Zone A Workshop

How to determine
Base Flood Elevation (BFE)
(100-year flood)

New Hampshire Office of
Energy and Planning

U.S. Geological Survey
Water Science Center
New Hampshire - Vermont

Zone A Workshop Outline

I. Sources of Flood and Watershed Information

II. How to Determine BFE: Simple Methods
Detailed Methods

III. Example of Determining Zone A BFE

IV. Questions and Answers

Sources of Flood and Watershed Information

Previous Flood Studies

- Draft flood studies (new or re-study)
  - FEMA
- Flood control projects
  - USACE, NRCS, Dam Bureau (NHDES)
- High flow design analysis (e.g. bridges)
  - FHA, NHDOT, County Highways, Public Works

Sources of Flood and Watershed Information

Federal Agencies

FEMA	Federal Emergency Management Agency
USACE	U.S. Army Corps of Engineers
FHA	Federal Highway Administration
USGS	U.S. Geological Survey
NRCS	Natural Resources Conservation Service
NOAA	National Oceanic and Atmospheric Administration

Sources of Flood and Watershed Information

State / Regional Agencies

NHOEP	N.H. Office of Energy and Planning
NHDOT	N.H. Department of Transportation
NHDES	N.H. Department of Environmental Services
RPCs	Regional Planning Commissions
NERCC	Northeast Regional Climate Center

Sources of Flood and Watershed Information

Local Agencies

County Highway Department

City / Town Engineer

Department of Public Works

Zone A Workshop Outline

I. Sources of Flood and Watershed Information

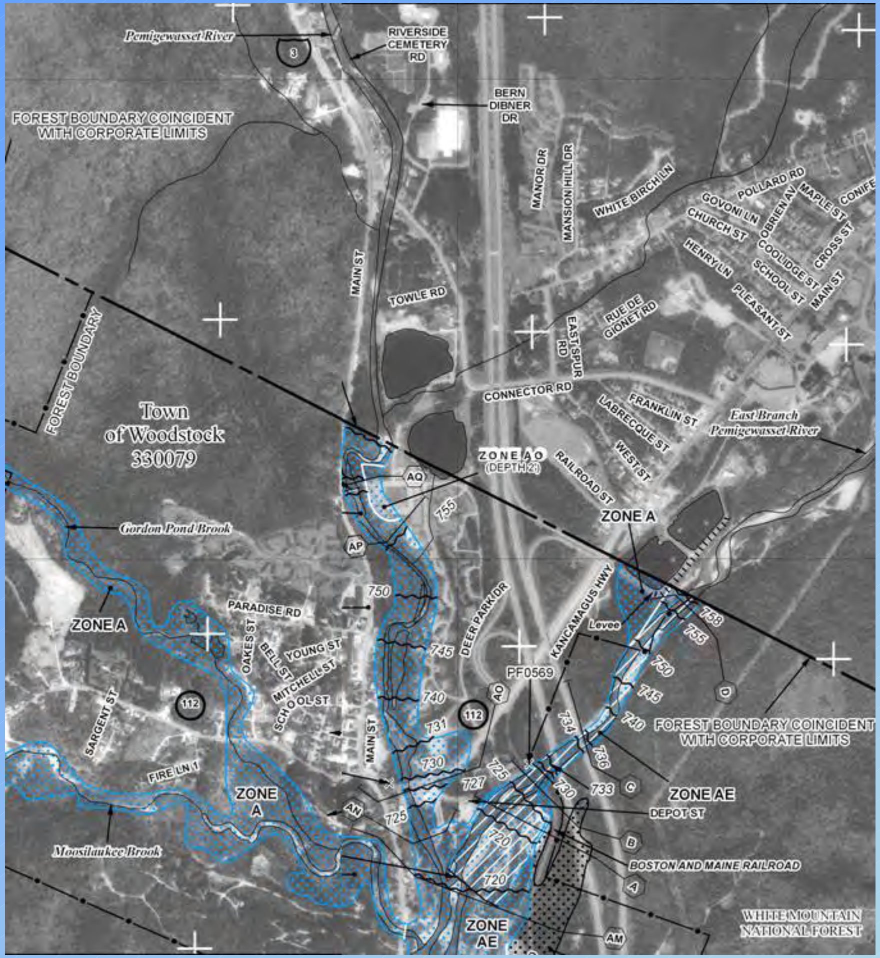
II. How to Determine BFE: **Simple Methods**
Detailed Methods

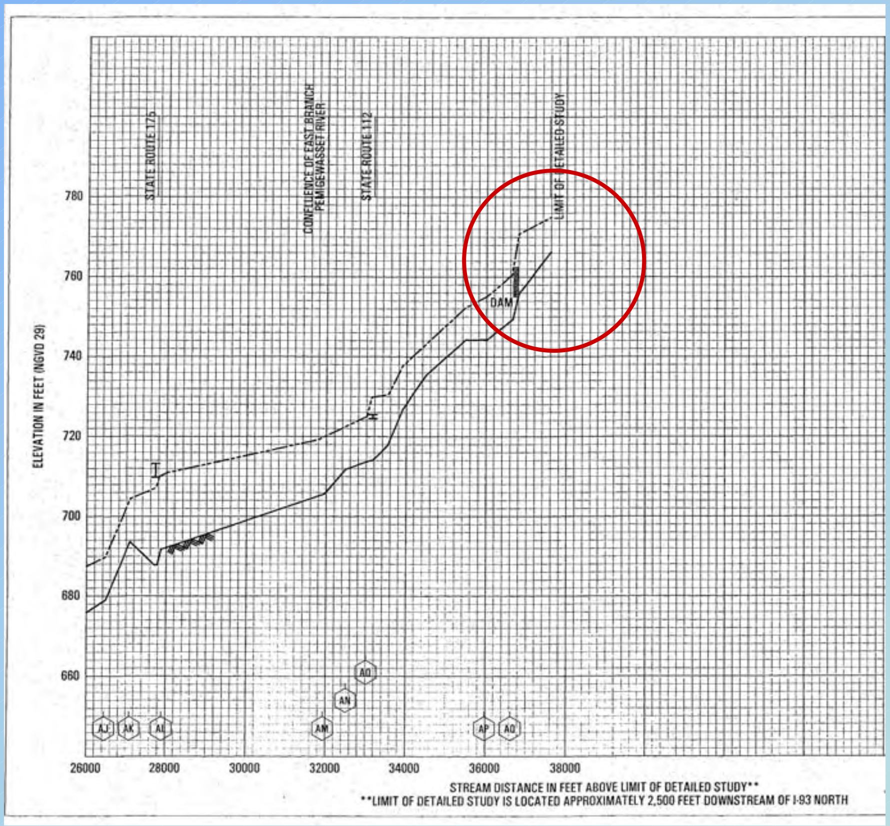
III. Example of Determining Zone A BFE

IV. Questions and Answers

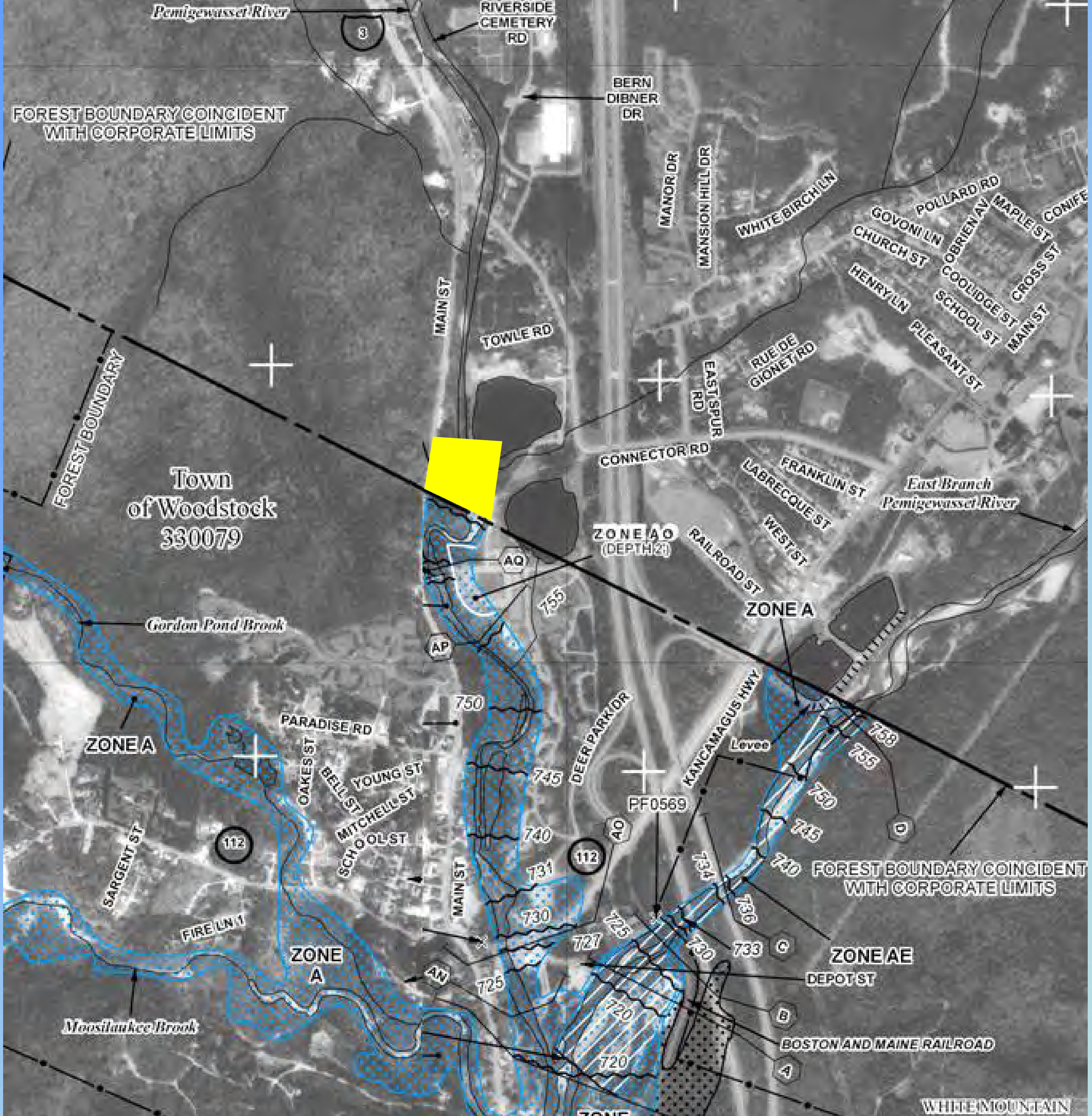
Extrapolation

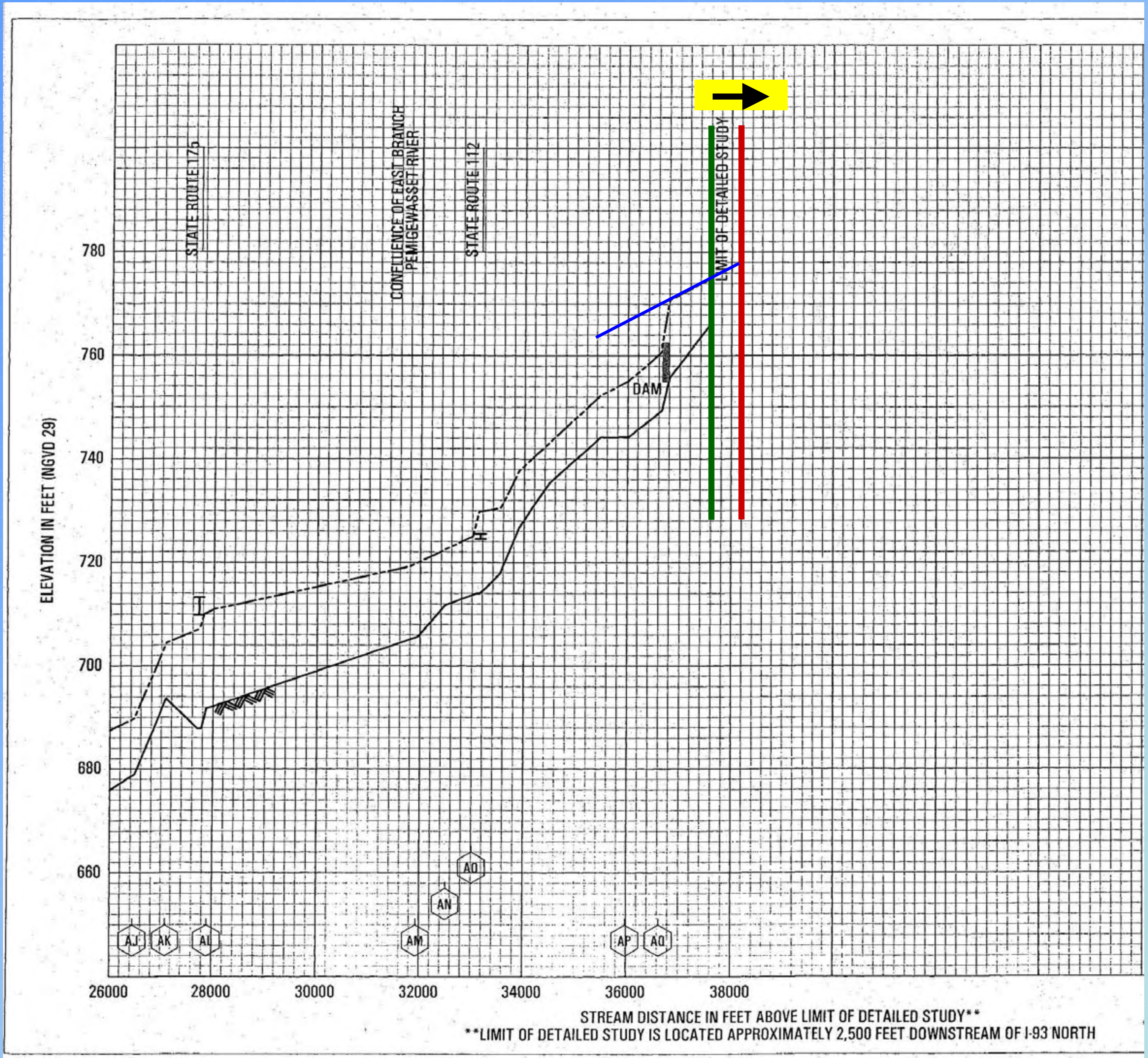
upstream from existing study





River profile

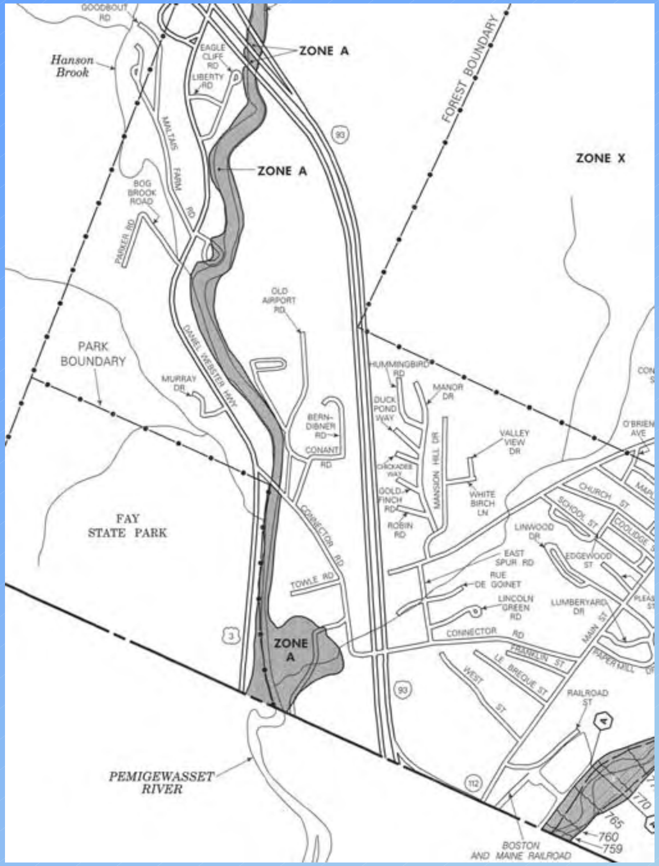

Pemigewasset River
RIVERSIDE CEMETERY RD
BERN DIBNER DR
FOREST BOUNDARY COINCIDENT WITH CORPORATE LIMITS
MANOR DR
MANSION HILL DR
WHITE BIRCH LN
POLLARD RD
GOVONI LN
MAPLE ST
CHURCH ST
OBRIEN AV
CROSS ST
HENRY LN
COOLIDGE ST
SCHOOL ST
MAIN ST
PLEASANT ST
TOWLE RD
RUE DE GIONET RD
EAST SPUR RD
FOREST BOUNDARY
Town of Woodstock 330079
CONNECTOR RD
FRANKLIN ST
LABRECQUE ST
East Branch Pemigewasset River
ZONE AO (DEPTH 2)
AQ
RAILROAD ST
WEST ST
ZONE A
Gordon Pond Brook
AP
PARADISE RD
DEER PARK DR
KANCAMAGUS HWY
Levee
OAKES ST
BELL ST
YOUNG ST
MITCHELL ST
SCHOOL ST
PF0569
SARGENT ST
FIRE LN 1
FOREST BOUNDARY COINCIDENT WITH CORPORATE LIMITS
ZONE AE
DEPOT ST
ZONE A
AN
Moosilaukee Brook
BOSTON AND MAINE RAILROAD
WHITE MOUNTAIN



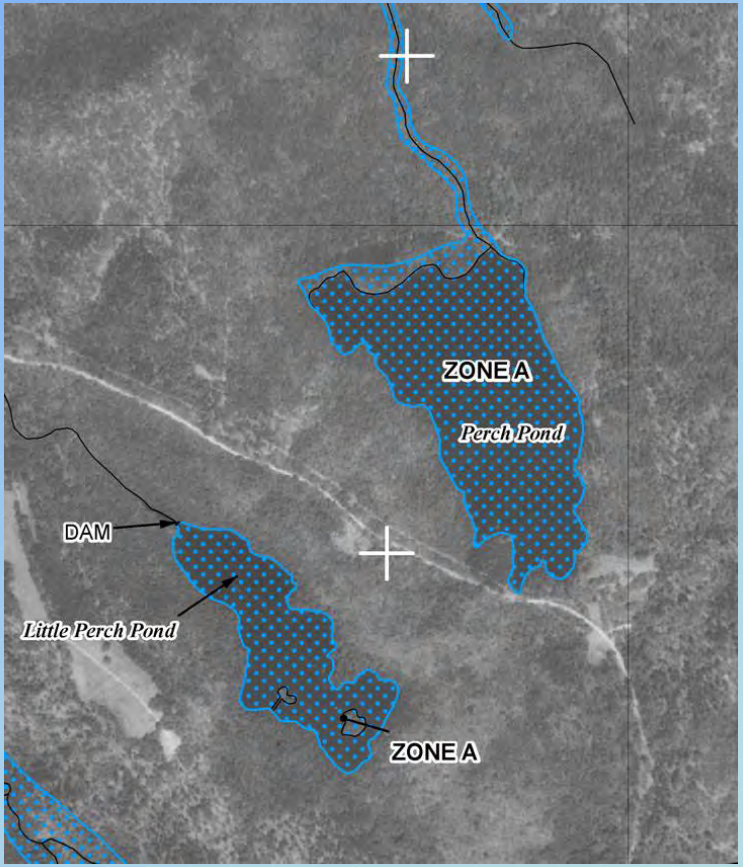
ELEVATION IN FEET (NGVD 29)
780
760
740
720
700
680
660
STATE ROUTE 175
CONFLUENCE OF EAST BRANCH PEMIGEWASSET RIVER
STATE ROUTE 112
LIMIT OF DETAILED STUDY
DAM
AJ
AK
AL
AM
AN
AO
AP
AQ
26000
28000
30000
32000
34000
36000
38000
STREAM DISTANCE IN FEET ABOVE LIMIT OF DETAILED STUDY**
**LIMIT OF DETAILED STUDY IS LOCATED APPROXIMATELY 2,500 FEET DOWNSTREAM OF I-93 NORTH

Contour Interpolation

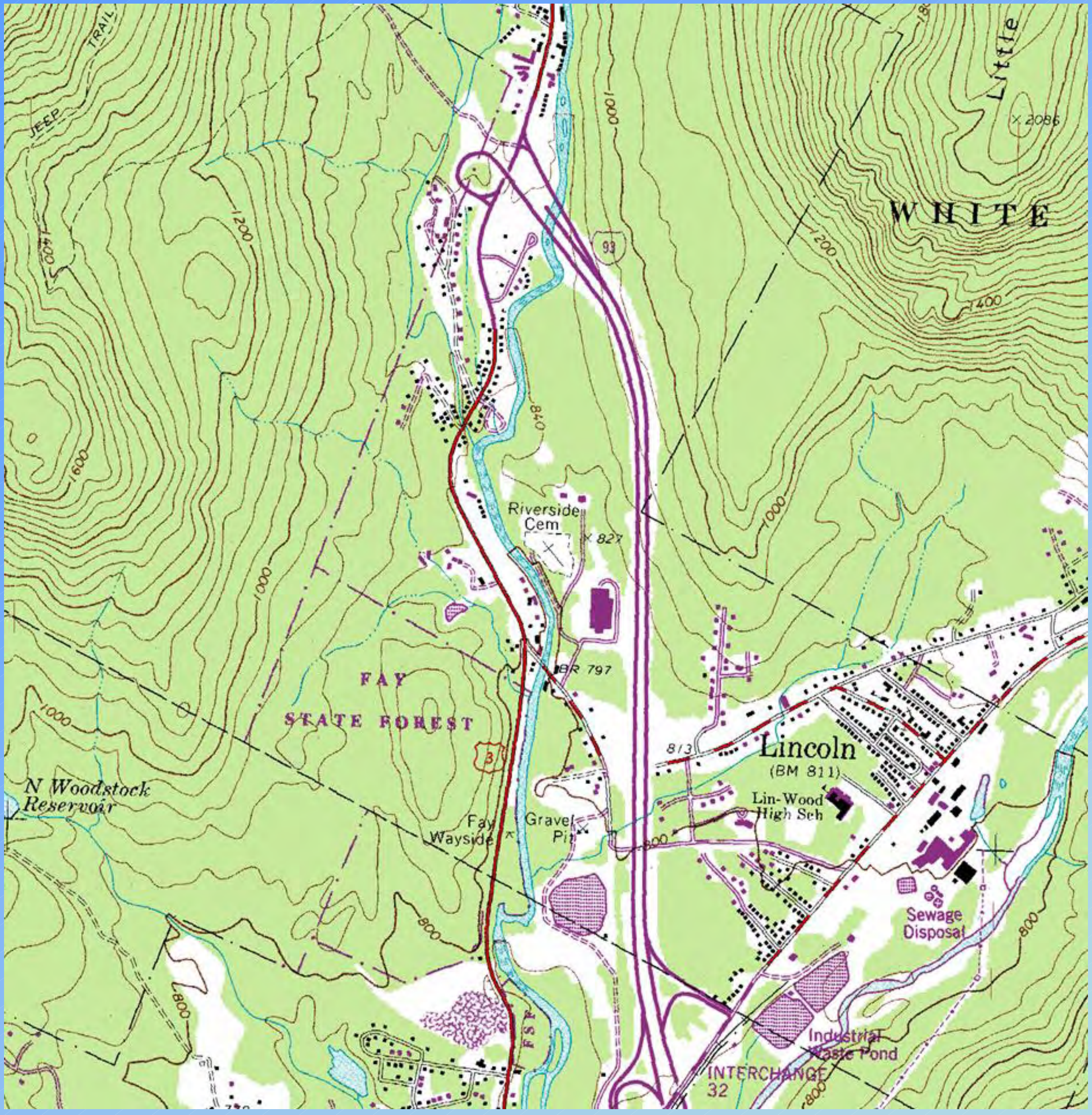
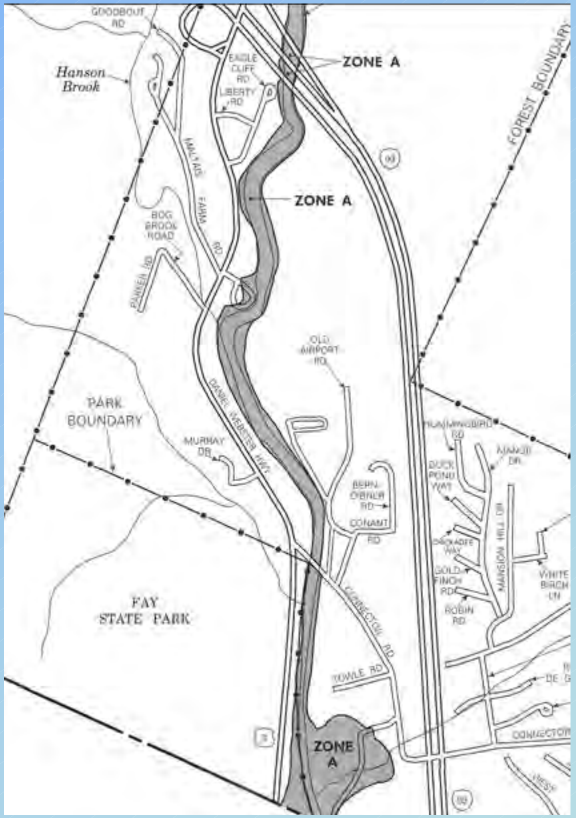
using topographic and Zone A maps

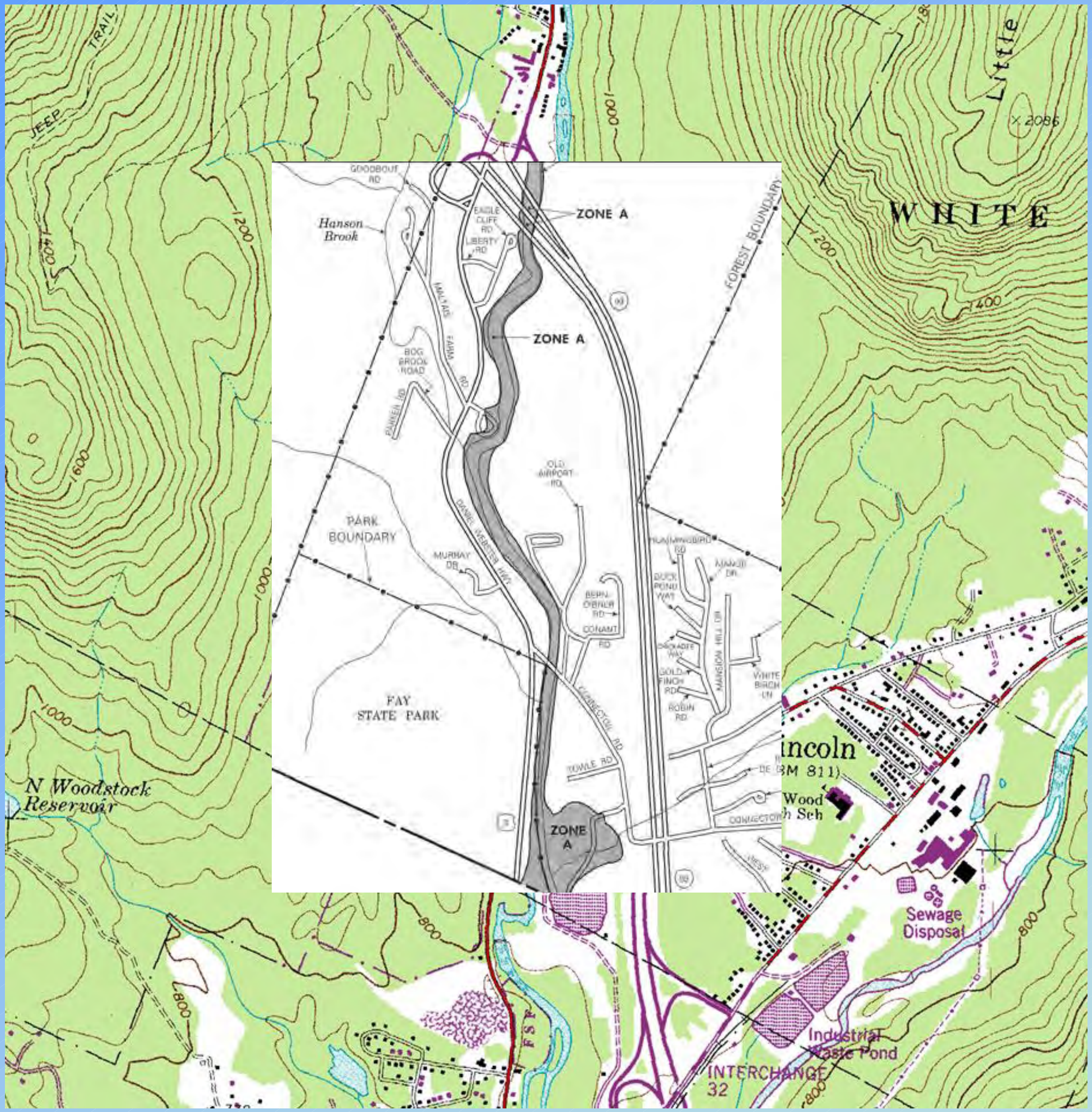


River Zone A

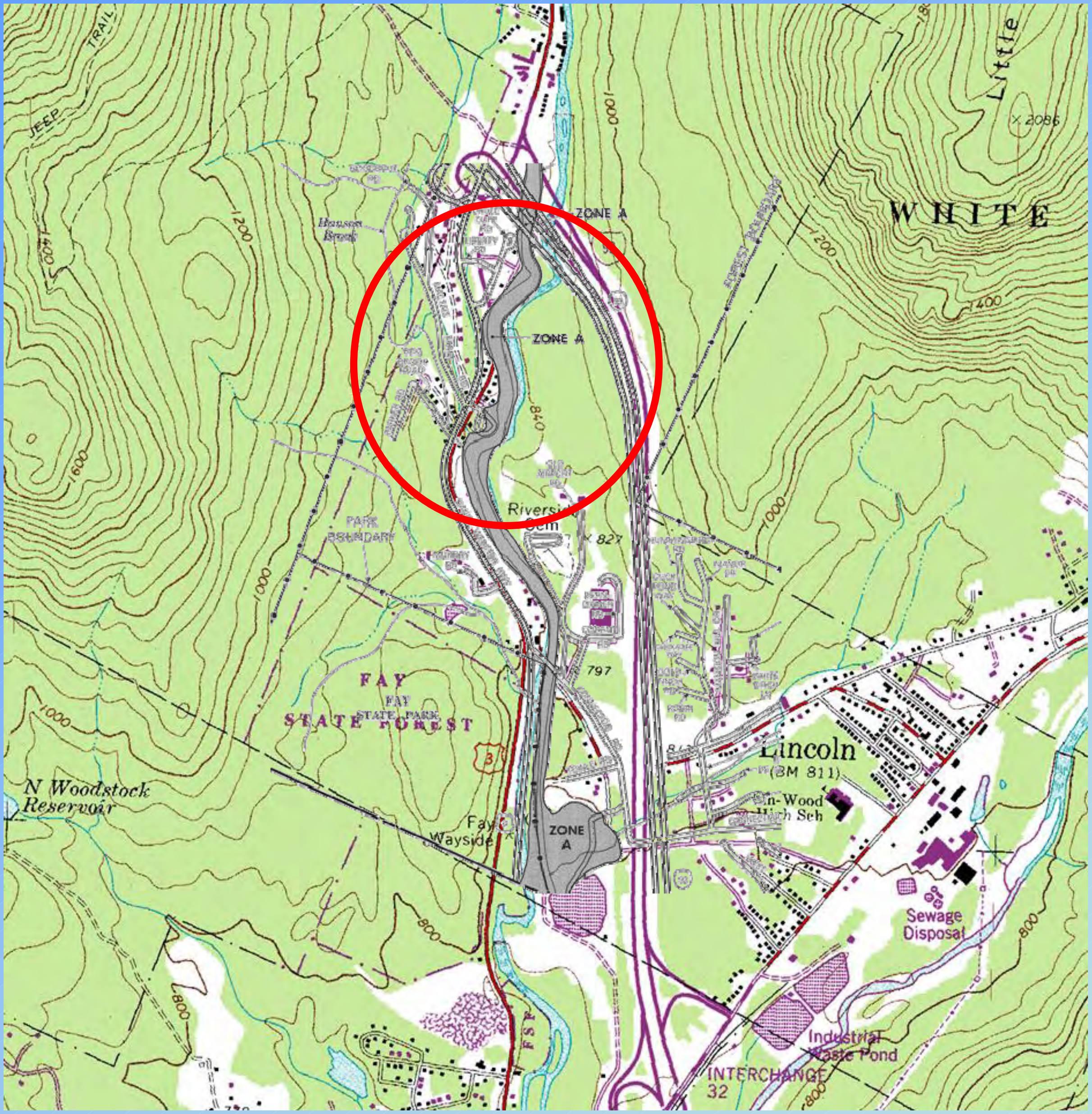


Lake/Pond Zone A

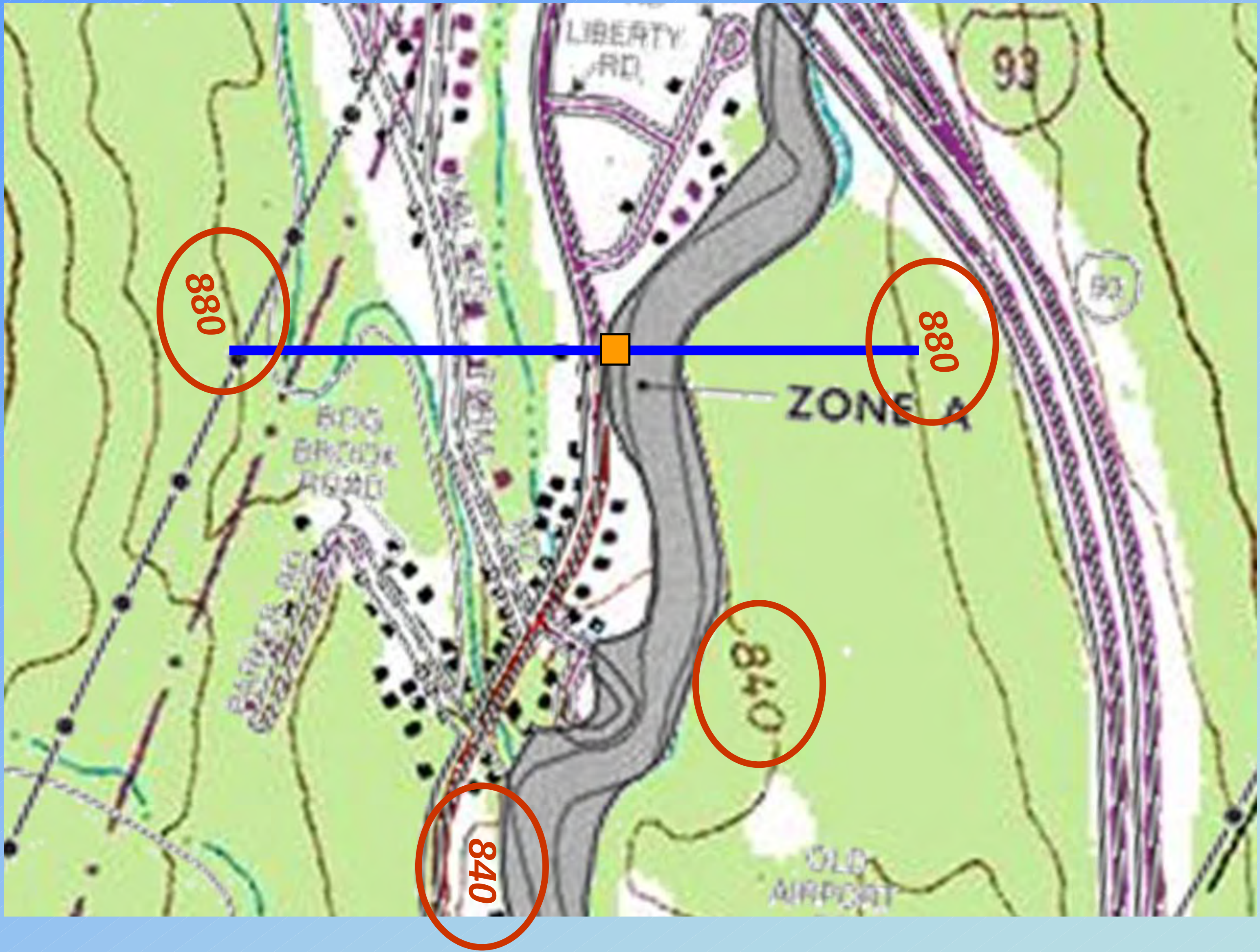

WHITE
Little
Riverside Cem
FAY STATE FOREST
Lincoln
(BM 811)
Lin-Wood High Sch
N Woodstock Reservoir
Fay Wayside
Gravel Pit
Sewage Disposal
Industrial Waste Pond
INTERCHANGE 32
JEEP TRAIL

ZONE A
ZONE A
ZONE A
Hanson Brook
GOODBOUT RD
EAGLE CLIFF RD
LIBERTY RD
BOG BROOK ROAD
PARK BOUNDARY
FAY STATE PARK
FOREST BOUNDARY
OLD AIRPORT RD
MURRAY DR
DANIEL WEBSTER HWY
CONANT RD
HUMMINGBIRD RD
DUCK POND WAY
ROBIN RD
WHITE BIRCH LN
MANSION HILL DR
CONNECTICUT RD
FOWLE RD



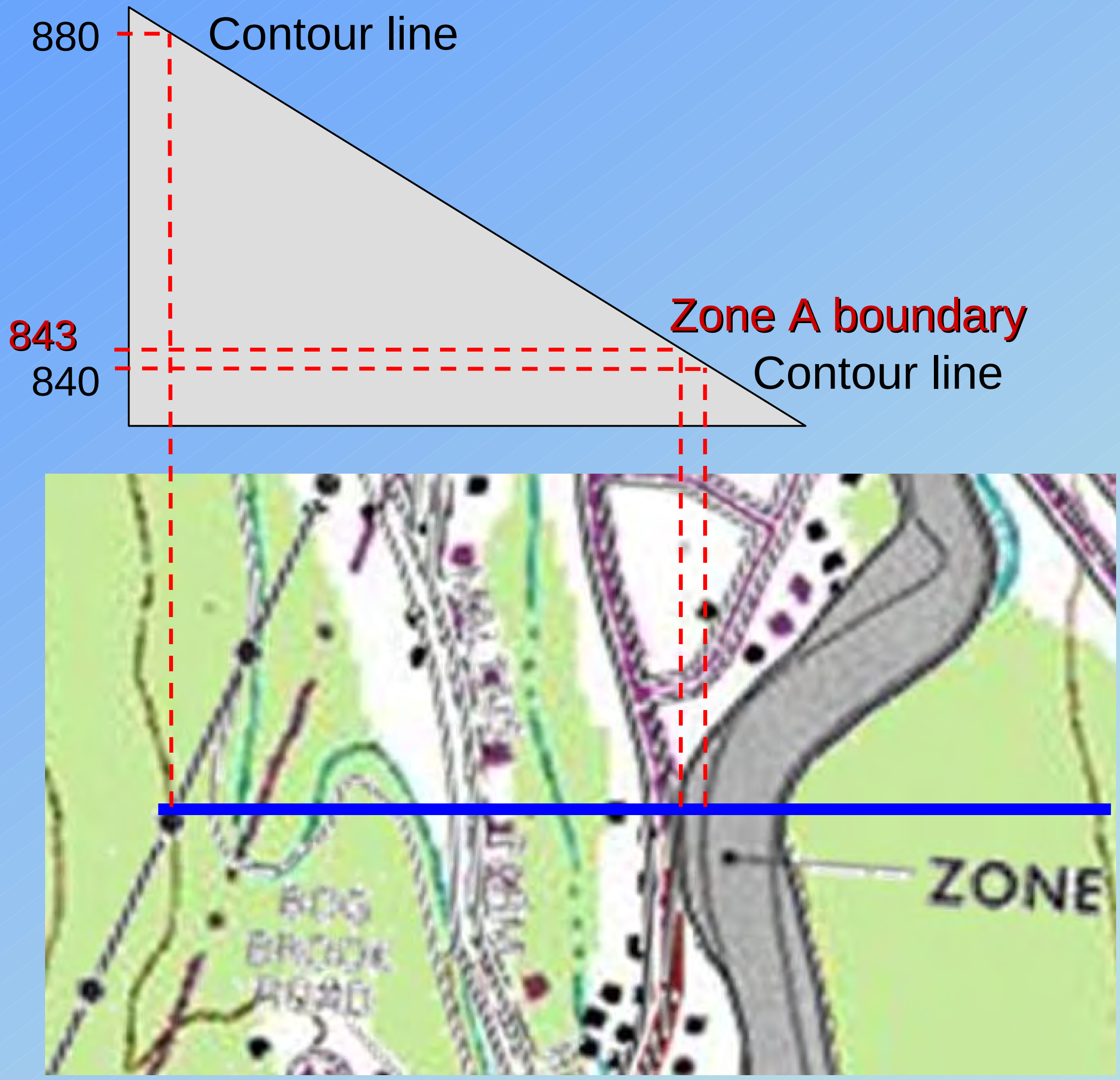
JEEP TRAIL
WHITE
Little
2086
1000
1200
1400
1600
800
GODBOUT RD
Hanson Brook
EAGLE CLIFF RD
LIBERTY RD
ZONE A
ZONE A
FOREST BOUNDARY
BOG BROOK ROAD
PARKER RD
OLD AIRPORT RD
PARK BOUNDARY
MURRAY DR
DANIEL WEBSTER HWY
HUMMINGBIRD RD
BERN-O'BNER RD
CONANT RD
FAY STATE PARK
TOWLE RD
CONNECTICUT RD
ZONE A
N Woodstock Reservoir
Lincoln
(BM 811)
Sewage Disposal
Industrial Waste Pond
INTERCHANGE 32



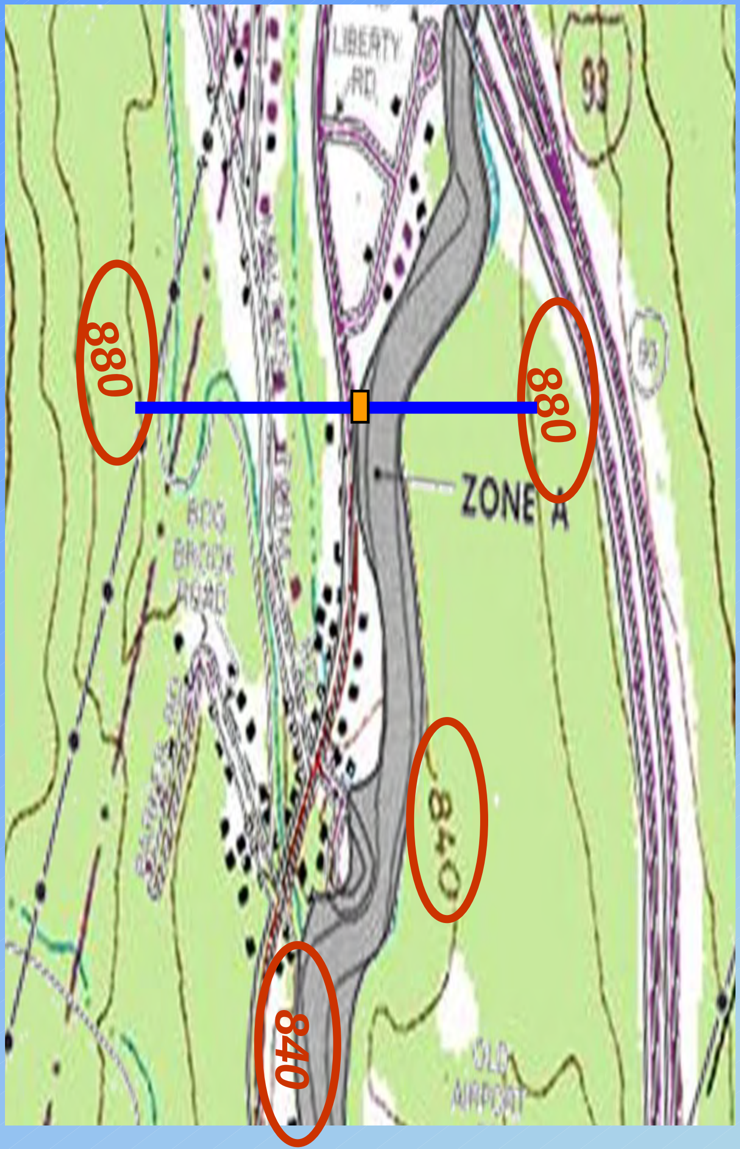
ZONE A
ZONE A
ZONE A
WHITE
Little
FAY STATE FOREST
FAY STATE PARK
PARK BOUNDARY
Lincoln
(BM 811)
Lin-Wood High Sch
Riverside Cem
Fay Wayside
N Woodstock Reservoir
Sewage Disposal
Industrial Waste Pond
INTERCHANGE 32
JEEP TRAIL


LIBERTY RD.
93
BOG BROOK ROAD
ZONE A
880
880
840
840
OLD AIRPORT

Contour Interpolation



Contour Interpolation



Contour interval = 40ft

Left Bank:
Zone A Boundary = 843 ft

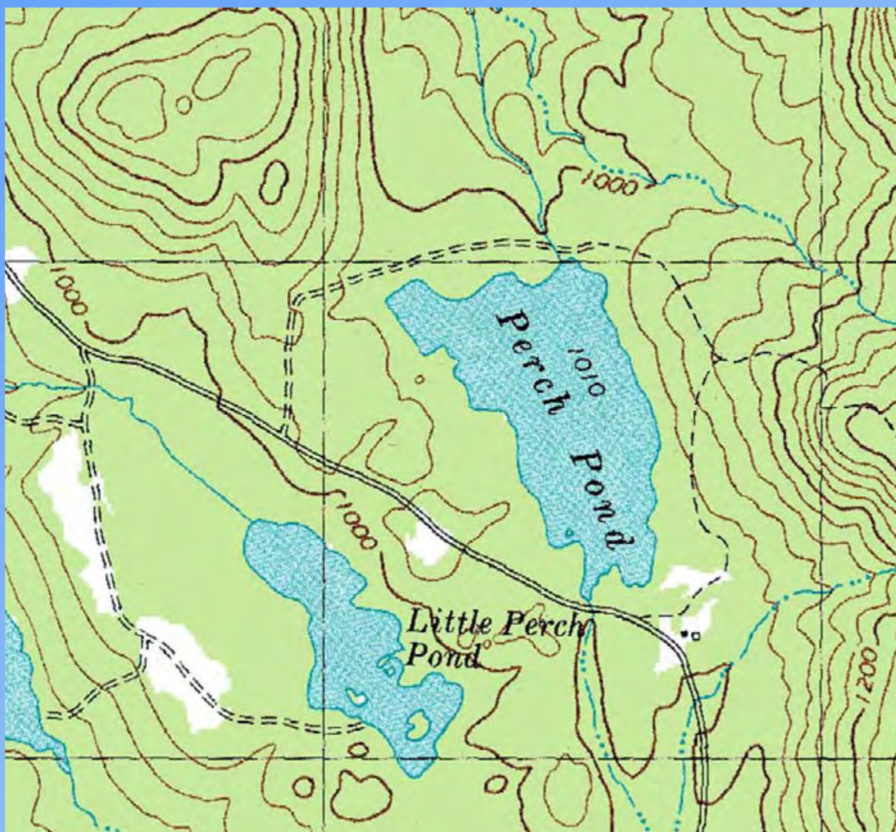
Right Bank
Zone A Boundary = 837 ft

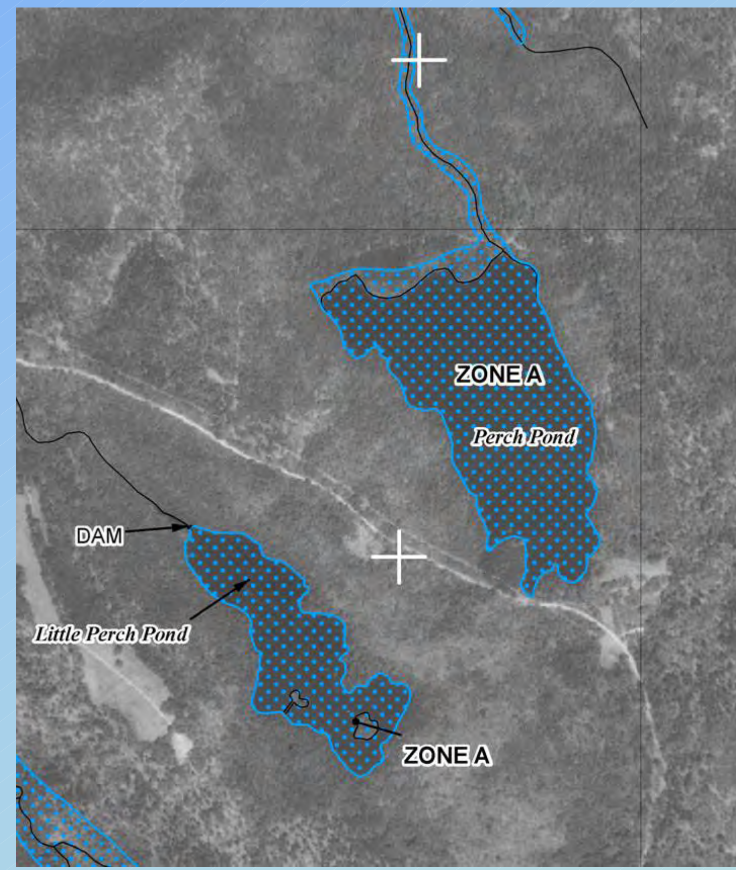
843-837 = 6 ft
OK (6<40/2)

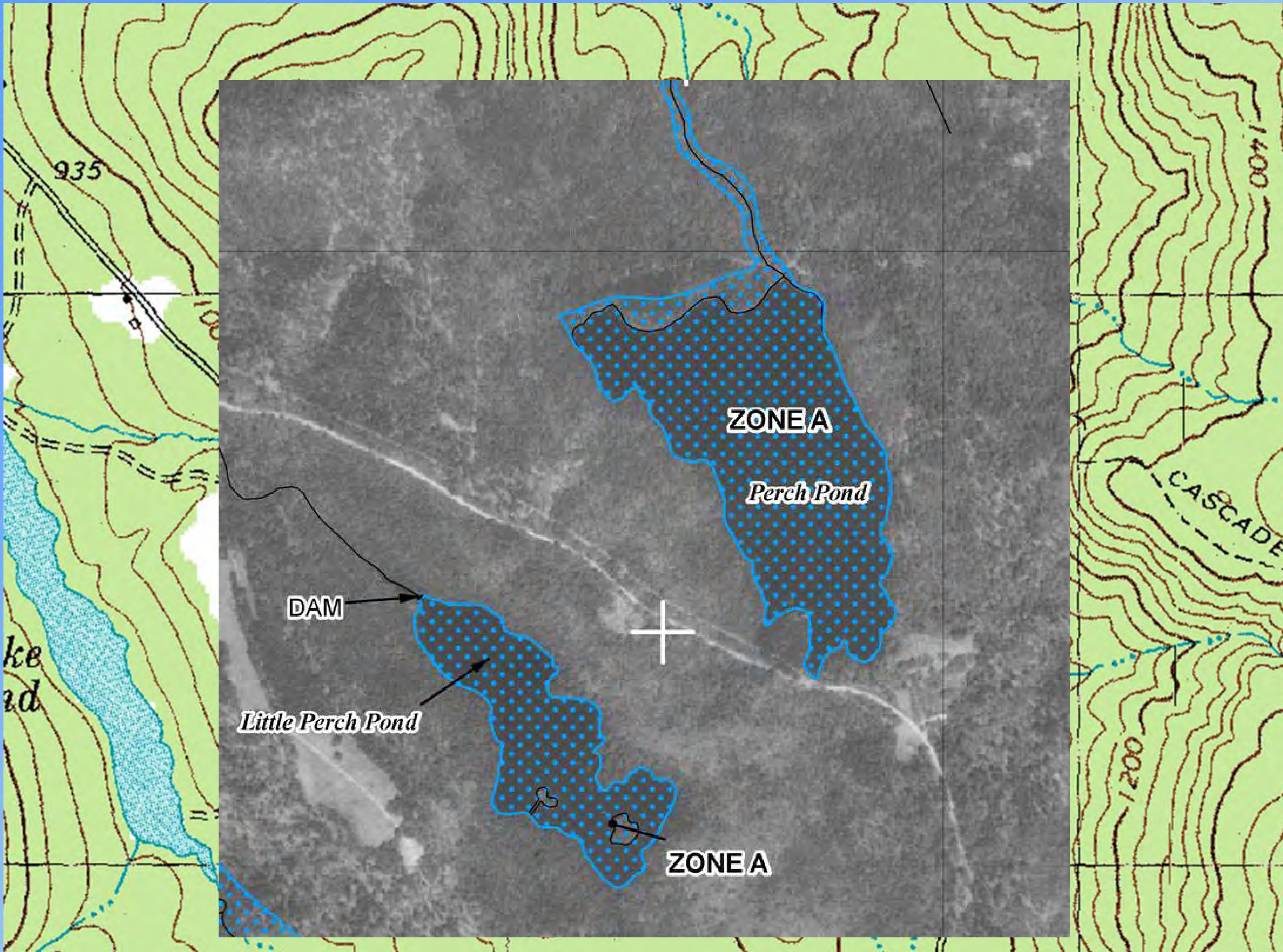
BFE = 837+40/2 = <u>857 ft</u>

Contour Interpolation

using topographic and Zone A maps

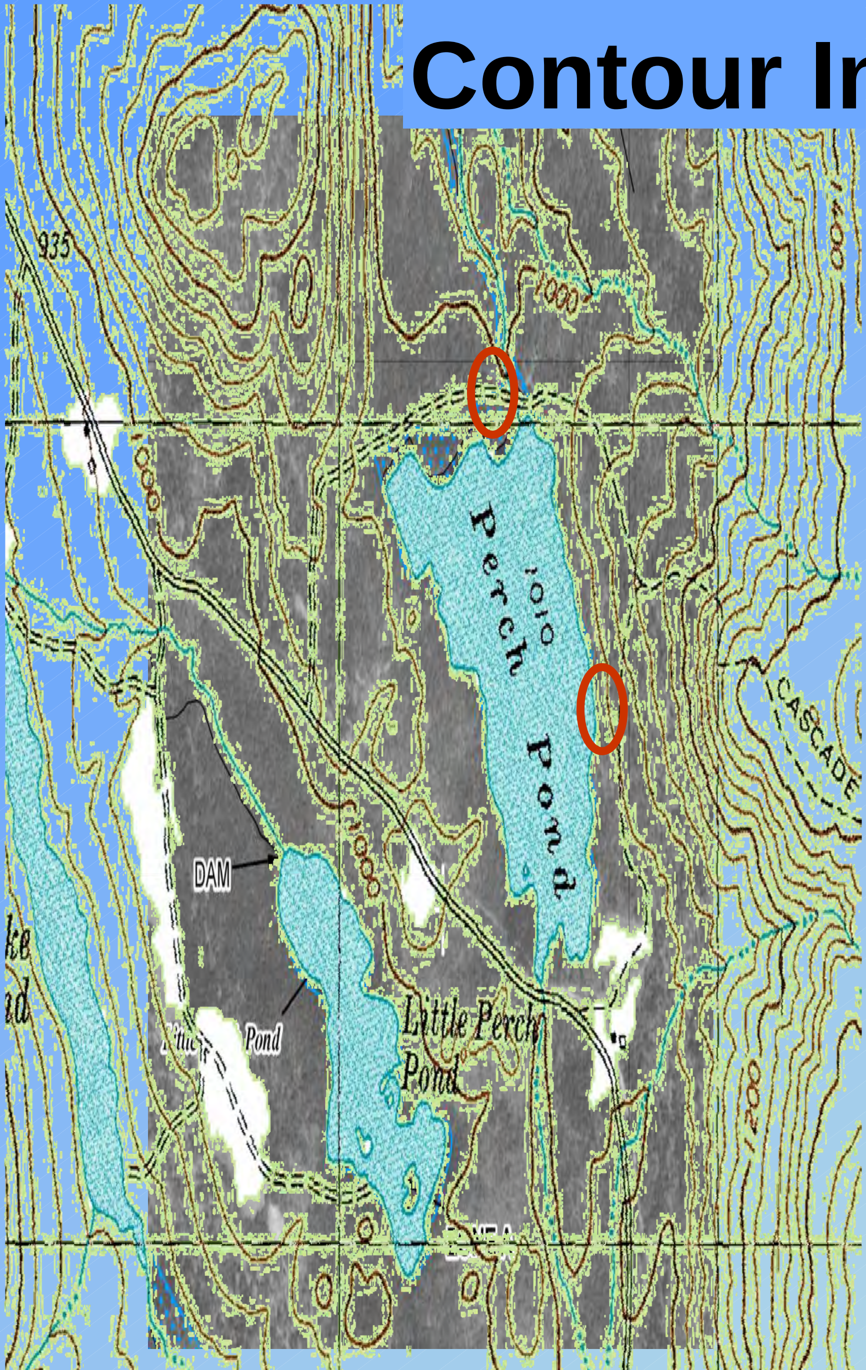





935
ZONE A
Perch Pond
CASCADE
DAM
Little Perch Pond
ZONE A
1200


935
1000
1000
1000
1010
Perch Pond
DAM
Little Perch Pond
CASCADE
1400
1200

Contour Interpolation



Contour interval = 40ft

Lowest perimeter point:
Zone A Boundary = 1010 ft

Highest perimeter point:
Zone A Boundary = 1021 ft

1021-1010 = 11 ft
OK (11<40/2)

BFE = 1010+40/2 = <u>1030 ft</u>

Zone A Workshop Outline

I. Sources of Flood and Watershed Information

II. How to Determine BFE: Simple Methods

Detailed Methods

III. Example of Determining Zone A BFE

IV. Questions and Answers

Steps to Determine BFE

1. **Hydrology:** 100-year discharge (flow, ft^3/s)
2. **Survey:** river and structures
3. **Hydraulics:** compute water elevation (BFE)

Hydrology: 100-yr flow

<u>Rivers and streams may be:</u>

Regulated *or* **Unregulated**

Gaged *or* **Ungaged**

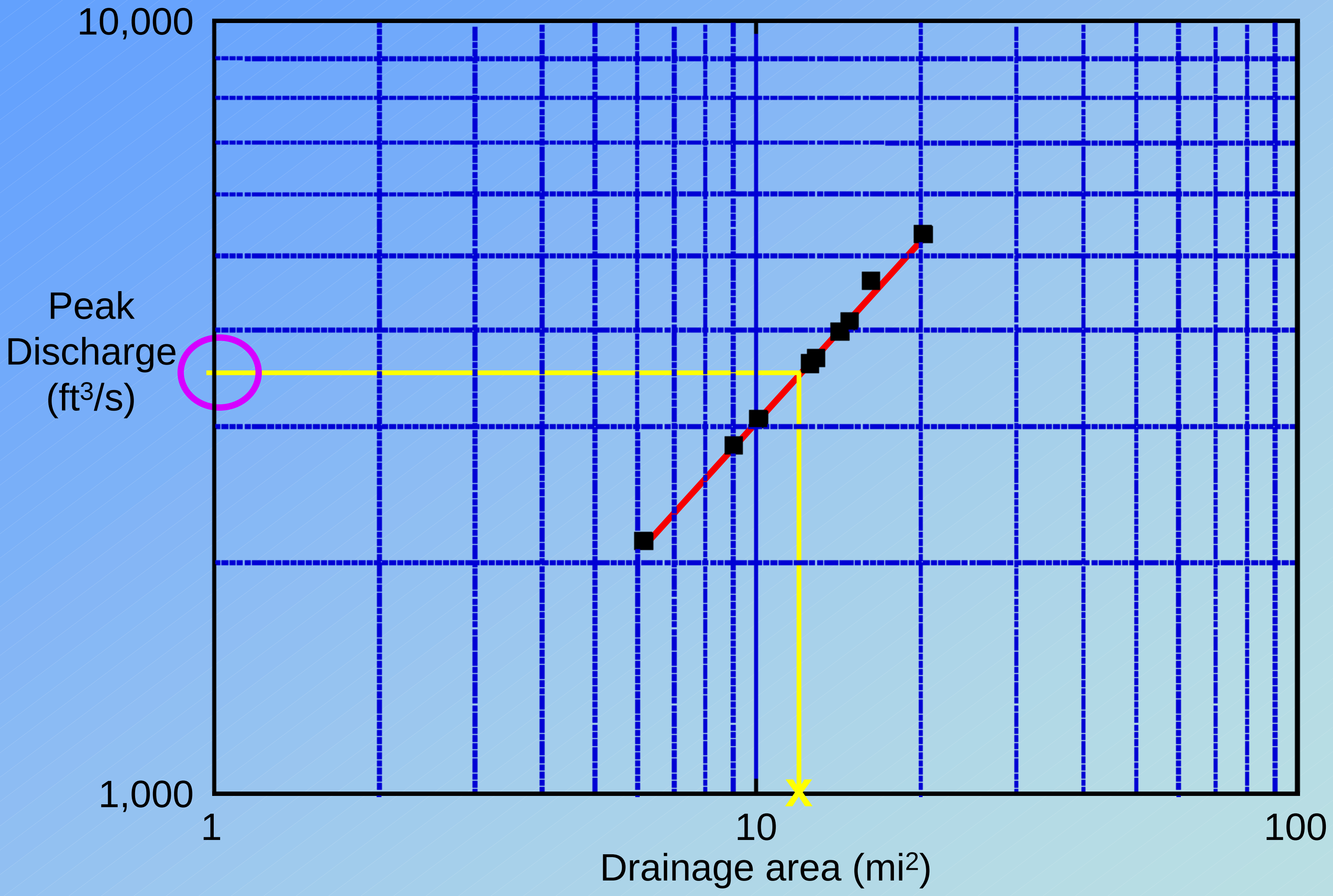
→ USGS *Streamstats*

Hydrology: 100-yr flow

Three common approaches:

- **Discharge / Drainage area**
- **Generalized equations**
  (USGS Streamstats)
- **Computer models**

Discharge / Drainage Area



Generalized Equations

- **Rational Formula**

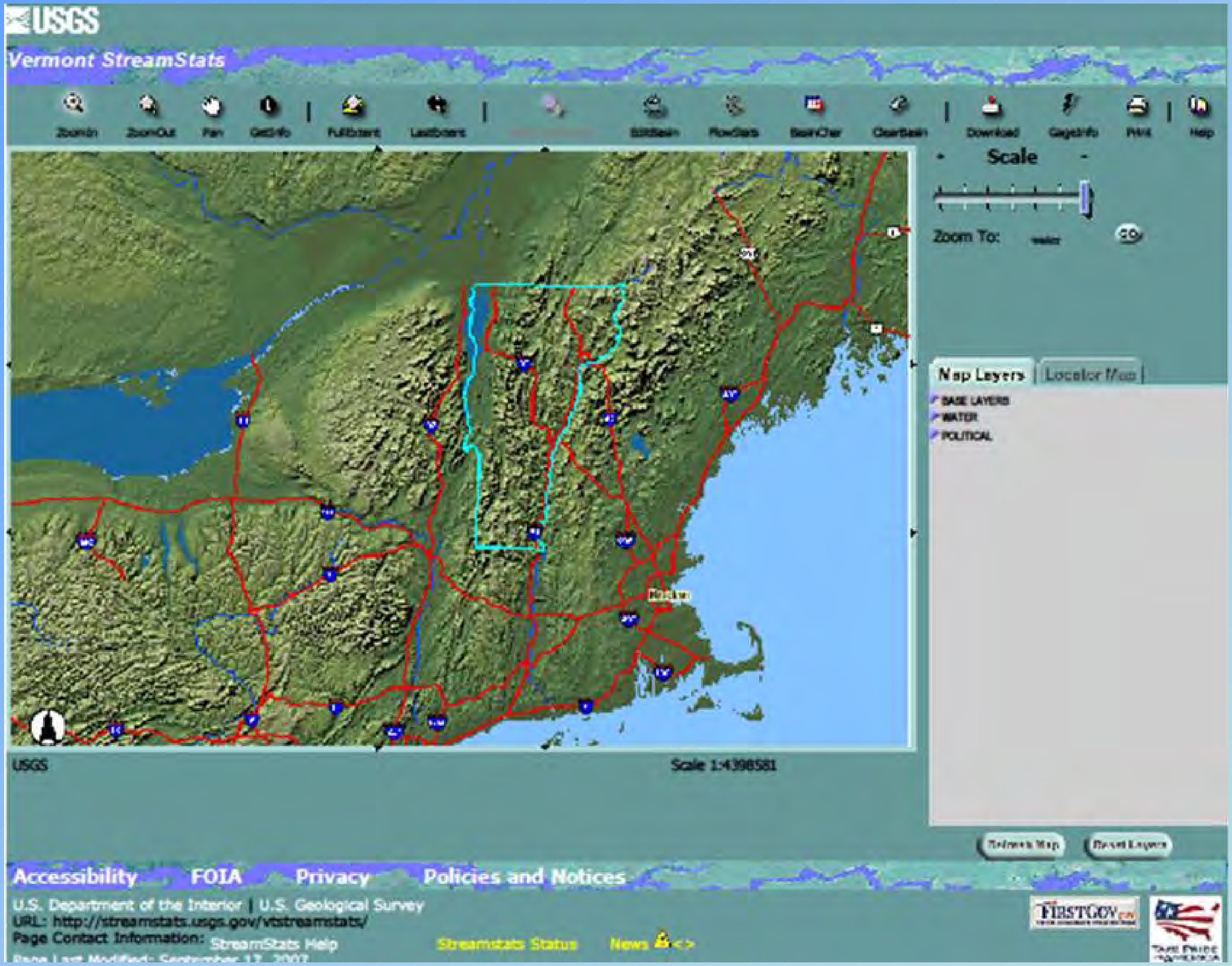
$$Q = C * i * A$$

- **Regression Equation**

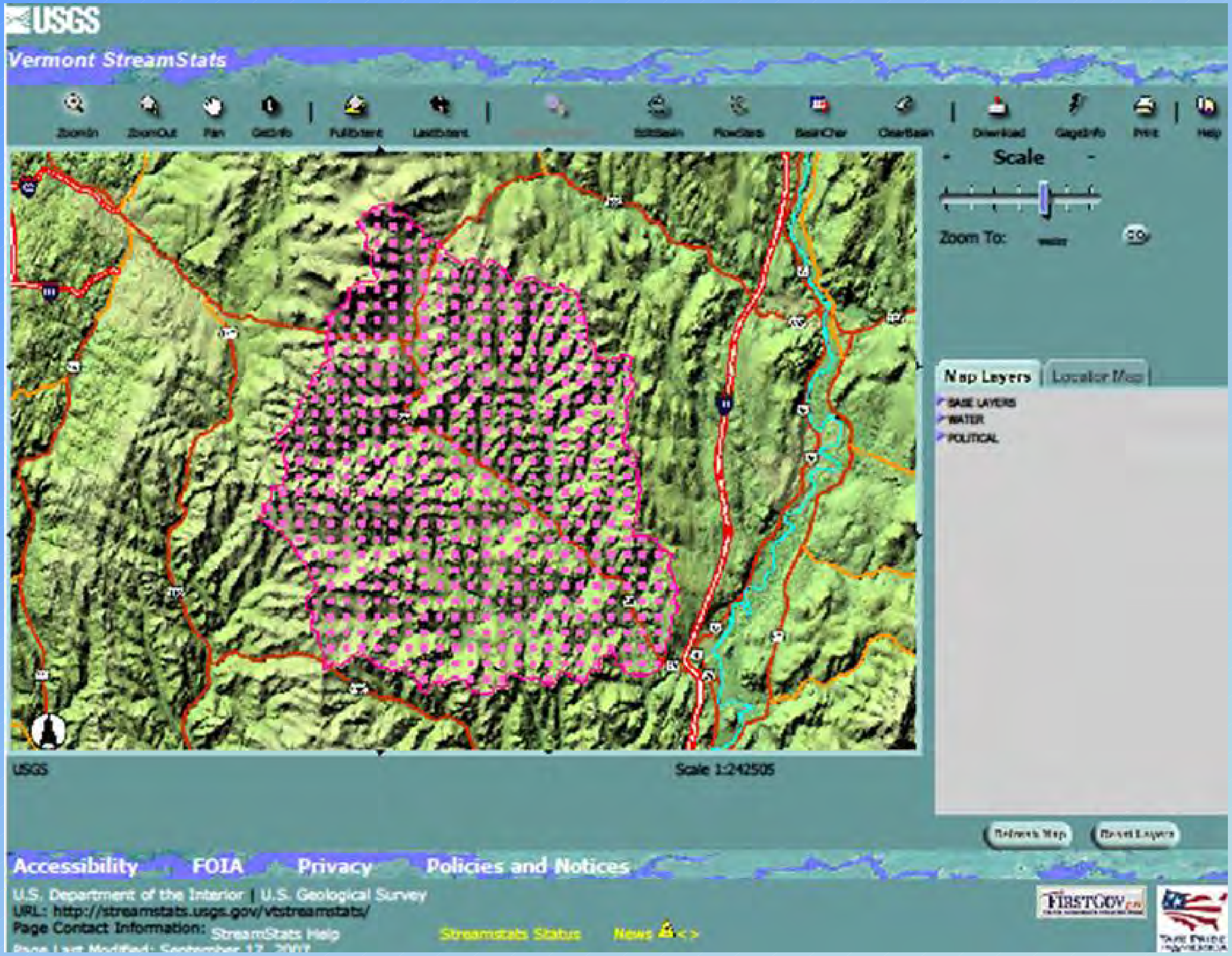
$$Q = 153A^{0.865} L^{-0.336} E^{0.125} Y^{-0.420}$$

Q = discharge, C = coefficient, i = rainfall intensity, A = drainage area
L = % lakes/ponds, E = % elevation >1200ft, Y = latitude factor

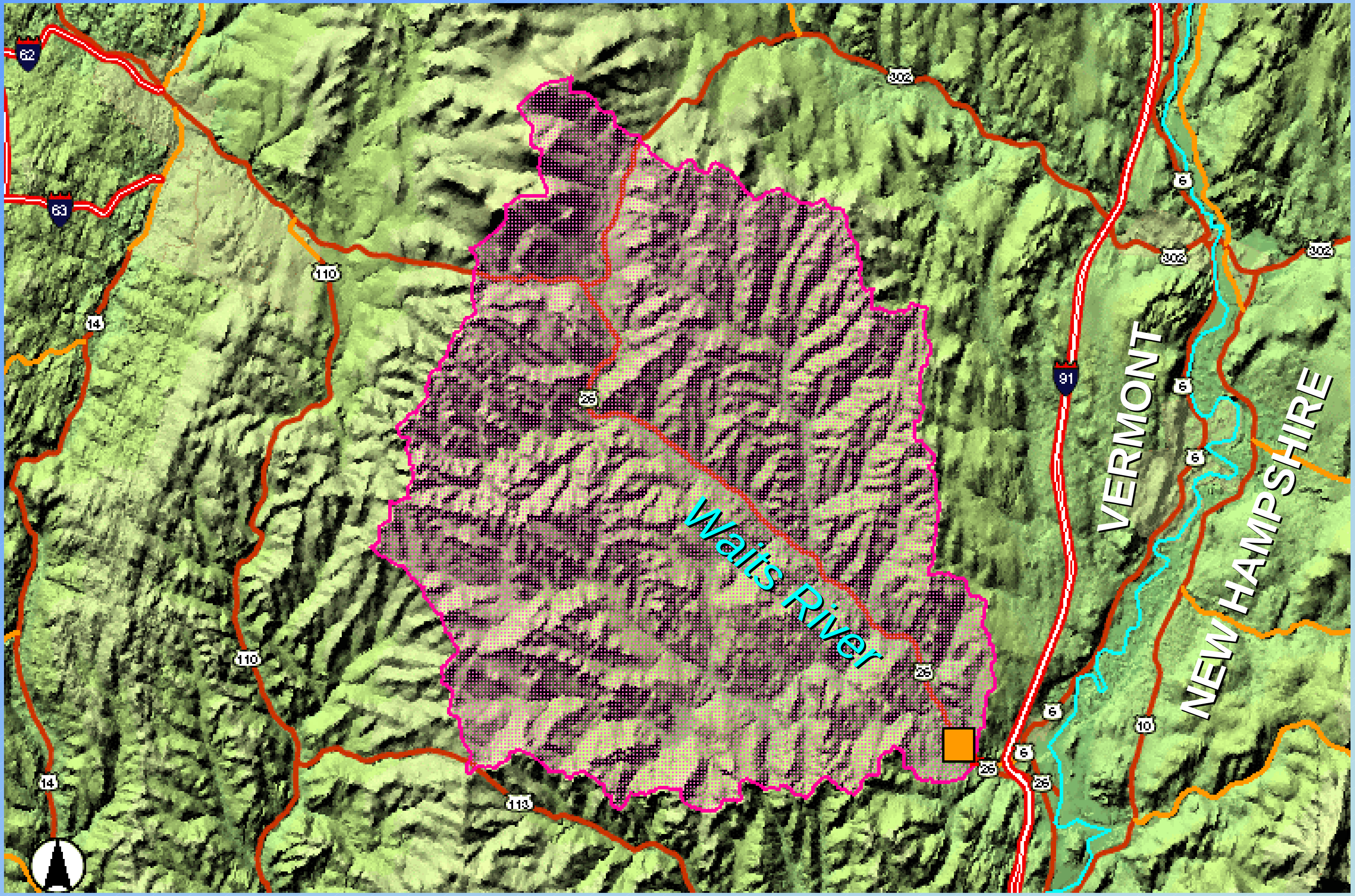
Hydrology: 100-yr flow



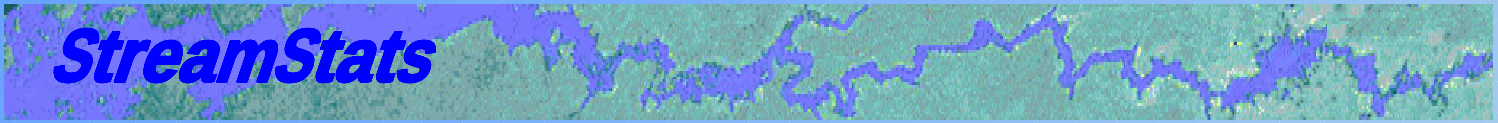
Hydrology: 100-yr flow



Hydrology: 100-yr flow



Hydrology: 100-yr flow



Basin Characteristics Report

Date: Fri Sep 12 2008 09:03:29
Latitude (NAD83): 43.9886 (43 59 19)
Longitude (NAD83): -72.1495 (-72 08 58)

Parameter	Value
Area in square miles	145
Mean annual precipitation in inches	40.4
Y coordinate of the centroid in map coordinates	174949.7
Percent of area covered by lakes and ponds	0.15
High Elevation Index - Percent of area with elevation > 1200 ft	67.1

Hydrology: 100-yr flow

USGS science for a changing world **StreamStats**

Streamflow Statistics Report

Site Location: Vermont
Latitude: 43.9886
Longitude: -72.1495
Drainage Area: 145 mi2

Streamflow Statistics					
Statistic	*Flow (ft^3/s)*	*Prediction Error (percent)*	*Equivalent years of record*	*90-Percent Prediction Interval*	
				Minimum	*Maximum*
Q2	4000	42	1.4	2080	7680
Q5	5810	40	2.3	3070	11000
Q10	7150	41	3.2	3740	13700
Q25	8990	42	4.6	4680	17300
Q50	10400	43	5.5	5360	20300
Q100	11900	44	6.3	5990	23800
Q500	15700	49	7.6	7360	33600

Hydrology: 100-yr flow

Hydrology: 100-yr flow

at USGS gaging station

StreamStats Data-Collection Station Report

USGS Station Number	01064500
Station Name	Saco River near Conway, NH

Descriptive Information

Station Type	Gaging Station, continuous record
Regulated?	Undefined
Period of Record	
Latitude (degrees NAD83)	43.99084167
Longitude (degrees NAD83)	-71.09047778
Hydrologic unit code	01060002
County	003-Carroll

Physical Characteristics

Characteristic Name	Value	Units
24_Hour_2_Year_Precipitation	3.3000	inches
Contributing_Drainage_Area	385	square miles
Drainage_Area	385.000	square miles
Main_Channel_Length	35.100	miles
March_Snow_Water_Equivalent	6.6700	inches
Mean_Annual_Precipitation	50.570	inches
Mean_Annual_Snowfall	101.000	inches
Mean_Basin_Elevation	1860.00	feet
Mean_Min_January_Temperature	9.0000	degrees F
Percent_Forest	94.800	percent
Percent_Lakes_and_Ponds	0.4200	percent
Percent_Storage	0.4800	percent
Soil_Infiltration	5.6000	inches
Stream_Slope_10_and_85_Method	50.990	feet per mi

Streamflow Statistics

Statistic Name	Value	Units
Peak-Flow Statistics		
10_Year_Peak_Flood	30400.0	cubic feet per second
100_Year_Peak_Flood	57600.0	cubic feet per second
2_Year_Pnak_Flood	15200.0	cubic feet per second
200_Year_Peak_Flood	67600.0	cubic feet per second
25_Year_Peak_Flood	40300.0	cubic feet per second
5_Year_Peak_Flood	23600.0	cubic feet per second
50_Year_Peak_Flood	48500.0	cubic feet per second
500_Year_Peak_Flood	83200.0	cubic feet per second
Log_Mean_of_Annual_Peaks	4.1800	Log base 10
Log_Skew_of_Annual_Peaks	0.0020	Log base 10
Log_STD_of_Annual_Peaks	0.2320	Log base 10
Mean_Annual_Flood	9850.00	cubic feet per second
Systematic_peak_years	56.000	years
WRC_Mean	4.1910	Log base 10
WRC_Skew	0.2140	Log base 10
WRC_STD	0.2323	Log base 10
Flood-Volume Statistics		
7_Day_10_Year_Maximum	8650.00	cubic feet per second
7_Day_2_Year_Maximum	5400.00	cubic feet per second
7_Day_50_Year_Maximum	12000.0	cubic feet per second
Low-Flow Statistics		
7_Day_10_Year_Low_Flow	96.700	cubic feet per second
7_Day_2_Year_Low_Flow	138.000	cubic feet per second
7_Day_20_Year_Low_Flow	88.300	cubic feet per second
Low_flow_years	54.000	years
Flow-Duration Statistics		
1_Percent_Duration	6880	cubic feet per second
10_Percent_Duration	2170	cubic feet per second
20_Percent_Duration	1250	cubic feet per second
25_Percent_Duration	996	cubic feet per second
30_Percent_Duration	824	cubic feet per second
40_Percent_Duration	595	cubic feet per second
5_Percent_Duration	3340	cubic feet per second
50_Percent_Duration	458	cubic feet per second
60_Percent_Duration	365	cubic feet per second
70_Percent_Duration	297	cubic feet per second
75_Percent_Duration	270	cubic feet per second
80_Percent_Duration	242	cubic feet per second
90_Percent_Duration	183	cubic feet per second
95_Percent_Duration	150	cubic feet per second
99_Percent_Duration	107	cubic feet per second
Annual Flow Statistics		
Daily_flow_years	55.000	years
Mean_Annual_Flow	921.000	cubic feet per second
Stand_Dev_of_Mean_Annual_Flow	207.000	cubic feet per second
Monthly Flow Statistics		
April_Mean_Flow	2590.00	cubic feet per second
April_STD	801.000	cubic feet per second
August_Mean_Flow	312.000	cubic feet per second
August_STD	182.000	cubic feet per second
December_Mean_Flow	750.000	cubic feet per second
December_STD	550.000	cubic feet per second
February_Mean_Flow	463.000	cubic feet per second
February_STD	317.000	cubic feet per second
January_Mean_Flow	527.000	cubic feet per second
January_STD	314.000	cubic feet per second
July_Mean_Flow	440.000	cubic feet per second
July_STD	286.000	cubic feet per second
June_Mean_Flow	848.000	cubic feet per second
June_STD	442.000	cubic feet per second
March_Mean_Flow	888.000	cubic feet per second
March_STD	961.000	cubic feet per second
May_Mean_Flow	2380.00	cubic feet per second
May_STD	937.000	cubic feet per second
November_Mean_Flow	922.000	cubic feet per second
November_STD	628.000	cubic feet per second
October_Mean_Flow	541.000	cubic feet per second
October_STD	408.000	cubic feet per second
September_Mean_Flow	393.000	cubic feet per second
September_STD	345.000	cubic feet per second
General Flow Statistics		
Average_daily_streamflow	937.562	cubic feet per second
Maximum_daily_flow	33900	cubic feet per second
Minimum_daily_flow	66	cubic feet per second
Std_Dev_of_daily_flows	1408.912	cubic feet per second
Base_Flow_Statistics		
Average_BFI_value	0.537	dimensionless
Number_of_years_to_compute_BFI	80	years
Std_dev_of_annual_BFI_values	0.065	dimensionless

USGS
science for a changing world

StreamStats Data-Collection Station Report

USGS Station Number 01064500
Station Name Saco River near Conway, NH

Descriptive Information

Station Type	Gaging Station, continuous record
Regulated?	Undefined
Period of Record	
Latitude (degrees NAD83)	43.99084167
Longitude (degrees NAD83)	-71.09047778
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Percent_Lakes_and_Ponds	0.4200	percent
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Streamflow Statistics

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50_Year_Peak_Flood	48500.0	cubic feet per second
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Log_Mean_of_Annual_Peaks	4.1800	Log base 10
Log_Skew_of_Annual_Peaks	0.0020	Log base 10
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Mean_Annual_Flood	9850.00	cubic feet per second
Systematic_peak_years	56.000	years
WRC_Mean	4.1910	Log base 10
WRC_Skew	0.2140	Log base 10
WRC_STD	0.2323	Log base 10
Flood-Volume Statistics		
7_Day_10_Year_Maximum	8650.00	cubic feet per second
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7_Day_50_Year_Maximum	12000.0	cubic feet per second
Low-Flow Statistics		
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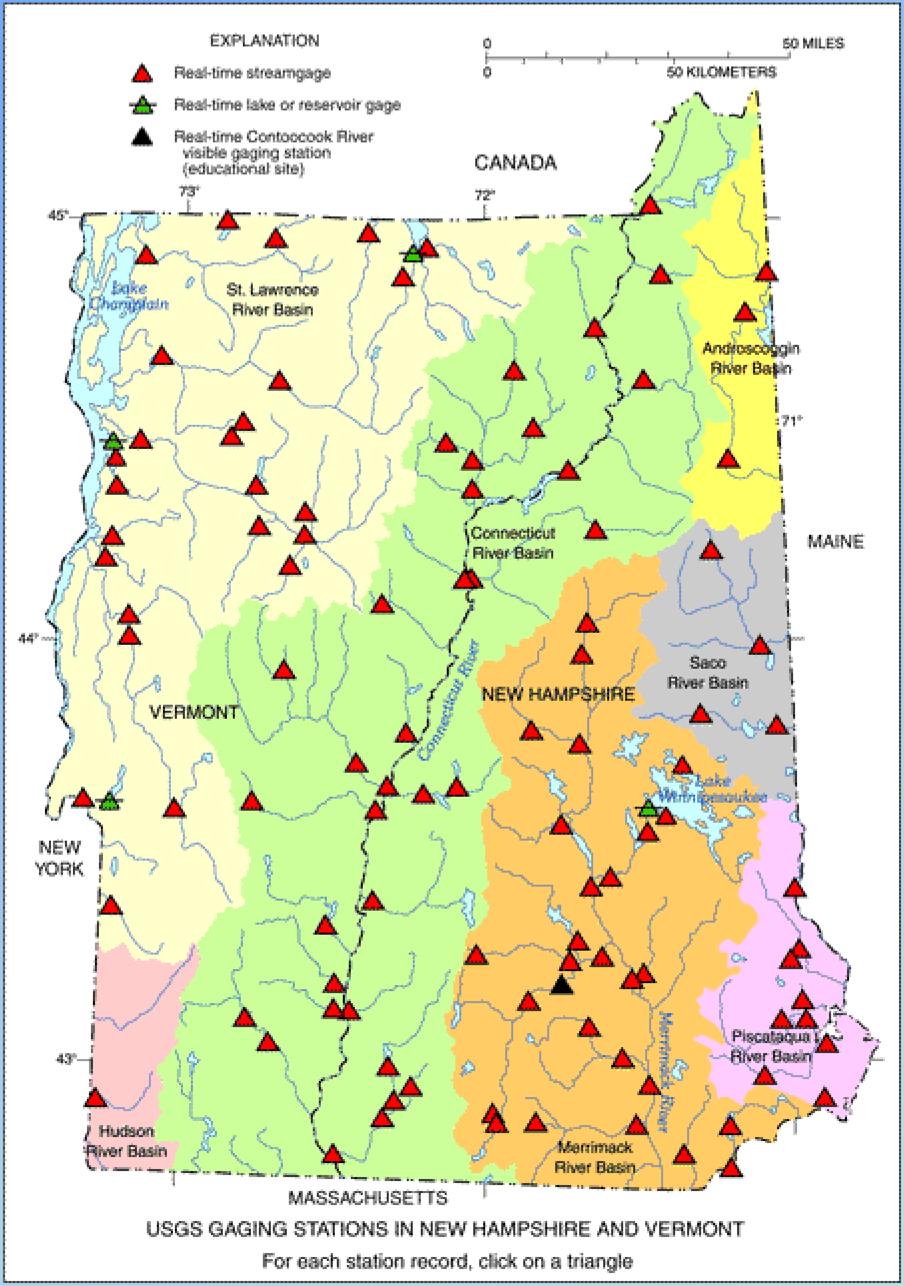
7_Day_20_Year_Low_Flow	88.300	cubic feet per second
Low_flow_years	54.000	years
Flow-Duration Statistics		
1_Percent_Duration	6880	cubic feet per second
10_Percent_Duration	2170	cubic feet per second

USGS Gaging Stations in New Hampshire and Vermont



Watershed Models

- **NRCS:** TR-55, TR-20
- **Corps of Engineers:** HEC-1

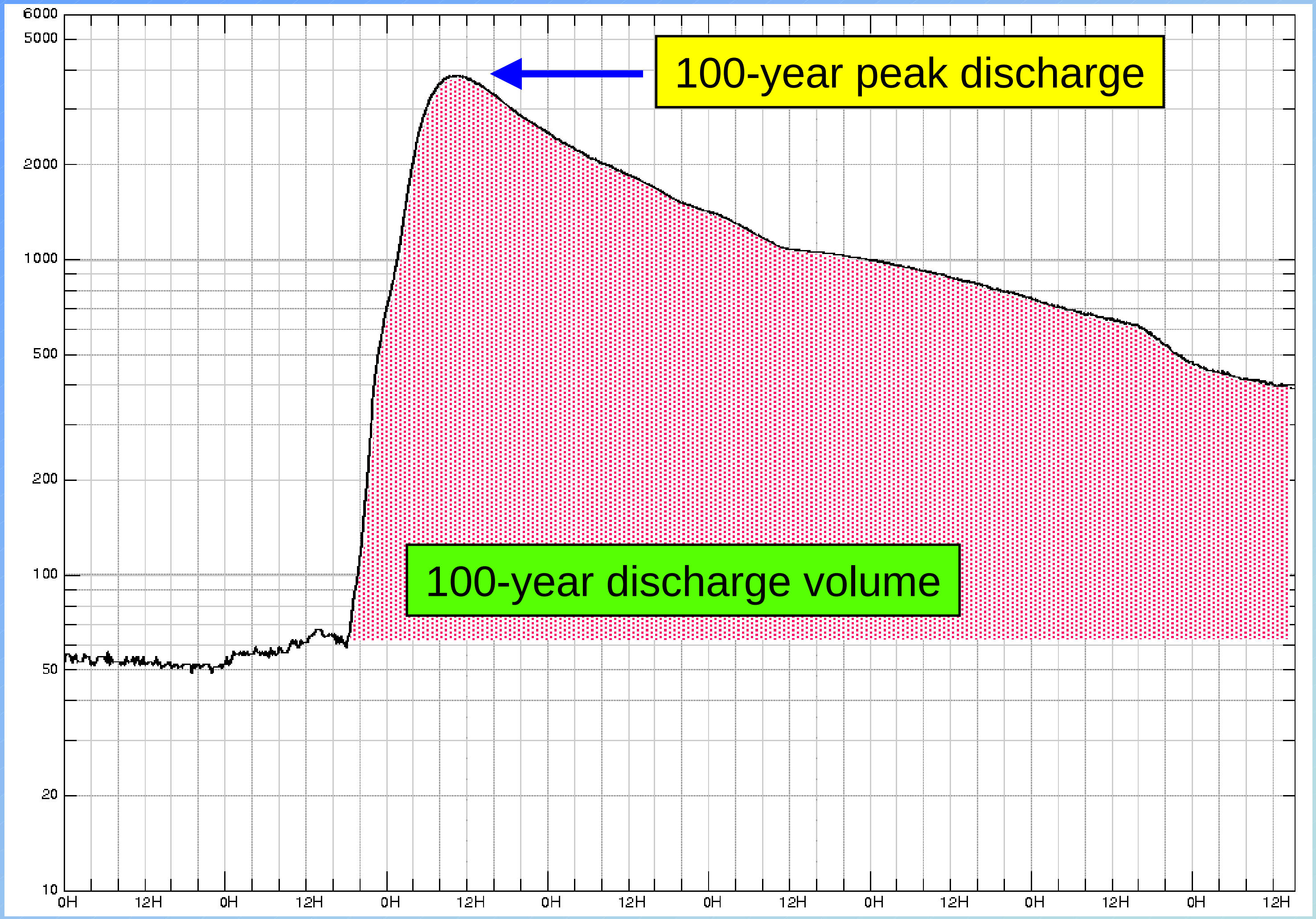
<u>Input</u> data needed include:

- Watershed characteristics (area, slope, land cover, soils)
- Channel conveyance (slope, shape, roughness)
- 100-yr rainfall intensity
- Flood storage
- Structures (dams, bridges)

<u>Output</u> data is:

- Flood hydrograph (peak = 100-yr discharge)

Flood Hydrograph



Flow

Time

Steps to Determine BFE

1. **Hydrology:** 100-year discharge (flow, ft^3/s)

2. **Survey:** river and structures

3. **Hydraulics:** compute water elevation (BFE)

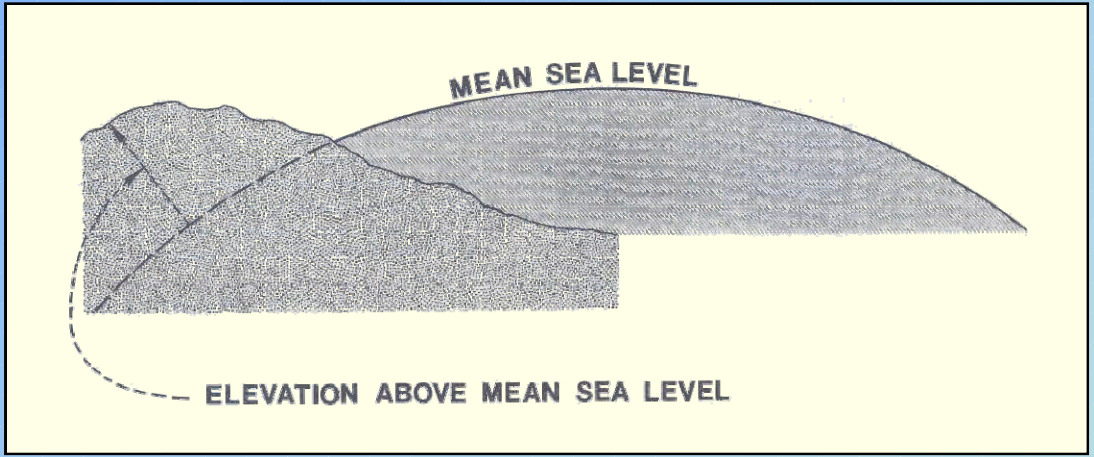
Field Survey

- **Vertical datum**
- **River cross sections**
  - **Number, elevations & distances**
- **Roughness coefficient**
  - **Manning's "*n*"**
- **Structures**
  - **Dams, bridges, culverts**

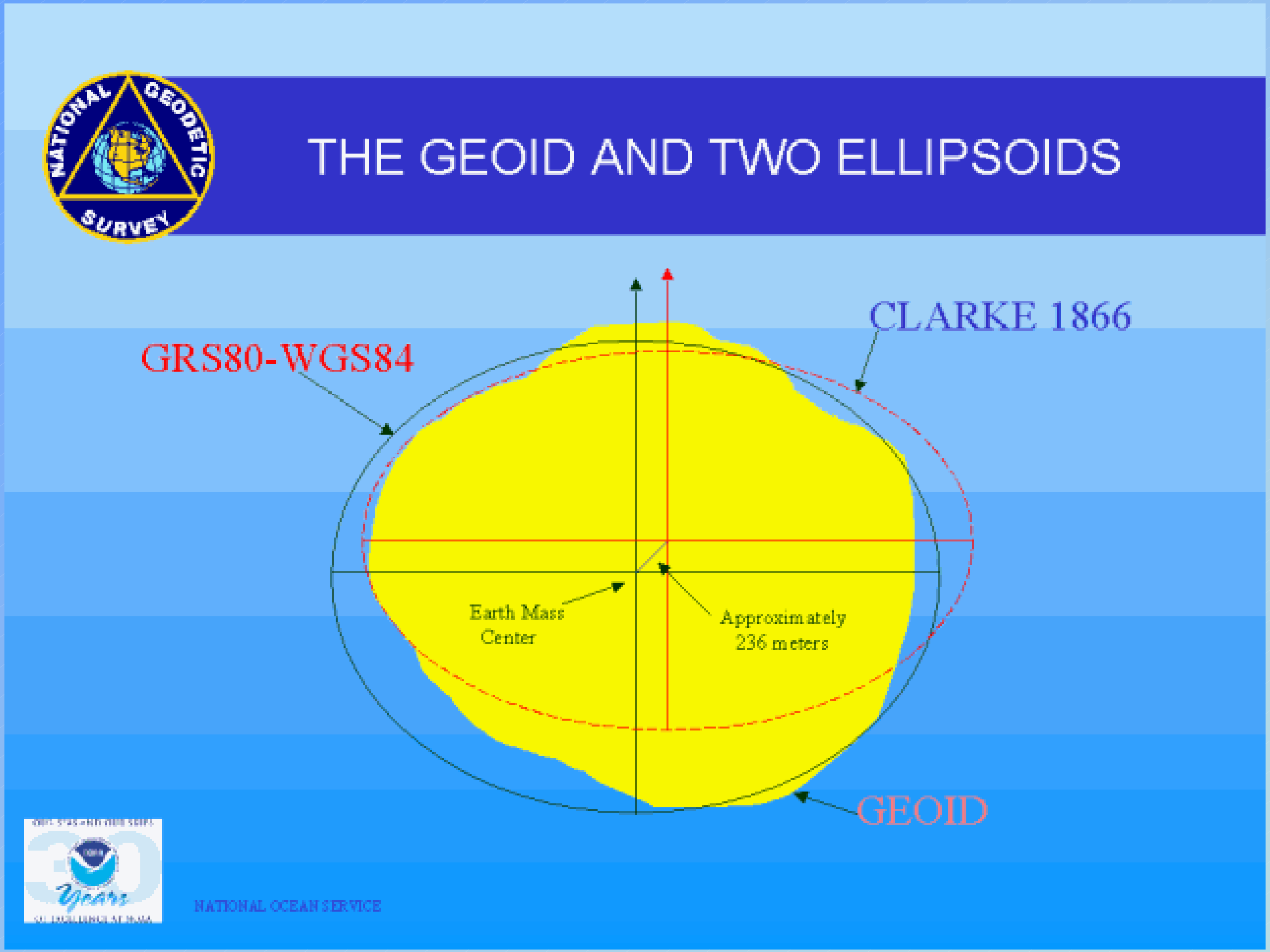
Vertical Datum

- **NGVD29**
  National Geodetic Vertical Datum of 1929
- **NAVD88**
  North American Vertical Datum of 1988

- Tie all survey points to known Reference Mark (RM)



Vertical Datum

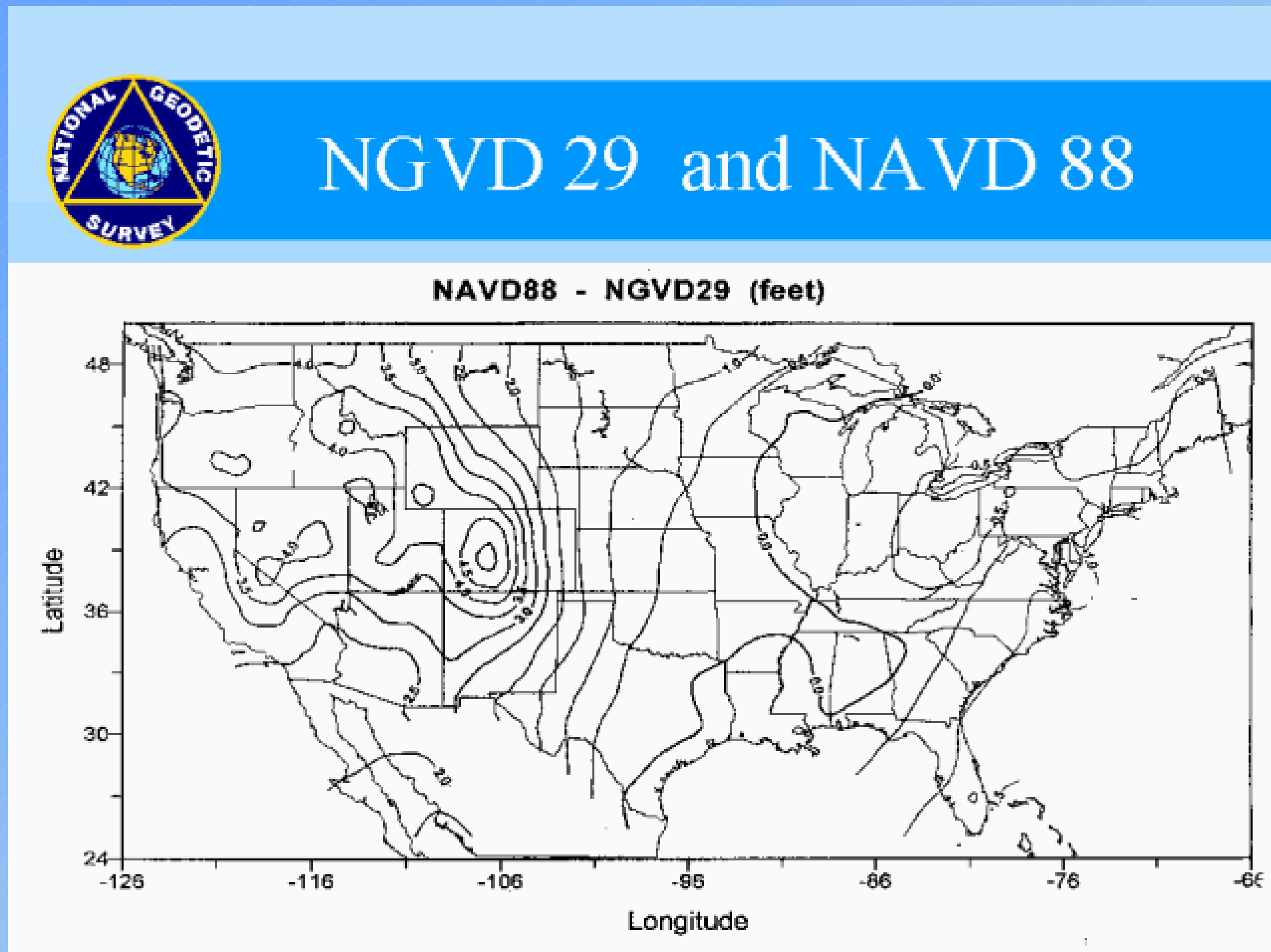


Vertical Datum

COMPARISON OF VERTICAL DATUM ELEMENTS

	NGVD 29	NAVD 88
DATUM DEFINITION	26 TIDE GAUGES IN THE U.S. & CANADA	FATHER'S POINT/RIMOUSKI QUEBEC, CANADA
BENCH MARKS	100,000	450,000
LEVELING (Km)	102,724	1,001,500
GEOID FITTING	Distorted to Fit MSL Gauges	Best Continental Model

Vertical Datum



Vertical Datum on FEMA's County DFIRMs in NH

- **National Geodetic Vertical Datum (NGVD) of 1929**
  - Grafton
  - Strafford
  - Rockingham

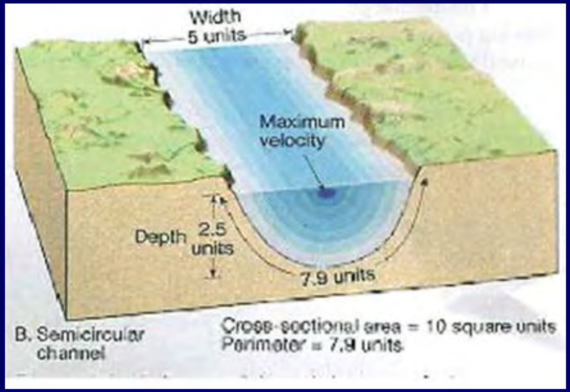
- **North American Vertical Datum (NAVD) of 1988**
  - Cheshire
  - Hillsborough (prelim)
  - Sullivan
  - Merrimack (prelim)

Field Survey

- Vertical datum
- **River cross sections**
  - Number, elevations & distances
- Roughness coefficient
  - Manning's "*n*"
- Structures
  - Dams, bridges, culverts

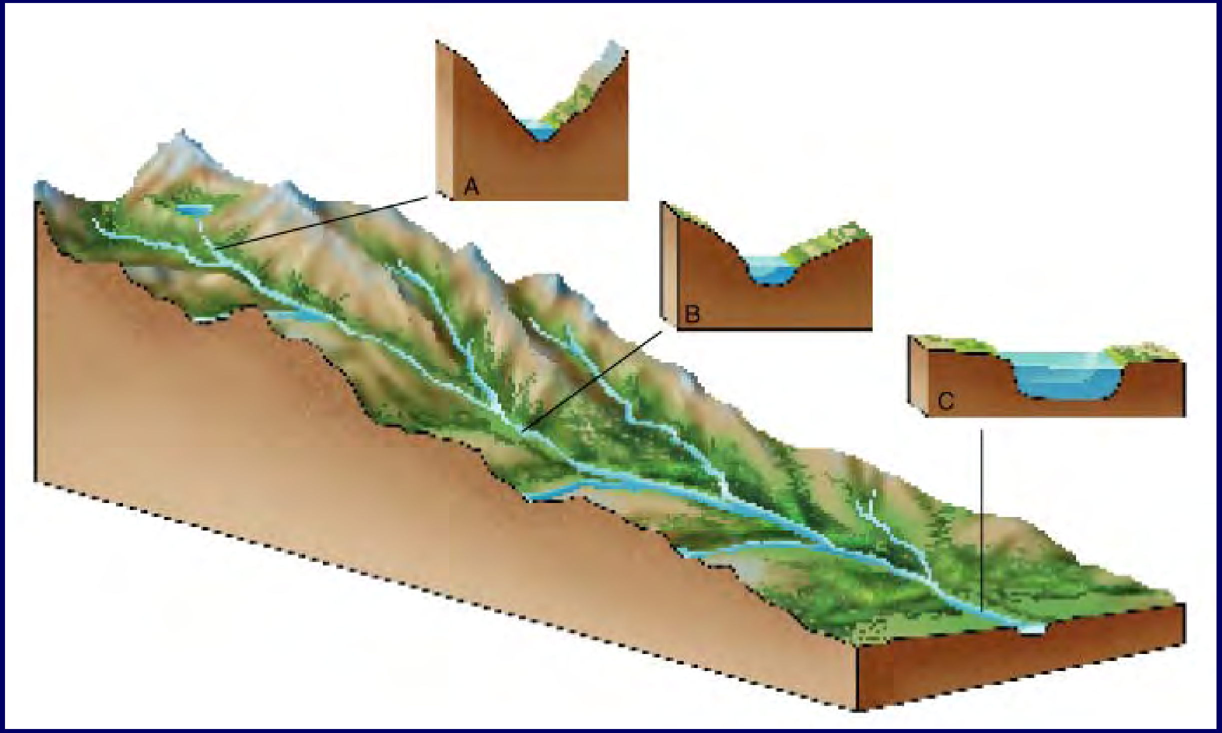
River Cross Sections

- **Minimum 1 x-sec for small lot**
  - Uniform flow, no obstructions
- **Minimum 2 x-secs for large lots**
  - < 500 ft between x-secs if ΔWSE > 1 ft

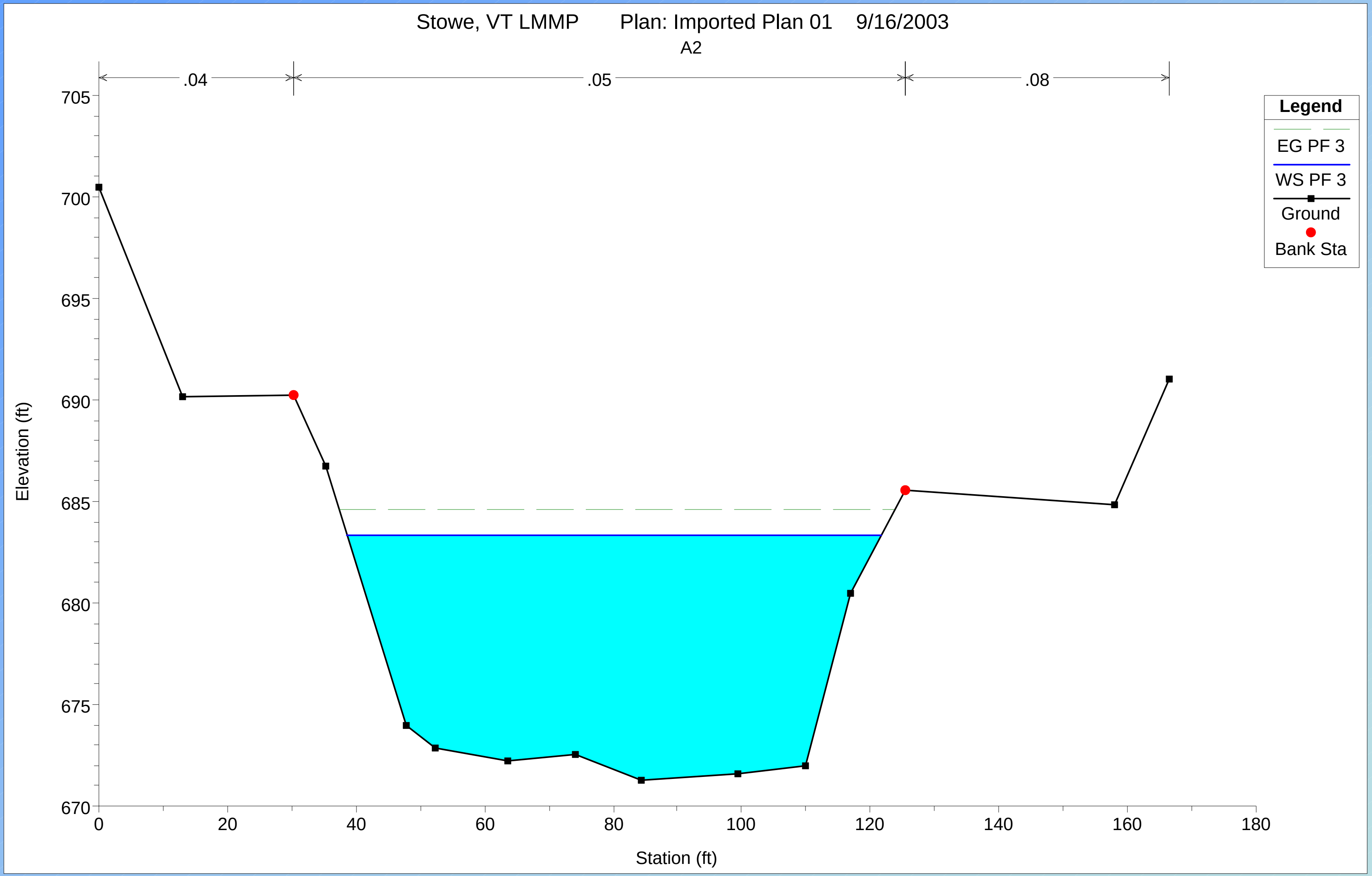


River Cross Sections

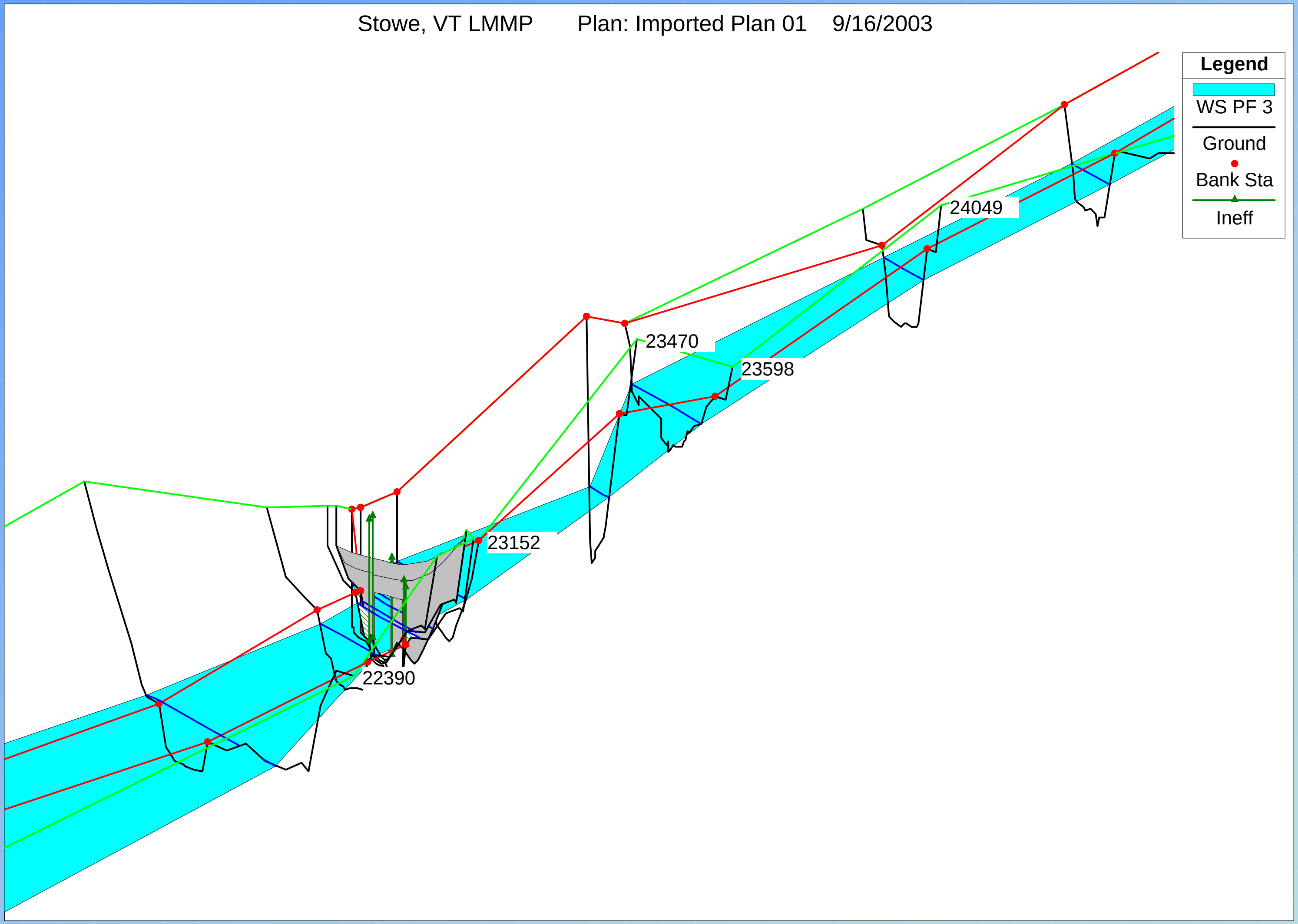
- **Represent channel changes**
  - Slope, shape, roughness
- **Show discharge changes**
  - Tributary inflow



River Cross Section



River Cross Sections



Field Survey

- Vertical datum
- River cross sections
  - Number, elevations & distances
- <u>Roughness coefficient</u>
  - Manning's "*n*"
- Structures
  - Dams, bridges, culverts

Field Survey: *n* values

- **Take photos and notes**

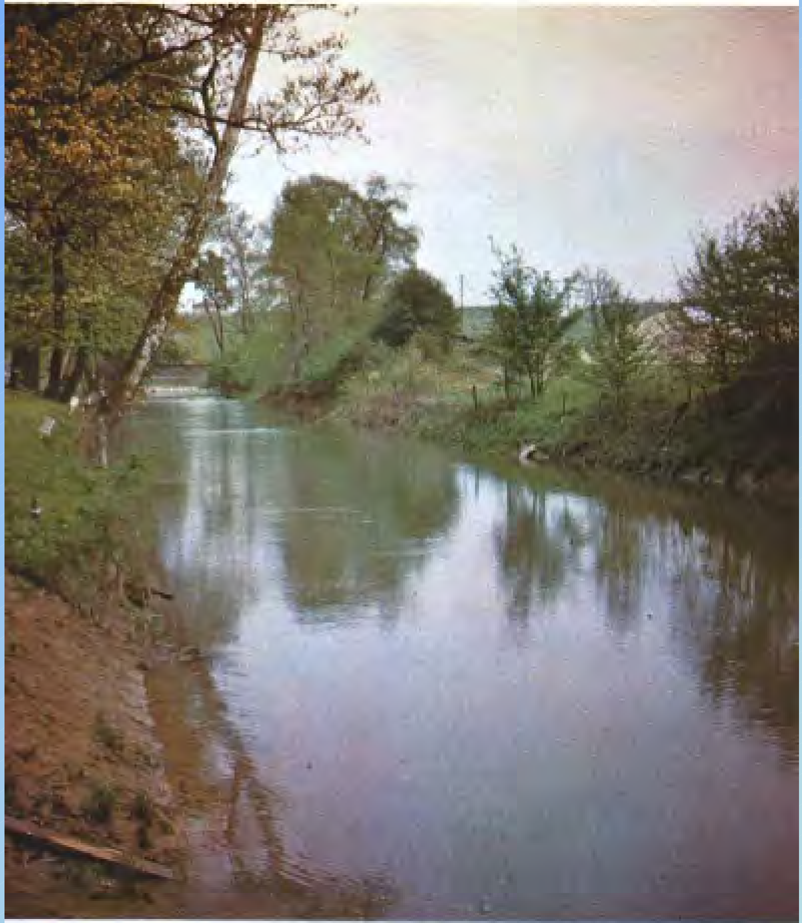
Lined channels	n [s/ m$^{1/3}$]	kst [m$^{1/3}$/s]
Cement Plaster	0.011	90.91
Wood planed	0.012	83.33
Wood unplaned	0.013	76.92
Concrete, troweled	0.012	83.33
Concrete, wood forms	0.015	66.67
Rubble in cement	0.020	50.00
Asphalt smoth	0.013	76.92
Asphalt rough	0.016	62.50
Natural Channels	**n**	**kst**
Gravel beds, straight	0.025	40.00
Gravel beds		
plus large boulders	0.040	25.00
Earth, straigh		
with some grass	0.026	38.46
Earth winding		
no vegetation	0.030	33.33
Earth winding	0.050	20.00

Field Survey: *n* values

Field Survey

n = 0.026

n = 0.026

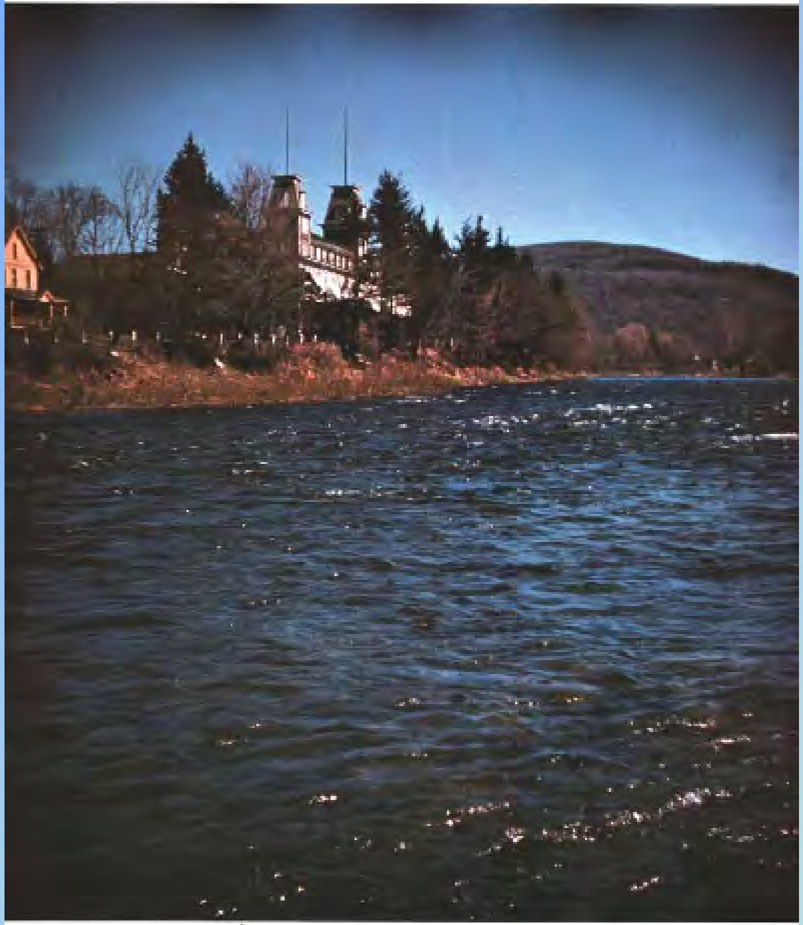


No. 327 upstream from right bank below section 3,
Indian Fork below Atwood Dam, near New Cumberland, Ohio.

16

Field Survey

$n = 0.033$

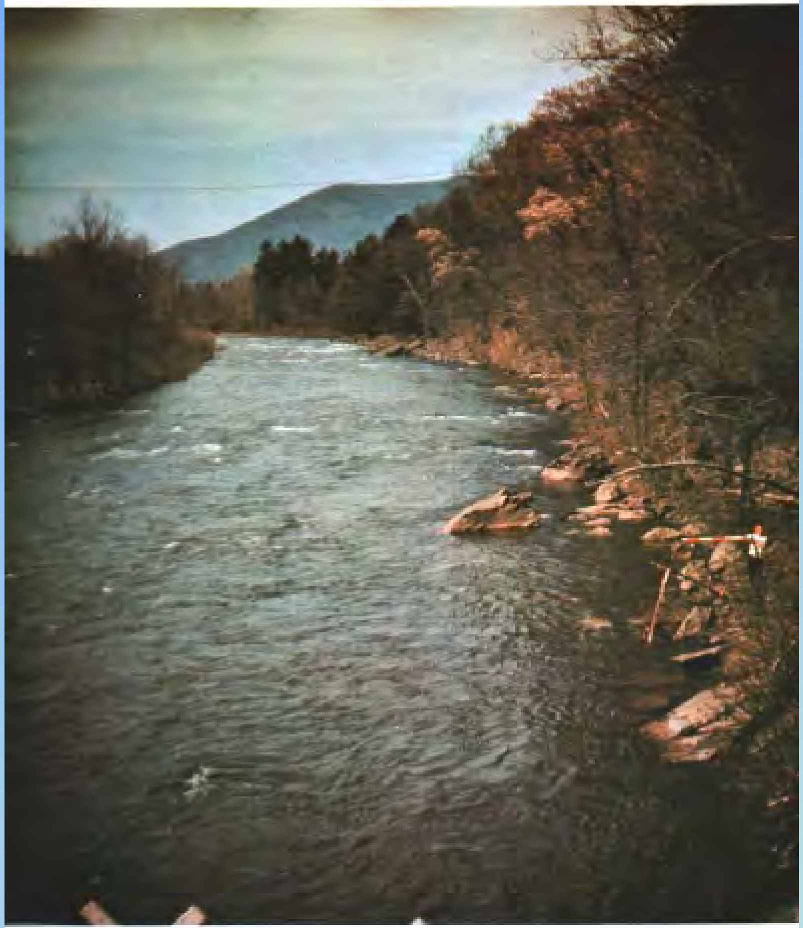


No. 366 upstream toward right bank from section 7, Beaver Kill at Cooks Falls, N.Y.

Field Survey

$n = 0.043$

$n = 0.043$



No. 359 upstream along left bank from below reach, Esopus Creek at Coldbrook, N.Y.

Field Survey

n = 0.052

n = 0.052; 0.047

No. 1179 upstream from section 2,
South Beaverdam Creek near Dewy Rose, Ga.

145

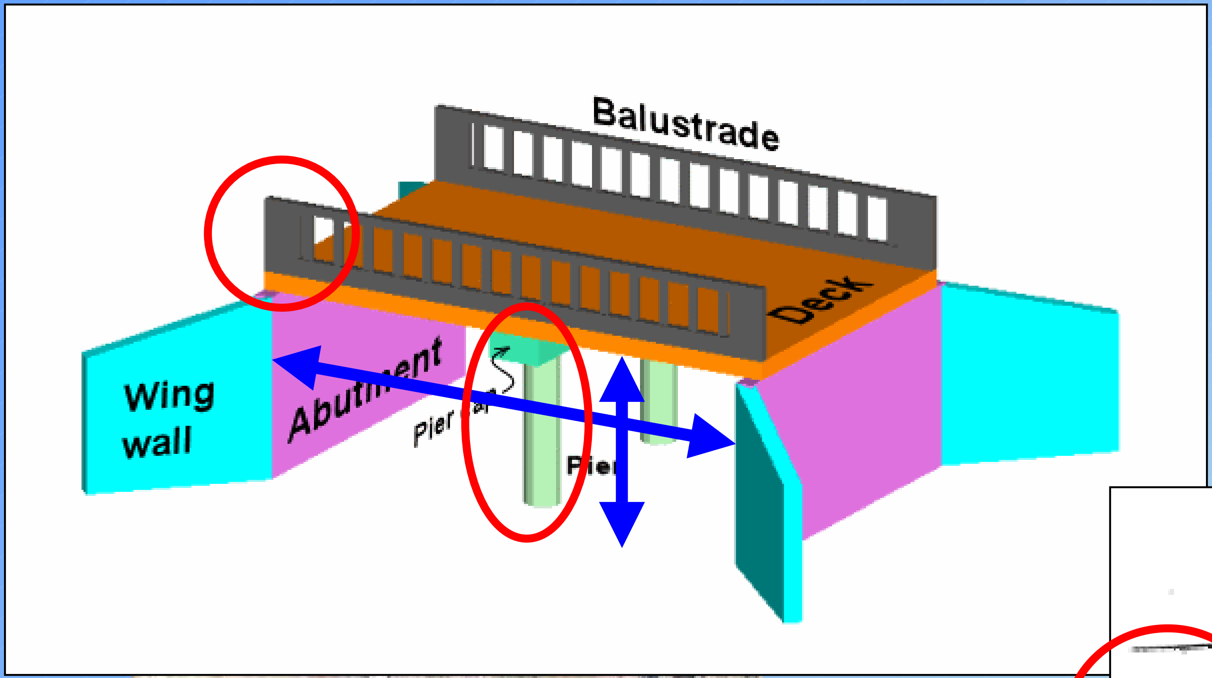
Field Survey

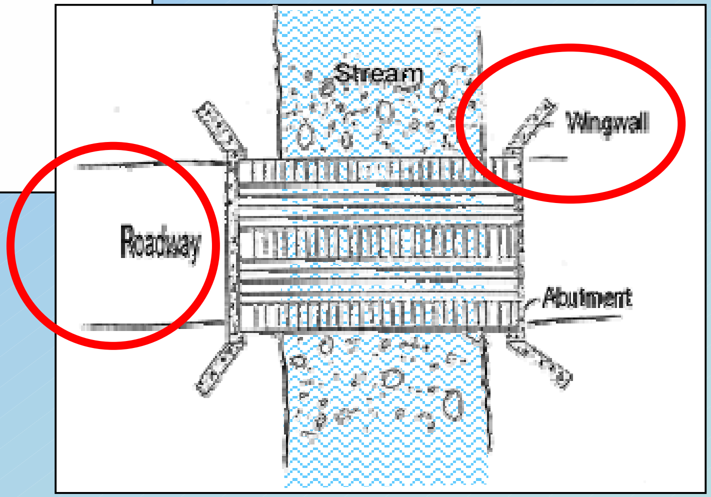
- **Vertical datum**
- **River cross sections**
  - **Number, elevations & distances**
- **Roughness coefficient**
  - **Manning's "*n*"**
- **<u>Structures</u>**
  - **Dams, bridges, culverts**

Field Survey: Bridges

- **Cross sections**
  - Approach & Exit
- **Bridge geometry**
  - Dimensions
  - Roadway
  - Wingwall
  - Piers, Skew

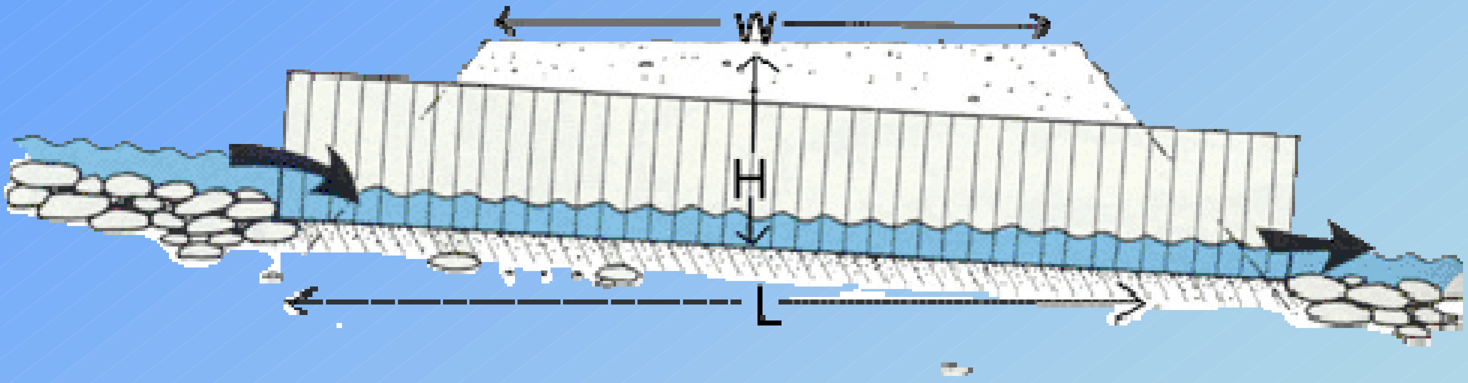
Field Survey: Bridges





Field Survey: Culverts

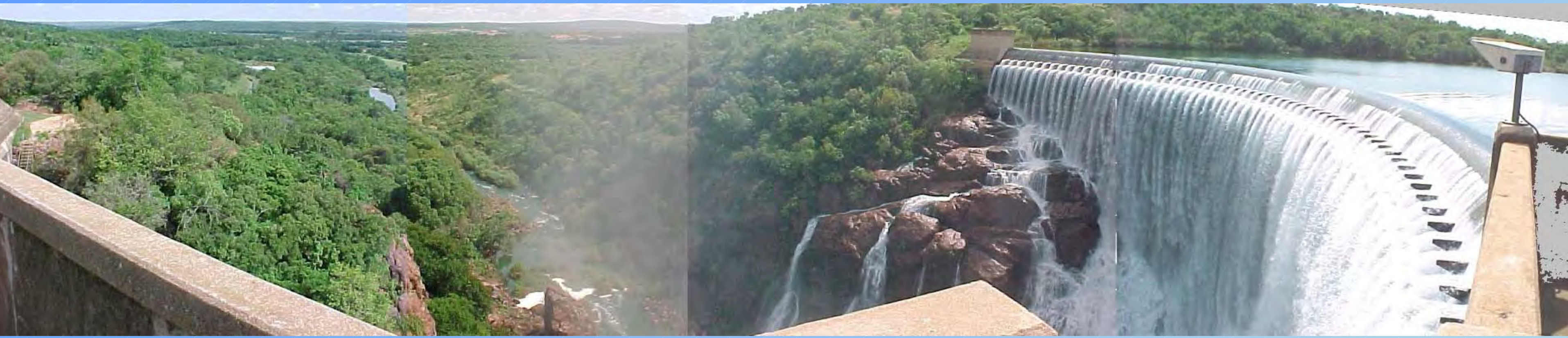
Field Survey: Culverts



Field Survey: Culverts

- **Cross sections**
  - Exit (& approach)
- **Culvert geometry**
  - H x W x L
  - Material & Type
  - Slope (elevations)
  - Entrance shape
    - wingwalls, mitered, rounding
  - Roadway

Field Survey: Dams



- Sluice gates, Flashboards, Spillway, Turbines
- Flow Regulation
- Standard Operating Procedures

Steps to Determine BFE

1. **Hydrology:** 100-year discharge (flow, ft^3/s)

2. **Survey:** river and structures

3. **Hydraulics:**
   compute water elevation (BFE)

Hydraulics: Base Flood Elevation

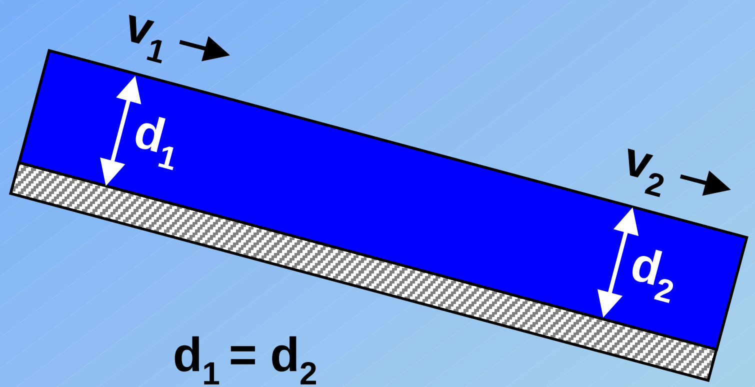
- **Normal & Critical Depths**
- **Step Backwater**

    Quick2, HEC-RAS
- **Structures**

    Weir and Conduit Flow

Hydraulics: Normal Depth

- **Uniform, Steady Flow**
- **No Obstructions**
- **Water Surface *parallel* to Bed Slope**



$d_1 = d_2$

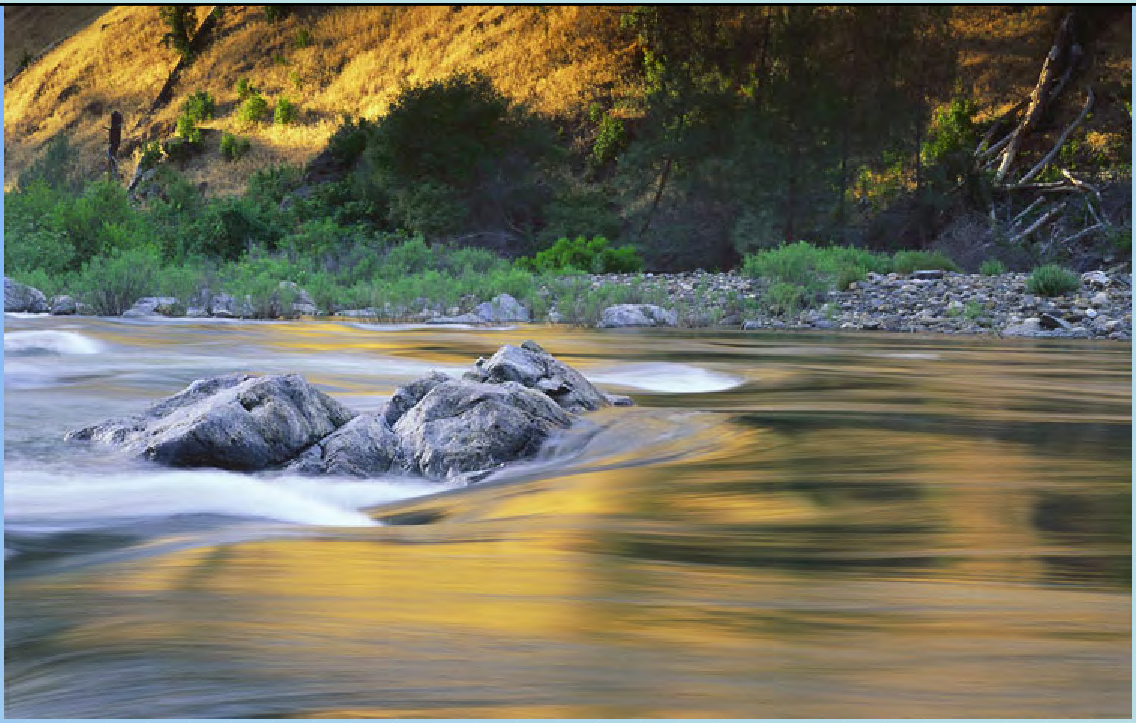
$v_1 = v_2$

Manning Equation:

$$Q = \frac{1.49\ A\ R^{2/3}\ S^{1/2}}{n}$$

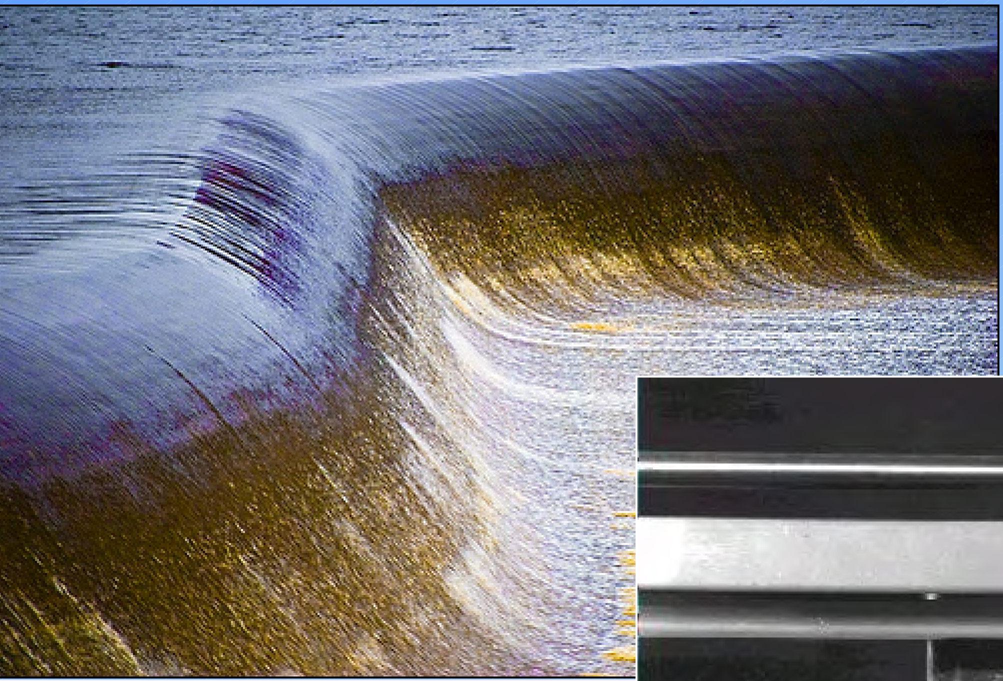
Hydraulics: Critical Depth

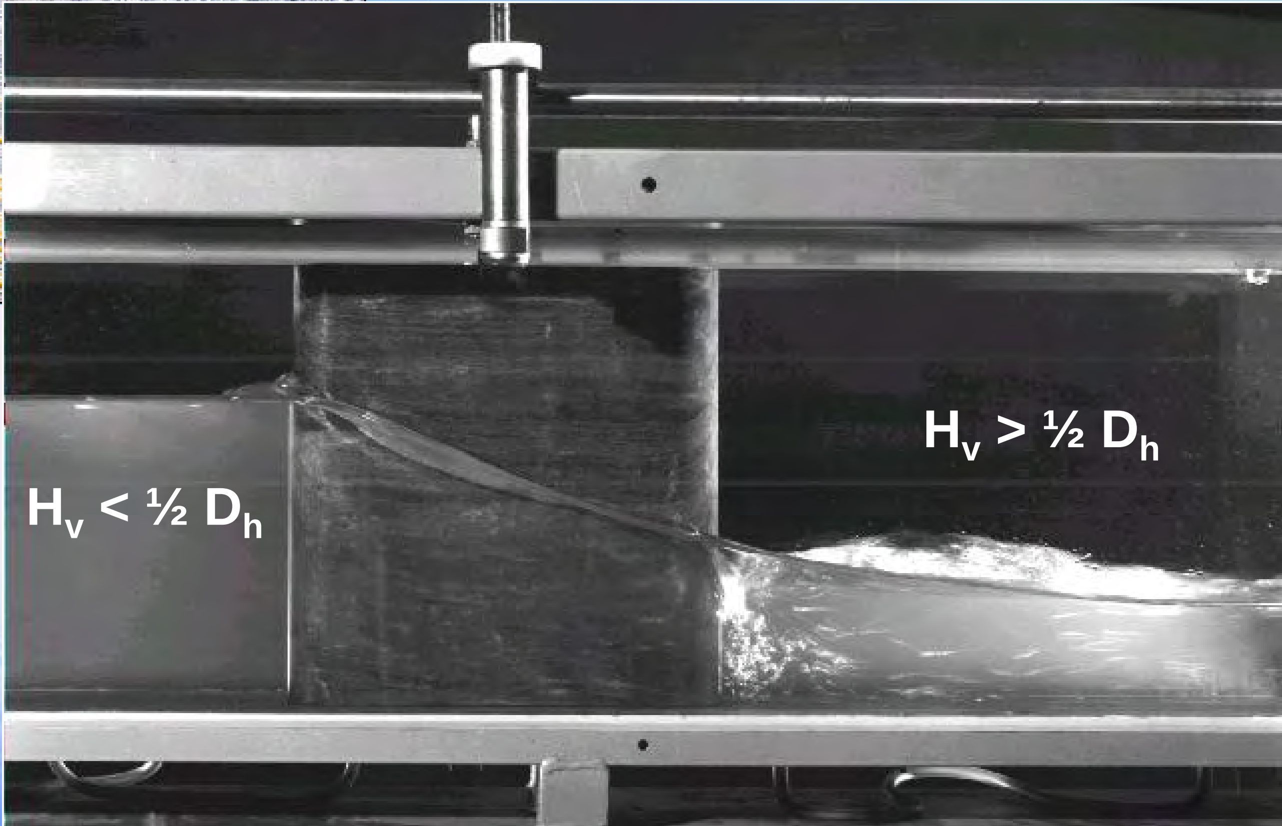
- Minimum specific energy
- Deeper is <u>sub</u>-critical flow (slow)
- Shallower is <u>super</u>-critical flow (fast)



Hydraulics: Supercritical Flow

BFE $\geq$ Critical Depth



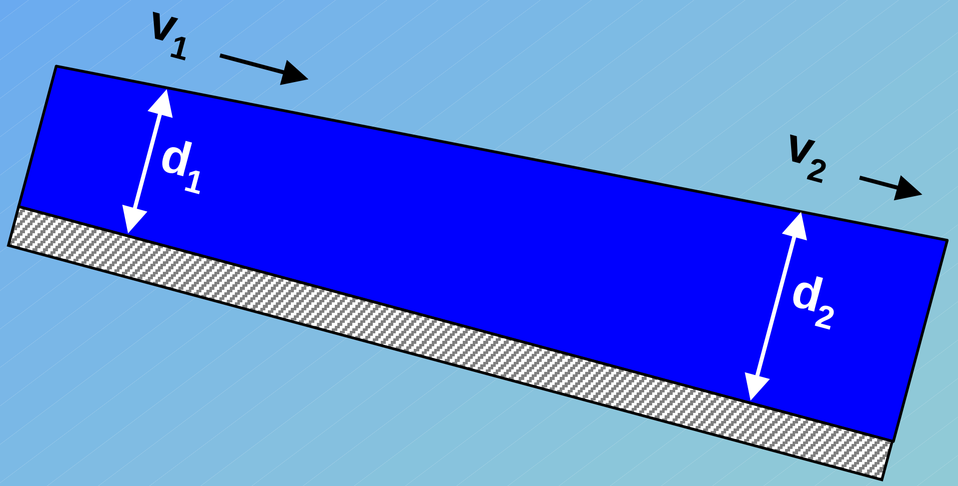


Hydraulics: Step Backwater

- Steady, Non-Uniform Flow
- Water Surface *not parallel* to Bed Slope

$d_1 \neq d_2$

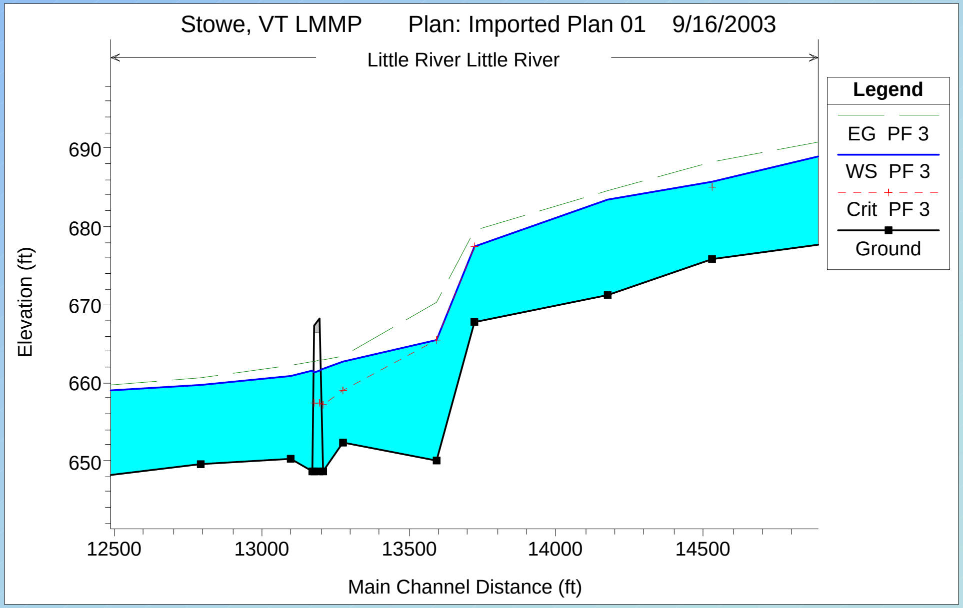
$v_1 \neq v_2$



Hydraulics: Step Backwater

- **Start with known depth downstream**
  normal depth, weir flow, etc.
- **Then work upstream step-by-step**
  compute energy & depth at each cross section
- **Based on energy losses between cross-sections**
  f(distance, slope, roughness, etc.)

- **Computer models**
  Quick2, HEC-RAS



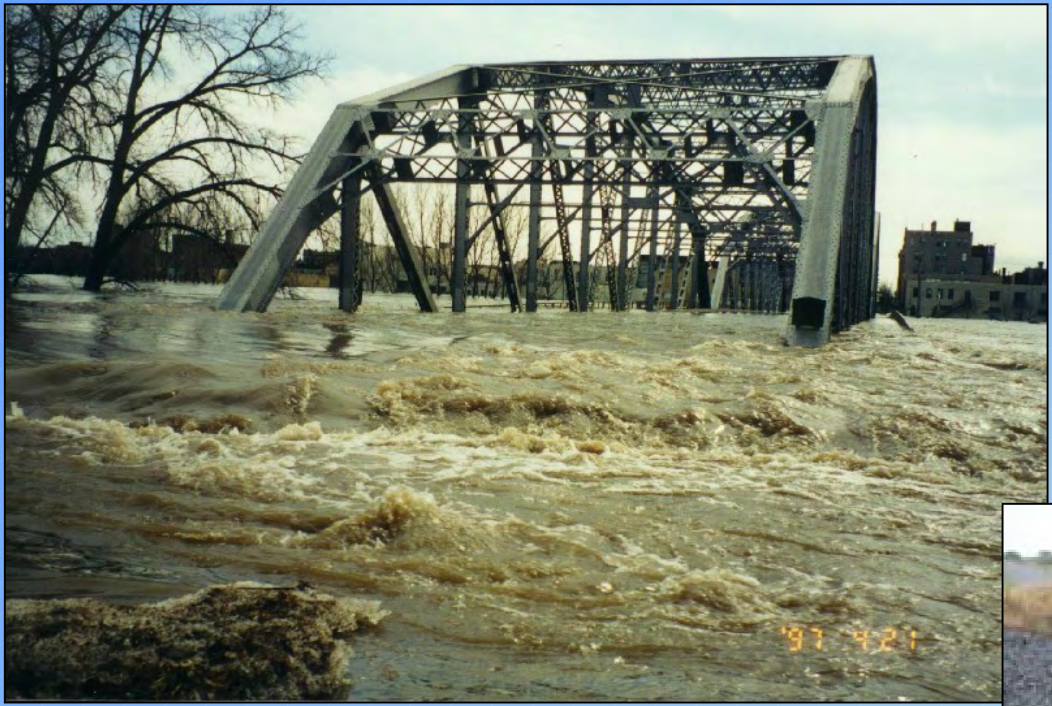
Hydraulics: Base Flood Elevation

- **Normal & Critical Depths**
- **Step Backwater**

  Quick2, HEC-RAS
- **Structures**

  Weir and Conduit Flow

Hydraulics: Bridges



Hydraulics: Bridges

Flow over roadway and/or bridge deck

Weir Flow

$$Q = k\ C\ b\ H^{1.5}$$

K = submergence factor

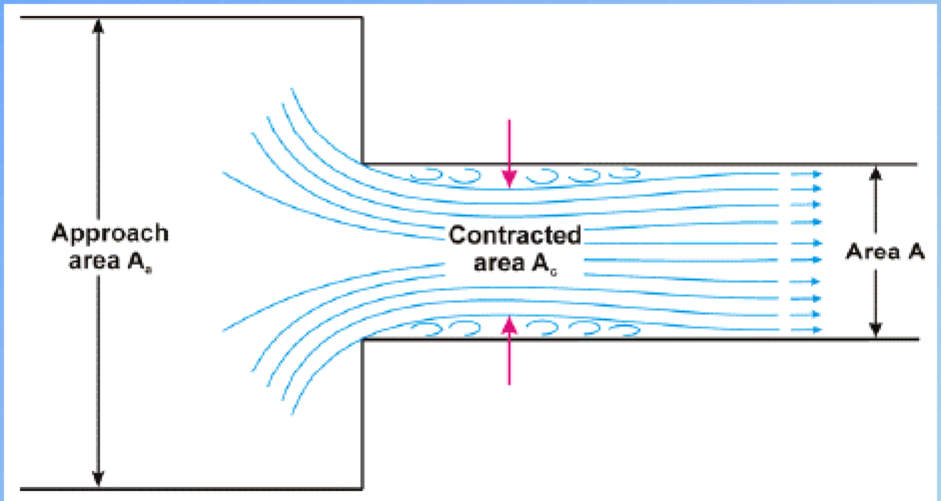
C = weir coefficient

b = weir width

H = water height above weir crest

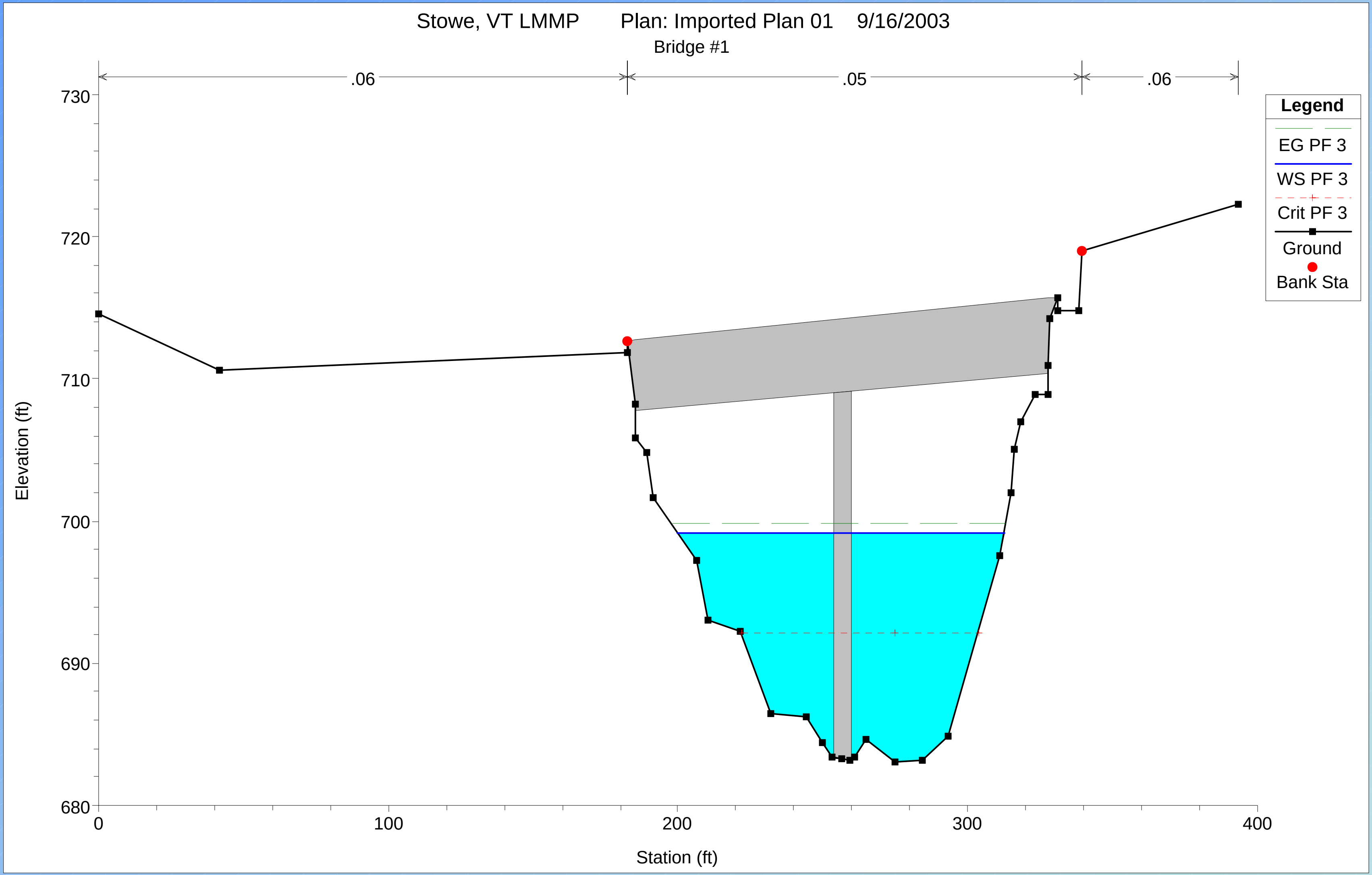
Hydraulics: Bridges

Flow through opening

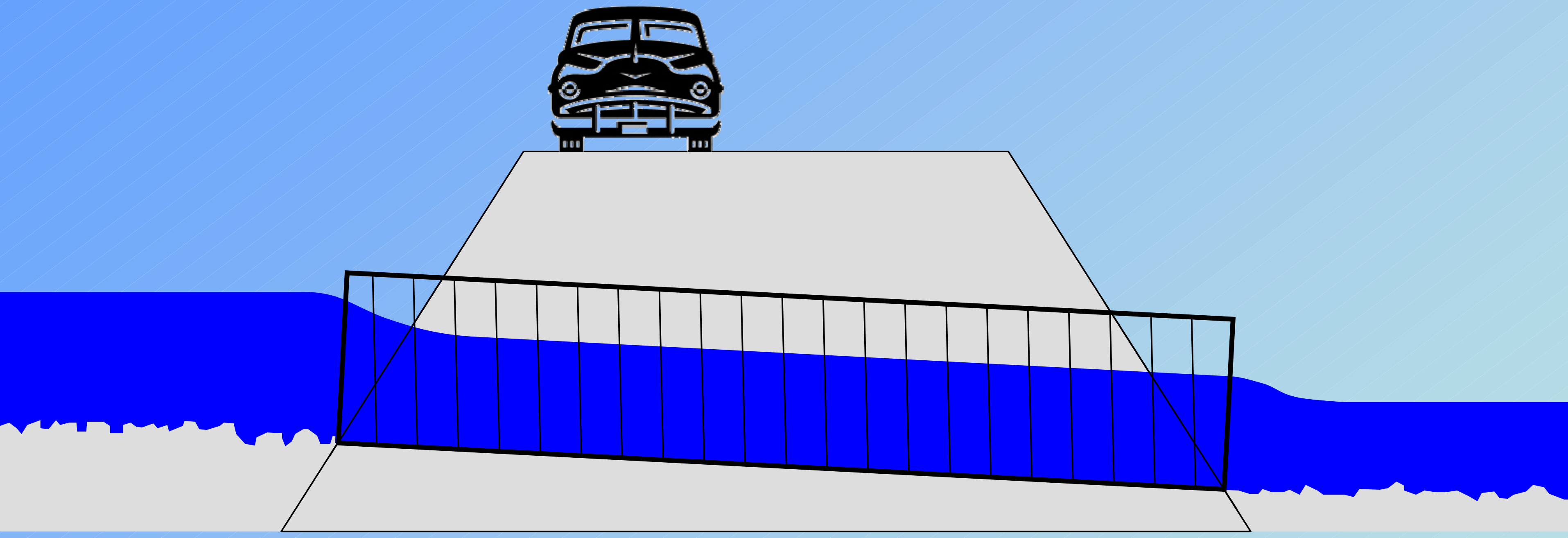


- Energy Losses from Contraction & Expansion
- Wingwall design, channel cross sections
- Computer model (e.g. HEC-RAS)

Hydraulics: Bridges



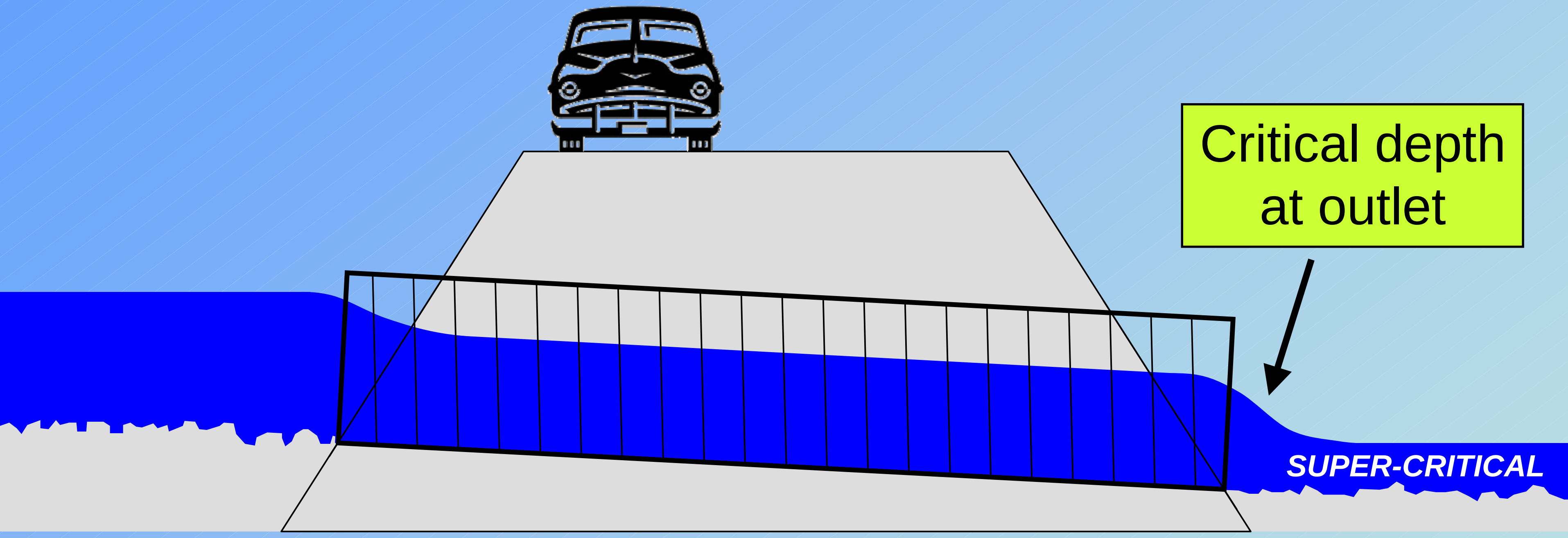
Hydraulics: Culverts



Tranquil flow throughout

$$Q = CA_3\sqrt{2g(h_1+\alpha_1(v_1^2/2g)-h_3-h_{f_{1.2}}-h_{f_{2.3}})}$$

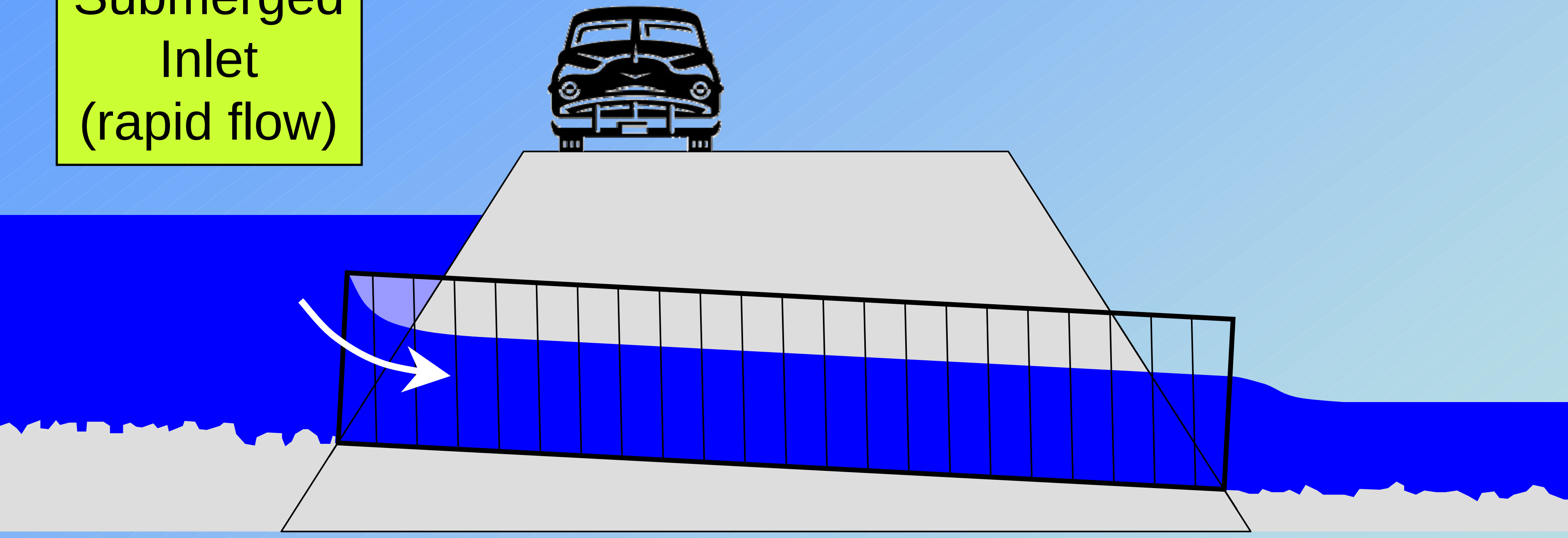
Hydraulics: Culverts



$$Q = CA_c\sqrt{2g(h_1+\alpha_1(v_1^2/2g)-d_c-h_{f_{1.2}}-h_{f_{2.3}})}$$

Hydraulics: Culverts

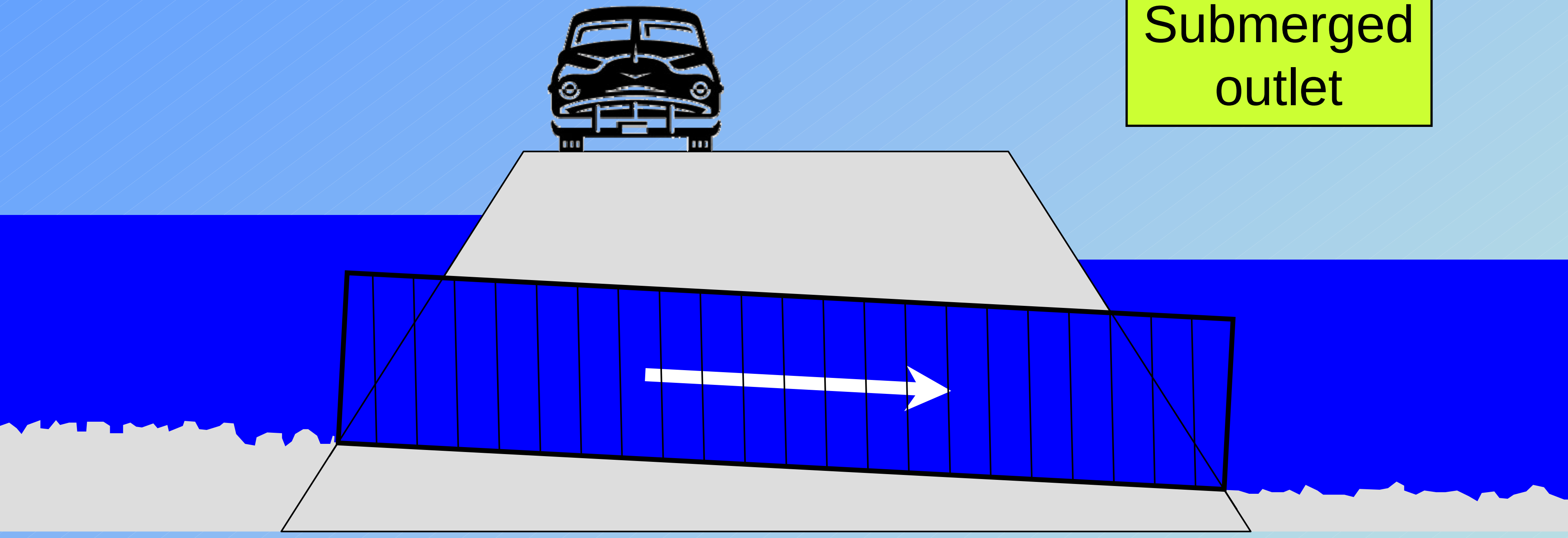
Submerged
Inlet
(rapid flow)



$$Q = CA_0\sqrt{2g(h_1 - z)}$$

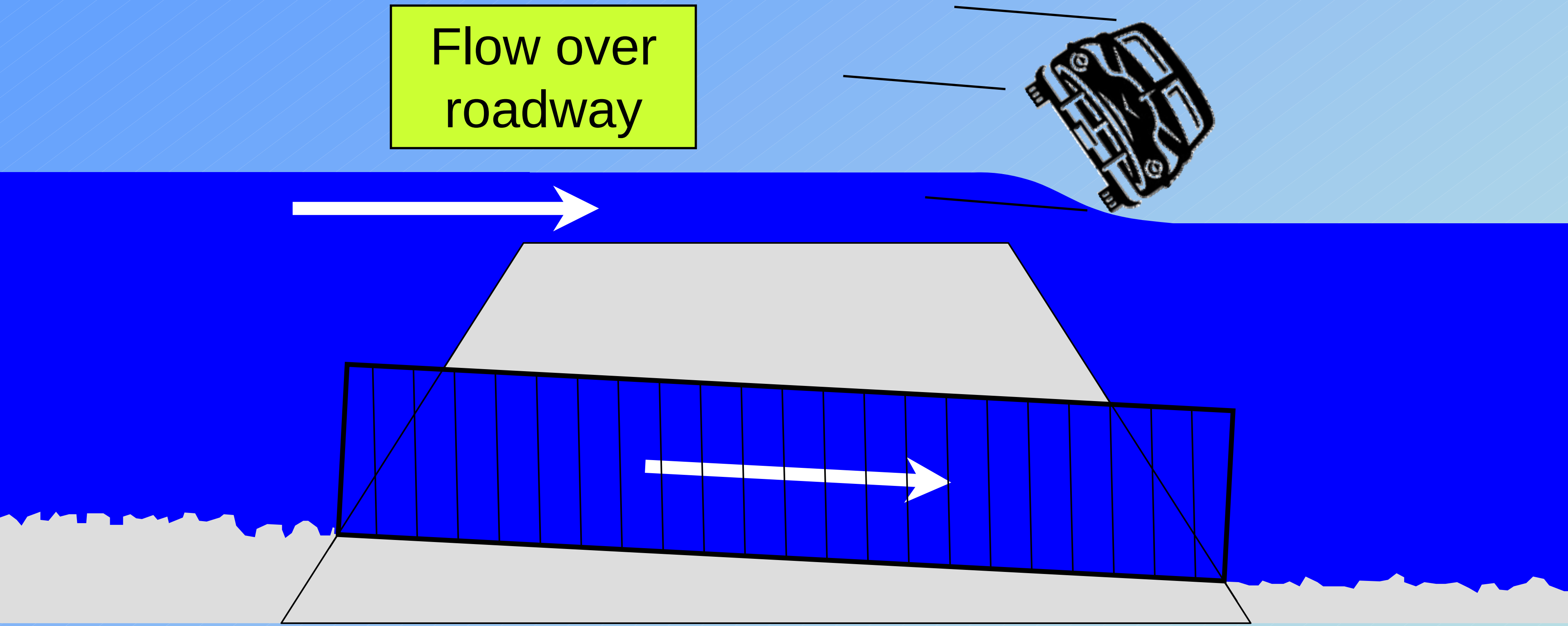
Hydraulics: Culverts

Submerged outlet



$$Q = CA_0\sqrt{2g(h_1-h_4)/(1+29C^2n^2L/R_0^{4/3})}$$

Hydraulics: Culverts



$$Q = CA_0\sqrt{2g(h_1-h_4)/(1+29C^2n^2L/R_0^{4/3})} + kCbH^{3/2}$$

Zone A Workshop Outline

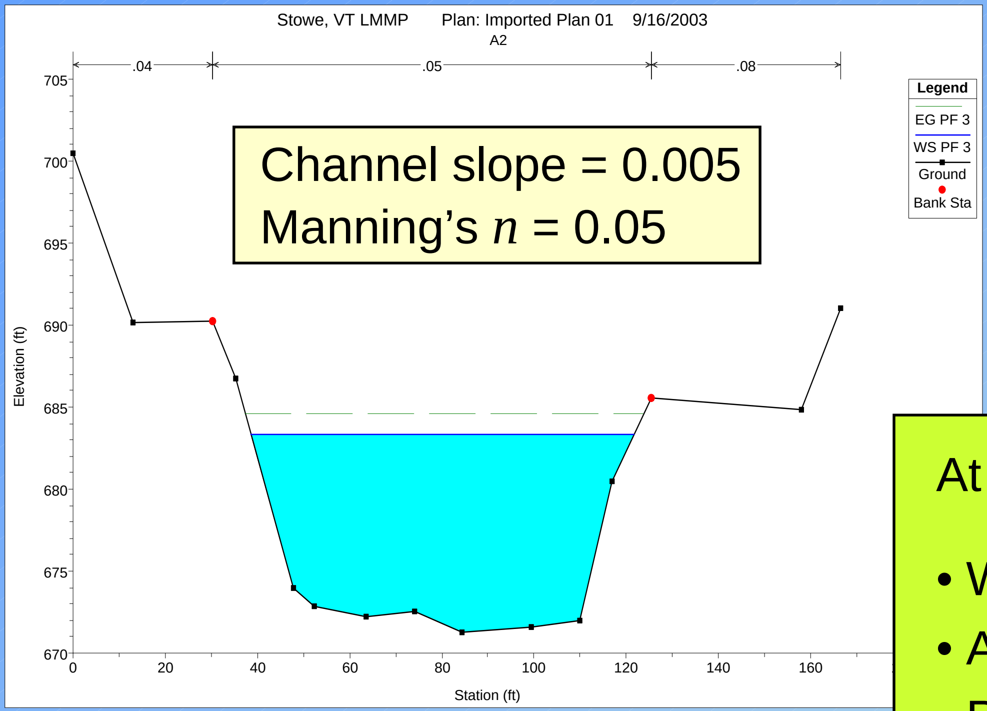
I. Sources of Flood and Watershed Information

II. How to Determine BFE: Simple Methods
Detailed Methods

III. **Example of Determining Zone A BFE**

IV. Questions and Answers

Example: Normal Depth BFE



Channel slope = 0.005
Manning's n = 0.05

Q_{100} = 7,200 ft^3/s

At water depth of 12.17 ft:

- WSE = **684.67 ft (NGVD29)**
- A (X-sec Area) = 807.28 ft^2
- P (Wetted Perimeter) = 92.33 ft
- R (Hydraulic Radius) = 8.743 ft
- Q (Discharge) = $(1.486\ A\ R^{2/3} S^{1/2})/n$
  = 7200 ft^3/s

H_v (Velocity Head) = $v^2/2g$ = 1.25 ft

½ D_h = ½ (A/W_t) = 4.84 ft

H_v < ½ D_h ⟶ **subcritical flow**

Zone A Workshop

How to determine
Base Flood Elevation (BFE)

? ? ? ? ? ?