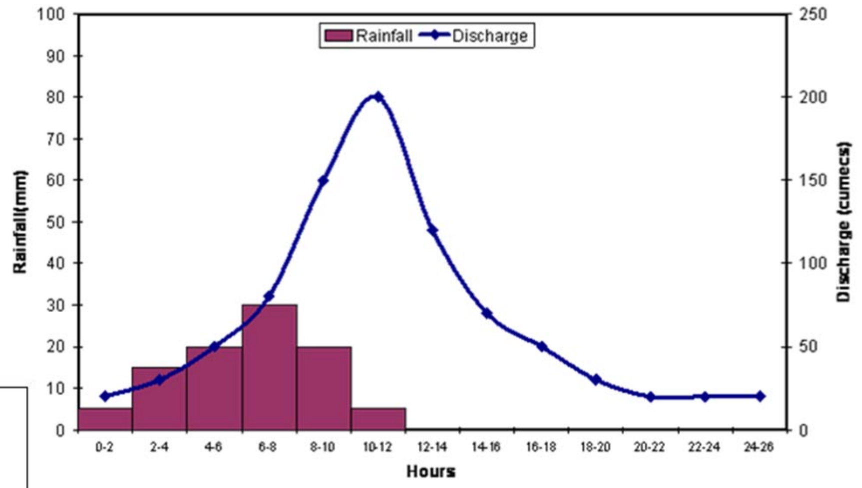
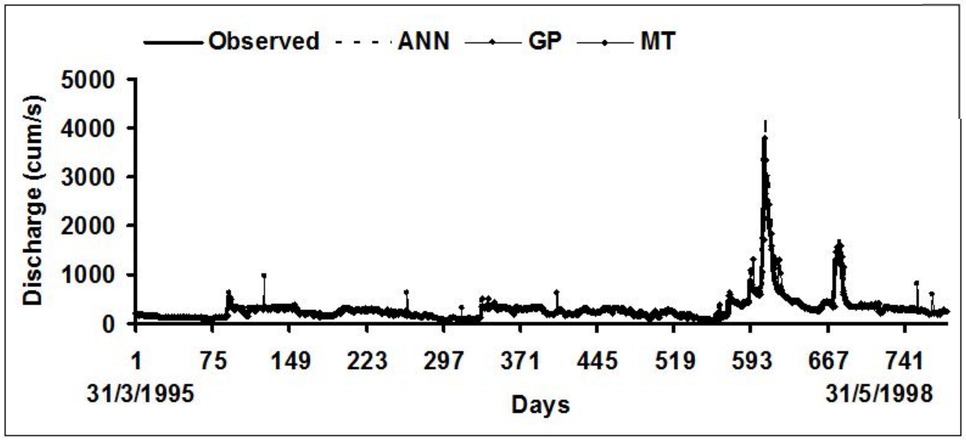
Lesson 2: Hydraulics and Hydrology Methods (HM Chapter 2)





H&H Methods

- What is the difference between Hydraulics and Hydrology?
- What are the different methods used by WSDOT to calculate flow?
- What tools and software models does WSDOT require for Hydraulic and Stormwater design on WSDOT projects?
- How do I design:
  - a roadway culvert?
  - a roadway ditch?
  - a pipe network including inlet/Catch Basin/Manhole spacing?

H&H Methods

What's the difference between Hydraulics and Hydrology anyways?

Hydrology - The study or science of transforming rainfall amount into quantity of runoff.

Hydraulics – The study or science of the motion of liquids in relation to disciplines such as fluid mechanics and fluid dynamics.

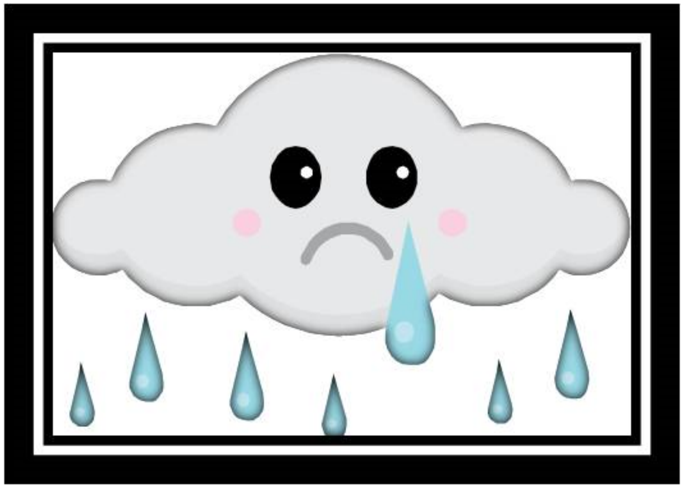
It rains and roadway surface runoff flows into the roadway ditch = hydrology

Determining the water level in the ditch and how fast the water is moving = hydraulics

Hydrology Methods

Hydrology Methods: Flow rates can be determined using:

- Santa Barbara Urban Hydrograph Method (SBUH)
- Continuous Simulation Method (western WA for stormwater design)
- United States Geological Survey (USGS) Regression Equations (StreamStats)
- USGS Streamflow Gages - Published Flow Records
- Rational Formula
- FEMA Flood Studies
- Documented Testimony – used to back up assumptions



Hydraulic Software/Tools

We take flow rates from the ***hydrology methods*** and use the following tools for ***hydraulic calculations***:

- StormShed3G – conveyance (storm sewer, culvert, pipe, and ditch) design statewide and stormwater BMP design in eastern WA
- MGSFlood - stormwater Best Management Practice (BMP) design and temporary construction stream bypass design in western WA
- FHWA HY-8 – culvert design
- HEC-RAS (one dimensional) and SRH2D (two dimensional) flow modeling to determine water surface profiles, scour design, fish passage design
- WSDOT inlet spacing and sag inlet spreadsheets
- WSDOT pipe sizing spreadsheet using Manning's equation

We want to design a culvert

We use this to develop the flow rate to the culvert

Type	MRI (...ears)[1]	Hydrology Method	Recommended Design Tools and Software[4]
	10	Rational	Inlet Spreadsheet
...n Inlet ...gitudina... ...curve	10 50	Rational Rational	Inlet Spreadsheet Sag Spreadsheet
...ns • Laterals • Trunk lines	25 2...	SBUH/SCS	StormShed or Storm Drain Spreadsheet[5]
Ditches...	10	SBUH/SCS	StormShed
Standard Culverts • Design for HW/D ratio[3] • Check for high flow damage	25 100	Published flow records, Flood reports (FIS), USGS Regression, or Rational Method	HY-8 or HEC-RAS
Bottomless Culverts • Design for HW depth[3]	100	Same as standard culverts (except rational method)	HY-8
Bridges • Design for flow passage and foundation scour • Check for high flow damage	100 500	Same as standard culverts (except rational method)	
Stormwater Best Management Practices (BMPs)	See HRM		

We use this software for design and sizing the culvert

[1]See Appendix 4C of HRM for further guidance on selecting design storms.

[2]More design guidance for roadside ditches can be found in Section 4-3.

[3]For temporary culvert design see Section 3-3.1.1.

[4]If a different method or software is selected other than those noted, the reason for not using the standard WSDOT method should be explained and approved as part of the 10 percent submittal. The following web link contains a detailed description of all current programs and design tools recommended by WSDOT. (www.wsdot.wa.gov/Design/Hydraulics/ProgramDownloads.htm)

[5]Must obtain prior approval from Region Hydraulic Engineer in order to use this method for designing storm drains.

Design Frequency for Hydraulic Structures
Figure 1-4

One Stop Shopping!

MGSFlood (western WA only) and StormShed3G (statewide) are hydraulic models that also develop hydrology for the basin of interest

MGSFlood is used for stormwater BMP sizing in western WA only

StormShed3G is used for conveyance design statewide

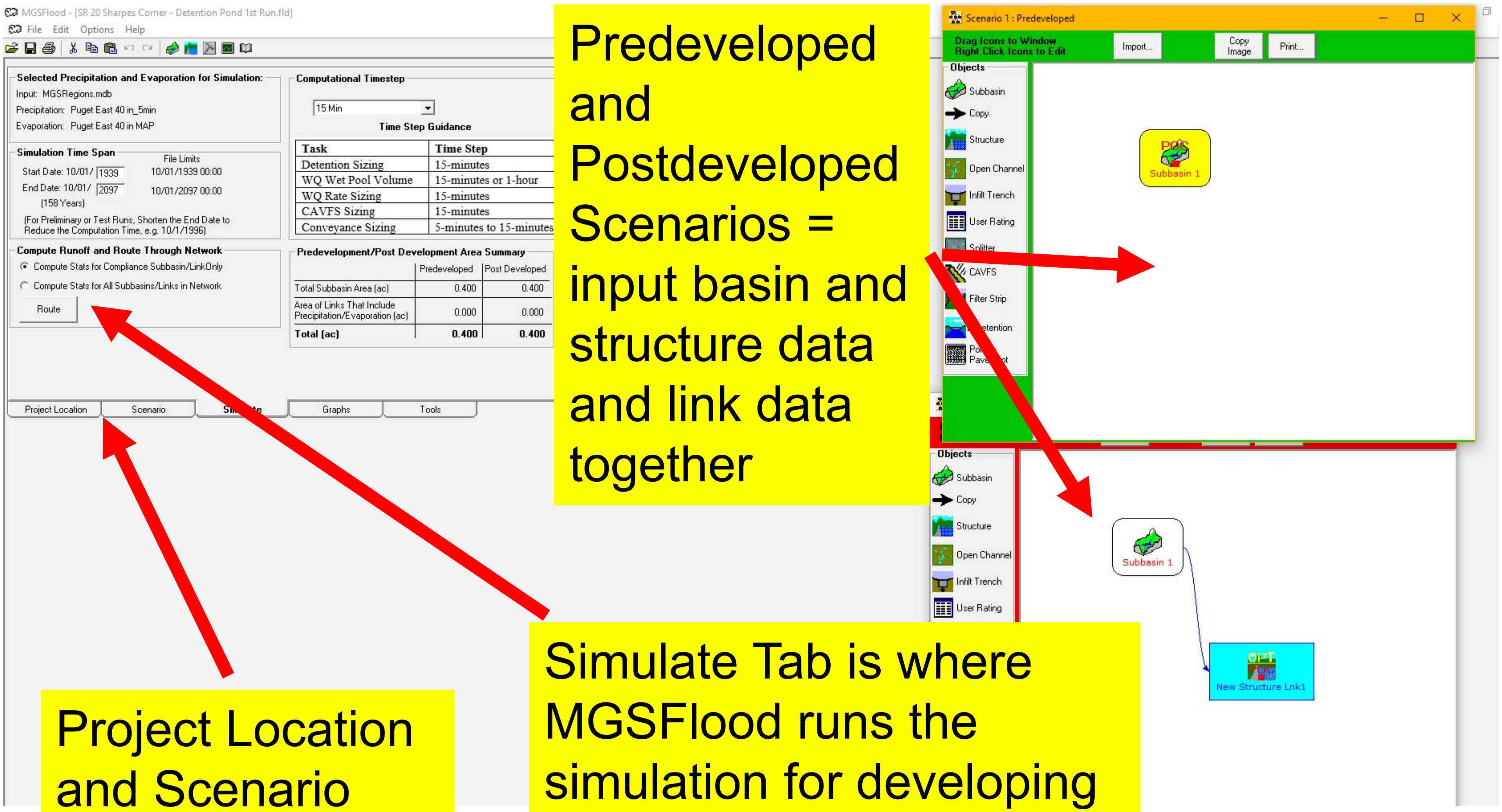
StormShed3G is used for stormwater BMP sizing in eastern WA only

MGSFlood

Here's what you will need to run the model for stormwater BMP design:

- Precipitation for your project area using mean annual precipitation maps or latitude and longitude coordinates
- Drainage basin sizes and land covers for predeveloped and post developed condition
  - Forest, Pasture, Grass, Saturated Soils, Impervious
  - **Use MGSFlood Inputs Spreadsheet on HRM Revisions webpage**
- Set up Basin to BMP links
- Use MGSFlood to size your BMP
- Use MGSFlood to design a temporary construction stream bypass when doing a fish passage or culvert replacement project.

MGSFlood



Task	Time Step
Detention Sizing	15-minutes
WQ Wet Pool Volume	15-minutes or 1-hour
WQ Rate Sizing	15-minutes
CAVFS Sizing	15-minutes
Conveyance Sizing	5-minutes to 15-minutes

	Predeveloped	Post Developed
Total Subbasin Area (ac)	0.400	0.400
Area of Links That Include Precipitation/Evaporation (ac)	0.000	0.000
Total (ac)	0.400	0.400

Predeveloped and Postdeveloped Scenarios = input basin and structure data and link data together

Simulate Tab is where MGSFlood runs the simulation for developing hydrology and sizing

Project Location and Scenario Tabs require different data

StormShed3G

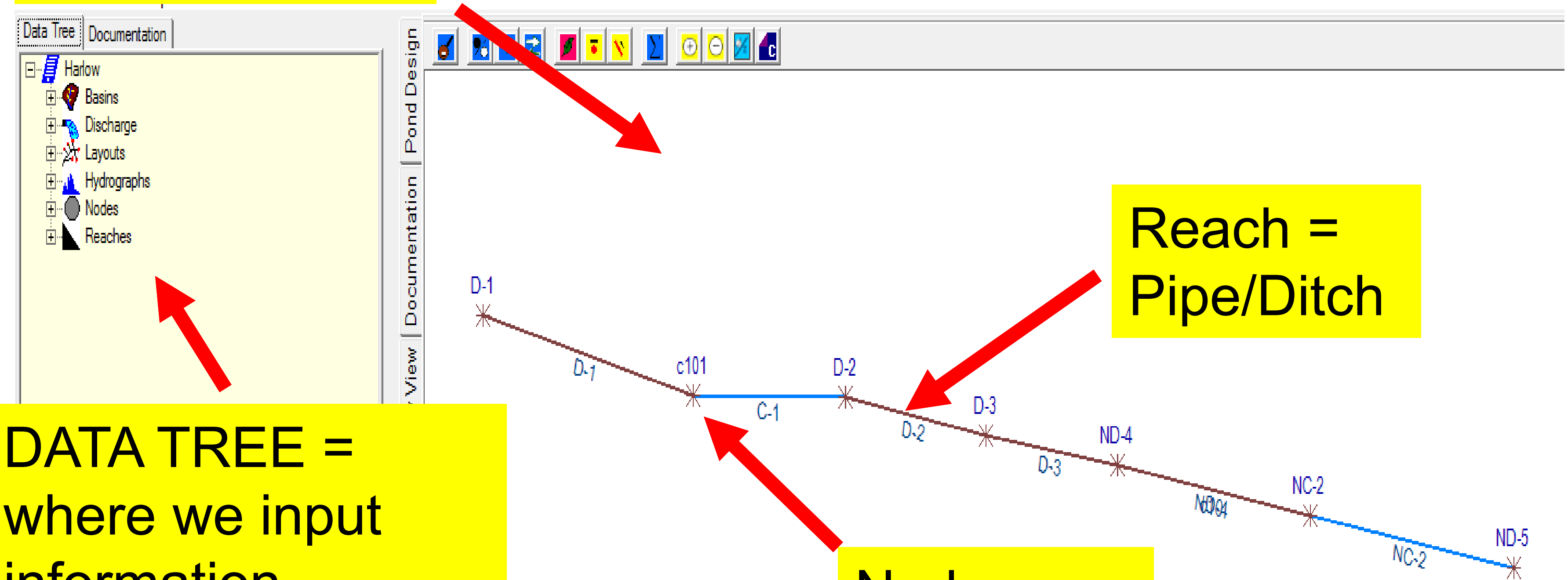
Here's what you will need to run the model for conveyance design:

- Precipitation for your project area using isopluvial maps
- Drainage basin sizes and land covers
  - Curve Numbers (CN) represent forest (CN= 70) to impervious land covers (CN = 98)
  - Time of concentration needs to be developed using sheet, shallow, and channelized flow inputs
- Pipe and/or ditch locations, elevations, and geometry to lay out conveyance network
- Define any downstream tail water conditions

There are StormShed3G classes that walk though detailed analysis method and examples

StormShed3G

Layout = where we link data together



Reach = Pipe/Ditch

DATA TREE = where we input information – CB/MH/PIPE/Ditch/ Basin Information

Nodes = CB/MH/GI

H&H Methods

Rain on Snow Design

$$\text{Snow Water Equivalent} = \frac{\text{Average Snow Depth (max. month (in/day))}}{5}$$

- **Snow Depth Chart (WRCC Data)**
- **Average Snow Depth > 2 inches/day**
- **Equation**
- **Max of 1.5 inches**
- **Additional considerations (Roadside drainage, retention ponds, frozen ground)**

Hydrology: Rational Method

RATIONAL METHOD FUN FACTS FOR WSDOT DESIGNS

- Generally overestimates flow rates but requires minimal input
- Is suitable for new facility designs since it incorporates a level of safety into the design
- May not be suitable for determining the existing condition or existing capacity of hydraulic structure

Hydrology: Rational Method

$$Q = \frac{CIA}{K_c}$$

Where:

Q = runoff in cubic feet per second (cubic meters per second)
C = runoff coefficient in dimensionless units
I = rainfall intensity in inches per hour (millimeters per hour)
A = drainage area in acres (hectares)
K_c = conversion factor of 1 for English (360 for Metric units)

- **Limitations**
- **C for different return intervals (Figure 2-5.2 applicable for 10-year frequency)**
  - **Increase C by 10% for 25-year frequency**
  - **Increase C by 20% for 50-year frequency**
  - **Increase C by 25% for 100-year frequency**

Hydrology: Rational Method

Rainfall Intensity

$$I = \frac{m}{(T_c)^n}$$

Where:

I = rainfall intensity in inches per hour (millimeters per hour)

T_c = time of concentration in minutes

m & n = coefficients in dimensionless units (Figures 2-5.4A and 2-5.4B)

- **m and n (HM Figure 2-5.4A)**
- **Coefficient assumptions**

Hydrology: Rational Method

Time of Concentration - Tc

$$T_t = \frac{L}{K\sqrt{S}} = \frac{L^{1.5}}{K\sqrt{\Delta H}}$$

$$T_c = T_{t1} + T_{t2} + \dots T_{tnz}$$

Where:

T_t = travel time of flow segment in minutes
T_c = time of concentration in minutes
L = length of segment in feet (meters)
ΔH = elevation change across segment in feet (meters)
K = ground cover coefficient in feet (meters)
S = slope of segment $\frac{\Delta H}{L}$ in feet per feet (meter per meter)

- **K (Figure 2-5.3)**
- **T_c = 5 minute minimum**

Rational Method Spreadsheet

http://www.wsdot.wa.gov/Design/Hydraulics/ProgramDownloads.htm

HYDROLOGY BY RATIONAL FORMULA (English or Metric Units)

This spreadsheet calculates runoff rate and volume using the rational method. Enter the data in the grey shaded areas only.

Project Name: | *SR :* | *Designed By:*

Project Number: | *Date:*

Q = Flow (cfs or m^3/s)

L = Length of drainage basin (ft or m)

S = Average slope (ft/ft, m/m)

K = Ground cover coeeficient (ft/min or m/mi

I = Rainfall intensity (in/hr or mm/hr)

T_c = time of concentration (min)

m & n = Rainfall coefficients

K_c = Conversion factor (1 for English, 360 for Metric)

C = Runoff coefficient

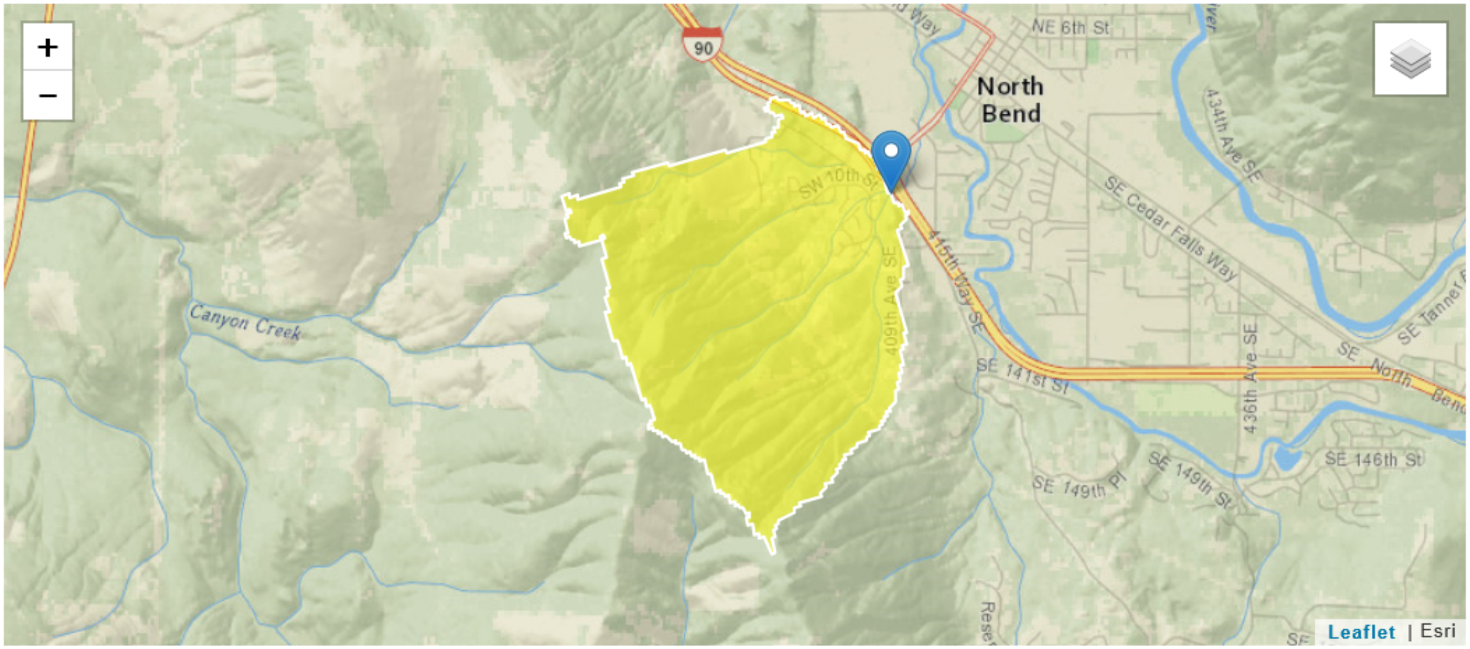
A = Drainage area (acres or ha)

Description of Area	MRI	L	S	K	T_c	Rainfall Coefficients		K_c	C	I	A	Q

USGS Regression Equations (StreamStats)

- Used for large rural or non-urban basins to develop flows for fish passage design and culvert design
- StreamStats Web Application - Uses USGS Regression Equations to develop flow rates at a certain point
  - Point and click and StreamStats gives basin information, flow rates, drainage area, etc.
- New regression equations and new 2 versions of StreamStats available

Workspace ID:	WA20170918224625752000
Clicked Point (Latitude, Longitude):	47.48639, -121.79571
Time:	2017-09-18 15:46:44 -0700



Low-Flow Statistics Parameters [Low Flow Western 2 var 2012 5078]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	2.32	square miles	0.1	48.9
PRECIP	Mean Annual Precipitation	79.9	inches	25.1	143

Low-Flow Statistics Flow Report [Low Flow Western 2 var 2012 5078]

PII: Prediction Interval-Lower, PIu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SE
7 Day 10 Year Low Flow	0.497	ft^3/s	114

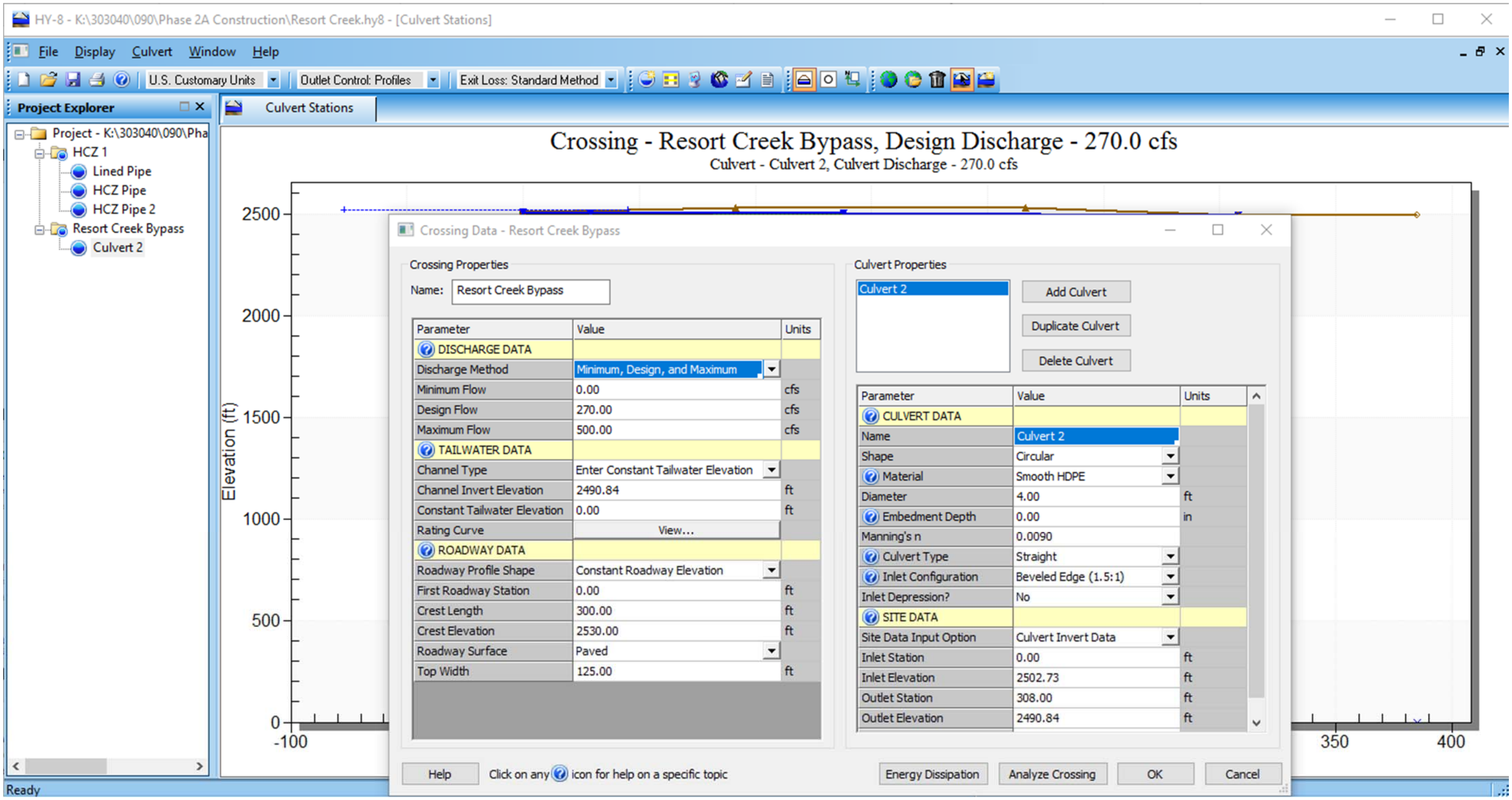
Low-Flow Statistics Citations

Curran, C.A., Eng, Ken, and Konrad, C.P.,2012, Analysis of low flows and selected methods for estimating low-flow characteristics at partial-record and ungaged stream sites in western Washington: U.S. Geological Survey Scientific Investigations Report 2012-5078, 46 p.

HY-8

- Developed by FHWA
- Based on FHWA's Hydraulic Design Series (HDS) 5 and Hydraulic Engineering Circular (HEC) 14
- Preferred method for culvert design
- Multiple culverts

HY-8



HY-8 - K:\303040\090\Phase 2A Construction\Resort Creek.hy8 - [Culvert Stations]
File Display Culvert Window Help
U.S. Customary Units
Outlet Control: Profiles
Exit Loss: Standard Method
Project Explorer
Culvert Stations
Project - K:\303040\090\Pha
HCZ 1
Lined Pipe
HCZ Pipe
HCZ Pipe 2
Resort Creek Bypass
Culvert 2
Crossing - Resort Creek Bypass, Design Discharge - 270.0 cfs
Culvert - Culvert 2, Culvert Discharge - 270.0 cfs
Elevation (ft)
Crossing Data - Resort Creek Bypass
Crossing Properties
Name: Resort Creek Bypass
Parameter | Value | Units
DISCHARGE DATA
Discharge Method | Minimum, Design, and Maximum
Minimum Flow | 0.00 | cfs
Design Flow | 270.00 | cfs
Maximum Flow | 500.00 | cfs
TAILWATER DATA
Channel Type | Enter Constant Tailwater Elevation
Channel Invert Elevation | 2490.84 | ft
Constant Tailwater Elevation | 0.00 | ft
Rating Curve | View...
ROADWAY DATA
Roadway Profile Shape | Constant Roadway Elevation
First Roadway Station | 0.00 | ft
Crest Length | 300.00 | ft
Crest Elevation | 2530.00 | ft
Roadway Surface | Paved
Top Width | 125.00 | ft
Culvert Properties
Culvert 2
Add Culvert
Duplicate Culvert
Delete Culvert
Parameter | Value | Units
CULVERT DATA
Name | Culvert 2
Shape | Circular
Material | Smooth HDPE
Diameter | 4.00 | ft
Embedment Depth | 0.00 | in
Manning's n | 0.0090
Culvert Type | Straight
Inlet Configuration | Beveled Edge (1.5:1)
Inlet Depression? | No
SITE DATA
Site Data Input Option | Culvert Invert Data
Inlet Station | 0.00 | ft
Inlet Elevation | 2502.73 | ft
Outlet Station | 308.00 | ft
Outlet Elevation | 2490.84 | ft
Help
Click on any icon for help on a specific topic
Energy Dissipation
Analyze Crossing
OK
Cancel
Ready

WSDOT Hydraulic Spreadsheets

- Most use Rational Method and Manning's Equation for sizing
  - Culvert Corrosion/Pipe Angle Calculation Worksheet
  - Storm Drain Design
  - Inlet Spacing and Sag Design
  - Short Duration Rainfall Depth Converter
  - Pond Hydraulics (orifice, wet pond, volume)
  - Biofiltration Swale (basic, wet, continuous)
  - CAVFS LID Calculator
  - MFD Underdrain
  - Slotted Pipe Flow Spreader

http://www.wsdot.wa.gov/Design/Hydraulics/ProgramDownloads.htm

http://www.wsdot.wa.gov/Environment/WaterQuality/Runoff/HighwayRunoffManual.htm

Inlet Spacing (Curb and Gutter)

- Rational Method flows
  - Design Frequency (10 year vs 50 year)
  - Coefficient (m, n, and C values)
- Inlet sizes
- Allowable spread width Z_d
- Inlet Spacing Spreadsheet
- Sag Inlet Worksheet

Inlet Spacing (Curb and Gutter)

Inlet Spacing Spreadsheet

INLET SPACING - CURB AND GUTTER SPREADSHEET (ENGLISH UNITS)

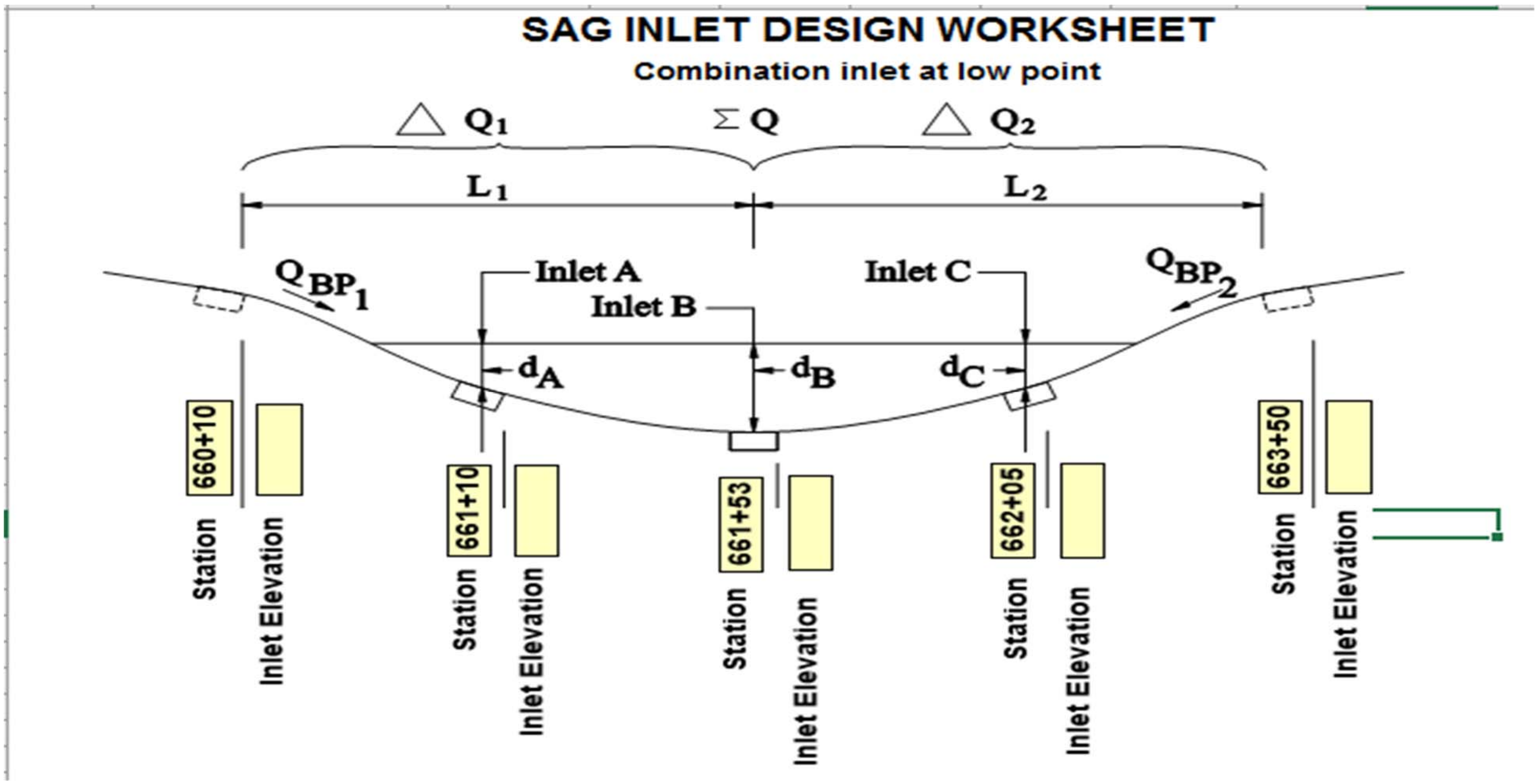
Tc =	5.00
C =	0.90
I =	2.39
m =	5.62
n =	0.53
Allowable Zd	10.50

Project Name:
Project #:
S.R.:
Designed By:
Date:
Updated:

Station	Distance	Width	ΔQ	ΣQ	Slope L	Super T	G.W.	G.L.	d	Z_d	Q_{bp}**	V continuous*	V side**	E_o	R_s	E	Q_i	Q_{bp}**	Z_d Check	Velocity Check	Q_{bp} Check	Comments (L/R)
12+00.00	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	
11+00.00	100	50.00	0.25	0.25	0.01	0.01	0.00	1.00	0.06	6.00	0.25								Zd ALLOWABLE > Zd DESIGN		NEED TO REDUCE Q_{bp}	

Sag Inlet Design

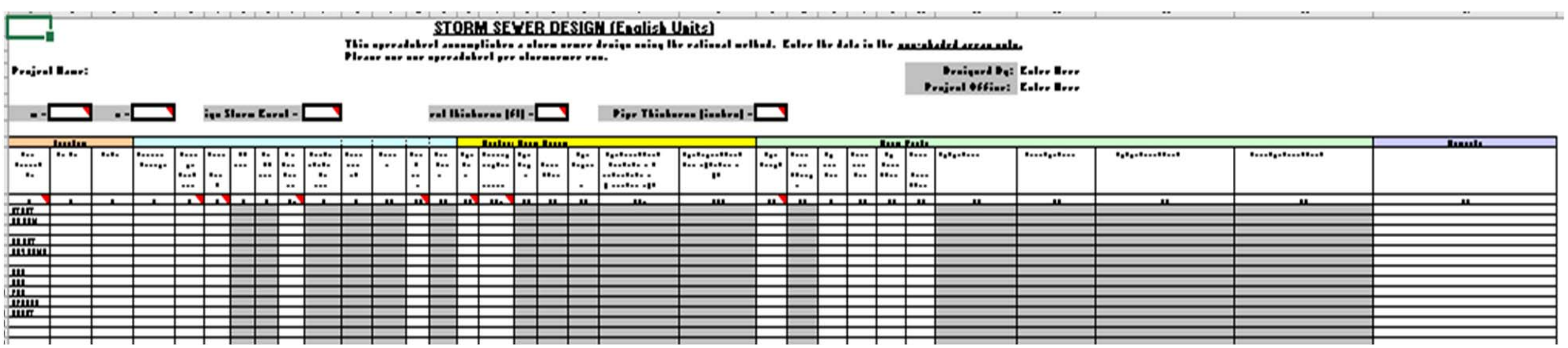
Sag Inlet Design Worksheet



Storm Drain Design (Pipe Sizing)

Storm Drain Design Spreadsheet

- Rational method
- Design frequency
- Contributing inflow
- Pipe info
- Checks (velocity, flow, cover)



Manning's Equation

$$V = \frac{1.486}{n} R^{2/3} \sqrt{S}$$

$$R = \frac{A}{P}$$

Where: V= Mean full velocity in the channel (ft/sec)

n = Manning's roughness coefficient (See Appendix 4-1)

S = Channel slope (ft/ft)

R = Hydraulic radius (ft)

A = Area of the cross section of water (ft^2)

P = Wetted perimeter (ft)

Velocity in the pipe related to Manning's roughness coefficient, the wetted area of the pipe, and the slope of the pipe

Storm Drain Design (Pipe Sizing)