Stream Restoration Symposium 2019

Lessons Learned from Stream Restoration in Other Jurisdictions

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5 | SMOOTH STONES
RESTORATION INC

Toronto and Region Conservation Authority

THE MANY USES FOR REGIONAL CURVES

Dave Bidelspach, Owner,
5 Smooth Stones Restoration PLLC., Fort Collins, CO

November 13, 2019

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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 Regional Curves

- Develop a tool to determine “bankfull” stage and discharge in un-gaged watersheds.
- Aid in Natural Channel Design.
- Aid in River Stability Assessment
- Can only be used in the same hydro-physiographic province??

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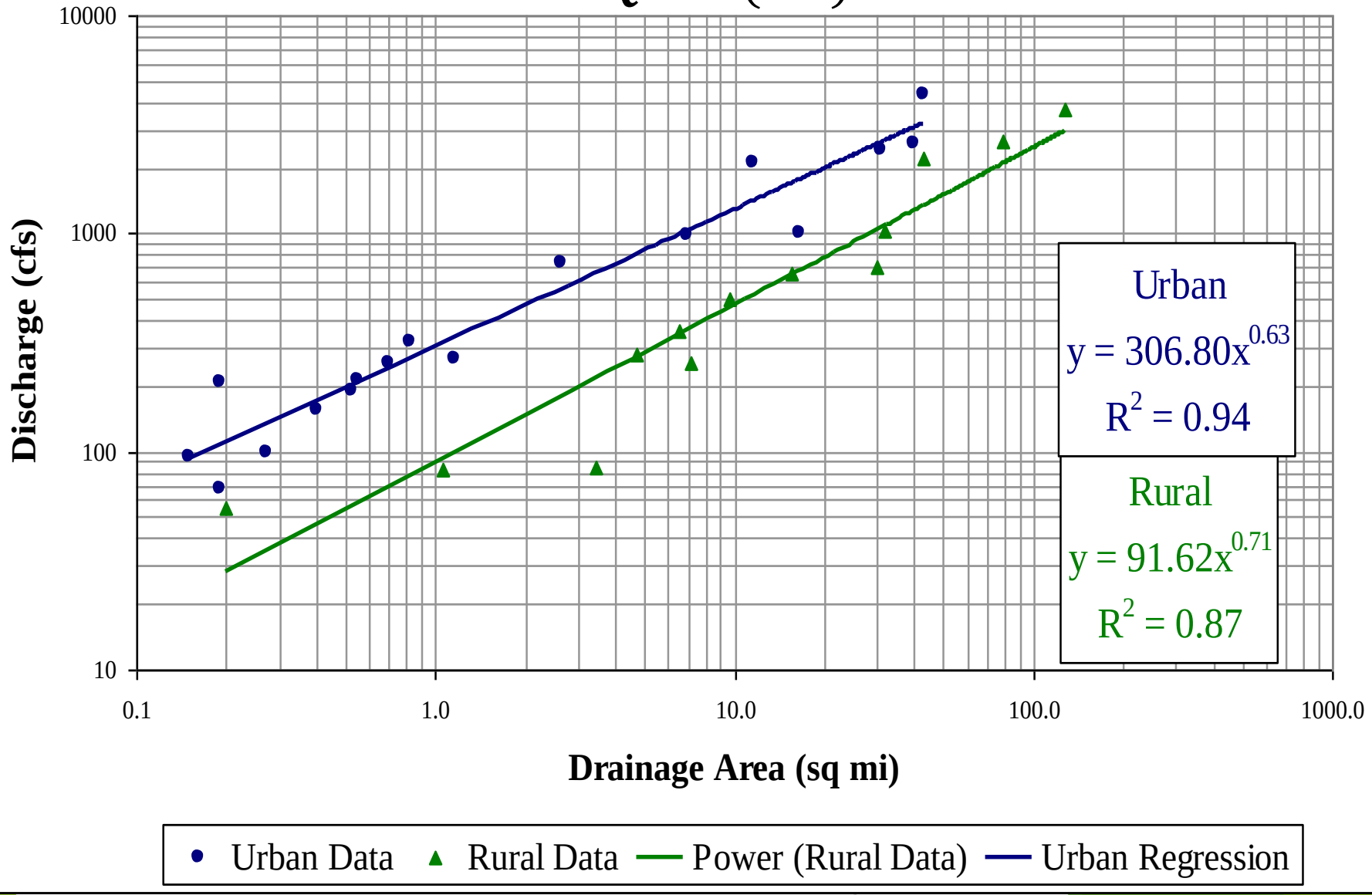
WARNING
STREAM FLOW
MEASURING STATION
UNITED STATES
GEOLOGICAL SURVEY

North Carolina Piedmont Regional Curve

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



Example Regional Curves

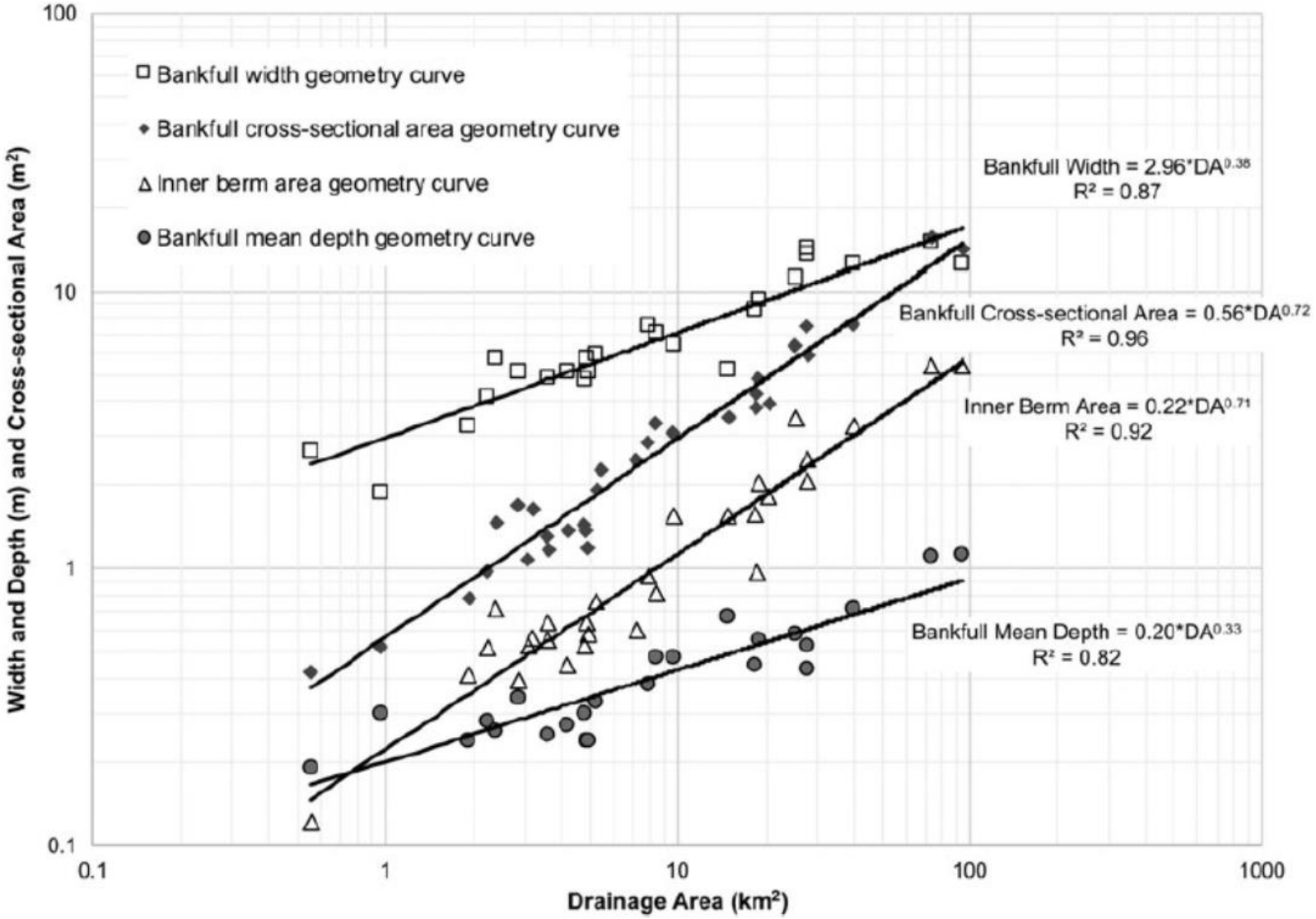
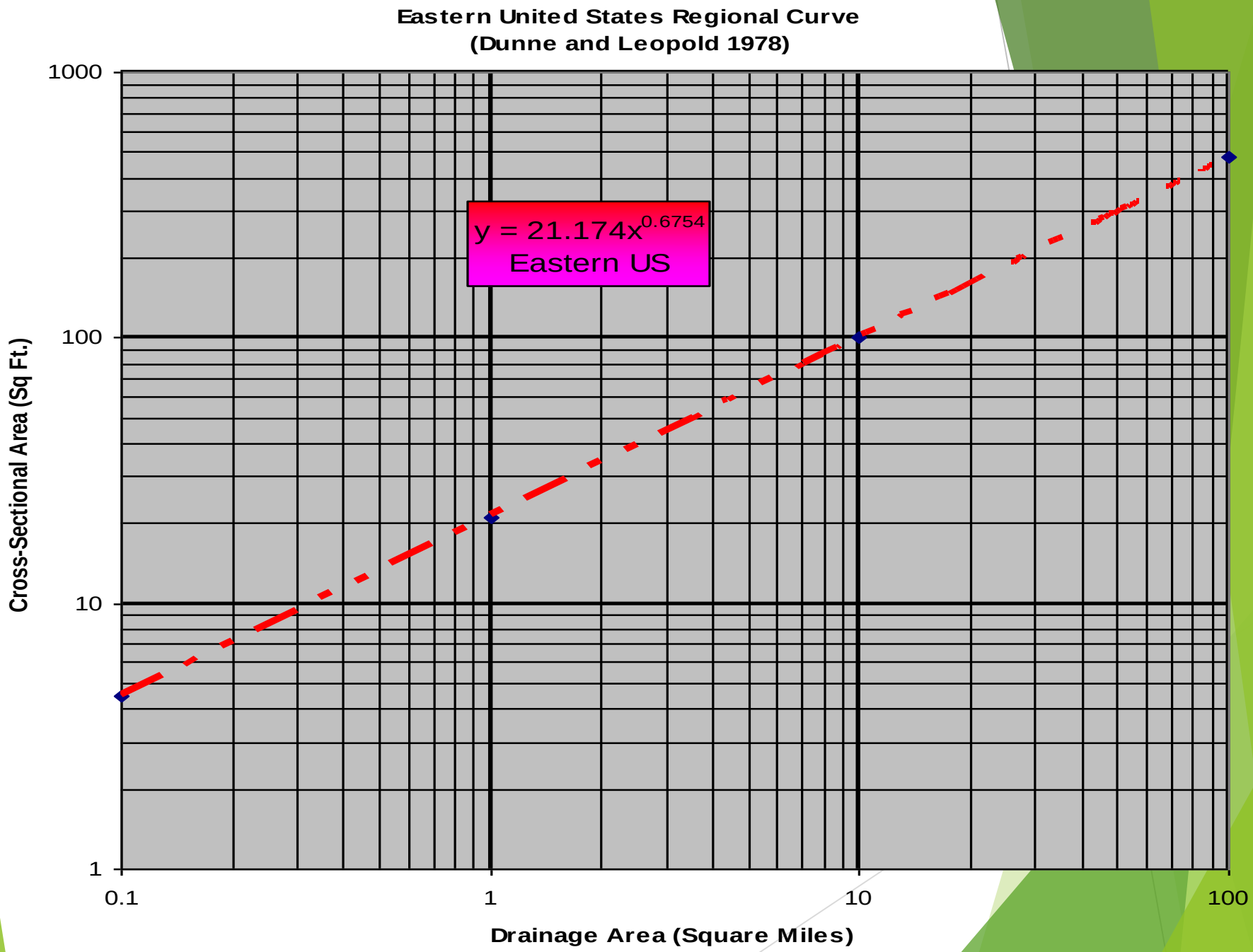
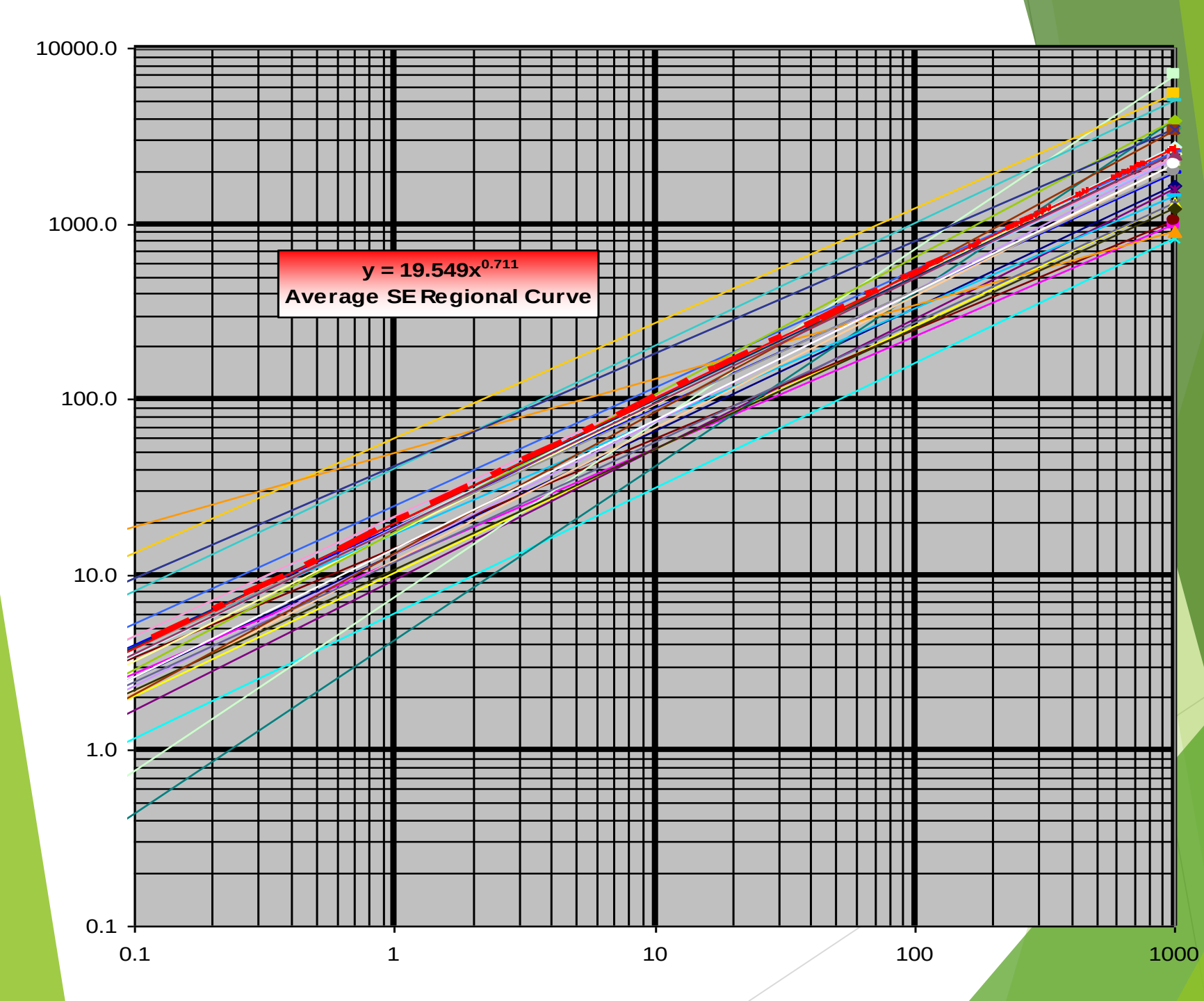
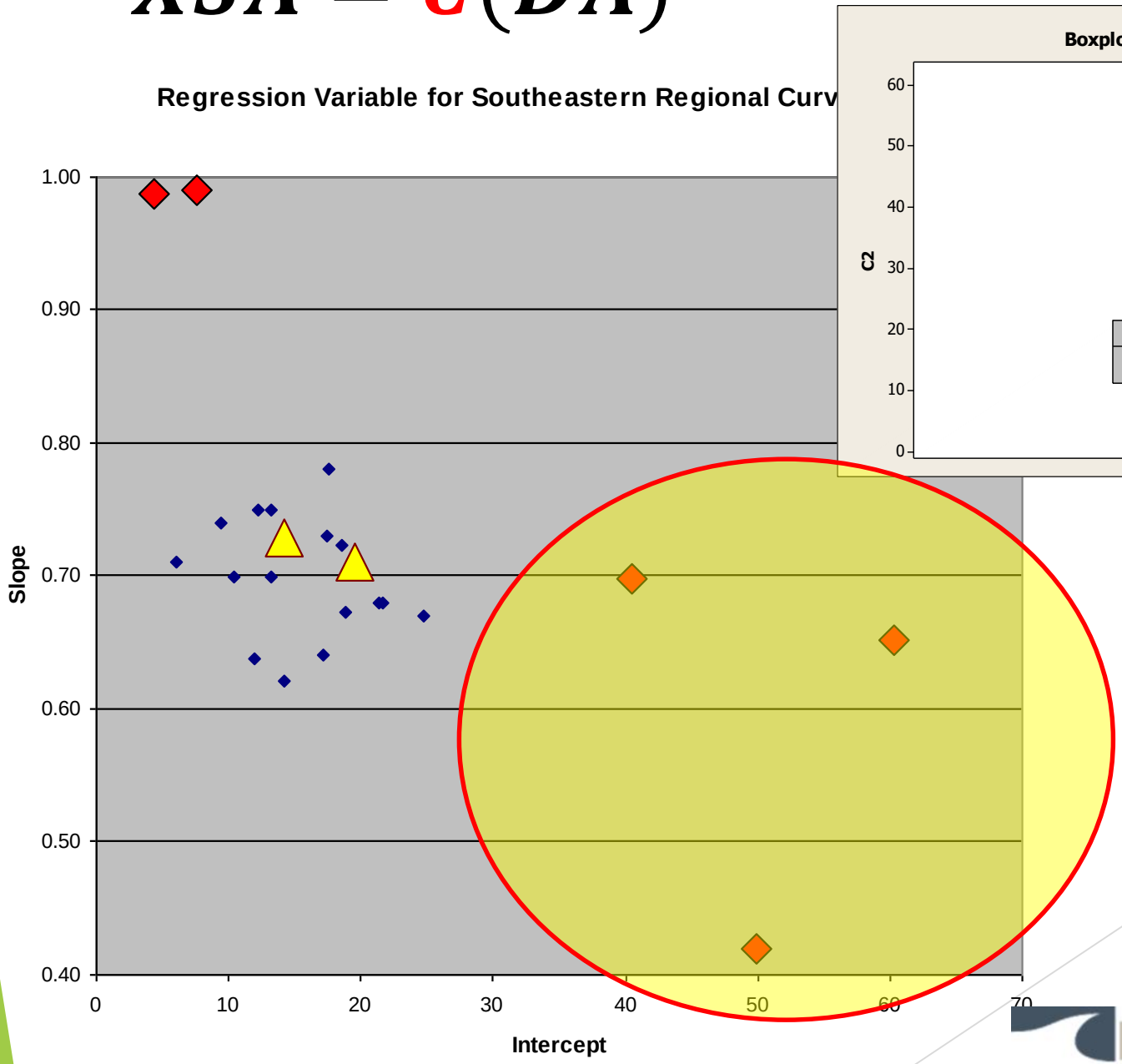


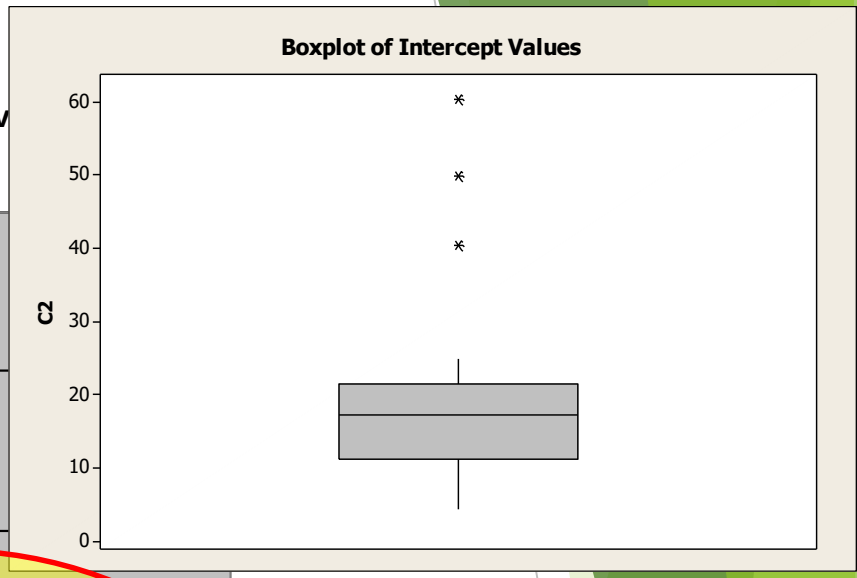
Figure 2. Composite hydraulic geometry curves for bankfull width, cross-sectional area, mean depth and inner berm cross-sectional area.


Eastern United States Regional Curve
(Dunne and Leopold 1978)
y = 21.174x^0.6754
Eastern US
Cross-Sectional Area (Sq Ft.)
1000
100
10
1
0.1
1
10
100
Drainage Area (Square Miles)


10000.0
1000.0
100.0
10.0
1.0
0.1
0.1
1
10
100
1000
y = 19.549x^0.711
Average SE Regional Curve

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





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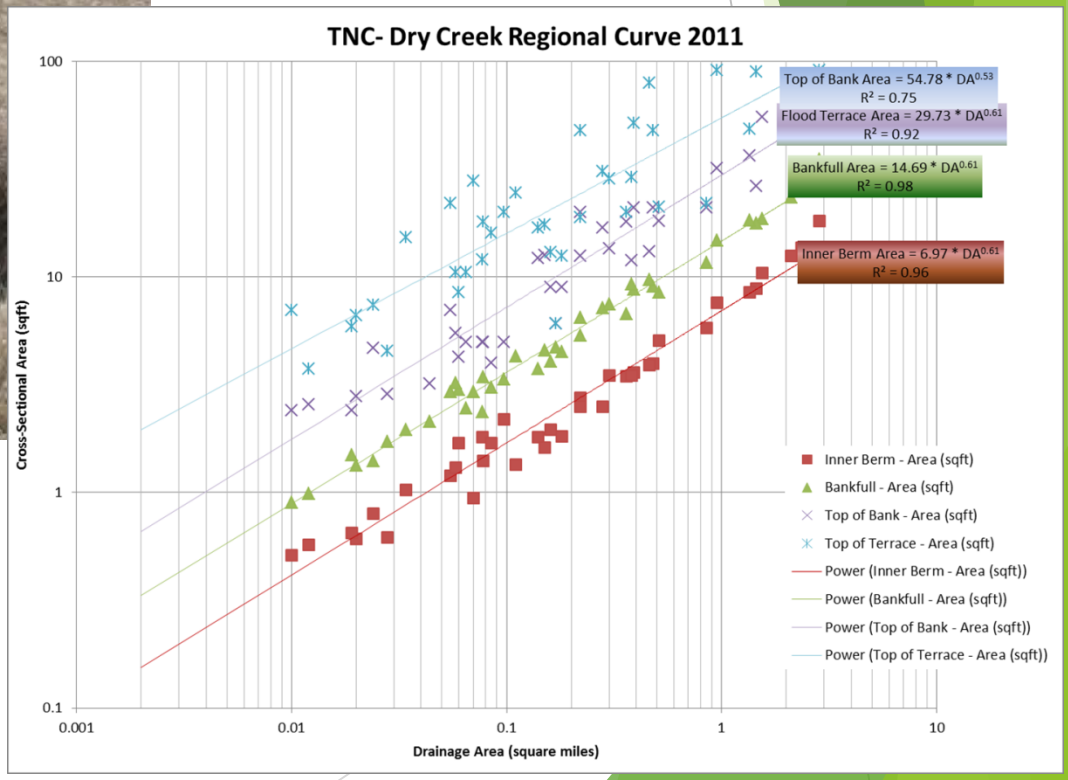
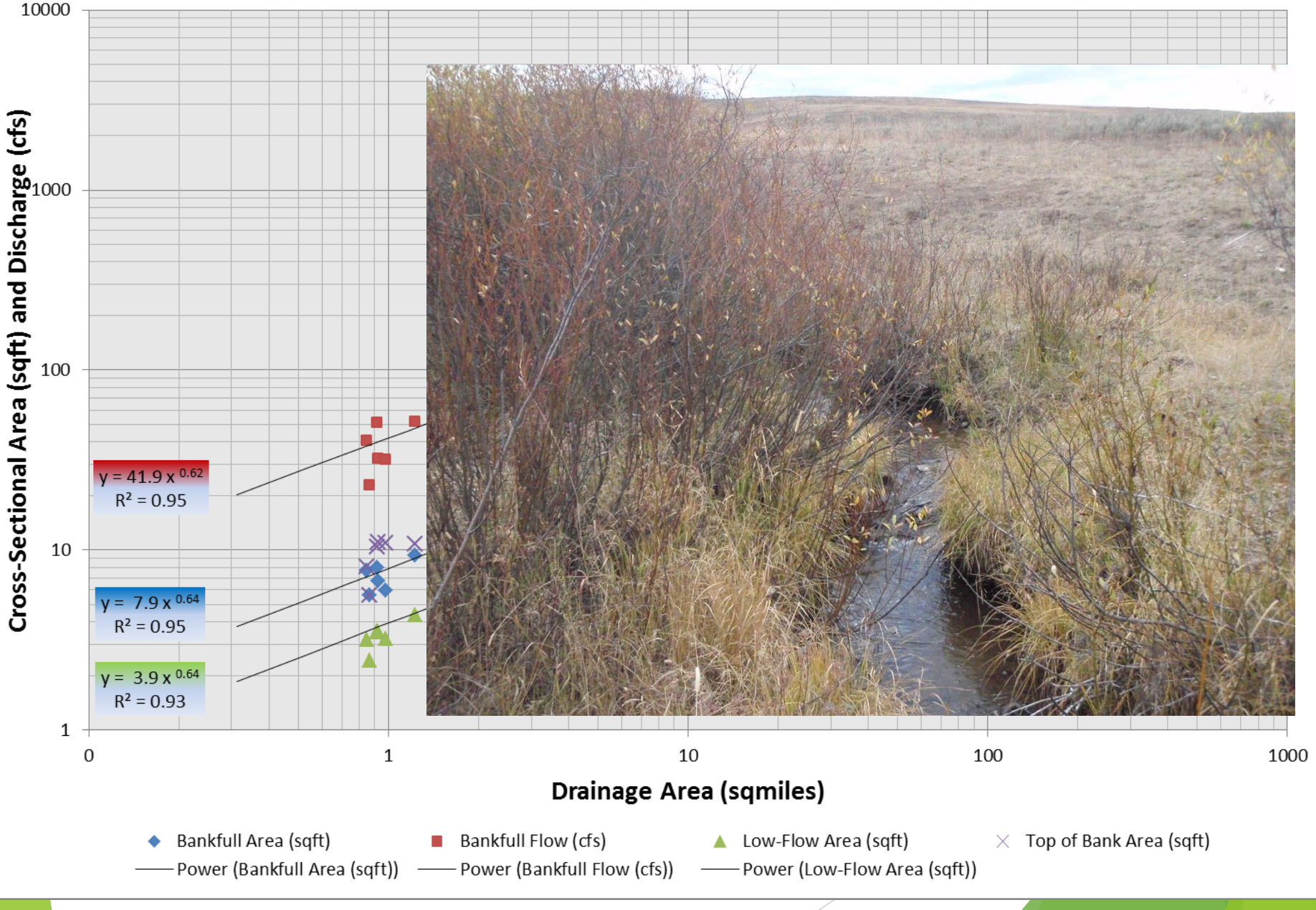
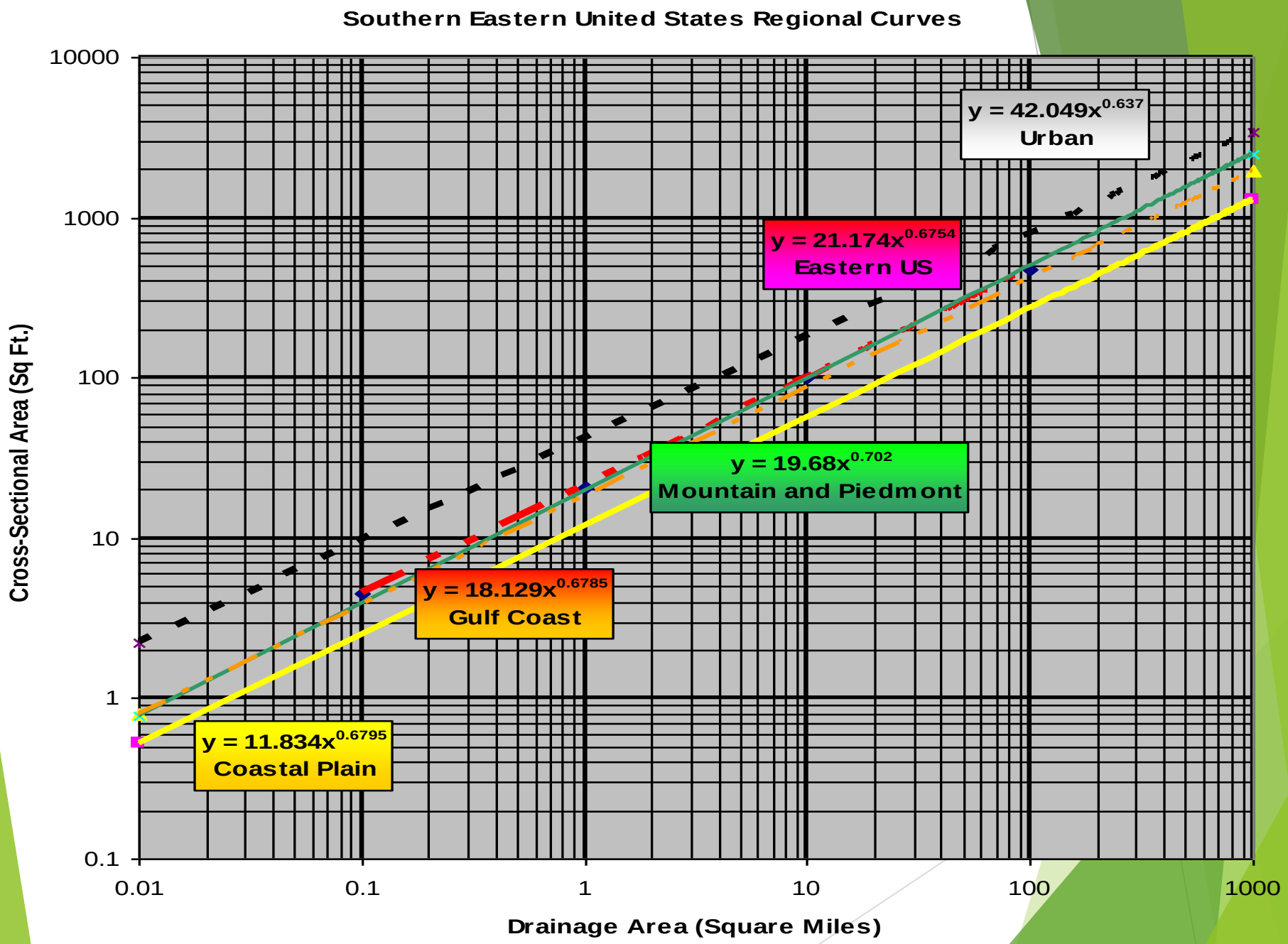
Inner Berm vs. Bankfull



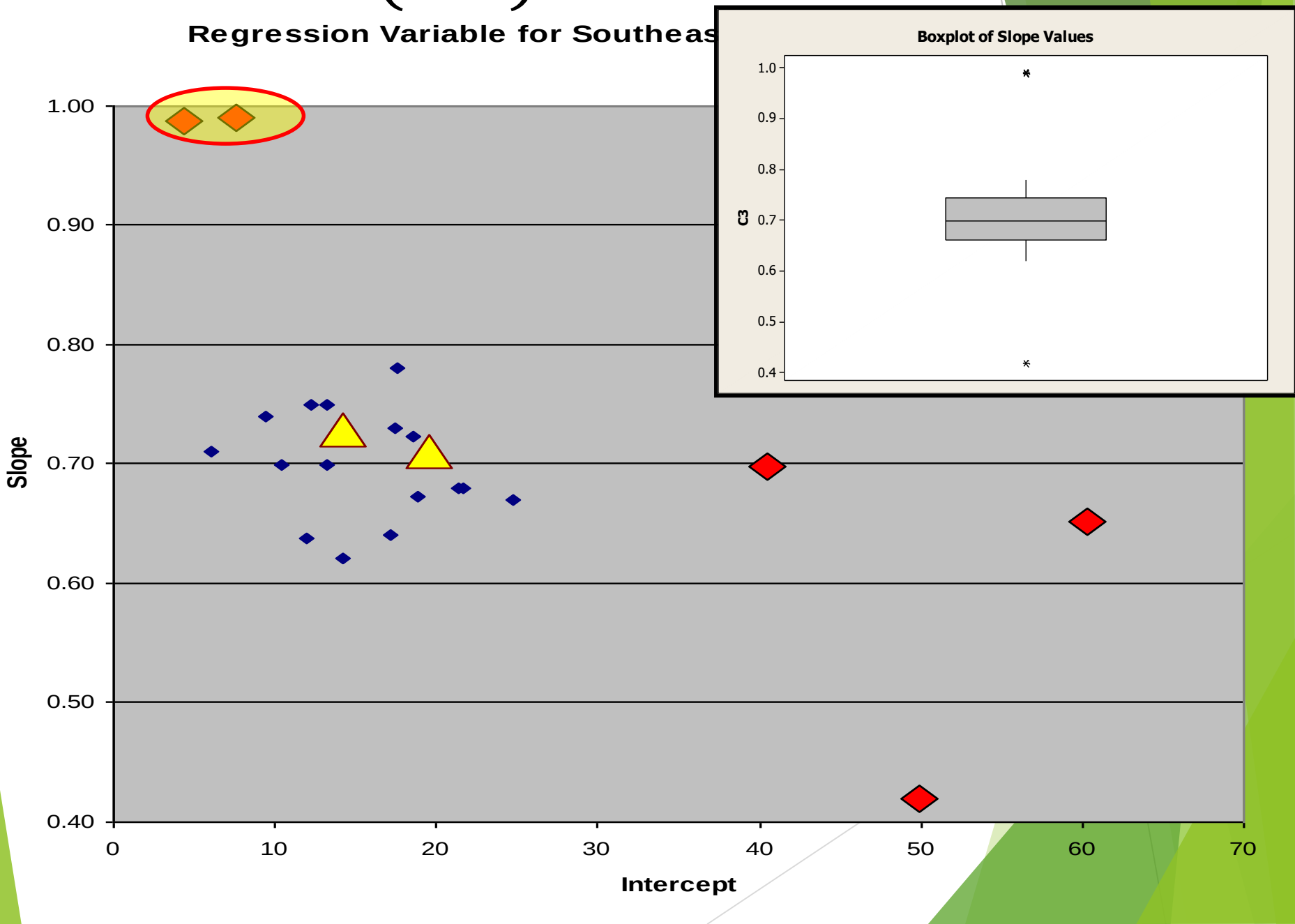
Mini-Regional Curve Relationship - California Park 2010



Survey Data Repeatability


Southern Eastern United States Regional Curves
Cross-Sectional Area (Sq Ft.)
10000
1000
100
10
1
0.1
0.01
0.1
1
10
100
1000
Drainage Area (Square Miles)
y = 42.049x^0.637
Urban
y = 21.174x^0.6754
Eastern US
y = 19.68x^0.702
Mountain and Piedmont
y = 18.129x^0.6785
Gulf Coast
y = 11.834x^0.6795
Coastal Plain

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


Regression Variable for Southeas
Boxplot of Slope Values
C3
1.0
0.9
0.8
0.7
0.6
0.5
0.4
Slope
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0
10
20
30
40
50
60
70
Intercept

- Time of Concentration
- Rainfall and runoff amounts
- Lag-times, in-phase

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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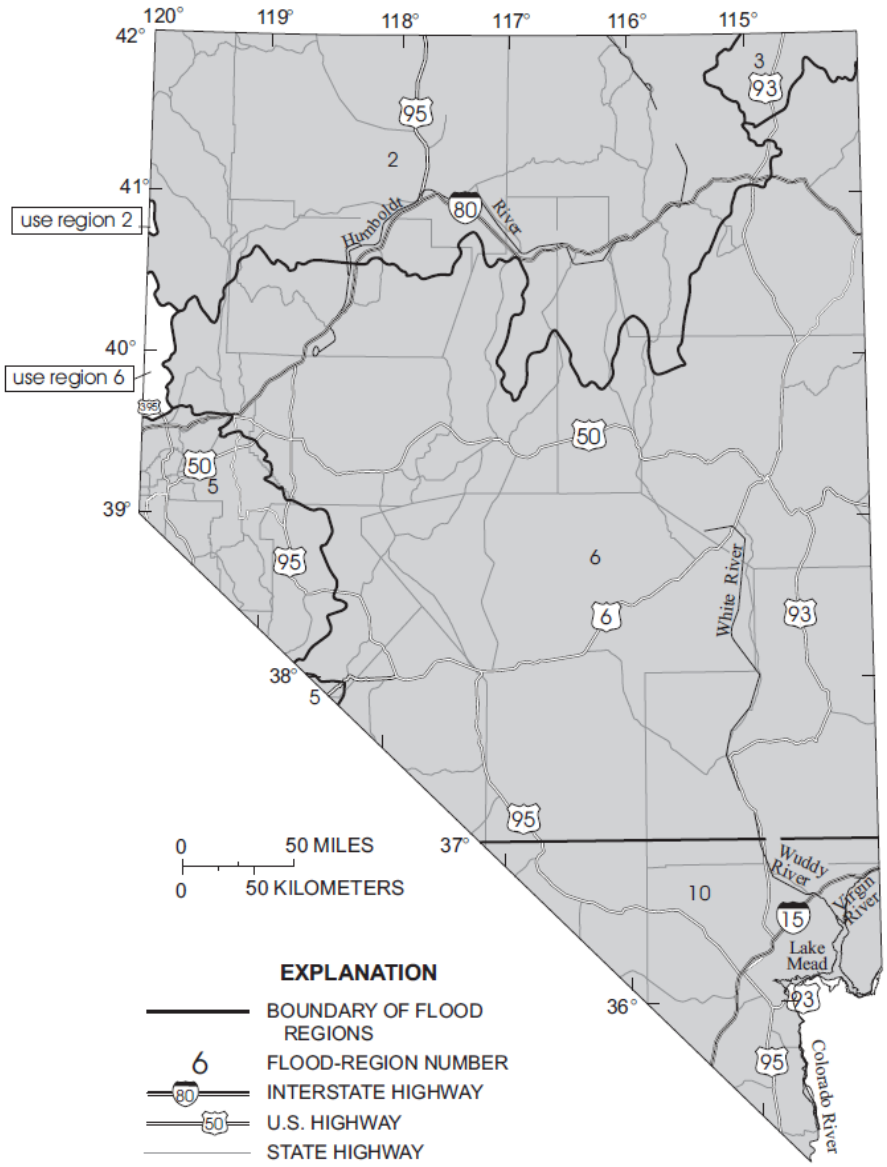
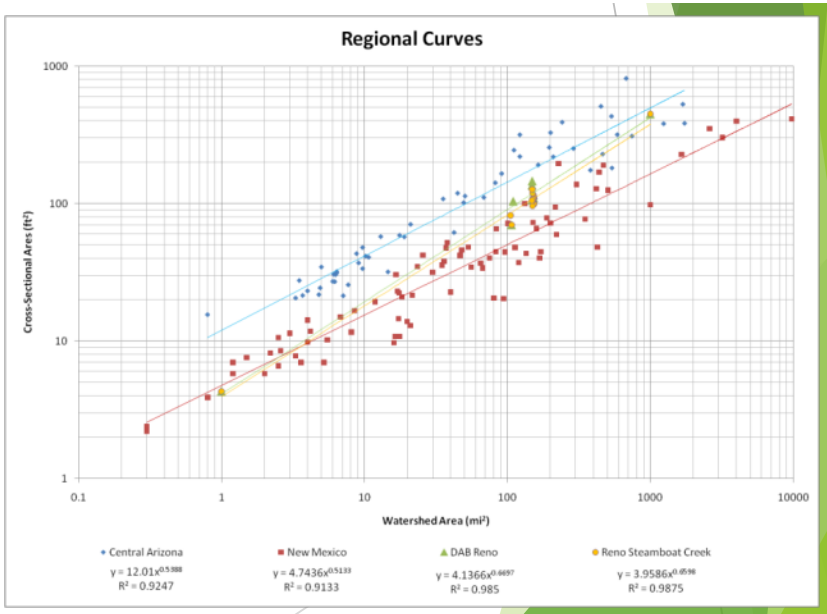


Regression equation	Estimated average standard error of regression, in log units	Equivalent years of record
Region 6 - 80 stations		
$Q_2 = 0$	--	--
$Q_5 = 32AREA^{0.80}(ELEV/1,000)^{-0.66}$	1.47	0.233
$Q_{10} = 590AREA^{0.62}(ELEV/1,000)^{-1.6}$	1.12	.748
$Q_{25} = 3,200AREA^{0.62}(ELEV/1,000)^{-2.1}$	.796	2.52
$Q_{50} = 5,300AREA^{0.64}(ELEV/1,000)^{-2.1}$	1.10	1.75
$Q_{100} = 20,000AREA^{0.51}(ELEV/1,000)^{-2.3}$	1.84	.794
Region 10 - 104 stations		
$Q_2 = 12\ AREA^{0.58}$	1.14	0.618
$Q_5 = 85\ AREA^{0.59}$	.602	3.13
$Q_{10} = 200\ AREA^{0.62}$	.675	3.45
$Q_{25} = 400\ AREA^{0.65}$	.949	2.49
$Q_{50} = 590\ AREA^{0.67}$	.928	3.22
$Q_{100} = 850\ AREA^{0.69}$	1.23	2.22



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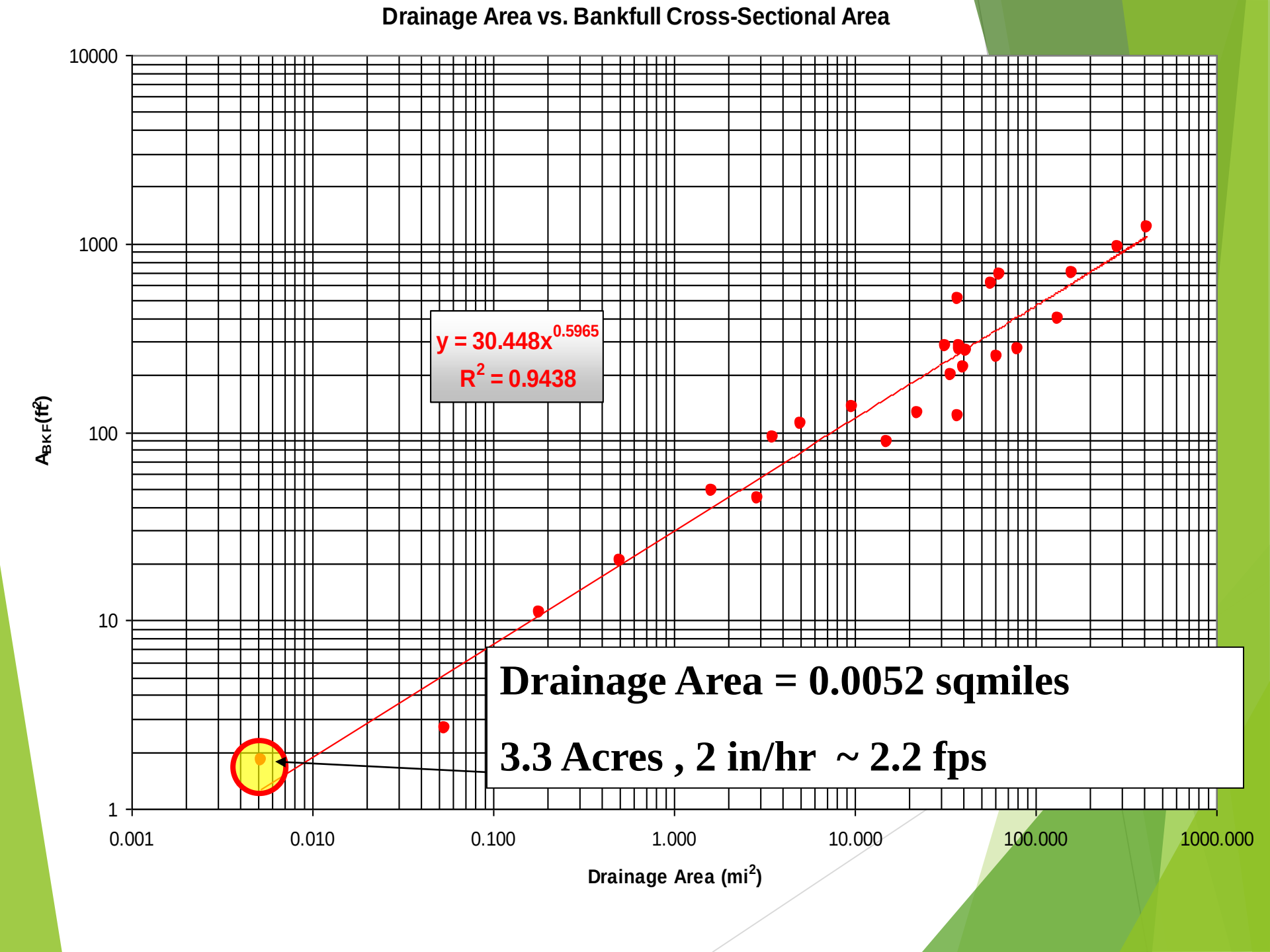
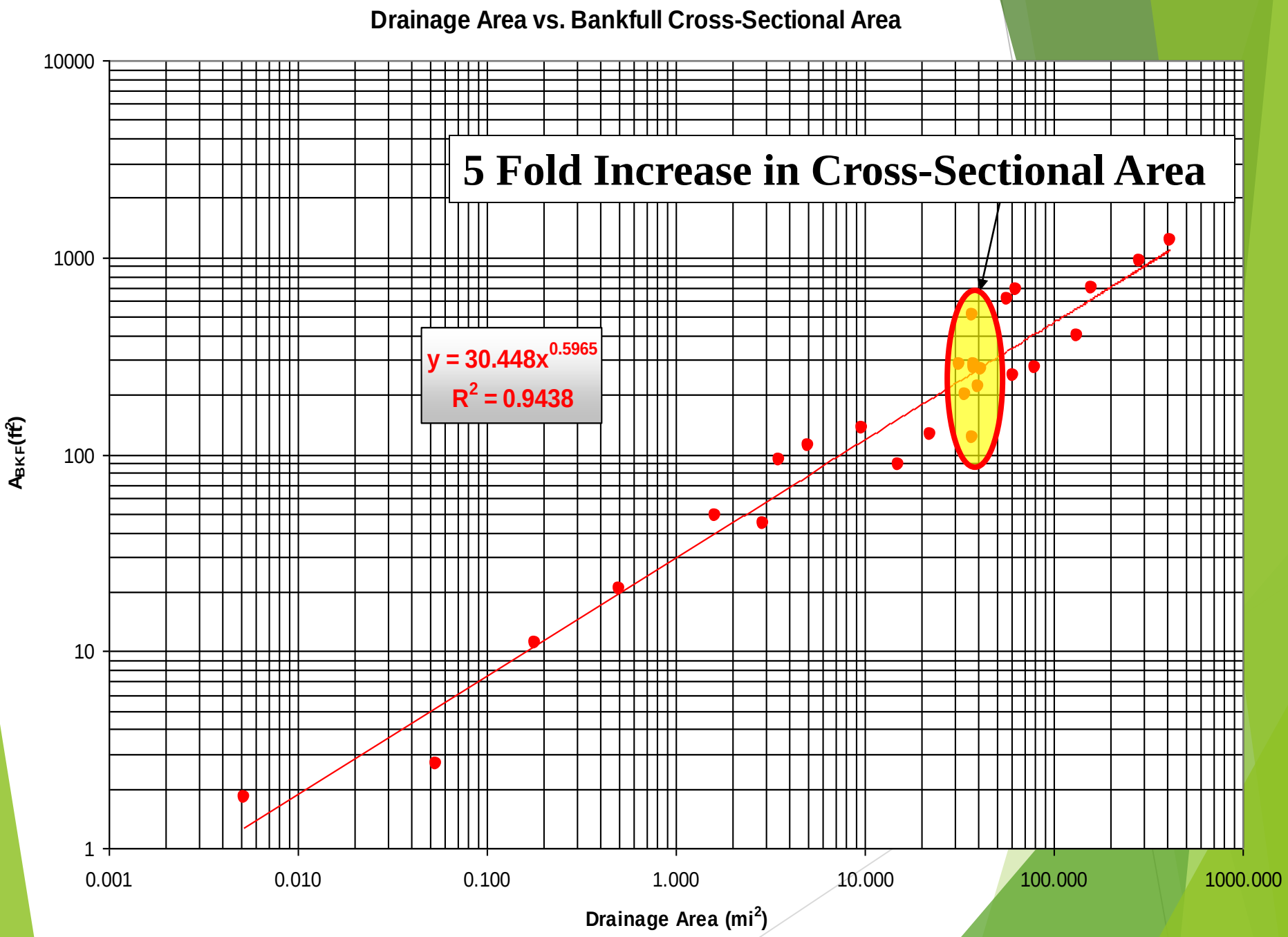
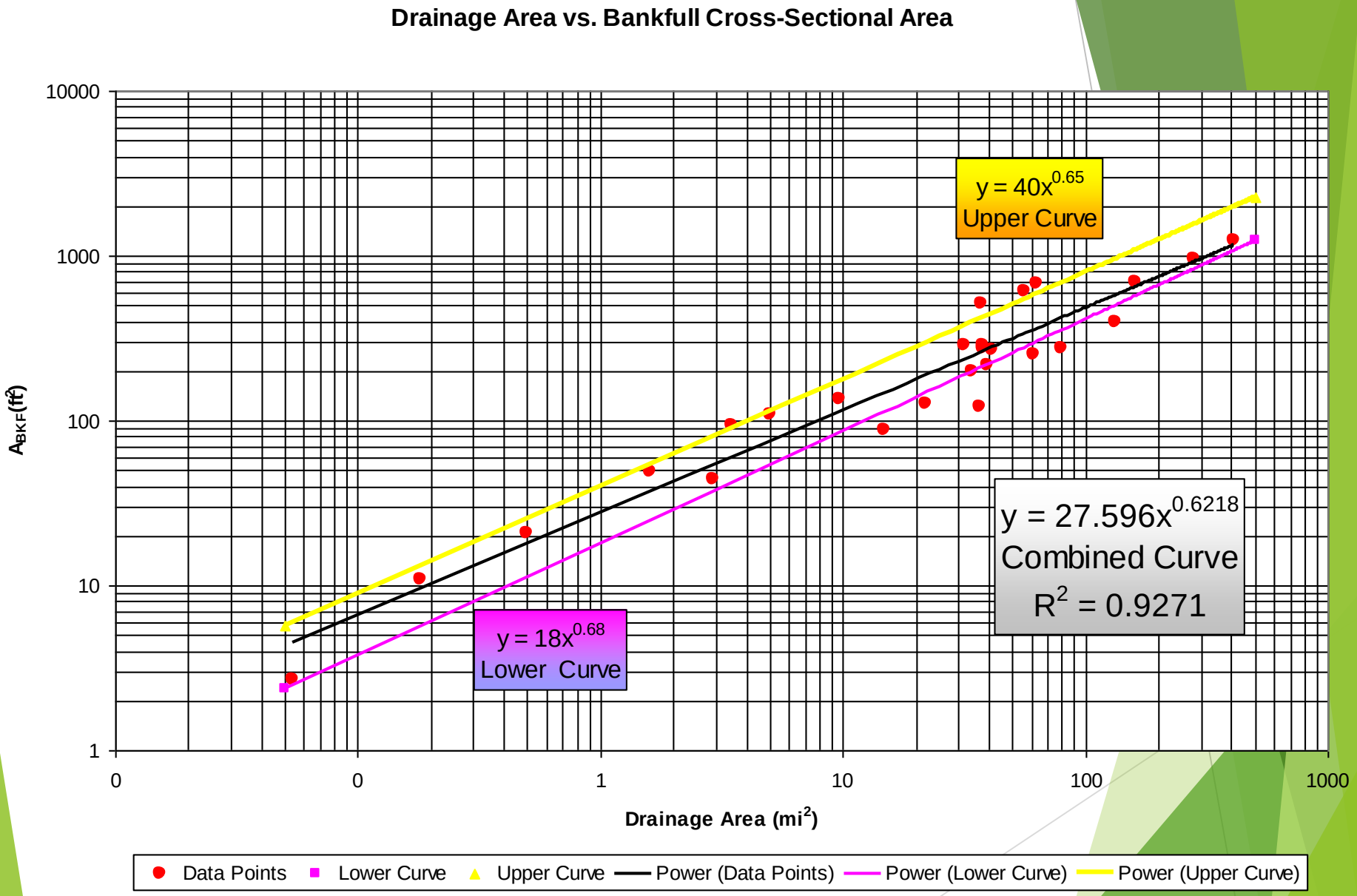
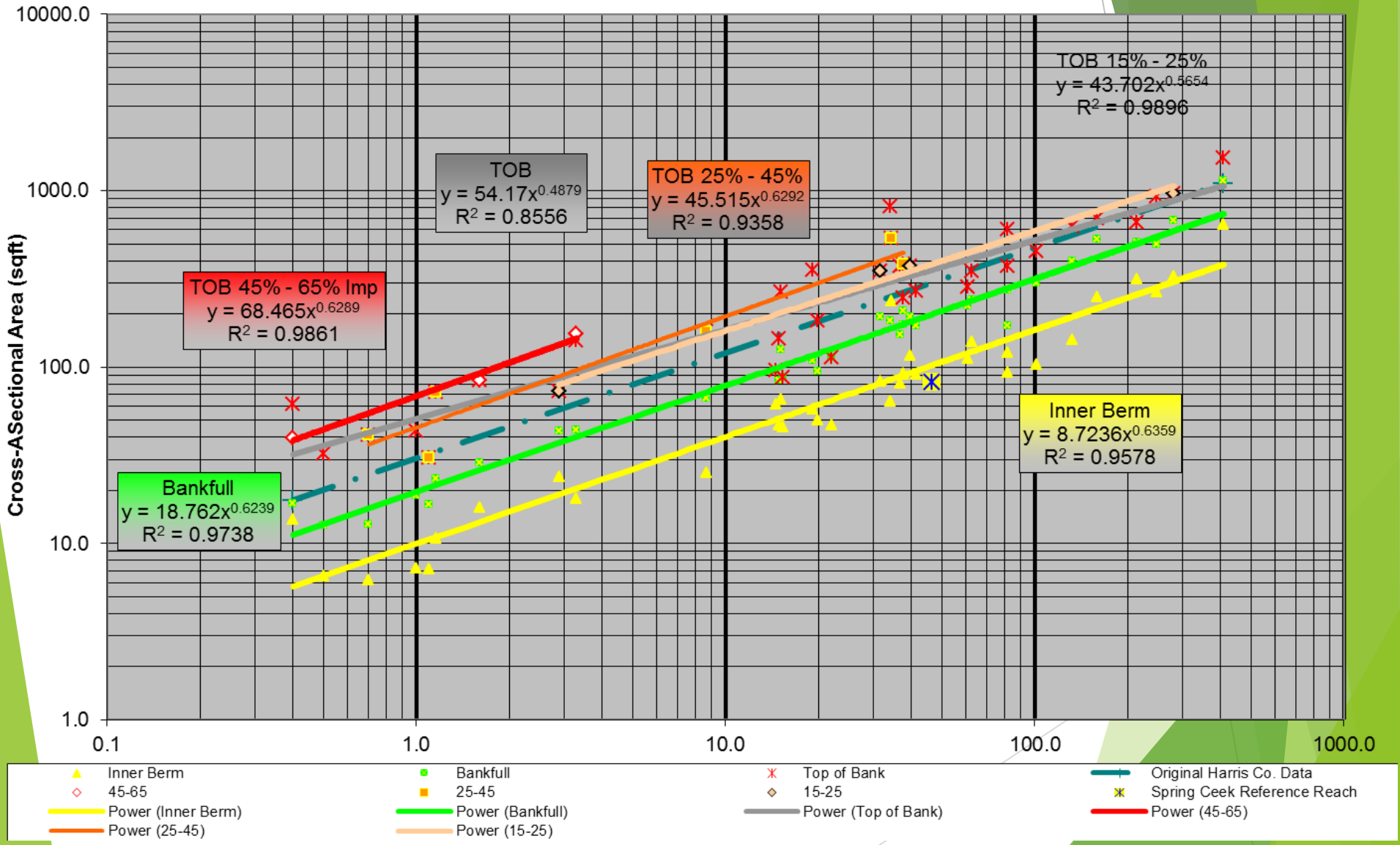
Questionable Data


Drainage Area vs. Bankfull Cross-Sectional Area
10000
1000
100
10
1
A_{BKF}(ft²)
y = 30.448x^0.5965
R² = 0.9438
Drainage Area = 0.0052 sqmiles
3.3 Acres , 2 in/hr ~ 2.2 fps
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Drainage Area (mi²)


Drainage Area vs. Bankfull Cross-Sectional Area
5 Fold Increase in Cross-Sectional Area
y = 30.448x^0.5965
R^2 = 0.9438
10000
1000
100
10
1
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
A_BKF (ft^2)
Drainage Area (mi^2)


Drainage Area vs. Bankfull Cross-Sectional Area
10000
1000
100
10
1
A_{BKF}(ft²)
0
0
1
10
100
1000
Drainage Area (mi²)
y = 40x^0.65
Upper Curve
y = 27.596x^0.6218
Combined Curve
R² = 0.9271
y = 18x^0.68
Lower Curve
Data Points
Lower Curve
Upper Curve
Power (Data Points)
Power (Lower Curve)
Power (Upper Curve)

Harris County 12-09-08
Regional Curve (DAB)

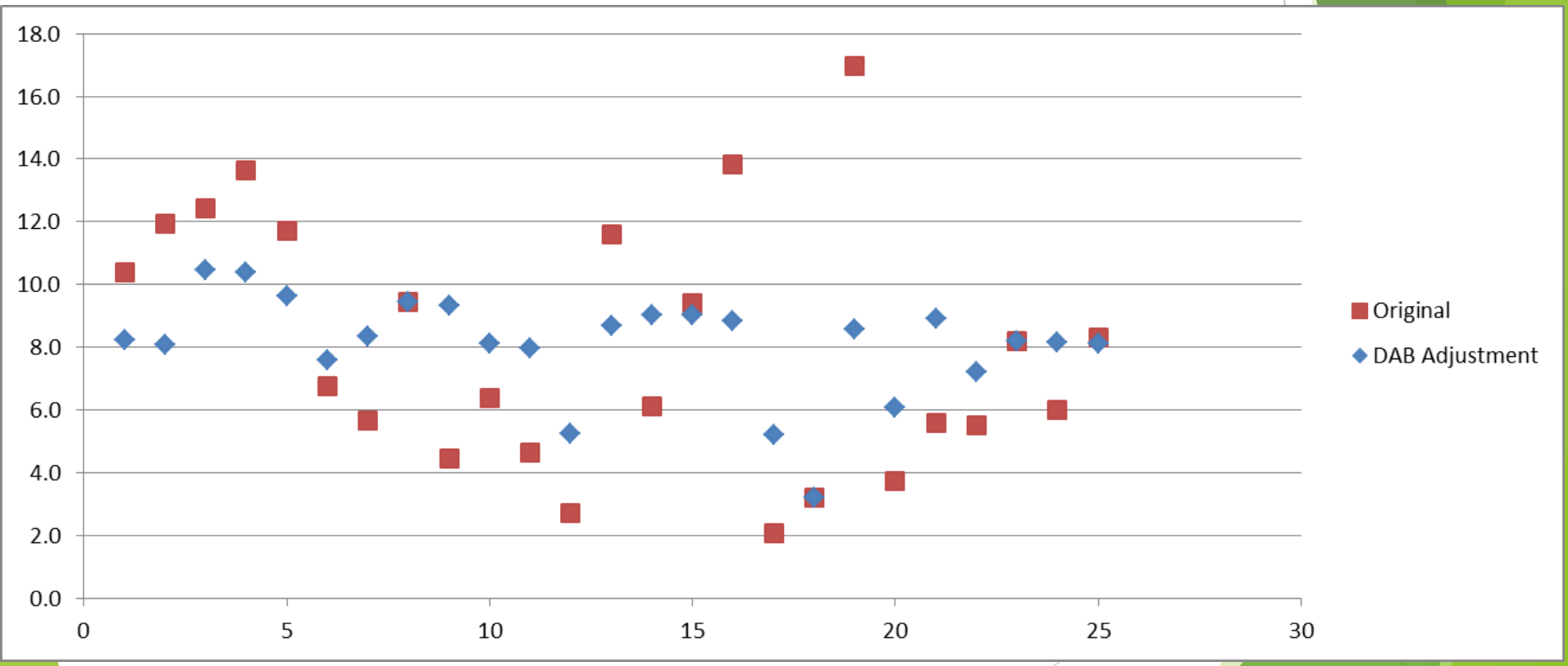


Gage Station ID	Stream Name	Stream Type	Drainage Area (sq mi)		C_2	Original XS Area	C_1	Discharge (cfs)
06301480	Coney Creek above Twin Lakes near Big Horn, WY	E4	3	2.1	8.2	21.7	10.4	6
09253400	Battle Creek near Encampment, WY	B3	13	5.6	8.1	66.6	11.9	28
06300500	East Fork Big Goose Creek near Big Horn, WY	B3c	20	7.4	10.5	92.6	12.4	39
06278300	Shell Creek above Shell Creek Reservoir, WY	C4	23	8.2	10.4	111.4	13.6	35
06301500	West Fork Big Goose Creek near Big Horn, WY	B3	24	8.4	9.6	98.4	11.7	36
06311000	North Fork Powder River near Hazelton, WY	B3c	25	8.6	7.6	58.4	6.8	26
06222700	Crow Creek near Tipperary, WY	C3	30	9.8	8.4	55.4	5.7	24
06622700	North Brush Creek near Saratoga, WY	B3	37	11.2	9.5	106.2	9.5	55
06299500	Wolf Creek at Wolf, WY	B3	38	11.4	9.3	51.0	4.5	19
06309200	Middle Fork Powder River near Barnum, WY	B3	45	12.8	8.1	81.6	6.4	39
06222500	Dry Creek near Burris, WY	B3	54	14.5	8.0	67.1	4.6	34
06223500	Willow Creek near Crowheart, WY	B3c	55	14.7	5.3	39.9	2.7	13
06632400	Rock Creek above King Canyon Canal near Arlington, WY	B3	63	16.1	8.7	186.0	11.6	103
06647500	Box Elder Creek at Boxelder, WY	B3c	63	16.1	9.0	98.5	6.1	39
06623800	Encampment River above Hog Park Creek near Encampment, WY	B3c	73	17.7	9.0	166.8	9.4	83
09203000	East Fork River near Big Sandy, WY	B3c	79	18.7	8.9	258.7	13.8	106
06265337	Cottonwood Cr at High Island Ranch nr Hamilton Dome	B4c	81	19.0	5.2	39.3	2.1	23
06260000	South Fork Owl Creek near Anchor, WY	B3c	87	19.9	3.2	63.8	3.2	32
06228350	South Fork Little Wind River above Reservoir near Ft Washakie,	B4c	90	20.4	8.6	346.0	17.0	95
06233000	Little Popo Agie River near Lander, WY	B3c	125	25.4	6.1	95.0	3.7	48
06646000	Deer Creek in Canyon near Glenrock, WY	B3c	139	27.3	8.9	152.7	5.6	69
06218500	Wind River near Dubois, WY	B3c	232	38.4	7.2	212.5	5.5	100
06280300	South Fork Shoshone River near Valley, WY	B3c	297	45.4	8.2	371.2	8.2	340
06220500	East Fork Wind River near Dubois, WY	C3	427	57.9	8.2	347.8	6.0	254
06279940	North Fork Shoshone River at Wapiti, WY	F3	699	80.5	8.1	669.1	8.3	595
					8.1			

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

Watershed Response Factor "C"

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



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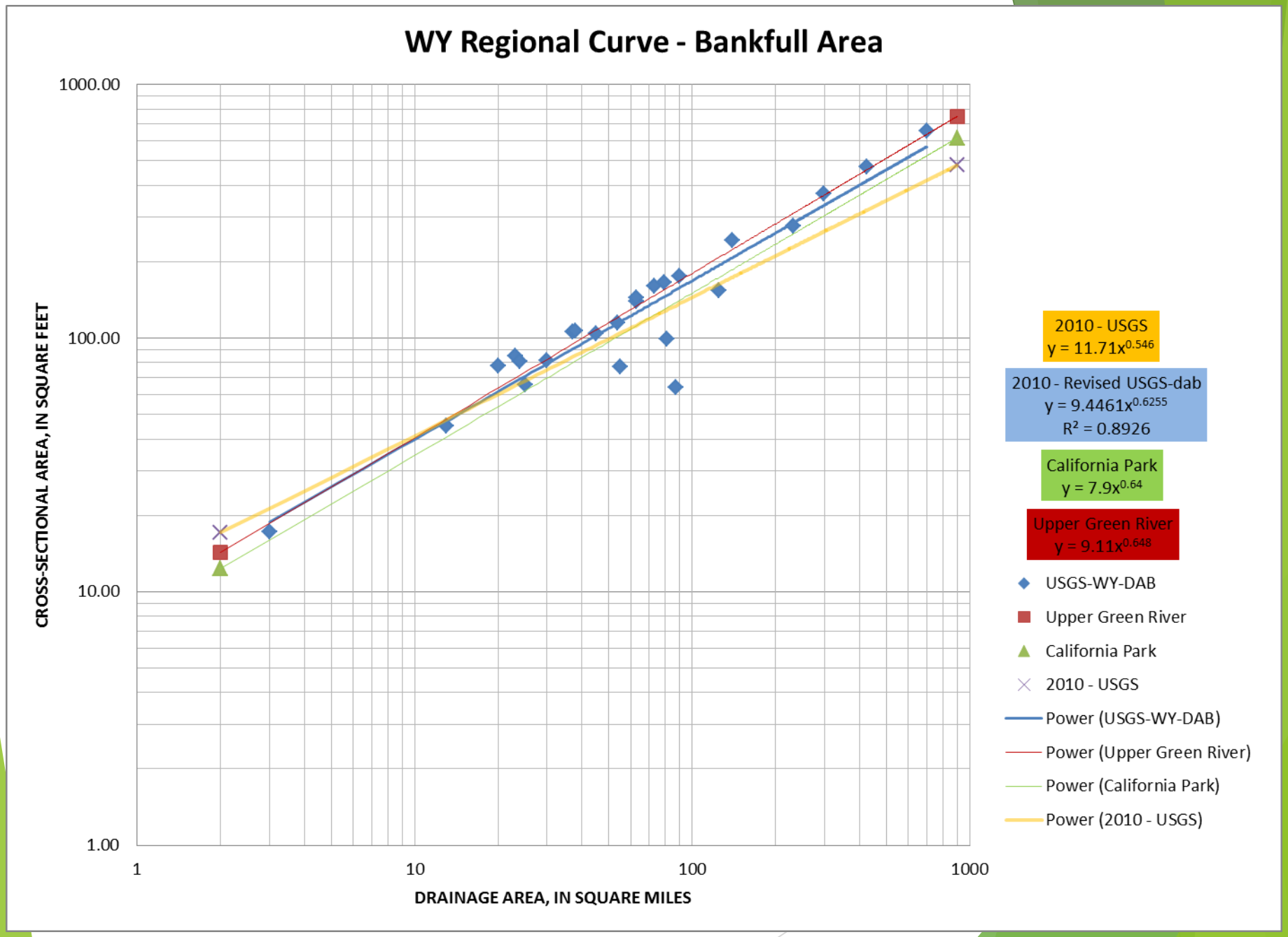
WY Regional Curve - Bankfull Area
1000.00
100.00
10.00
1.00
CROSS-SECTIONAL AREA, IN SQUARE FEET
1
10
100
1000
DRAINAGE AREA, IN SQUARE MILES
2010 - USGS
y = 11.71x^0.546
2010 - Revised USGS-dab
y = 9.4461x^0.6255
R² = 0.8926
California Park
y = 7.9x^0.64
Upper Green River
y = 9.11x^0.648
USGS-WY-DAB
Upper Green River
California Park
2010 - USGS
Power (USGS-WY-DAB)
Power (Upper Green River)
Power (California Park)
Power (2010 - USGS)

Use of Regional Curves

- Geomorphic assessment
  - Departure analysis
  - Watershed health
- Design
  - Conceptual design
    - Good use of published regional curves
  - Final design
    - Bad idea to use published regional curves
    - Create localized mini-regional curve for design watershed

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Localized Mini-Regional Curve

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

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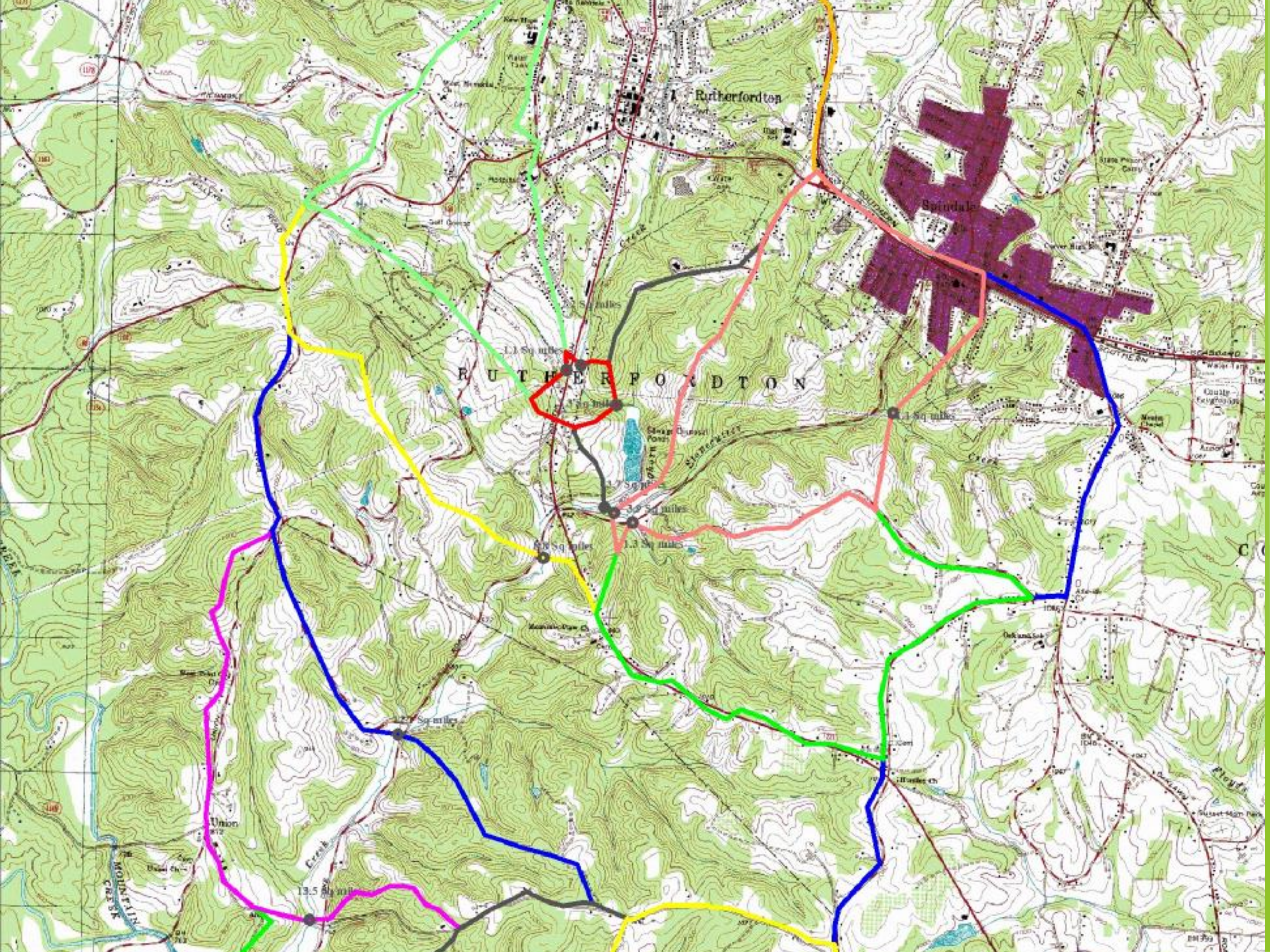
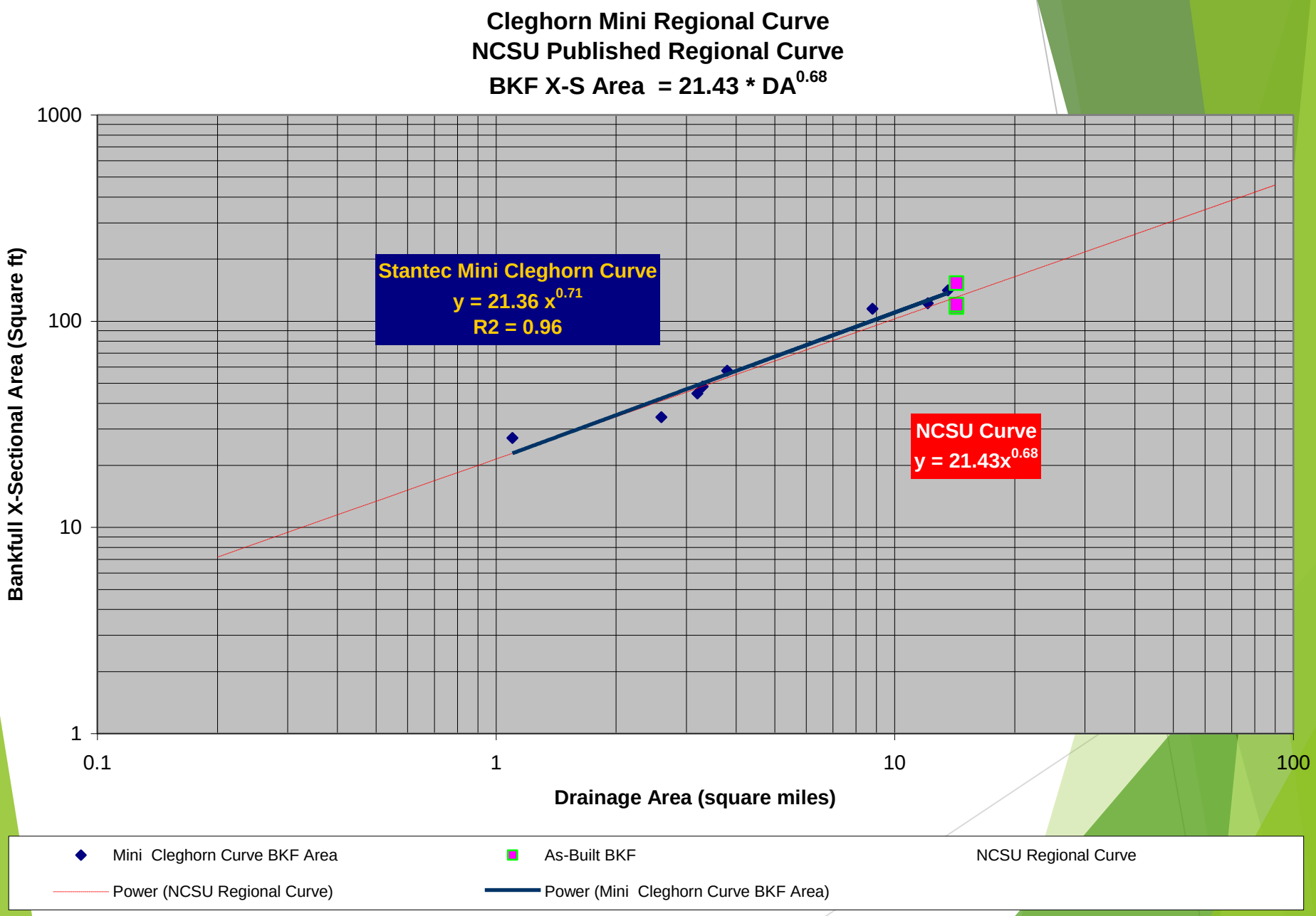
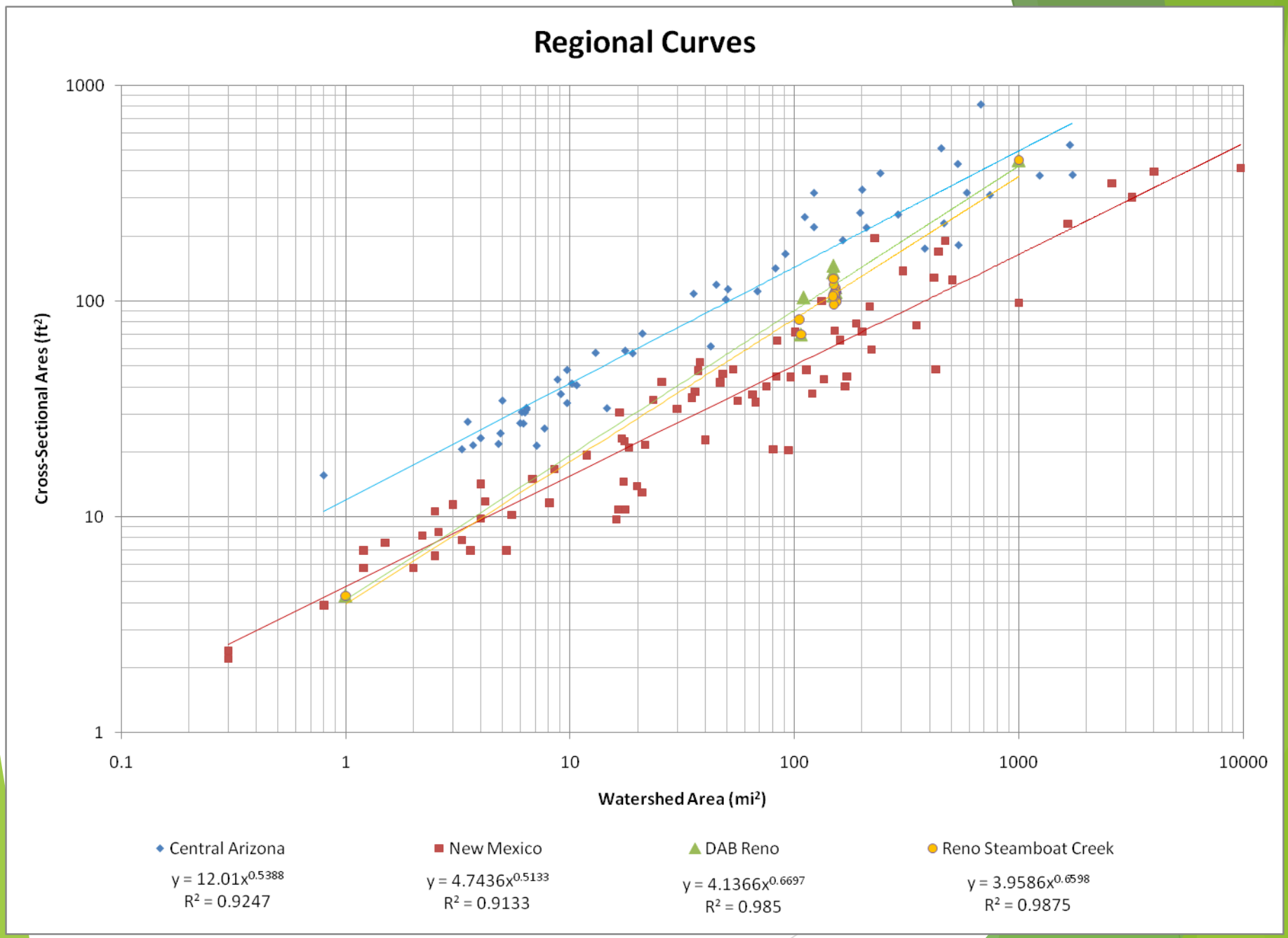
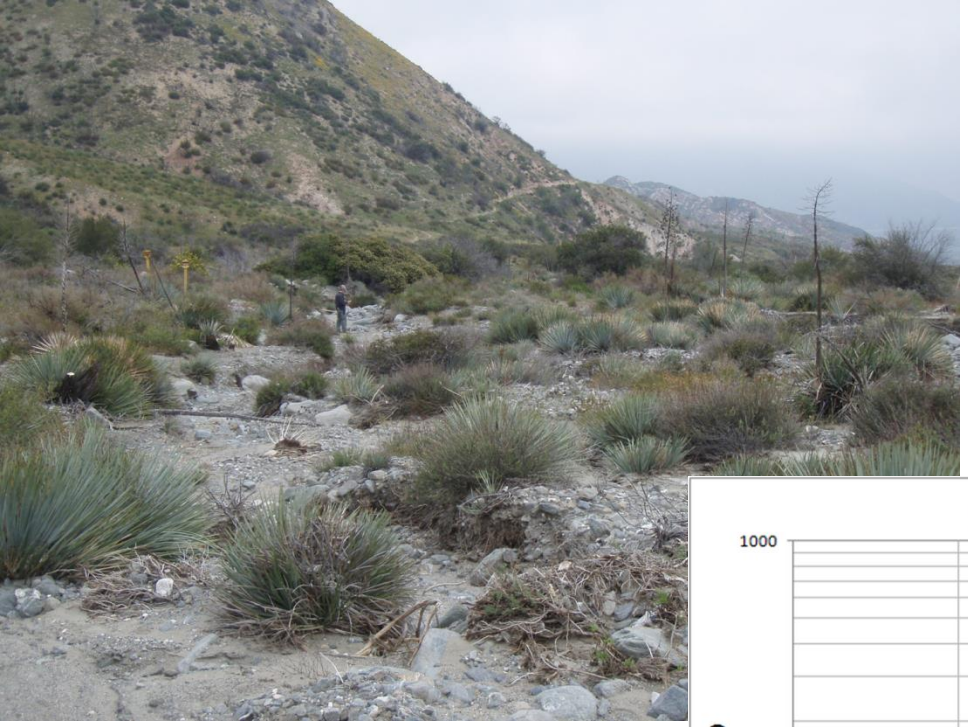
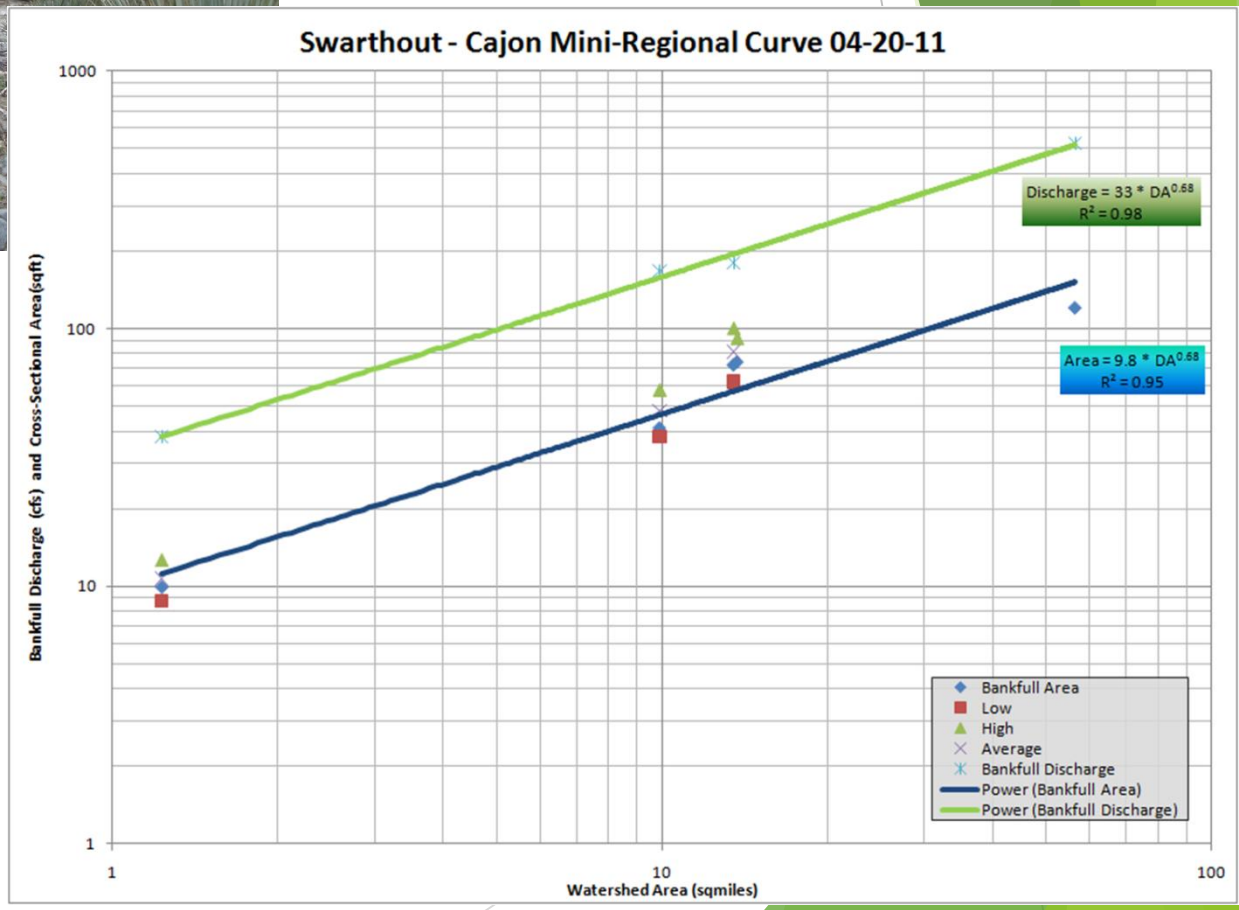


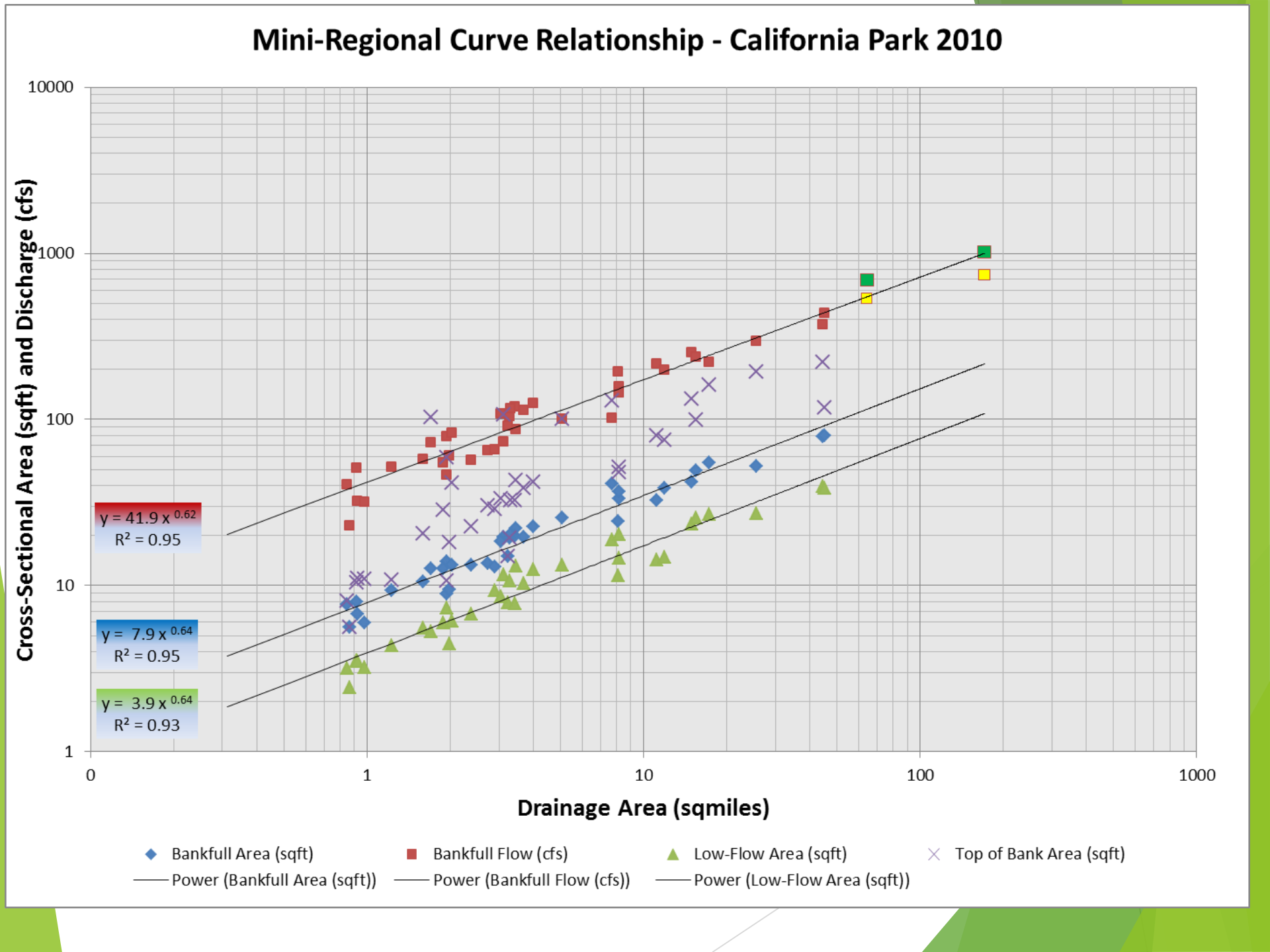
Rutherfordton
Spindale
R U T H E R F O R D T O N
1.1 Sq miles
1.3 Sq miles
Union
13.5 Sq miles


Cleghorn Mini Regional Curve
NCSU Published Regional Curve
BKF X-S Area = 21.43 * DA^0.68
Bankfull X-Sectional Area (Square ft)
1000
100
10
1
0.1
1
10
100
Drainage Area (square miles)
Stantec Mini Cleghorn Curve
y = 21.36 x^0.71
R2 = 0.96
NCSU Curve
y = 21.43x^0.68
Mini Cleghorn Curve BKF Area
As-Built BKF
NCSU Regional Curve
Power (NCSU Regional Curve)
Power (Mini Cleghorn Curve BKF Area)

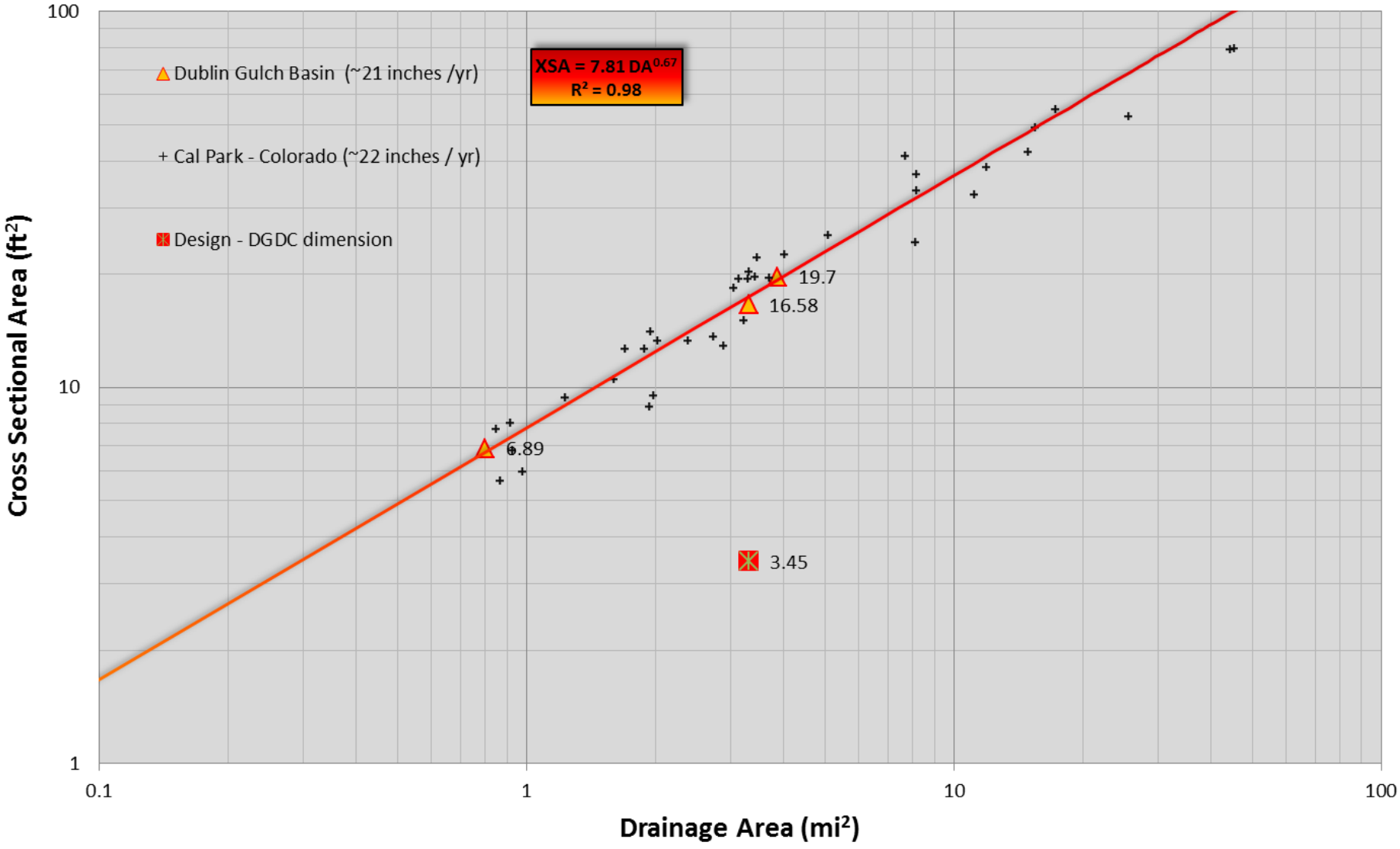

Regional Curves
1000
100
10
1
Cross-Sectional Ares (ft²)
0.1
1
10
100
1000
10000
Watershed Area (mi²)
Central Arizona
y = 12.01x^0.5388
R² = 0.9247
New Mexico
y = 4.7436x^0.5133
R² = 0.9133
DAB Reno
y = 4.1366x^0.6697
R² = 0.985
Reno Steamboat Creek
y = 3.9586x^0.6598
R² = 0.9875



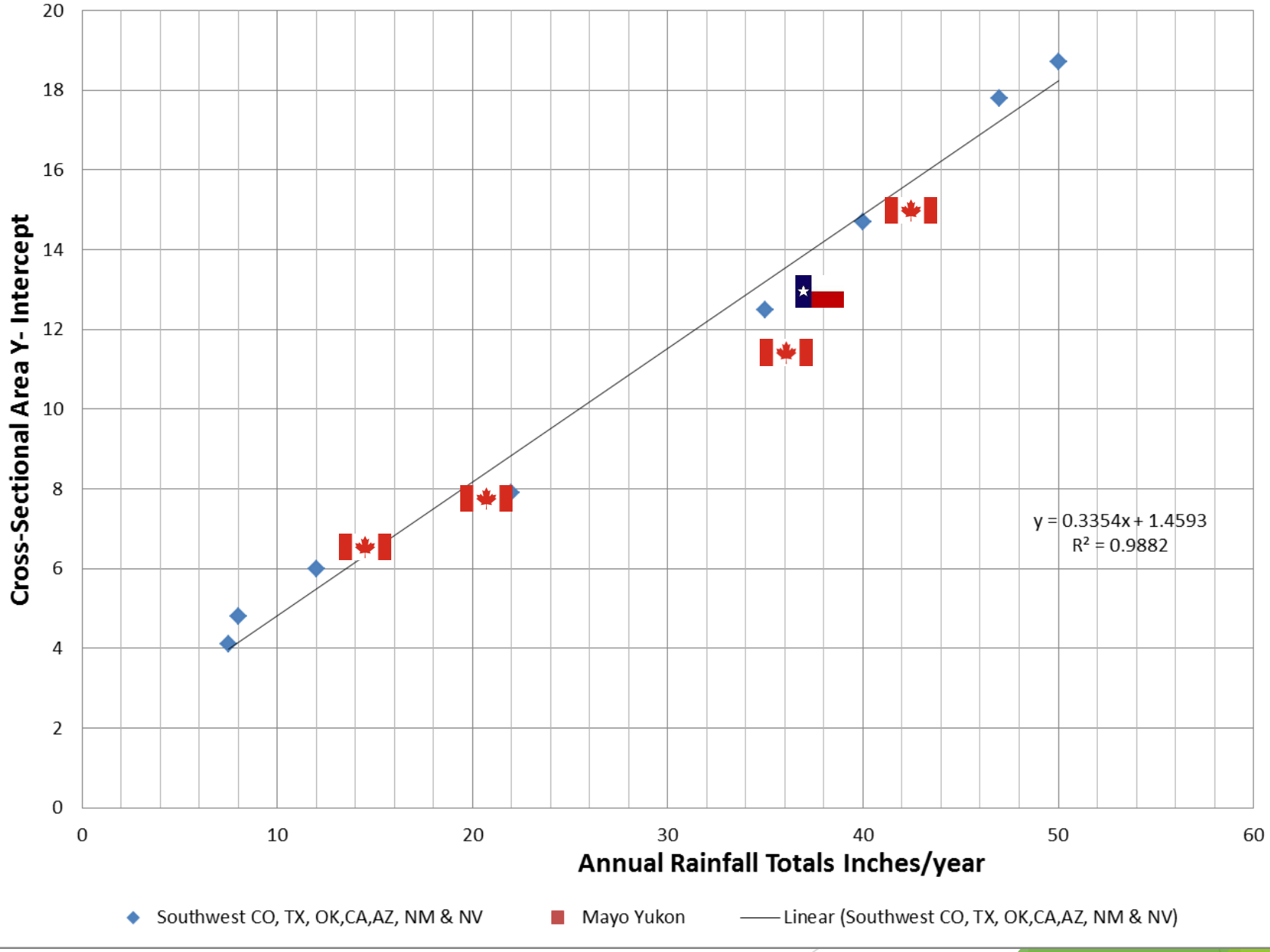

Swarthout - Cajon Mini-Regional Curve 04-20-11
Bankfull Discharge (cfs) and Cross-Sectional Area(sqft)
Watershed Area (sqmiles)
1000
100
10
1
1
10
100
Discharge = 33 * DA^0.68
R² = 0.98
Area = 9.8 * DA^0.68
R² = 0.95
Bankfull Area
Low
High
Average
Bankfull Discharge
Power (Bankfull Area)
Power (Bankfull Discharge)


Mini-Regional Curve Relationship - California Park 2010
Cross-Sectional Area (sqft) and Discharge (cfs)
10000
1000
100
10
1
0
1
10
100
1000
Drainage Area (sqmiles)
y = 41.9 x 0.62
R² = 0.95
y = 7.9 x 0.64
R² = 0.95
y = 3.9 x 0.64
R² = 0.93
Bankfull Area (sqft)
Bankfull Flow (cfs)
Low-Flow Area (sqft)
Top of Bank Area (sqft)
Power (Bankfull Area (sqft))
Power (Bankfull Flow (cfs))
Power (Low-Flow Area (sqft))

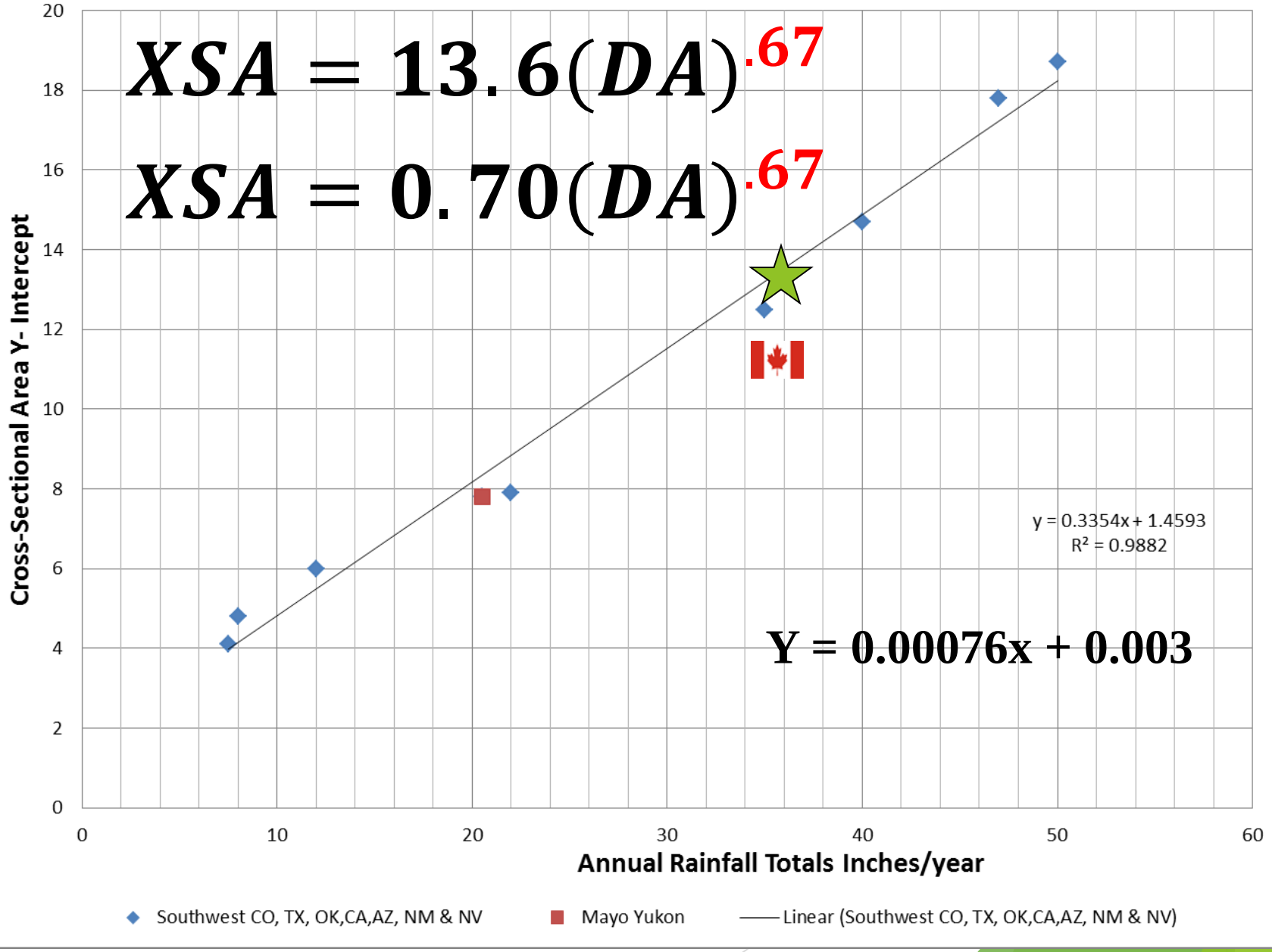
Dublin Gultch Basin -VIT
Watershed Regional Relationships



Watershed Response Factor – Y-Intercept



Watershed Response Factor – Y-Intercept
~36” (916mm) Waterloo, York-Durham and Peel



Taylor & Francis
Taylor & Francis Group

Canadian Water Resources Journal / Revue canadienne des ressources hydriques

$$XSA = 0.56(DA)^{.72}$$

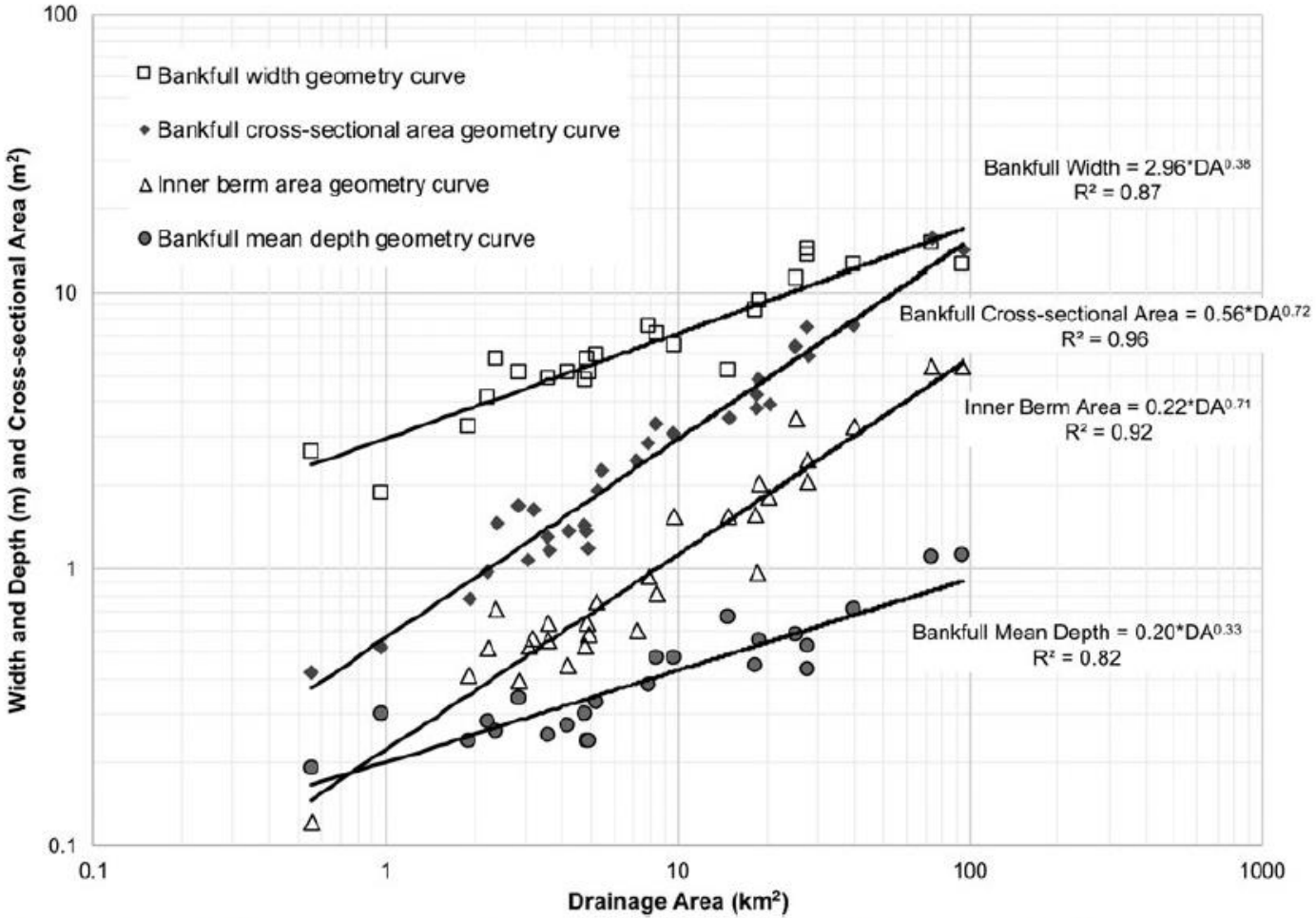
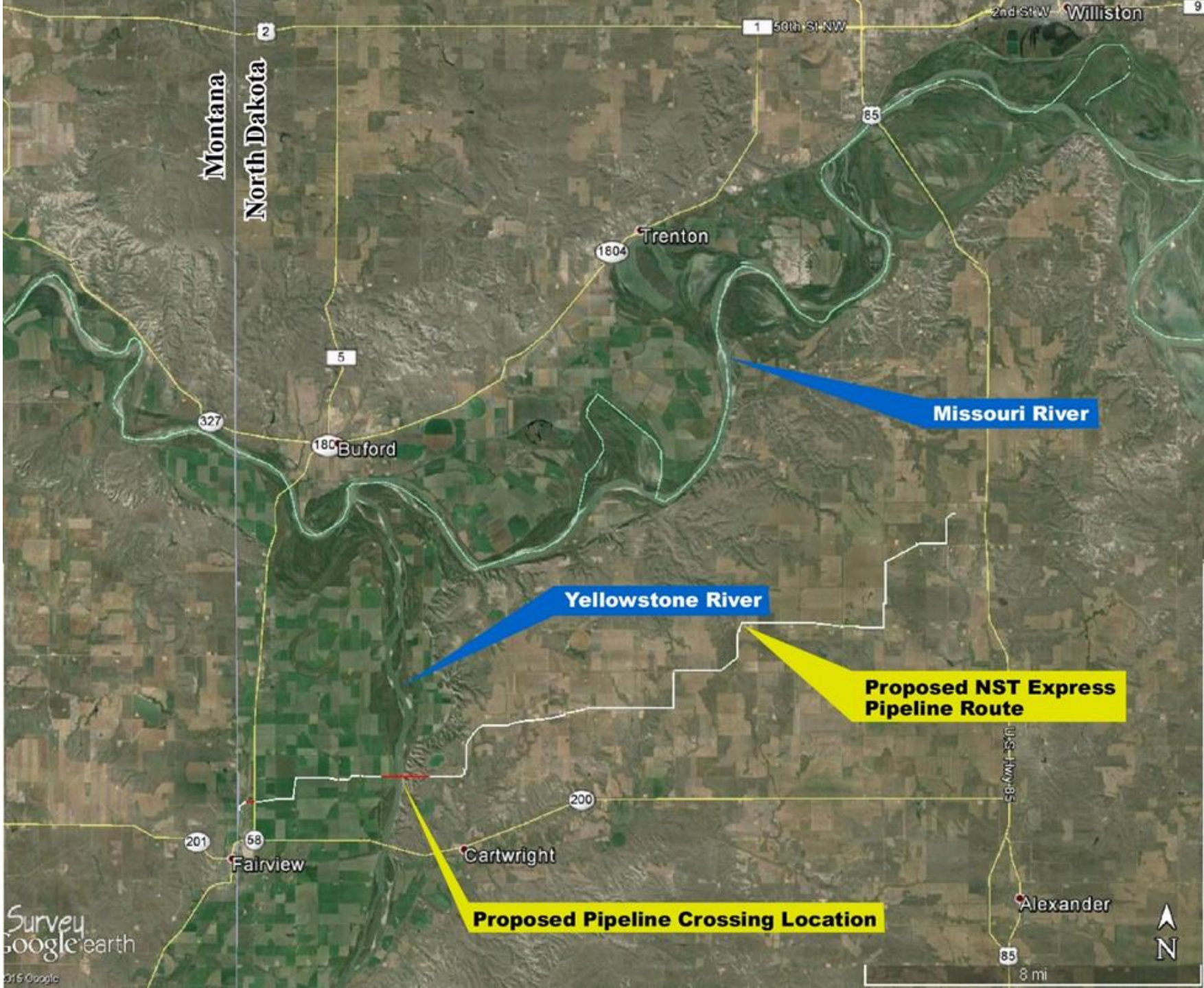
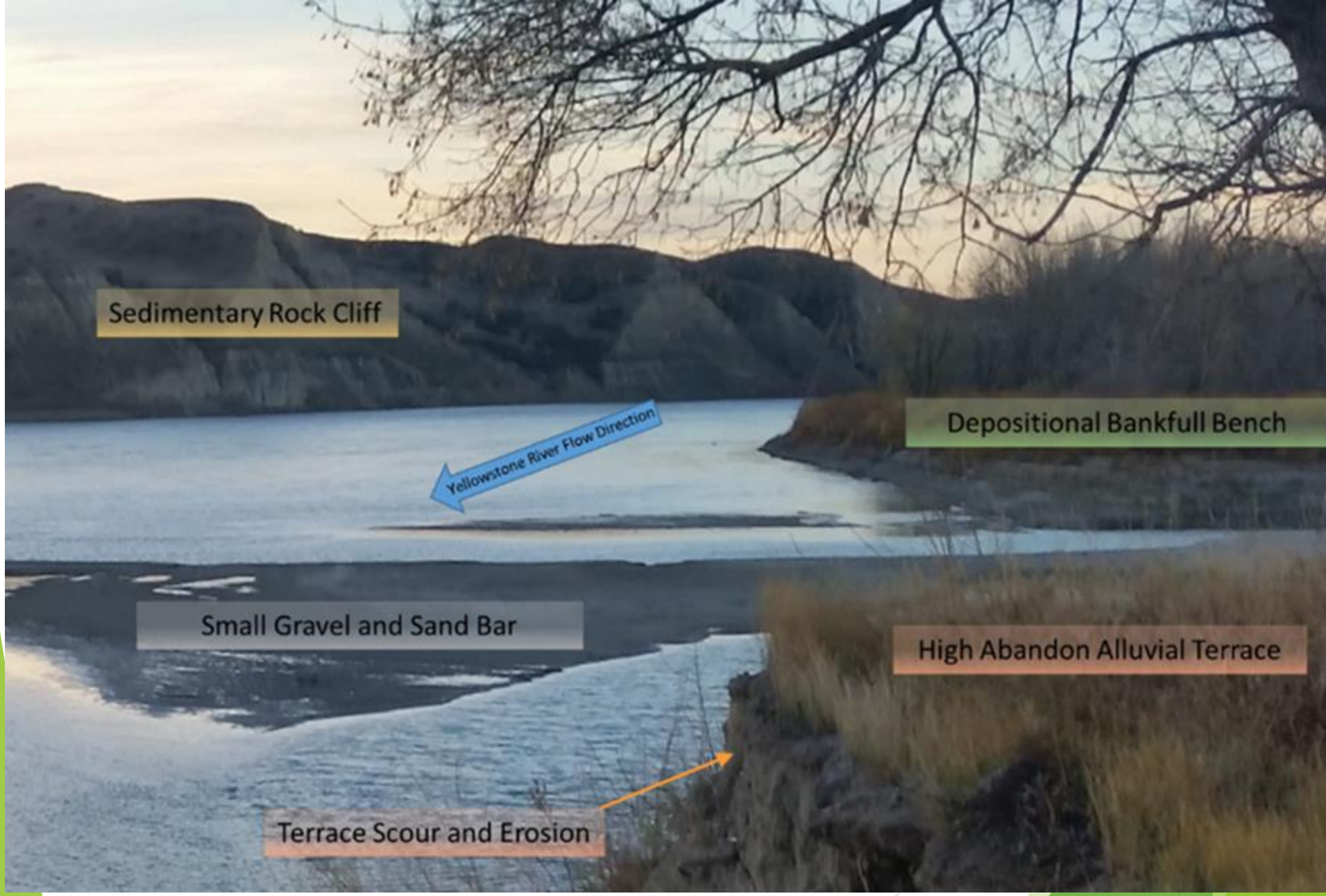
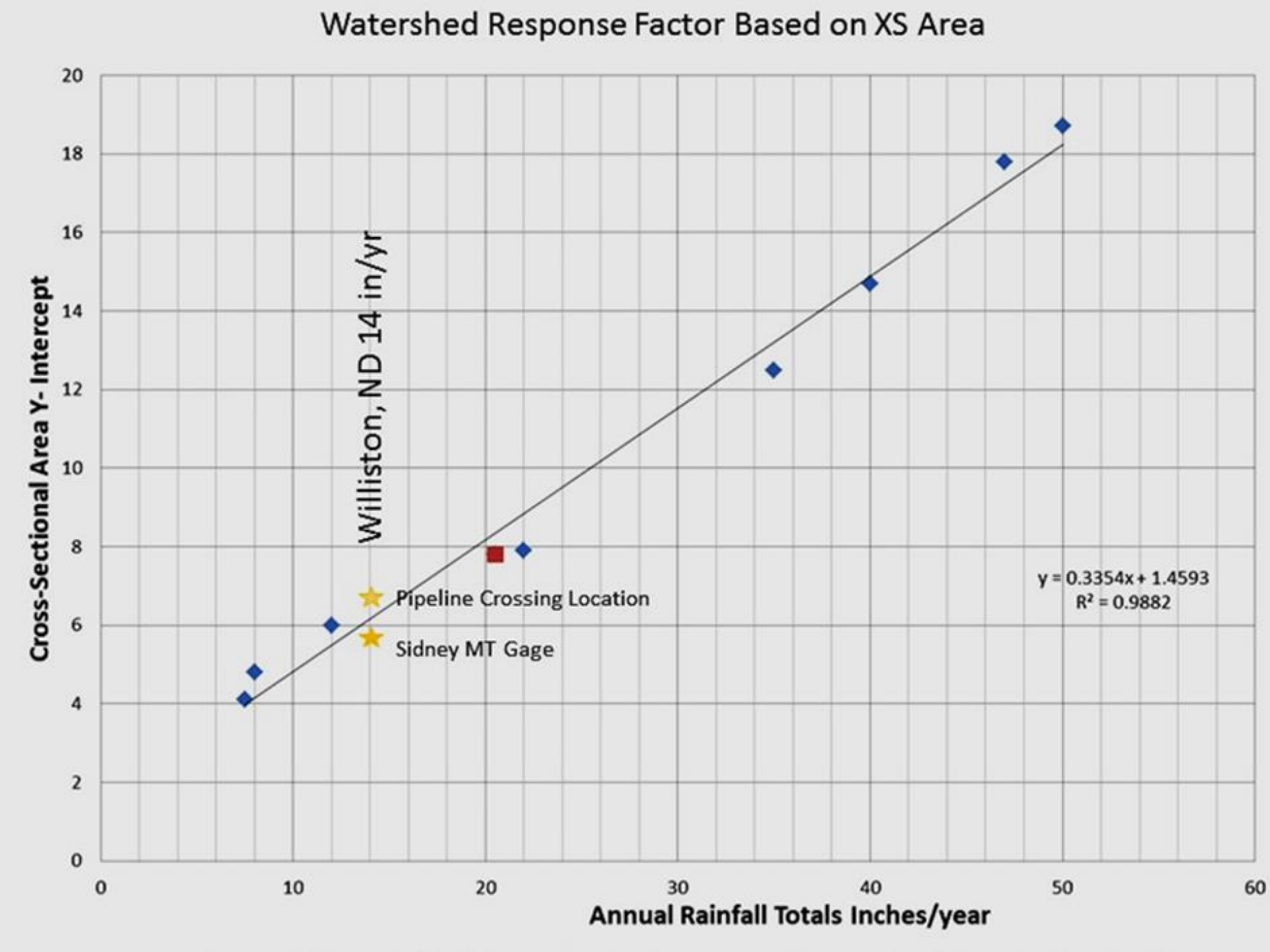
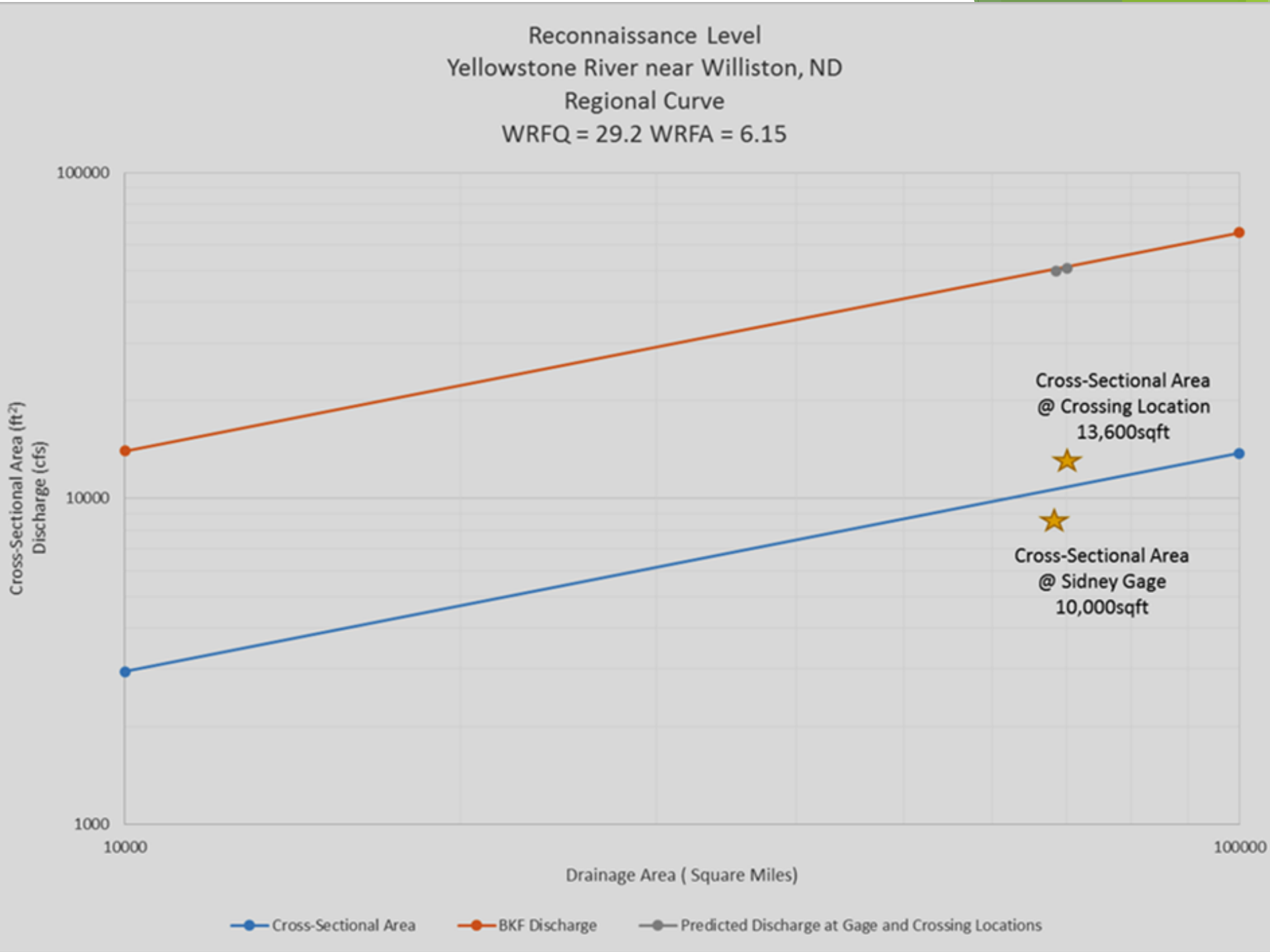


Figure 2. Composite hydraulic geometry curves for bankfull width, cross-sectional area, mean depth and inner berm cross-sectional area.


Montana
North Dakota
Williston
2nd St W
50th St NW
Trenton
1804
Buford
Missouri River
Yellowstone River
Proposed NST Express Pipeline Route
Proposed Pipeline Crossing Location
Cartwright
Fairview
Alexander
US-HWY-85
N
8 mi
Survey
Google earth


Sedimentary Rock Cliff
Yellowstone River Flow Direction
Depositional Bankfull Bench
Small Gravel and Sand Bar
High Abandon Alluvial Terrace
Terrace Scour and Erosion


Watershed Response Factor Based on XS Area
Cross-Sectional Area Y- Intercept
Annual Rainfall Totals Inches/year
Williston, ND 14 in/yr
Pipeline Crossing Location
Sidney MT Gage
y = 0.3354x + 1.4593
R² = 0.9882
0
2
4
6
8
10
12
14
16
18
20
0
10
20
30
40
50
60


Reconnaissance Level
Yellowstone River near Williston, ND
Regional Curve
WRFQ = 29.2 WRFA = 6.15
100000
10000
1000
Cross-Sectional Area (ft²)
Discharge (cfs)
Cross-Sectional Area
@ Crossing Location
13,600sqft
Cross-Sectional Area
@ Sidney Gage
10,000sqft
10000
100000
Drainage Area (Square Miles)
Cross-Sectional Area
BKF Discharge
Predicted Discharge at Gage and Crossing Locations

Take Home Points - Regional Curves

- 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
- Urban channel may require nested geomorphic channels

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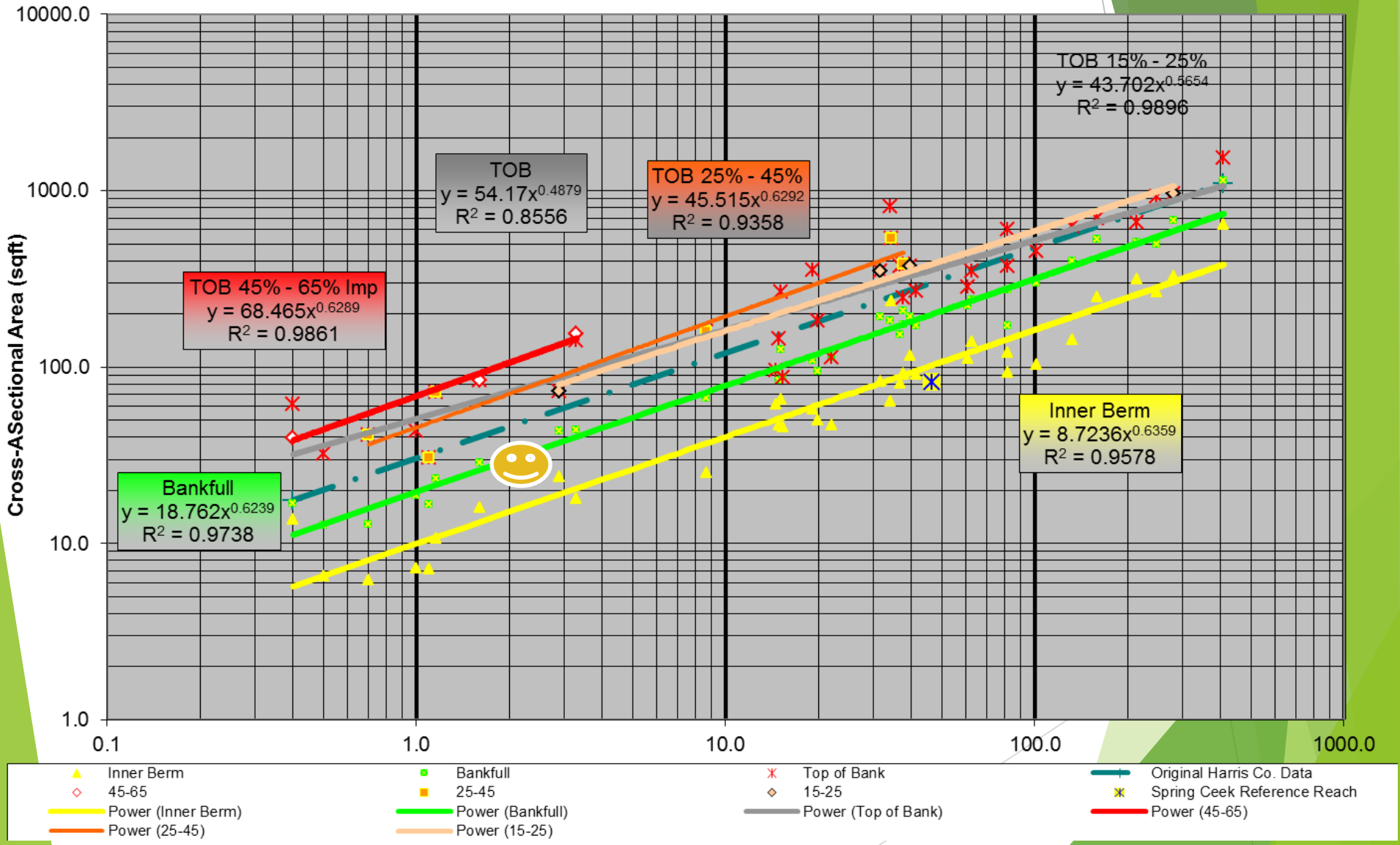
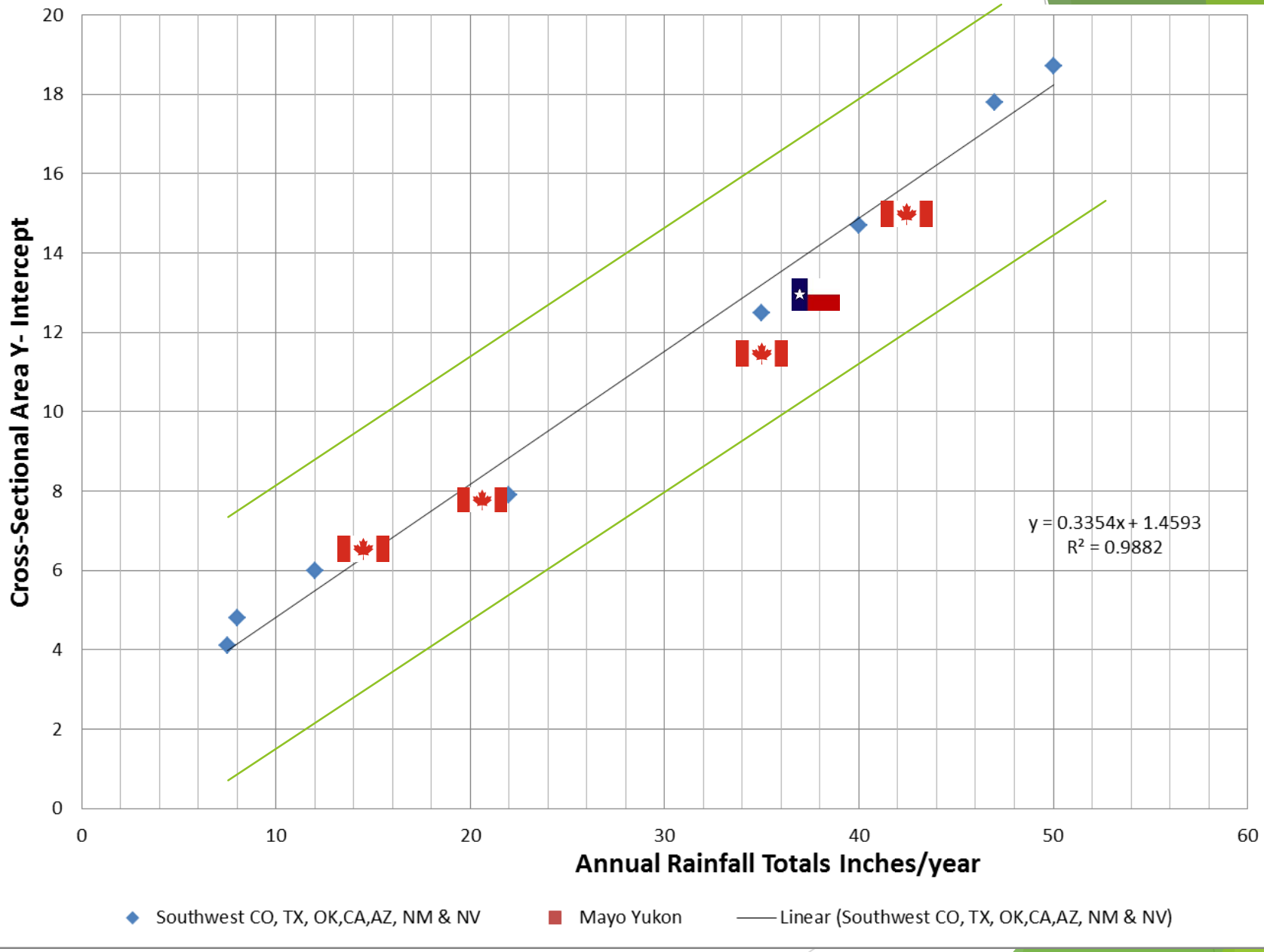
Take Home Points - Continued

- 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

Harris County 12-09-08
Regional Curve (DAB)



Watershed Response Factor – Y-Intercept



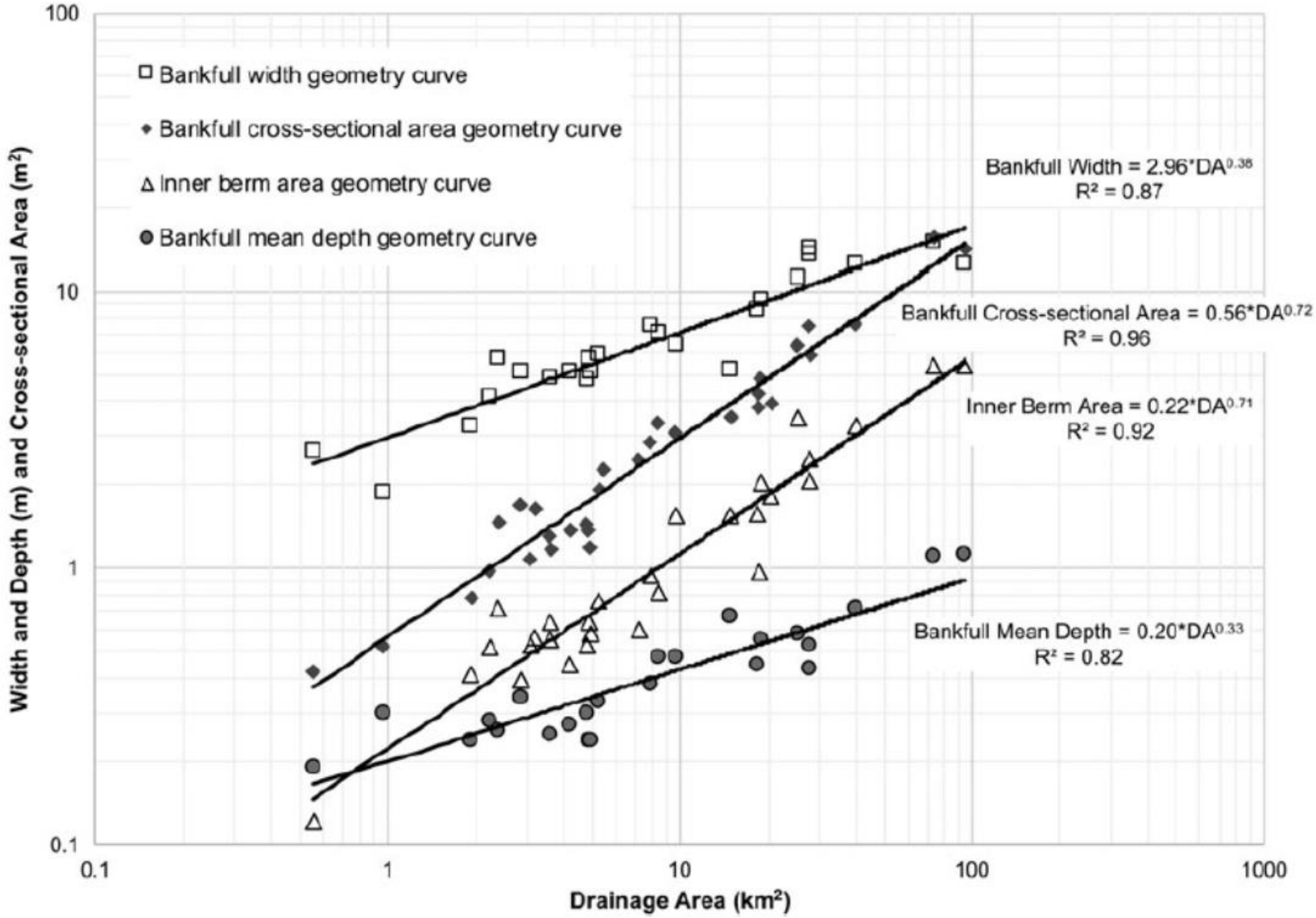


Figure 2. Composite hydraulic geometry curves for bankfull width, cross-sectional area, mean depth and inner berm cross-sectional area.

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