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… Delivering Solutions

Sensitivity of Hydraulic Models to Manning's n in Computing WSEL with Different Stream Sizes

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Objectives of Presentation

- **Describe the significance of roughness coefficient, Manning's n, in computations of Water Surface Profiles in one-dimensional hydraulic models, and relate it with the theory of hydraulics.**

- **Describe the procedure for conducting the sensitivity analyses for this study.**

- **Provide some examples for sensitivity of roughness coefficient to computed water surface profiles for different size streams.**

- **Provide guidelines for the appropriate selection of roughness coefficient for use in the one-dimensional hydraulic models.**

Roughness Coefficient in 1-D Hydraulic Models

- Baker as the PTS Contractor for Risk MAP receives a large number of hydraulic studies for review to process map revision requests

- The ultimate objective of the flood hazard studies is to compute Base Flood Elevations (BFEs) along the reaches of the stream.

- It has been observed that Roughness coefficient is very sensitive for some streams, which can affect the BFEs.

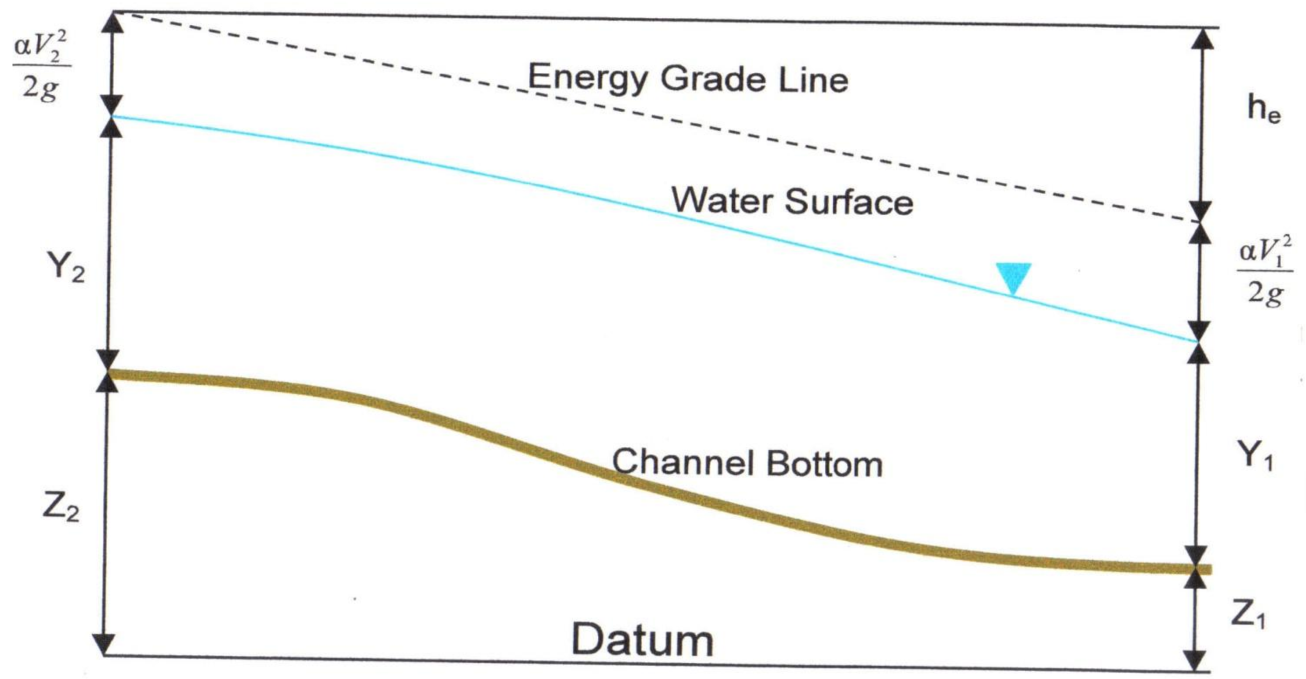
- A small change in the Manning's n can affect the BFE, and thus raise the issues of (a) appropriate selection of Manning's n, and (b) accuracy of computed WSEL for NFIP studies and water resources planning and mitigation studies

Theory of Hydraulics - Assumptions

- **Steady flow**
- **Gradually varied flow**
- **Small channel slope**
- **Frictional slope constant between two adjacent cross sections**
- **Rigid channel boundaries**

Energy Balance at Two Cross Sections

$$Y_2 + Z_2 + \frac{\alpha_2 v_2^2}{2\,g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2\,g} + h_e \qquad (1)$$



Energy Losses

h_e = Friction loss + transitional Loss

$$h_e = L\,S_f + C\,[\,\Delta Vh]\qquad (2)$$

L = Discharge weighted reach length

S_f = Friction slope

ΔVh = Absolute differences in the velocity head

C = Contraction and expansion loss coefficients

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Energy Losses

$L\,S_f \quad = \quad$ Friction loss

$Q \quad = \; K\,S_f^{1/2}$

$S_f \quad = \quad (Q/K)^2$

where $K = (1.49/n)\,A\,R^{2/3}$

Accuracy of Computations of WSEL

- WSEL = f (slope, velocity, friction losses, transitional losses)

- Any deviations from the assumption made regarding energy balance and head loss equations may cause instability in the computation of energy losses, and potential inaccuracy in computed water surface elevation (WSEL).

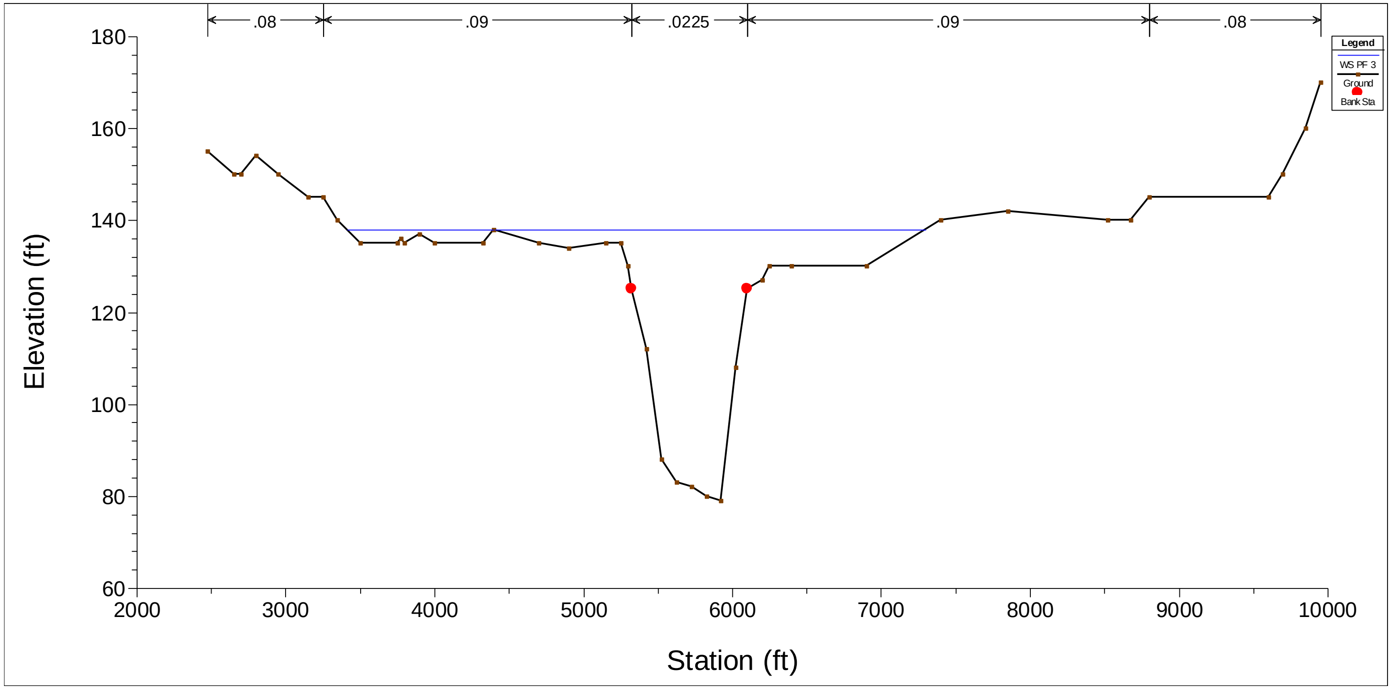
- When the program can not balance the energy equation at a cross section, it is usually caused by an inadequate number of cross sections or bad cross section data, including Manning’s n.

Manning's Equation

- Manning’s equation is also used for evaluating of drag force which is a component of momentum equation

- The momentum equation is utilized in situations where water surface profile is rapidly varied

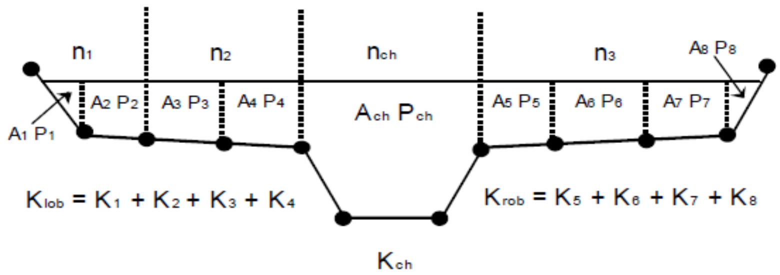
Application of Roughness coefficient in hydraulic model



- **For less variable roughness, three n values (Left overbank, channel and Right overbank) are sufficient to describe the channel geometry.**
- **For more variable, horizontal variation of n value is used**
- **Defining ineffective flow area by assigning artificially high roughness coefficients**

Application of Roughness coefficient in hydraulic model

- **Cross sections subdivision for lateral variation of n values**



- **Composite Manning's n for the Main Channel**

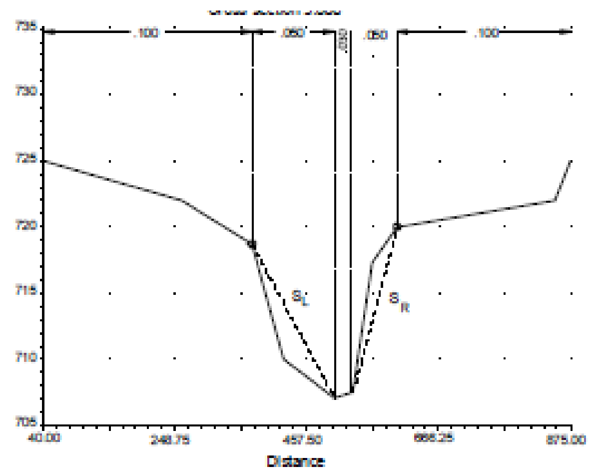
$$n_c = \left[\frac{\sum_{i=1}^{N}(P_i {n_i}^{1.5})}{P}\right]^{2/3}$$

n_c = composite or equivalent coefficient of roughness

P = Wetted perimeter of entire main channel

P_i = Wetted perimeter of subdivision i

n_i = coefficient of roughness of subdivision i



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Procedure for Conducting Sensitivity Analyses of Manning’s n

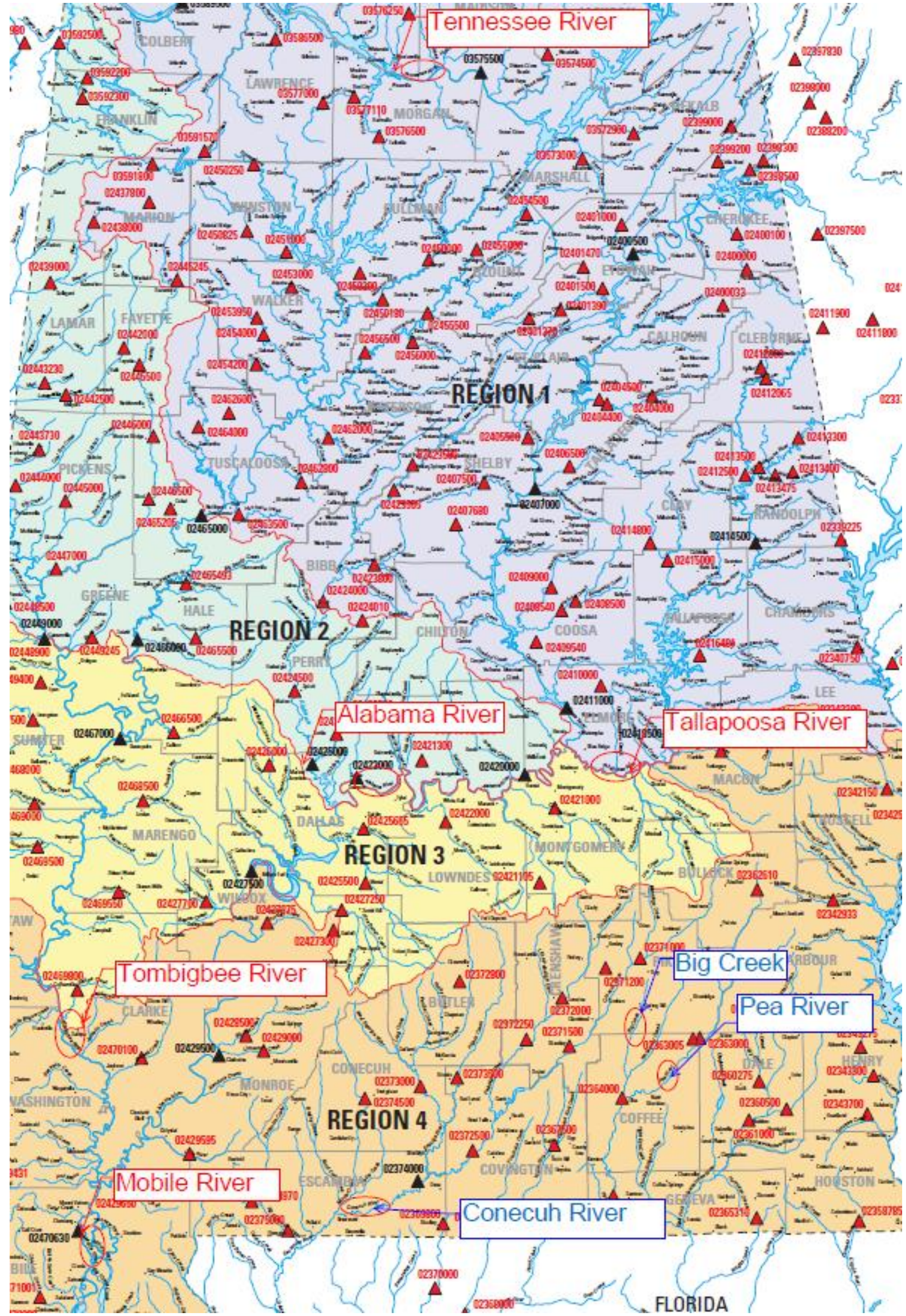
- **We selected a few streams from the State of Alabama, with varying 1% annual chance discharge rates.**

- **We ran the models with the effective n Values for each stream, and considered the model run as a control for that stream.**

- **We varied the Manning's Channel n values from + 10% to +50%, and -10% to -50% from the value used in the effective analysis.**

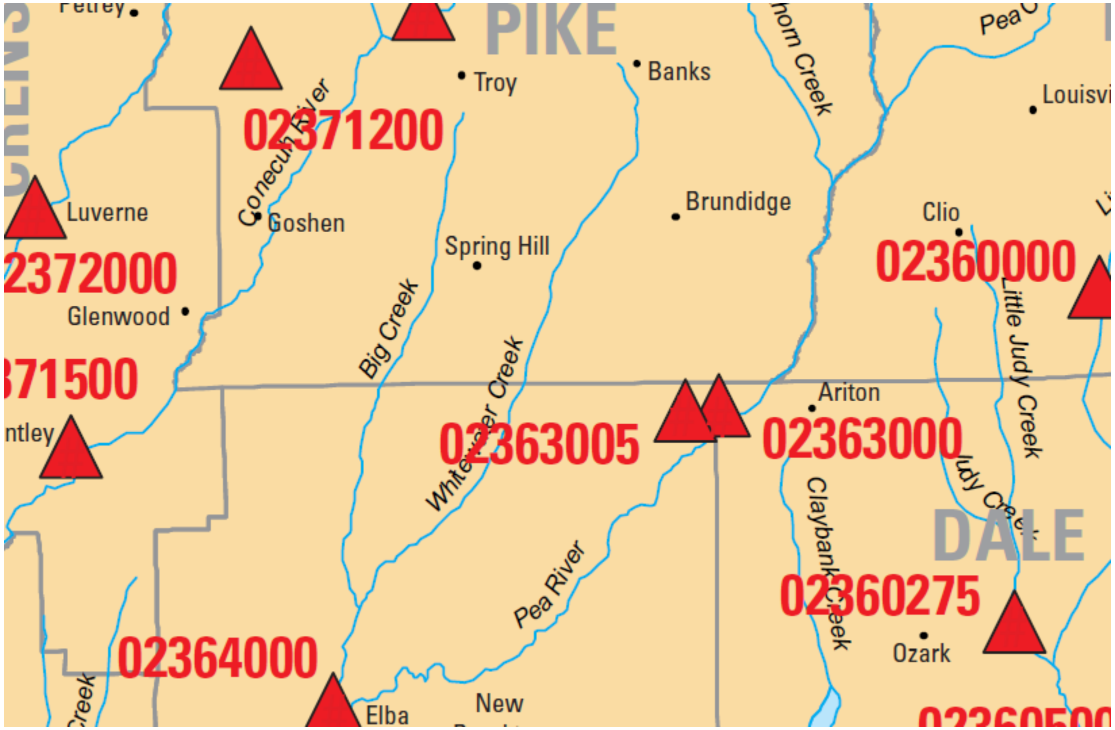
- **Then we compared the computed depths from step 3 with the effective computed depth, and determined maximum and minimum change in depths along the streams.**

Stream locations

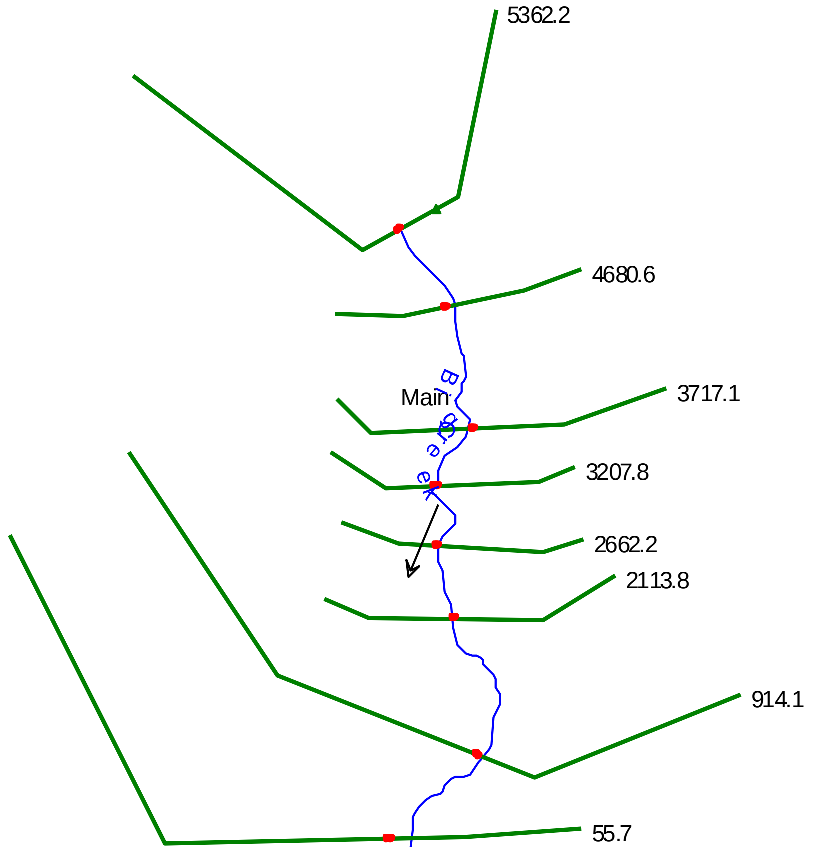


Sensitivity of Manning's values for Big Creek

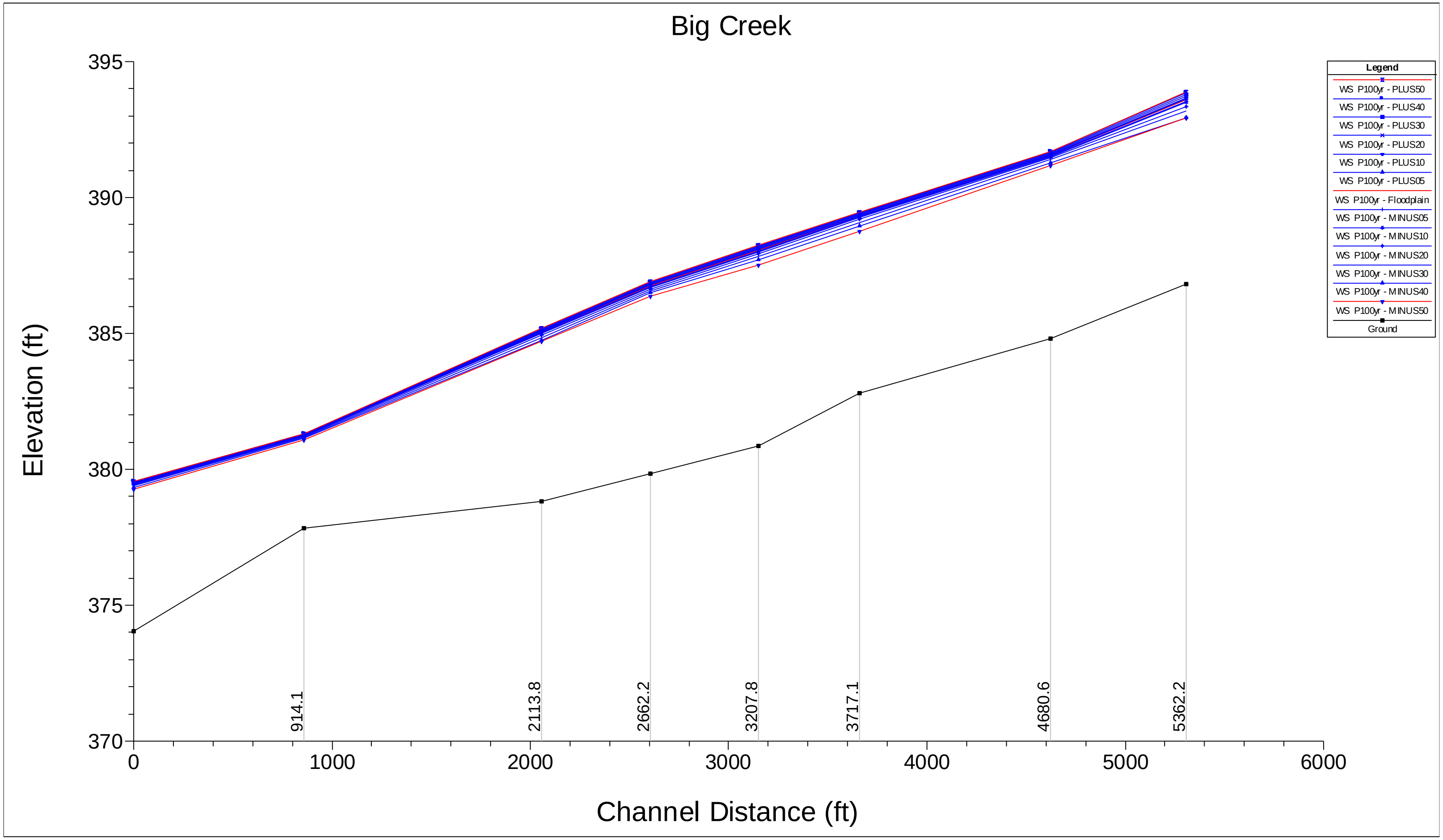
Location:	Pike County, AL
Channel n values:	0.055
Overbank n values:	0.12
Flow Range:	2,000 cfs – 2,371 cfs
Average Slope:	0.0025 (0.25 %)



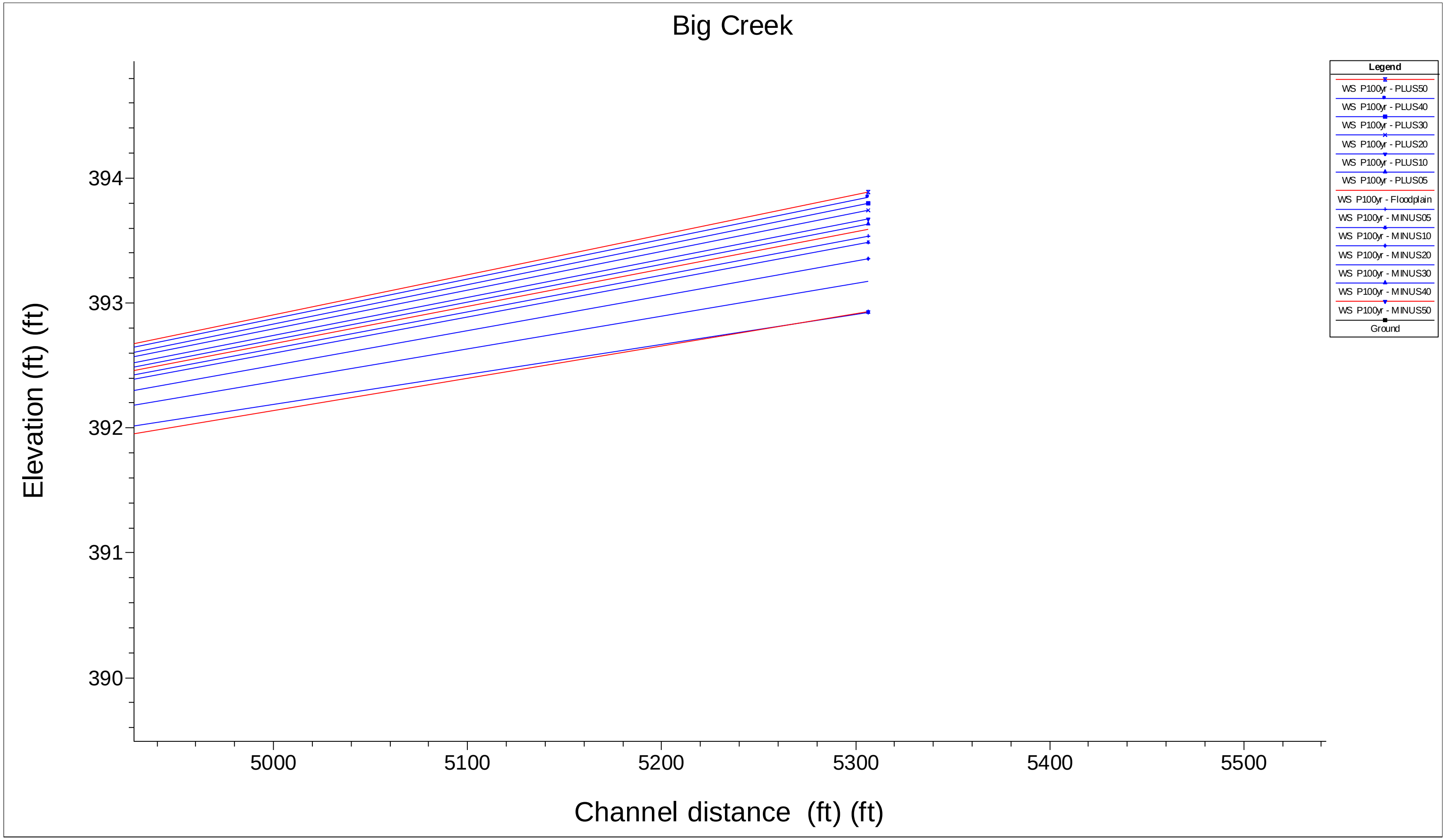
Sensitivity of Manning's values for Big Creek



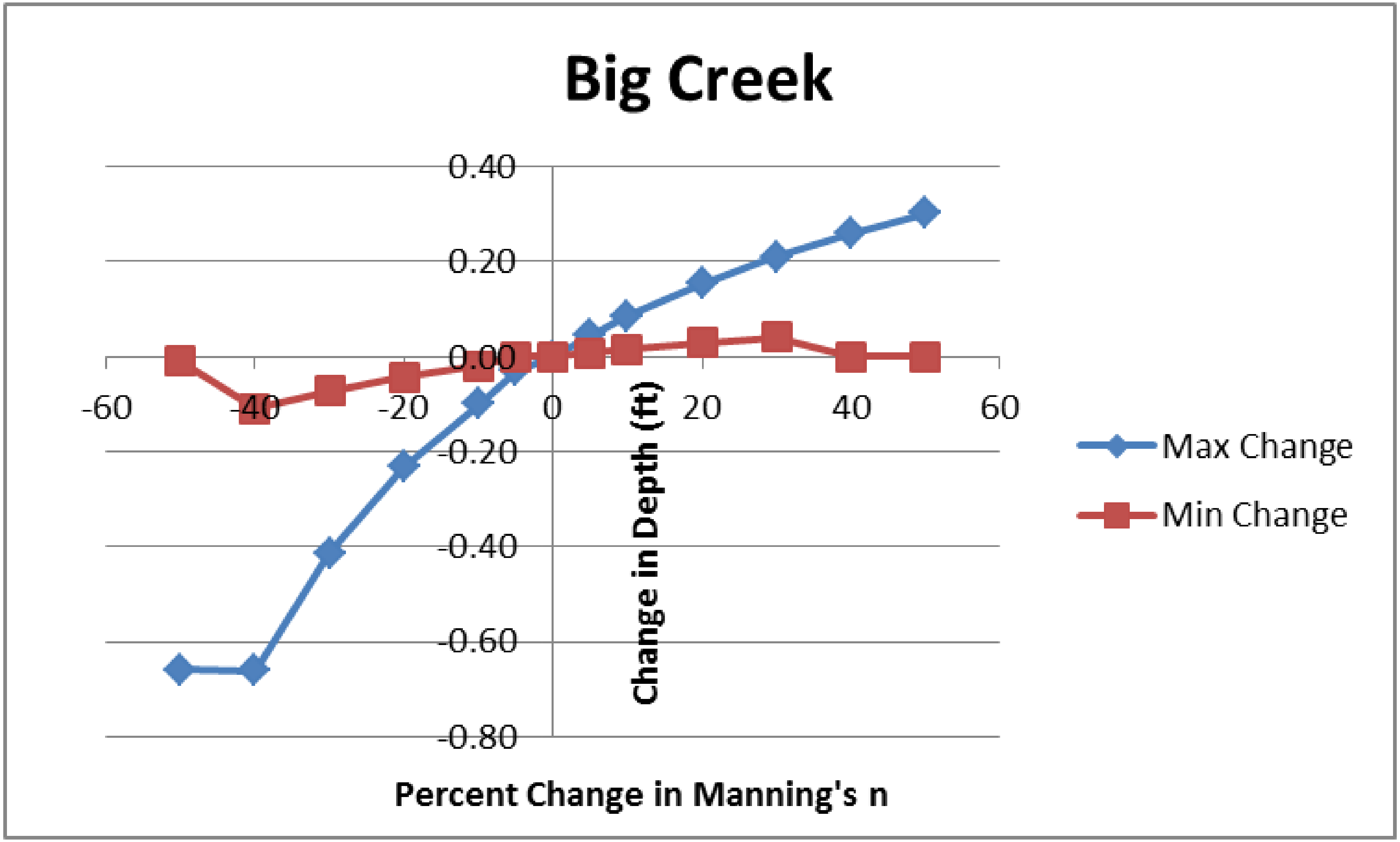
Sensitivity of Manning's values for Big Creek



Sensitivity of Manning's values for Big Creek

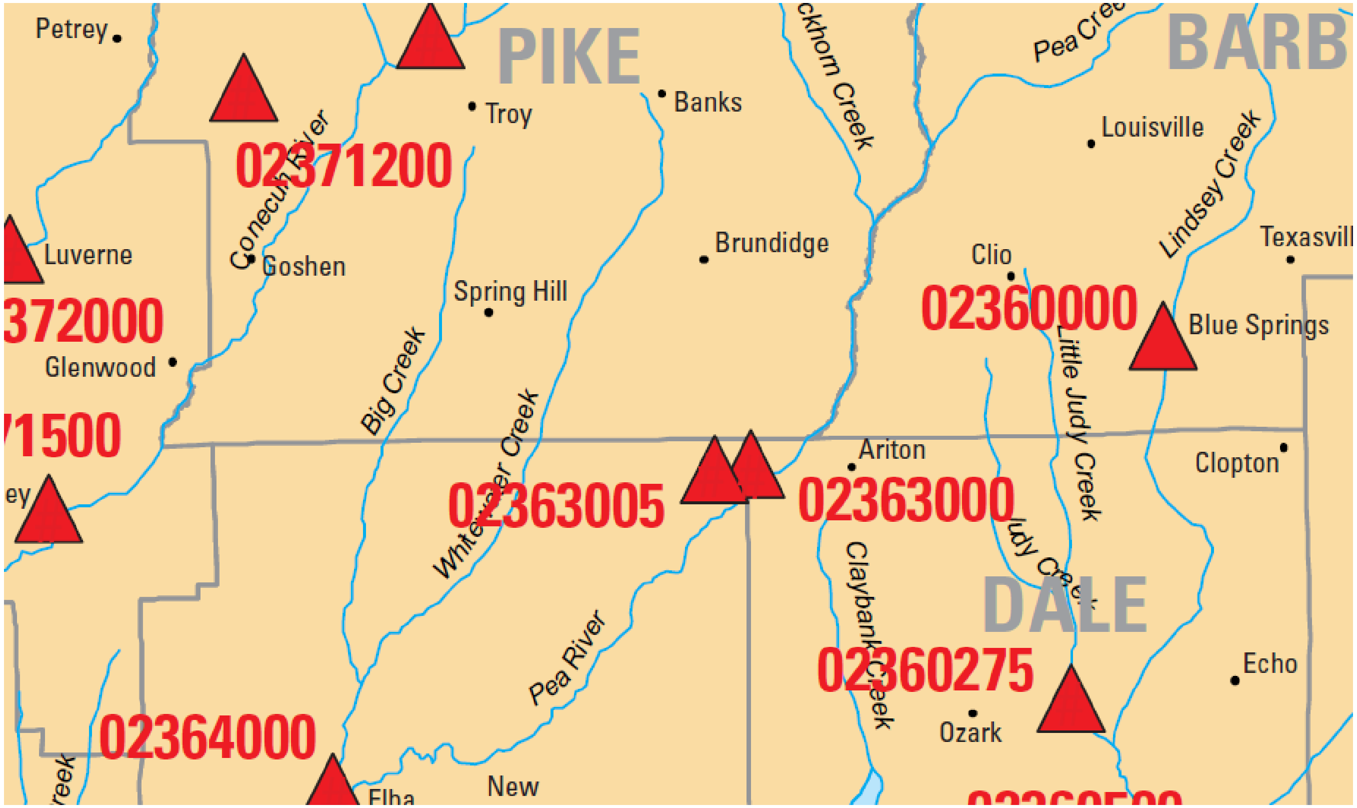


Sensitivity of Manning's n values for Big Creek

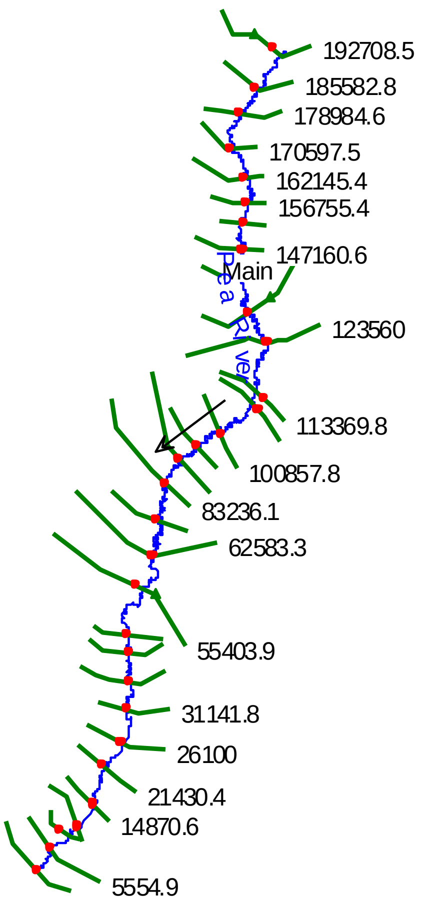


Sensitivity of Manning's values for Pea River

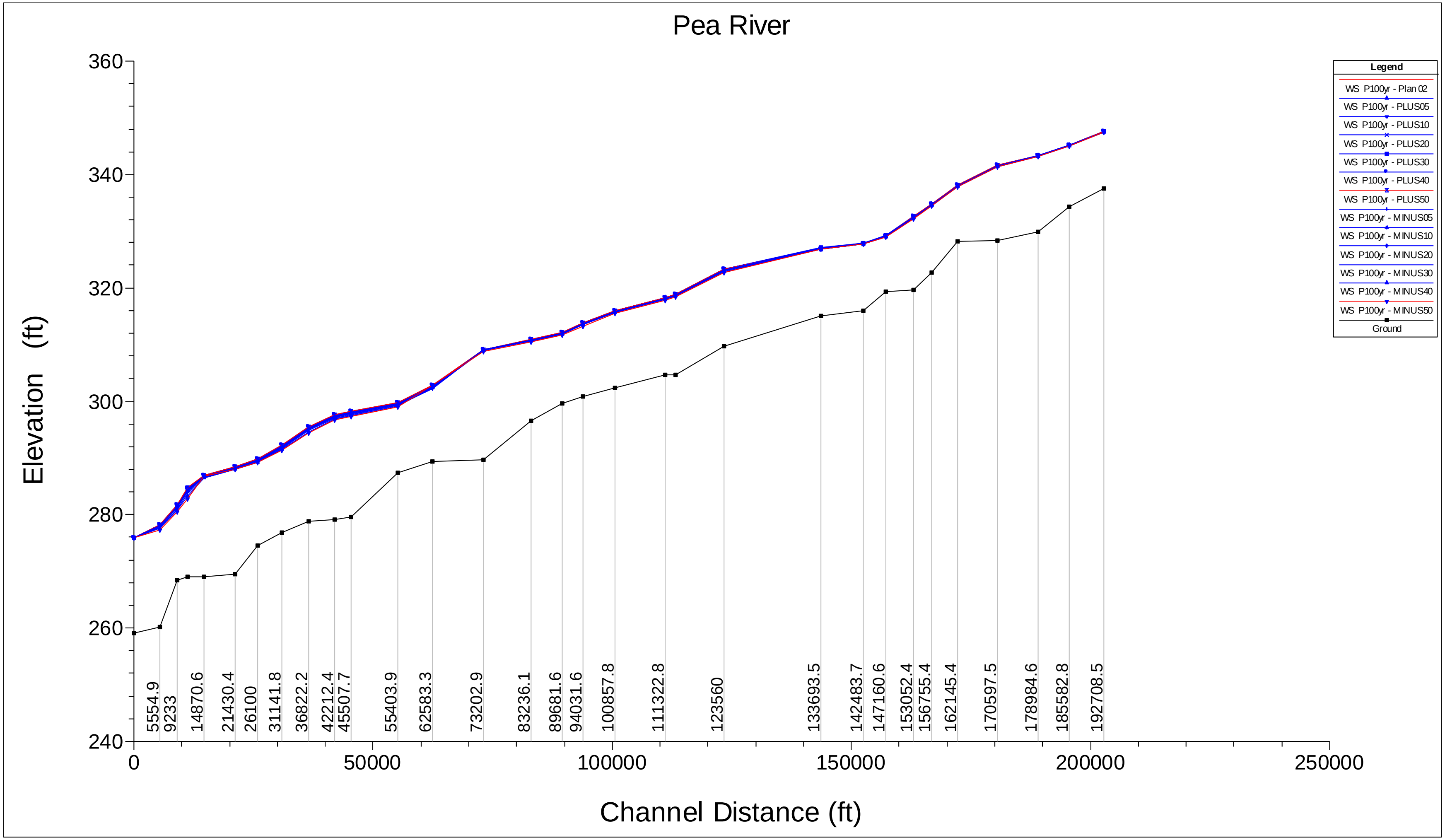
Location:	Pike County, AL
Channel n values:	0.05
Overbank n values:	0.11
Flow Range:	23,490 cfs – 46,357 cfs
Average Slope:	0.00037 (0.037%)



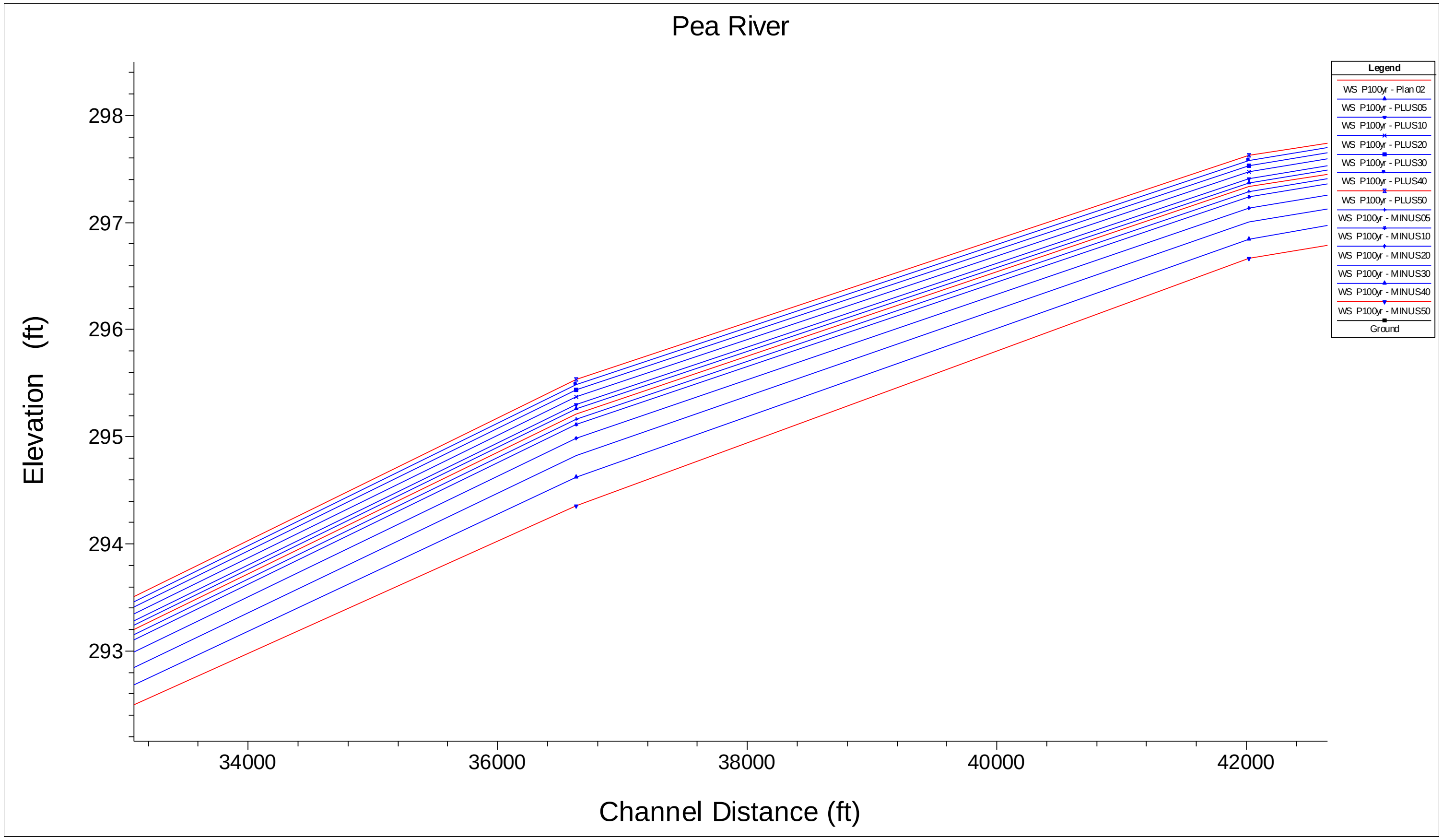
Sensitivity of Manning's values for Pea River



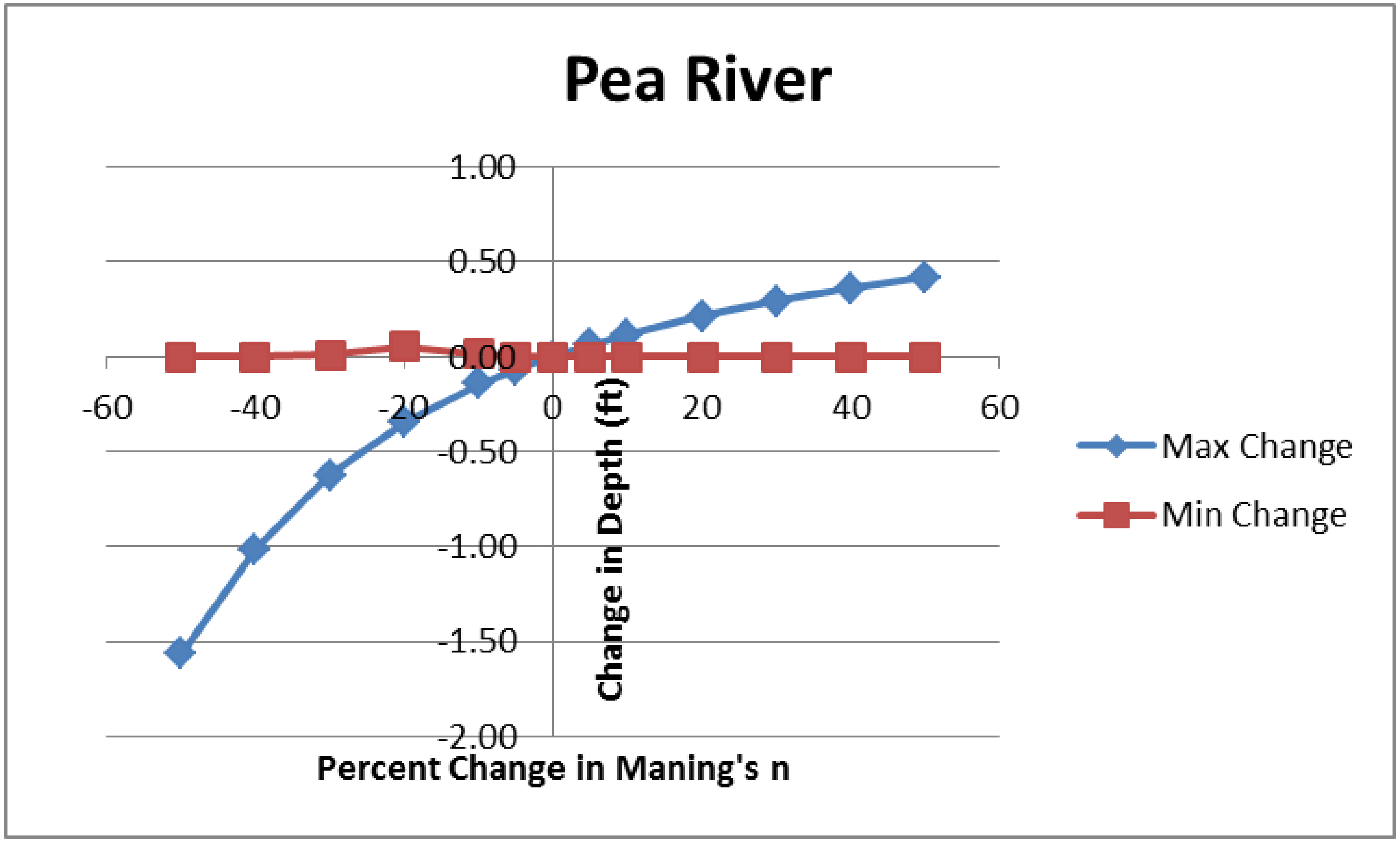
Sensitivity of Manning's values for Pea River



Sensitivity of Manning's values for Pea River

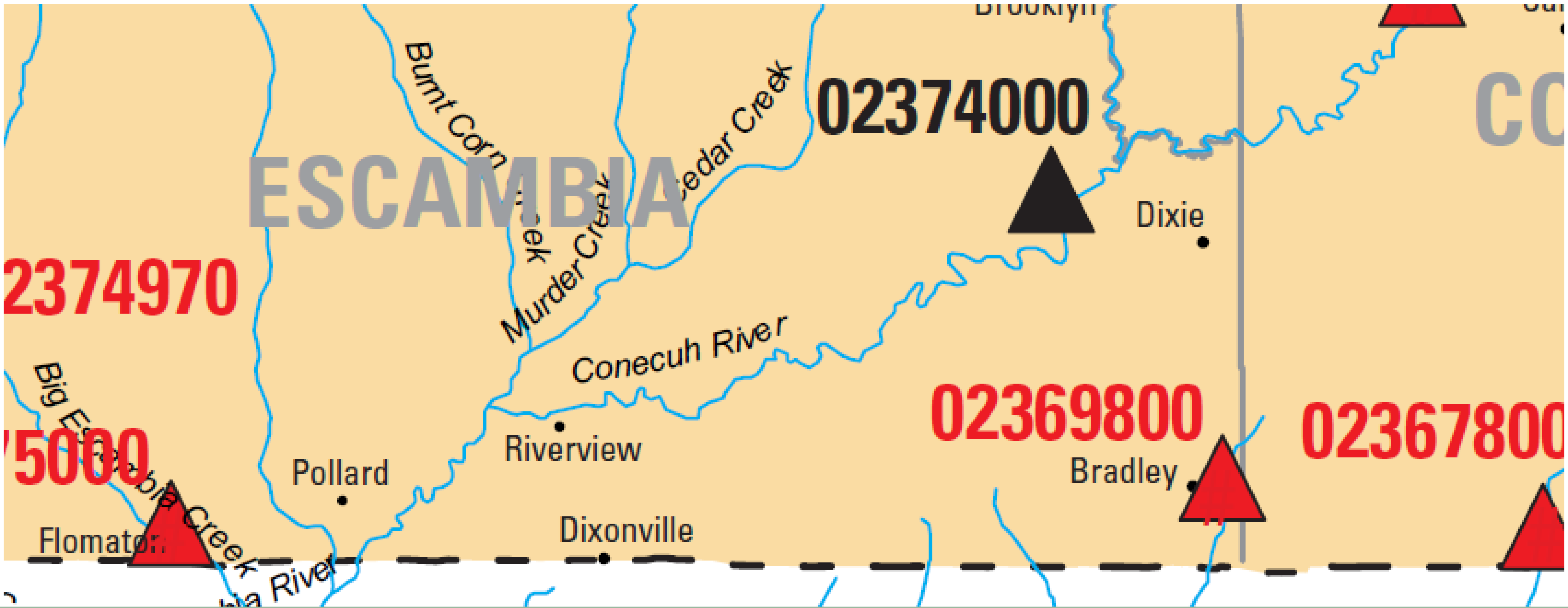


Sensitivity of Manning's n values for Pea River

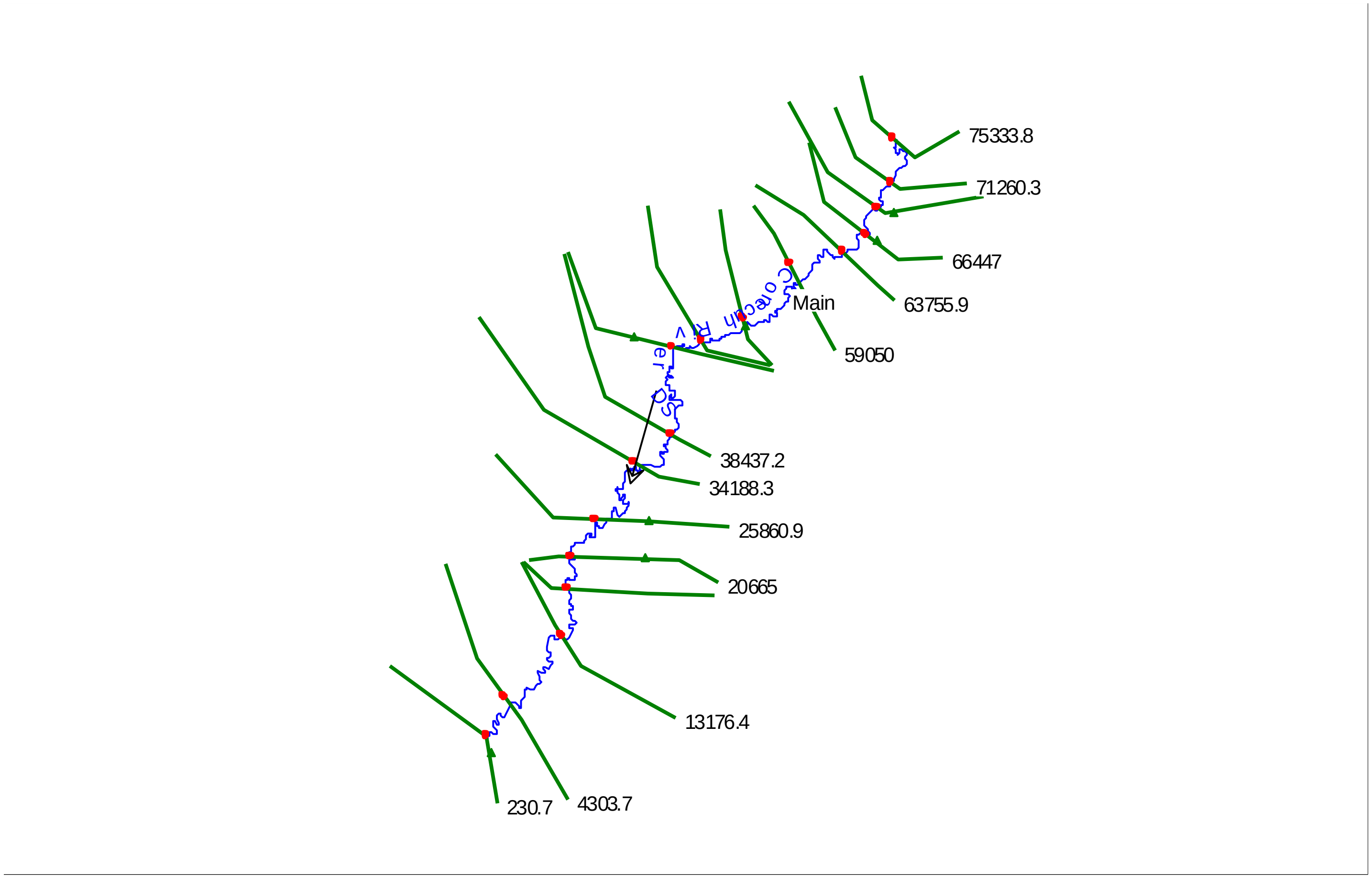


Sensitivity of Manning's values for Conecuh Creek

Location:	Escambia, AL
Channel n values:	0.045
Overbank n values:	0.12
Flow Range:	46,976 cfs
Average Slope:	0.00038 (0.038 %)



Sensitivity of Manning's values for Conecuh Creek



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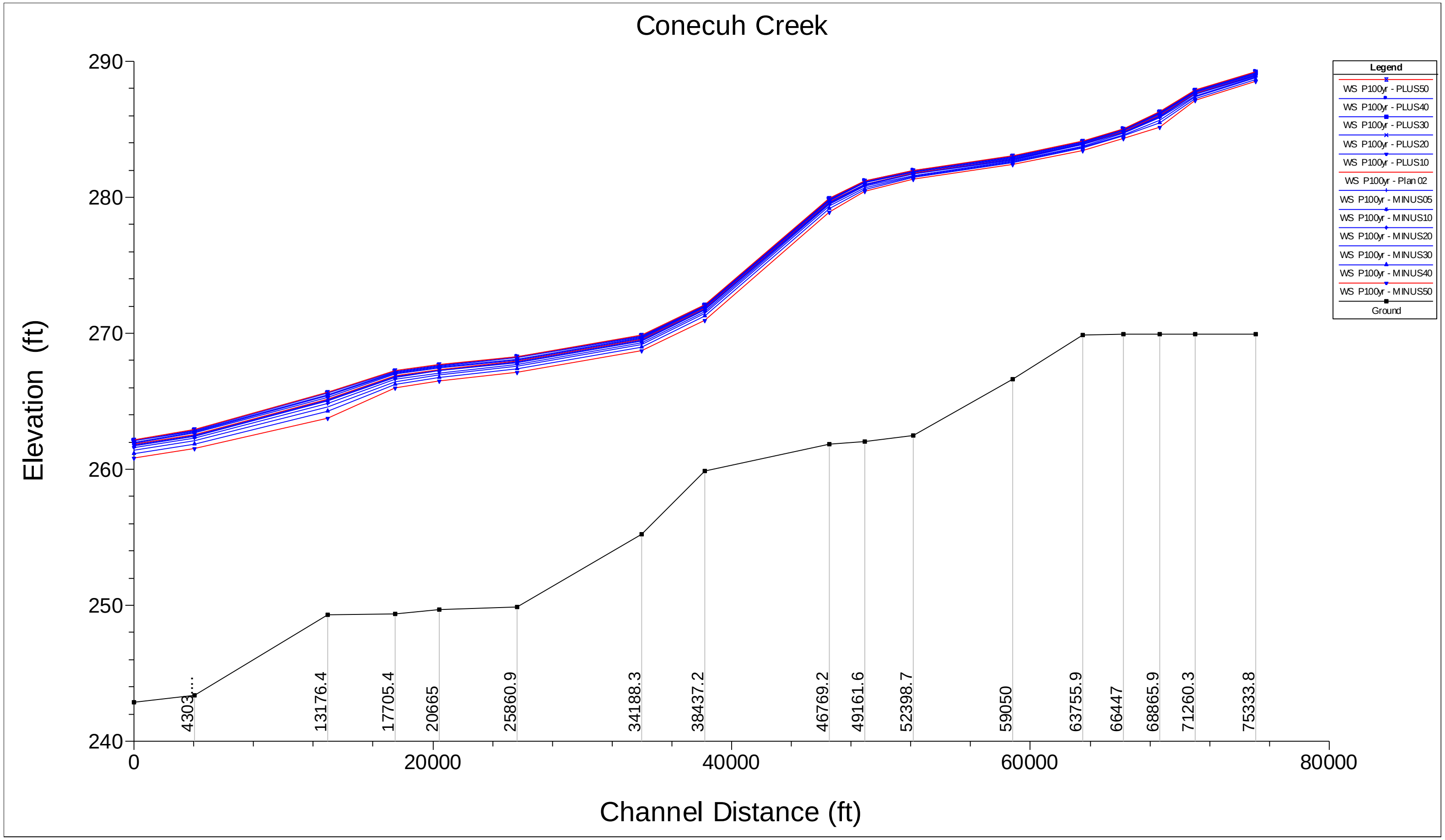
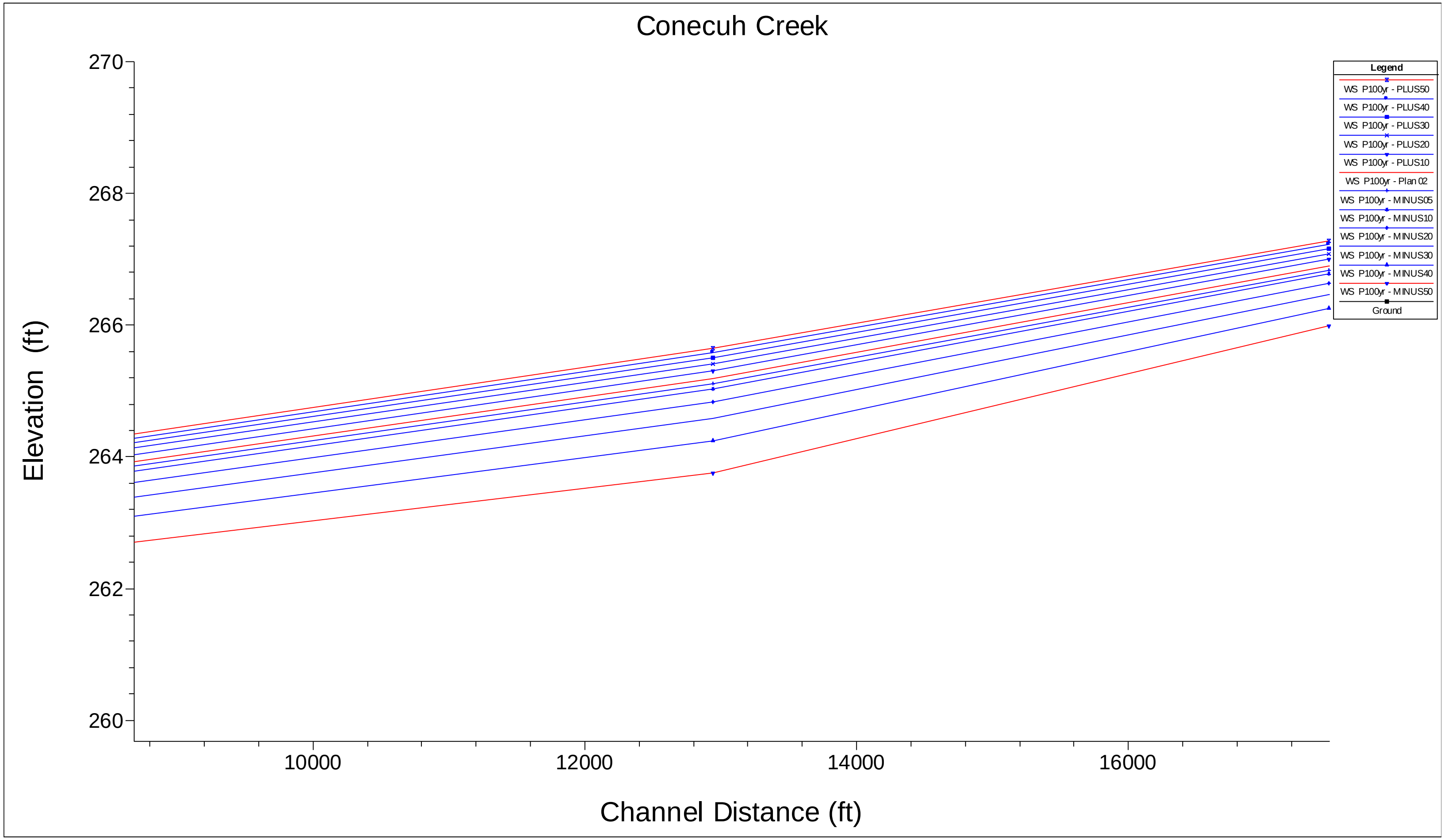
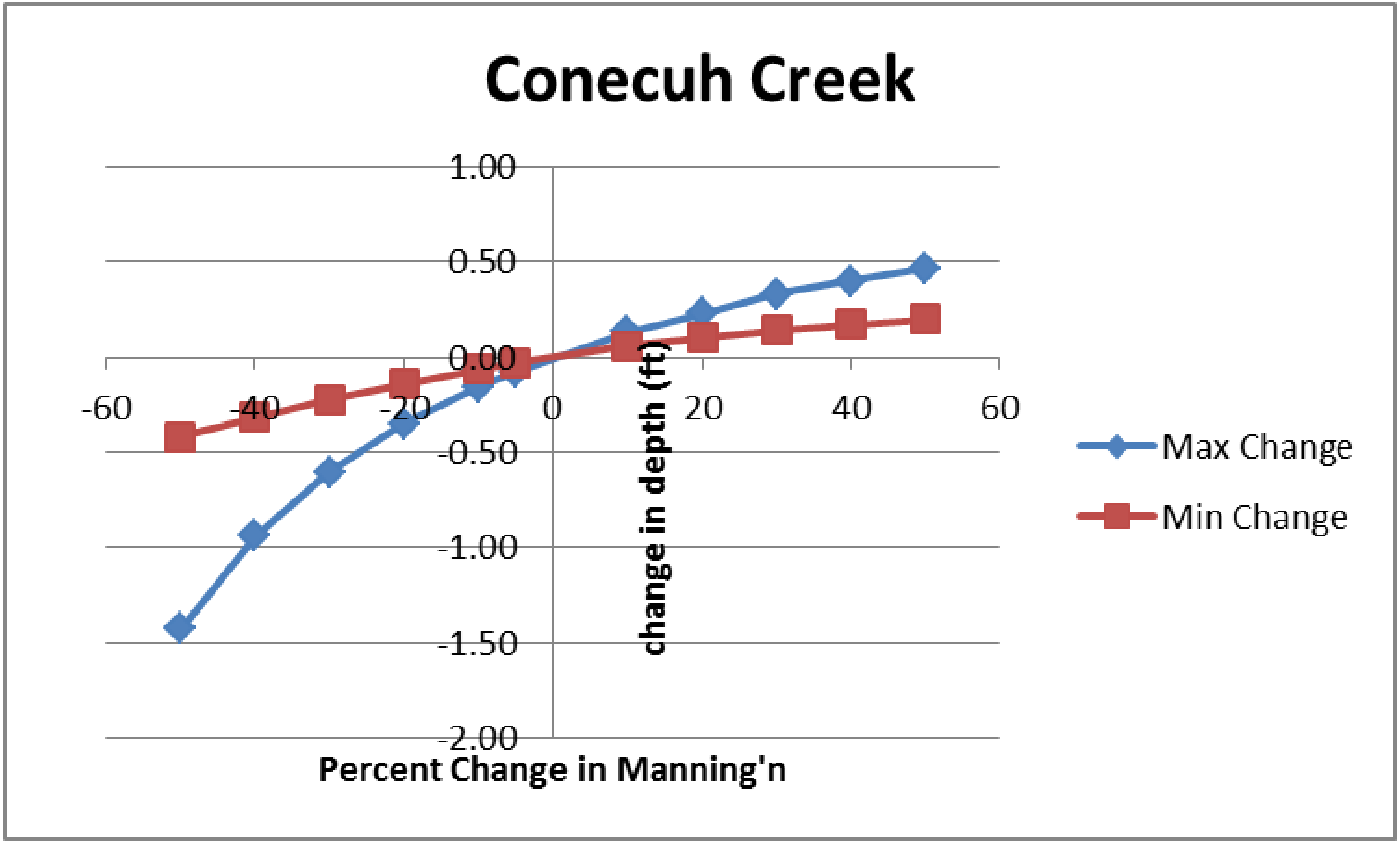
Sensitivity of Manning's values for Conecuh Creek



Sensitivity of Manning's values for Conecuh Creek

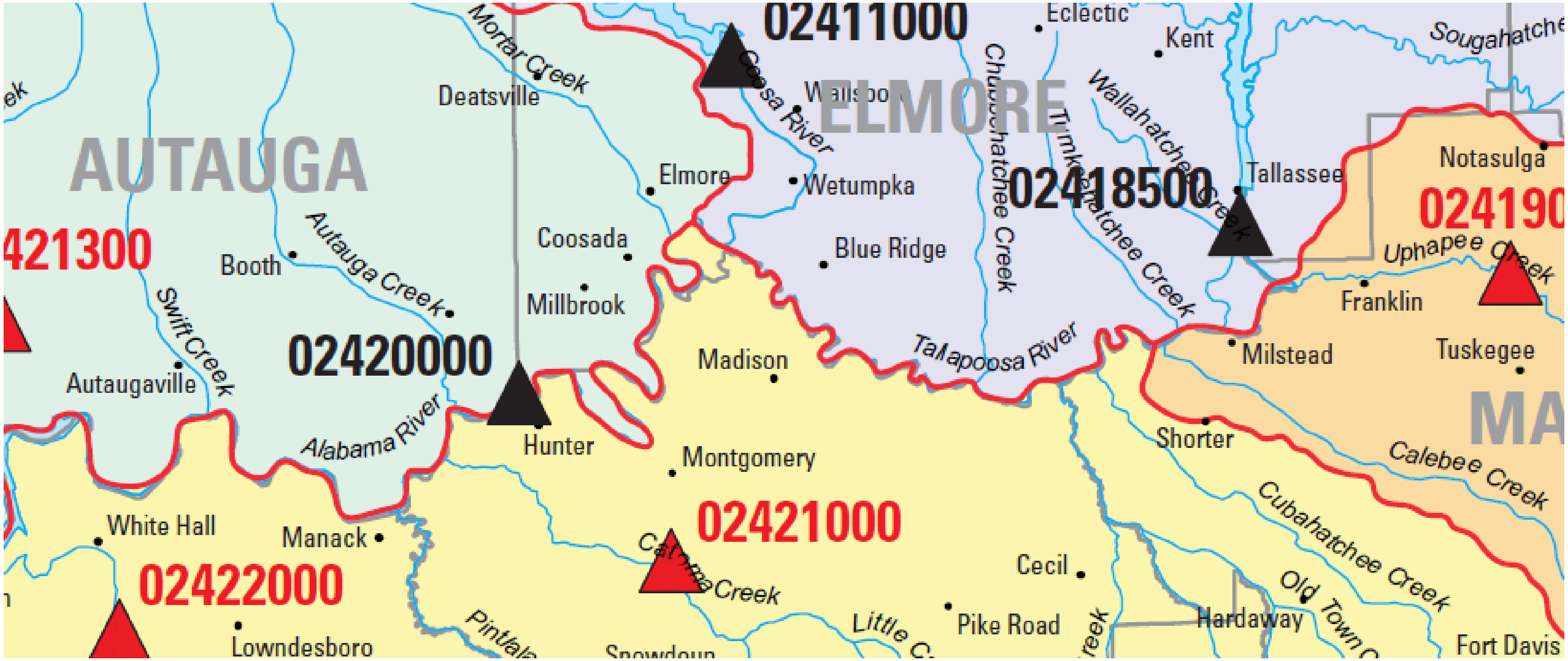


Sensitivity of Manning's n values for Conecuh Creek

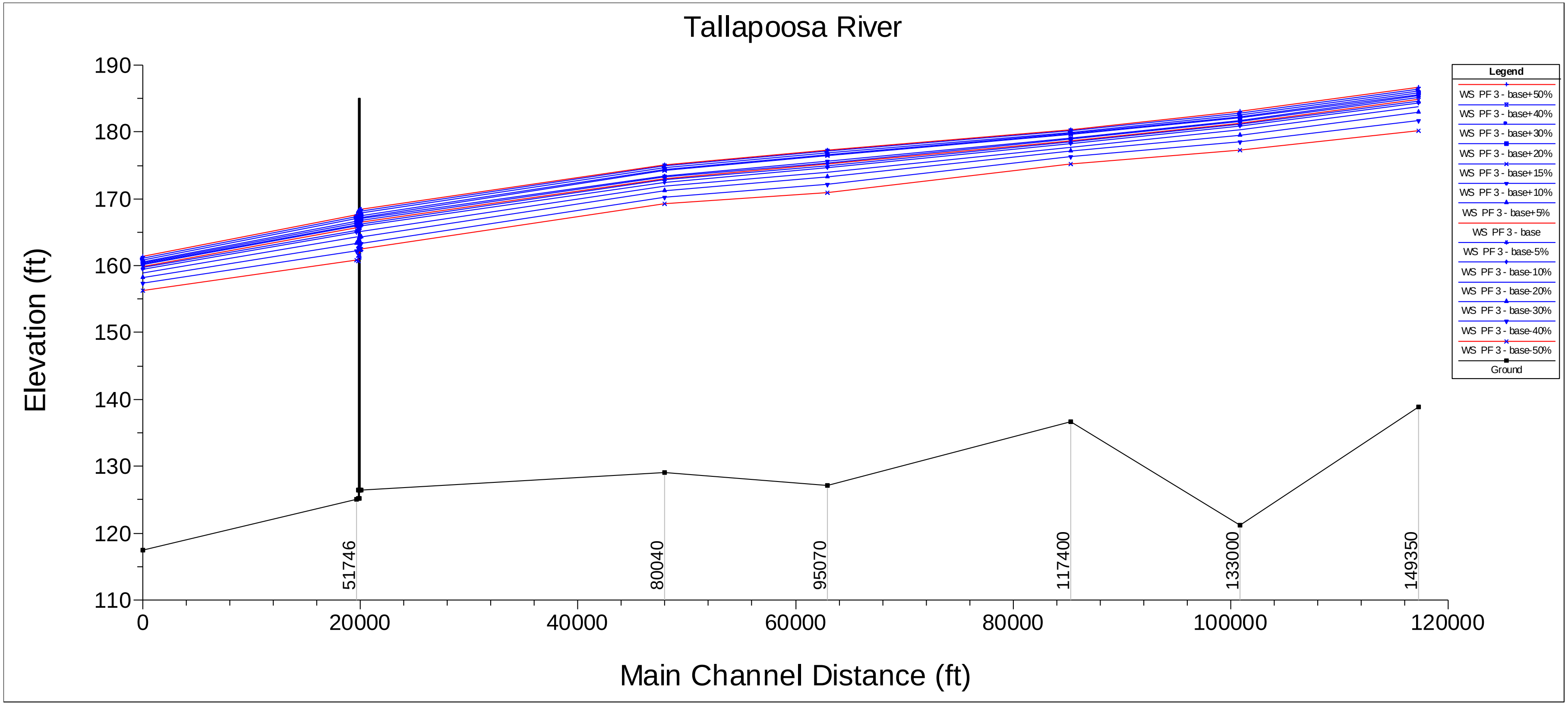


Sensitivity of Manning's values for Tallapoosa River

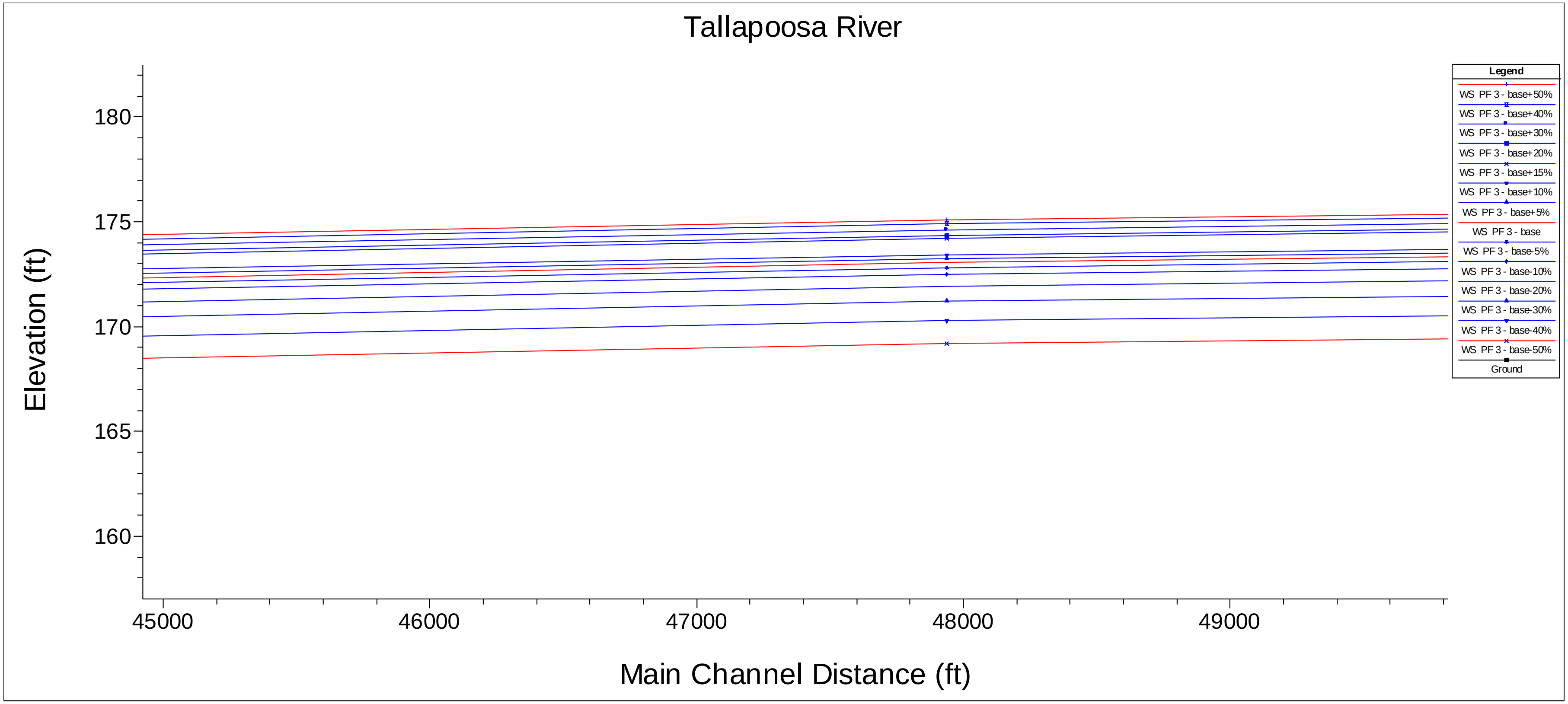
Location:	Elmore County and Montgomery County, AL (River
Channel n values:	0.04
Overbank n values:	0.12
Flow Range:	199,800 cfs – 204,000 cfs
Average Slope:	0.00007 (0.007%)



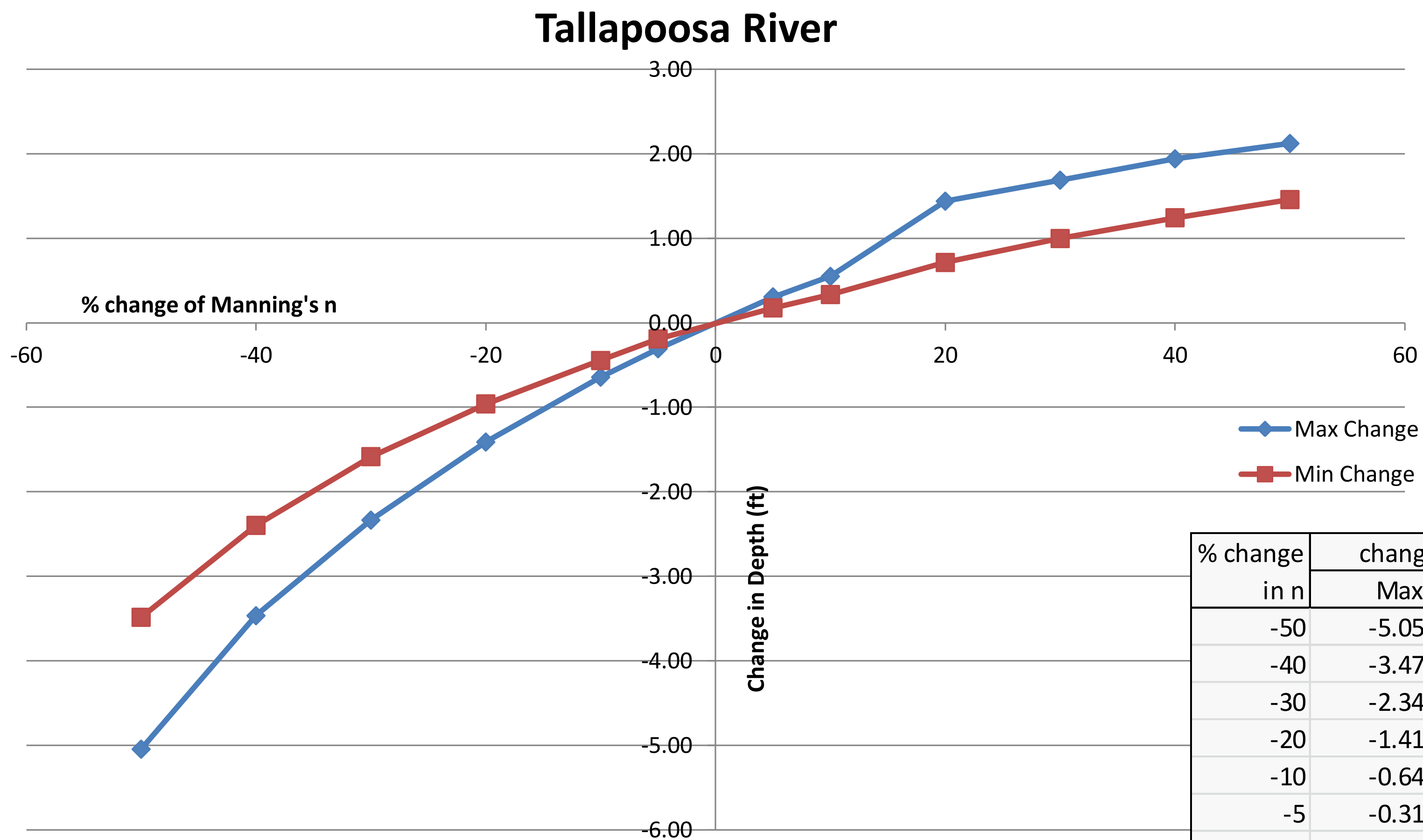
Sensitivity of Manning's values for Tallapoosa River (Contd)



Sensitivity of Manning's values for Tallapoosa River (Contd)



Sensitivity of Manning's values for Tallapoosa River (Contd)



% change in n	change in depth	
	Max	Min
-50	-5.05	-3.49
-40	-3.47	-2.40
-30	-2.34	-1.58
-20	-1.41	-0.96
-10	-0.64	-0.45
-5	-0.31	-0.19
5	0.31	0.18
10	0.55	0.33
20	1.44	0.71
30	1.69	1.00
40	1.94	1.24
50	2.12	1.46

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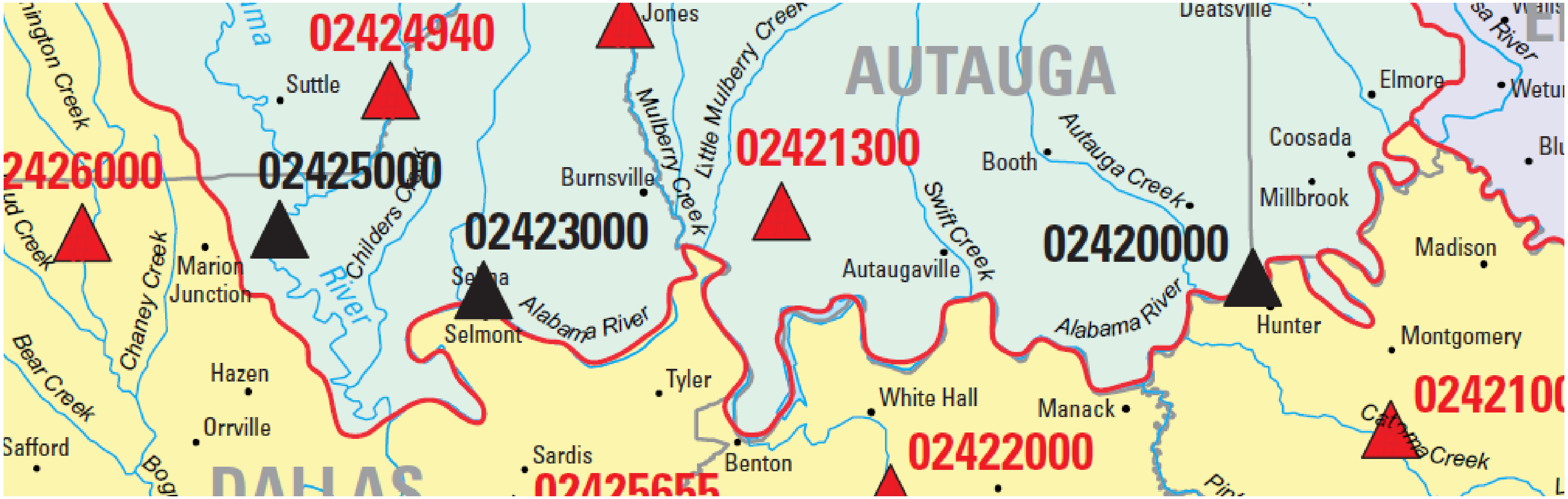
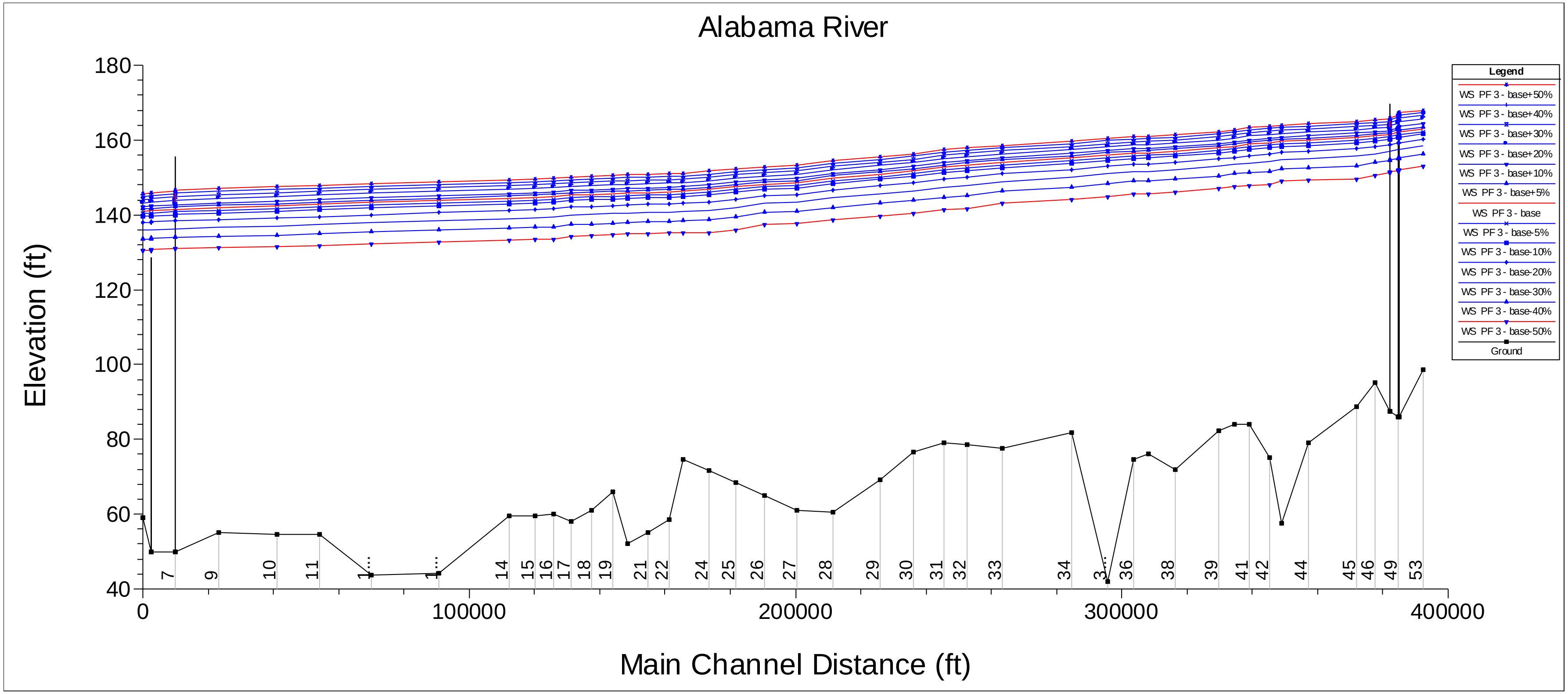
Sensitivity of Manning's values for Alabama River

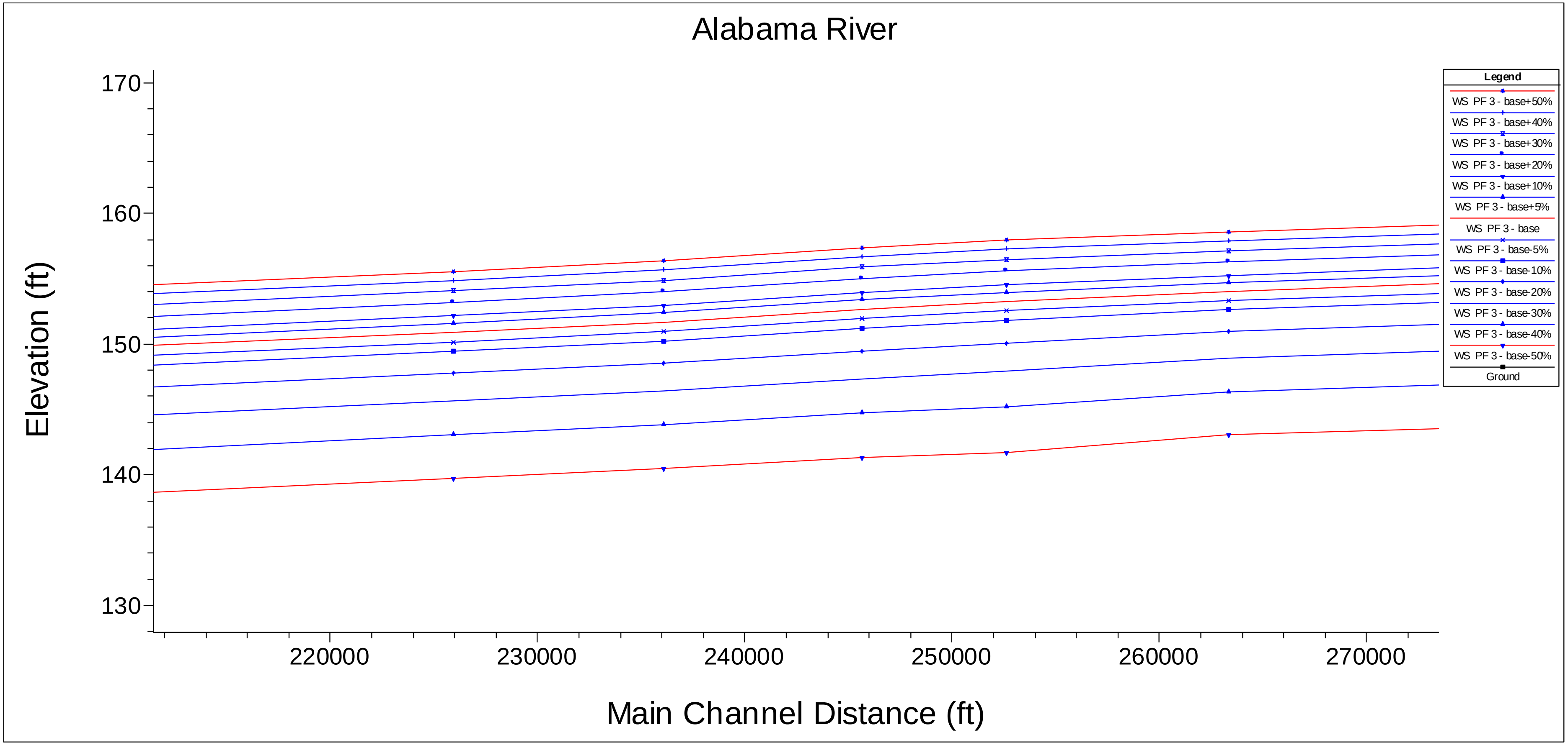
Location:	Autauga County, Dallas County, Lowndes County and Montgomery County, AL
Channel n values:	0.04 – 0.05
Overbank n values:	0.08 – 0.12
Flow Range:	252,000 cfs - 324,000 cfs
Average Slope:	0.00012 (0.012%)



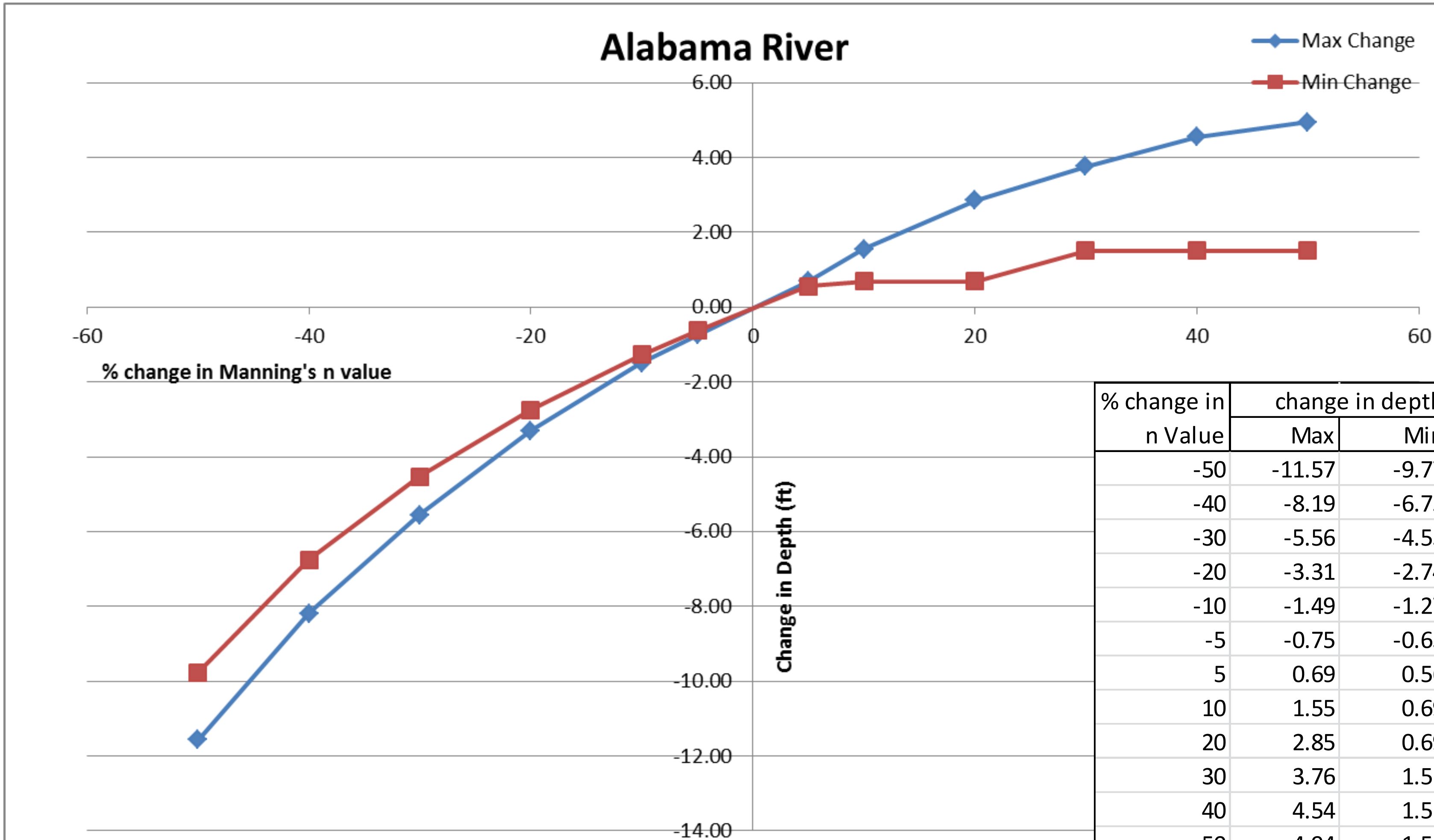
Sensitivity of Manning's values for Alabama River (Contd)



Sensitivity of Manning's values for Alabama River (Contd)



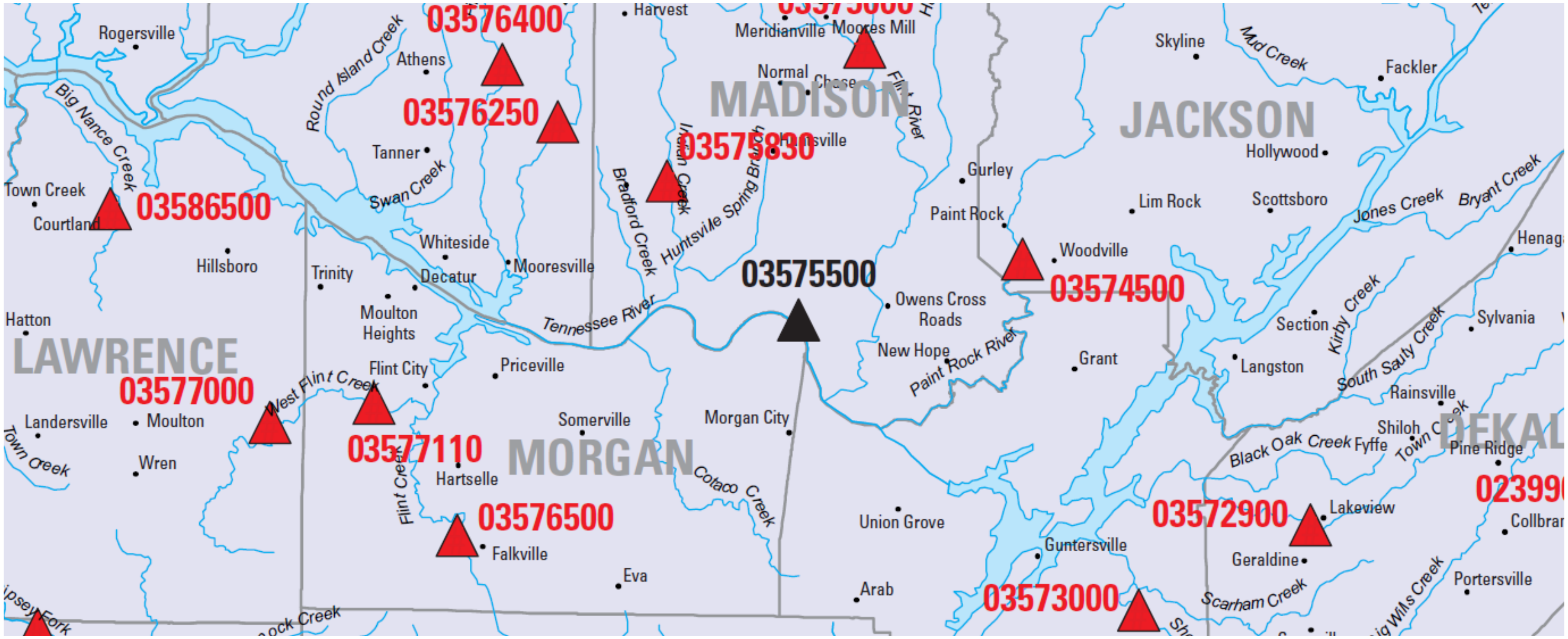
Sensitivity of Manning's values for Alabama River (Contd)



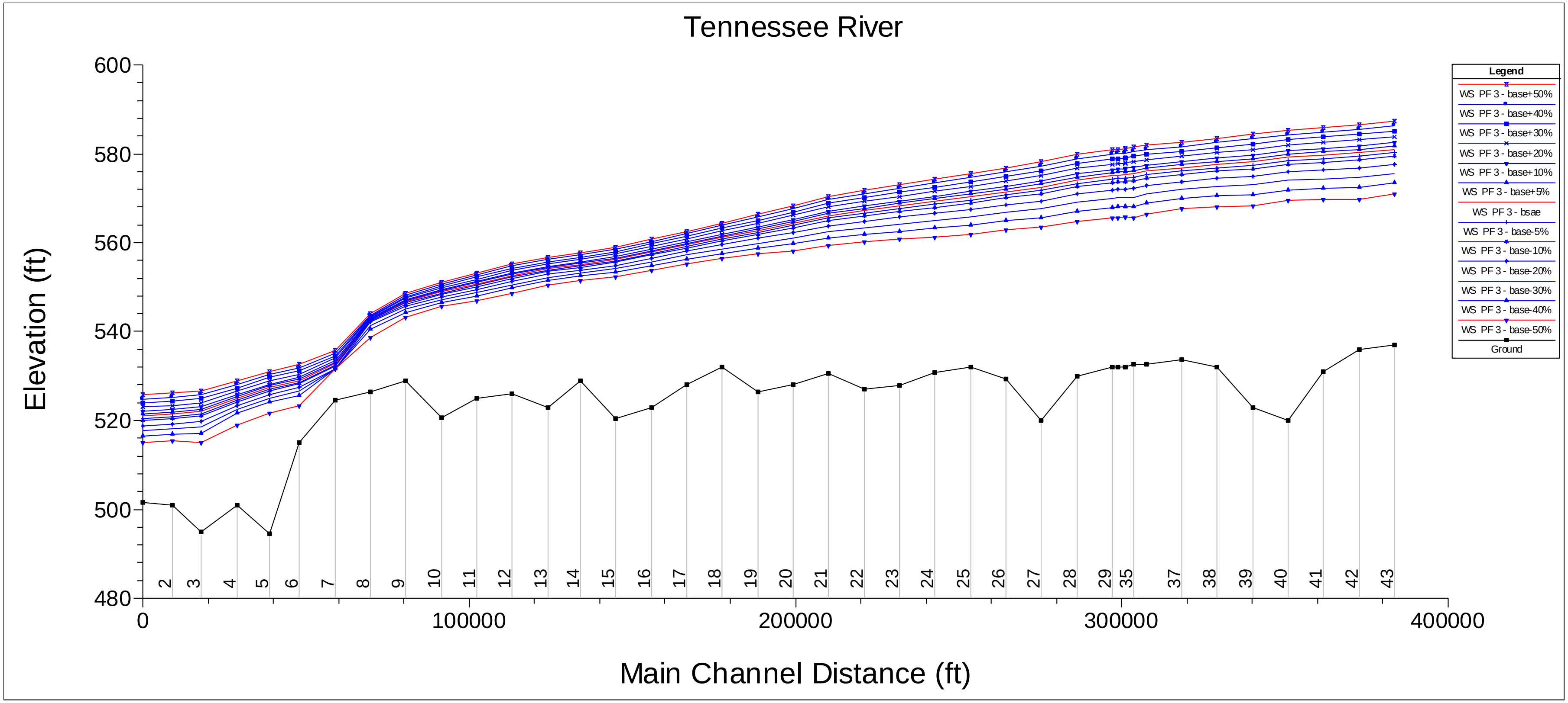
% change in n Value	change in depth Max	Min
-50	-11.57	-9.77
-40	-8.19	-6.75
-30	-5.56	-4.53
-20	-3.31	-2.74
-10	-1.49	-1.27
-5	-0.75	-0.63
5	0.69	0.56
10	1.55	0.69
20	2.85	0.69
30	3.76	1.51
40	4.54	1.51
50	4.94	1.51

Sensitivity of Manning's values for Tennessee River

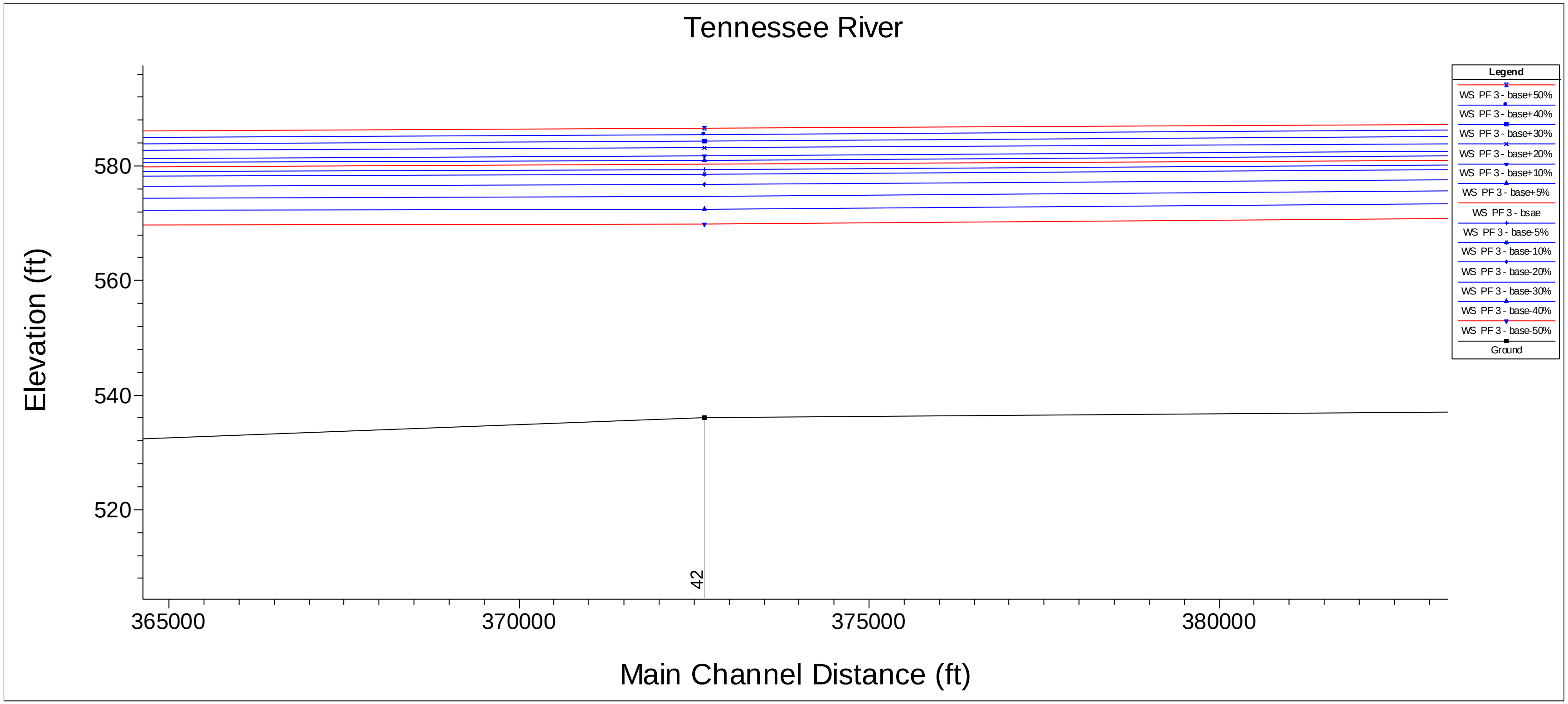
Location:	Madison County, AL (River mile 316.5 to 342.4)
Channel n values:	0.02 – 0.03
Overbank n values:	0.02 – 0.15
Flow Range:	305,000 cfs - 405,000 cfs
Average Slope:	0.00013 (0.013%)



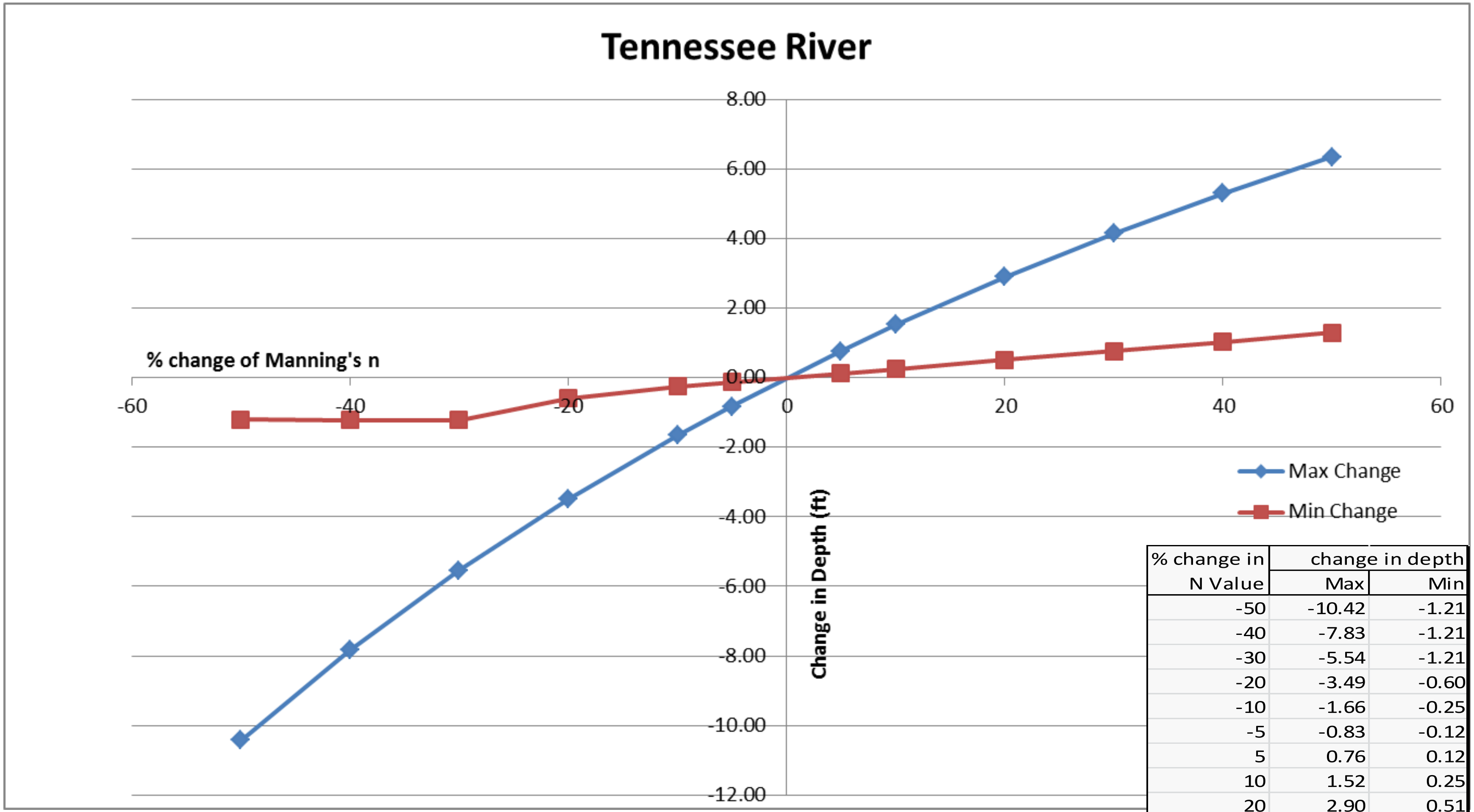
Sensitivity of Manning's values for Tennessee River (Contd)



Sensitivity of Manning's values for Tennessee River (Contd)



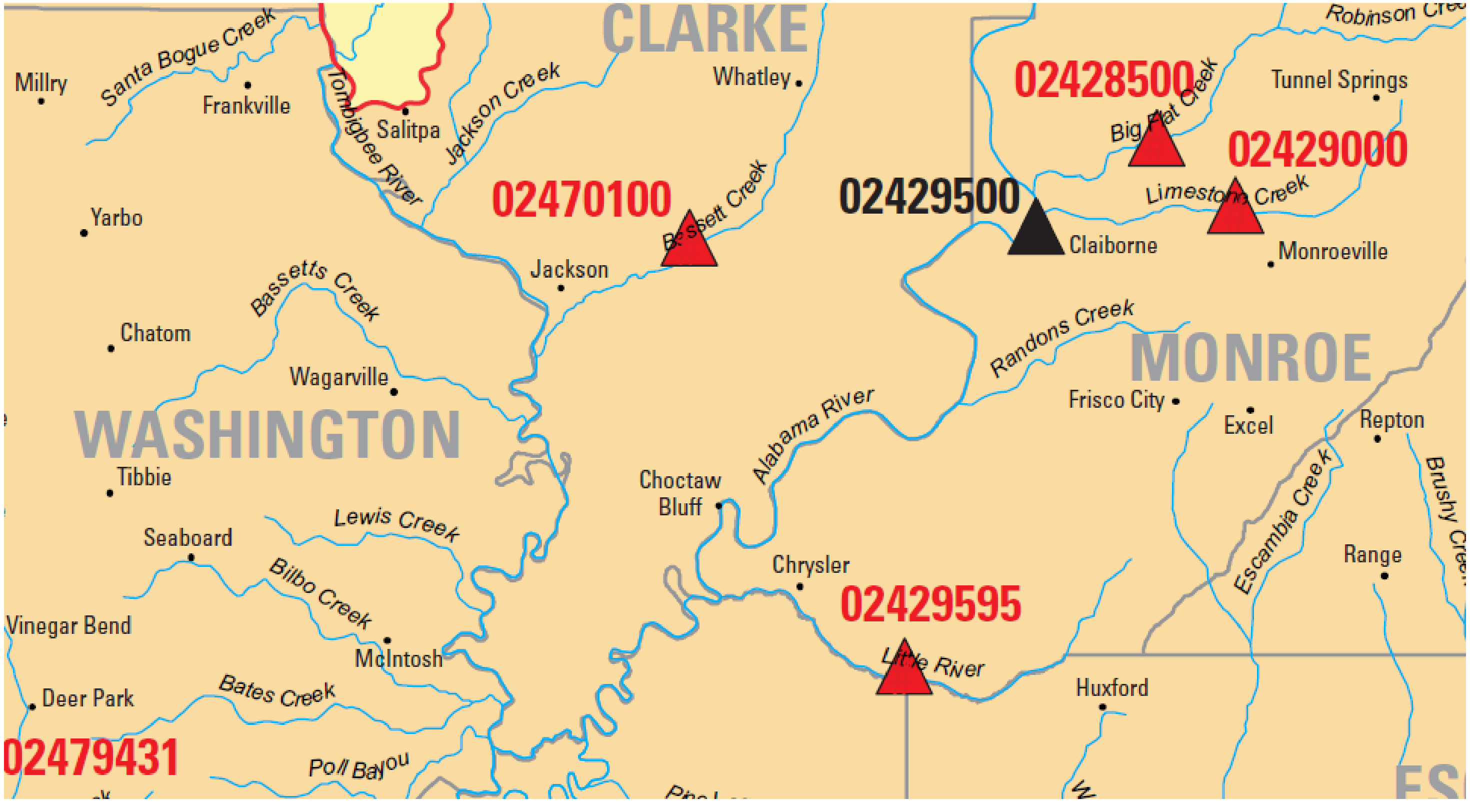
Sensitivity of Manning's values for Tennessee River (Contd)



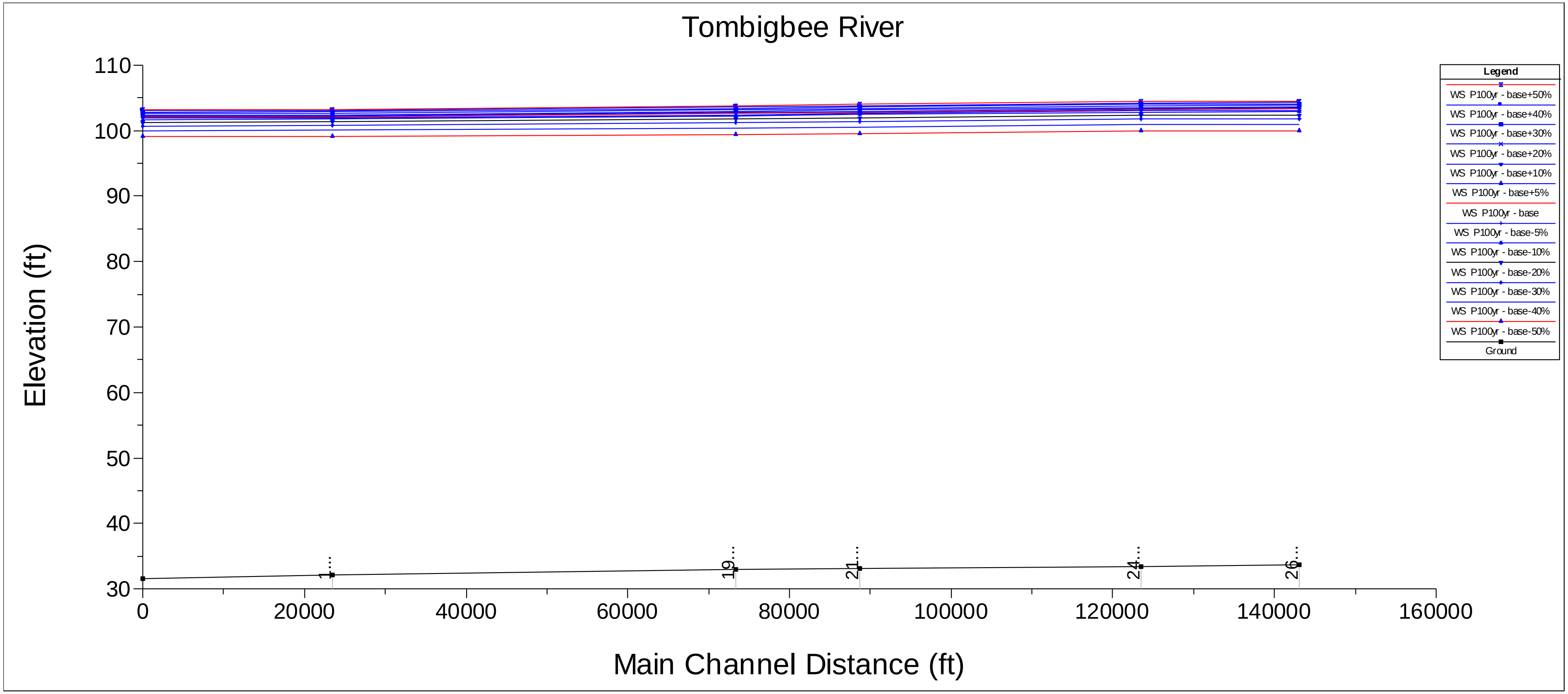
% change in N Value	change in depth Max	Min
-50	-10.42	-1.21
-40	-7.83	-1.21
-30	-5.54	-1.21
-20	-3.49	-0.60
-10	-1.66	-0.25
-5	-0.83	-0.12
5	0.76	0.12
10	1.52	0.25
20	2.90	0.51
30	4.15	0.77
40	5.30	1.03
50	6.35	1.30

Sensitivity of Manning's values for Tombigbee River

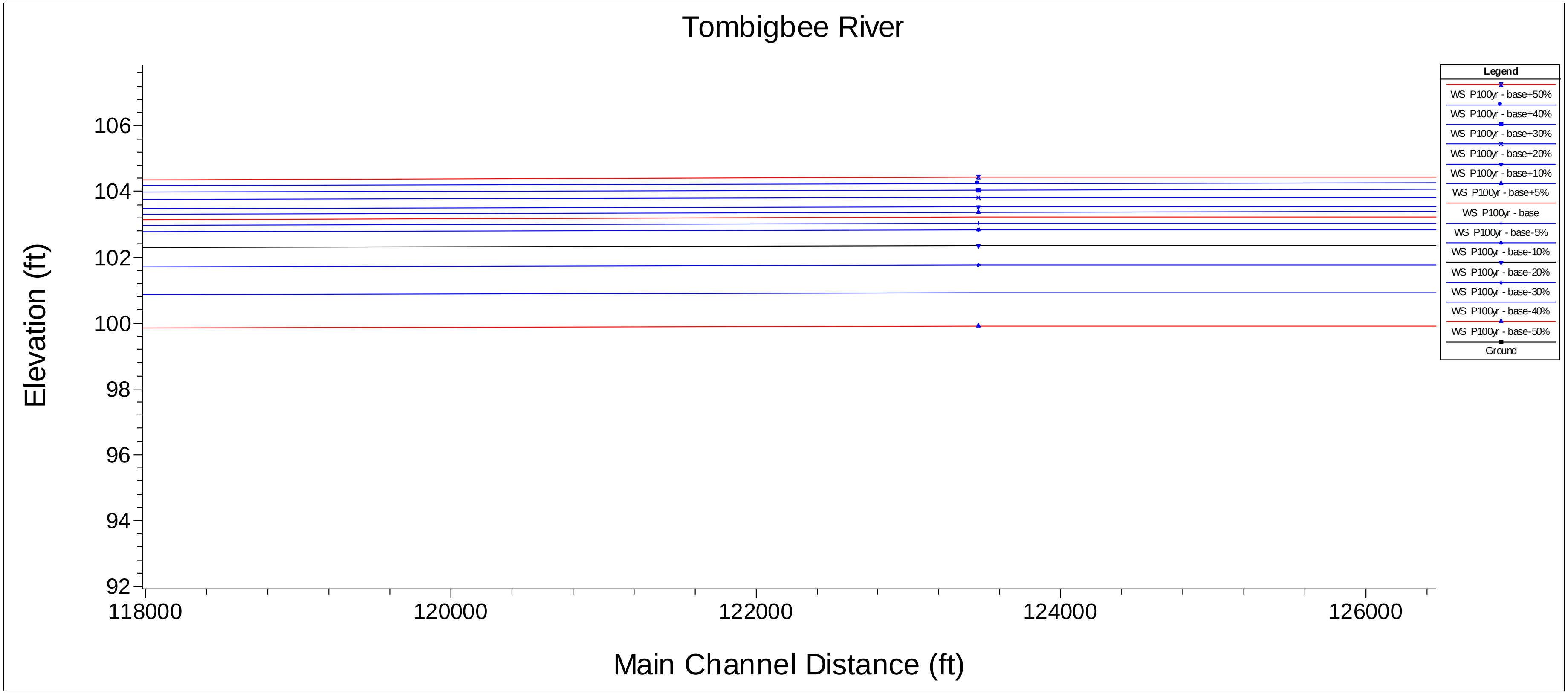
Location:	Washington County, AL
Channel n values:	0.035
Overbank n values:	0.08
Flow Range:	367,000 cfs
Average Slope:	0.00001



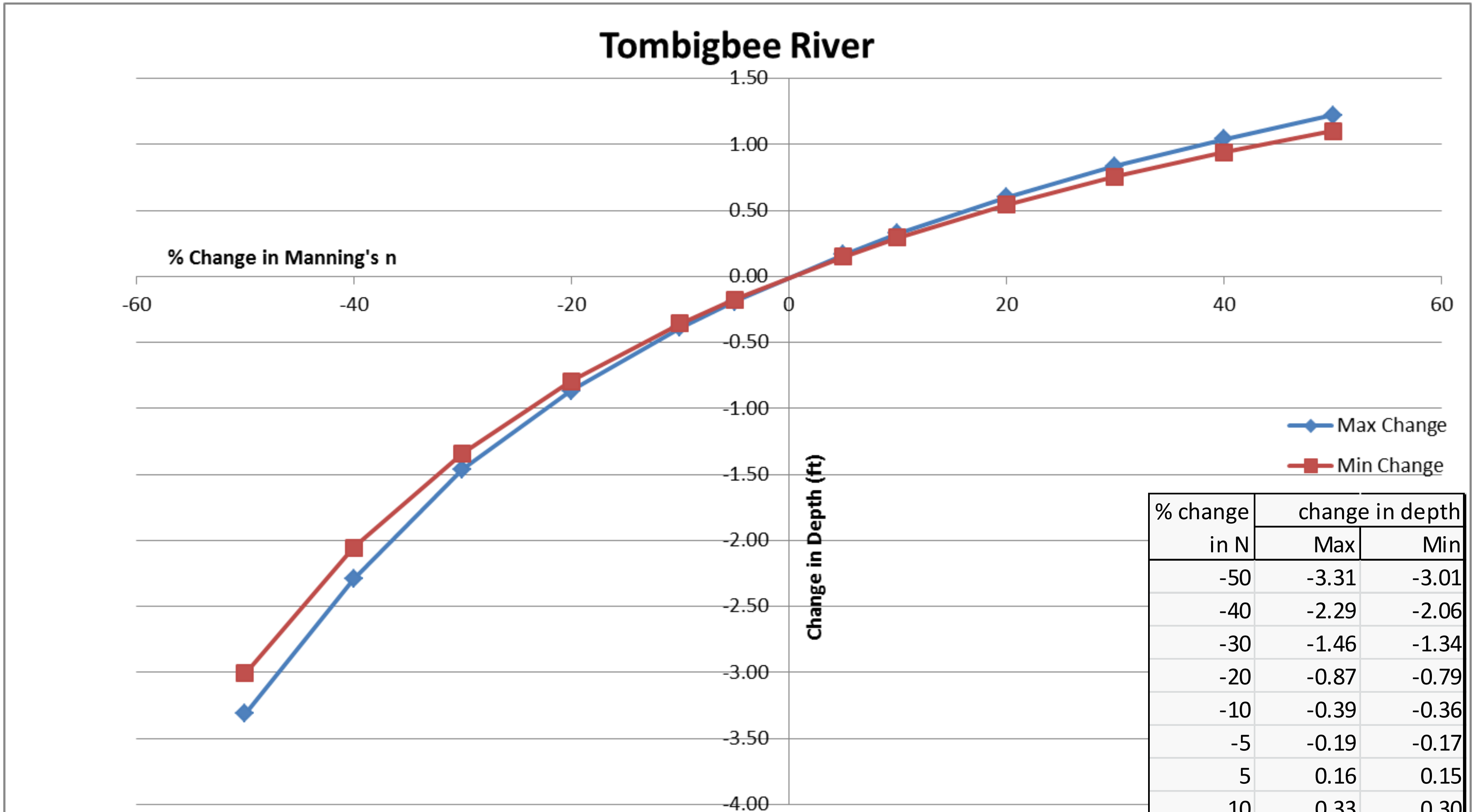
Sensitivity of Manning's values for Tombigbee River (Contd)



Sensitivity of Manning's values for Tombigbee River (Contd)



Sensitivity of Manning's values for Tombigbee River (Contd)



% change in N	change in depth Max	Min
-50	-3.31	-3.01
-40	-2.29	-2.06
-30	-1.46	-1.34
-20	-0.87	-0.79
-10	-0.39	-0.36
-5	-0.19	-0.17
5	0.16	0.15
10	0.33	0.30
20	0.60	0.54
30	0.84	0.76
40	1.04	0.94
50	1.22	1.10

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Summary and Conclusions

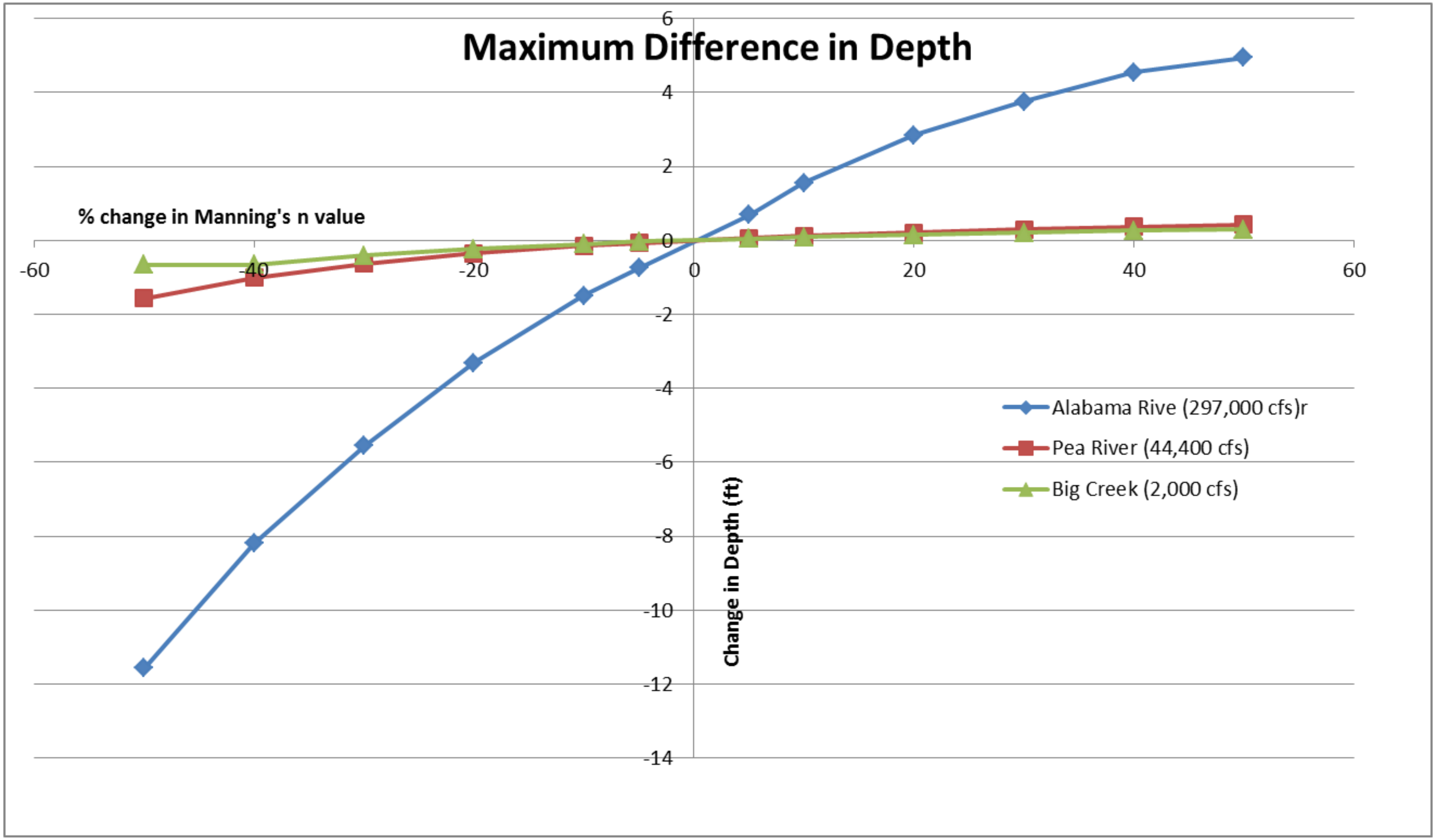
- **The results of sensitivity analyses for Manning's n for various streams sizes, with different discharge rates have been presented.**

- **The roughness coefficient, Manning's n, is highly sensitive for larger stream with discharge rates in the range of 200, 000 CFS+.**

- **The roughness coefficient, Manning's n, is less sensitive in the streams with lower discharge rates.**

- **The roughness coefficient is less sensitive when increasing the n values, and is more sensitive when decreasing the n values in computing the water surface elevations.**

Summary and Conclusions



Summary and Conclusions (contd.)

- **Appropriate selection of Manning's n is very crucial for larger streams, with flow > 200,000+ cfs, as a small change in n values can affect the computed water surface elevations and affect the reasonableness/ accuracy of computed water surface elevations.**
- **The guidelines need to be followed for the proper selection of Manning’s n.**

Guidelines for Selecting Manning’s n

- Selecting Manning’s n value actually means to estimate the resistance to flow, which is really a matter of intangibles.
- Although Tables in the textbook may provide a single value for channel; however, the value of n is variable, and depends on a number of factors.
- Proper determination of the roughness coefficient requires the understanding the factors that affect the values of n.

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Guidelines for Selecting Manning’s n

- **Factors affecting Manning’s n**

(a) Surface Roughness

(b) vegetation

(c) Channel irregularities

(d) Channel Alignment

(e) silting and scouring

(f) obstructions

(g) stage and discharge

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Guidelines for Determining Roughness Coefficient

1. Analytical Method

Cowan (1956) proposed a procedure for estimating Manning's *n* that accounts for various factors that affect the roughness coefficient

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m$$

n_b =a base value of n
n_1 =a correction factor for the effect of surface irregularities
n_2 =a value for variations in shape and size of the channel/flood-plain cross section
n_3 =a value for obstructions
n_4 =a value for vegetation and flow condition
m=a correction factor for sinuosity

Chow (1959)
Engineering Hydraulic Manual (1994) by U.S. Army Corps of Engineers
USGS Water-supply Paper 2339

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Guidelines for Determining Roughness Coefficient (Contd)

2. **Consulting with several available tables:**

   Tabulation of roughness coefficients by Scobey (1933), Chow (1959), Yen (1991)

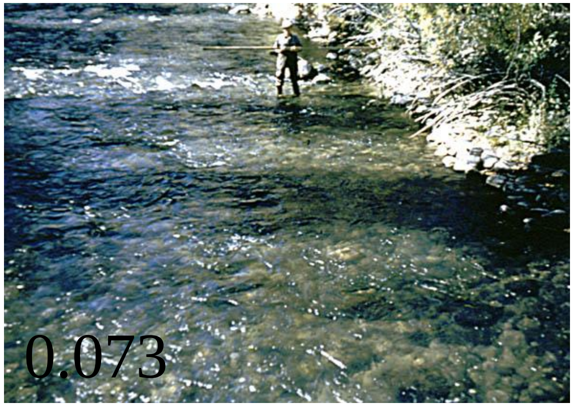
Type of channel and description	Minimum	Normal	Maximum
D. Natural Streams			
D-1. Minor streams (top width at flood stage <100 ft)			
a. Streams on plain			
1. Clean, straight, full stage, no rifts or deep pods	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
D-3. Major streams (top width at flood stage >100 ft). The n value is less than that for minor streams of similar description, because banks offer less effective resistance.			
a. Regular section with no boulders or brush	0.025	.....	0.060
b. Irregular and rough section	0.035	.....	0.100

Guidelines for Determining Roughness Coefficient (Contd)

3. Comparison of photographs

   photographs of channels with determined Manning's n values

   Chow (1959), Barnes (1967), Hicks and Mason (1998), and others

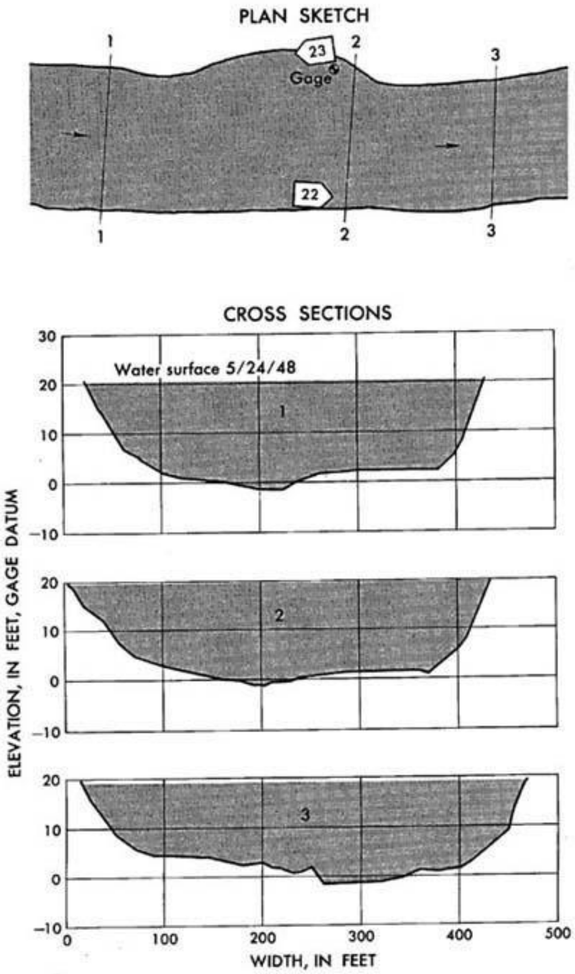


Guidelines for Determining Roughness Coefficient (Contd)

4. Field Measurement

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

With a discharge measurement, known cross-sectional area and slope, n may be back-calculated



5. Calibration

Manning's n values should be calibrated whenever observed water surface profile information (gaged data, or high water marks) is available.

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Questions?

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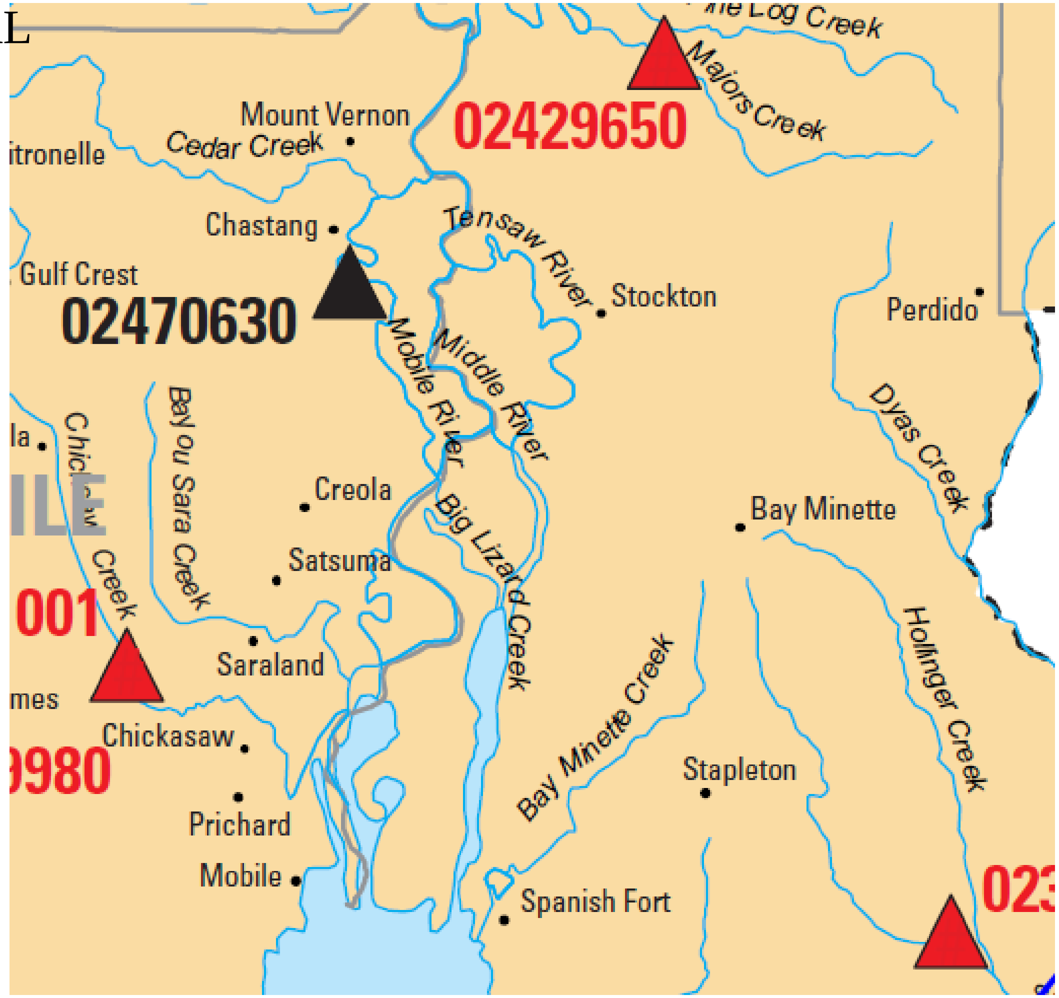
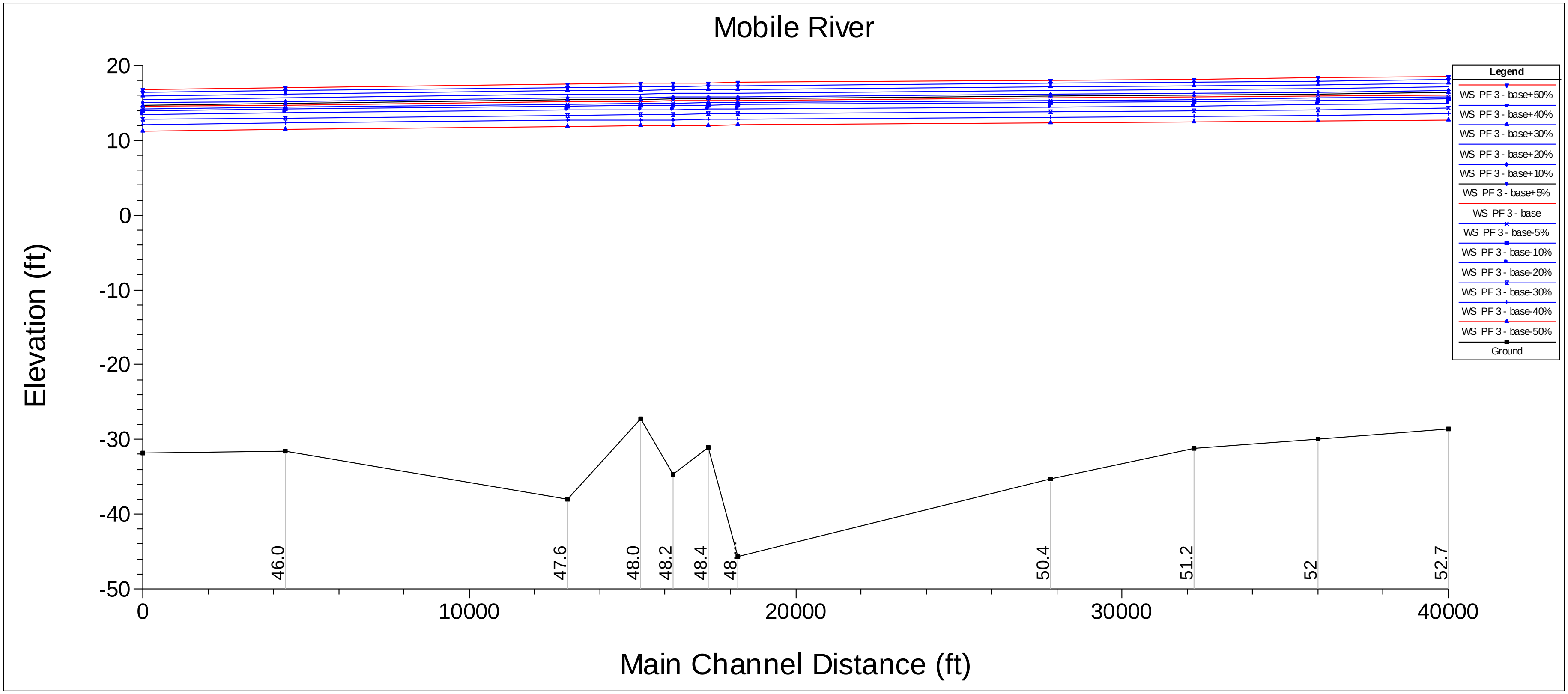
Sensitivity of Manning's values for Mobile River

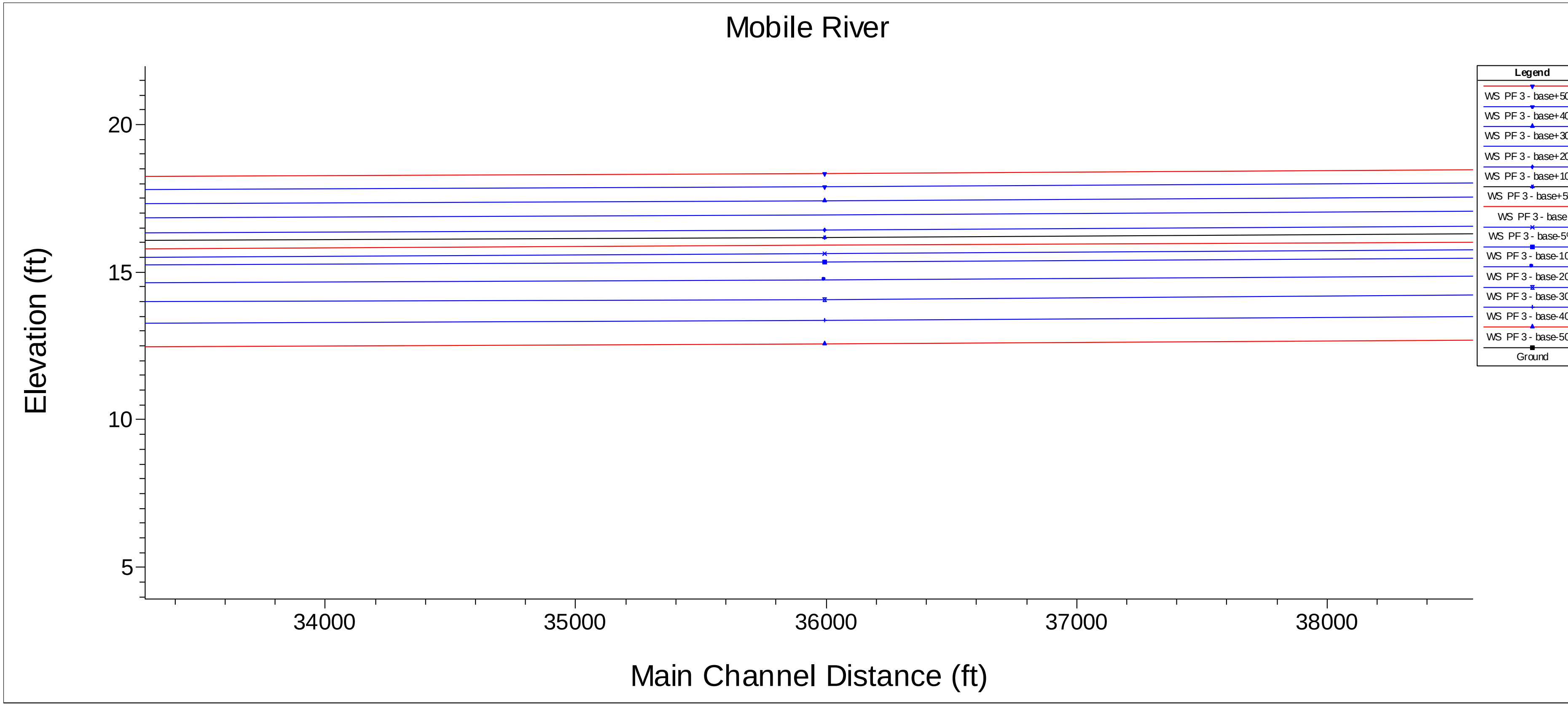
Location : Mobile County, AL
Channel n values: 0.035
Overbank n values : 0.1
Flow Range : 443,552 cfs
Average Slope : 0.00006



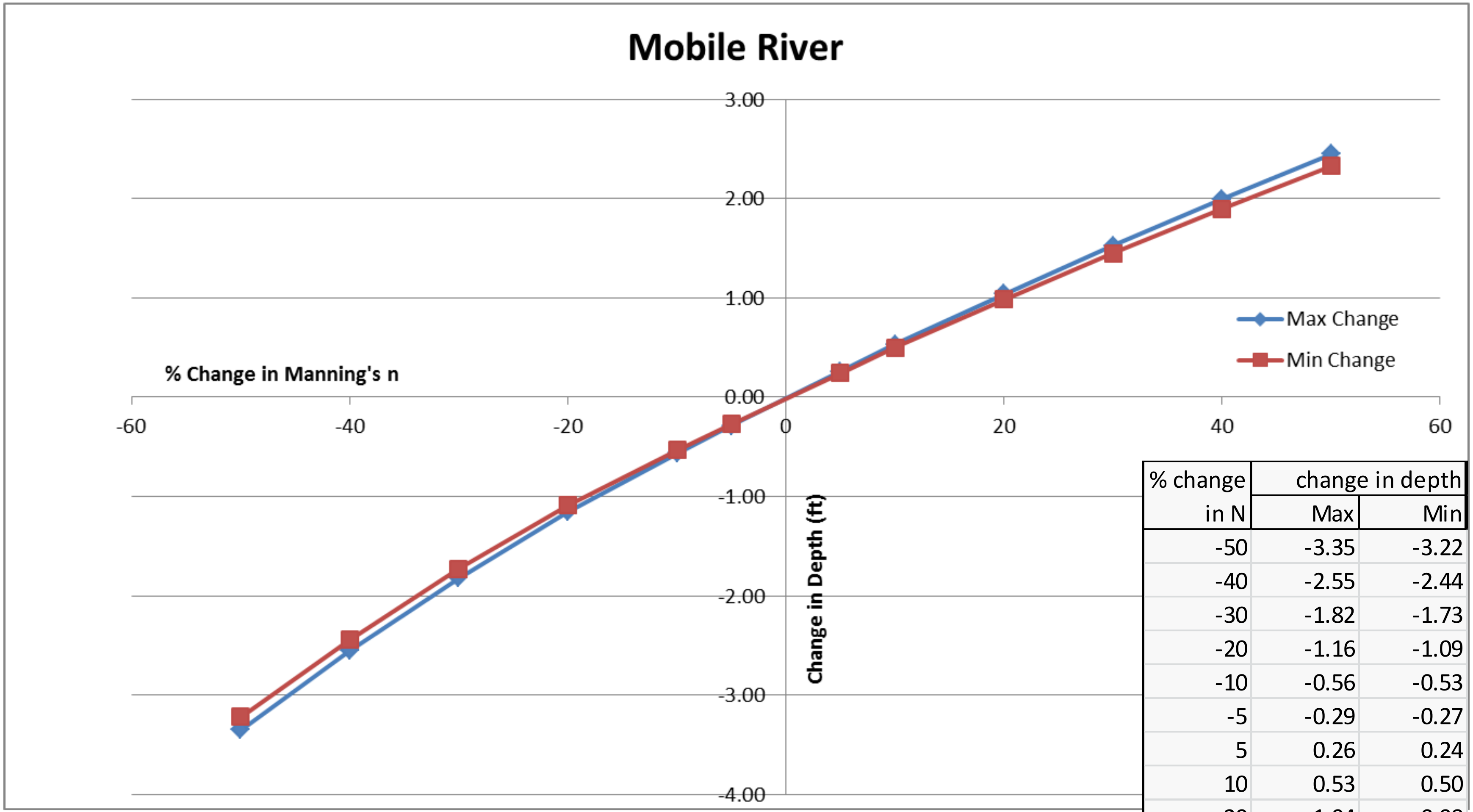
Sensitivity of Manning's values for Mobile River (Contd)



Sensitivity of Manning's values for Mobile River (Contd)



Sensitivity of Manning's values for Mobile River (Contd)



% change in N	change in depth Max	Min
-50	-3.35	-3.22
-40	-2.55	-2.44
-30	-1.82	-1.73
-20	-1.16	-1.09
-10	-0.56	-0.53
-5	-0.29	-0.27
5	0.26	0.24
10	0.53	0.50
20	1.04	0.98
30	1.53	1.45
40	2.00	1.90
50	2.45	2.33