
June	1.20	8.14
July	0.55	10.70
August	0.63	9.42
September	0.80	5.90
October	1.17	2.58
November	2.08	0.92
December	2.20	0.51

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APPENDIX 5A – EXAMPLE CALCULATION: WEIGHTING CURVE NUMBERS

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-square-foot homes with 500-square-foot driveways;
  - 1.30 acres of road impervious areas; and,
  - No sidewalks are proposed.

CALCULATIONS

1. Use Table 5-1 to find the CNs for the lawn areas and the roofs, driveways, and streets:

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

   CN = 98 for streets, driveways, and roofs (impervious areas)

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

   Total driveway area = (38 driveways)(500 square feet/driveway)

   = 19,000 square feet = 0.44 acres

   Total connected impervious area = 0.44 +1.30 = 1.74 acres

   CN FOR THE IMPERVIOUS BASIN = 98

3. Compute the CN for the pervious 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 are not hydraulically connected to the roads or driveways.

   Total roof area = (38 houses)(1500 square feet/house)

   = 57,000 square feet = 1.31 acres

   Total lawn area = Total site – total impervious area

   $= 10 - 1.74 - 1.31 = 6.95 \cdot acres$

   Total pervious basin = $1.31 + 6.95 = 8.26 \cdot acres$

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

CN FOR THE PERVIOUS BASIN = 67

APPENDIX 5B – 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.
- Post-developed site conditions consist of:
  - 20 – 10,000 square foot lots;
  - 1,500-square-foot homes with 500-square-foot 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%;
  - 300 feet of gutter flow @ 1%; and,
  - 300 feet of pipe flow @ 2%.
- The proponent proposes a pond with drywells for stormwater runoff disposal.
- Field samples were collected at the proposed location of the drywells. Using the Spokane County 200 Method, it was estimated that the drywell outflow rate is 1 cfs.

CALCULATIONS

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

From Table 5-5:

C = 0.15 pervious areas – lawns (sandy soils, rolling terrain)

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

Total roof area	=	20(1,500 square feet)
	=	30,000 square feet.
	=	0.69 acres
Total driveway area	=	20(500 square feet)
	=	10,000 square feet
	=	0.23 acres
Total impervious area	=	0.69 + 0.23 + 0.5 = 1.42 acres
Total permeable area:		5 – 1.42 acres = 3.58 acres

Weighted C: $= \dfrac{3.58(0.15)+1.42(0.90)}{5} = 0.36$

2. Determine the time of concentration (T_C).

   Ground Cover Coefficient (K): (use Table 5-6)

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

FLOW SEGMENT	LENGTH (feet)	SLOPE (feet/foot)	K (feet/minute)	T_t (minutes)
Overland Flow	100	0.01	420	2.38
Gutter Flow	300	0.01	1500	2.00
Pipe Flow	300	0.02	3000	0.71
Total Time of Concentration				5.09 min

3. Determine the intensity using Equation 5-13.

$$I = \frac{m}{T_C^n}$$

From Table 5-7; m and n are 6.98 and 0.609, respectively, for the 10-year storm.

$$I = \frac{6.98}{5.09^{0.609}} = 2.59 \text{ inches/hour}$$

4. Determine the peak flow rate t = T_c using Equation 5-10.

$$Q_P = CIA = 0.36(2.59 \text{ inches/hour})(5 \text{ acres}) = 4.66 \text{ cfs}$$

5. Compute the volume for t = T_c using Equation 5-15.

$$V(t) = 1.34 Q_P t = 1.34(4.66 \text{ cfs})(5.09 \text{ min})(60 \text{ sec/min}) = 1{,}907 \text{ cubic feet}$$

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

   Q_{OUT} = 1.0 cfs (Given)

7. Compute the outflow volume (V_{OUT}) for t = T_c using Equation 5-17.

$$V_{OUT} = Q_{OUT}\,\mathrm{t} = (1.0\ \mathrm{cfs})(5.09\ \mathrm{min})(60\ \mathrm{sec/min}) = 305\ \text{cubic feet}$$

8. 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, 5-13, 5-15, 5-16 and 5-17. This is simply done in a spreadsheet program, as shown in the sample spreadsheet on Figure 5B-1

9. The required storage is obtained as the maximum difference between inflow and outflow volumes (see spreadsheet, Figure 5B-1).

BOWSTRING METHOD (TEN YEAR STORM DESIGN)

PROJECT: PROJECT NAME
PROJECT NO: PROJECT NUMBER
BASIN: **BASIN NAME**
DESIGNER: DESIGNER NAME
DATE: 03/14/06

NUMBER OF DRYWELLS PROPOSED
0 Single (type A) 1 Double (type B)

Time of Conc. (min)	5.09		
Area (Acres)	5.00		
Weighted "C"	0.36		
Volume Provided	1650	storm:	1603
Outflow (cfs)	1.0	Drywell	
Area * C	1.80		

#1 Time (min.)	#2 Time (sec.) (#1*60)	#3 Intensity (in./hr.)	#4 Q dev. (cfs) (A*C*#3)	#5 V in (cu. ft.)	#6 V out (cu. ft.) (Outf.*#2)	#7 Storage (cu. ft.) (#5-#6)
5.09	305.40	2.59	4.66	1909	305.40	1603
5	300	2.62	4.71	1895	300	1595
10	600	1.72	3.09	2176	600	1576
15	900	1.34	2.41	2424	900	1524
20	1200	1.13	2.03	2643	1200	1443
25	1500	0.98	1.77	2838	1500	1338
30	1800	0.88	1.58	3014	1800	1214
35	2100	0.80	1.44	3177	2100	1077
40	2400	0.74	1.33	3327	2400	927
45	2700	0.69	1.24	3468	2700	768
50	3000	0.64	1.16	3600	3000	600
55	3300	0.61	1.09	3726	3300	426
60	3600	0.58	1.04	3845	3600	245
65	3900	0.55	0.99	3959	3900	59
70	4200	0.53	0.95	4067	4200	-133
75	4500	0.50	0.91	4172	4500	-328
80	4800	0.48	0.87	4272	4800	-528
85	5100	0.47	0.84	4370	5100	-730
90	5400	0.45	0.81	4463	5400	-937
95	5700	0.44	0.78	4554	5700	-1146
100	6000	0.42	0.76	4642	6000	-1358

DRYWELL REQUIREMENTS - 10 YEAR DESIGN STORM

Maximum storage by Bowstring = required: 1603 cu. ft.
provided: 1650 cu. ft. **OK!**

Number and type of drywells required = 0 SINGLE
1 DOUBLE

Figure 5B-1 – Bowstring Method Spreadsheet Example

APPENDIX 5C – EXAMPLE CALCULATION: WATER BUDGET (PREFERRED METHOD)

GIVEN

- The project is located in Section 31, Township 26 N, Range 42 E
- Pre-developed Site Conditions
  - Woods and grass combination, good condition CN = 58
- Post-developed Site Conditions
  - Total basin = 14 acres
  - Impervious basin CN = 98, 1.75 acres
  - Pervious basin CN = 67 (includes roofs and lawns), 8.00 acres
  - Remaining open area = to be used as open space or drainage
  - Open Space CN = 61
  - Pond Area CN = 98

CALCULATIONS

Spreadsheets referred to in these calculations are available from the local jurisdiction for a given project. Figure 5C-1 shows a sample spreadsheet.

1. Determine the ARC II CN values for the pervious and impervious surfaces. Refer to Appendix 5A for an example.

2. 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
61	78
67	83
98	99

3. Input the impervious basin and total basin size, in acres, into the spreadsheet:

   Total impervious area = 1.75 acres

   Total pervious area = 8.0 acres

   Total basin area = 14.0 ac (includes pond areas & open areas)

4. Input the mean annual precipitation, in inches:

Mean annual precipitation = 17.0 inches (Figure 5-6)

5. Input the proposed pond side slopes into the spreadsheet:

   Assume: 3:1 for side slopes

6. Input the proposed pond depth into the spreadsheet pond depth:

   Assume: 1.5 feet for maximum surface water elevation

7. Input the pond bottom area in square feet:

   Assume: 10% of the total developed area

   Pond bottom area $= 0.10 * (9.75 acres) * (43{,}560 squarefeet / acre)$

   = 42,471 square feet

8. 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 Preferred method.

   RESULTS OF THE EVAPORATIVE CELL

   The pond bottom area required is 35,700 square feet

   The depth of the evaporative cell is 1.5 feet *1.2 = 1.8 feet
   (1.2 is the factor of safety; refer to Section 7.7.2)

   This is the size of the first cell of a separated (two-cell) system, or the lower portion of a stacked (one-cell) system.

9. 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 5.3.4 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 5.3.4 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 stacked system (one cell), the detention portion of the cell is placed on top of the evaporative portion. 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 portion is designed per the criteria specified in Section 7.3 and shall have a 1 foot freeboard above the maximum water surface elevation.

Evaporative / Detention
Combination Pond

Preferred Method

Project : Name of Project	
Job No.: number	
Date: 12/5/07	
Designe: designer	
Pond Bottom Area:	35,700 sq. ft.
Pond Bottom Perimeter:	756 ft
Pond Side Slopes:	3 : 1
Assumed Pond Depth:	1.5 ft
Assumed Pond Volume:	53,550 c.ft.

Mean Annual Precipitation

Airport	16.11
Project Site	17.00
Multiplier	1.06

		AMC II	AMC III	- -
		Normal	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:	0.00	1.74 acres		
Impervious Pond Size:	0.00	0.82 acres		
Pervious Basin Size:	14.00	11.44 acres		
	14.00	14.00 acres		14.00

Month	Precip. "P" (in.)	Adj. "P" (in)	Imp pre-dev (P-0.2S)	Perm. pre-dev (P-0.2S)	Imp post-dev (P-0.2S)	Perm post-dev (P-0.2S)	Imp pre-dev Runoff Depth (in)	Perm pre-dev Runoff Depth (in)	Imp post-dev Runoff Depth (in)	Perm post-dev Runoff Depth (in)	Imp pre-dev runoff volume (cft)	Perm pre-dev runoff volume (cft)	TOTAL PRE VOL (cft)	Imp post-dev runoff volume (cft)	Perm post-dev runoff volume (cft)	TOTAL POST VOL (cft)	NET Increase in Volume (cft)	Pan Evap. (in.)	Evap Volume Out (cft) 28% Adj.	Total Volume to Handle (cft)	Current Volume in Pond (cft)	Spill Volume to Detention < PRE (cft)
Oct.	1.22	1.29	1.25	0.00	1.25	0.30	1.07	0.00	1.07	0.02	0	0	0	9,953	726	10,679	10,679	2.58	5,526	5,153	5,153	0
Nov.	2.02	2.13	2.11	1.50	2.11	1.72	2.01	0.48	2.01	0.79	0	24,549	24,549	18,722	32,661	51,383	26,834	0.92	1,971	54,565	53,550	1,015
Dec.	2.22	2.34	2.32	2.24	2.32	2.24	2.23	1.81	2.23	1.81	0	92,050	92,050	20,679	75,221	95,900	3,850	0.51	1,092	148,357	53,550	94,807
Jan.	2.05	2.16	2.14	2.06	2.14	2.06	2.05	1.64	2.05	1.64	0	83,287	83,287	19,015	68,060	87,075	3,788	0.61	1,307	139,319	53,550	85,769
Feb.	1.57	1.66	1.64	1.55	1.64	1.55	1.54	1.16	1.54	1.16	0	58,874	58,874	14,321	48,110	62,431	3,558	1.11	2,378	113,604	53,550	60,054
Mar.	1.38	1.46	1.44	0.82	1.44	1.05	1.34	0.17	1.34	0.35	0	8,678	8,678	12,466	14,699	27,164	18,486	2.28	4,884	75,831	53,550	22,281
Apr.	1.11	1.17	1.13	0.00	1.13	0.19	0.96	0.00	0.96	0.01	0	0	0	8,898	282	9,179	9,179	4.45	9,532	53,197	53,197	0
May	1.37	1.45	1.40	0.00	1.40	0.46	1.23	0.00	1.23	0.04	0	0	0	11,397	1,636	13,033	13,033	6.69	14,330	51,901	51,901	0
June	1.27	1.34	1.30	0.00	1.30	0.36	1.12	0.00	1.12	0.02	0	0	0	10,434	992	11,425	11,425	8.14	17,436	45,890	45,890	0
July	0.50	0.53	0.49	0.00	0.49	0.00	0.34	0.00	0.34	0.00	0	0	0	3,187	0	3,187	3,187	10.7	22,919	26,158	26,158	0
Aug.	0.60	0.63	0.59	0.00	0.59	0.00	0.44	0.00	0.44	0.00	0	0	0	4,093	0	4,093	4,093	9.42	20,178	10,073	10,073	0
Sept.	0.80	0.84	0.80	0.00	0.80	0.00	0.64	0.00	0.64	0.00	0	0	0	5,952	0	5,952	5,952	5.9	12,638	3,388	3,388	0
Oct.	1.22	1.29	1.25	0.00	1.25	0.30	1.07	0.00	1.07	0.02	0	0	0	9,953	726	10,679	10,679	2.58	5,526	8,540	8,540	0
Nov.	2.02	2.13	2.11	1.50	2.11	1.72	2.01	0.48	2.01	0.79	0	24,549	24,549	18,722	32,661	51,383	26,834	0.92	1,971	57,953	53,550	4,403
Dec.	2.22	2.34	2.32	2.24	2.32	2.24	2.23	1.81	2.23	1.81	0	92,050	92,050	20,679	75,221	95,900	3,850	0.51	1,092	148,357	53,550	94,807
Jan.	2.05	2.16	2.14	2.06	2.14	2.06	2.05	1.64	2.05	1.64	0	83,287	83,287	19,015	68,060	87,075	3,788	0.61	1,307	139,319	53,550	85,769
Feb.	1.57	1.66	1.64	1.55	1.64	1.55	1.54	1.16	1.54	1.16	0	58,874	58,874	14,321	48,110	62,431	3,558	1.11	2,378	113,604	53,550	60,054
Mar.	1.38	1.46	1.44	0.82	1.44	1.05	1.34	0.17	1.34	0.35	0	8,678	8,678	12,466	14,699	27,164	18,486	2.28	4,884	75,831	53,550	22,281
Apr.	1.11	1.17	1.13	0.00	1.13	0.19	0.96	0.00	0.96	0.01	0	0	0	8,898	282	9,179	9,179	4.45	9,532	53,197	53,197	0
May	1.37	1.45	1.40	0.00	1.40	0.46	1.23	0.00	1.23	0.04	0	0	0	11,397	1,636	13,033	13,033	6.69	14,330	51,901	51,901	0
June	1.27	1.34	1.30	0.00	1.30	0.36	1.12	0.00	1.12	0.02	0	0	0	10,434	992	11,425	11,425	8.14	17,436	45,890	45,890	0
July	0.50	0.53	0.49	0.00	0.49	0.00	0.34	0.00	0.34	0.00	0	0	0	3,187	0	3,187	3,187	10.7	22,919	26,158	26,158	0
Aug.	0.60	0.63	0.59	0.00	0.59	0.00	0.44	0.00	0.44	0.00	0	0	0	4,093	0	4,093	4,093	9.42	20,178	10,073	10,073	0
Sept.	0.80	0.84	0.80	0.00	0.80	0.00	0.64	0.00	0.64	0.00	0	0	0	5,952	0	5,952	5,952	5.9	12,638	3,388	3,388	0
Oct.	1.22	1.29	1.25	0.00	1.25	0.30	1.07	0.00	1.07	0.02	0	0	0	9,953	726	10,679	10,679	2.58	5,526	8,540	8,540	0
																			114190.02			

Total Annual Pre 267,438 | Total Annual Post 381,503 | 114,065 Net Increase | Amount Spilled 267,313

16.11 17.00 Mean Annual Precipitation for Project Site

Figure 5C-1 – Evaporative Pond Spreadsheet Example (Preferred Method)

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APPENDIX 5D – EXAMPLE CALCULATION: WATER BUDGET (ALTERNATIVE METHOD)

GIVEN

- The project is located in Section 31, Township 26 N, Range 42 E
- Pre-Developed Site Conditions
  - Woods and grass combination, good condition CN = 58
- Post Developed Site Conditions
  - Total basin = 14 acres
  - Impervious basin CN = 98, 1.75 acres
  - Pervious basin CN = 67 (includes roofs and lawns), 8.00 acres
  - Remaining open area = to be used as open space or drainage
  - Open Space CN = 61
  - Pond Area CN = 98

CALCULATIONS

Spreadsheets referred to in these calculations are available from the local jurisdiction for a given project. Figure 5D-1 shows a sample spreadsheet.

1. Determine the ARC II CN values for the pervious and impervious surfaces. Refer to Appendix 5A for an example.

2. 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
61	78
67	83
98	99

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

   Total impervious area = 1.75 ac

   Total pervious area = 8.0 ac

   Total basin area = 14.0 ac (includes pond areas & open areas)

4. Input the mean annual precipitation, in inches.

   Mean annual precipitation = 17.0 inches (Figure 5-6)

5. Input the proposed pond side slopes into the spreadsheet.

   Use: 3:1 for side slopes

6. Input the pond bottom area in square feet

   Assume 30% of the total area developed.

   Pond bottom area $= 0.30 * (9.75 acres) * (43{,}560 squarefeet / acre)$

   = 127,413 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.

7. Adjust the pond bottom area up and down until the month in which the “Total Volume Stored” in the pond (STORAGE column) is the largest and shows a decrease from Year 1 to Year 2 of the water budget cycle.

   - The month with the largest volume requirements is March in this example
   - The pond bottom area required is 137,000 square feet
   - The depth of the evaporative cell is 2.21 feet
   - Apply the factor of safety to the depth:
     2.21 feet x 1.2 = 2.66 feet
   - Add the freeboard to determine total pond depth:
     2.66 feet + 1.0 foot = 3.66 feet

Project : Name of Project			
Plat / BSP / Proj No:	number	Engineer:	designer
Date:	3/24/2008		
Pond Bottom Area:	138,000 sq. ft.		
Pond Bottom Perimeter:	1,486 ft		
Pond Side Slopes:	3 : 1		
Impervious Basin Size (Constant):	1.75 acres		
Impervious Basin Size (Pond Area):	3.17 acres		
Permeable Basin Size:	8.00 acres		
Off-Site Upstream Basin:	1.10 acres		
Total Basin Size:	14.02 acres		
Mean Annual Prec. - Airport:	16.11 in		
Mean Annual Prec. - Site:	17.00 in		
Multiplier:	1.06		
100-Year, 24 Hour, Prec.:	2.50 in		

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

Alternate Method

	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:	61	79	95
Impervious S:	0.20	0.10	0.10
Permeable S:	4.93	2.05	0.53
Off-Site S:	6.39	2.66	0.53

						INFLOW				OUTFLOW		STORAGE	POND DATA	
Month	Precipitation (in)	Adjusted 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) 72% Adj.	Total Volume Stored In Pond (cu ft)	Pond Depth (ft)	Pond Capacity (%)
													0.00	0
Oct.	1.22	1.29	1.07	0.02	0.00	19,124	508	0	19,632	2.58	21,362	0	0.00	0
Nov.	2.02	2.13	2.01	0.79	0.60	35,973	22,839	2,400	61,212	0.92	7,618	53,595	0.39	17
Dec.	2.22	2.34	2.23	1.81	1.81	39,733	52,600	7,233	99,566	0.51	4,276	148,885	1.08	47
Jan.	2.05	2.16	2.05	1.64	1.64	36,537	47,593	6,544	90,673	0.61	5,227	234,331	1.70	74
Feb.	1.57	1.66	1.54	1.16	1.16	27,518	33,642	4,626	65,786	1.11	9,695	290,422	2.10	92
Mar.	**1.38**	**1.46**	**1.34**	**0.35**	**0.24**	**23,952**	**10,278**	**953**	**35,183**	**2.28**	**20,162**	**305,443**	**2.21**	**97**
Apr.	1.11	1.17	0.96	0.01	0.00	17,096	197	0	17,293	4.45	39,480	283,256	2.05	90
May	1.37	1.45	1.23	0.04	0.00	21,899	1,144	17	23,060	6.69	59,066	247,250	1.79	78
June	1.27	1.34	1.12	0.02	0.00	20,048	693	2	20,744	8.14	71,300	196,694	1.43	62
July	0.50	0.53	0.34	0.00	0.00	6,124	0	0	6,124	10.70	92,675	110,142	0.80	35
Aug.	0.60	0.63	0.44	0.00	0.00	7,865	0	0	7,865	9.42	80,009	37,999	0.28	12
Sept.	0.80	0.84	0.64	0.00	0.00	11,437	0	0	11,437	5.90	49,287	149	0.00	0
Oct.	1.22	1.29	1.07	0.02	0.00	19,124	508	0	19,632	2.58	21,363	0	0.00	0
Nov.	2.02	2.13	2.01	0.79	0.60	35,973	22,839	2,400	61,212	0.92	7,618	53,595	0.39	17
Dec.	2.22	2.34	2.23	1.81	1.81	39,733	52,600	7,233	99,566	0.51	4,276	148,885	1.08	47
Jan.	2.05	2.16	2.05	1.64	1.64	36,537	47,593	6,544	90,673	0.61	5,227	234,331	1.70	74
Feb.	1.57	1.66	1.54	1.16	1.16	27,518	33,642	4,626	65,786	1.11	9,695	290,422	2.10	92
Mar.	**1.38**	**1.46**	**1.34**	**0.35**	**0.24**	**23,952**	**10,278**	**953**	**35,183**	**2.28**	**20,162**	**305,443**	**2.21**	**97**
Apr.	1.11	1.17	0.96	0.01	0.00	17,096	197	0	17,293	4.45	39,480	283,256	2.05	90
May	1.37	1.45	1.23	0.04	0.00	21,899	1,144	17	23,060	6.69	59,066	247,250	1.79	78
June	1.27	1.34	1.12	0.02	0.00	20,048	693	2	20,744	8.14	71,300	196,694	1.43	62
July	0.50	0.53	0.34	0.00	0.00	6,124	0	0	6,124	10.70	92,675	110,142	0.80	35
Aug.	0.60	0.63	0.44	0.00	0.00	7,865	0	0	7,865	9.42	80,009	37,999	0.28	12
Sept.	0.80	0.84	0.64	0.00	0.00	11,437	0	0	11,437	5.90	49,287	149	0.00	0

Resulting Pond Volume:	305,443 cu ft
Resulting Pond Depth:	2.21 ft
Factor of Safety to Depth:	2.66
Including 1' freeboard:	3.66 ft
Total Pond Capacity without freeboard:	316,363 cu ft

Figure 5D-1 – Evaporative Pond Spreadsheet Example (Alternate Method)

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APPENDIX 5E - HYDROLOGIC SOIL SERIES FOR WASHINGTON STATE

Soil Type	Hydrologic Soil Group	Soil Type	Hydrologic Soil Group
Agnew	C	Dimal	D
Ahl	B	Dragoon	C
Aits	C	Dupont	D
Alderwood	C	Earlmont	C
Arents, Alderwood	B	Edgewick	C
Arents, Everett	B	Eld	B
Ashoe	B	Eloika	B
Athena	B	Elwell	B
Baldhill	B	Emdent	D
Barneston	C	Esquatzel	B
Baumgard	B	Everett	A
Beausite	B	Everson	D
Belfast	C	Freeman	C
Bellingham	D	Galvin	D
Bellingham variant	C	Garfield	C
Bernhill	B	Garrison	B
Boistfort	B	Getchell	A
Bong	A	Giles	B
Bonner	B	Glenrose	B
Bow	D	Godfrey	D
Brickel	C	Green Bluff	B
Bridgeson	D	Greenwater	A
Briscot	D	Grove	C
Buckley	C	Hagen	B
Bunker	B	Hardesty	B
Cagey	C	Harstine	C
Caldwell	C	Hartnit	C
Carlsborg	A	Hesseltine	B
Casey	D	Hoh	B
Cassolary	C	Hoko	C
Cathcart	B	Hoodsport	C
Cedonia	B	Hoogdal	C
Centralia	B	Hoypus	A
Chehalis	B	Huel	A
Cheney	B	Indianola	A
Chesaw	A	Jonas	B
Cinebar	B	Jumpe	B
Clallam	C	Kalaloch	C
Clayton	B	Kapowsin	C/D
Coastal beaches	variable	Katula	C
Cocolalla	D	Kilchis	C
Colter	C	Kitsap	C
Custer	D	Klaus	C
Custer, Drained	C	Klone	B
Dabob	C	Konner	D

Soil Type	Hydrologic Soil Group	Soil Type	Hydrologic Soil Group
Dearyton	C	Lakesol	B
Delphi	D	Laketon	C
Dick	A	Lance	B
Larkin	B	Poulsbo	C
Latah	D	Prather	C
Lates	C	Puget	D
Lebam	B	Puyallup	B
Lummi	D	Queets	B
Lynnwood	A	Quilcene	C
Lystair	B	Ragnar	B
Mal	C	Rainier	C
Manley	B	Raught	B
Marble	A	Reardan	C
Mashel	B	Reed	D
Maytown	C	Reed, Drained or Protected	C
McKenna	D	Renton	D
McMurray	D	Republic	B
Melbourne	B	Riverwash	variable
Menzel	B	Rober	C
Mixed Alluvial	variable	Salal	C
Molson	B	Salkum	B
Mondovi	B	Sammamish	D
Moscow	C	San Juan	A
Mukilteo	C/D	Scamman	D
Naff	B	Schneider	B
Narcisse	C	Schumacher	B
Nargar	A	Seattle	D
National	B	Sekiu	D
Neilton	A	Semiahmoo	D
Newberg	B	Shalcar	D
Nez Perce	C	Shano	B
Nisqually	B	Shelton	C
Nooksack	C	Si	C
Norma	C/D	Sinclair	C
Ogarty	C	Skipopa	D
Olete	C	Skykomish	B
Olomount	C	Snahopish	B
Olympic	B	Snohomish	D
Orcas	D	Snow	B
Oridia	D	Solduc	B
Orting	D	Solleks	C
Oso	C	Spana	D
Ovall	C	Spanaway	A/B
Palouse	B	Speigle	B
Pastik	C	Spokane	C
Peone	D	Springdale	A
Pheeney	C	Sulsavar	B
Phelan	D	Sultan	C
Phoebe	B	Sultan variant	B
Pilchuck	C	Sumas	C
Potchub	C	Swantown	D
Tacoma	D	Vailton	B

Soil Type	Hydrologic Soil Group	Soil Type	Hydrologic Soil Group
Tanwax	D	Vassar	B
Tanwax, Drained	C	Verlot	C
Tealwhit	D	Wapato	D
Tekoa	C	Warden	B
Tenino	C	Wethey	C
Tisch	D	Whidbey	C
Tokul	C	Wilkeson	B
Townsend	C	Winston	A
Triton	D	Wolfeson	C
Tukwila	D	Woodinville	B
Tukey	C	Yelm	C
Uhlig	B	Zynbar	B
Urbana	C		

Notes:

Hydrologic Soil Group Classifications, as defined by the Soil Conservation Service:

A = (Low runoff potential) Soils having low runoff potential and high infiltration rates, even when thoroughly wetted. They consist chiefly of deep, well- to excessively drained sands or gravels, and have a high rate of water transmission (greater than 0.30 in/hr).

B = (Moderately low runoff potential) Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well- to well-drained soils, with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15–0.3 in/hr).

C = (Moderately high runoff potential) Soils having low infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine textures. These soils have a low rate of water transmission (0.05–0.15 in/hr).

D = (High runoff potential) Soils having high runoff potential. They have very low 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 material. These soils have a very low rate of water transmission (0–0.05 in/hr).

* = From SCS, TR-55, Second Edition, June 1986, Exhibit A-1. Revisions made from SCS, Soil Interpretation Record, Form #5, September 1988 and various county soil surveys.

This information can also be found online at: websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx

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