9. Hydrology

Dale Higgins
Hydrologist
Chequamegon-Nicolet National Forest, WI

Contributors

- Mark Weinhold (Civil Engineer/Hydrologist, White River NF)
- Dan Cenderelli (Hydrologist, Stream Systems Technology Center)
- John Potyondy (Hydrologist, Stream Systems Technology Center)
- Bob Gubernick (Engineering Geologist, Tongass National Forest
- Traci Sylte (Hydrologist, Lolo National Forest)
- Mike Furniss (Hydrologist, Pacific Northwest Research Station)

Successful stream simulation design and construction requires:

- Knowledge of the local hydrology
- An ability to estimate a wide range of flows (transfer data from gaged to ungaged sites)

Presentation Outline

- What and Why?
- General Hydrology - Ohio
- Estimating Peak Flood Flows: Q_2 - Q_{100}
- Bankfull Flow and Elevation
- Culvert Hydraulics and Capacity
- Estimating Flows for Fish Passage and Construction

What flow data are needed? Annual Flood Peaks

- Peak hydraulic design flow
  - Determines the peak flow capacity of the structure
  - Flood-frequency analysis for 100-yr flood
  - Consider checking 500-yr flood
- Sediment mobility and stability
  - Model hydraulics to determine bed mobility and stability
  - Flood-frequency analysis for 1.5 or 100-yr flood
- Bankfull flow
  - Model hydraulics to help verify bankfull elevation
  - Flood-frequency analysis for 1.5 or 2-yr flood

Nomenclature

Recurrence Interval:

$$\text{Recurrence Interval} = \frac{1}{\text{Exceedance Probability}}$$

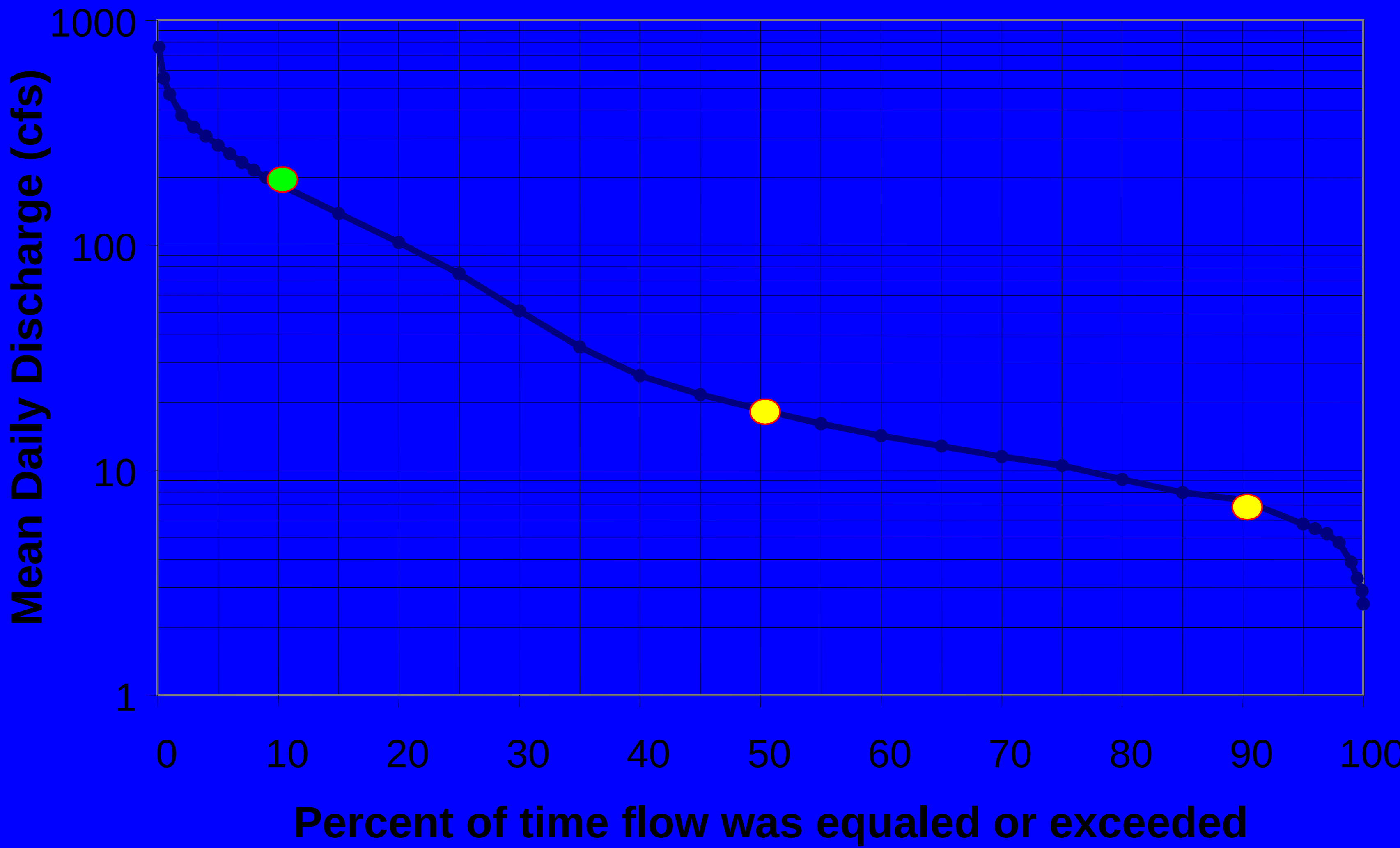
100 yr flood = 0.01 (1%) exceedance probability

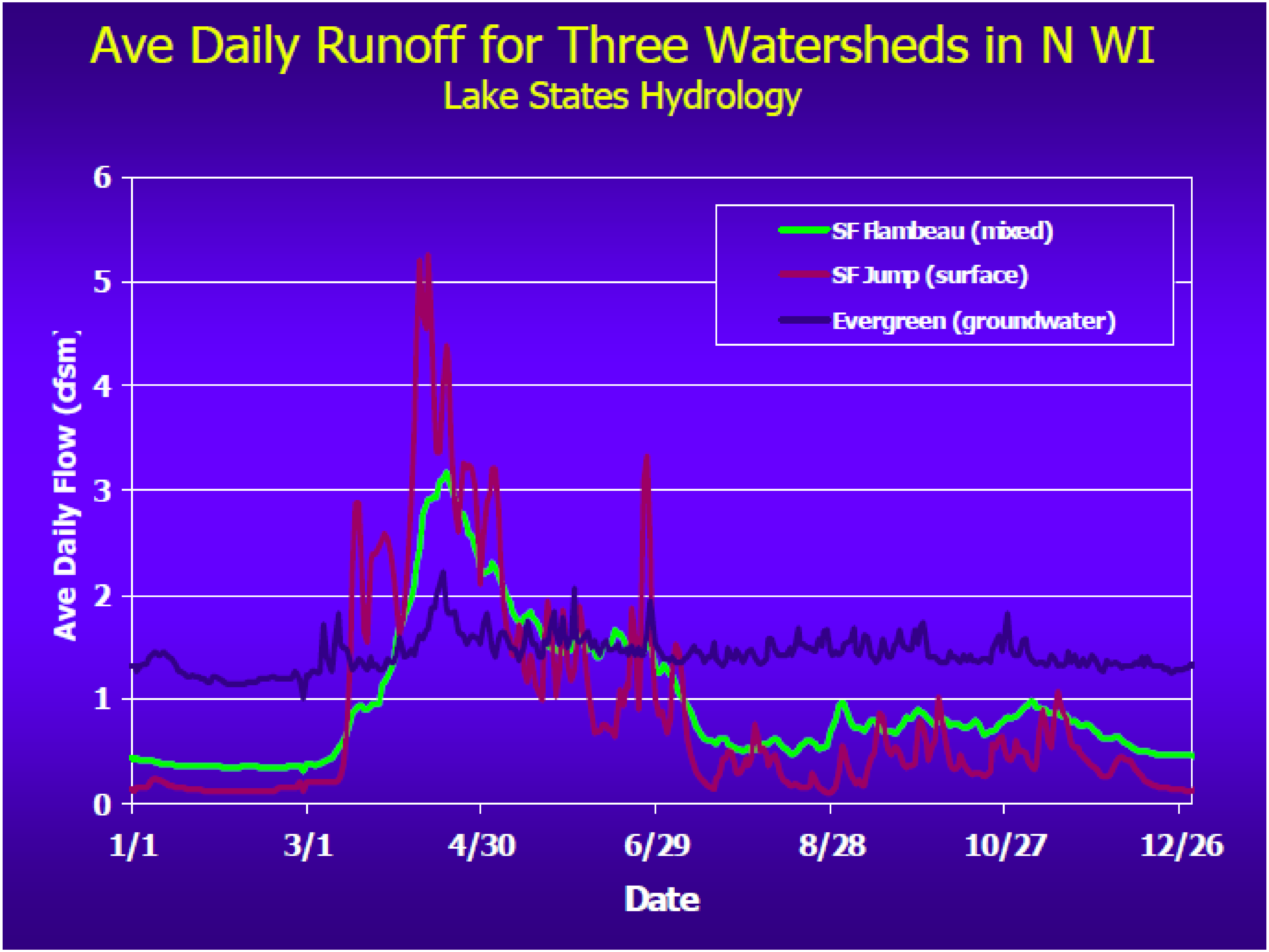
2 yr flood = 0.50 (50%) exceedance probability

What flow data are needed? Average Daily Flows

- **Construction flow**
  - Determine construction time and duration
  - Average monthly flow for that time period
  - Additional capacity or 2-yr flood for extended construction period (weeks-months, state req.)
- **High fish passage flow**
  - Determines the **velocity threshold** for fish passage
  - Typically an exceedance percentage from flow duration curve (1%-10%) or some percentage of the 2-year flood
- **Low fish passage flow**
  - Determines the **depth threshold** for fish passage
  - Exceedance percentage from flow duration curve or the 2-year, 7-day low flow

Nomenclature - Flow Duration





Ave Daily Runoff for Three Watersheds in N WI
Lake States Hydrology
6
5
4
3
2
1
0
Ave Daily Flow (cfsm)
SF Flambeau (mixed)
SF Jump (surface)
Evergreen (groundwater)
1/1
3/1
4/30
6/29
8/28
10/27
12/26
Date

Flow data and design methods

Stream Simulation Design Method

- Mimics the natural stream processes within a culvert; culvert functions as a natural channel

Requires **Peak Hydraulic Design Flow** (100-year flood), **BF Q Check**, **By-pass Flows**

Hydraulic Design Method

- Matches the hydraulic performance of a culvert with the swimming capabilities of a target species and age class of fish

Requires **High and Low Fish Passage Flows**

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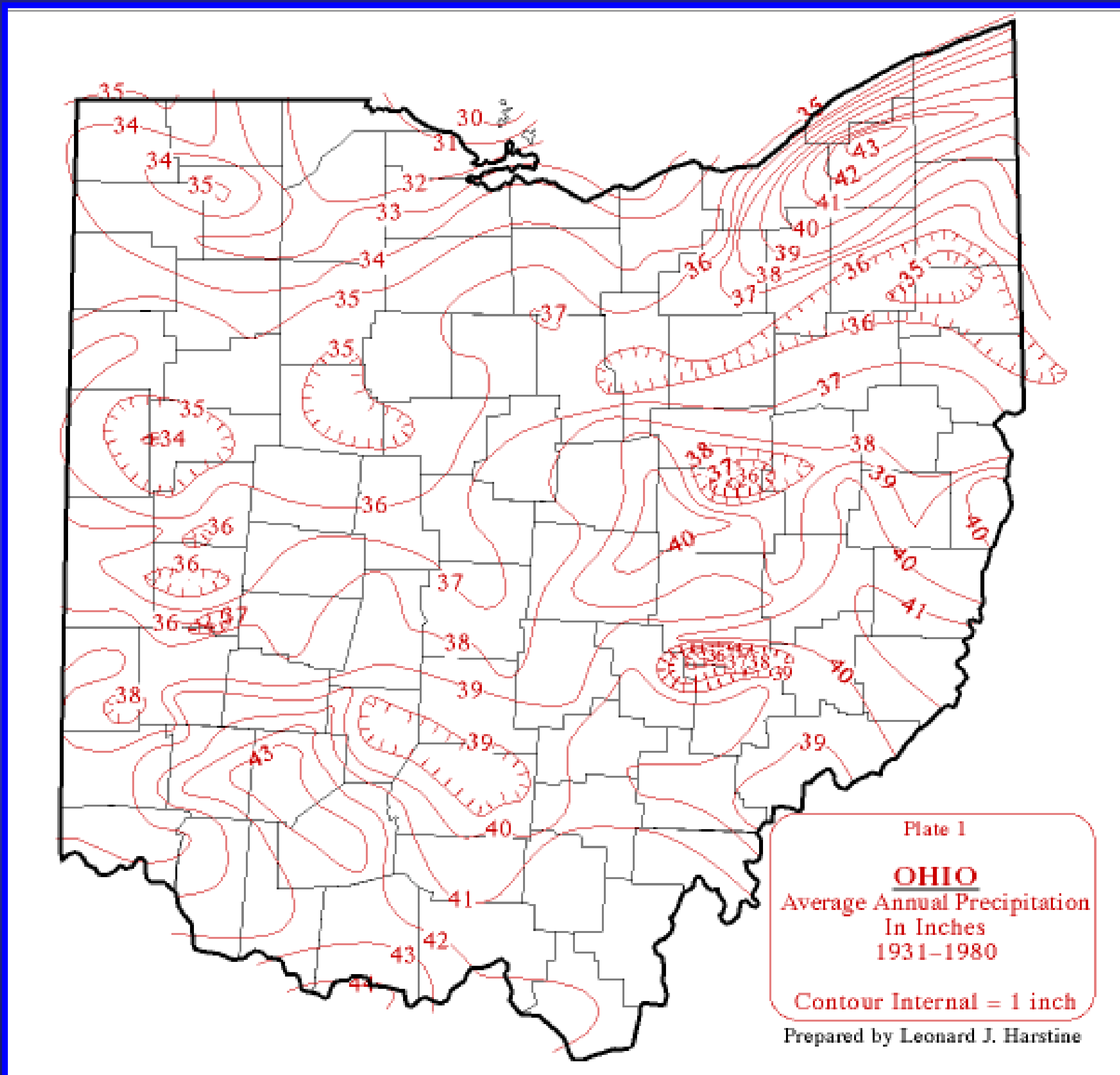
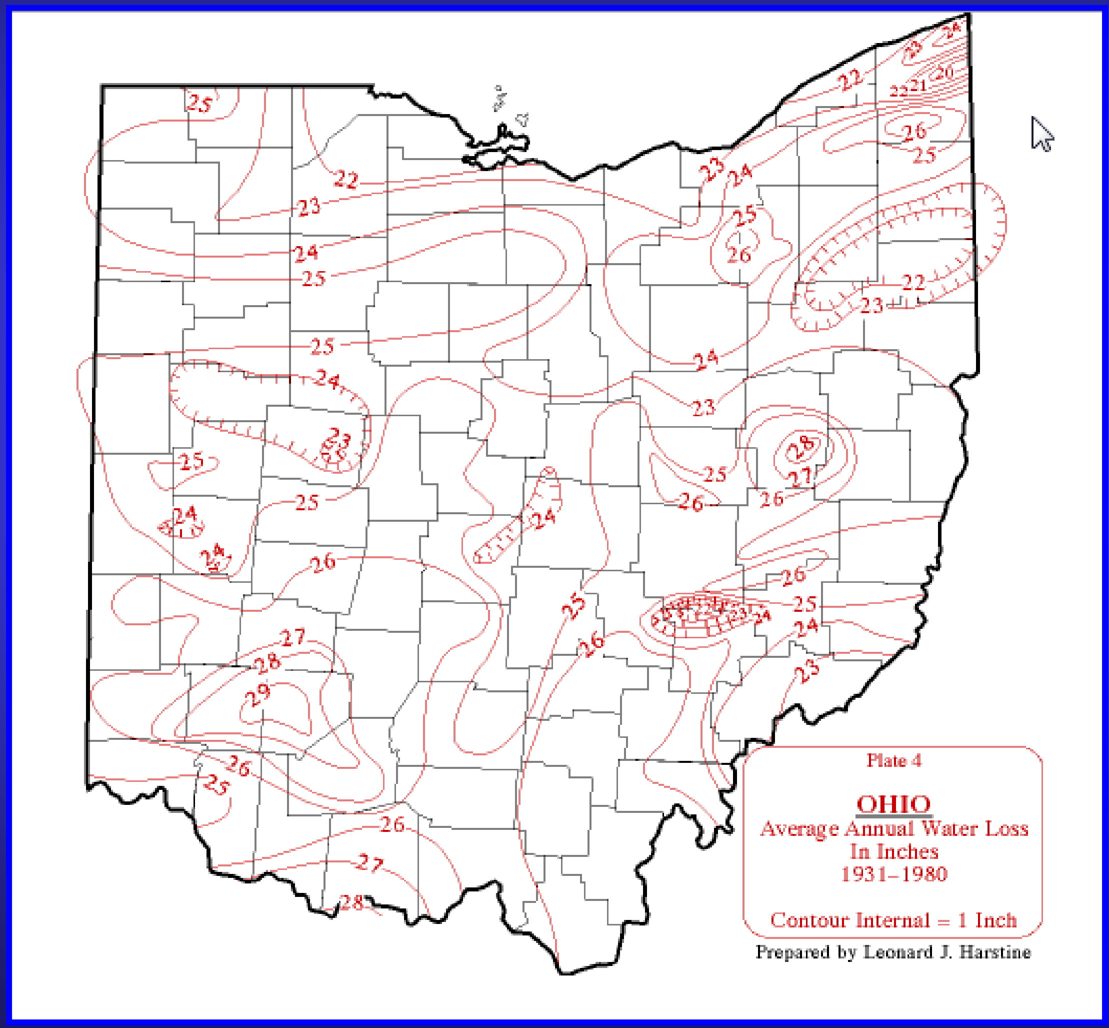
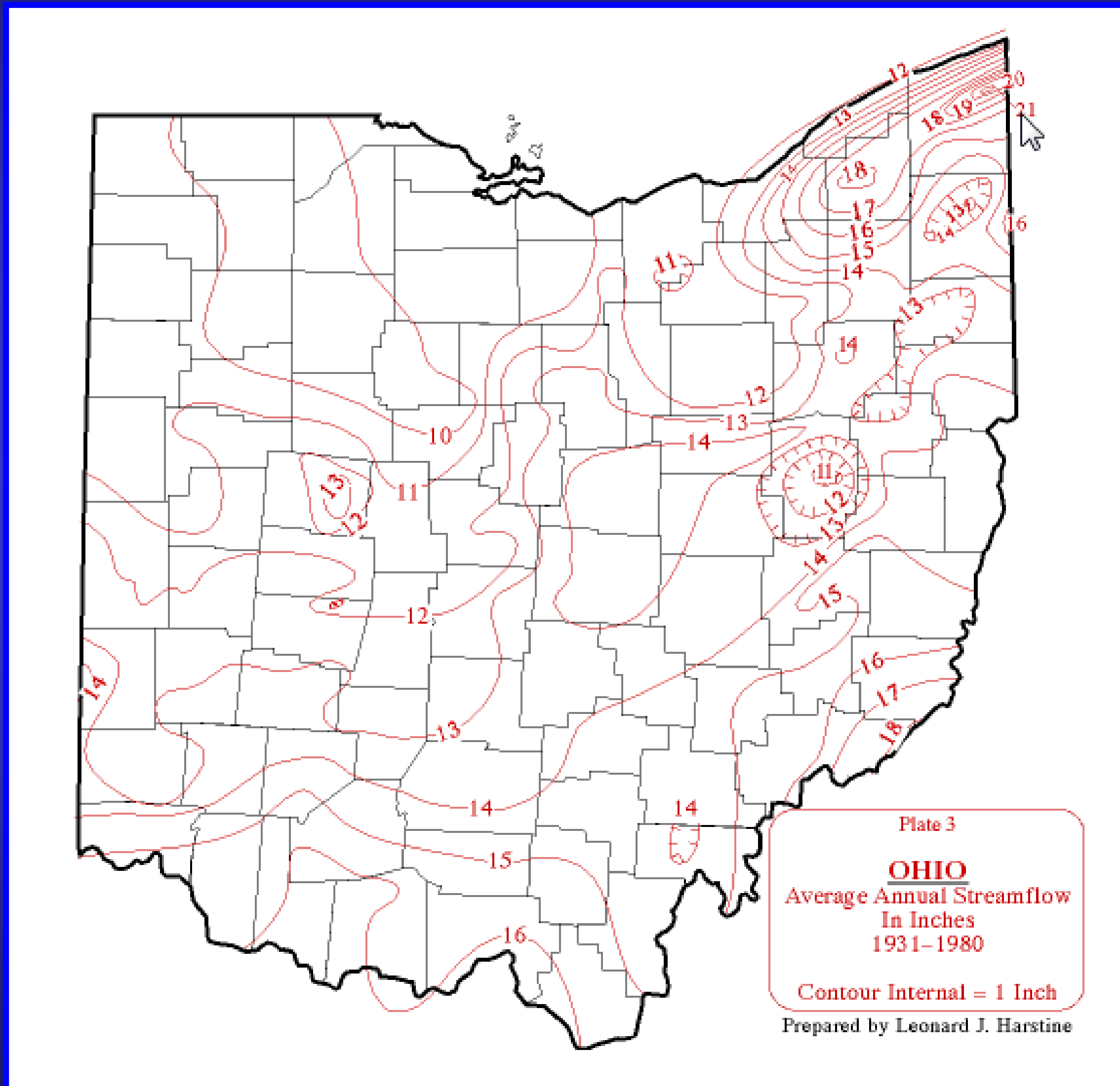
Local Hydrology: Annual Precipitation



Local Hydrology: Annual Evapo-Transpiration



Local Hydrology: Annual Runoff



Local Hydrology: Annual Water Balance

Region	Ppt (in)	ET (in)	RO (in)	RO (cfsm)
Columbus, OH	37	24	13	0.96

Sources of flow data: US Geological Survey

– Web site – National Water Information Systems (NWIS) (http://water.usgs.gov/nwis/)
  - Instantaneous peak
  - mean daily
  - mean monthly values
– Published data summaries
  - Peak flow T-year return period flows
  - annual and monthly flow with exceedance
– Custom data retrievals
  - Anything you want if you have the money, such as 7-day, 2-year low flow statistics

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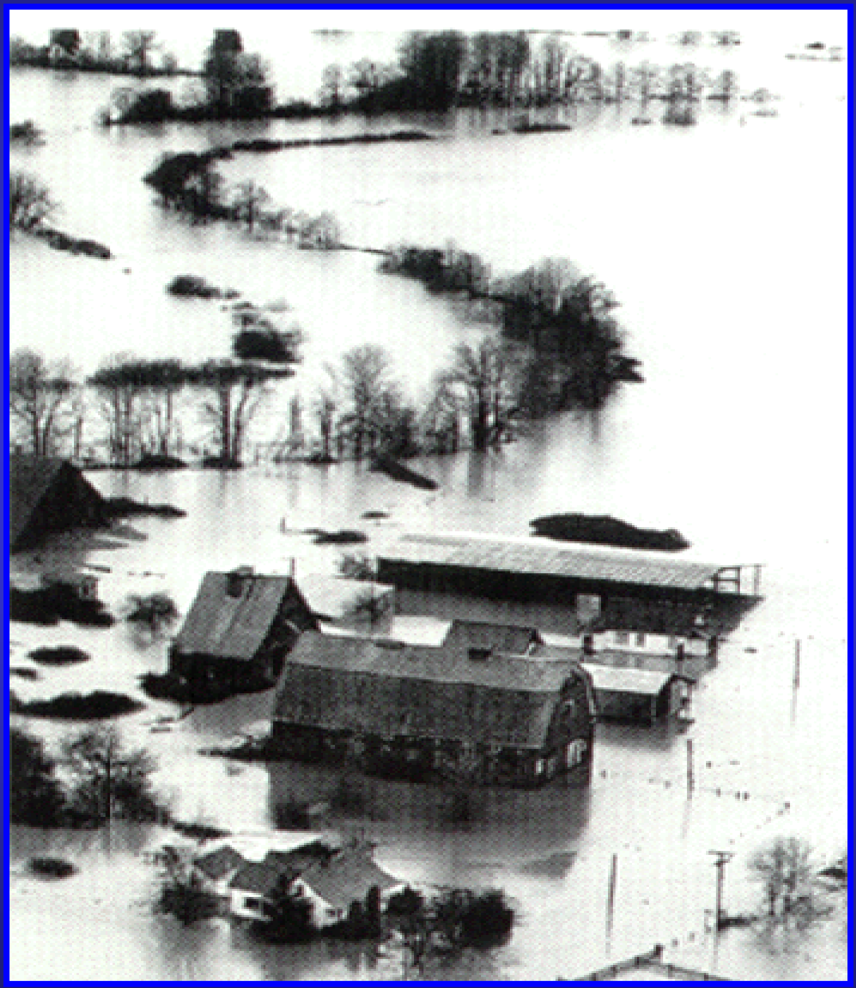
Estimating Flood Flows

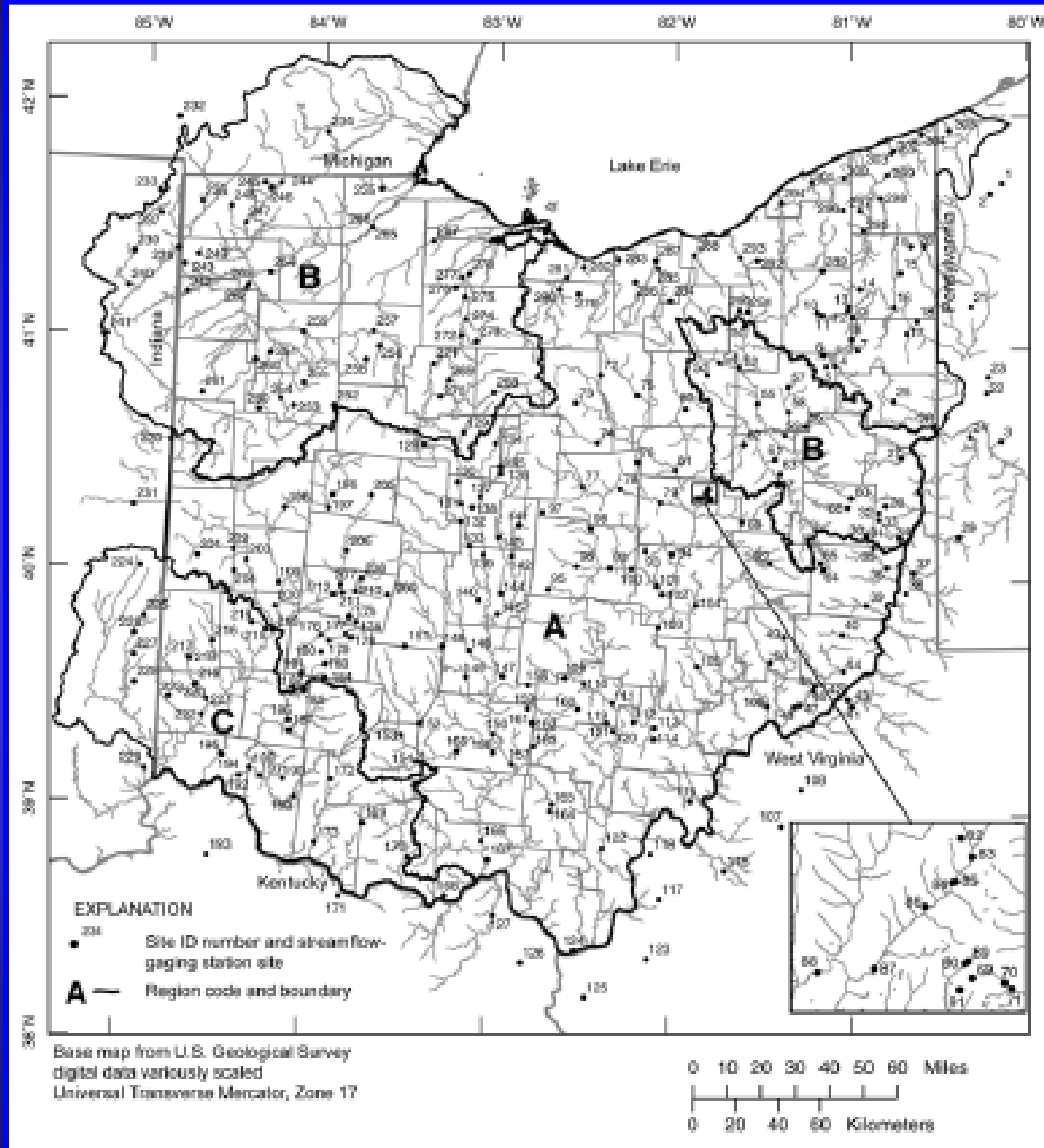


1. **Gaged sites**

2. **Sites near gaged sites on the same stream**

3. **Ungaged sites:**
   Regional regression equations

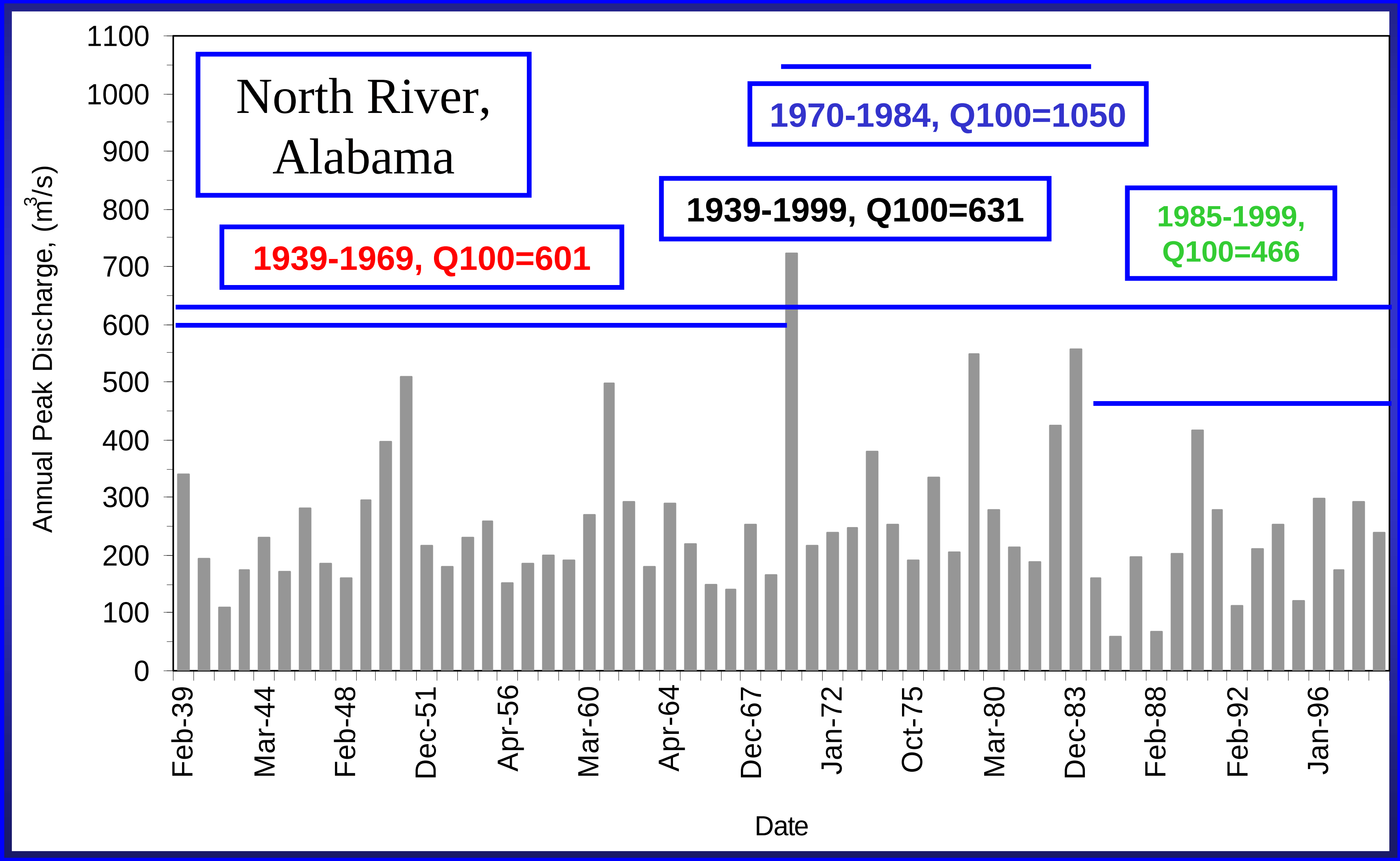
1. Gaged sites in Ohio



1. Gaged Sites: 305 in Ohio

- Use reported data
- Gaging Station Name, Number, Location
- Peak Flow for Given Recurrence Interval
  (2, 5, 10, 25, 50, 100, 500)
- Consider period of record

Importance of data length



2) Sites near gages – same stream

- **Extrapolate gaged data to ungaged location**
  - Assumes similar topography, geology, vegetation, and other characteristics that may affect flood magnitude
  - Refer to state publication
  - General Rule: Ungaged drainage area should be **50-150% of gaged drainage area**

$$Q_{100(ungaged)} = Q_{100(gaged)}\left(\frac{A_{ungaged}}{A_{gaged}}\right)^{X}$$

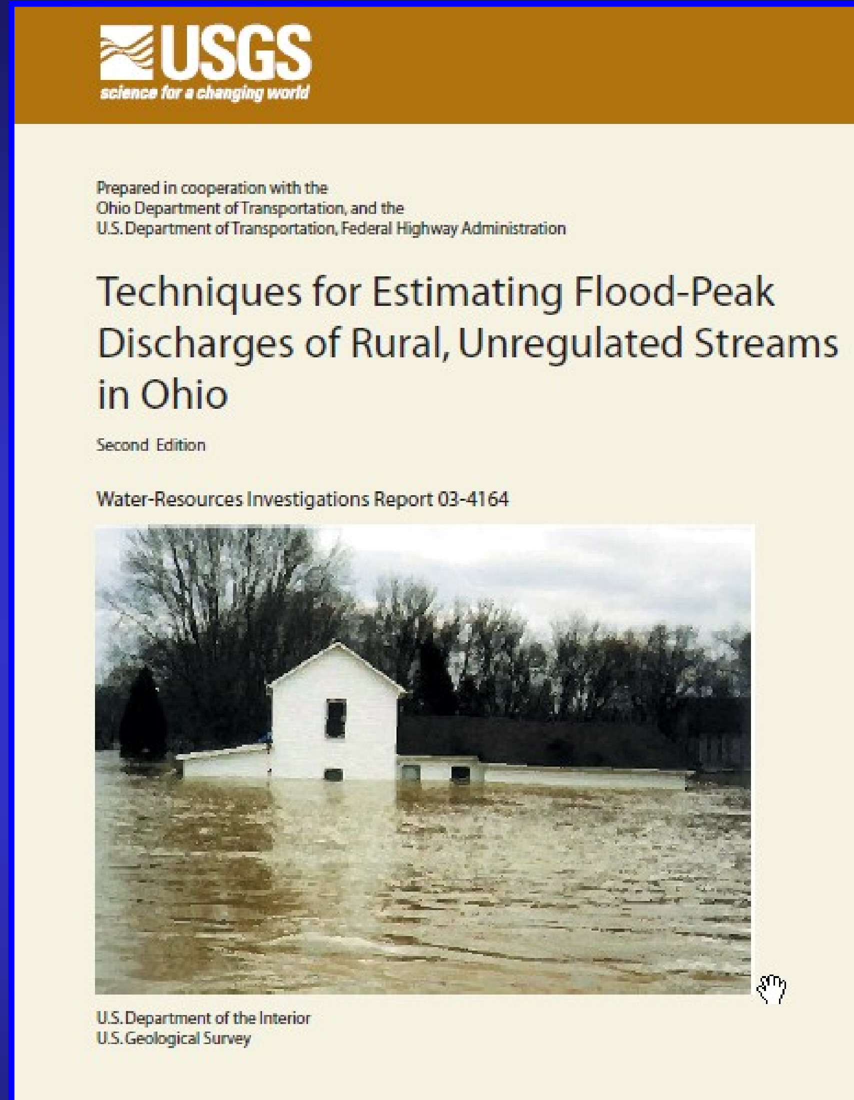
(x = can vary by flood region and recurrence interval)

3) Ungaged Sites: USGS Equations

Publications available from:
U.S. Geological Survey
Publication Distribution Center
(303) 202-4200 or (800) 435-4200
http://water.usgs.gov/software/NFF/
http://water.usgs.gov/osw/streamstats/

The Source in Ohio:

Water-Resources Investigations Report 03-4164


USGS
science for a changing world

Prepared in cooperation with the
Ohio Department of Transportation, and the
U.S. Department of Transportation, Federal Highway Administration

Techniques for Estimating Flood-Peak Discharges of Rural, Unregulated Streams in Ohio

Second Edition

Water-Resources Investigations Report 03-4164

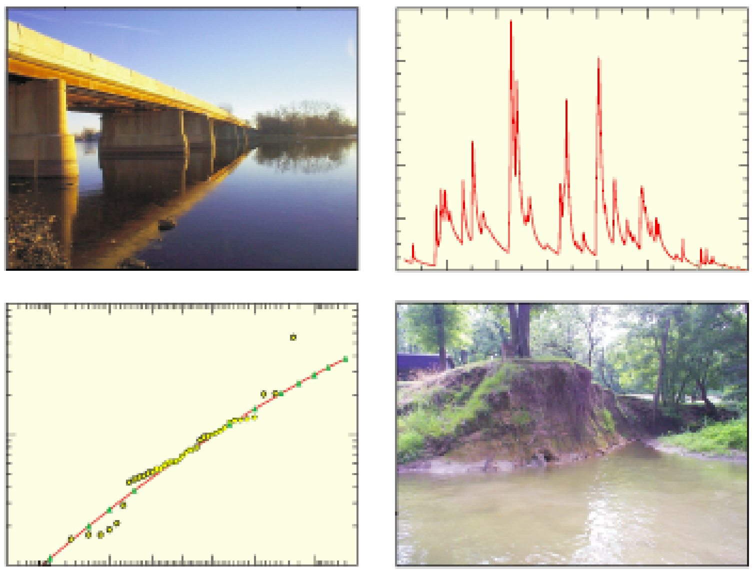
U.S. Department of the Interior
U.S. Geological Survey

By **G.F. Koltun, 2003**

Sources in Illinios and Indiana

In cooperation with the Illinois Department of Natural Resources, Offices of Water Resources, Realty and Environmental Planning–Conservation 2000 Program, and Resource Conservation; and with the Illinois Department of Transportation

Estimating Flood-Peak Discharge Magnitudes and Frequencies for Rural Streams in Illinois



Scientific Investigations Report 2004-5103

U.S. Department of the Interior
U.S. Geological Survey

Final Report

FHWA/IN/JTRP-2005/18

FLOOD FREQUENCY RELATIONSHIPS FOR INDIANA

by

A. Ramachandra Rao
Professor Emeritus
Principal Investigator
School of Civil Engineering
Purdue University

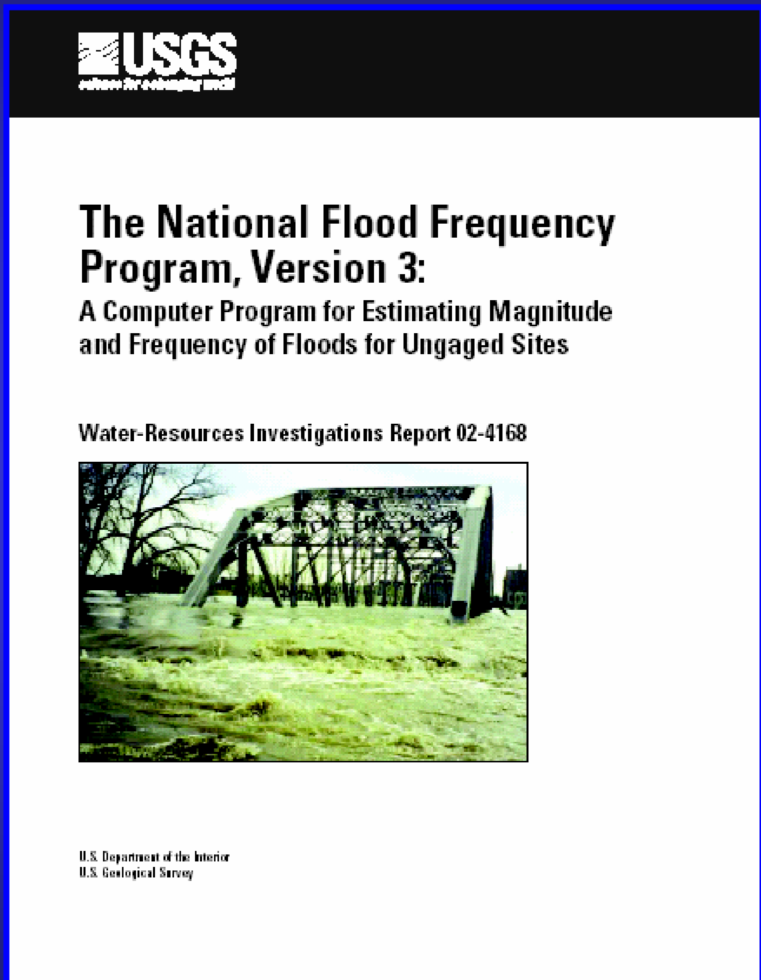
Joint Transportation Research Program
Project No. C-36-62O
File No. 9-8-15
SPR-2858

Prepared in Cooperation with the
Indiana Department of Transportation and the
Federal Highway Administration
U.S. Department of Transportation

The contents of this report reflect the views of the authors who are responsible for the fats and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration and the Indiana Department of Transportation. The report does not constitute a standard, specification, or regulation.

School of Civil Engineering
Purdue University
March 2006

National Flood Frequency (NFF) Program


USGS

The National Flood Frequency Program, Version 3:
A Computer Program for Estimating Magnitude and Frequency of Floods for Ungaged Sites

Water-Resources Investigations Report 02-4168

U.S. Department of the Interior
U.S. Geological Survey

- **Regional equations for each state in the United States**

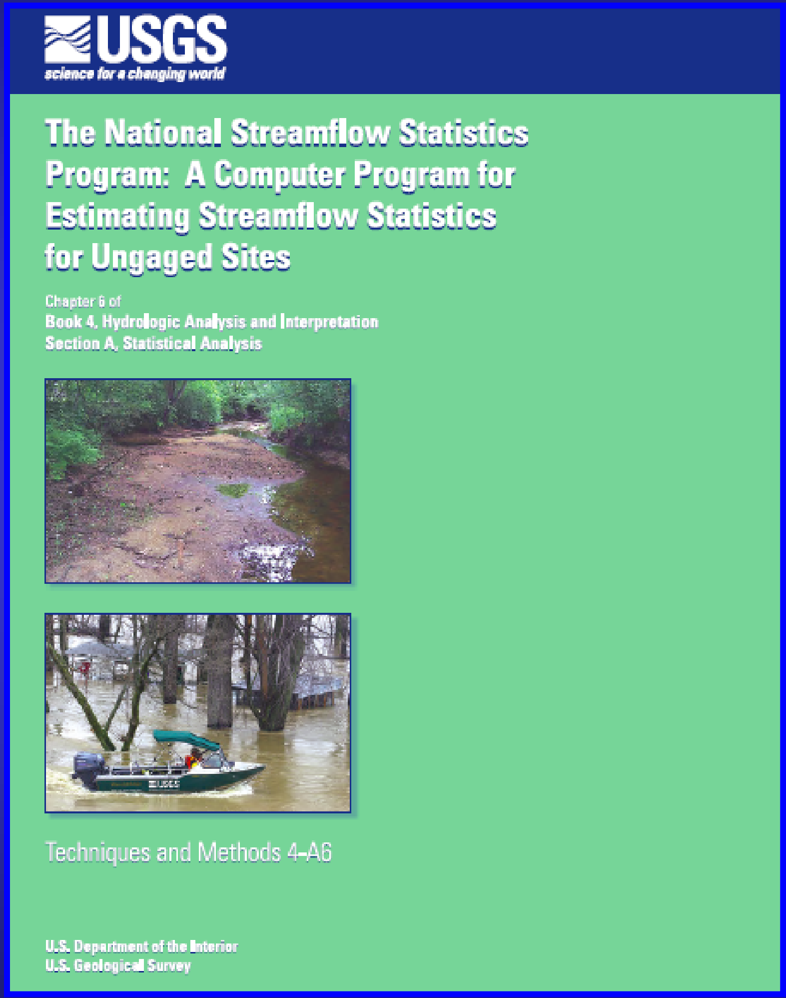
- **Computer Program**: NFF Version
  - Download software
  - Technical papers for each State
  - Latest equations for each State

http://water.usgs.gov/software/nff.html

National Streamflow Statistics (NSS) Program

- **Regional equations for each state in the United States**
- **Replacing NFF**
- **Computer Program**:
  - Download software
  - Technical papers for each State
  - Latest equations for each State

http://water.usgs.gov/software/NSS/



Ungaged sites – the typical approach

- USGS regional regression equations
  - Available for each State divided into hydrologic regions
  - Discharges at gaged sites computed using Log Pearson Type III distribution
  - Multiple regression of flow on watershed and climatic characteristics, yielding prediction equations of the form:

$$Q_T = aA^b B^c \ldots. N^n$$

  - The analysis also provides measure of accuracy; standard errors of the estimate are commonly in the range of ± 30 to 80%

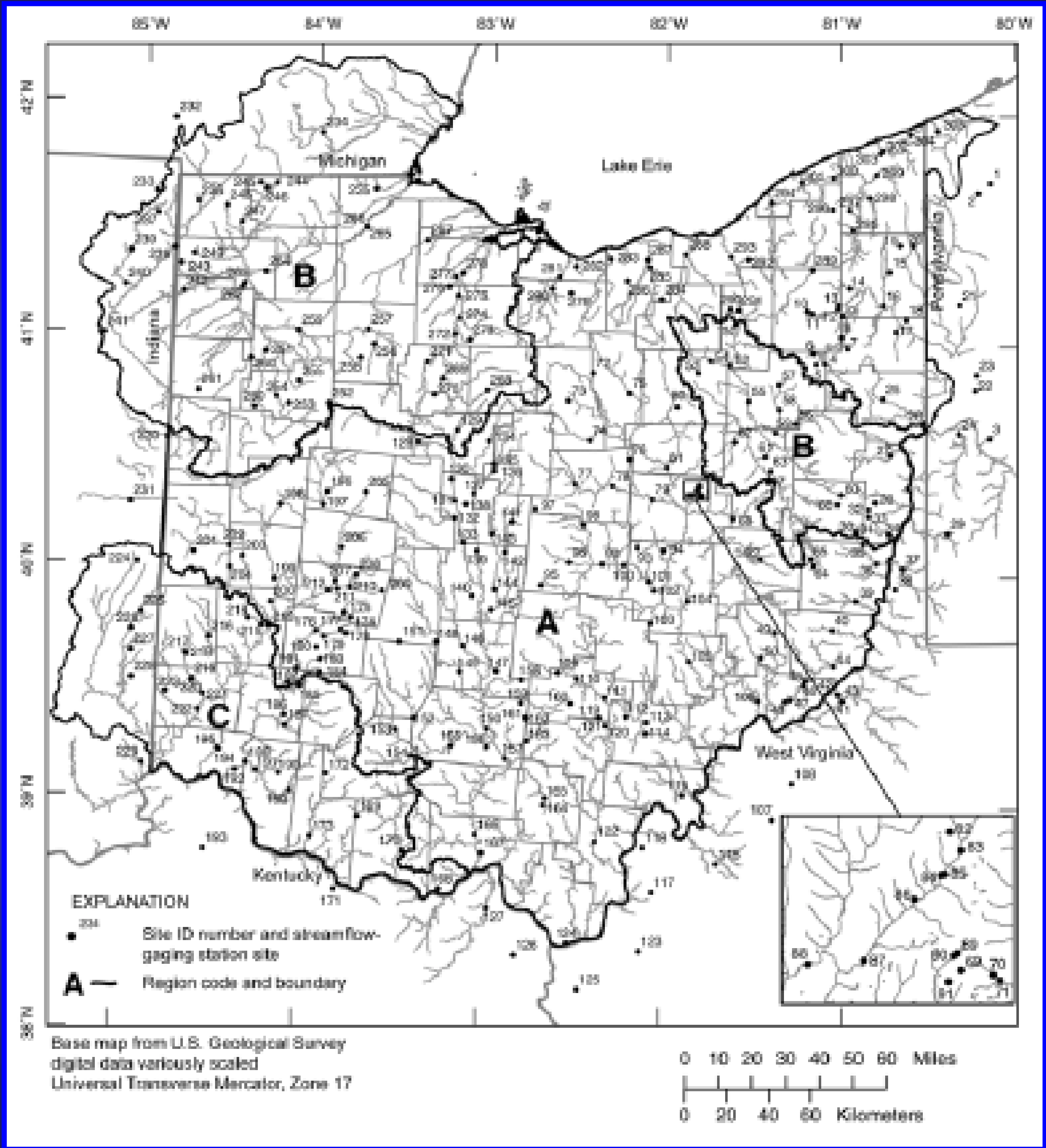
Independent Variables

- Drainage area (A)
- Mean annual precipitation (P)
- 2-year, 24-hour rainfall (I)
- Mean basin slope (S)
- Area of forests, percent (F)
- Main channel slope (SL)
- Mean basin elevation (E)
- Percent lakes, ponds and wetlands (ST)
- Basin high elevation index (% basin>6000 ft +10)
- Main channel length
- Basin shape factor
- Mean minimum January air temperature (J)
- etc….

Flood Frequency Regions in Ohio

Unique regional regression coefficients for each region and recurrence interval

3 variables for all regions: drainage area, main channel slope and water+wetlands



Sample Predictive Equations for Unregulated Streams in Ohio

(National Streamflow Statistics Program)

Hydrologic Region A:

$\mathbf{Q_2} = 58.9\ (\mathbf{DA})^{0.785}\ (\mathbf{SL})^{0.174}\ (\mathbf{W+1})^{-0.178}$	SE: 36%
$\mathbf{Q_{100}} = 197.7\ (\mathbf{DA})^{0.750}\ (\mathbf{SL})^{0.248}\ (\mathbf{W+1})^{-0.281}$	SE: 37%

Where: regression coefficients vary by region and recurrence interval

DA = drainage area (sq mi)

SL = main channel slope (ft/mi)

W = portion of basin as water and wetland (%)

Blendon Woods Upper Crossing
(National Streamflow Statistics Program)

Hydrologic Region A:

$$Q_2 = 58.9\ (DA)^{0.785}\ (SL)^{0.174}\ (W+1)^{-0.178} \qquad \text{SE: } 36\%$$

$$Q_{100} = 197.7\ (DA)^{0.750}\ (SL)^{0.248}\ (W+1)^{-0.281} \qquad \text{SE: } 37\%$$

Where: Q_2 RC = 58.9 and Q_{100} RC = 197.7

DA = drainage area (sq mi) = 0.68

SL = main channel slope (ft/mi) = 48.5

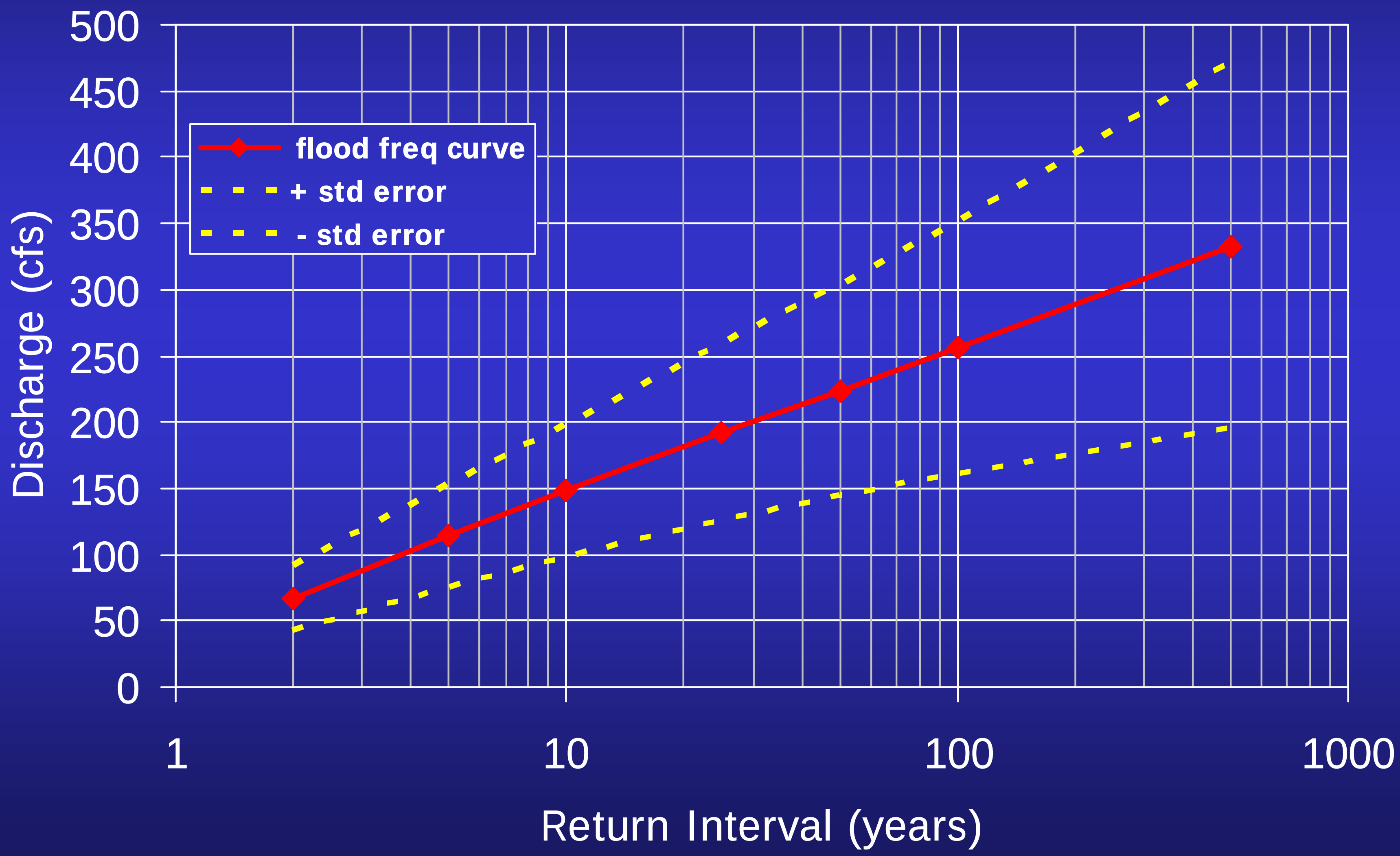
W = portion of basin as water and wetland (%) = 3.32

Results:

Q_2 = 66.7 cfs (98 cfsm)

Q_{100} = 256 cfs (376 cfsm)

Estimated Flood Frequency Curve and Prediction Error: Blendon Upper Crossing



Regional Regression Limitations

- Derive input variables using the same methods as those used to develop the equations
- Standard Errors of 33-41%
- Beware extrapolating flood estimates beyond the input data used to develop the equations
  - Typically we need estimates for small watersheds
  - Most of USGS gaging data are from larger watersheds
  - Remember that peak flow per unit area increases in smaller tributary areas (less storage and water gets to the channel faster) so adjust estimates accordingly

Regional Regression Limitations

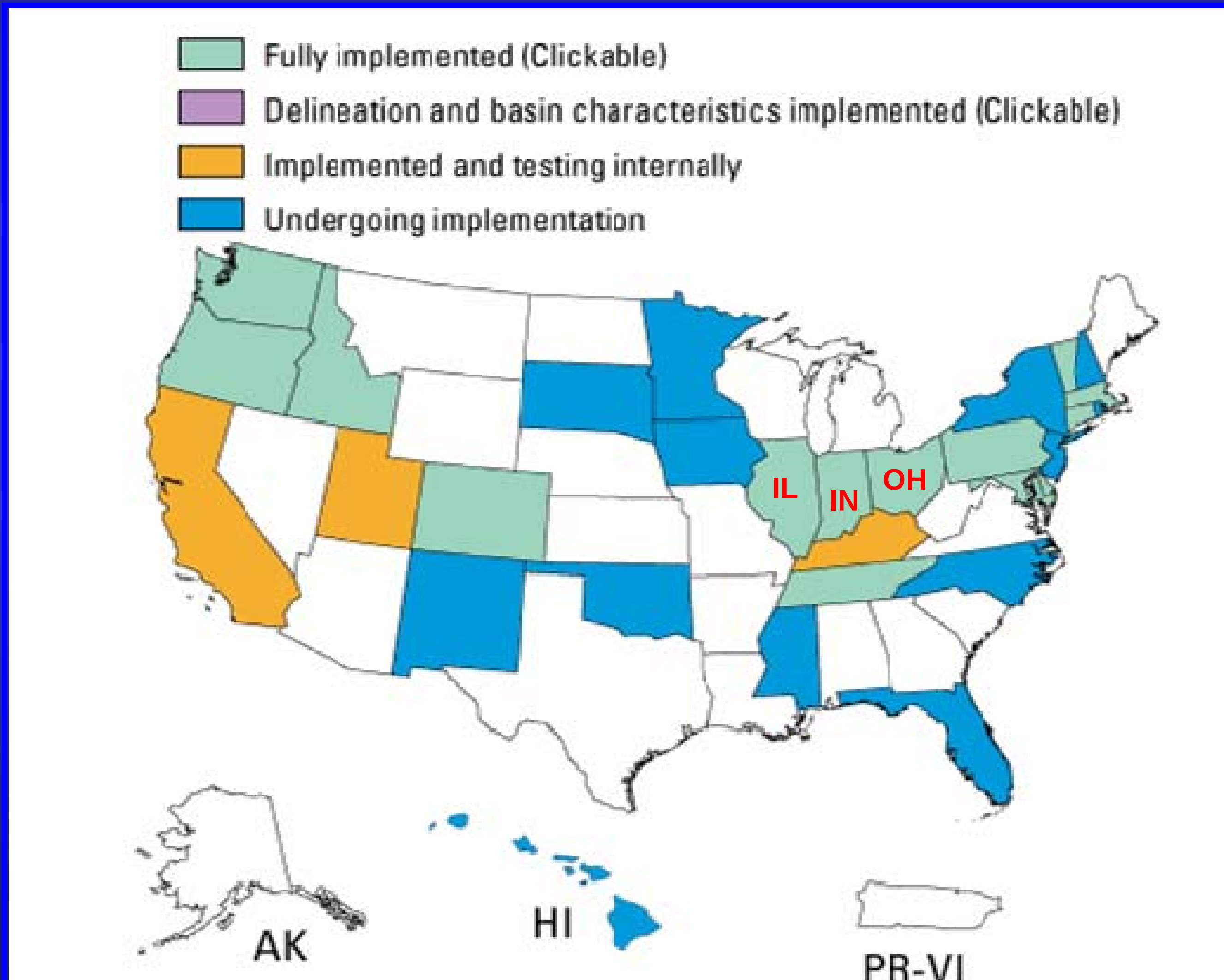
Table 3. Statistics of selected basin characteristics, by region, for streamflow-gaging stations used in the regression analyses

[*DA*, drainage area; *SL*, main channel slope; *W*, percentage of the basin classified as water and wetlands; mi^2, square miles; ft/mi, feet per mile]

Region	Statistic	*DA* (mi^2)	*SL* (ft/mi)	*W* (percent)
A	Maximum	7,422	994	25.8
	Minimum	.01	1.89	.00
	Mean	290.5	54.7	2.13
	Median	64.3	15.3	0.67
B	Maximum	6,330	500	7.78
	Minimum	.04	.97	.00
	Mean	414	25.4	1.95
	Median	60.6	8.94	1.28
C	Maximum	1,713	253	1.13
	Minimum	.25	6.56	.00
	Mean	192.	39.5	.39
	Median	68.7	16.1	.26

Developing Stream Stats Technology

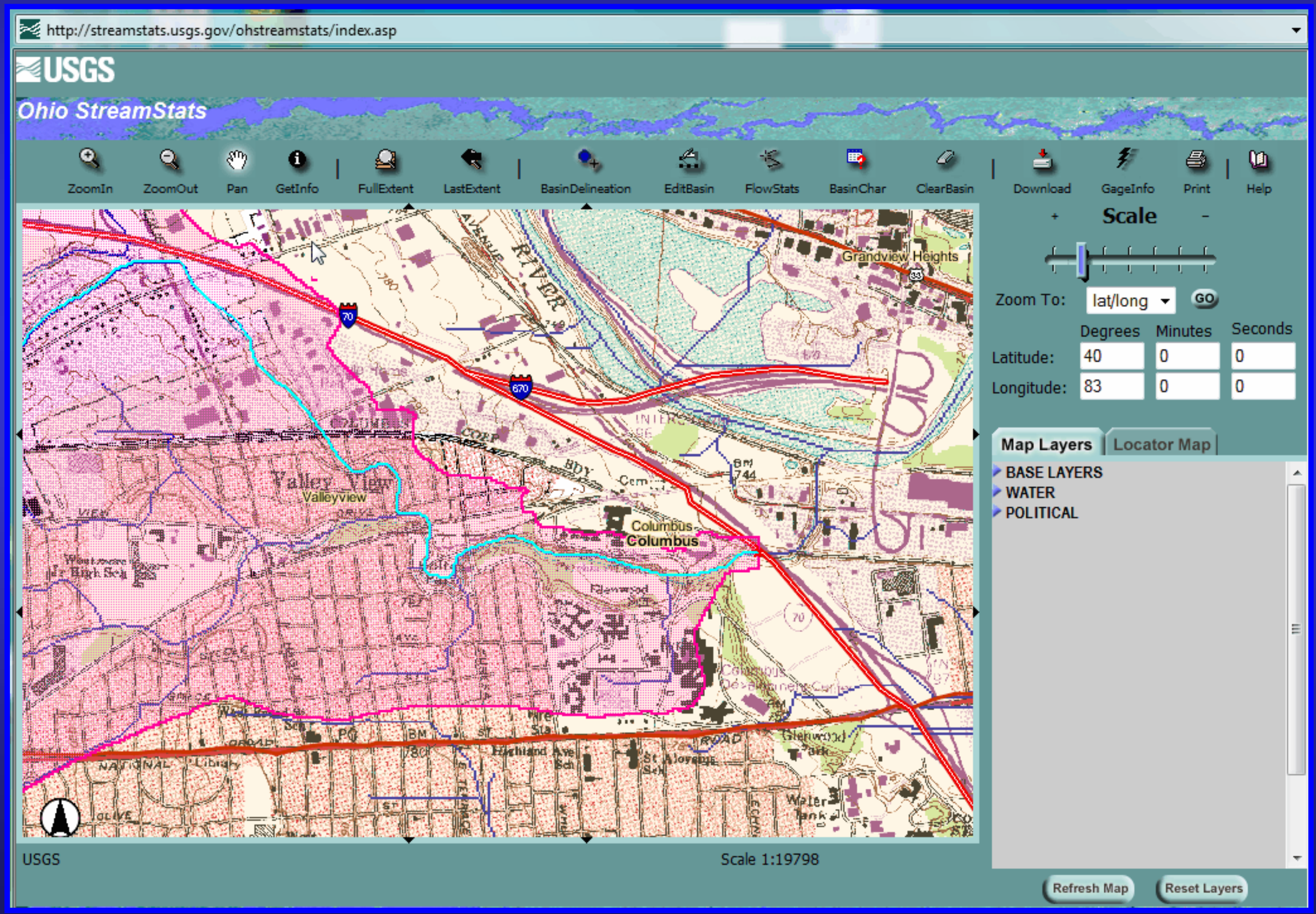
Web-based GIS integrated flow prediction



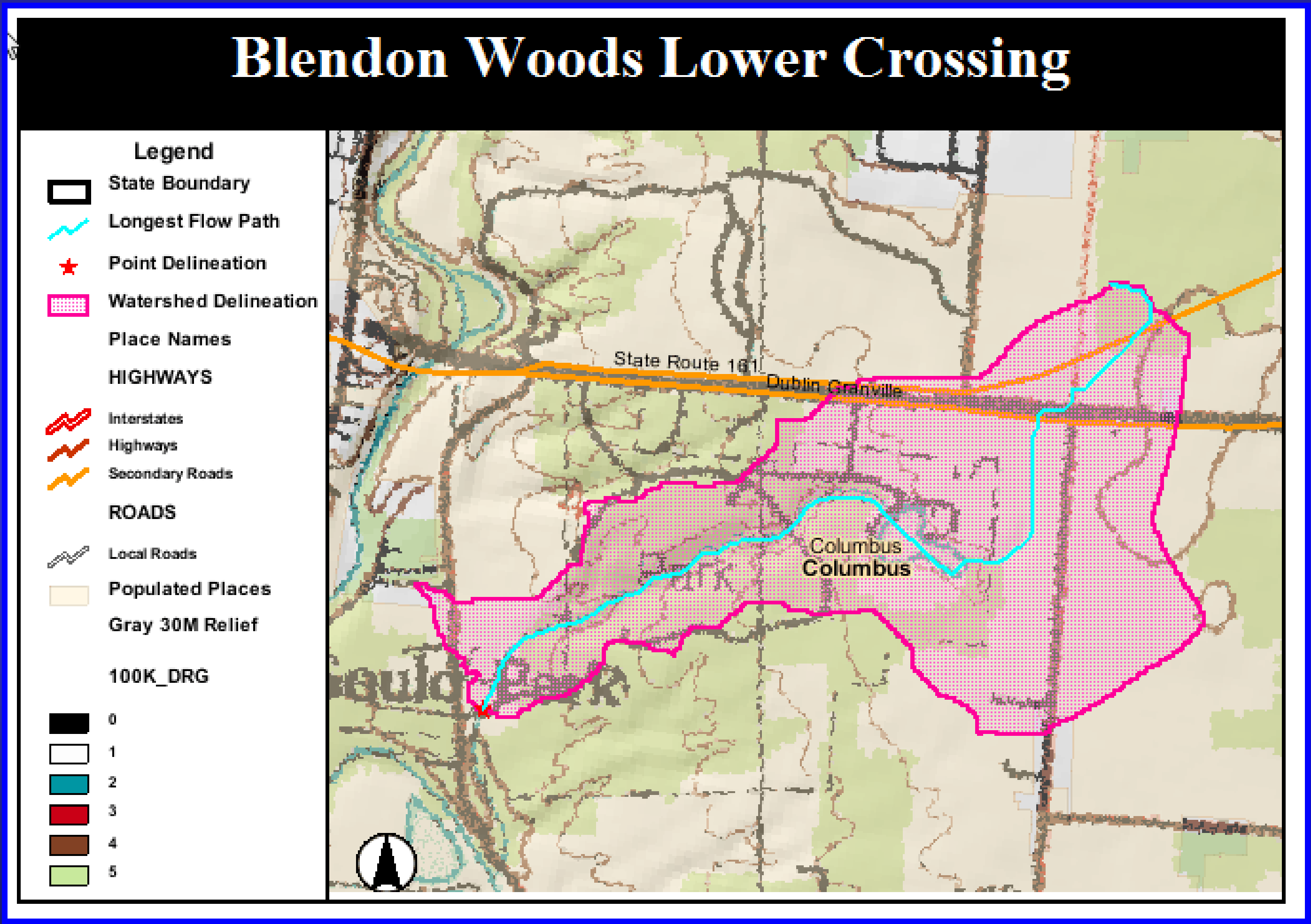
StreamStats

Web/GIS/Database

http://water.usgs.gov/osw/streamstats/



StreamStats Example: WS Delineation



StreamStats Example: Data

Parameter	Units	Blendon Metro Park: Upper Ripple Rock Cr	Blendon Metro Park: Lower Ripple Rock	Pickerington: George's N at Trail	ODOT: Scioto Trib at I-70
Drainage Area	(sq mi)	0.68	1.03	1.83	7.71
Main Slope	(ft/mi)	48.5	66.8	46.3	34.2
Storage	(%)	3.32	2.24	0.8	0.78
Forest	(%)	29	45.9	7.35	9.16
Q_{ave}	(cfs)	0.64	0.97	1.8	7.6
$Q_{75\%}$	(cfs)	0.10	0.13	0.29	0.53
$Q_{50\%}$	(cfs)	0.28	0.38	0.76	1.96
$Q_{25\%}$	(cfs)	0.76	1.06	1.87	6.33
$Q_{2\text{-}yr}$	(cfs)	67	101	169	496
$Q_{5\text{-}yr}$	(cfs)	114	177	295	843
$Q_{10\text{-}yr}$	(cfs)	148	232	389	1100
$Q_{25\text{-}yr}$	(cfs)	192	304	510	1430
$Q_{50\text{-}yr}$	(cfs)	224	357	601	1670
$Q_{100\text{-}yr}$	(cfs)	256	412	694	1930
$Q_{500\text{-}yr}$	(cfs)	333	540	914	2520

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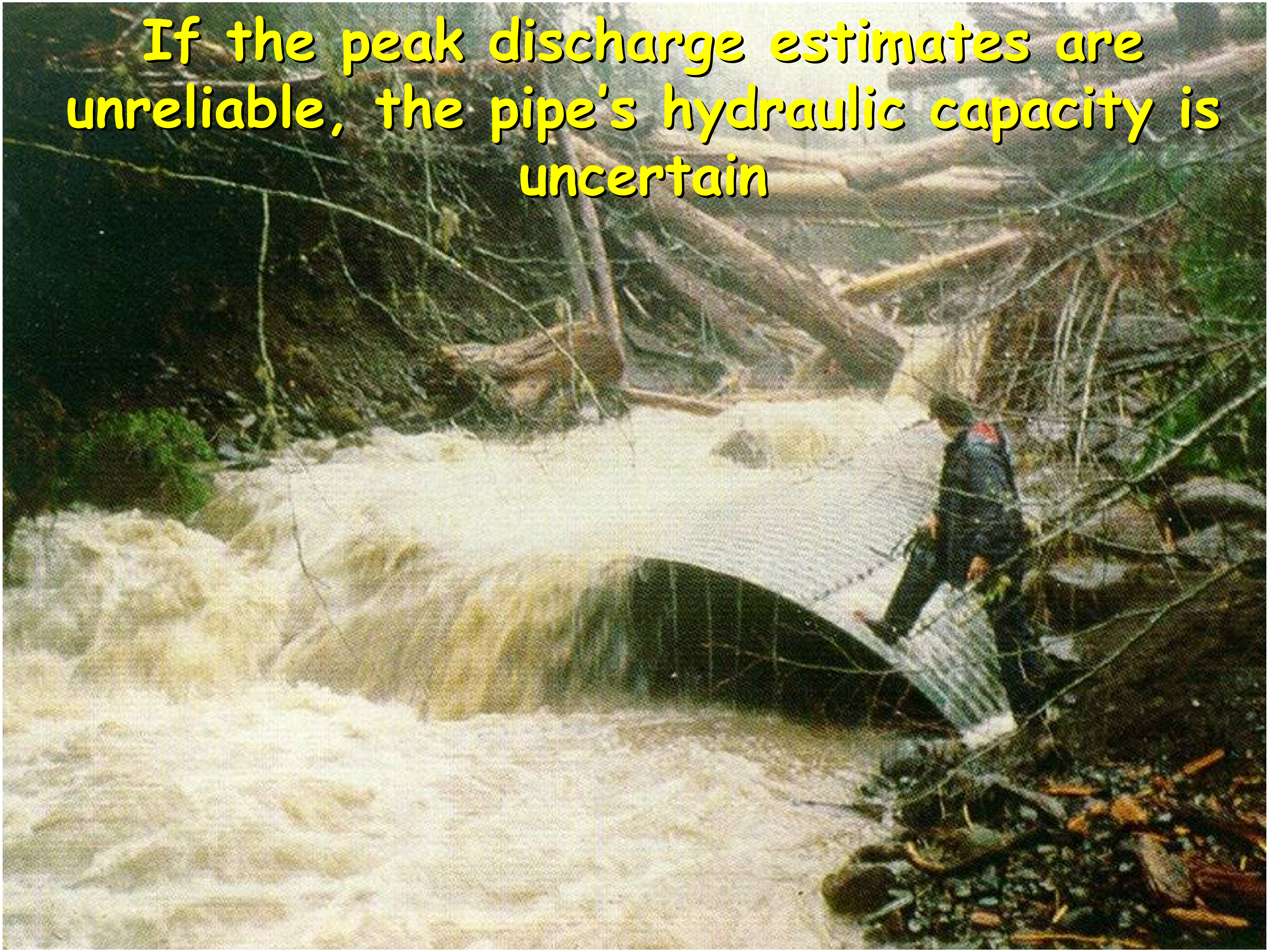
Storage	(%)	3.32	2.24	0.8	0.78
Forest	(%)	29	45.9	7.35	9.16
Qave	(cfsm)	0.94	0.94	0.98	0.99
Q75%	(cfsm)	0.15	0.13	0.16	0.07
Q50%	(cfsm)	0.41	0.37	0.42	0.25
Q25%	(cfsm)	1.12	1.03	1.02	0.82
Q2-yr	(cfsm)	98	98	92	64
Q5-yr	(cfsm)	168	172	161	109
Q10-yr	(cfsm)	218	225	213	143
Q25-yr	(cfsm)	282	295	279	185
Q50-yr	(cfsm)	329	347	328	217
Q100-yr	(cfsm)	376	400	379	250
Q500-yr	(cfsm)	490	524	499	327

If the peak discharge estimates are unreliable, the pipe's hydraulic capacity is uncertain



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Model Bankfull Discharge (Est $Q_{1.5}$ or Q_2)

- Use results to help identify and verify bankfull elevation
- Where bankfull elevations are good, use analysis to verify the relative accuracy of the regression equations

Model Bankfull Discharge

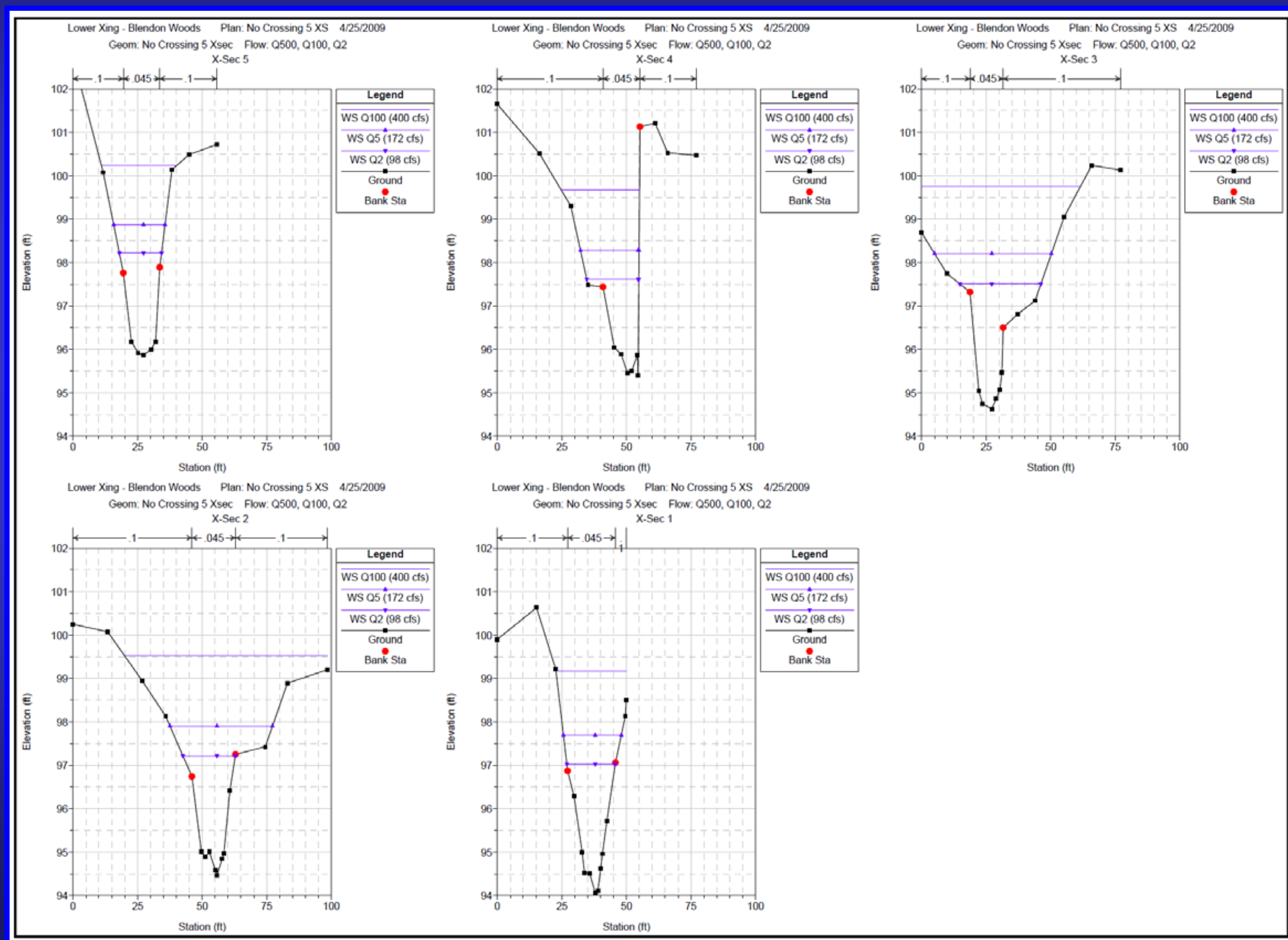
- Model bankfull discharge with Manning Equation

$$Q_{bf} = \frac{1.49}{n} A_{bf} R_{bf}^{2/3} S^{1/2}$$

- Model bankfull discharge using a cross section analysis tool (e.g., WINXSPRO) or a step-backwater model (e.g. HEC-RAS)

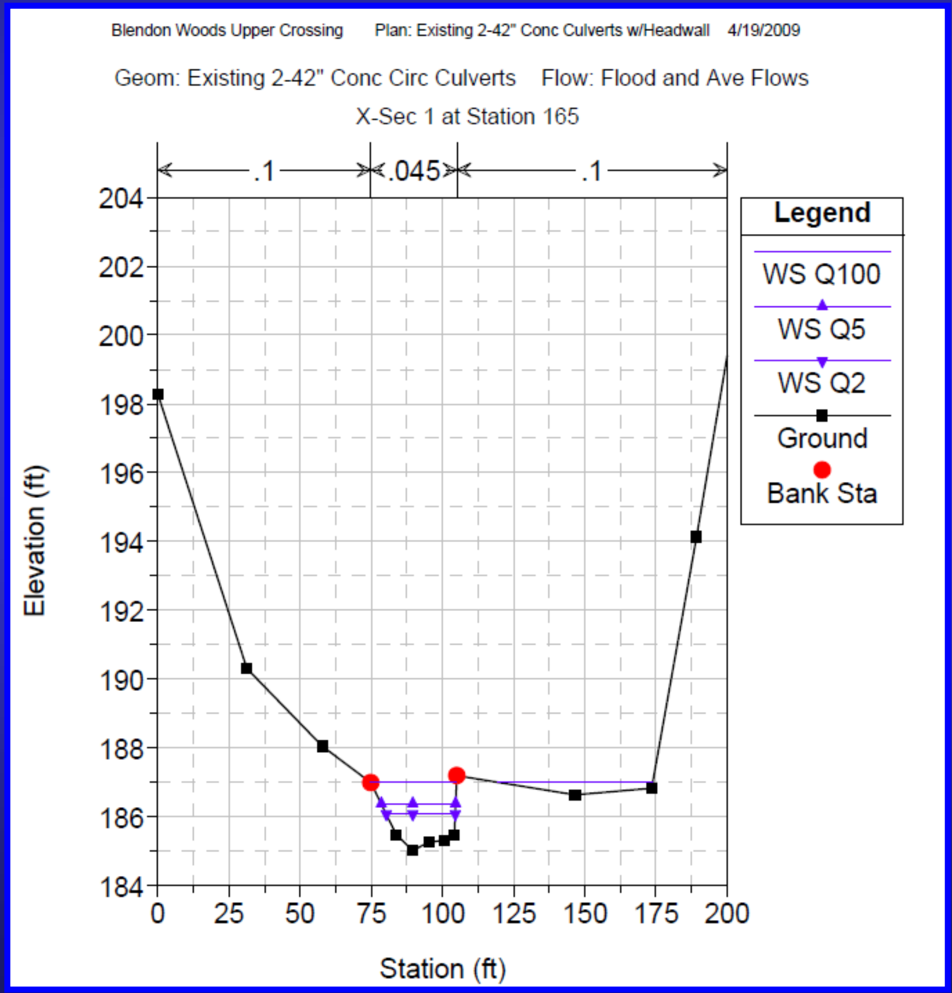
Model BF Q to Verify BF Elevation

Lower Blendon Crossing Example



Model BF Q to Verify BF Elevation

Upper Blendon Crossing Example



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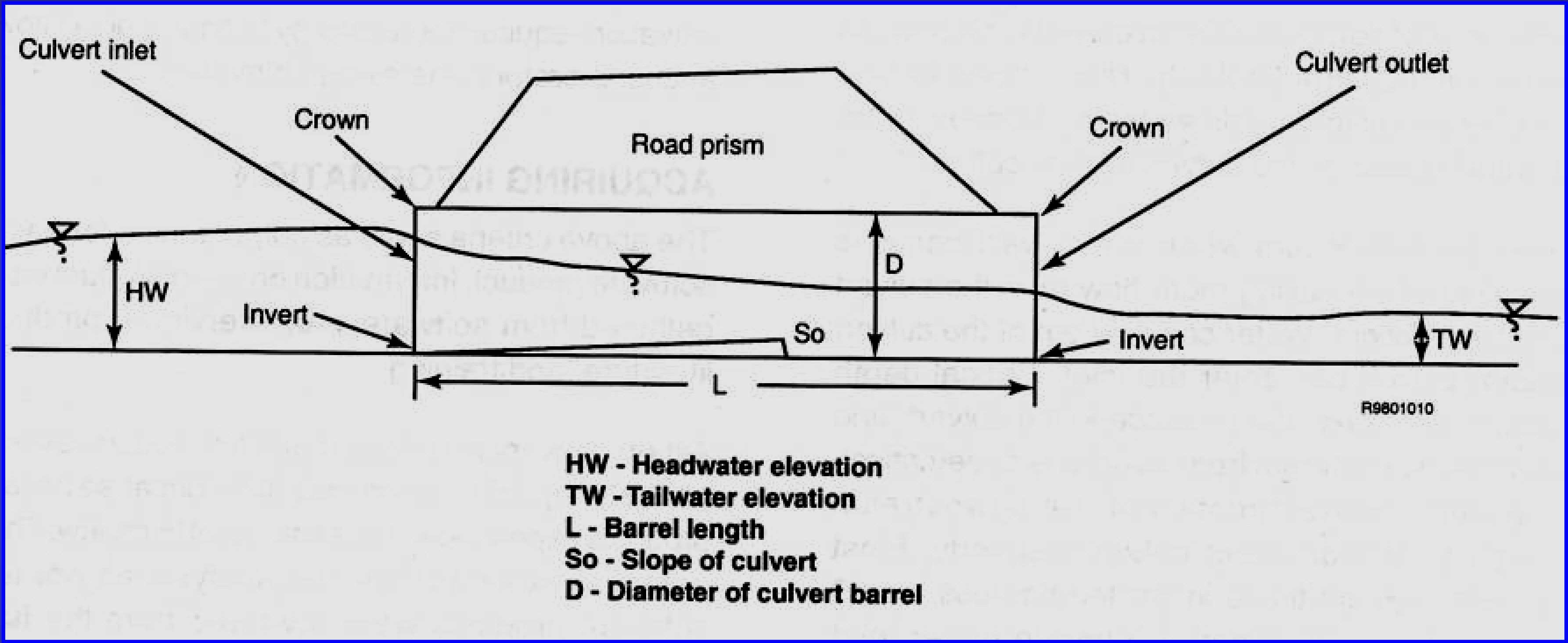
Culvert Hydraulics Terms



- **Invert, Headwater (HW), Tailwater (TW)**
- **Headwater/Depth Ratio (HW/D): HW / pipe diameter or depth**
- **Supercritical Flow: high velocity, shallow water**
- **Subcritical Flow: low velocity, deep water**

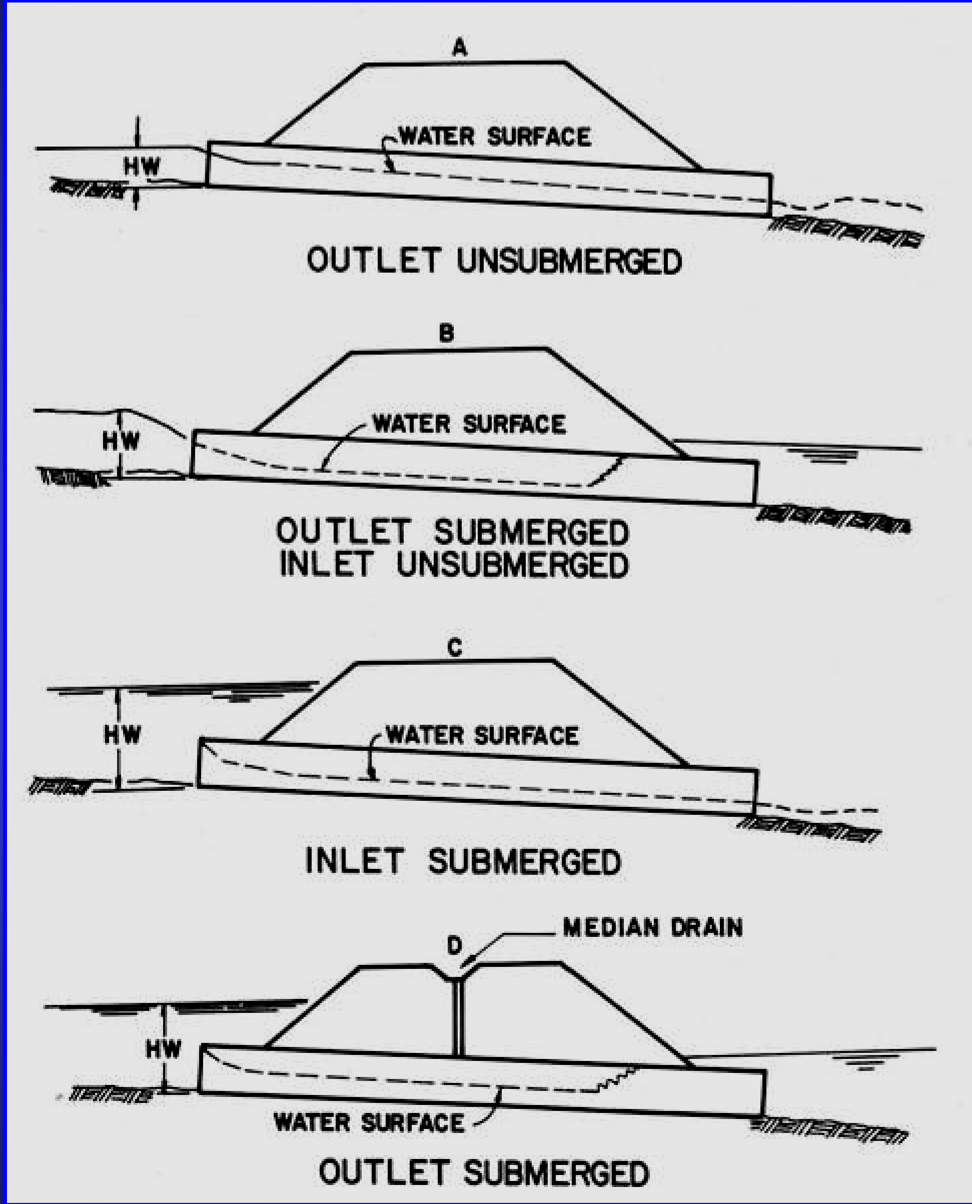
Inlet Control

Culvert Hydraulics

- Culvert geometry at inlet controls flow
  - Flow determined by HW elev and inlet characteristics
  - Flow in culvert is supercritical
  - Culvert can convey more flow than inlet will accept

Inlet Control

Culvert Hydraulics



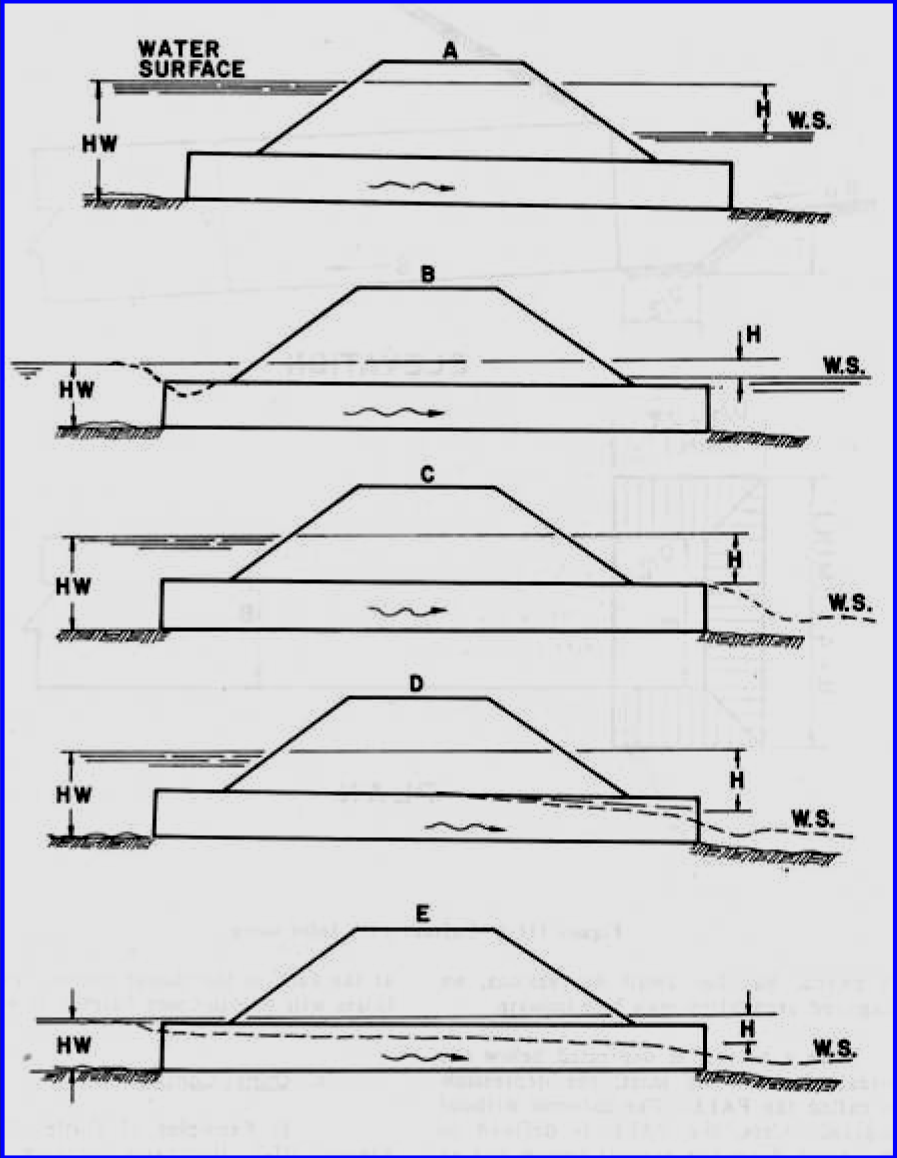
Outlet Control

Culvert Hydraulics

- Tailwater, culvert inlet and barrel characteristics (slope, length, roughness) control flow
- Flow in culvert is subcritical or under pressure
- Culvert inlet can convey more flow than barrel

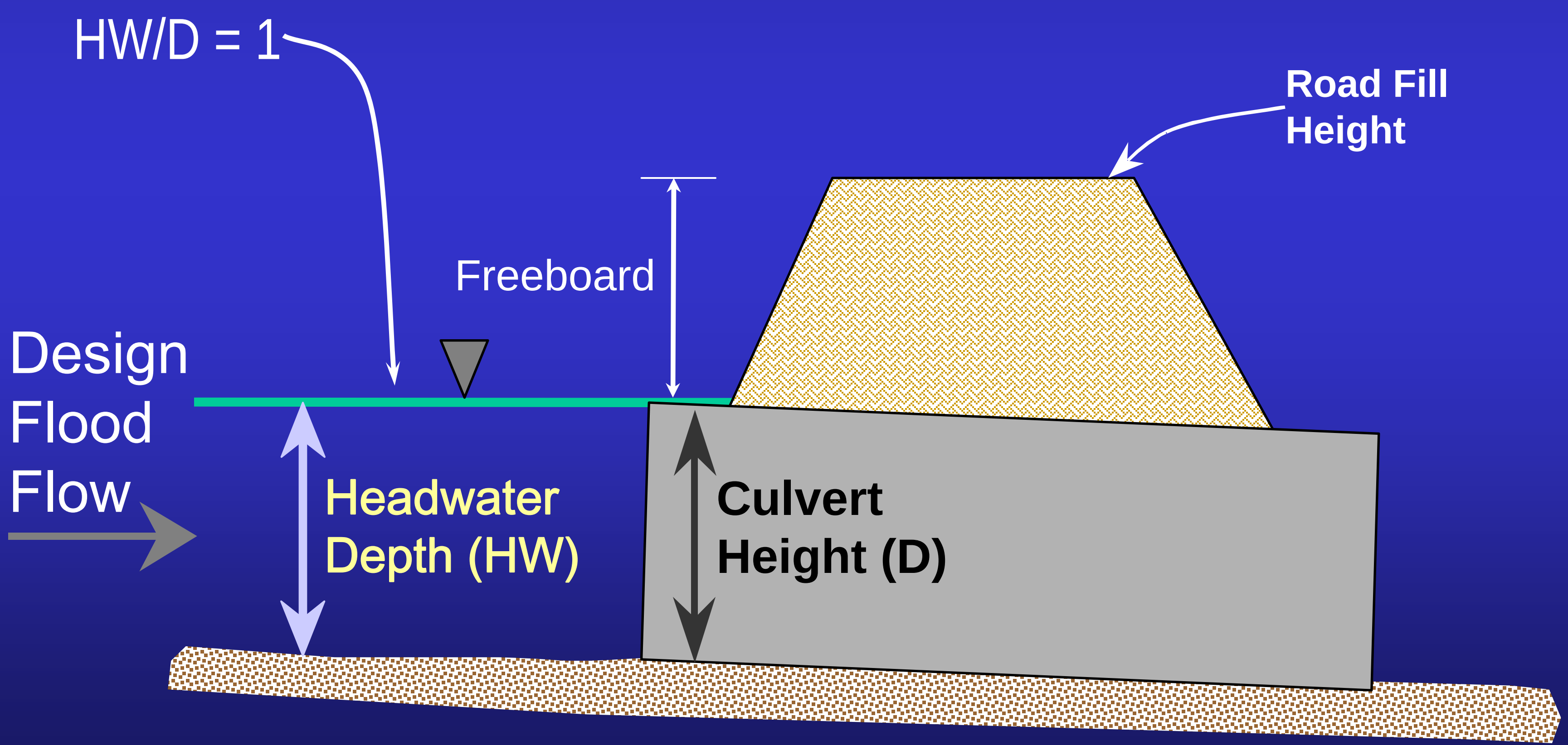
Outlet Control

Culvert Hydraulics



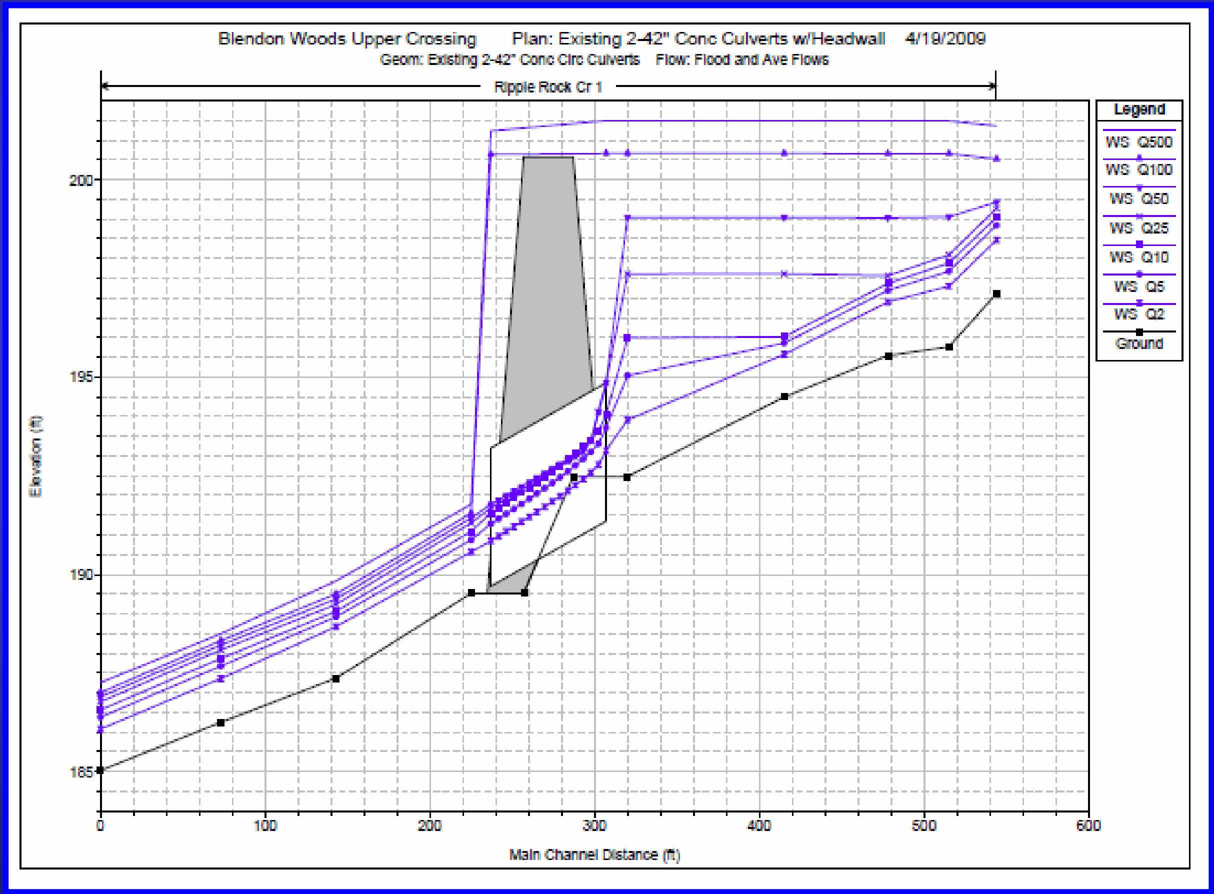
Culvert Capacity

At the design flood flow (Q_{100}), headwater depth should be less than 1.

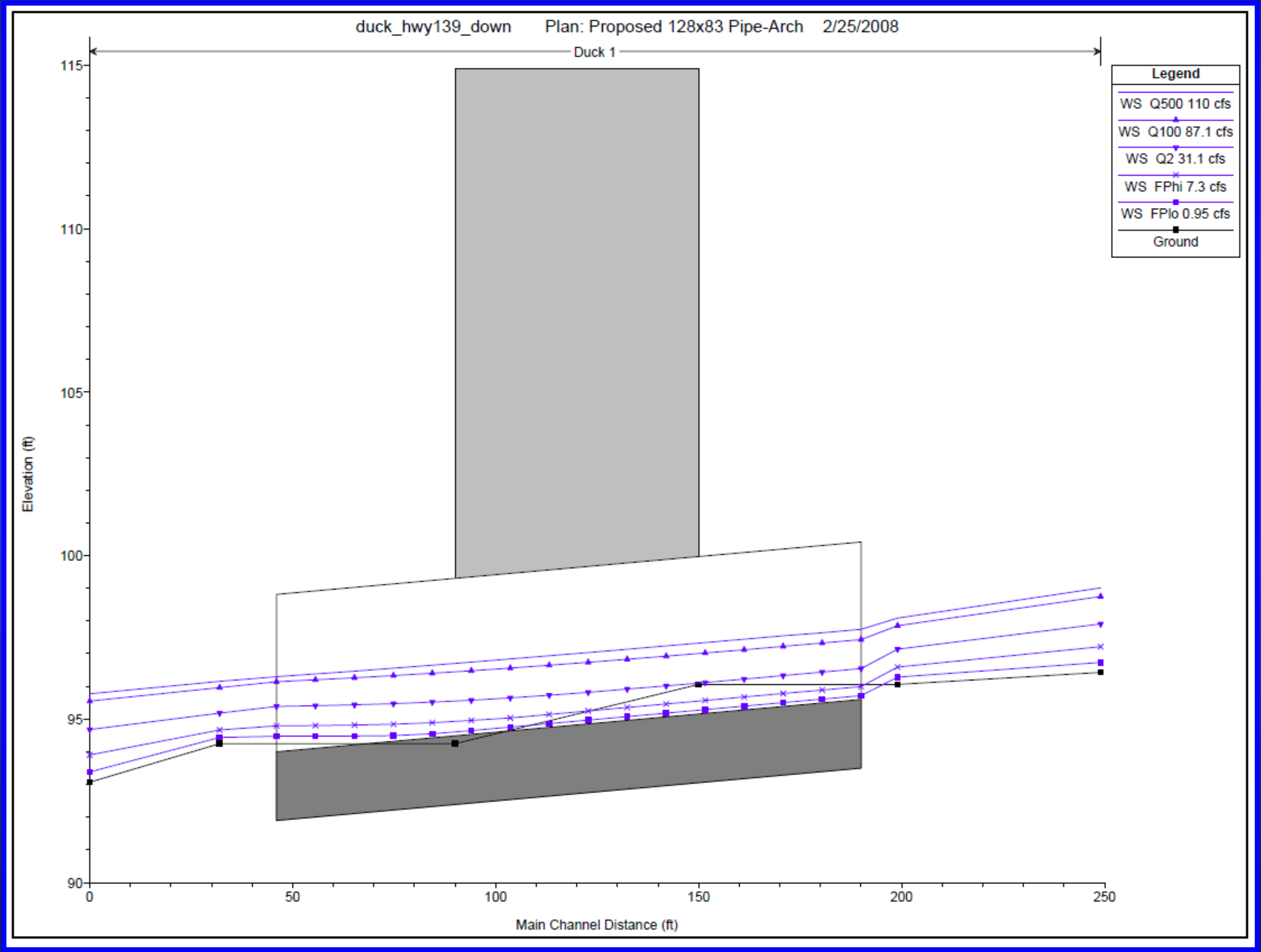


Culvert Hydraulic Models

- **HEC-RAS – USACOE**
- **HY8 – FHWA**
- **Culvert Master – Haestad Methods**
- **FishXing – USFS**



Ex: Stream Simulation Q_{100} Capacity Check with Hec-Ras, Duck Cr at Hwy 139, WI



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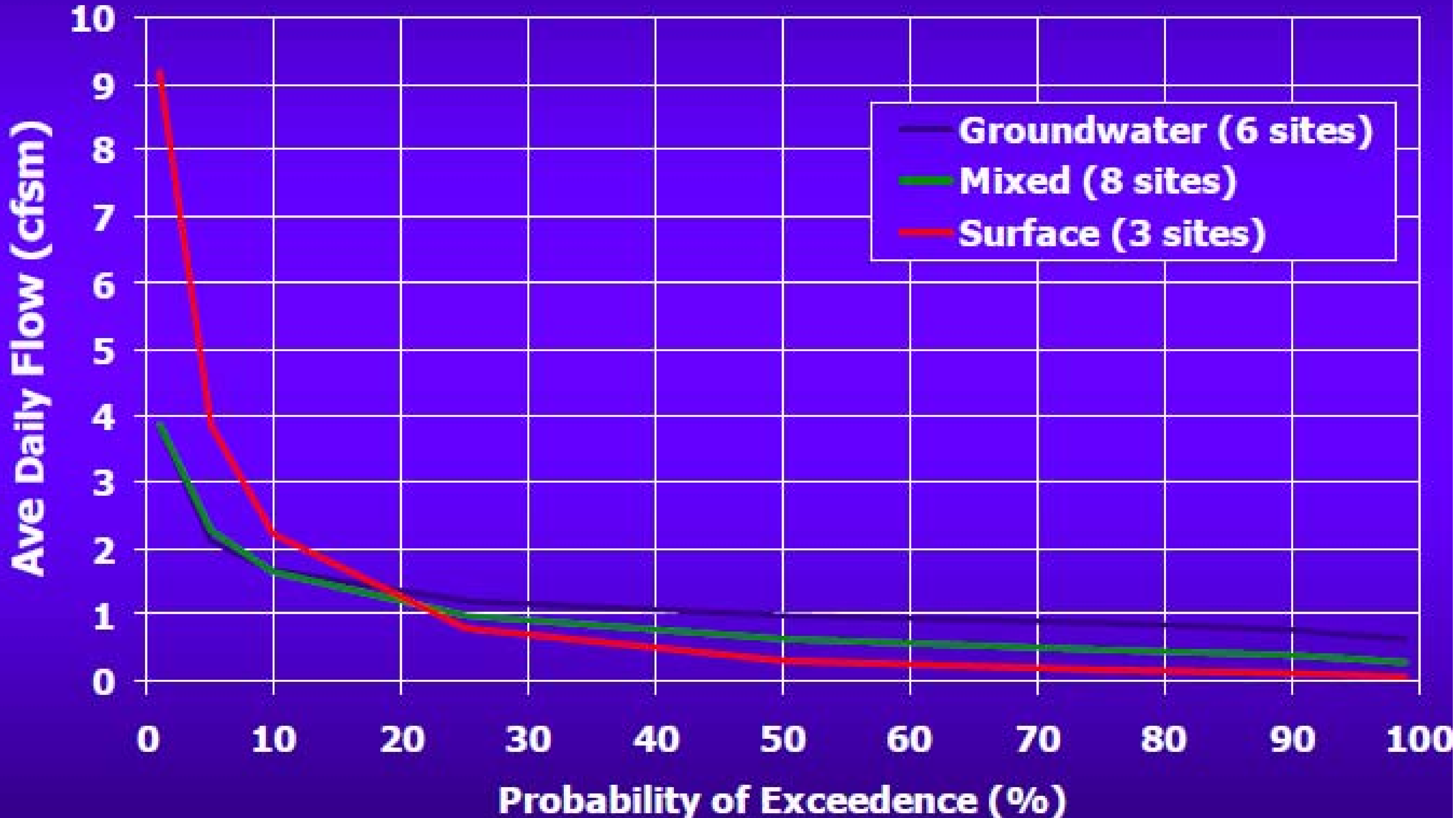
Methods for Estimating Fish Passage and Construction Flows

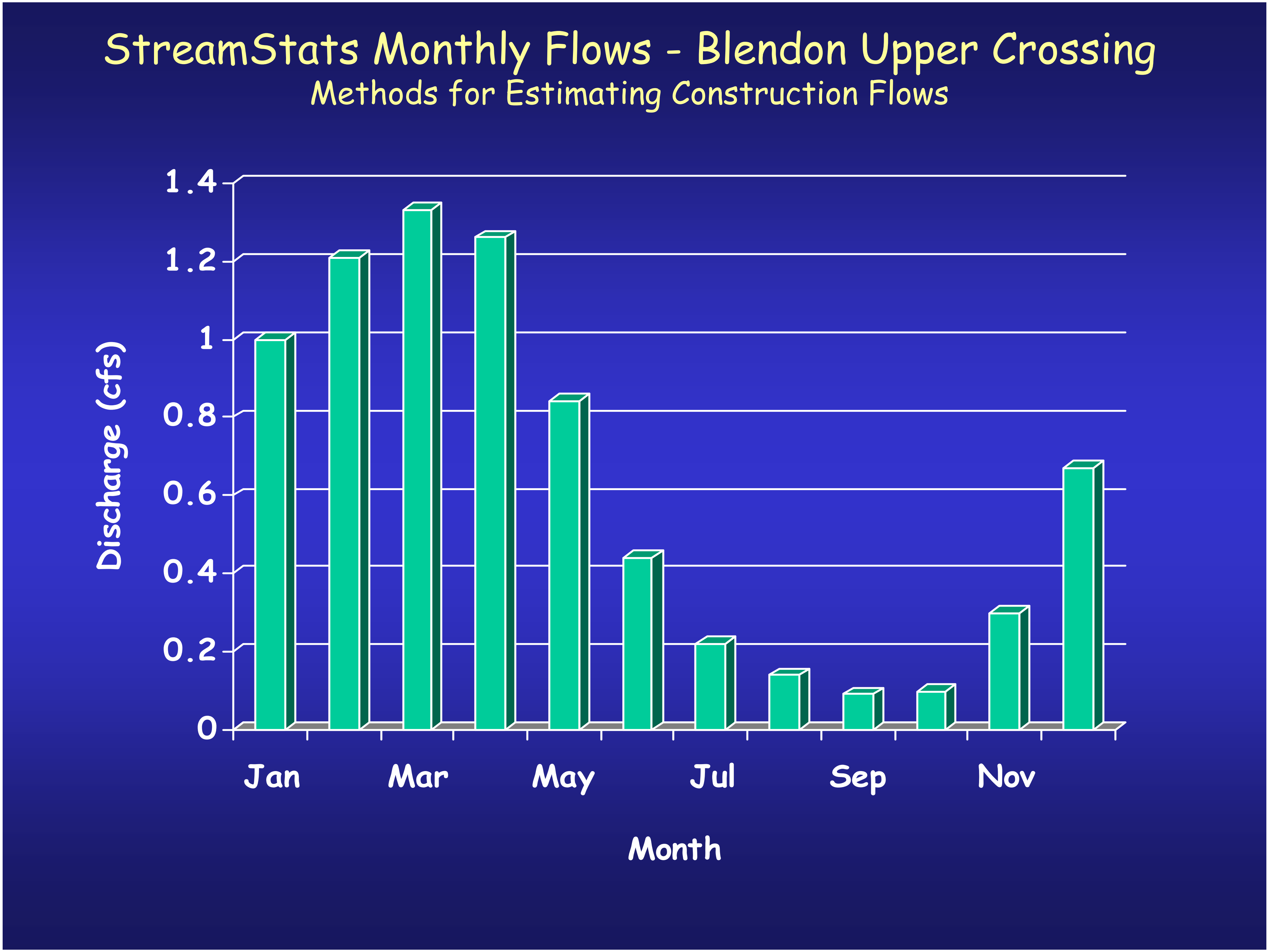
- High Fish Passage Flow:
  - 1-10% annual exceedence flow
- Low Fish Passage Flow:
  - 90-99% annual exceedence flow
- Construction flows:
  - Short-term (days) - average annual or monthly flow
  - Long-term (weeks) - Q2 (?)

Note: Check state requirements

Flow Duration Curves by Flow Regime in N WI

Fish Passage and Construction Flows




StreamStats Monthly Flows - Blendon Upper Crossing
Methods for Estimating Construction Flows
Discharge (cfs)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Jan
Mar
May
Jul
Sep
Nov
Month

By-Pass Flow Example: Blendon Upper Crossing

Apr-May Construction Period: ave flow 0.8-1.3 cfs; plan to pass 3-4 cfs; 18" circ with HW/D=0.8

For extended period, pass Q2 = 67 cfs; 36" circular pipe with HW/D=2.2; 24" cir would pass 24 cfs with HW/D=2.0