Culvert Design Process

Hydrology

↓

Site Assessment

↓

Alignment and Profile

↓

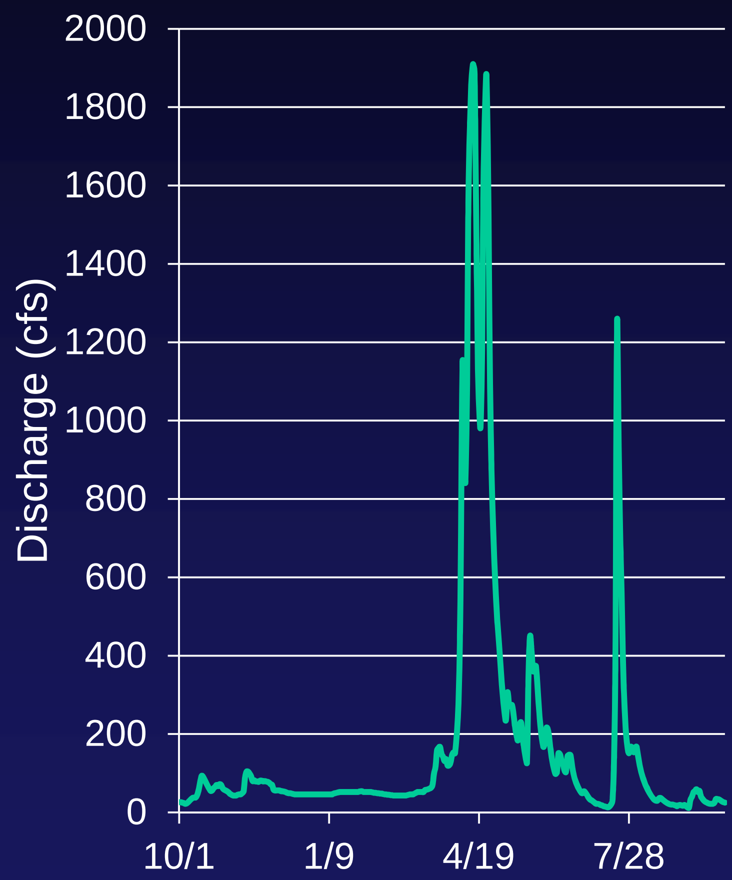
Bed and Banks

↓

Structure

↓

Sediment Mobility & Stability



Presentation outline

- What and Why?
- General hydrology - Minnesota
- Estimating peak flood flows: $Q_{1.5}$ - Q_{100}
- Bankfull flow and elevation
- Estimating flows for by-pass during construction

Hydrology: why and what

- Hydraulic analysis requires hydrologic data (hydrology part of H&H)
- Two basic types of hydrology data
  - Instantaneous peak flows
  - Average daily flows
- Streamflow data
  - Collected at streamflow gaging stations
  - Used to estimate flows at ungaged sites

Flood frequency terms

$$\text{recurrence interval or return period} = \frac{1}{\text{exceedance probability}}$$

100-yr flood (Q_{100}) = 0.01 (1%) exceedance probability

2-yr flood (Q_2) = 0.50 (50%) exceedance probability

What hydrologic data are needed? Estimates of flood magnitudes and frequencies

- Peak hydraulic design flow
  - Verify structure has adequate flood capacity
  - Recommended min capacity Q_{100} with HW/D<1
  - Consider checking Q_{500}
- Bankfull flow
  - Model hydraulics to help verify bankfull elevation
  - $Q_{1.5}$ or Q_2
- Sediment mobility and stability
  - Model hydraulics for bed mobility and stability
  - $<Q_{1.5}$ to $>Q_{100}$

Annual flood peaks:

Swan River Tributary at Warba, MN

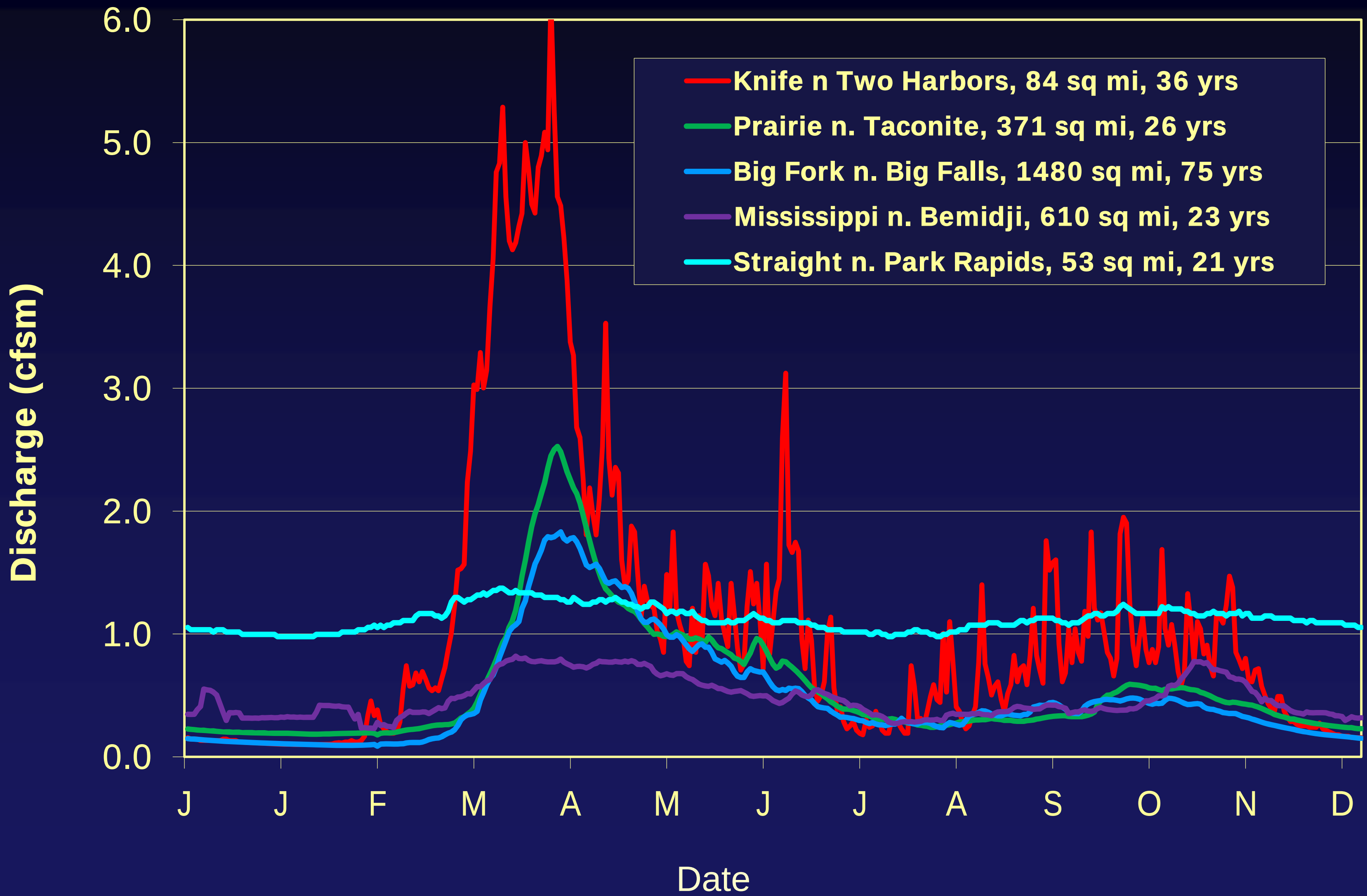
05216980, DA=3.95 sq mi, period of record=1961-1985

Water Year	Date	Gage Height (ft)	Discharge (cfs)
1977	Sep. 09, 1977	5.34	21
1978	Aug. 23, 1978	6.64	70
1979	Apr. 21, 1979	7.08	50
1980	Apr. 12, 1980	5.64	28
1981	Aug. 05, 1981	6.76	70
1982	Apr. 15, 1982	7.15	43
1983	Aug. 03, 1983	6.74	74
1984	Jun. 08, 1984	5.83	38
1985	Jul. 18, 1985	6.68	40

What flow data are needed?
Estimates of average daily flows

- Construction flows
  - 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 flows
  - 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 flows
  - Determines the **depth threshold** for fish passage
  - Exceedance percentage from flow duration curve or the 2-year, 7-day low flow

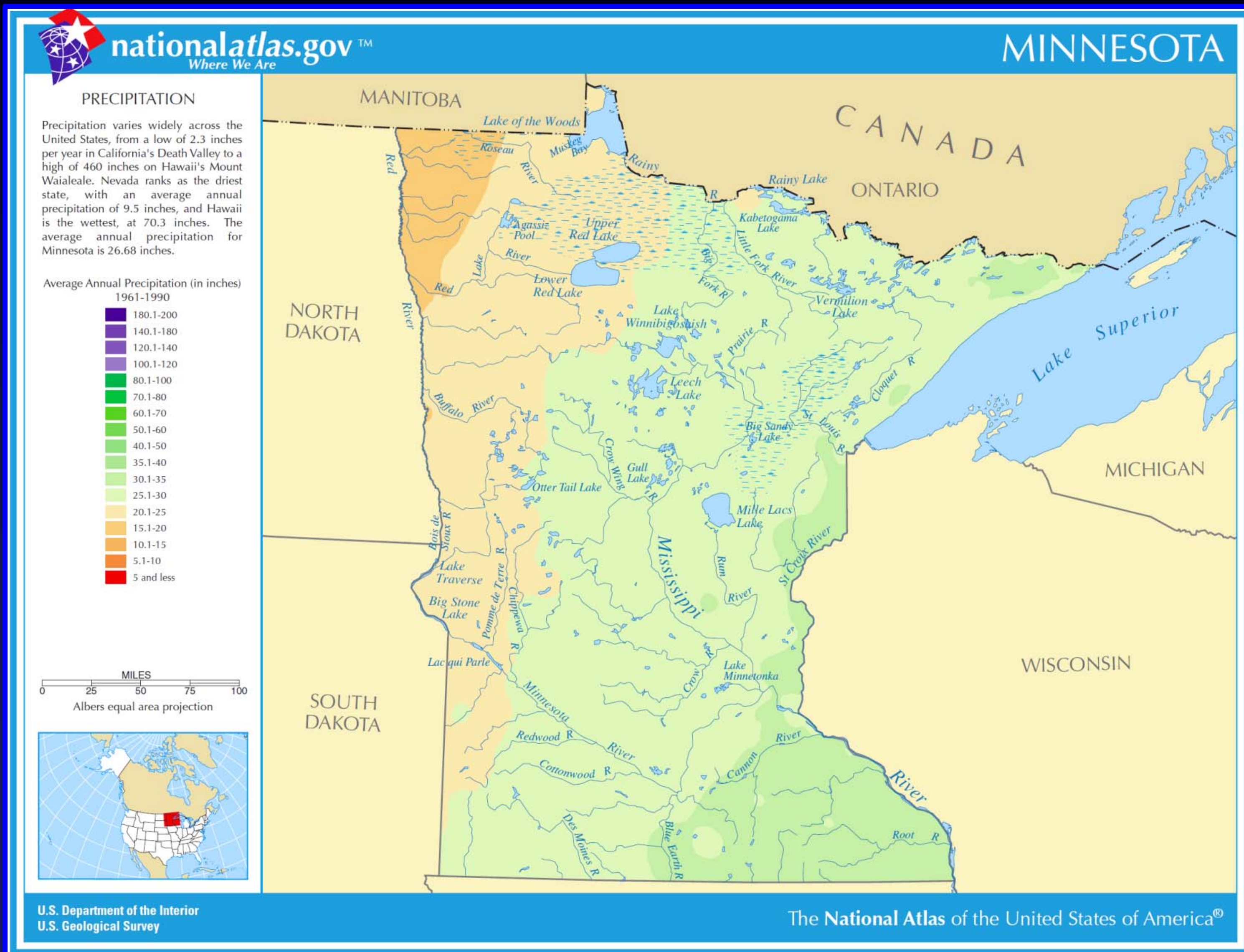
Average daily flows for 5 sites in N MN



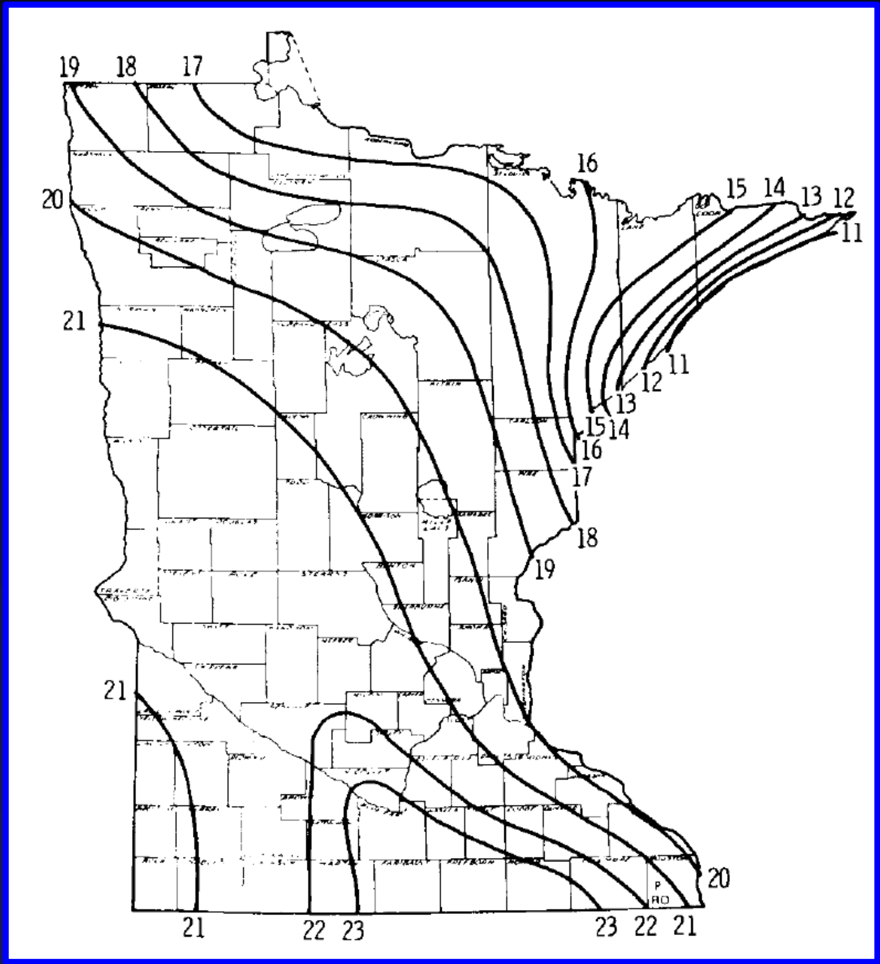
Presentation outline

- Why and What?
- General Hydrology - Minnesota
- Estimating eak flood flows: $Q_{1.5}$ - Q_{100}
- Bankfull flow and elevation
- Estimating flows for by-pass during construction

Local hydrology: annual precipitation

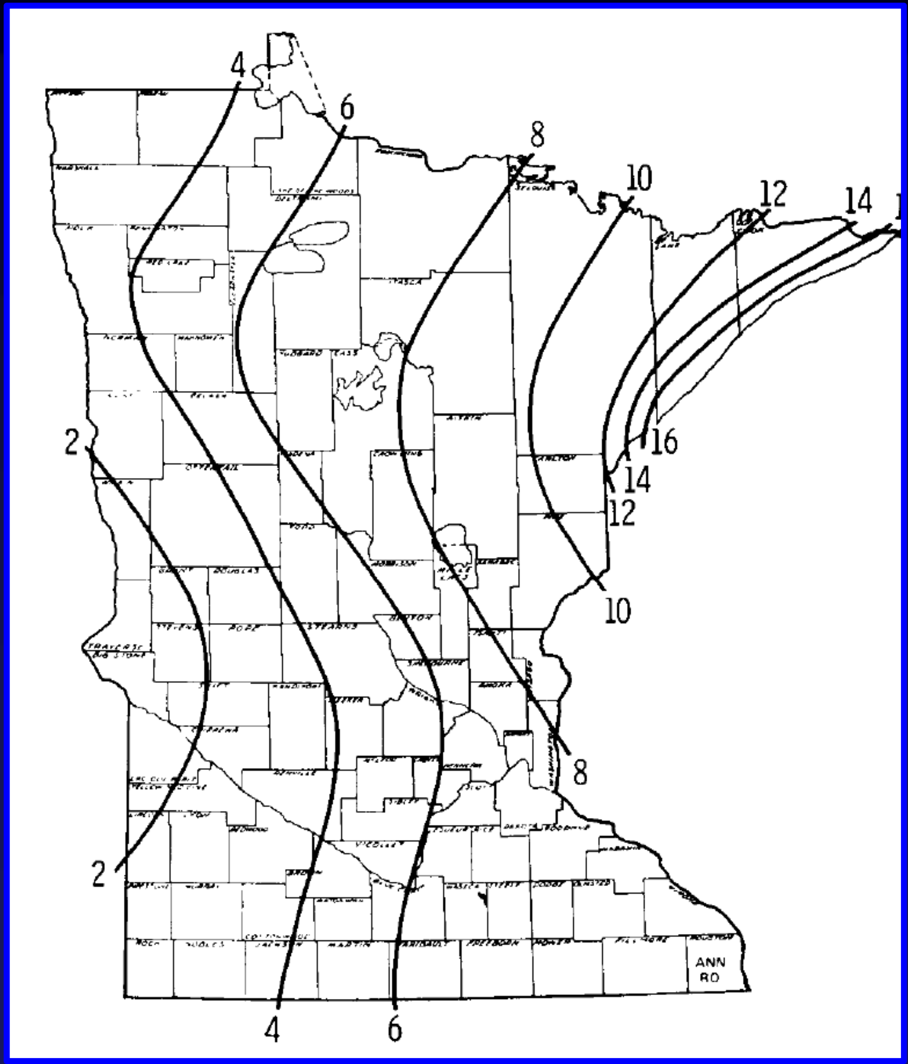


Local hydrology: annual evapo-transpiration



(Source: Baker et. al. 1979. Climate of MN, Part XII – The Hydrologic Cycle and Soil Water, Technical Bulletin 322, Ag. Exp. Sta., U of MN, 23 p.)

Local hydrology: annual runoff



(Source: Baker et. al. 1979. Climate of MN, Part XII – The Hydrologic Cycle and Soil Water, Technical Bulletin 322, Ag. Exp. Sta., U of MN, 23 p.)

Local hydrology:
annual water balance

Region	Ppt (in)	ET (in)	RO (in)	RO (cfsm)
Grand Rapids, MN	27	19	8	0.59
Duluth, MN	28	16	12	0.89
N WI	32	20	12	0.89

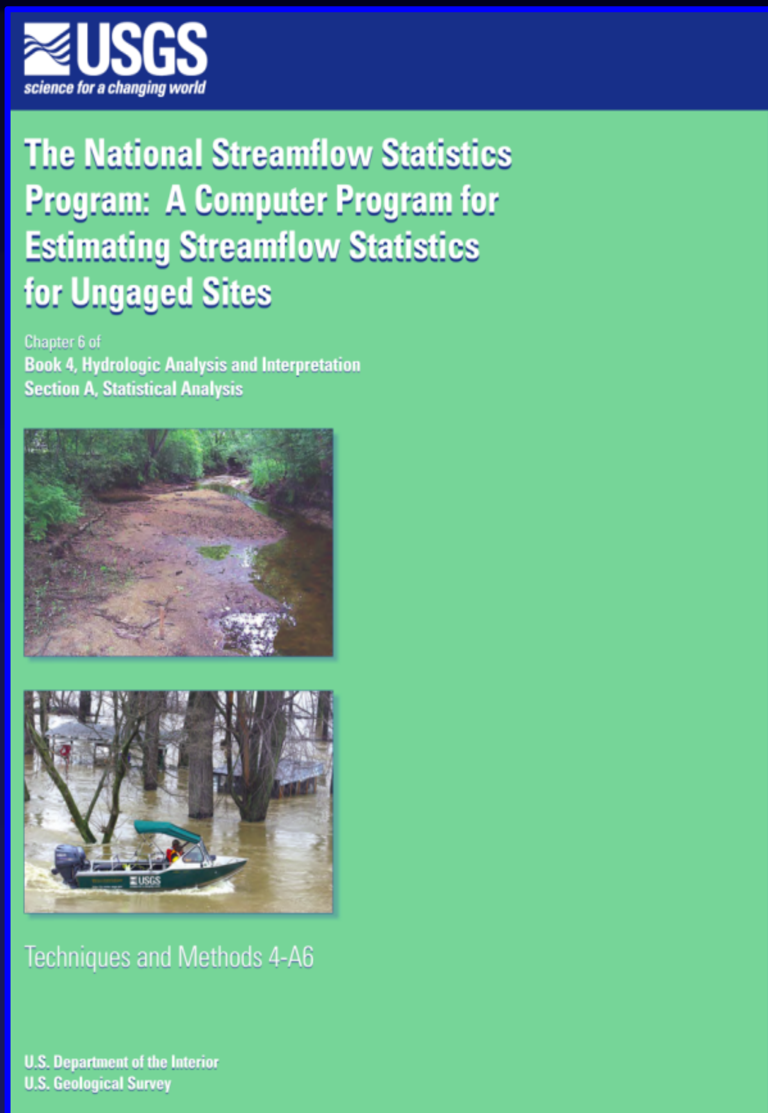
Sources of flow data: US Geological Survey

- 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

Presentation Outline

- What and Why?
- General hydrology - Minnesota
- Estimating peak flood flows: $Q_{1.5}$ - Q_{100}
- Bankfull flow and elevation
- Estimating flows for by-pass during construction

National Streamflow Statistics (NSS) program



- Summary of flood frequencies at gage stations
- Methods for extrapolating data to ungaged sites
- Regional equations for flood frequencies and other streamflow statistics
- Computer Program: Version 4
  - Download software
  - Technical papers for each State
  - Latest equations for each State

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

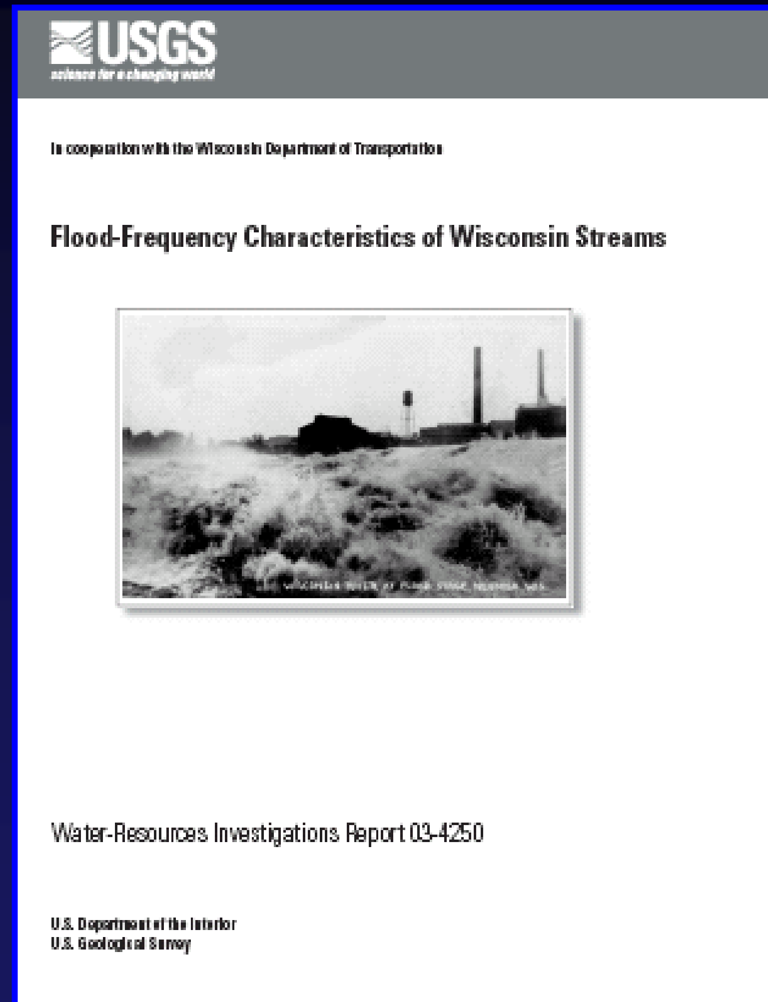
Technical publications for each state


Prepared in cooperation with the Minnesota Department of Transportation
and the Minnesota Pollution Control Agency

Techniques for Estimating the Magnitude and Frequency of Peak Flows on Small Streams in Minnesota Based on Data through Water Year 2005

Scientific Investigations Report 2009–5250

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


USGS
science for a changing world

In cooperation with the Wisconsin Department of Transportation

Flood-Frequency Characteristics of Wisconsin Streams

Water-Resources Investigations Report 03-4250

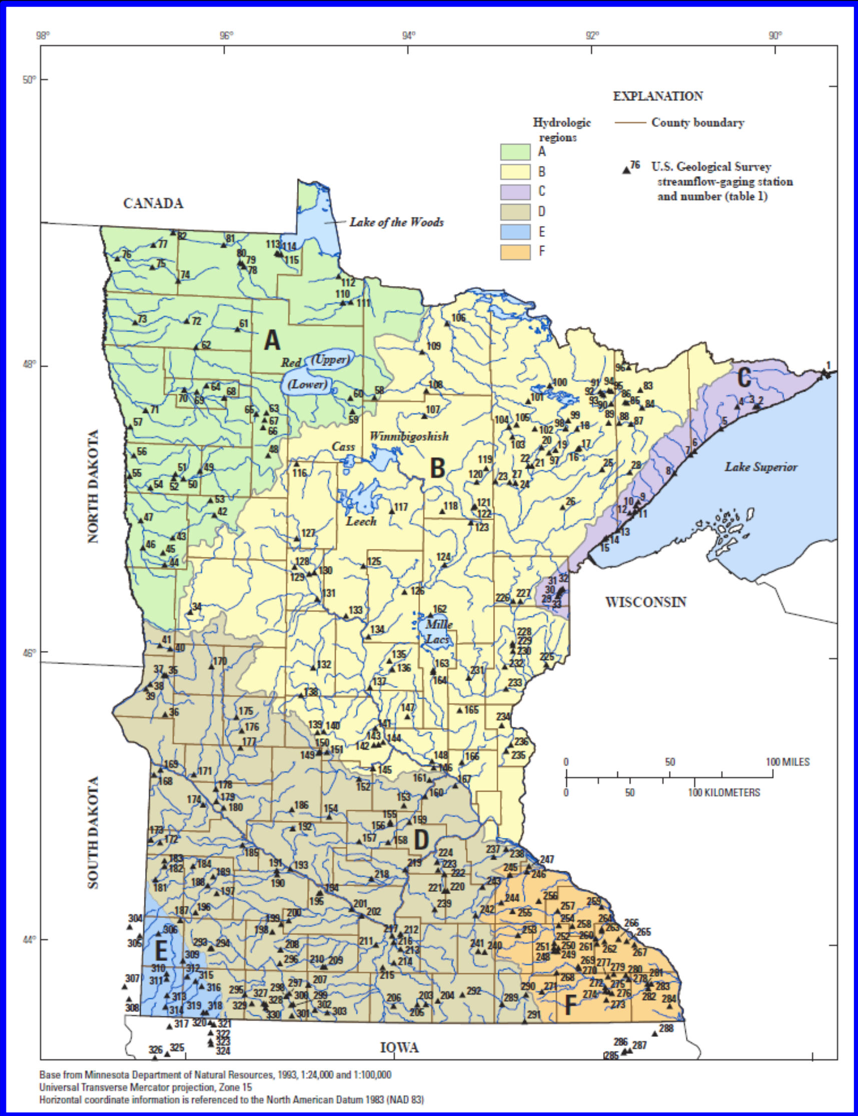
U.S. Department of the Interior
U.S. Geological Survey

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

Flood frequency regions in Minnesota

Unique regional regression coefficients for each region and recurrence interval

Region B variables: drainage area (sq mi), % lake area, % hydro soil group A and mean annual runoff (in)



Example: Clearwater Cr at Hwy 60

(National Streamflow Statistics Program)

Hydrologic Region B:

$\mathbf{Q_{1.5}} = 3.44(\mathbf{DA})^{0.067(9.031+\log(DA))} (\mathbf{LK}+1)^{-0.368}(\mathbf{SA}+1)^{-0.104} (\mathbf{RO})^{0.916}$ SE: 33%

$\mathbf{Q_{100}} = 87.7(\mathbf{DA})^{0.107(3.959+\log(DA))} (\mathbf{LK}+1)^{-0.561}(\mathbf{SA}+1)^{-0.198} (\mathbf{RO})^{0.529}$ SE: 47%

Where: regression coefficients vary by region and recurrence interval

DA = drainage area (sq mi) = 60.3 sq mi

LK = lake area (ft) = 22.13 % (above max of 13%)

SA = Hydrologic Soil Group A (%) = 14.16 %

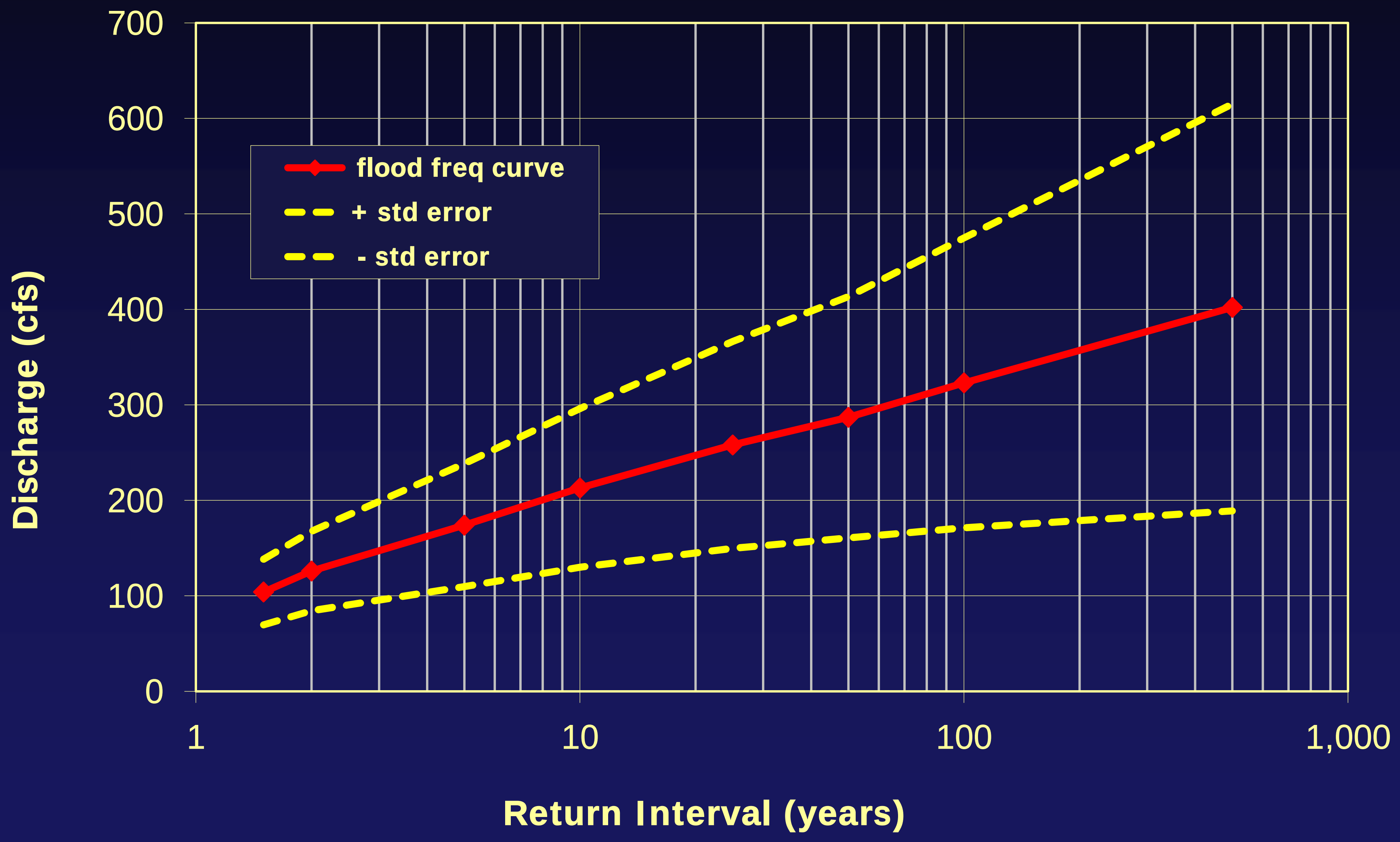
RO = generalized mean annual runoff (in) = 7.81 in

Results:

$Q_{1.5}$ = 104 cfs (1.7 cfsm)

Q_{100} = 323 cfs (5.4 cfsm)

Estimated flood frequency curve and prediction error: Clearwater Cr at Hwy 60



StreamStats Example: Clearwater Cr at Hwy 60 Data

Peak Flow Basin Characteristics			
100% Region B (60.3 mi2)			
Parameter	Value	Regression Equation Valid Range	
		Min	Max
Drainage Area (square miles)	60.3	0.23	1700
Percent Lakes and Ponds (percent)	22.13 (above max value 13)	0	13
Percent Hydrologic Soil Type A (percent)	14.16	0	33
Generalized Runoff (inches)	7.81	3	12.2
Log of Drainage Area (dimensionless)	1.78	-0.6383	3.2305

Warning: Some parameters are outside the suggested range. Estimates will extrapolations with unknown errors.

Regional regression limitations

- Derive input variables using the same methods as those used to develop the equations
- Standard Errors of 22-59%
- 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

Presentation outline

- What and Why?
- General hydrology - Minnesota
- Estimating peak flood flows: $Q_{1.5}$ - Q_{100}
- Bankfull flow and elevation
- Estimating flows for by-pass during construction

Bankfull discharge and elevation (estimate $Q_{1.5}$ or Q_2)

- Use results to help identify and verify bankfull elevation (and channel dimensions)
- Where bankfull elevations are good, use analysis to verify the relative accuracy of the regression equations and/or hydraulic model

Model bankfull discharge

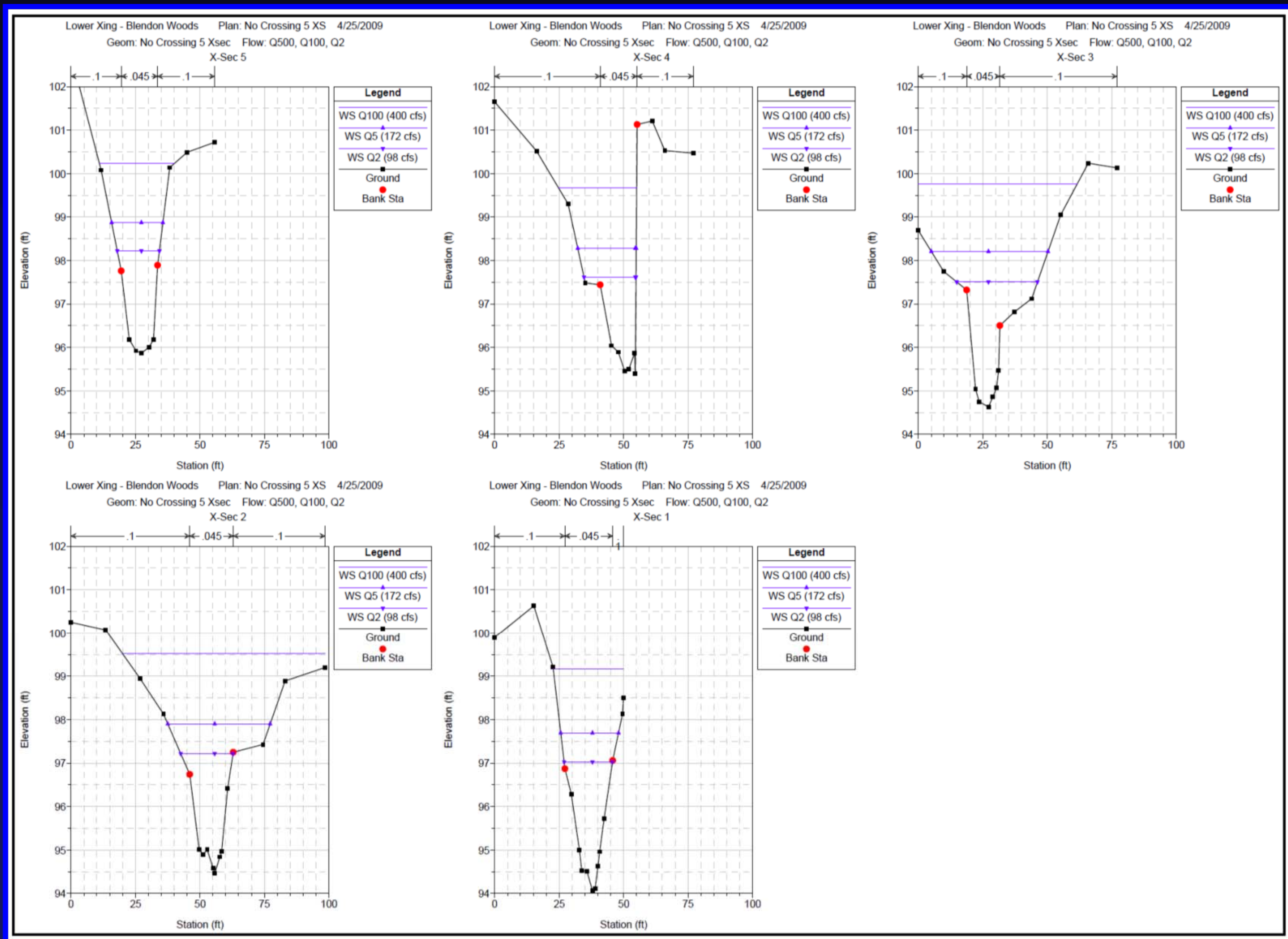
- Model bankfull discharge with Manning Equation

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

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

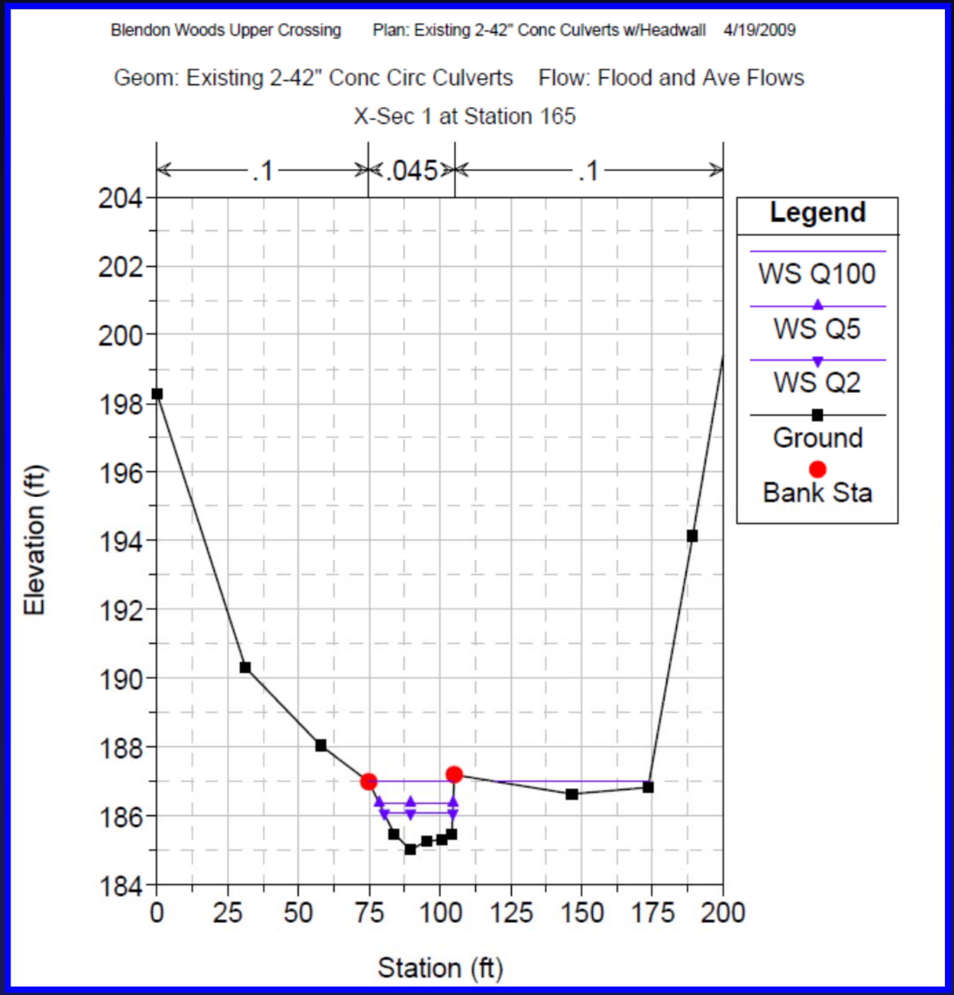
Model BF Q to verify BF elevation

Example: Lower Blendon Crossing, OH



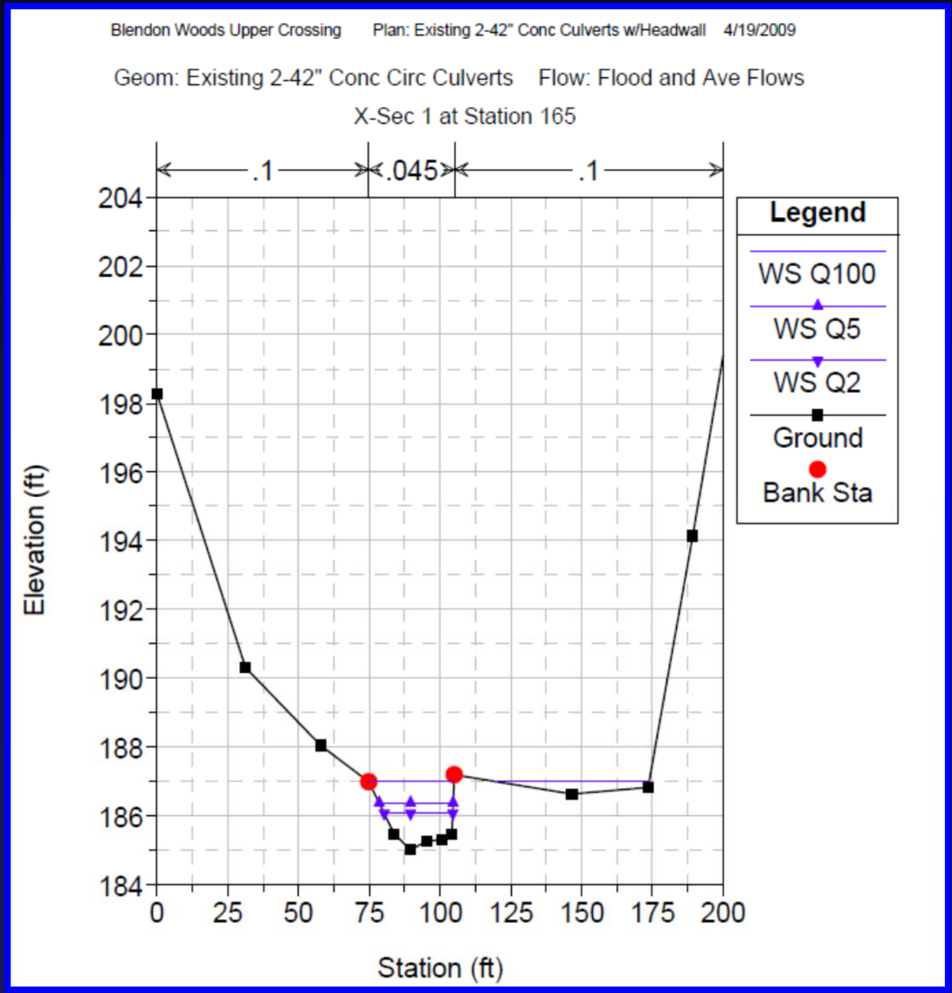
Model BF Q to verify BF elevation

Example: Upper Blendon crossing, OH



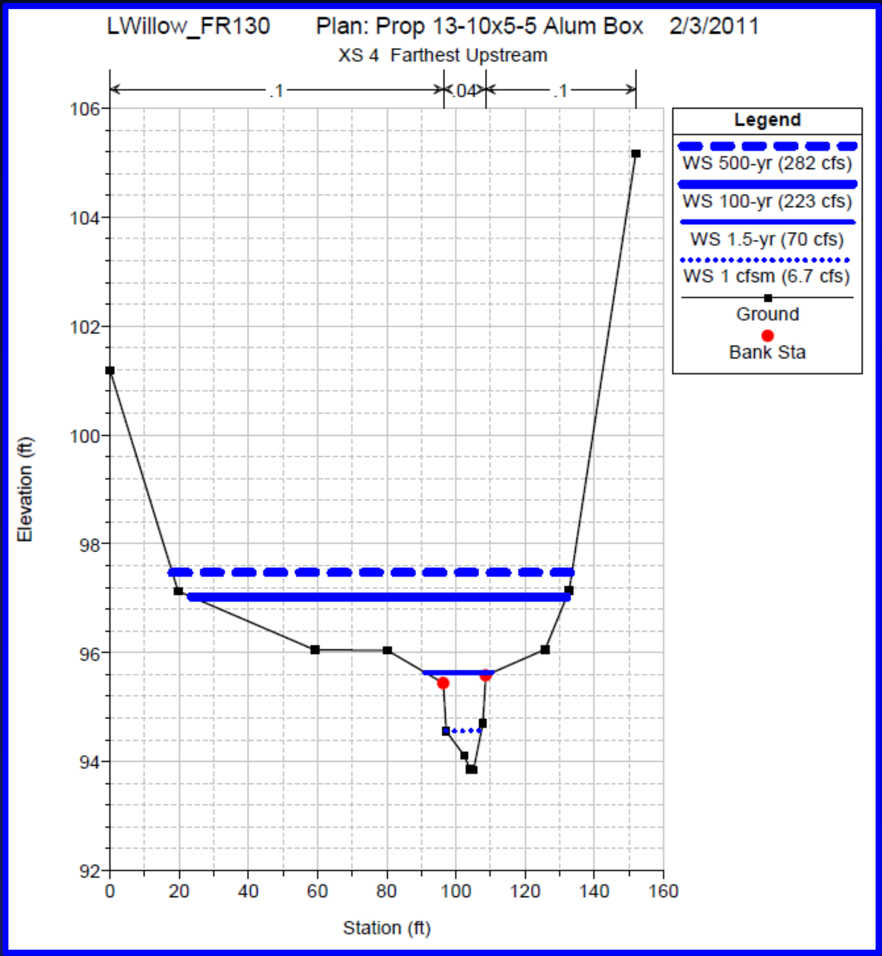
Model BF Q to verify BF elevation

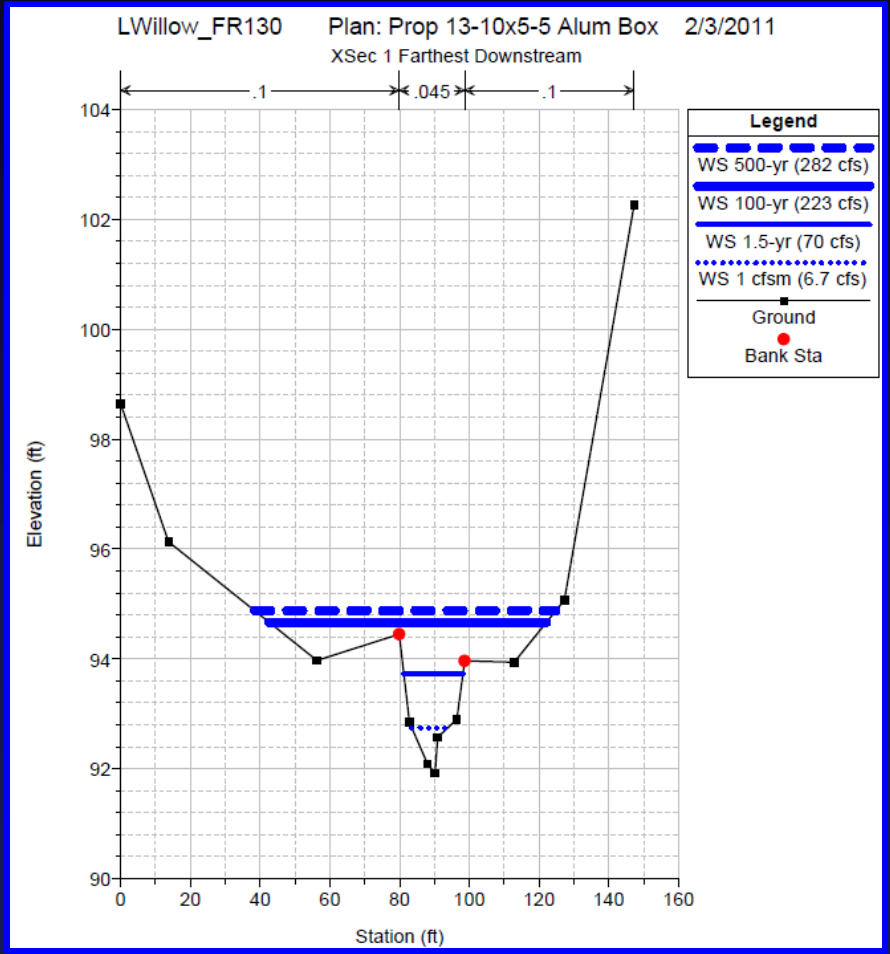
Example: Upper Blendon crossing, OH



Model BF Q to verify BF elevation

Example: L Willow crossing, WI





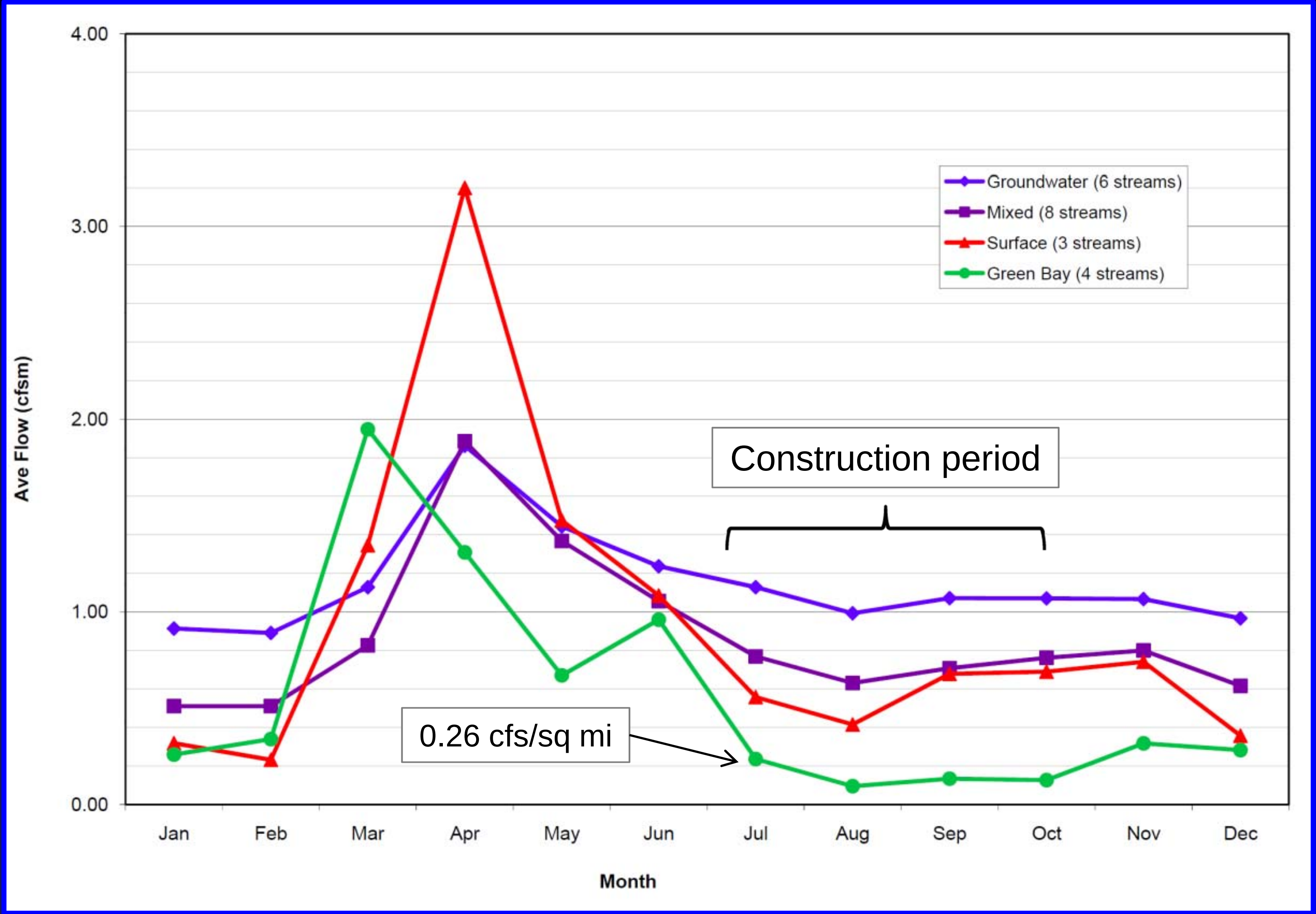
Presentation outline

- What and Why?
- General hydrology - Minnesota
- Estimating peak flood flows: $Q_{1.5}$ - Q_{100}
- Bankfull flow and elevation
- Estimating flows for by-pass during construction

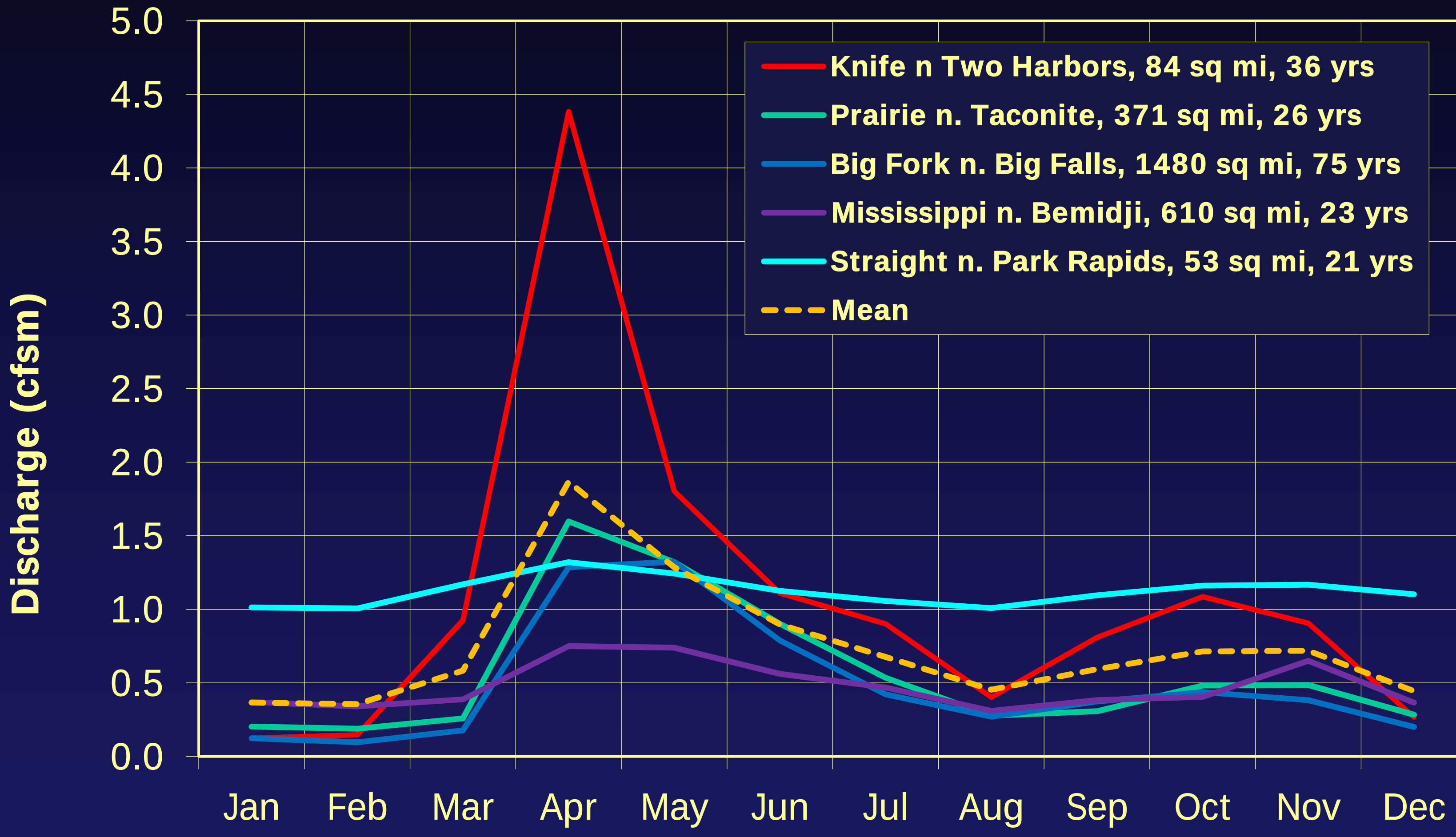
Estimating and designing for by-pass flows

- Determine construction season
- Determine required time for construction
- High base flows/long construction period:
  - Days to weeks
  - Diversion channel or culvert
  - Sized for Q_2 or local requirements
- Low flows/short construction period:
  - 1 to a few days
  - By-pass pump opportunity
  - Size capacity for highest average monthly flow or flow duration curve (ex. 50%)

Ave monthly runoff near Green Bay, WI and three flow regimes in N. WI



Ave monthly flows for 5 sites in N MN



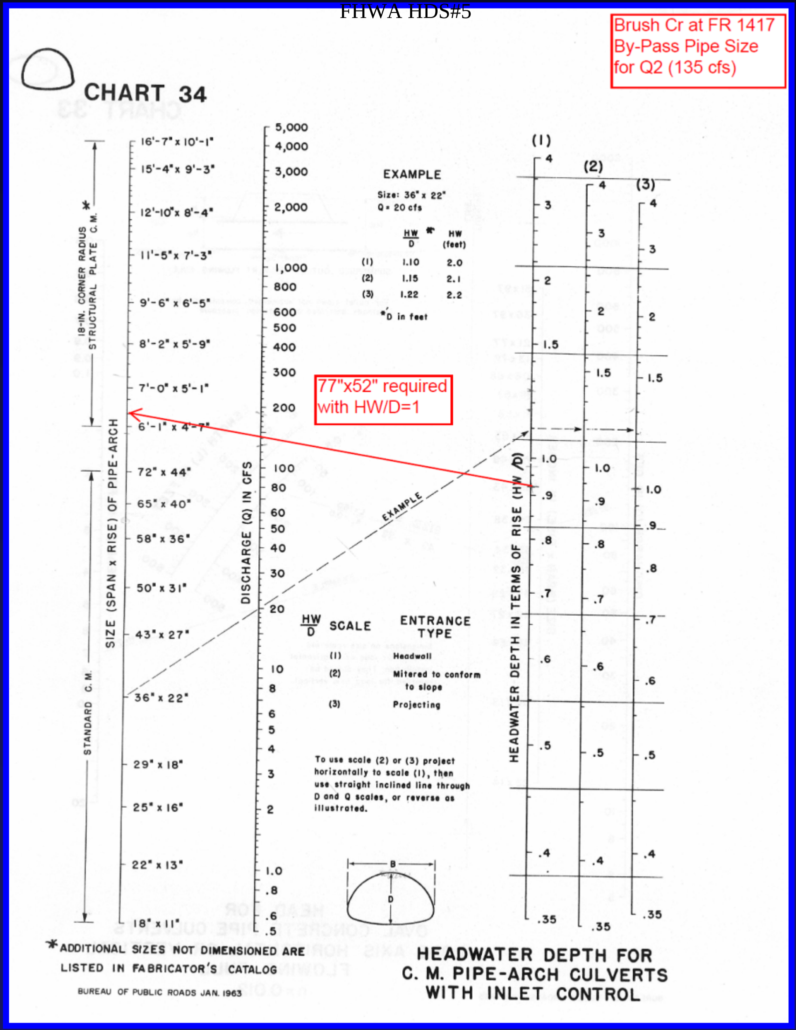
By-pass pumping capacity estimate based on average monthly flow

Brookside Cr site, drainage area = 3.91 sq mi

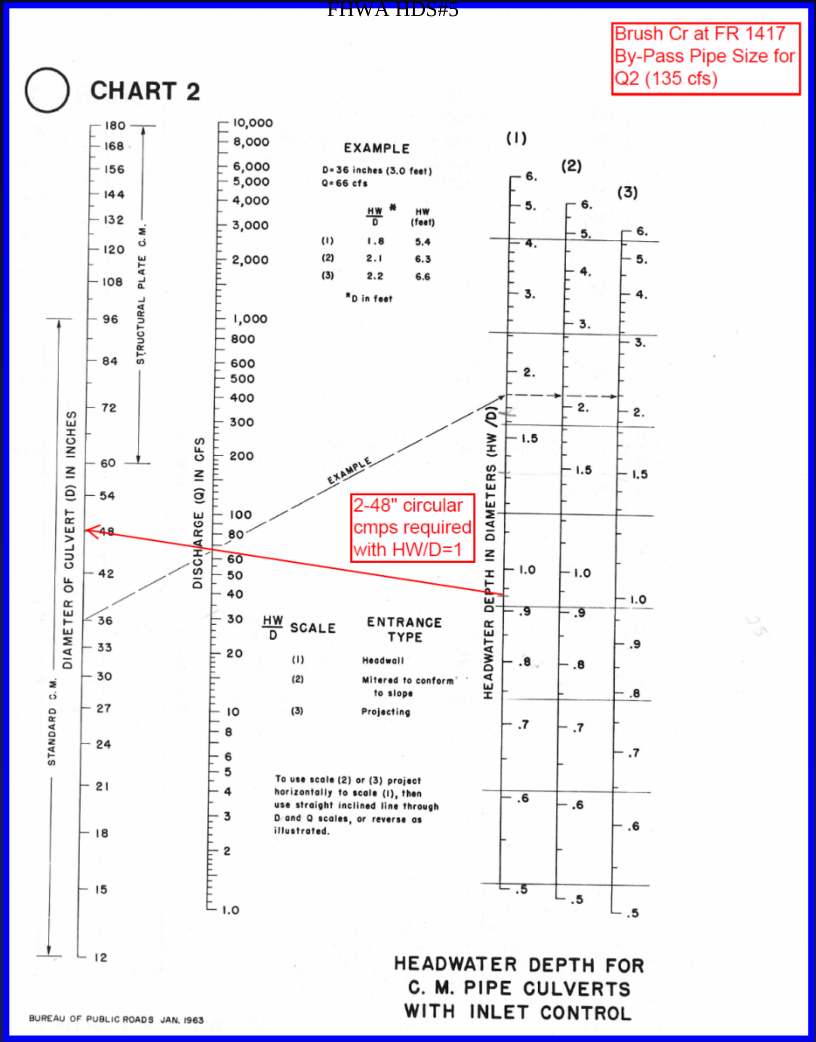
July ave flow = 0.24 cfs/sq mi x 3.91 sq mi = 0.94 cfs or 422 gal/min

By-pass culvert design based on Q_2 Brush Cr at FR 1417, WI

FHWA HDS#5



FHWA HDS#5



By-pass culvert design based on Q_2 Brush Cr at FR 1417, WI

- Drainage area = 4.32 sq mi
- 2-yr flood flow est = 135 cfs
- Culvert invert elevations:
  - Upstream = 90.0
  - Downstream = 89.0
- Sheetpiling elevations:
  - Upstream = 94.5
  - Downstream = 93.0

Occurrence of annual flood peaks

Swan River Trib (05216980), Itasca County, MN

Consideration for construction flows