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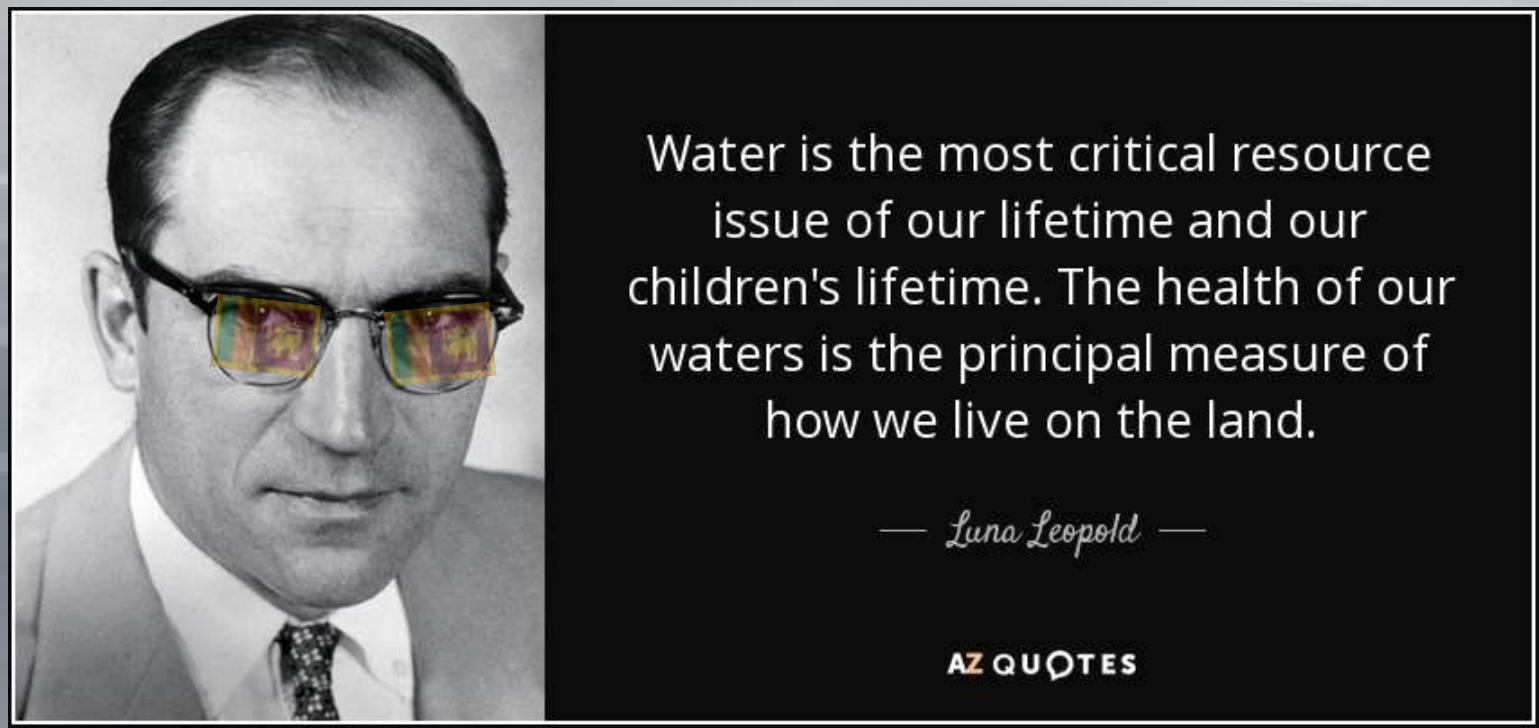
Testing and Evaluating in a Southeast Asian Region with Precipitation Events Outside a Precipitation-Based Regional Curve Model's Typical Rainfall Range

Tuesday August 22nd

4:30pm

Presented By : Imanthie Bandara and David Bidelspach

Basith Weerasundara, Greg Jennings, Mike Geenen, Ryan Baird, Brad Fairley and George Kelly



Water Security - Concerns

- Urbanization
- Terrorism
- Runoff Rates
- Evaporation/Transpiration
- Waste of Agricultural Water
- Drought
- Industrialization
- Earthquakes
- Climate Change

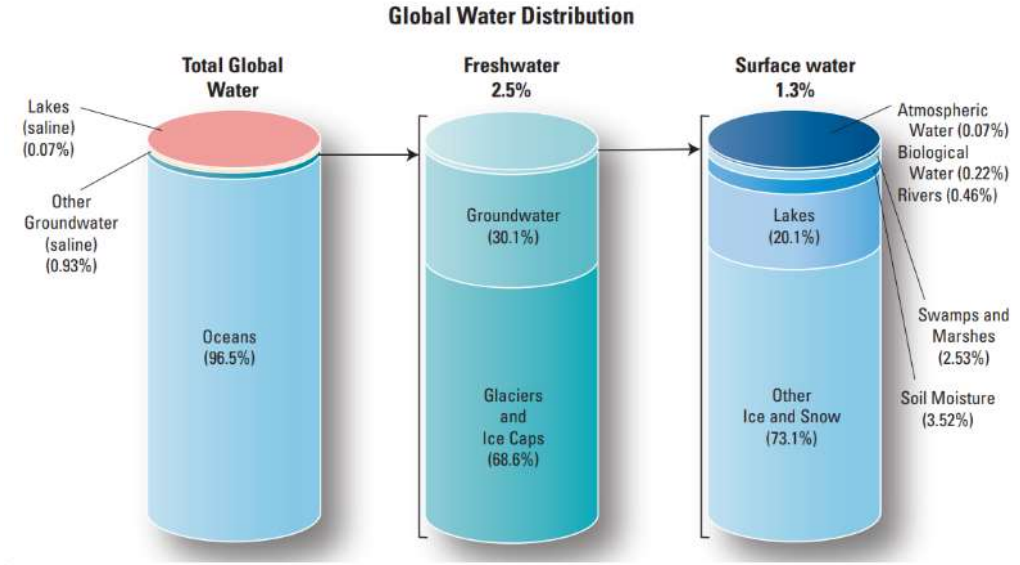


Figure 1. Data taken from United Nations Educational, Scientific, and Cultural Organization, 2006.

- World Bank is aware of the seriousness of water-security issues.
  (Young 2006)

- Since ancient times, limiting access to water has been used as a weapon through the destruction of water resources and distribution facilities

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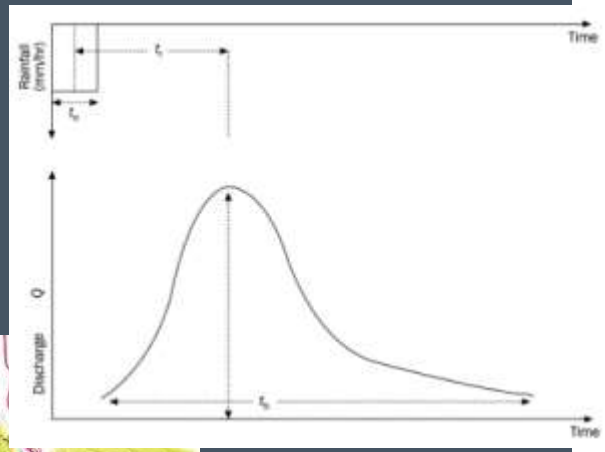
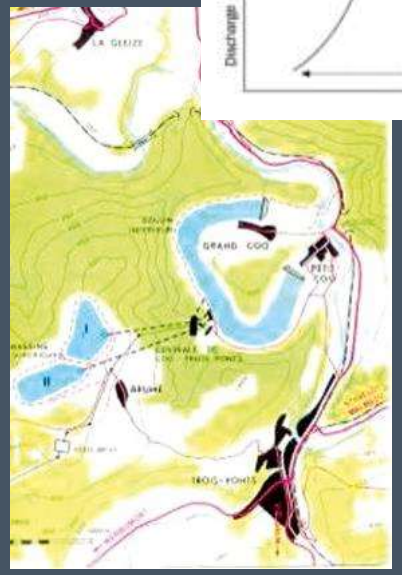
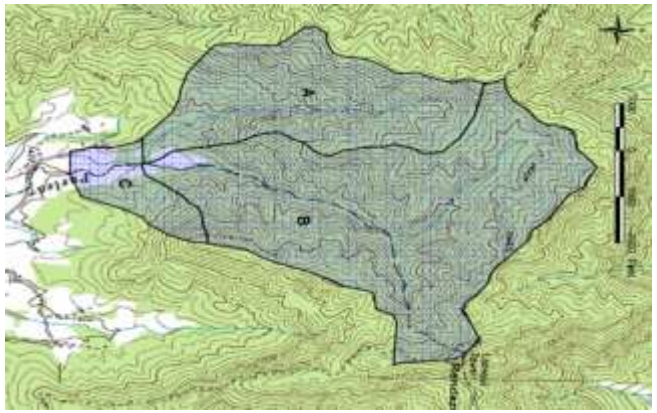
Unit Hydrograph and Water Security

Concerns





- Catchments
- Diversions
- Cross-basin transfers
- Urbanization
- Stormwater BMPS
- Shape of Watersheds
- Characteristics of Watersheds
- Rainfall Intensity
- Rainfall Quantity
- Unknown concerns



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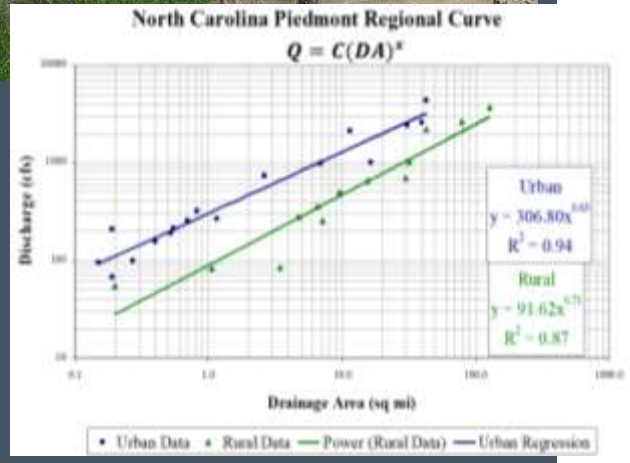
Bankfull Regional Curves
(Hydraulic Geometry Relationships)



- Serves as a “data supported” basis for estimating the bankfull discharge and bankfull channel dimension (cross-sectional area, width and depth) at selected un-gaged sites, with a known watershed or drainage area.

- Bankfull Discharge - Fills a stable channel up to the elevation of the “active” floodplain.

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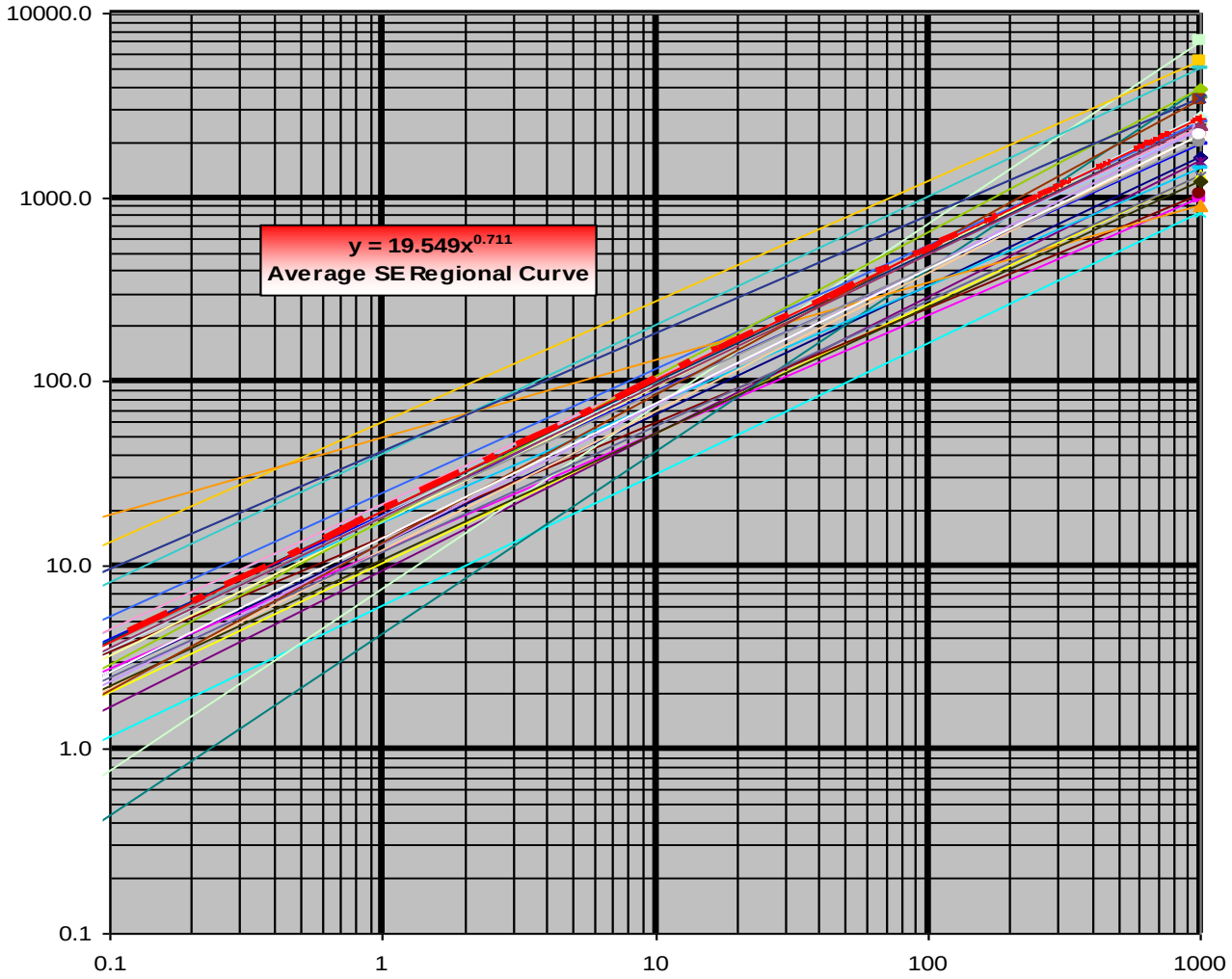
Purpose Bankfull Regional Curves

- Develop a tool to determine “bankfull” stage and discharge in un-gaged watersheds.
  - Bankfull is the surrogate for the full range of flows

    M. Gordon ‘Reds’ Wolman

- Aid in Natural Channel Design.
- Aid in River Stability Assessment
- Can only be used in the same hydro-physiographic province?
- How do we know if a Regional Curve is “Wrong”?



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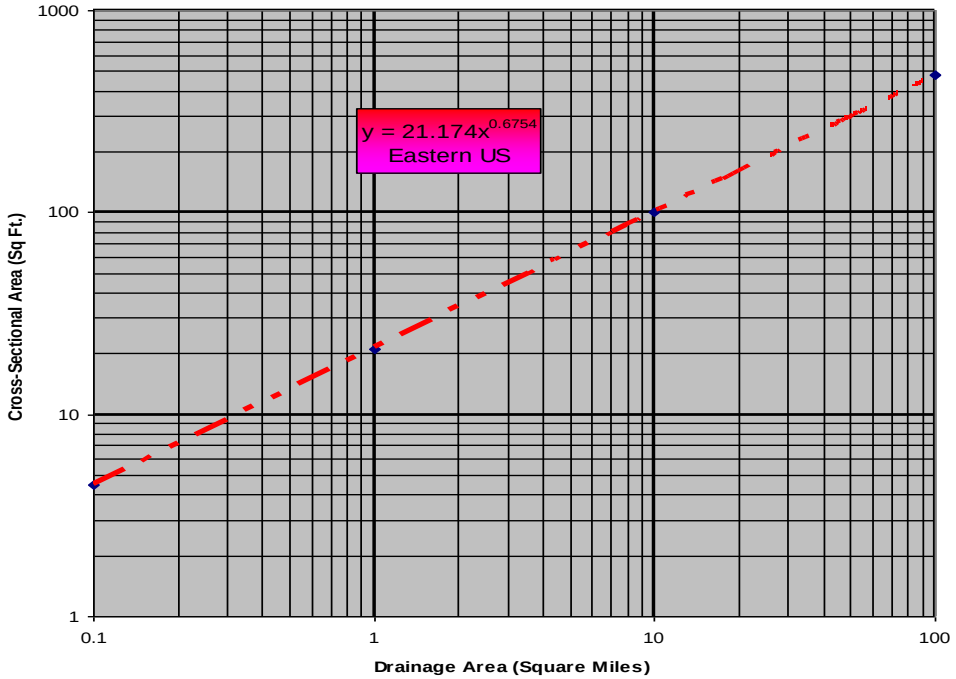
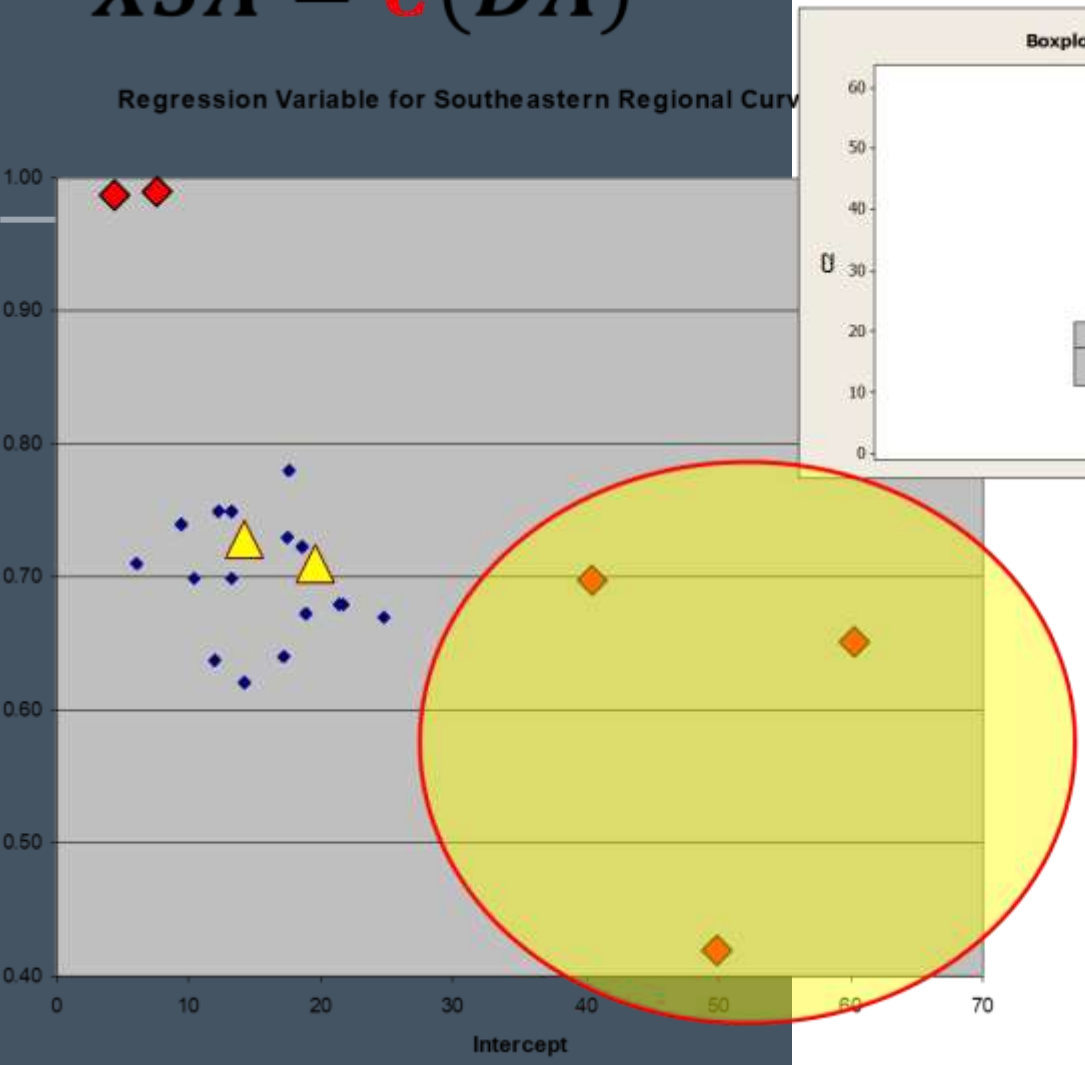
- Greg Jennings
  NCSU 2004

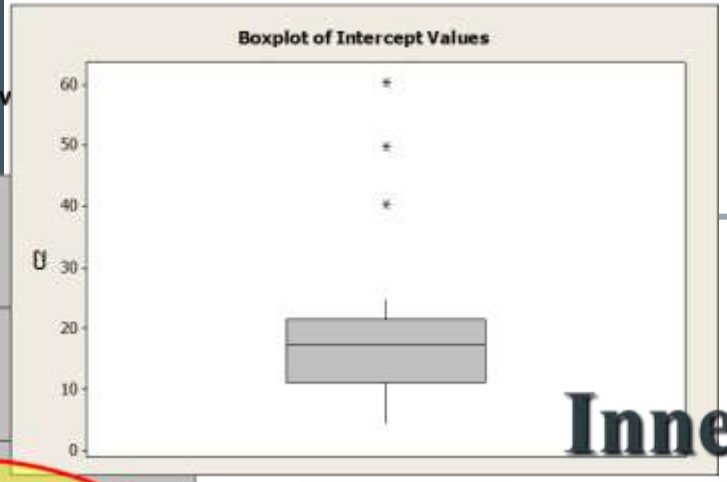
Eastern United States Regional Curve

Dunne and Leopold 1978



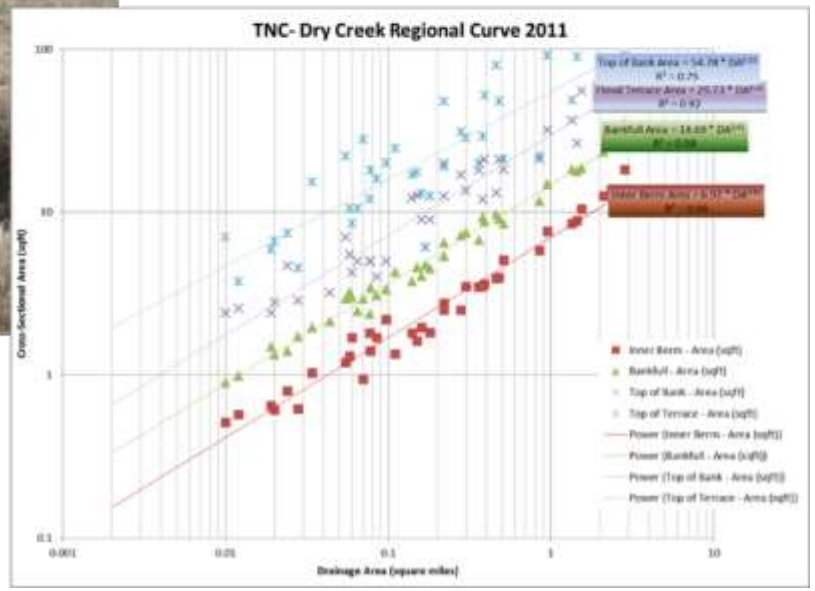
$$XSA = C(DA)^x$$





"C" = Y Intercept

Inner Berm vs. Bankfull



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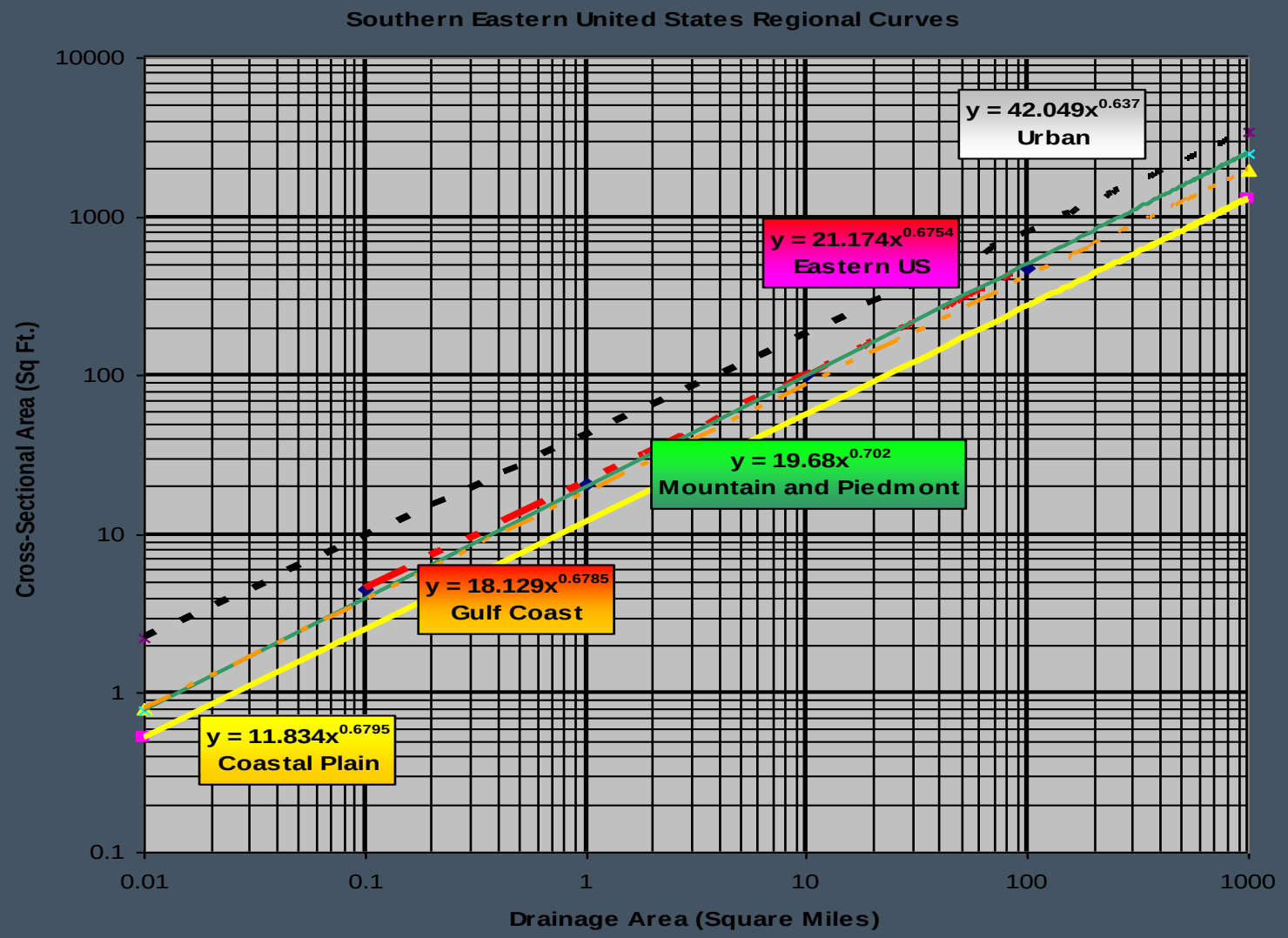
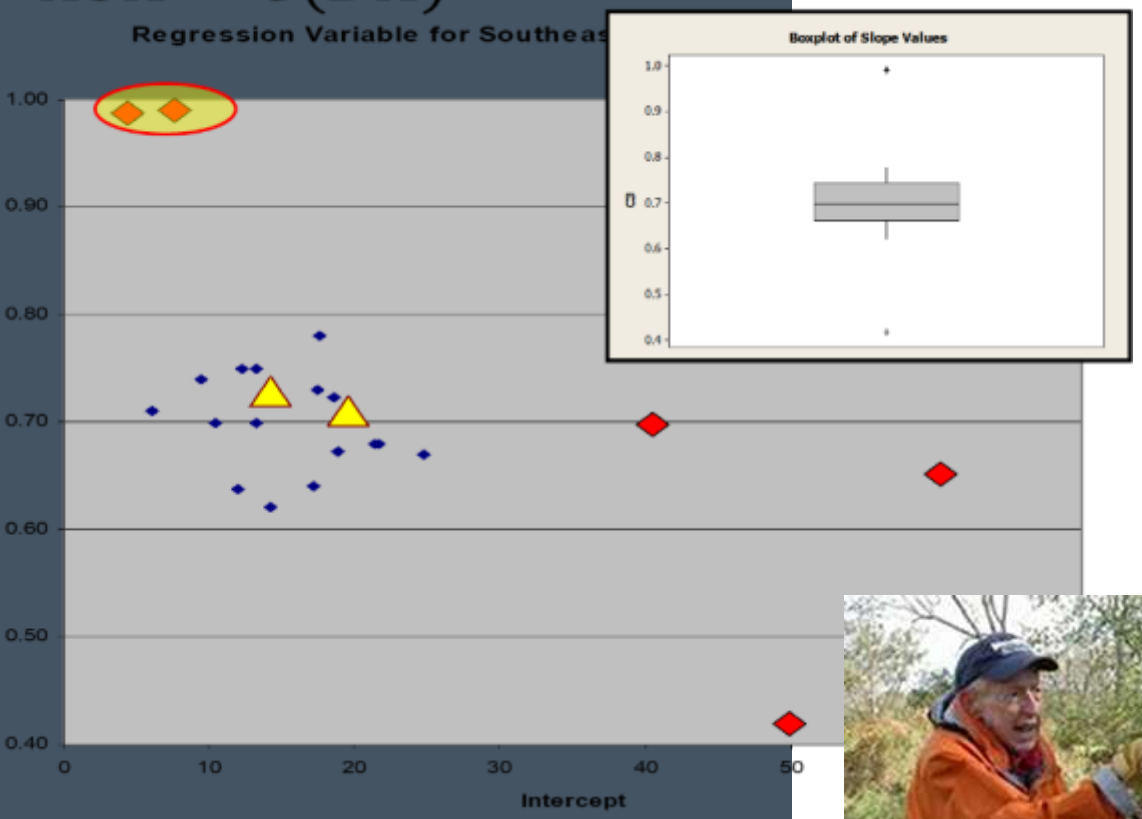
Regional Curve -Regions and Urbanization

- Bankfull can have a high degree of uncertainty
- Inner-Berm and other Geomorphic Features should be separated on curves
- There are multiple geomorphic indicators not just bankfull
- It is ok to not “know bankfull”
  - Know where it is not “BKFH” or “BKFL”



"x" = Power Function Slope

$$XSA = C(DA)^{x}$$



Rural flood recurrence interval (years)	Hydrologic area		
	Blue Ridge-Piedmont	Coastal Plain	Sand Hills
	90 DA $^{0.71}$		
2	135 DA $^{0.702}$	64.7 DA $^{0.673}$	33.5 DA $^{0.712}$
5	242 DA $^{0.677}$	129 DA $^{0.635}$	55.5 DA $^{0.701}$
10	334 DA $^{0.662}$	188 DA $^{0.615}$	72.9 DA $^{0.697}$
25	476 DA $^{0.645}$	281 DA $^{0.593}$	98.1 DA $^{0.693}$
50	602 DA $^{0.635}$	367 DA $^{0.579}$	120 DA $^{0.691}$
100	745 DA $^{0.625}$	468 DA $^{0.566}$	143 DA $^{0.688}$
200	908 DA $^{0.616}$	586 DA $^{0.554}$	170 DA $^{0.686}$
500	1,160 DA $^{0.605}$	773 DA $^{0.539}$	210 DA $^{0.684}$

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Regional Curve
- Constant Slopes x = 0.68

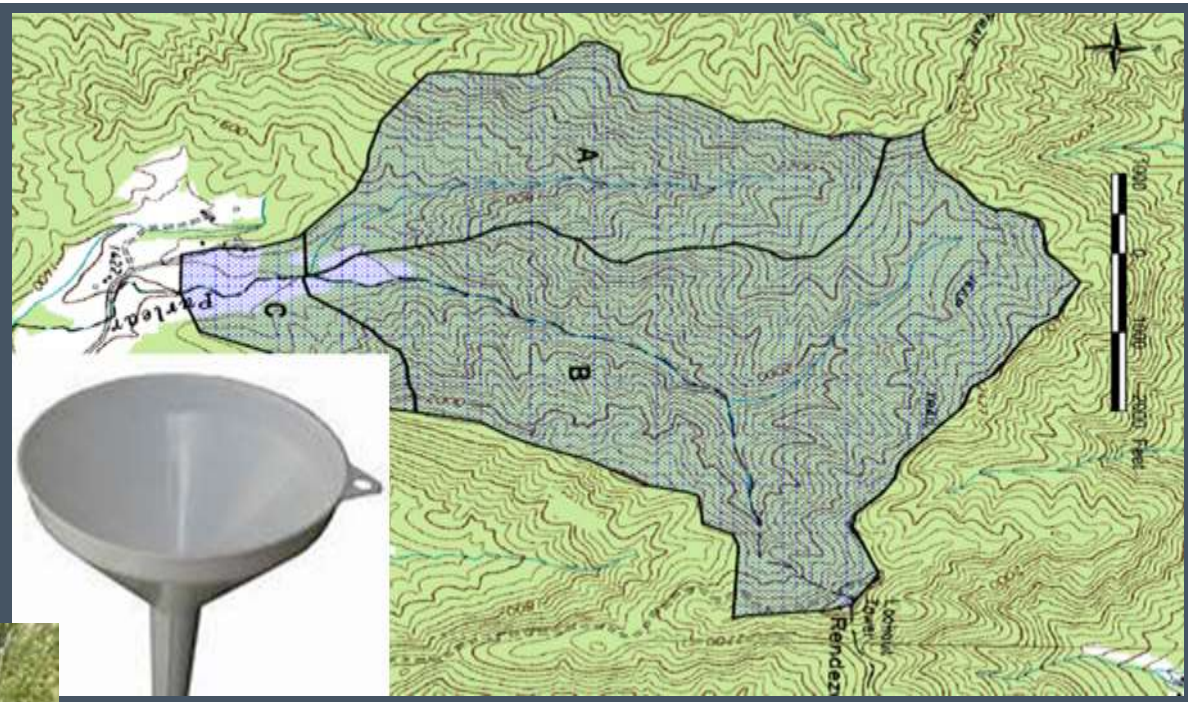
- Time of Concentration
- Rainfall and runoff amounts
- Lag-times, in-phase
- Watersheds can't have a linear Regression Slope

- Average Regression Slope ~0.68 Range 95% (0.61 – 0.76)

- Localized mini-regional curves can be used for design purposes

- Local data (upstream, downstream, nearby streams) are always essential to add confidence to predictive relationships developed elsewhere.

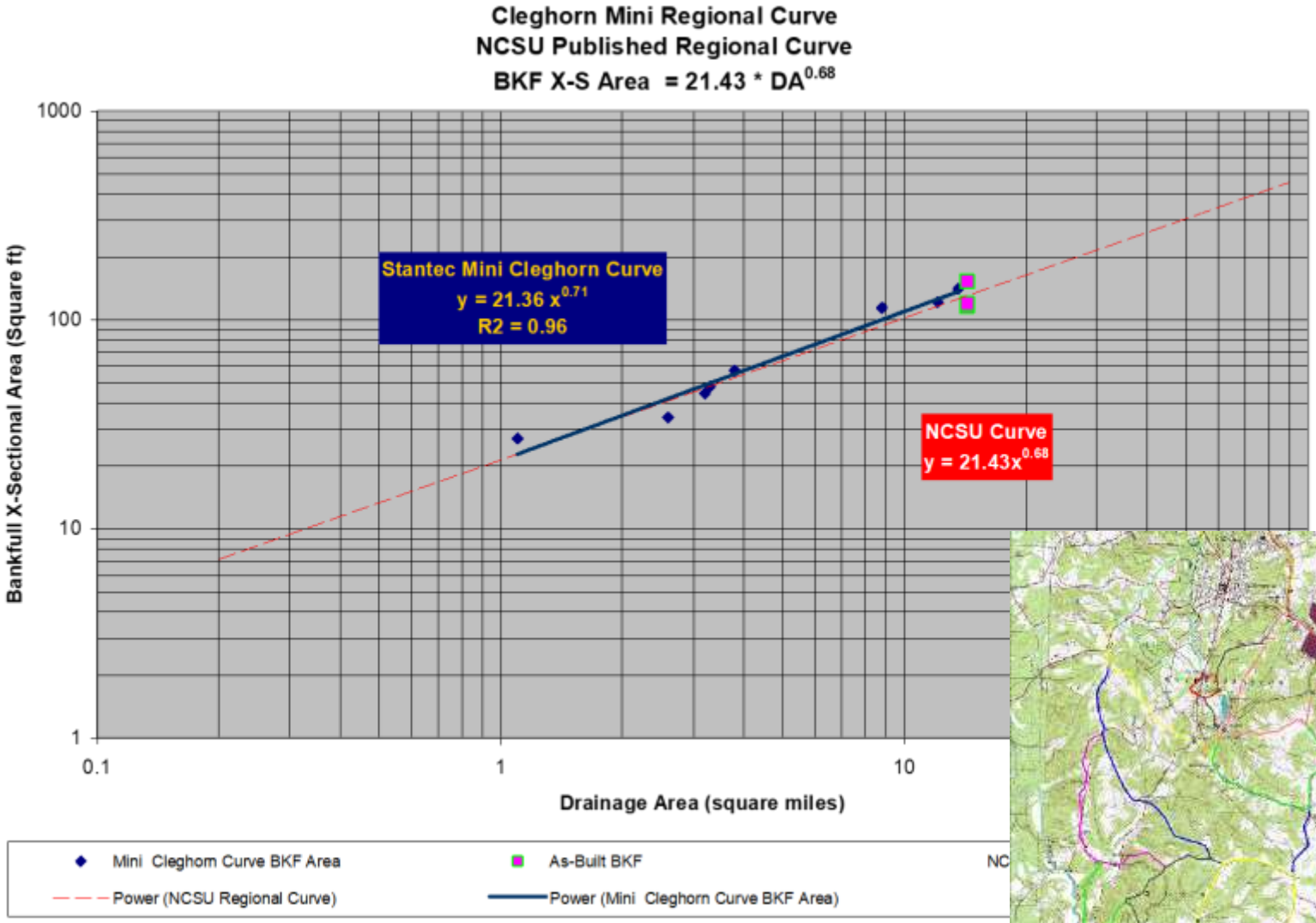
- It is ok to not "know bankfull"



Use Mini-Regional Curves

Without or Without Gages

- Bankfull stage can not always be identified (Local data is useful)
- Use as a tool to determine a design bankfull dimension
- Bankfull dimensions do not always match the local regional relationship



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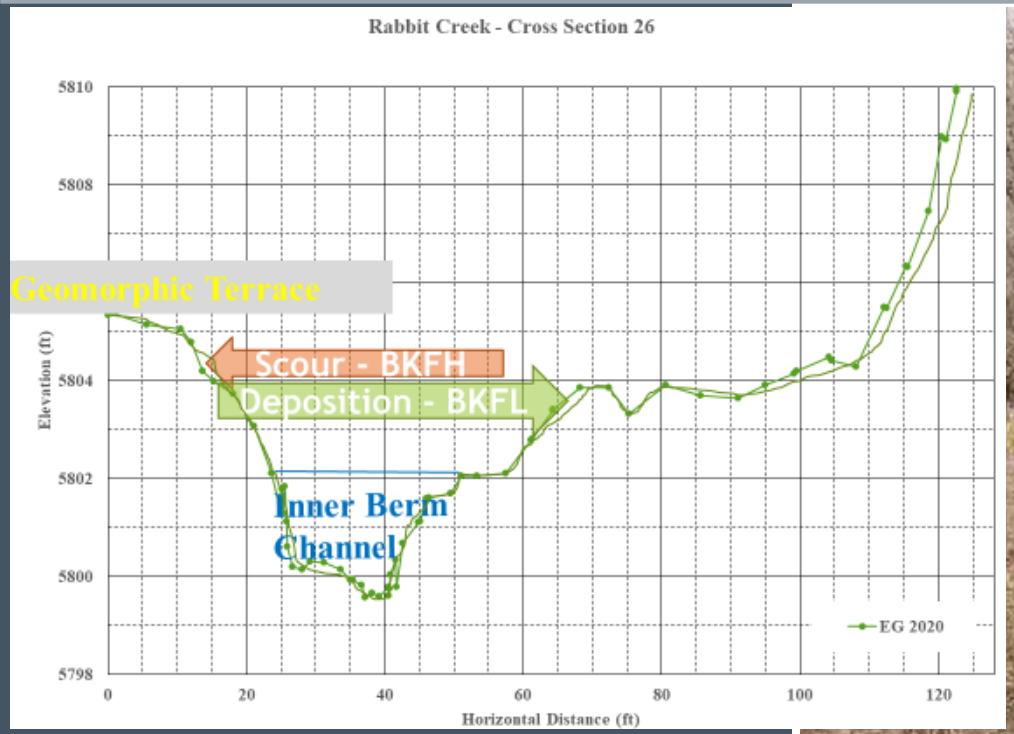
Mini- Regional Curves

– When you don't know bankfull



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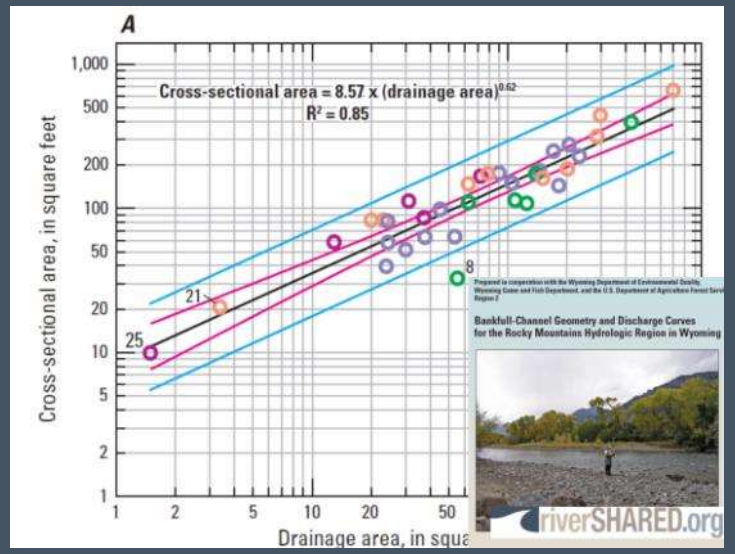
Comparison of Mini-Curves

-to Published Data



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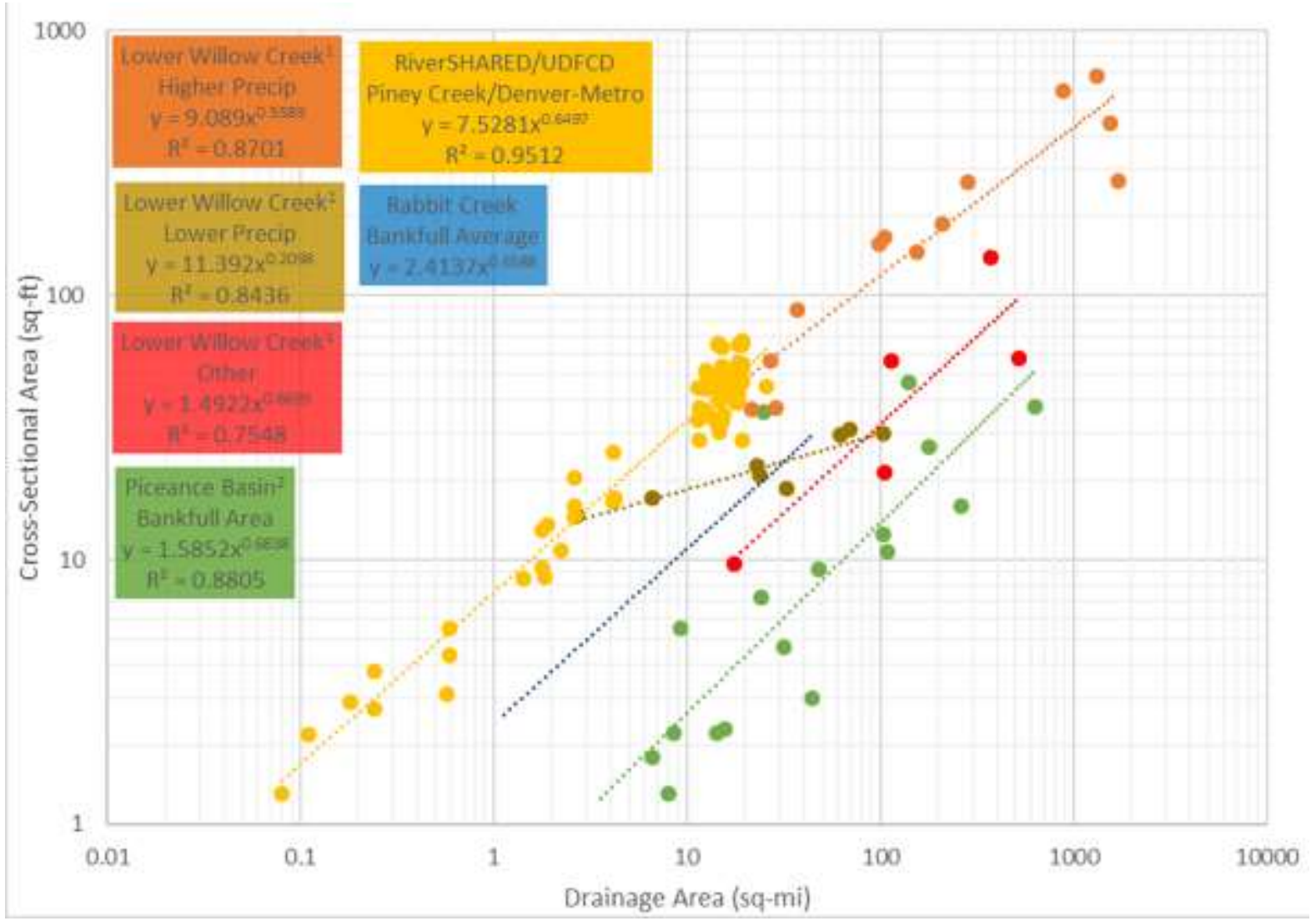
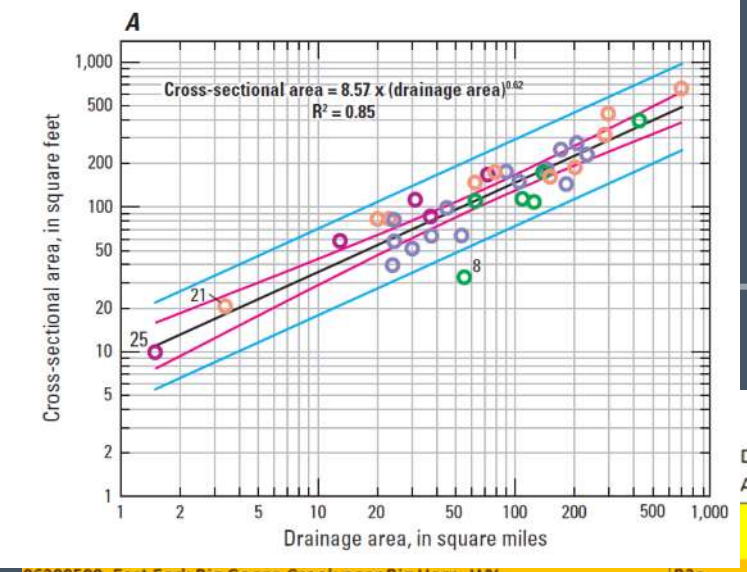


Watershed Response Factor – "C"

- Wyoming Regional Curve – USGS -2012



			Drainage Area (sq mi)		C_2	Original XS Area	C_1	Discharge (cfs)	Mean Annual Precipitation (in)	Velocity (ft/s)	XS Area (sq ft)	Width (ft)	Depth (ft)	BKF WS Slope (ft/ft)	Return Interval (RI)	Exceedence Probability (%)	Log DA	Log Q	Log XS Area	Log Width	Log Depth
			3	2.1	8.2	21.7	10.4	66	30.7	3.04	17.17	17.67	1.31	0.00056	1.4	73.7	0.477121	1.819544	1.23477	1.247237	0.117271
			13	5.6	8.1	66.6	11.9	287	48.6	4.31	45.10	30.67	2.18	0.03363	1.8	57.1	1.113943	2.457882	1.654177	1.486714	0.338456
06300500	East Fork Big Goose Creek near Big Horn, WY	B3c	20	7.4	10.5	92.6	12.4	393	31.2	4.23	78.00	38.76	2.41	0.01373	1.3	76	1.30103	2.594393	1.892095	1.588384	0.382017
06278300	Shell Creek above Shell Creek Reservoir, WY	C4	23	8.2	10.4	111.4	13.6	358	31.9	3.21	84.80	52.0	2.2	0.00191	1.0	98.1	1.361728	2.553883	1.928396	1.715836	0.334454
06301500	West Fork Big Goose Creek near Big Horn, WY	B3	24	8.4	9.6	98.4	11.7	360	29.7	3.66	81.10	58.12	1.69	0.01972	1.3	80	1.380211	2.556303	1.909021	1.764326	0.227887
06311000	North Fork Powder River near Hazelton, WY	B3c	25	8.6	7.6	58.4	6.8	260	25.4	4.69	65.45	37.23	1.6	0.01134	1.6	61.5	1.39794	2.414973	1.81591	1.570893	0.20412
06222700	Crow Creek near Tipperary, WY	C3	30	9.8	8.4	55.4	5.7	241	25.8	3.99	81.6	31.3	1.77	0.013	1.5	75.8	1.477121	2.382017	1.91169	1.495544	0.247973
06622700	North Brush Creek near Saratoga, WY	B3	37	11.2	9.5	106.2	9.5	555	35.9	5.22	106.23	44.47	2.39	0.0209	1.7	59.6	1.568202	2.744293	2.026247	1.648067	0.378398
06299500	Wolf Creek at Wolf, WY	B3	38	11.4	9.3	51.0	4.5	190	24.6	4.07	106.75	30.16	1.69	0.02422	1.3	76.2	1.579784	2.278754	2.028368	1.479431	0.227887
06309200	Middle Fork Powder River near Barnum, WY	B3	45	12.8	8.1	81.6	6.4	394	25.3	4.83	103.9	36.89	2.21	0.02346	1.3	76	1.653213	2.595496	2.016616	1.566909	0.344392
06222500	Dry Creek near Burris, WY	B3	54	14.5	8.0	67.1	4.6	348	26.7	5.18	115.25	59.34	1.19	0.02953	1.8	59	1.732394	2.541579	2.061641	1.773348	0.075547
06223500	Willow Creek near Crowheart, WY	B3c	55	14.7	5.3	39.9	2.7	137	20.5	3.44	77.1	34.44	1.18	0.01428	1.3	76.3	1.740363	2.136721	1.887054	1.537063	0.071882
06632400	Rock Creek above King Canyon Canal near Arlington, WY	B3	63	16.1	8.7	186.0	11.6	1030	34.9	5.54	139.3	54.78	3.4	0.00669	1.7	58.9	1.799341	3.012837	2.143951	1.738622	0.531479
06647500	Box Elder Creek at Boxelder, WY	B3c	63	16.1	9.0	98.5	6.1	392	24.2	3.98	144.8	44.08	2.15	0.01073	1.5	65.4	1.799341	2.593286	2.160769	1.644242	0.332438
06623800	Encampment River above Hog Park Creek near Encampment, WY	B3c	73	17.7	9.0	166.8	9.4	838	45.1	5.02	159.95	58.5	2.87	0.01353	1.4	72.3	1.863323	2.923244	2.203984	1.767156	0.457882
09203000	East Fork River near Big Sandy, WY	B3c	79	18.7	8.9	258.7	13.8	1068	30.4	4.13	165.4	97.81	2.7	0.00351	1.3	75	1.897627	3.028571	2.218536	1.990383	0.431364
06265337	Cottonwood Cr at High Island Ranch nr Hamilton Dome	B4c	81	19.0	5.2	39.3	2.1	231	16.9	5.82	99.2	29.51	1.41	0.00734	1.5	68.4	1.908485	2.363612	1.996512	1.469969	0.149219
06260000	South Fork Owl Creek near Anchor, WY	B3c	87	19.9	3.2	63.8	3.2	323	21.5	5.07	63.77	43.38	1.54	0.01509	1.3	74.4	1.939519	2.509203	1.804616	1.63729	0.187521
06228350	South Fork Little Wind River above Reservoir near Ft Washakie,	B4c	90	20.4	8.6	346.0	17.0	955	29.9	2.76	174.7	132.28	2.82	0.00012	1.6	62.5	1.954243	2.980003	2.242293	2.121494	0.450249
06233000	Little Popo Agie River near Lander, WY	B3c	125	25.4	6.1	95.0	3.7	480	22.1	5.06	154.35	47.86	1.98	0.00381	1.5	67.1	2.09691	2.681241	2.188507	1.679973	0.296665
06646000	Deer Creek in Canyon near Glenrock, WY	B3c	139	27.3	8.9	152.7	5.6	698	22.8	4.57	243.05	64.01	2.42	0.01862	2.0	50	2.143015	2.843855	2.385696	1.806248	0.383815
06218500	Wind River near Dubois, WY	B3c	232	38.4	7.2	212.5	5.5	1000	28.3	4.67	277.2	71.65	3	0.0053	1.5	64.9	2.365488	3	2.442793	1.855216	0.477121
06280300	South Fork Shoshone River near Valley, WY	B3c	297	45.4	8.2	371.2	8.2	3400	32.6	8.2	371.21	126.38	2.94	0.00474	1.5	68.5	2.472756	3.531479	2.56962	2.101678	0.468347
06220500	East Fork Wind River near Dubois, WY	C3	427	57.9	8.2	347.8	6.0	2542	24.8	7.31	472.8	152.45	2.29	0.0061	1.4	71.9	2.630428	3.405176	2.674677	2.183127	0.359835
06279940	North Fork Shoshone River at Wapiti, WY	F3	699	80.5	8.1	669.1	8.3	5955	30.8	8.9	654.7	158.51	4.23	0.00688	1.8	54.5	2.844477	3.774882	2.816042	2.200057	0.62634

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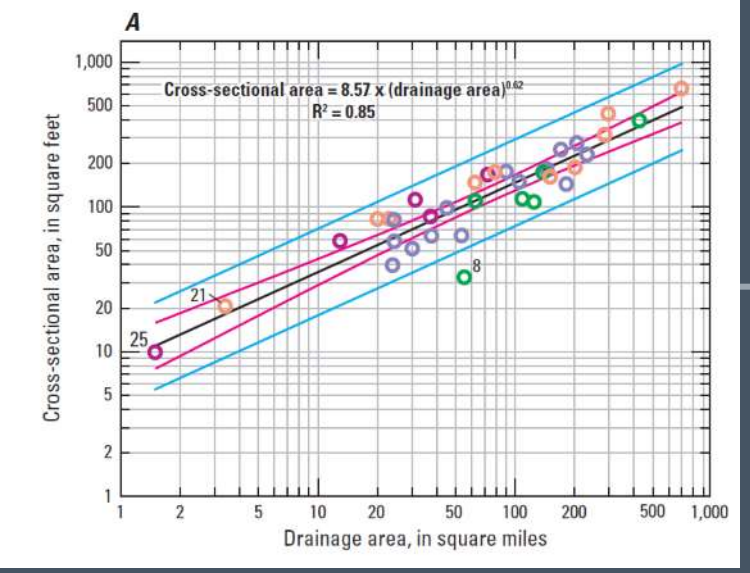
$$\text{"C"} = A_{BKF} / DA^{0.68}$$

Watershed Response Factor – "C"

- Wyoming Regional Curve – USGS - 2012



- Geomorphic Assessment
  - Departure analysis
  - Watershed health

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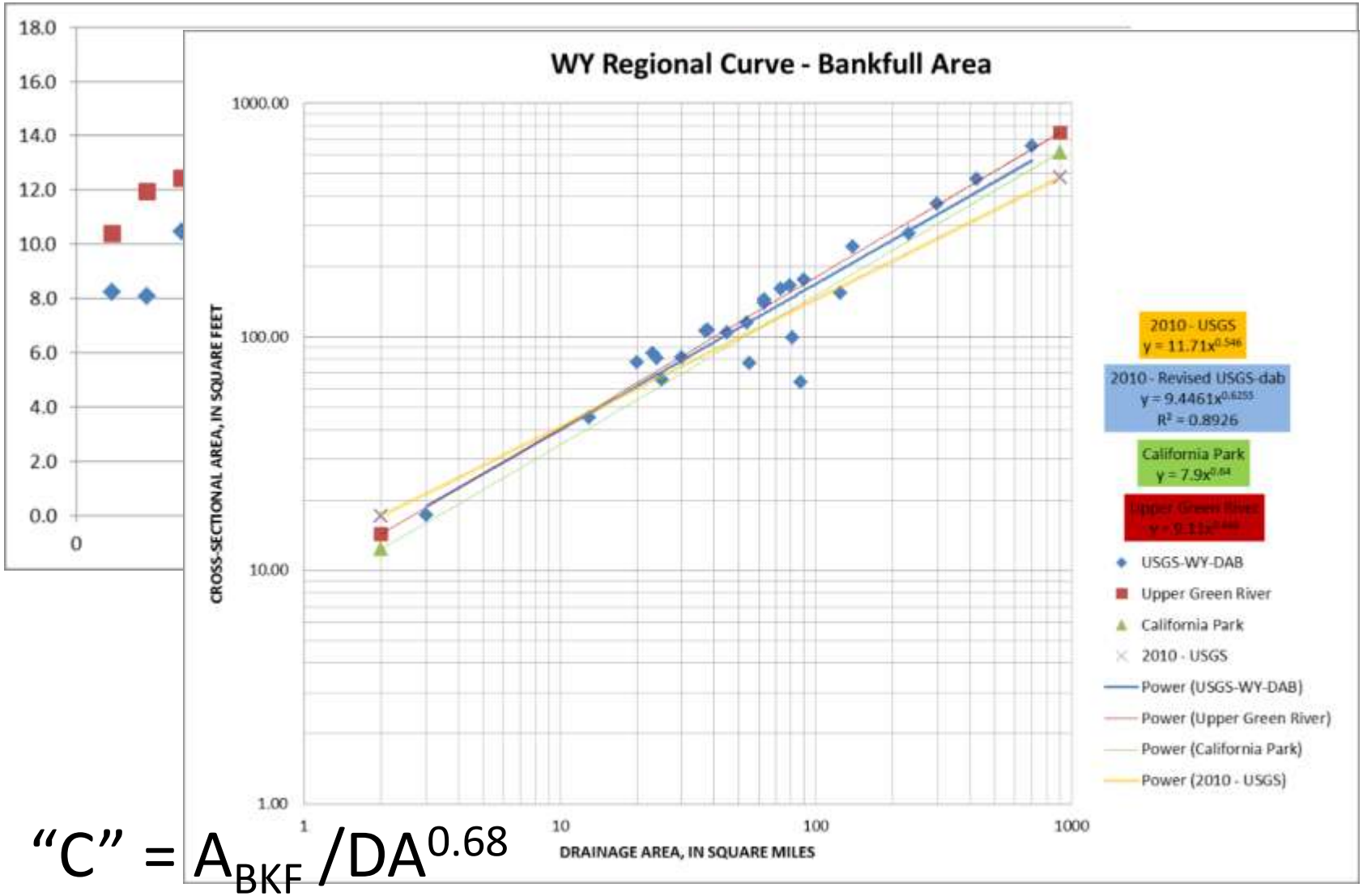

$$\text{"C"} = A_{BKF} / DA^{0.68}$$

“C” = A_{BKF} /$DA^{0.68}$

Ryan Baird – Spring 2022

Dr. Peter Nelson – CSU Department of Civil and Environmental Engineering

Figure 1. Physiographic Map of the United States (Fenneman and Johnson 1946)

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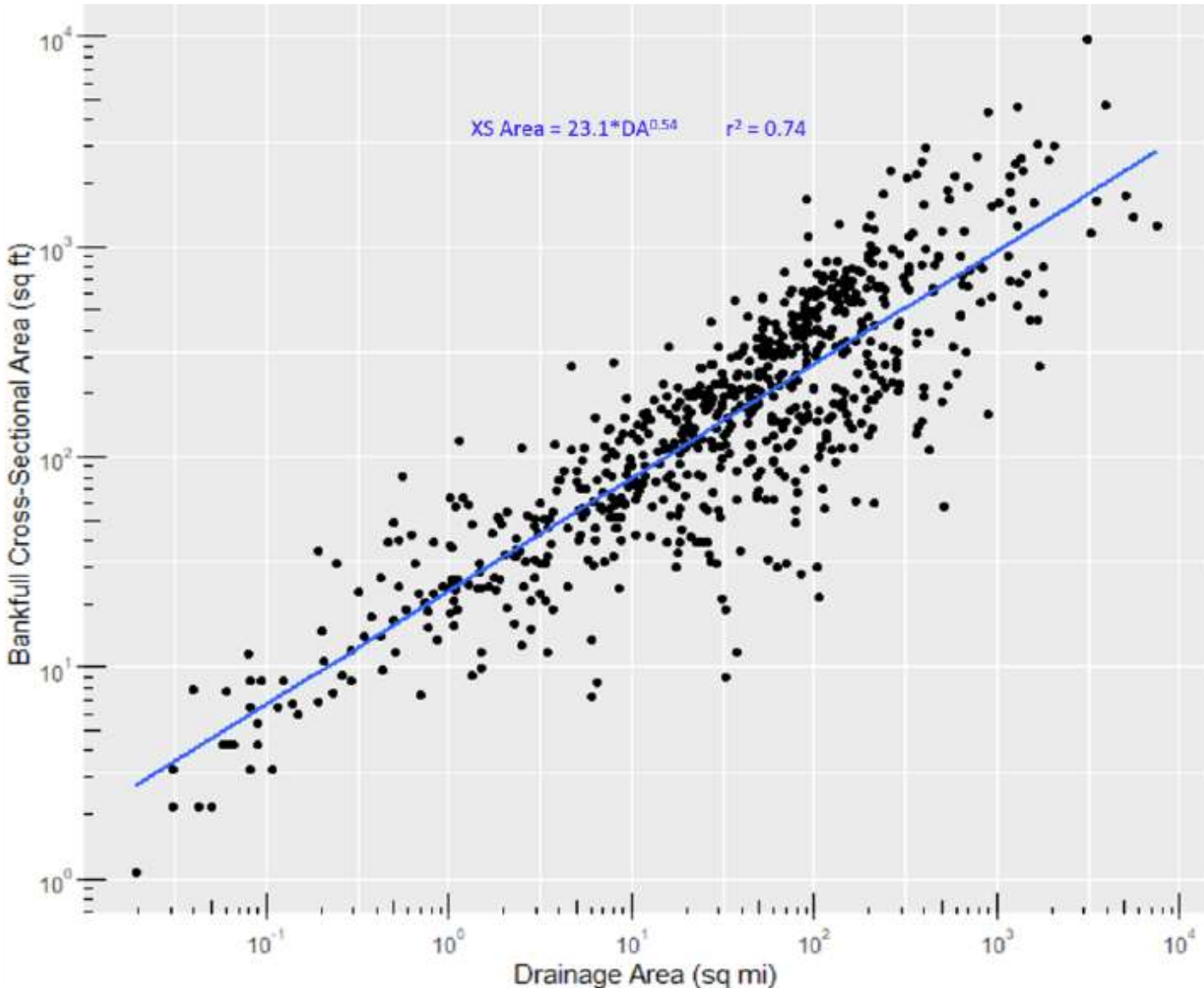
Number	Curve ID	
1	AL_1	(Bran
2	AL_2	(Bran
3	AL_3	(Met
4	AR_1	(Pugh
5	AZ_1	(Moc
6	CO_1	(Ellio
7	CO_2a	(Yoch
8	CO_2b	(Yoch
9	CO_2c	(Yoch
10	FL_1	(Met
11	FL_2	(Met
12	FL_3a	(Met
13	FL_3b	(Met
14	ID_1	(Cast
15	ID_2	(Emn
16	IN_1a	(Robi
17	IN_1b	(Robi
18	IN_1c	(Robi
19	MA_1	(Bent
20	MD_1	(McC
21	MD_2	(McC
22	MD_3	(McC
23	MD_4	(Krst
24	MI_1	(Rach



“C” = A_{BKF} /$DA^{0.68}$

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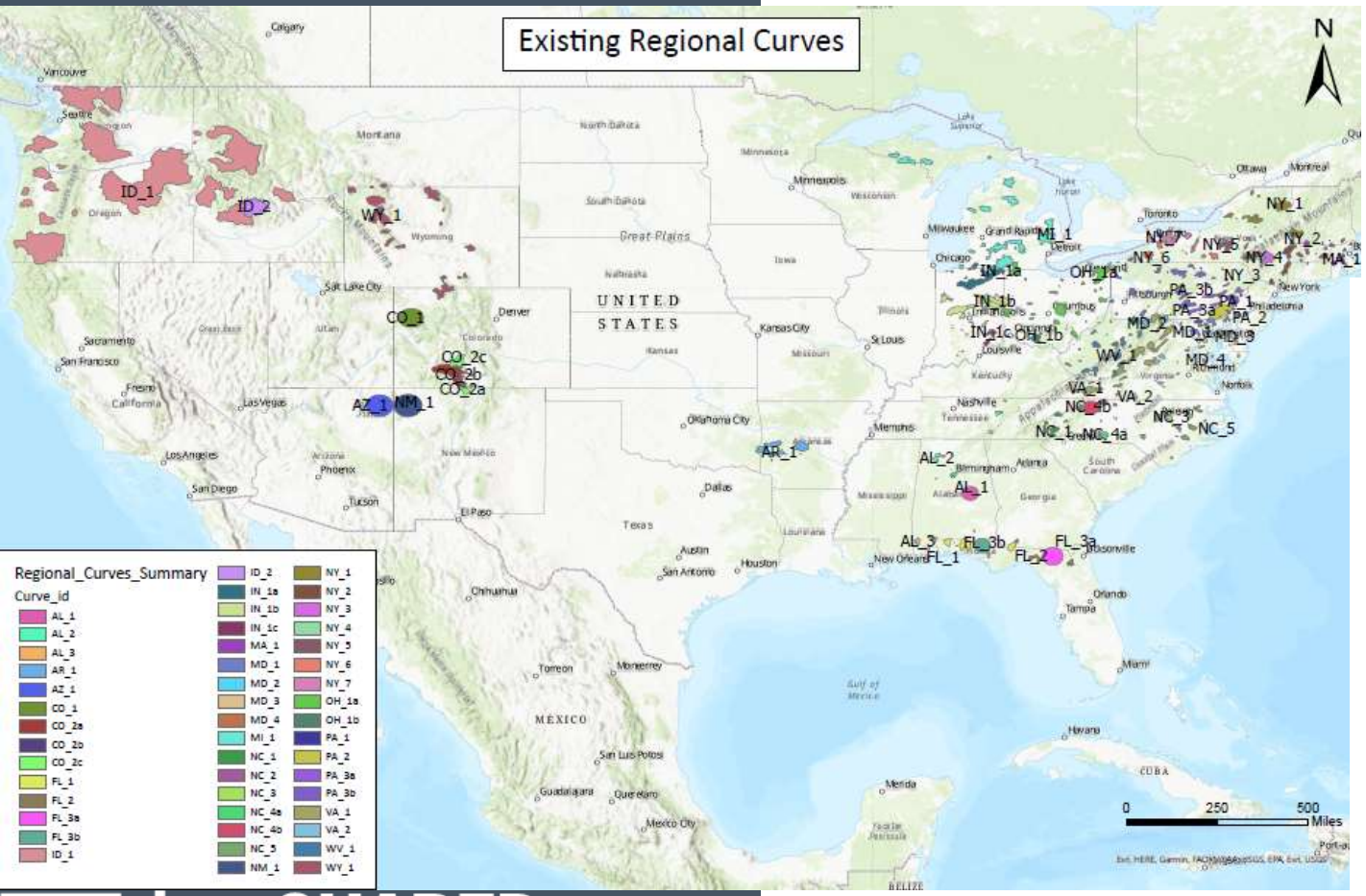

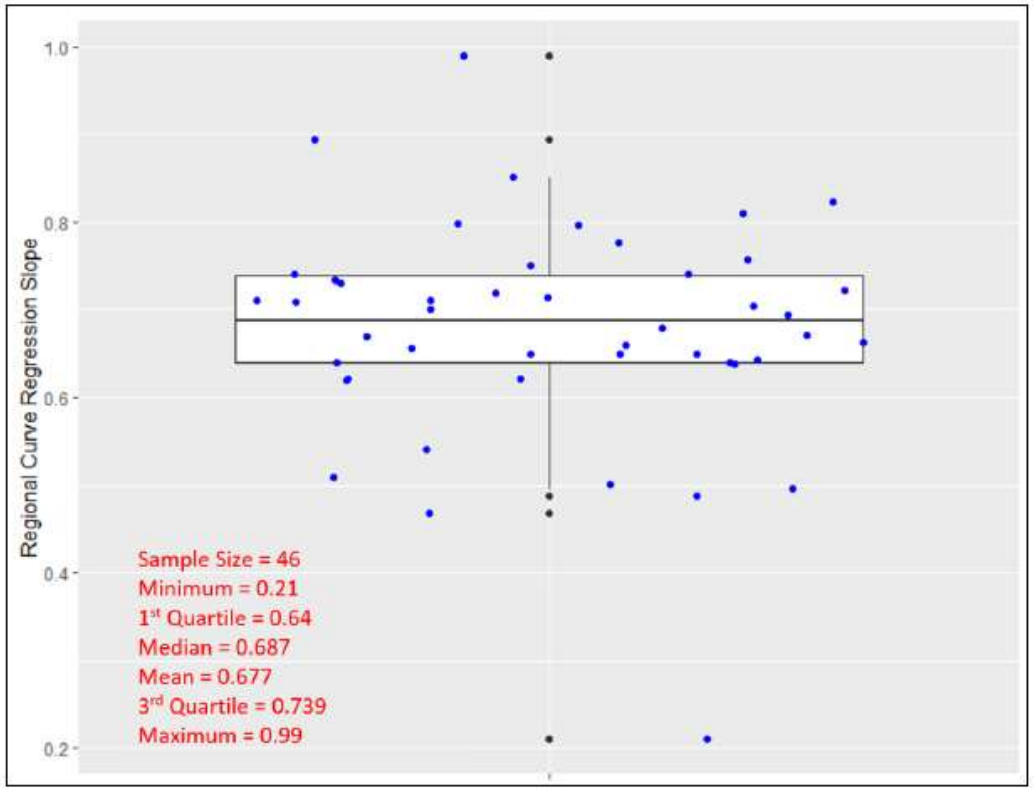

Figure 5. Existing regional curve regression slope distribution

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Watershed Response Factor

- Properly size a river channel

$$\text{“C”} = A_{BKF} / DA^{0.68}$$

- Urbanization
  - 4-stage urban channels
  - Do not over widen bankfull discharge
- Terrorism
  - Encourage groundwater recharge
  - Reduce the need for surface water Infrastructure
- Runoff Rates
  - Encourage groundwater storage and
  - Reduced stormwater discharge rates
- Evaporation/Transpiration
  - Reduce the need for surface water infrastructure with large E/T Losses
- Agricultural Water
  - Promote subirrigation
  - Groundwater recharge
- Drought
  - Usable groundwater storage

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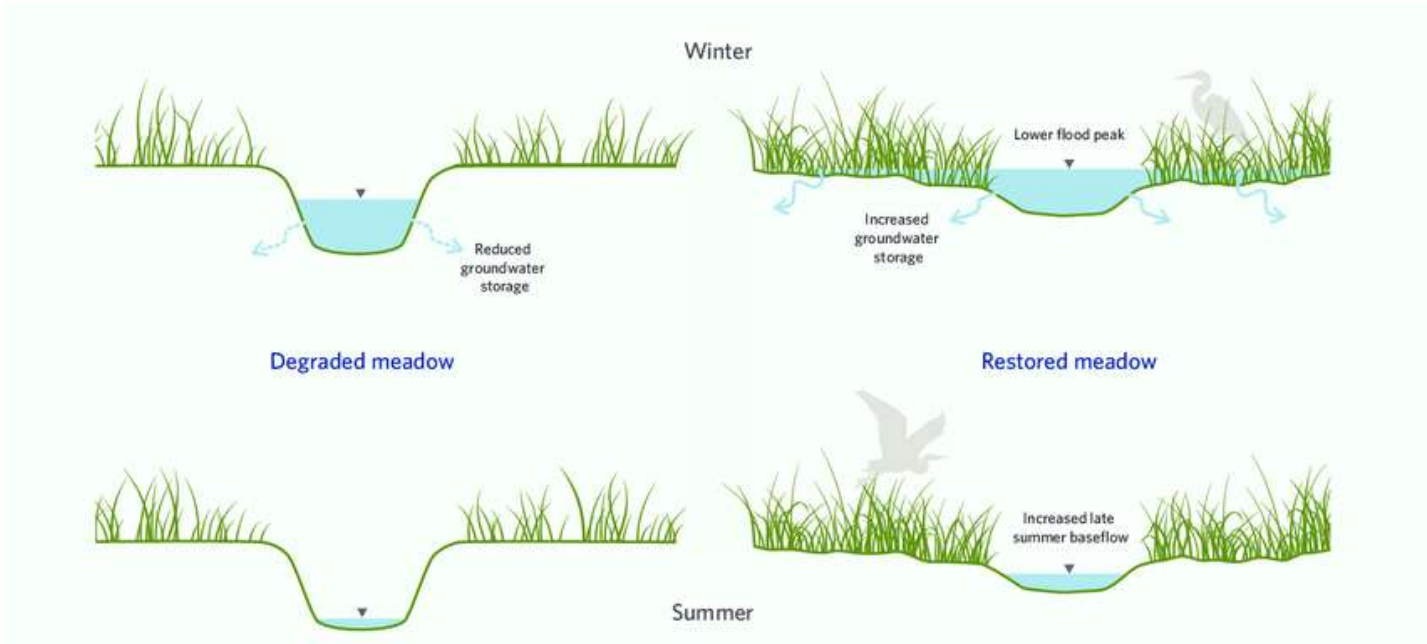
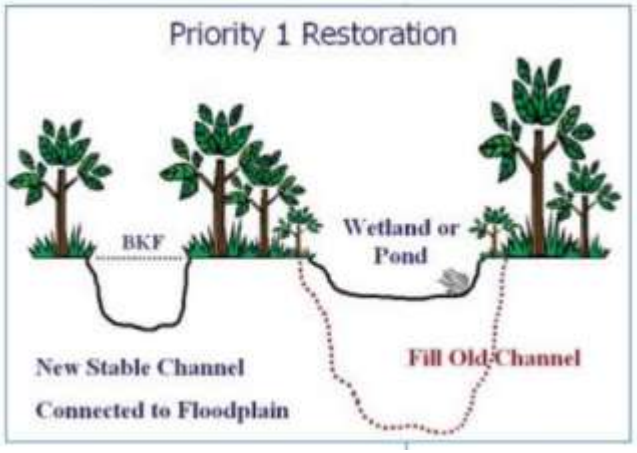
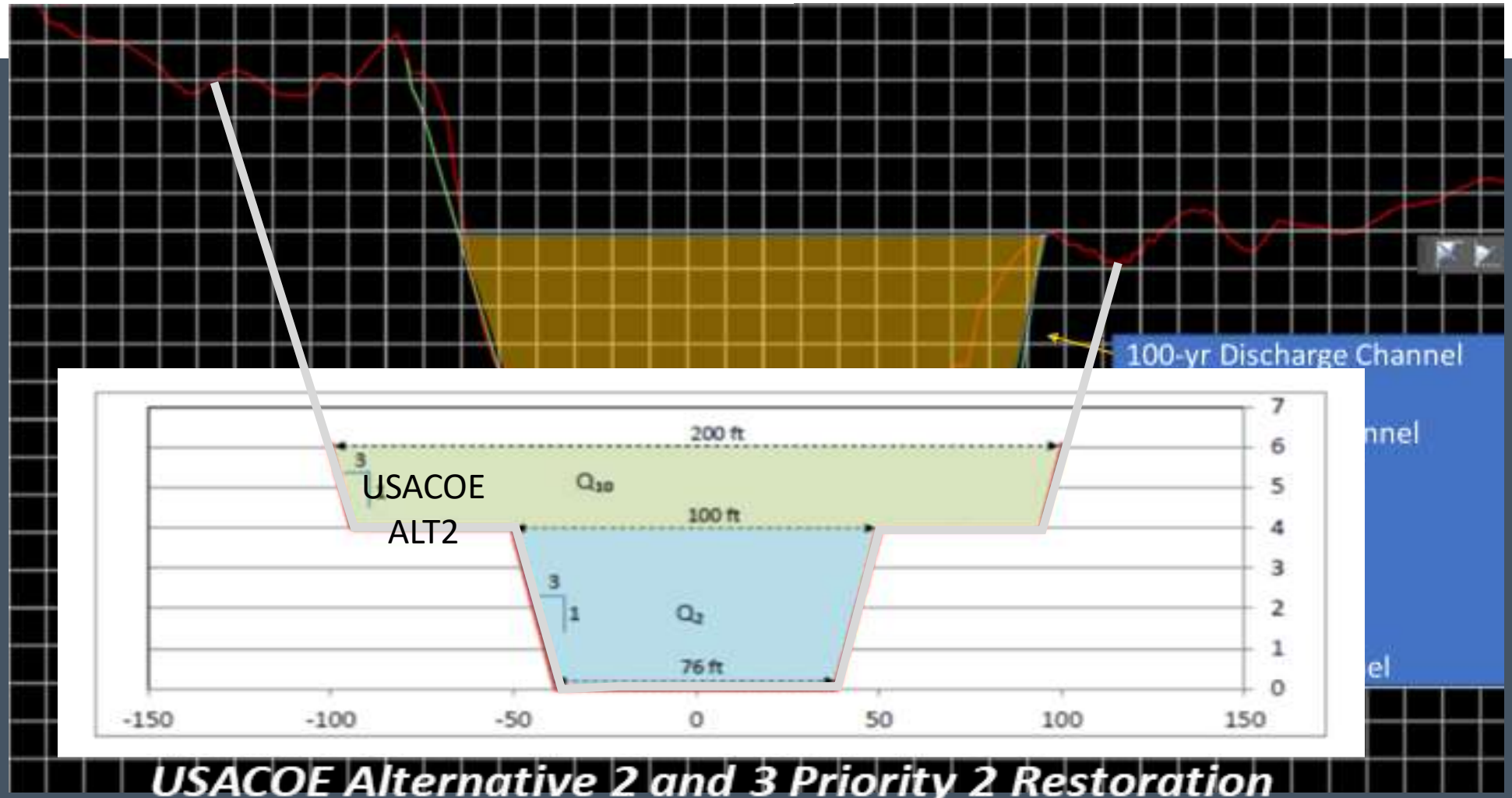




Watershed Response Factor

- Global implications for using a tool to address water security



Watershed Response Factor

- Global implications for using a tool to address water security

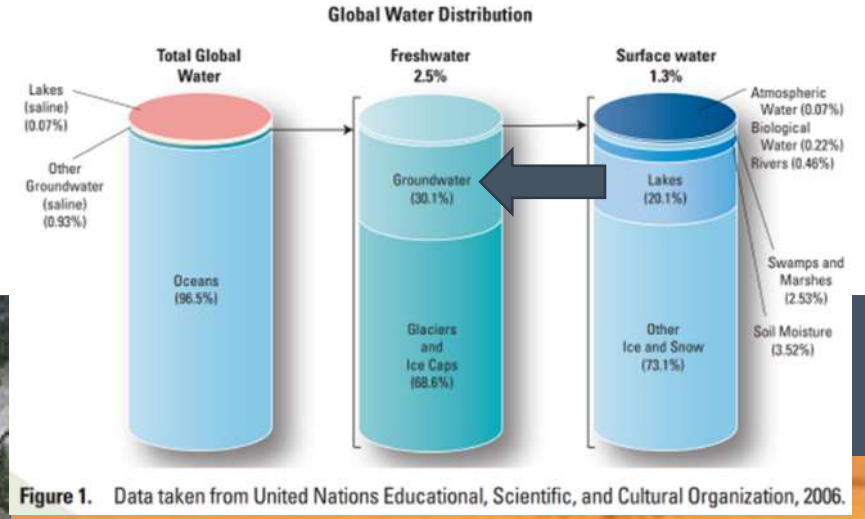
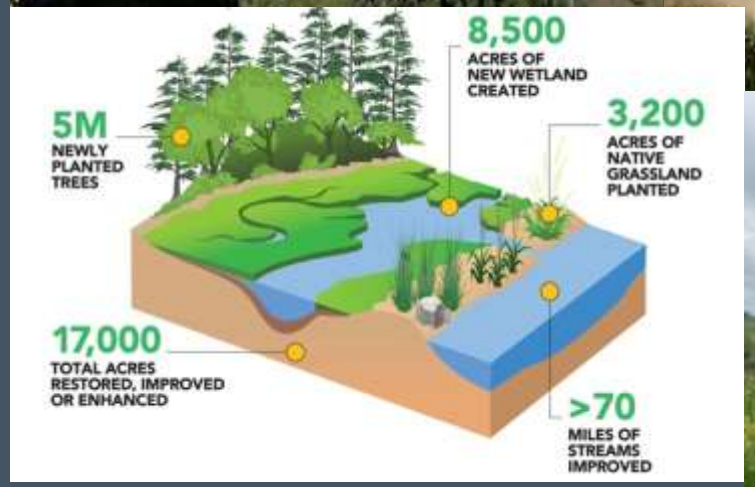


Figure 1. Data taken from United Nations Educational, Scientific, and Cultural Organization, 2006.

Summary:

- Bankfull can have a high degree of uncertainty
- Inner-Berm and other Geomorphic Features should be separated on curves
- Average Regression Slope ~0.68 Range 95% (0.61 – 0.76)
- Watersheds can't have a linear Regression Slope
- Watershed Response Factor as a geomorphic indicator
- Compare relationships to published USGS Regressions as well as other bankfull regional curves
- Regional curve development for new regions should always be compared to existing data as a reference
- Localized mini-regional curves can be used for design purposes
- Local data (upstream, downstream, nearby streams) are always essential to add confidence to predictive relationships developed elsewhere.



Watershed Response Factor

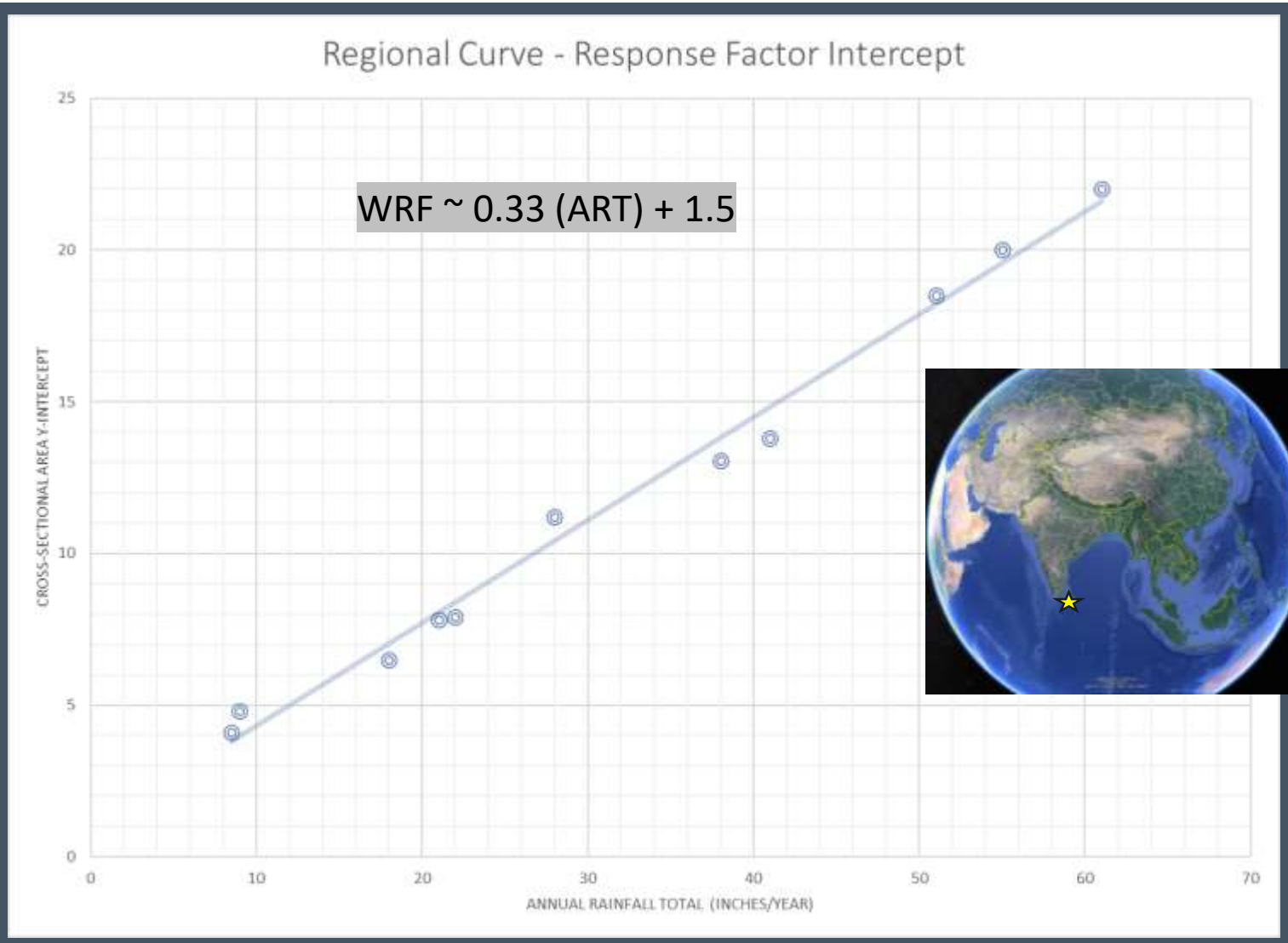
Watershed Response Factor as a geomorphic indicator

Compare relationships to published USGS Regressions as well as other bankfull regional curves

Regional curve development for new regions of the Southwest US should always be compared to existing data as a reference

The Y-intercept is strongly dependent on Rainfall

Localized mini-regional curves can be used for design purposes



Site Location for Stream Channel Measurements

Several stream cross-section measurements were taken at a location along Nanu Oya, west of Kandy, SL (yellow star)

Nanu Oya is a major tributary to Mahaweli Ganga, “Great Sandy River”, longest river in SL

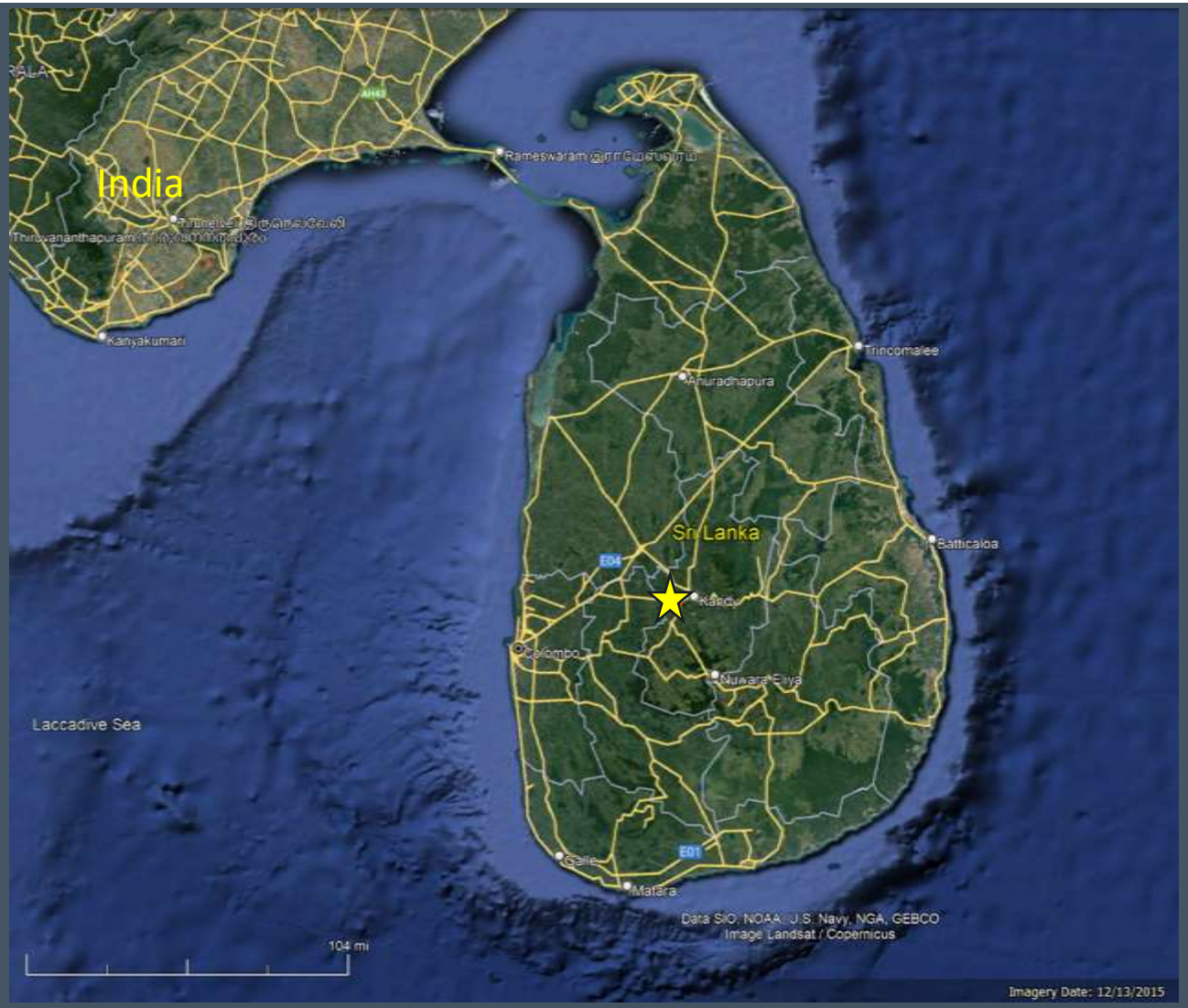
“Oya” means stream in Sinhalese, one of the native languages of Sri Lanka

A total of 6 cross-sections were measured in this location

~58in/year of Rainfall in Kandy at Confluence with Mahaweli Ganga

~91 in/year of Rainfall in Kadugannawa at Headwaters of Nanu Oya

Average ~ 74.5 in/year over the watershed



Map of the Location of Measured Cross Sections

~58in/year of Rainfall in Kandy near Confluence with Mahaweli Ganga

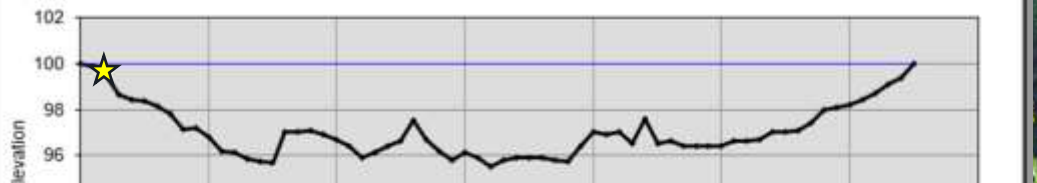
91”

~91 in/year of Rainfall in Kadugannawa at Headwaters of Nanu Oya (Cloud Forest)

Average ~ 74.5 in/year over the watershed

XS -1

Cross Section 1

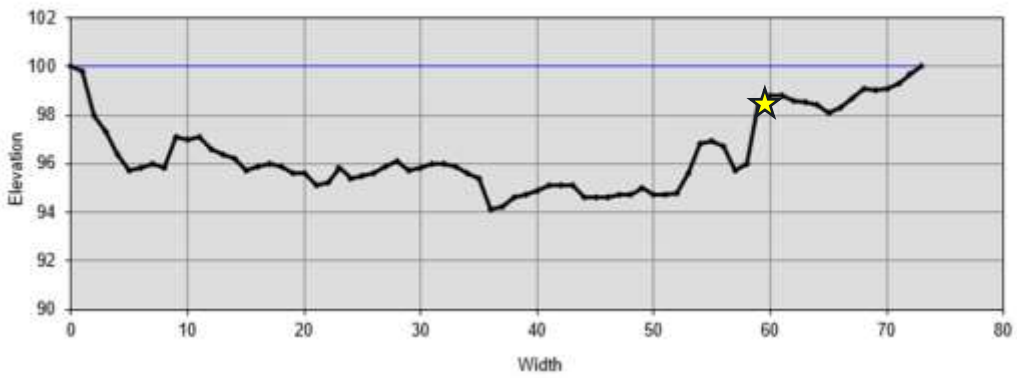


Bankfull Dimensions		Flood Dimensions		Materials	
195.3	x-section area (ft.sq.)	68.0	W flood prone area (ft)		D50 Riffle (mm)
65.0	width (ft)	1.0	entrenchment ratio		D84 Riffle (mm)
3.0	mean depth (ft)	---	low bank height (ft)		threshold grain size (mm)
0.0	max depth (ft)	---	low bank height ratio		
70.1	wetted parimeter (ft)				
2.8	hyd radi (ft)				
21.6	width-depth ratio				

Bankfull Flow		Flow Resistance		Forces & Power	
---	velocity (ft/s)	---	Manning's roughness		channel slope (%)
---	discharge rate (cfs)	---	D'Arcy-Weisbach fric.		shear stress (lb/sq.ft.)
---	Froude number	---	resistance factor u/u*		shear velocity (ft/s)
		---	relative roughness	---	unit strm power (lb/ft/s)

XS-2

Cross Section 2

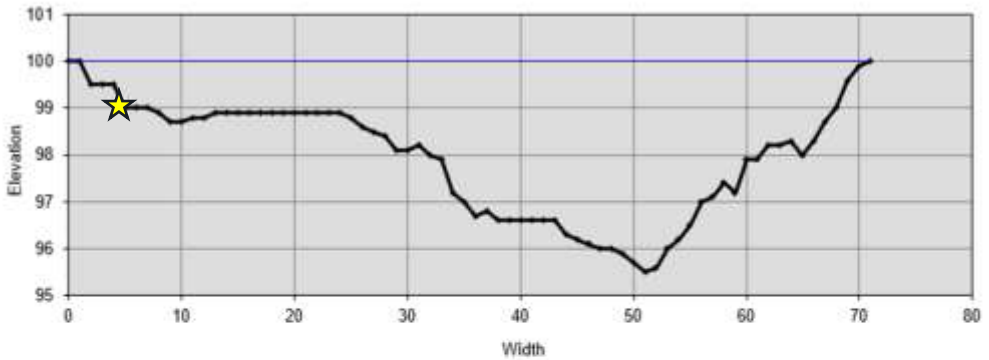


Bankfull Dimensions		Flood Dimensions		Materials	
262.3	x-section area (ft.sq.)	73.0	W flood prone area (ft)	33	D50 Riffle (mm)
71.0	width (ft)	1.0	entrenchment ratio	81	D84 Riffle (mm)
3.7	mean depth (ft)	---	low bank height (ft)	---	threshold grain size (mm)
0.0	max depth (ft)	---	low bank height ratio		
78.9	wetted parimeter (ft)				
3.3	hyd radi (ft)				
19.2	width-depth ratio				

Bankfull Flow		Flow Resistance		Forces & Power	
---	velocity (ft/s)	---	Manning's roughness		channel slope (%)
---	discharge rate (cfs)	---	D'Arcy-Weisbach fric.		shear stress (lb/sq.ft.)
---	Froude number	---	resistance factor u/u*		shear velocity (ft/s)
			relative roughness		unit strm power (lb/ft/s)

XS-3

Cross Section 3

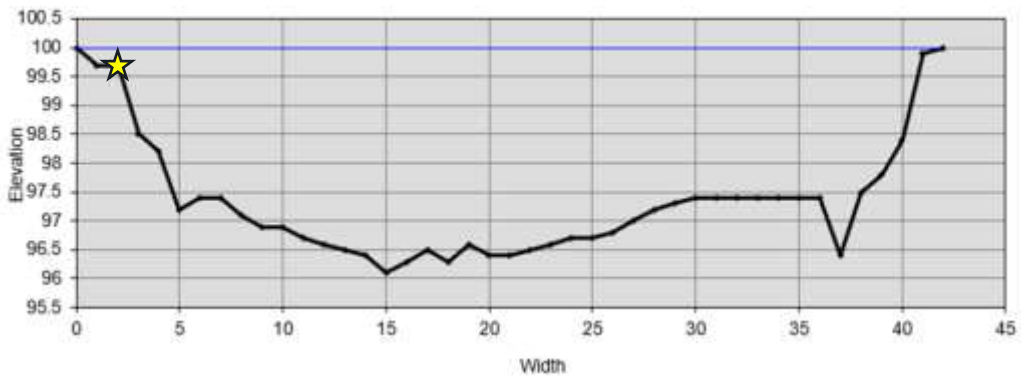


Bankfull Dimensions		Flood Dimensions		Materials	
147.2	x-section area (ft.sq.)	---	W flood prone area (ft)		D50 Riffle (mm)
70.0	width (ft)	---	entrenchment ratio		D84 Riffle (mm)
2.1	mean depth (ft)	---	low bank height (ft)	---	threshold grain size (mm)
4.5	max depth (ft)	---	low bank height ratio		
71.8	wetted parimeter (ft)				
2.0	hyd radi (ft)				
33.3	width-depth ratio				

Bankfull Flow		Flow Resistance		Forces & Power	
	velocity (ft/s)		Manning's roughness		channel slope (%)
---	discharge rate (cfs)		D'Arcy-Weisbach fric.		shear stress (lb/sq.ft.)
	Froude number		resistance factor u/u*		shear velocity (ft/s)
			relative roughness		unit strm power (lb/ft/s)

XS-4

Cross Section 4

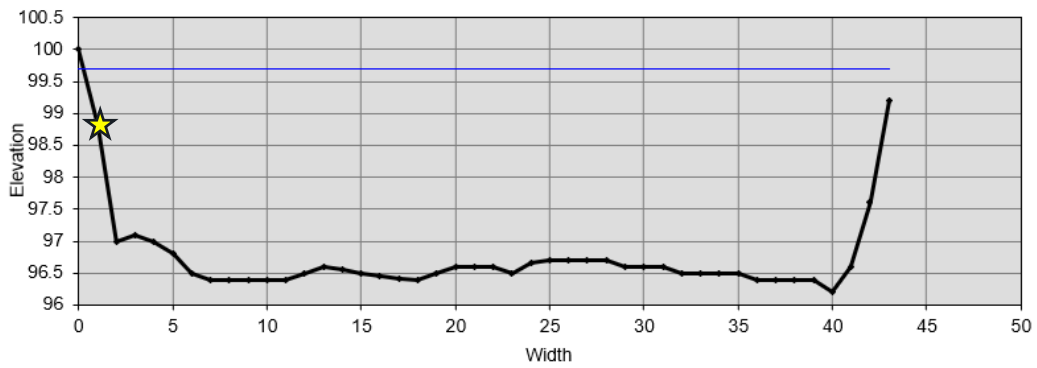


Bankfull Dimensions		Flood Dimensions		Materials	
113.6	x-section area (ft.sq.)	42.0	W flood prone area (ft)		D50 Riffle (mm)
42.0	width (ft)	1.0	entrenchment ratio		D84 Riffle (mm)
2.7	mean depth (ft)	---	low bank height (ft)		threshold grain size (mm)
0.0	max depth (ft)	---	low bank height ratio		
45.3	wetted parimeter (ft)				
2.5	hyd radi (ft)				
15.5	width-depth ratio				

Bankfull Flow		Flow Resistance		Forces & Power	
---	velocity (ft/s)	---	Manning's roughness		channel slope (%)
---	discharge rate (cfs)	---	D'Arcy-Weisbach fric.		shear stress (lb/sq.ft.)
---	Froude number	---	resistance factor u/u*		shear velocity (ft/s)
		---	relative roughness	---	unit strm power (lb/ft/s)

XS-5

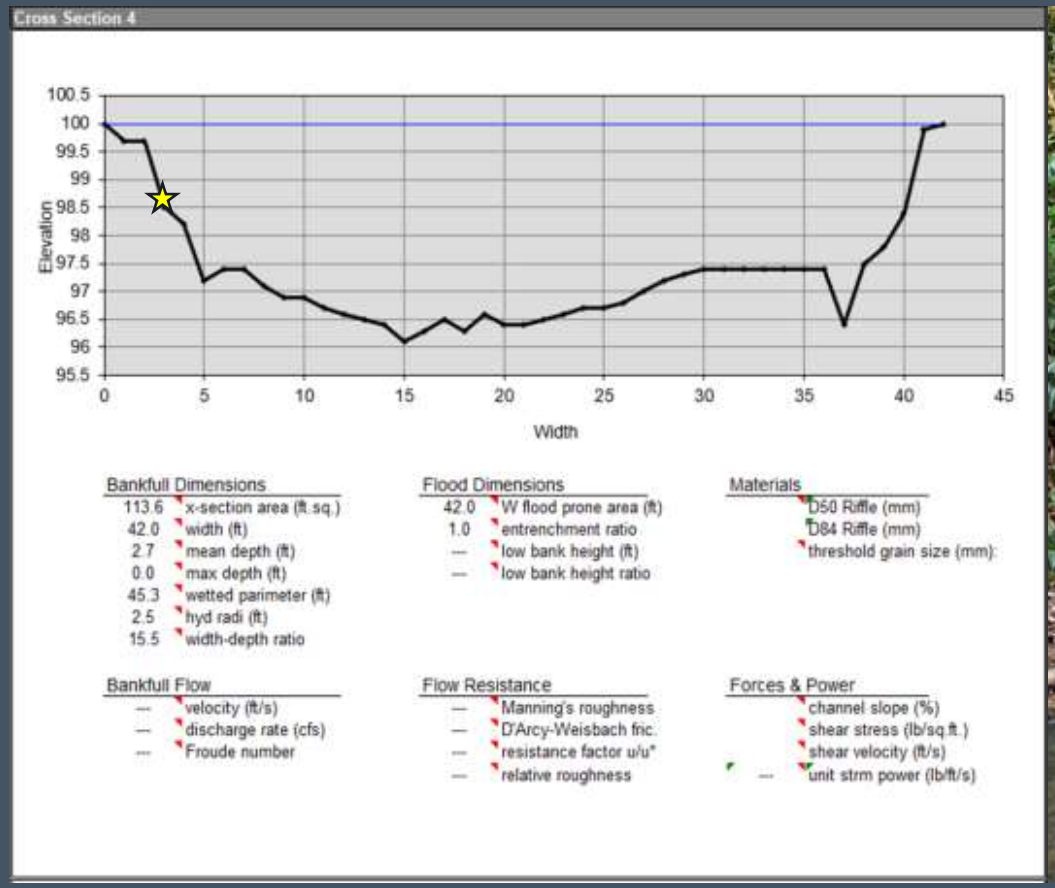
Cross Section 5



Bankfull Dimensions		Flood Dimensions		Materials	
128.9	x-section area (ft.sq.)	---	W flood prone area (ft)		D50 Riffle (mm)
42.8	width (ft)	---	entrenchment ratio		D84 Riffle (mm)
3.0	mean depth (ft)	---	low bank height (ft)		threshold grain size (mm):
0.0	max depth (ft)	---	low bank height ratio		
45.8	wetted parimeter (ft)				
2.8	hyd radi (ft)				
14.2	width-depth ratio				

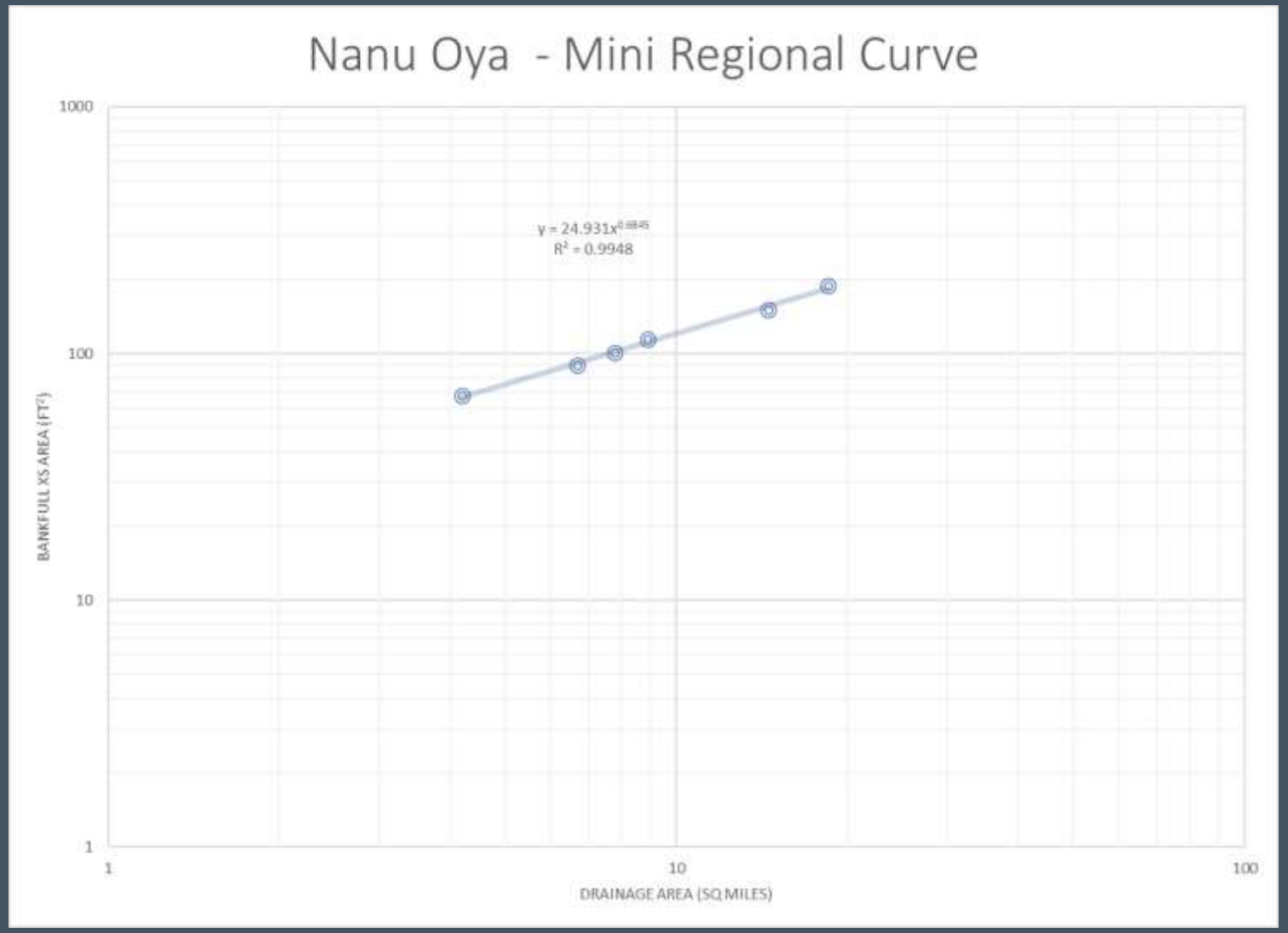
Bankfull Flow		Flow Resistance		Forces & Power	
---	velocity (ft/s)	---	Manning's roughness		channel slope (%)
---	discharge rate (cfs)	---	D'Arcy-Weisbach fric.		shear stress (lb/sq.ft.)
---	Froude number	---	resistance factor u/u*		shear velocity (ft/s)
		---	relative roughness		unit strm power (lb/ft/s)

XS-6


Cross Section 4
100.5
100
99.5
99
98.5
98
97.5
97
96.5
96
95.5
Elevation
0
5
10
15
20
25
30
35
40
45
Width
Bankfull Dimensions
113.6 x-section area (ft.sq.)
42.0 width (ft)
2.7 mean depth (ft)
0.0 max depth (ft)
45.3 wetted parimeter (ft)
2.5 hyd radi (ft)
15.5 width-depth ratio
Flood Dimensions
42.0 W flood prone area (ft)
1.0 entrenchment ratio
--- low bank height (ft)
--- low bank height ratio
Materials
D50 Riffle (mm)
D84 Riffle (mm)
threshold grain size (mm)
Bankfull Flow
--- velocity (ft/s)
--- discharge rate (cfs)
--- Froude number
Flow Resistance
--- Manning's roughness
--- D'Arcy-Weisbach fric.
--- resistance factor u/u*
--- relative roughness
Forces & Power
channel slope (%)
shear stress (lb/sq.ft.)
shear velocity (ft/s)
--- unit strm power (lb/ft/s)

Nanu Oya - Mini Regional Curve

Location	Drainage Area	XS Area	WRF
XS1	18.5	188	26.6
XS2	14.5	151	25.2
XS3	8.9	114	26.4
XS4	7.8	101	25.5
XS5	6.7	90	25.2
XS6	4.2	68	26.0

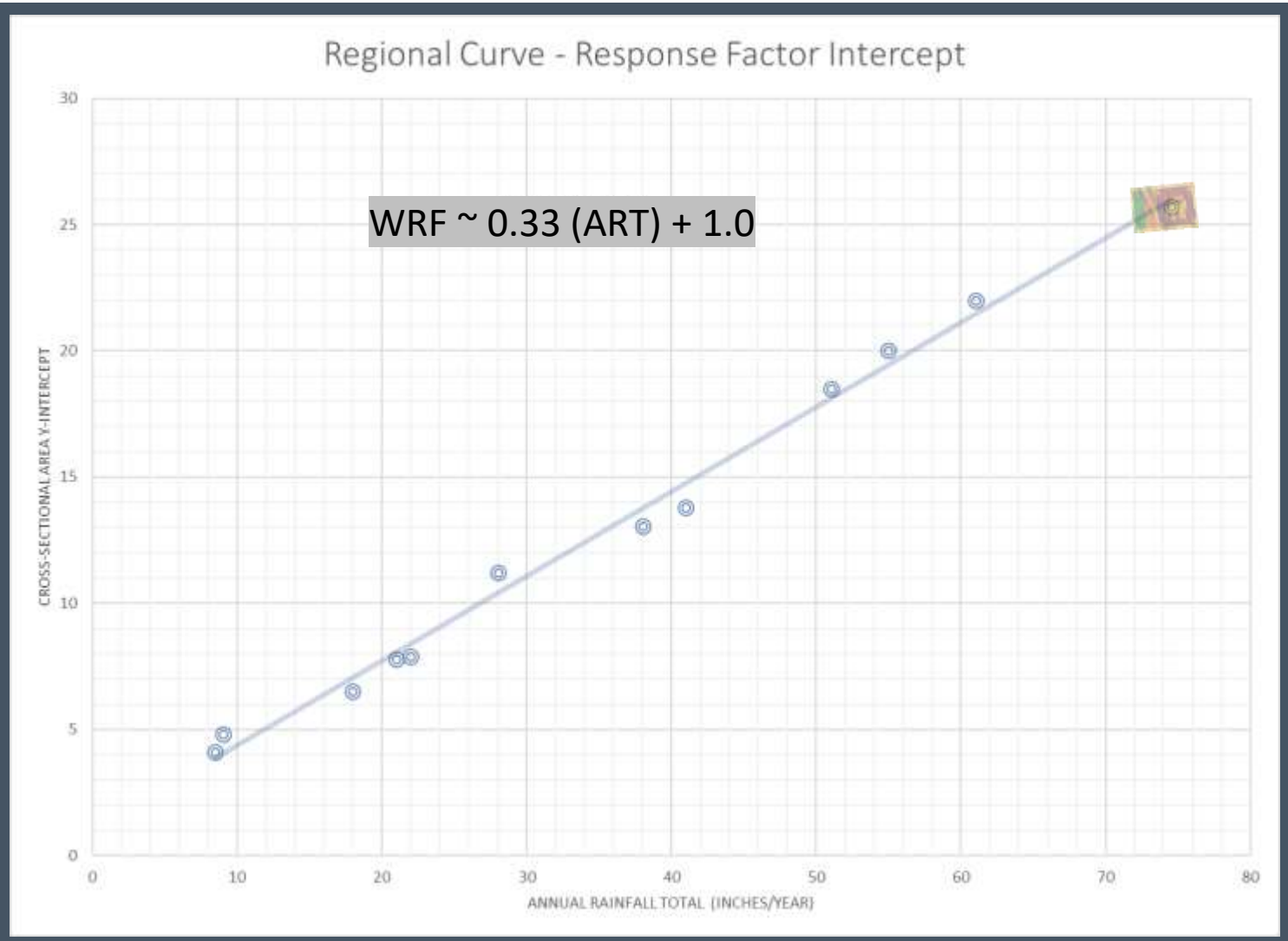


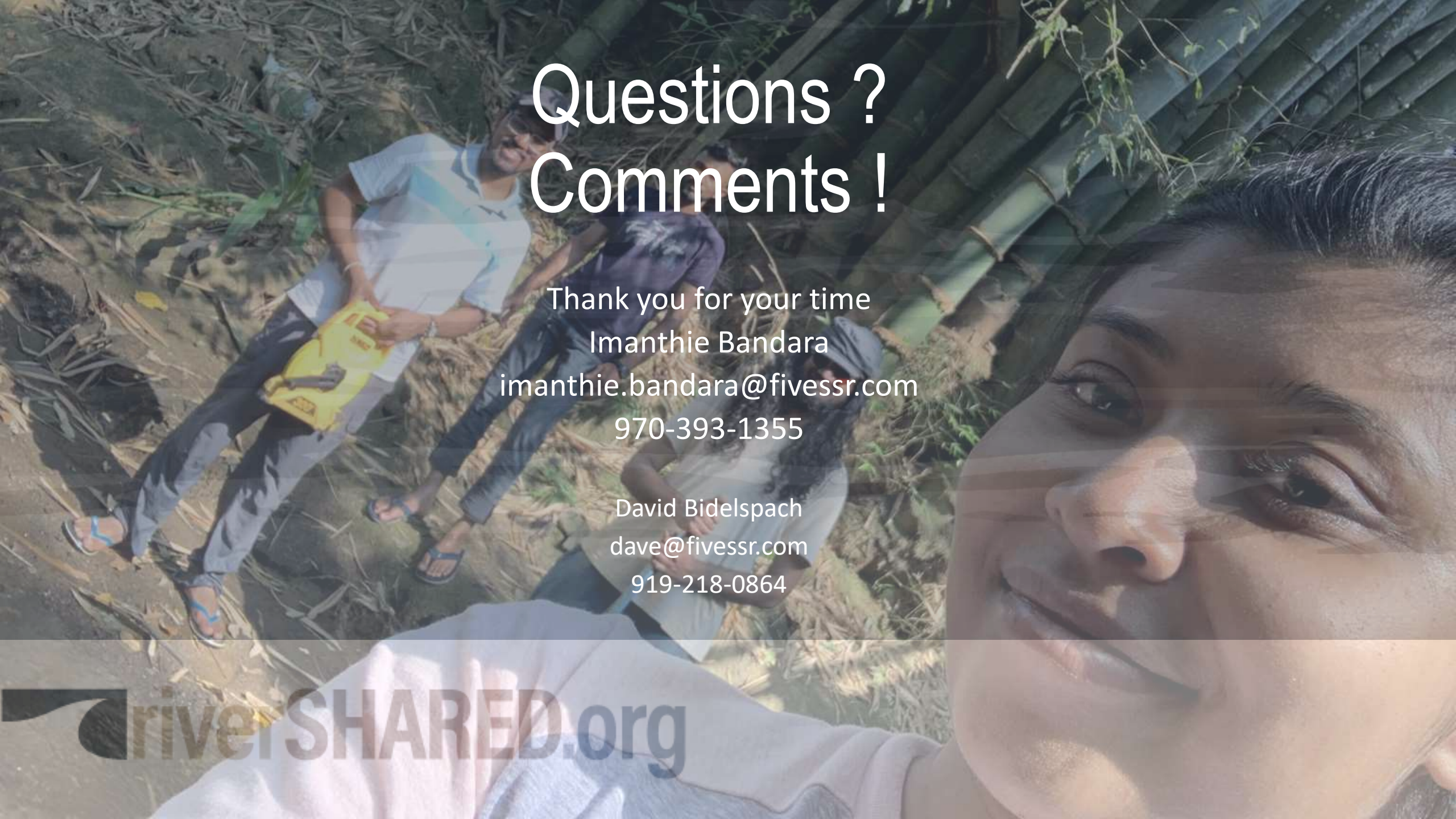
Nanu Oya – Mini-Regional Curve

Summary - Good Comparison with Rough Data

Next Steps

- Collect Better Topographic Data
- Resurvey the data with Total Station (Maybe Summer/Fall 2024)
- Short Courses with University of Peradeniya (Maybe Summer/Fall 2024)
- Collect more Sri- Lankan River Data
- Create an Elementary, Summer VBS/Camp or After School Stream Program
- Adventure with RiverSHARED for a week in Sri Lanka Summer/Fall 2024 (Small group ~5 team members)
  - Mini-Regional Curve Development - Training
  - Learn about Fluvial Geomorphology of Sri Lanka - Training
  - Help teach Short Courses at UP
  - Help Organize a River Day with Youth Program
  - Safari with Elephants on the beach of the Indian Ocean
  - See Sri Lanka – The country is beautiful, and the currency exchange is generous
  - Have a cup of Tea and tour a plantation




Questions ?
Comments !
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