Regional Curves of Hydraulic Geometry for Wadeable Streams in Marin and Sonoma Counties San Francisco Bay Area

May 7, 2013

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Watershed Sciences

Background

- Funded in 2009 under EPA 2100 Grant for $30k and managed by SFEP
- Project Goals:
  - Update original Leopold curve for SF Bay Area for Marin and Sonoma for area/width/depth
  - Assess major factors (i.e. precip, geology, % urbanization) impact channels
  - Collected and analyzed 58 data points
- Phase I report analyzes for several variables
- [Hopefully] a Phase II to further stratify and analyze data

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The Hydraulic Geometry of Stream Channels and Some Physiographic

The Virtual Luna Leopold Project

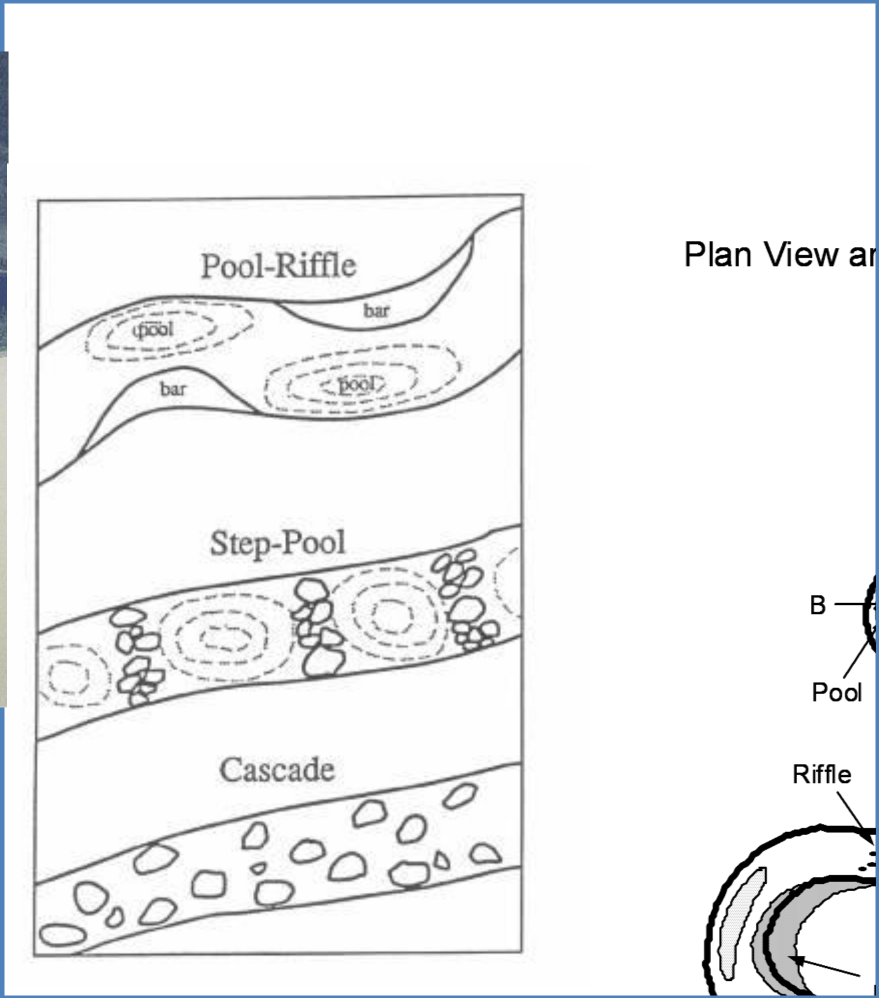
On February 23, 2006, Luna Leopold died at the age of 90. Luna was a vital force, a man of extraordinary creativity and originality, whose passion about science and the natural world permeated all he did. He wrote with a clarity, simplicity, and insightfulness that inspired generations of researchers. Nearly all of Luna's papers precede the time when publishing houses make pdf's available. In order to avoid Luna's seminal papers becoming “classics” (papers often cited but never read), we have created a web page where the majority of Luna's papers have been scanned and made available on line as pdf's. Luna assisted with this work, reviewing the publication list and helping us find originals of papers.

GEOLOGICAL SURVEY PROFESSIONAL PAPER 252

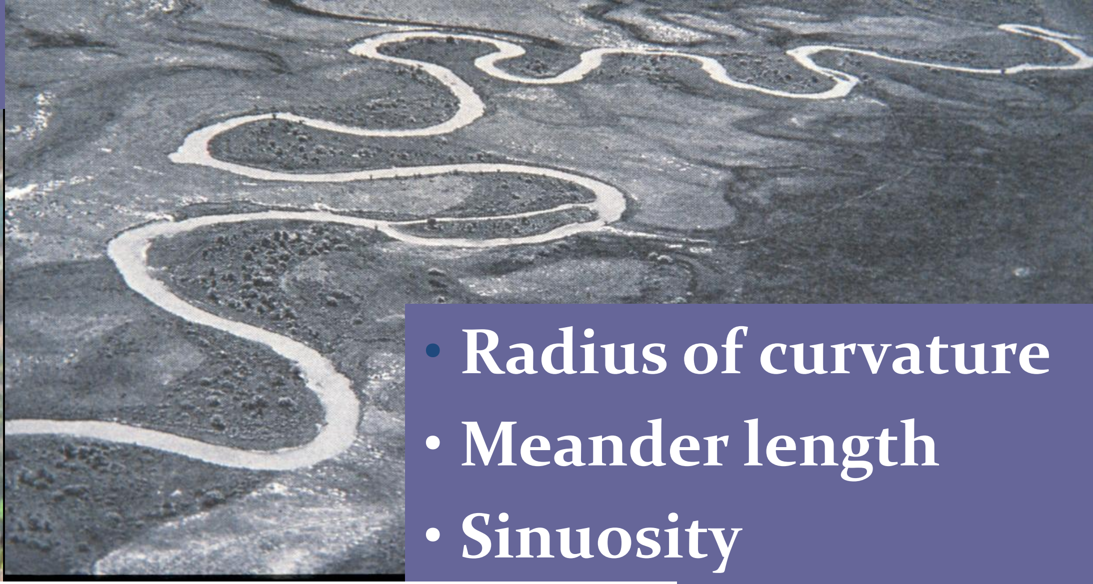
Quantitative measurement of some of the hydraulic factors that help to determine the shape of natural stream channels: depth, width, velocity, and suspended load, and how they vary with discharge as simple power functions. Their interrelations are described by the term “hydraulic geometry.”

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C[redacted]ents (paper cover)
Price 40 cents

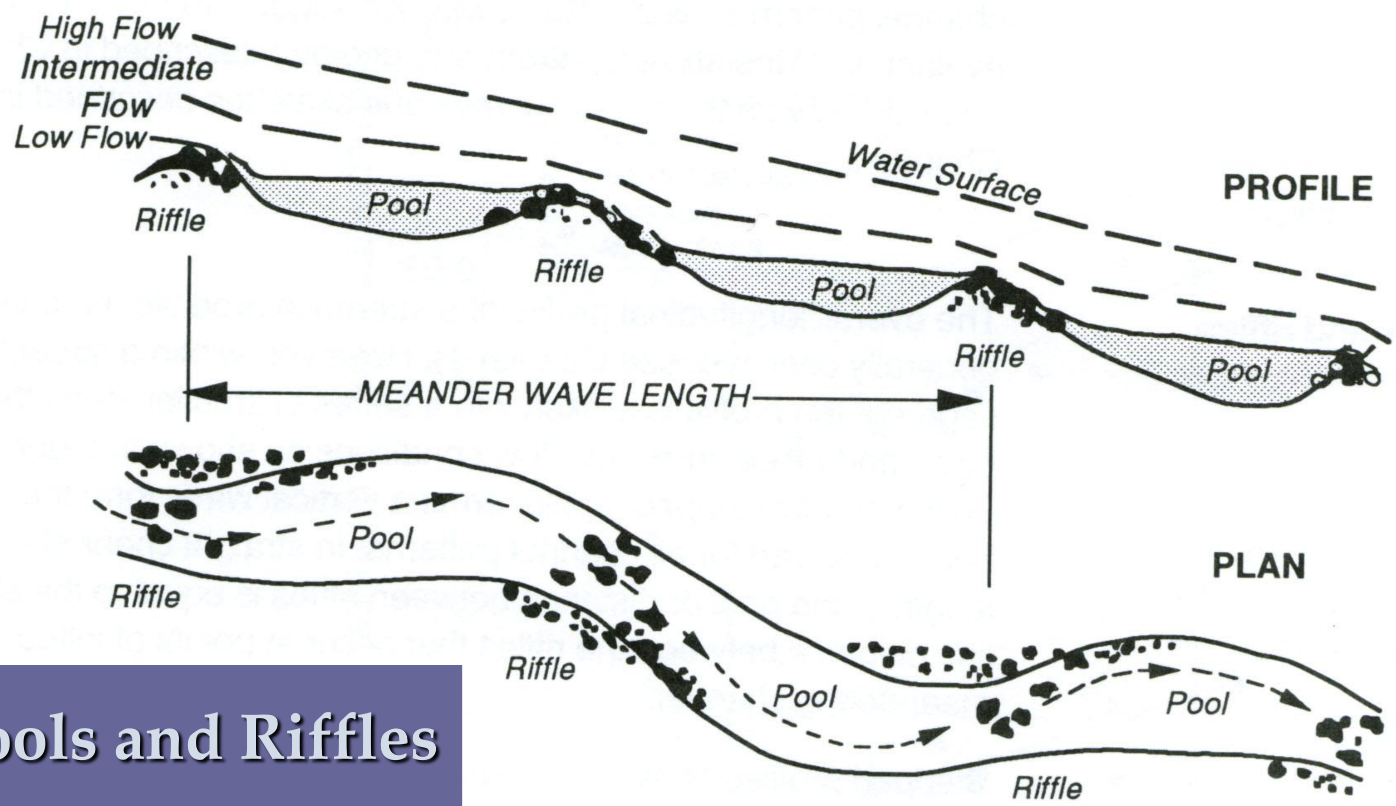
Go Forth and Measure - Plan Form



Conduct a Pebble Count



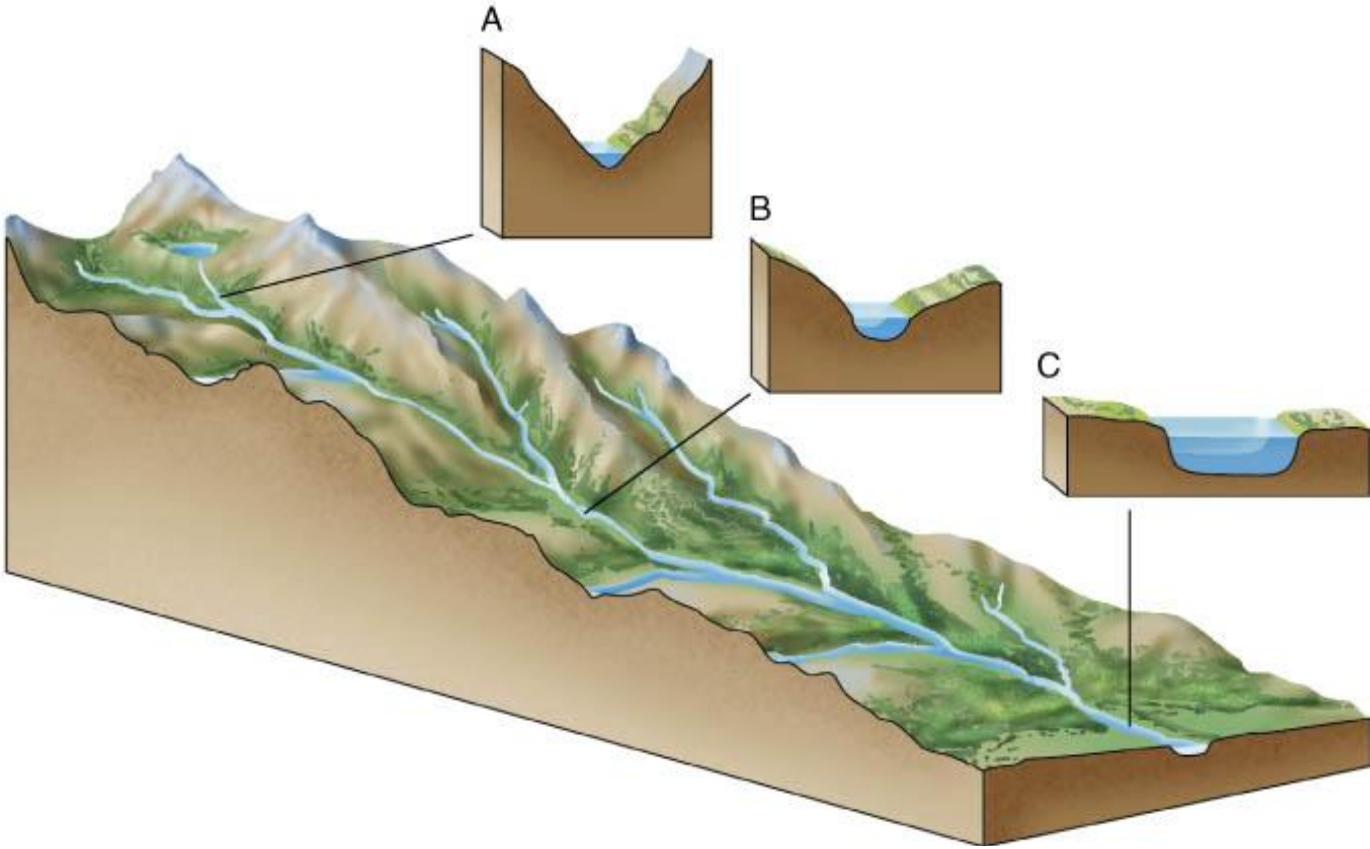
- Radius of curvature
- Meander length
- Sinuosity

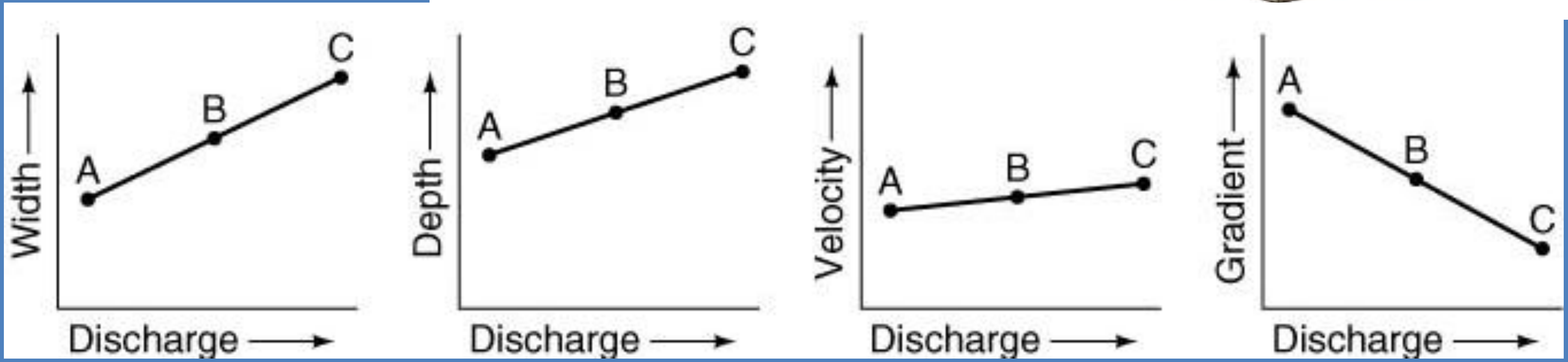


Pools and Riffles

Major Downstream Trends

- discharge ↑
- width ↑
- depth ↑
- velocity ↑
- gradient ↓
- grain size ↓

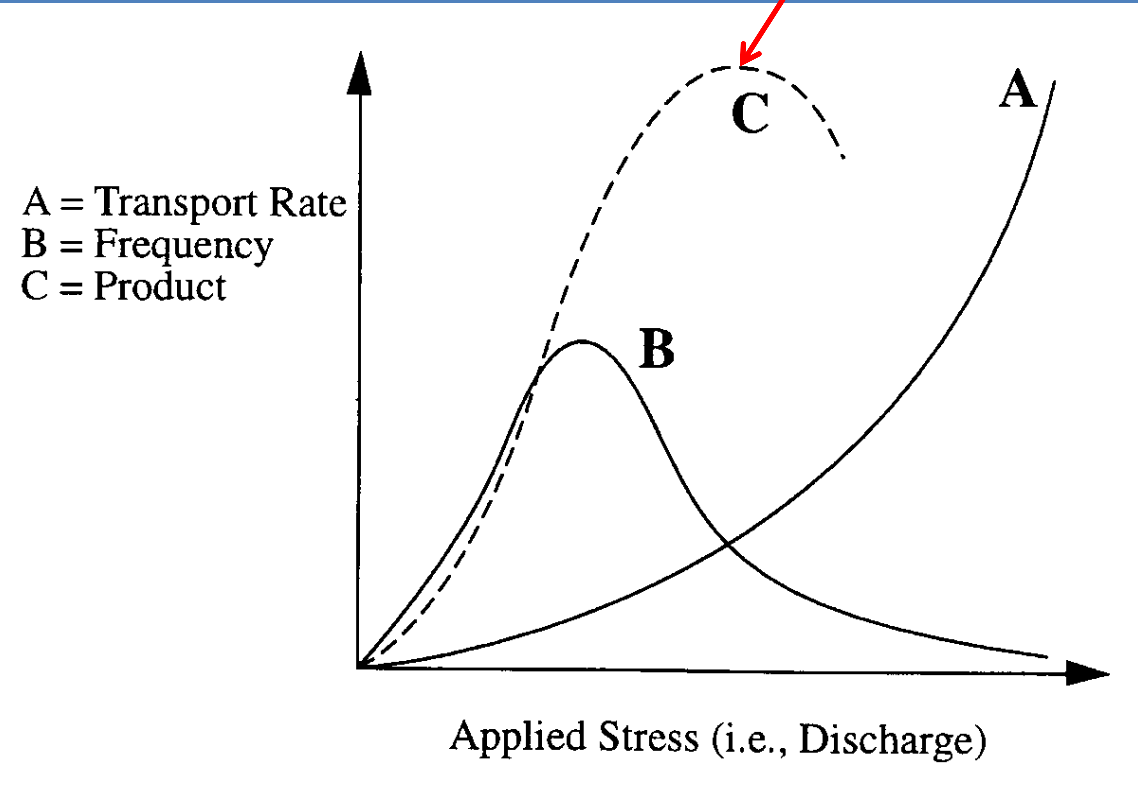




Bankfull or Effective Flow

- For alluvial rivers - “author of their own geometry”
- “The flow that over time forms the equilibrium channel dimensions”
- ~ 1.5 yr RI flow
- Must be found from “bankfull” indicators in field

Maximum sediment transport occurs at relatively high-frequency, low-magnitude events.



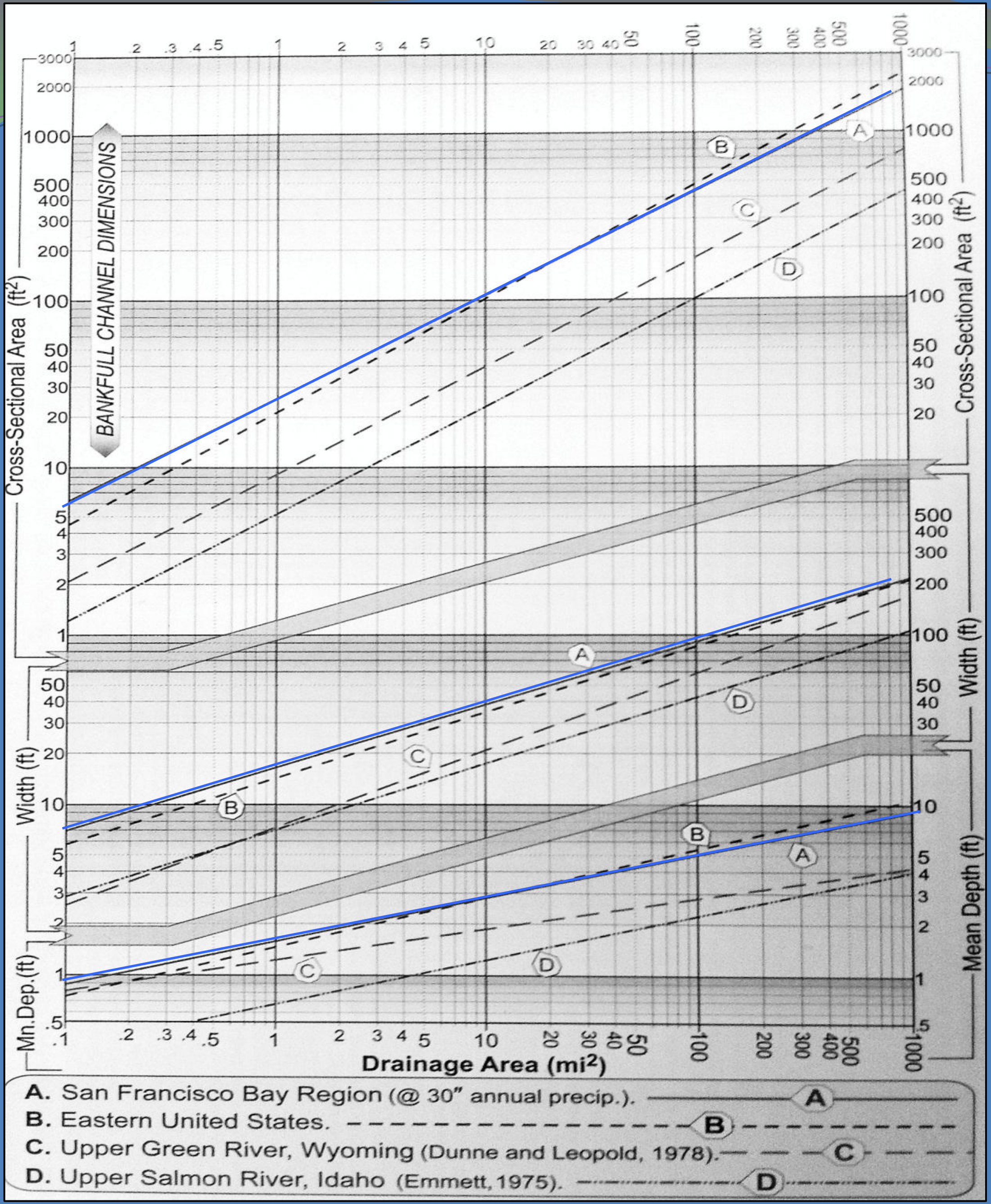
Hydraulic Geometry and Creek Restoration

- Channel parameters described with power functions using Q as the sole independent variable: $BFw = aQ^b$ $BFd = cQ^f$ $BFv = kQ^m$

  therefore... a*c*k=1 and b+f+m = 1 (continuity)

- An important design tool used in many restoration project designs – regional curves are plots of "stable" or "equilibrium" sites

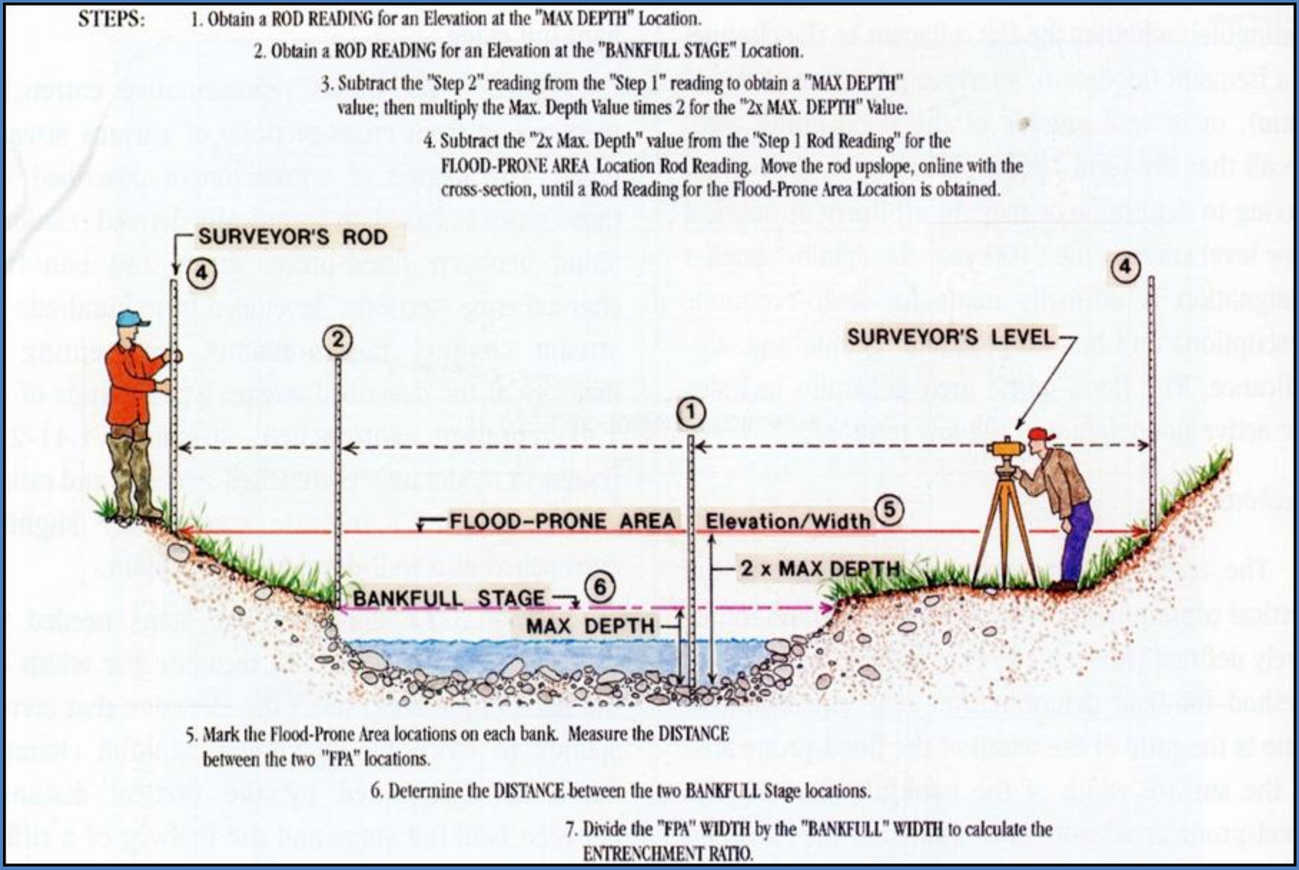
- Plots of field sites are "regional curves"



- 1978 - One curve for SF Bay Region at 30" MAP (curve A)
- Data points not plotted
- Assumed 1.5 RI and plotted A, W and D from gaging records at USGS gage sites
- Best done as <u>local</u> dataset like i-d-f curves (our project)

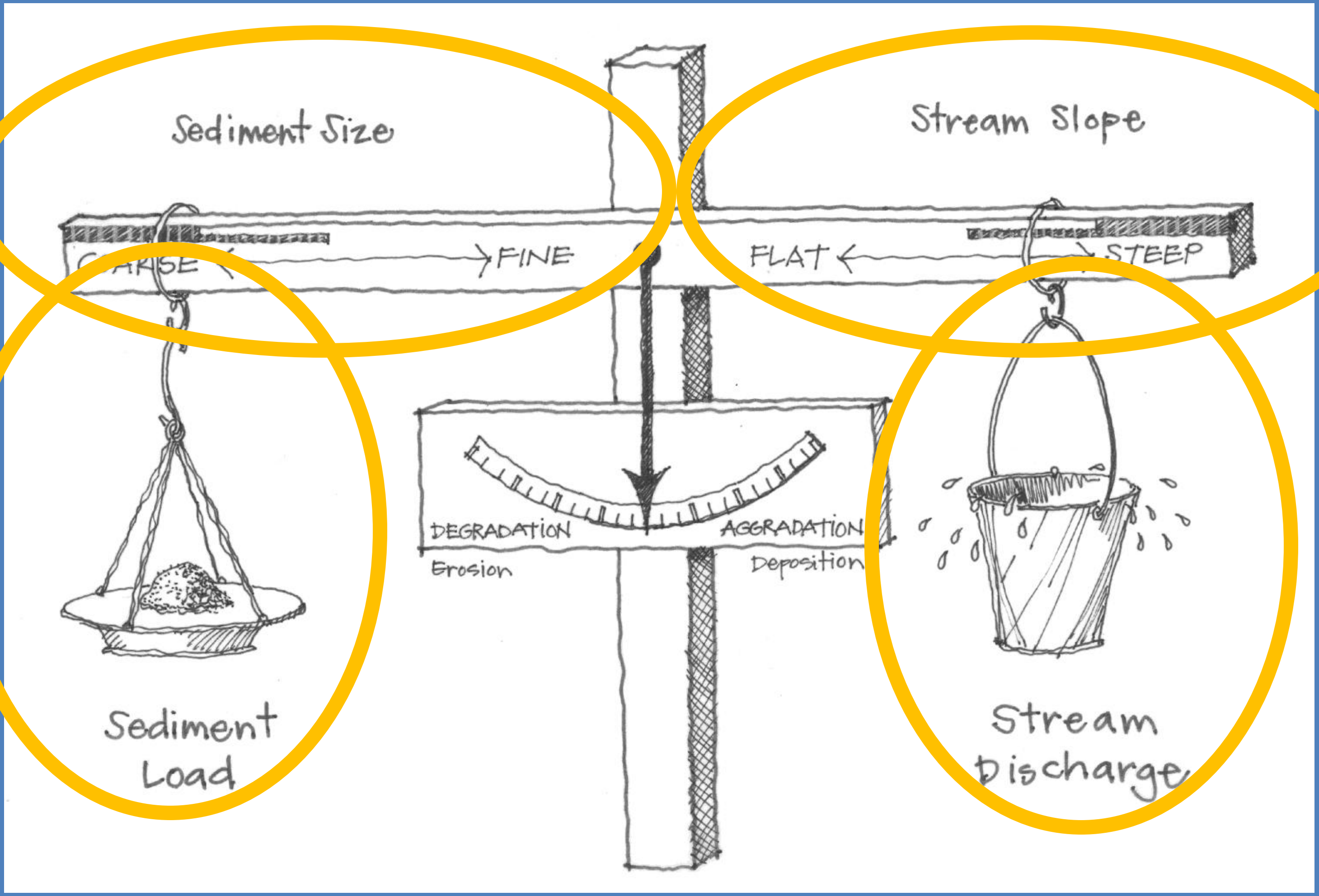
Finding bankfull elev…textbooks

- Finding bankfull elevation is not always easy
- A depositional feature not always present
- Most Bay Area streams are incising
- Semi-arid regions?

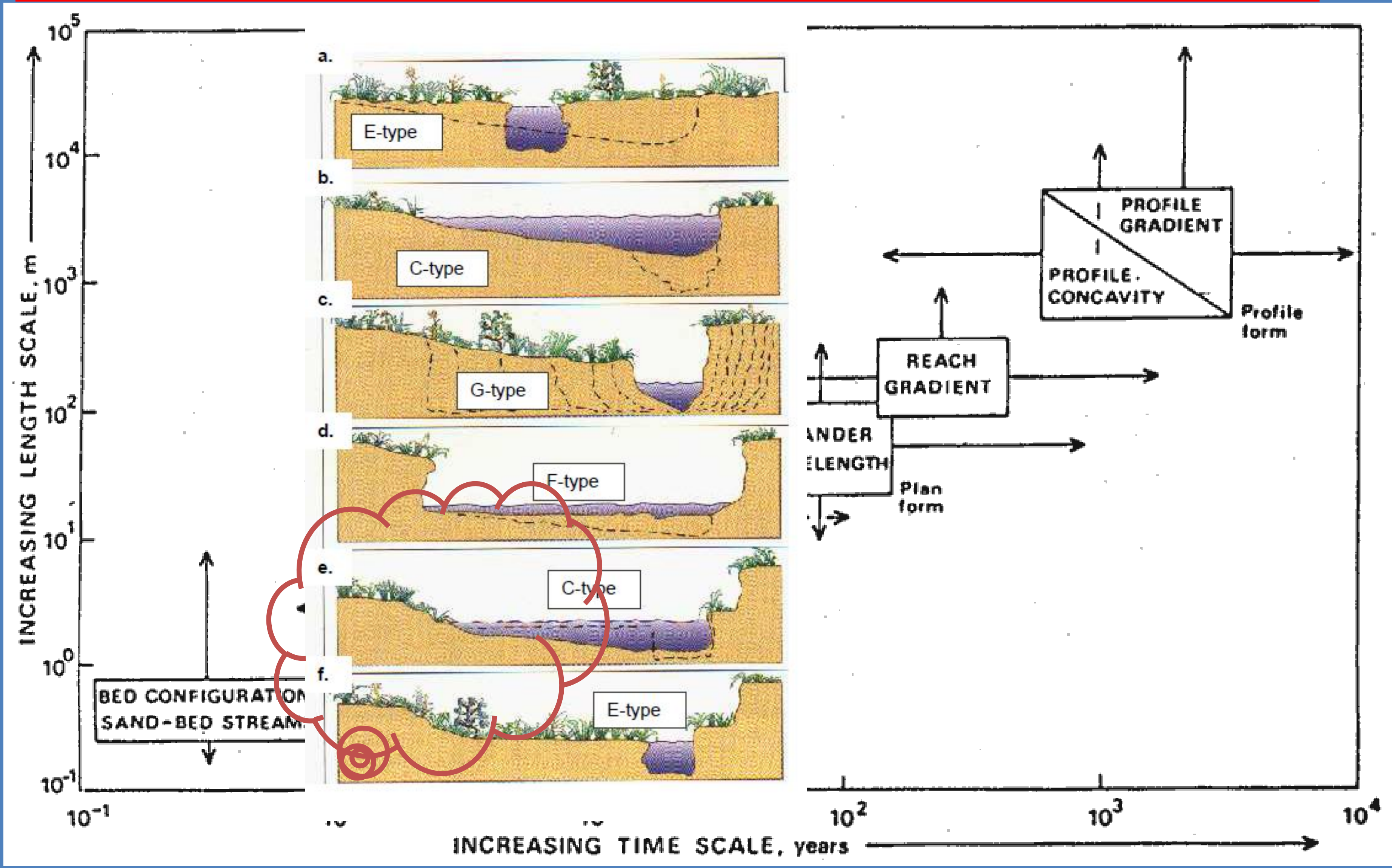


Finding bankfull in the real world…

Lane's Balance



Adjustments in the Fluvial System



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Hydraulic Geometry: A Geomorphic Design Tool for Tidal Marsh Channel Evolution in Wetland Restoration Projects

Philip B. Williams[1,2]
Michelle K. Orr[1]
Nicholas J. Garrity[1]

Abstract

Empirical hydraulic geometry relationships for tidal marsh channels are a practical geomorphically based design tool that can assist in the planning of tidal wetland restoration projects. This study provides hydraulic geometry relationships for predicting the depth, width, and cross-sectional area of mature tidal channels as functions of contributing marsh area or tidal prism. The relationships are based on data from San Francisco Bay coastal salt marshes ranging in size from 2 to 5,700 ha. These hydraulic geometry relationships refine and expand on earlier relationships. Relationships for mature marshes can be used to predict the direction and rate of evolution of a channel in an immature or perturbed marsh system. Channel evolution data for three youthful tidal channels, ages 4 to 13 years, suggest that the channels are converging on their predicted equilibrium morphology. Two channels are eroding in response to significant increases in upstream tidal prism. They have enlarged first by deepening, in one case after 13 years to beyond the predicted equilibrium depth, and then widening through slumping of the channel banks. The third channel, a new one forming in a depositional mudflat, is converging on its equilibrium morphology after 13 years but will likely take several decades to equilibrate.

Key words: hydraulic geometry, restoration, salt marsh, San Francisco Bay, tidal channel.

Introduction

Since at least the 17th century observers have noted how the depth and width of tidal marsh channels are affected by anthropogenic alterations in the upstream tidal prism or volume of water exchanged upstream of a point during a tidal cycle. This understanding was stated perceptively in 1637 by ship owners in the town of Cley in Norfolk, England, who were petitioning to have newly installed dikes on tidal marshes upstream of the shipping channel in their harbor removed.

> The banke of earth . . . taketh away . . . the indraught of water 80 rodds and upwards in breadth and one myle at least in length [an area larger than 65 ha] . . . so that what sylt or mudd the flood tide bringeth in doth settle and remaine in the navigable channel . . . through want of the ebb tide which formely overflowed the aforesaid 80 rodds of ground in breadth and one myle in length (Cozens-Hardy 1927).

Intrinsic in this description is a concept that there is an equilibrium form of a tidal channel for a given-sized marsh with a particular tidal range within an estuary that is relatively stable over long periods of time. This form is the expression of a dynamic equilibrium between erosional and depositional processes.

It was not until the 1960s that scientists (Myrick & Leopold 1963) attempted to systematize an understanding of the relationship between tidal flows and channel geometry of tidal marsh channels using equations of hydraulic geometry, as had been done for alluvial rivers and canals 30 years before. These equations relate channel cross-sectional geometry to discharge according to the power functions: $W = aQ^b$, $D = cQ^f$, and $v = kQ^m$, where W is the width, Q is the characteristic discharge, D is the average depth, and v is the characteristic velocity. By continuity of flow the sum of the constants a, c, and k and the sum of the exponents b, f, and m are both equal to 1. Various researchers have measured flow and channel cross-sectional parameters and then calculated the exponential parameters for downstream changes in hydraulic geometry. (See Allen 2000 for a succinct de-

Marin Field Sites

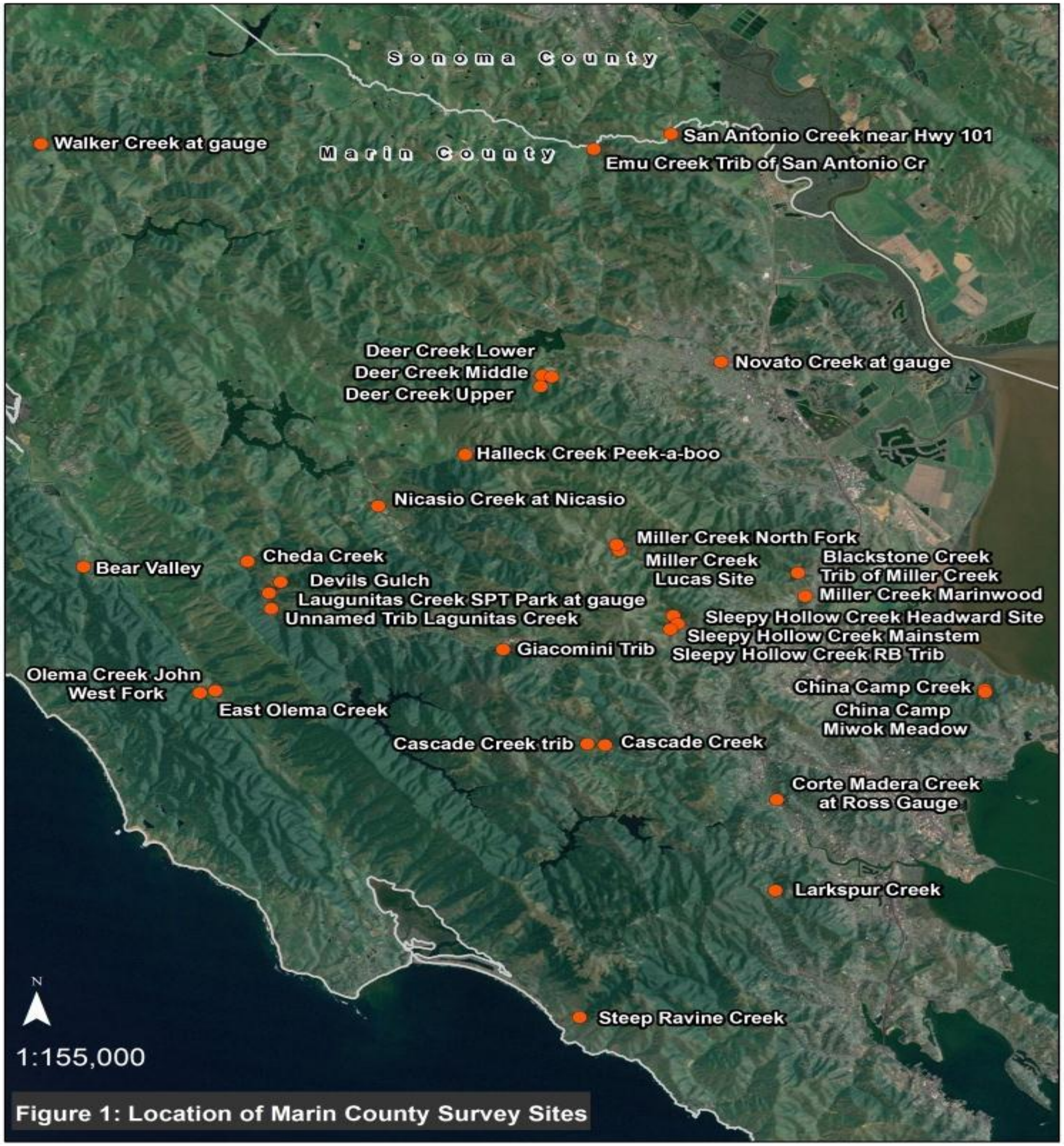


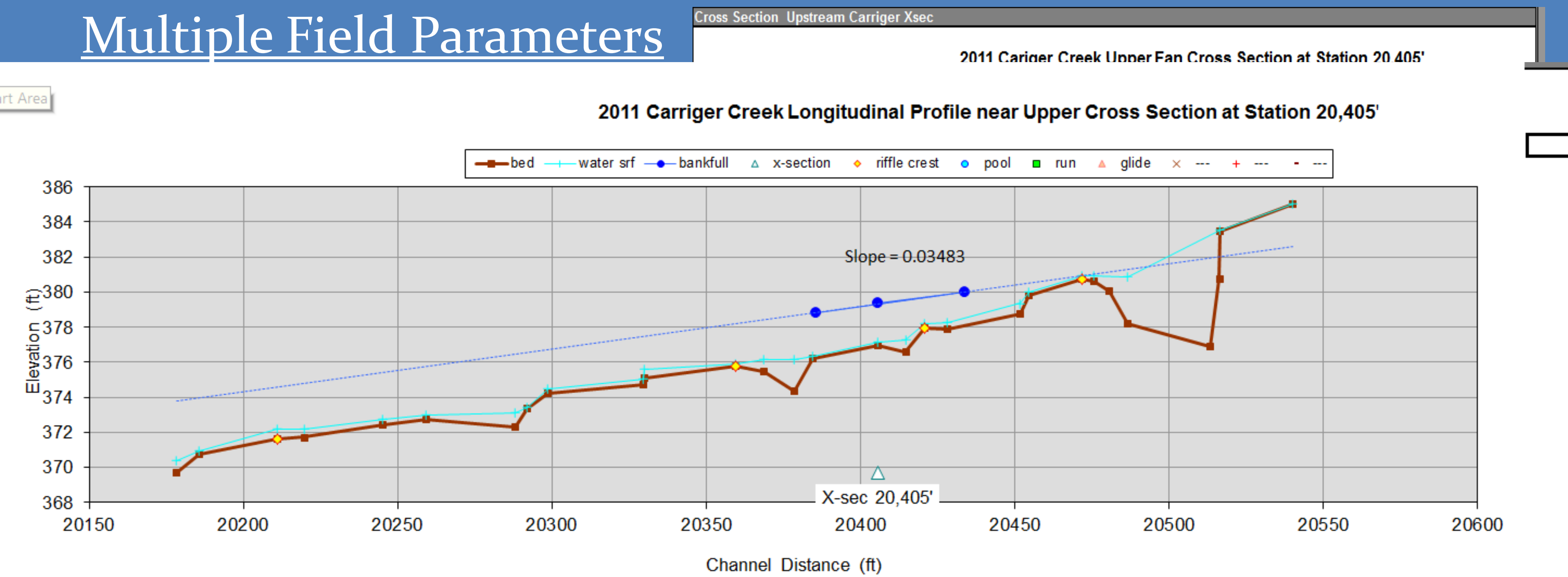
Figure 1: Location of Marin County Survey Sites

Sonoma County Sites

Figure 2: Location of Sonoma County Survey Sites

Data Collection and Analysis

Multiple Field Parameters



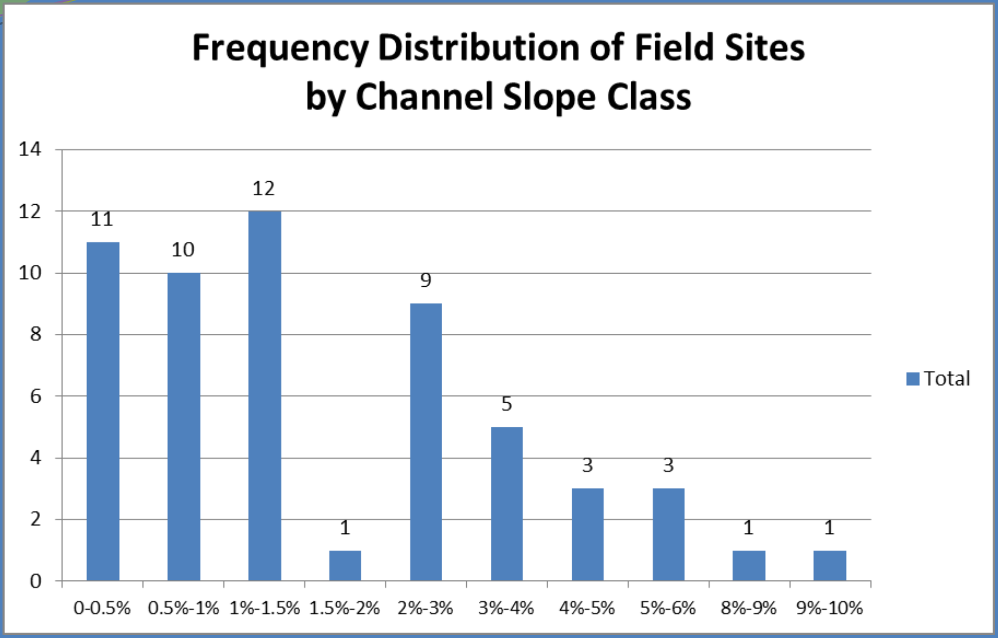
	slope (%)	slope ratio	length (ft)	length ratio	pool-pool spacing (ft)	p-p ratio
reach	---	---	20539.9 (748.4 channel widths	---	---	---
riffle	-4.15 (0 - -2.48)	---	-81.5 (-148.8 - -43.7)	---	---	---
pool	---	---	---	---	---	---

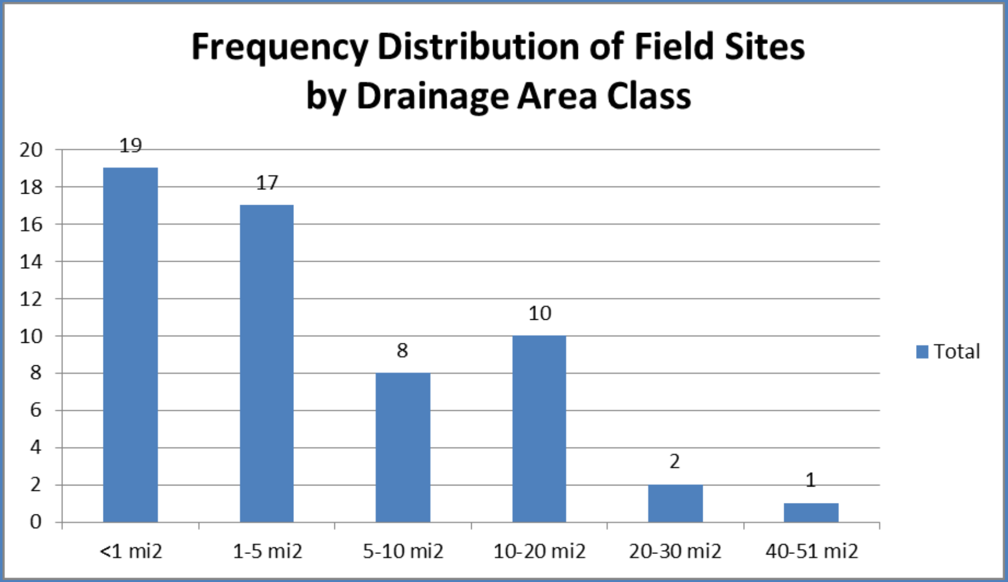
- BF flow, area, velocity, W/D ratio, SS many more

Results…

- Over 20 different graphs and tables in the report
- Showing only a few today
- New analysis of the required floodplain width and channelized network length

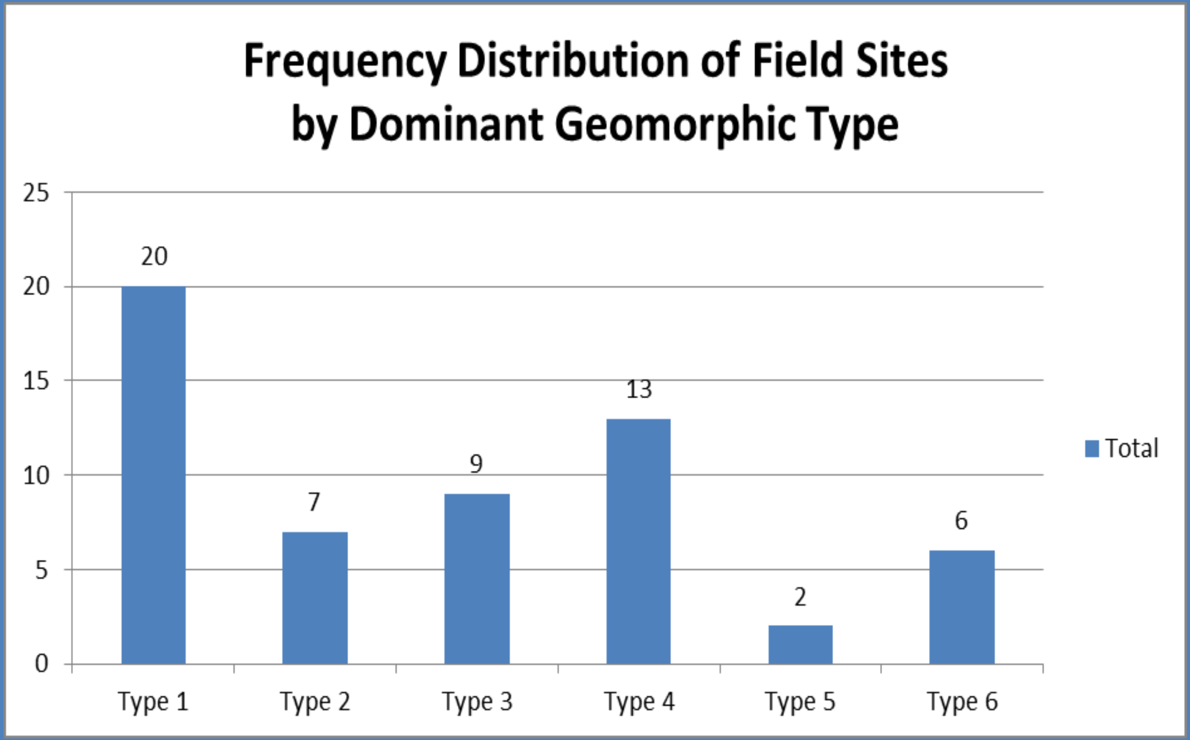
Slope and DA Frequency Plots





- 14 sites > 3% slope – fills in data gap for steeper streams
- Fills in data gap for smaller streams

Dominant Geomorphic Setting

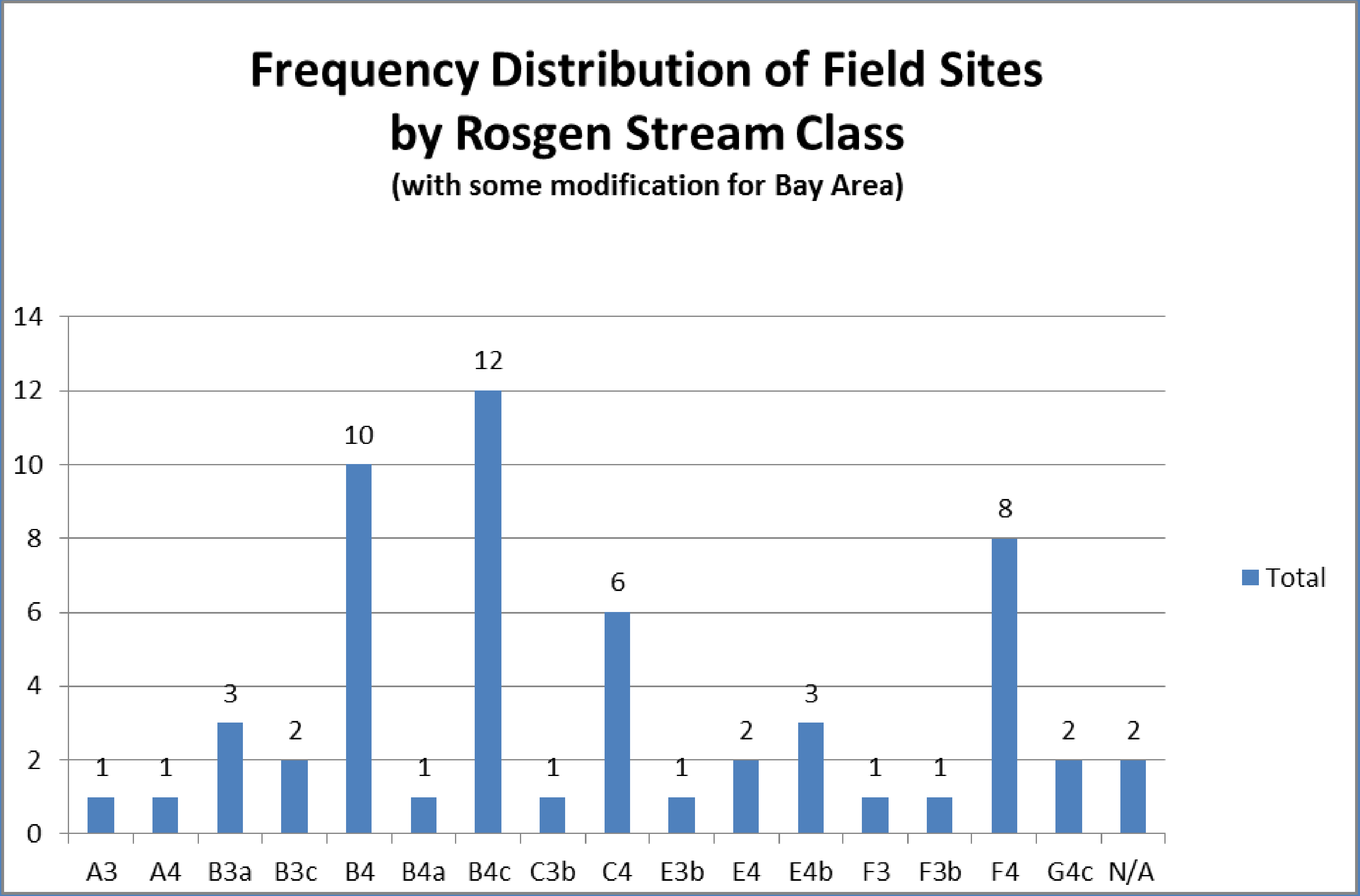


Types

1. Wide alluvial valley
2. Narrow predominantly alluvial valley
3. Moderately wide alluvial valley
4. Alluvial fan*
5. Narrow, predominantly colluvial valley or canyon
6. Steep, mostly bedrock confined canyon
7. Plain, often uplands transitional to tidelands

** Active alluvial fans most problematic*

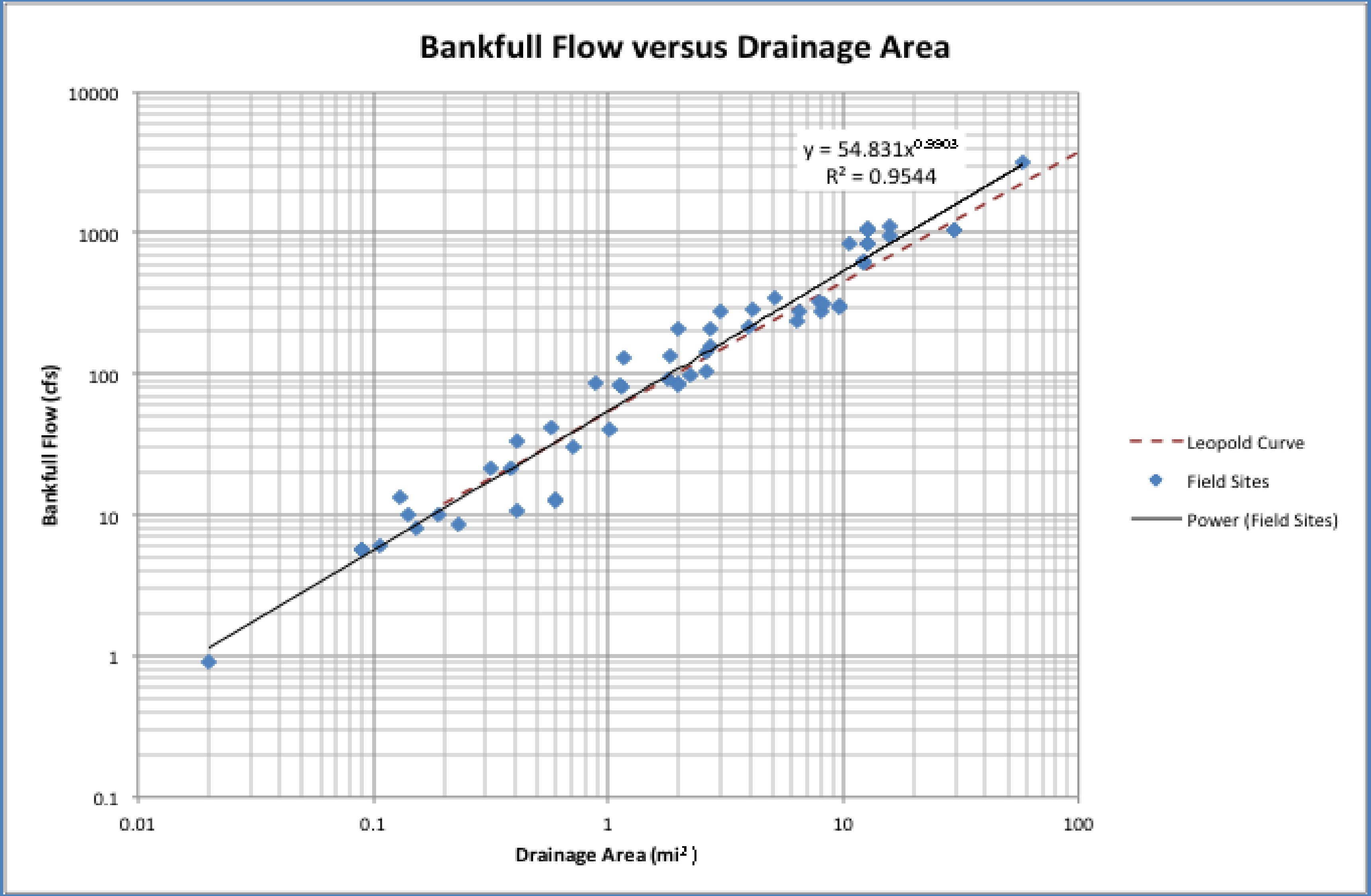
Rosgen Classification



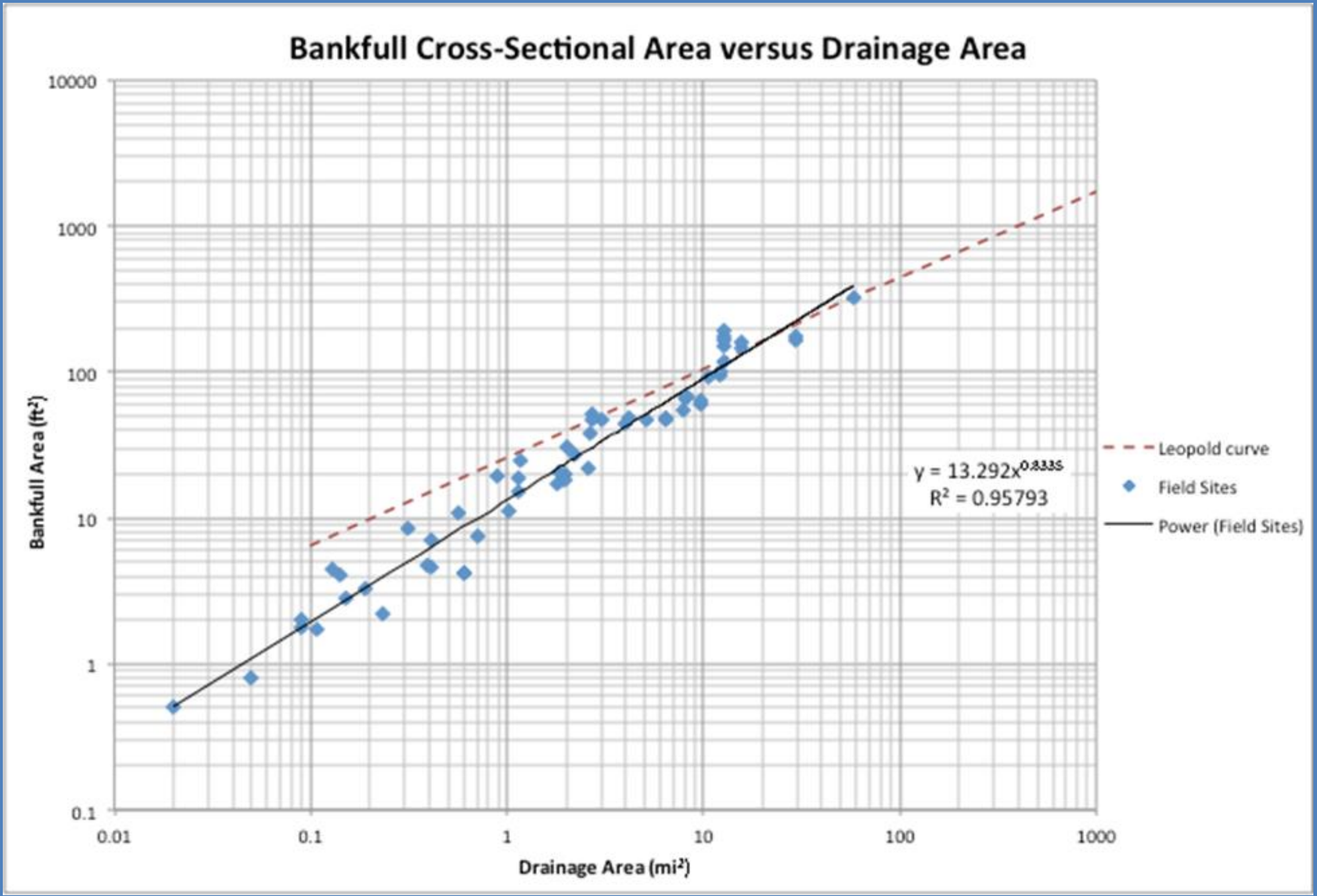
USGS Gage Sites

Site	Bankfull Discharge (cfs)	Reservoir Upstream	Approximate Recurrence Interval (years)
Corte Madera Creek at Ross Gage Site 11460000	953	Yes	1.3
Lagunitas Creek at Samuel P. Taylor Park, Gage Site 1146400	842	Yes	1.1
Novato Creek at Novato, Gage Site 11459500	303	Yes	1.2
Sonoma Creek at Agua Caliente, Gage Site 11458500	3139	No	1.2
Walker Creek near Marshall, Gage Site 11460750	1065	Yes	1.5
Note: Recurrence intervals were determined from a flood frequency analysis of Peak Annual flows from USGS data.			

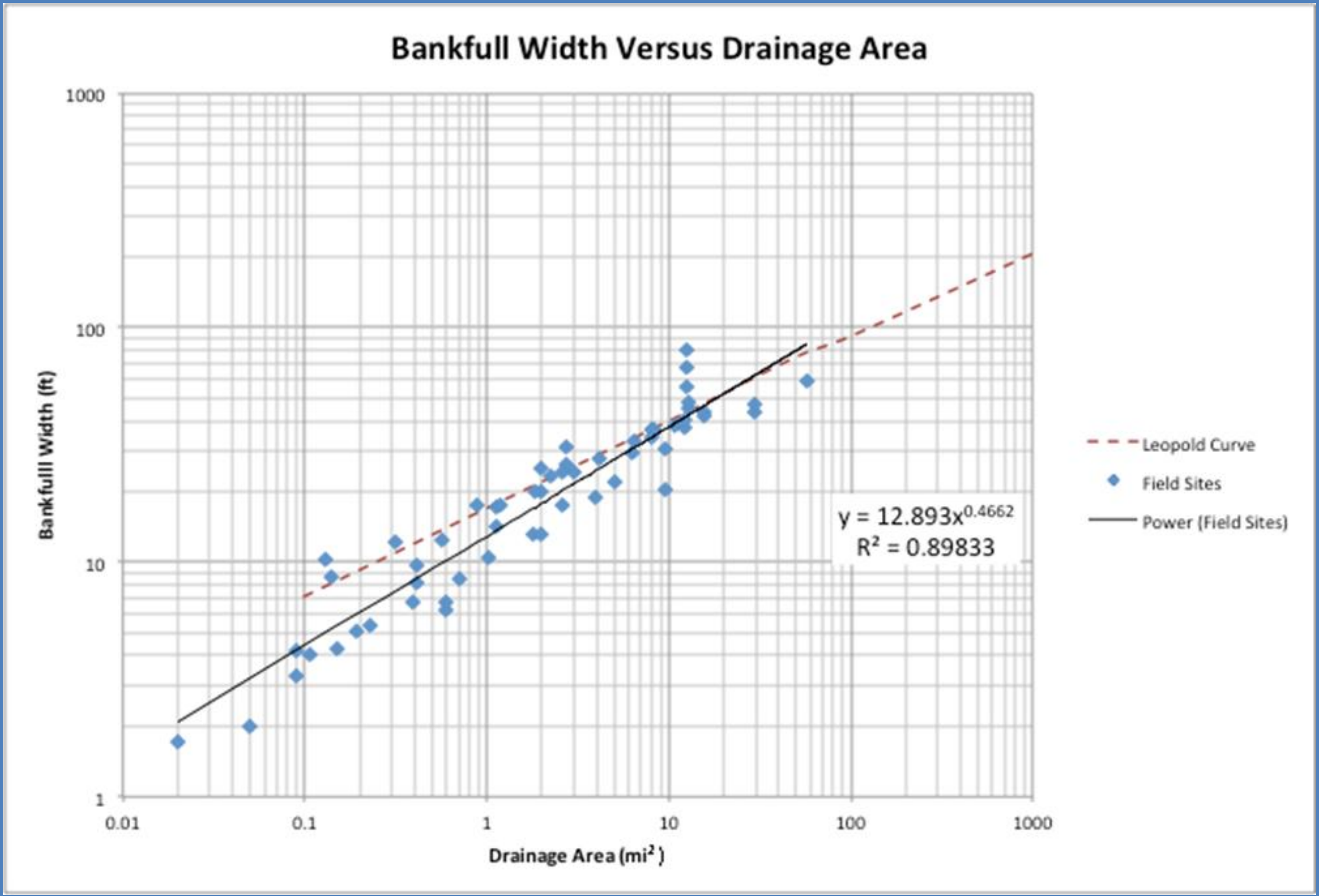
Bankfull Flow versus Drainage Area



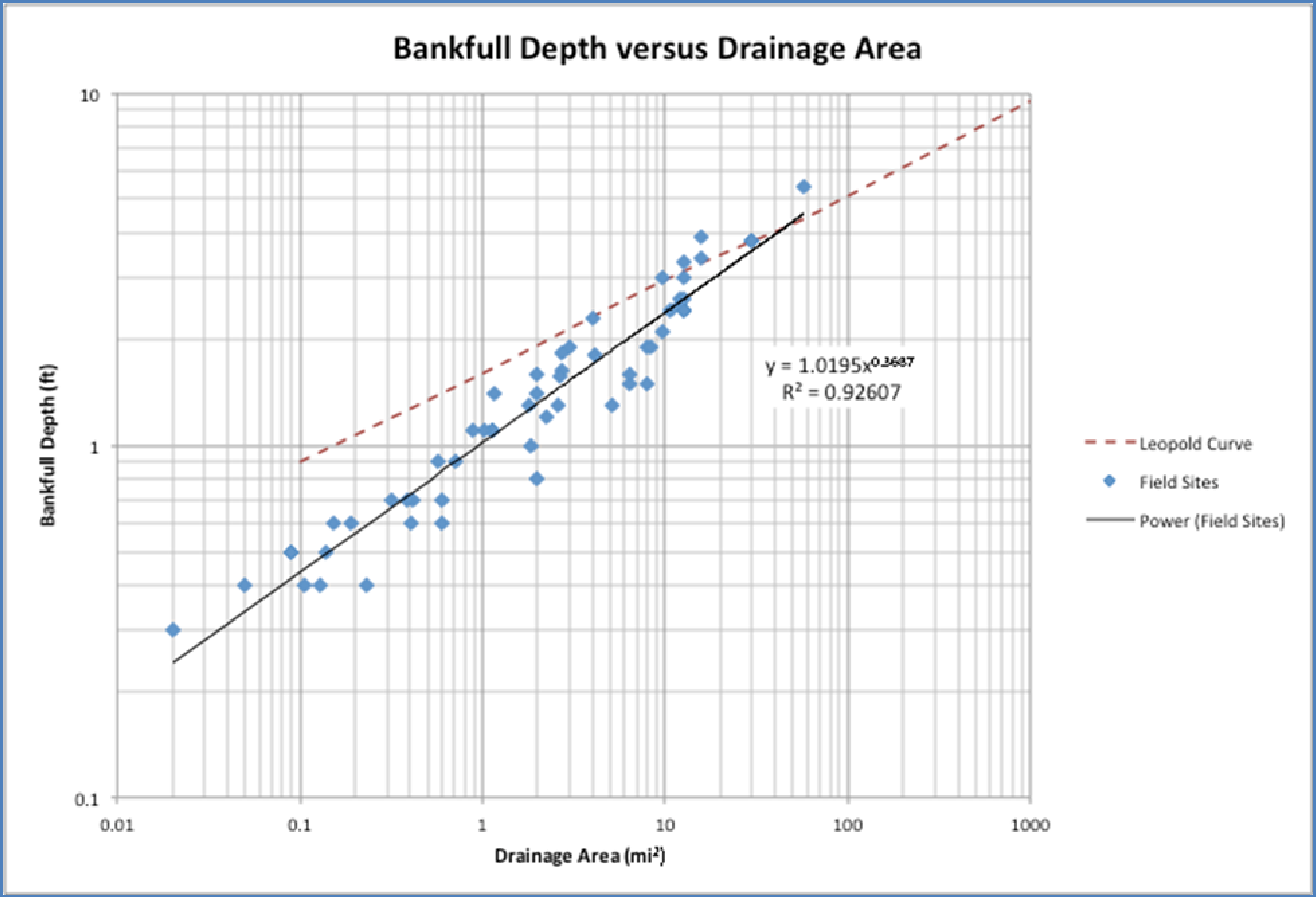
Regional Curve – X-Sectional Area



Regional Curve – Bankfull Width

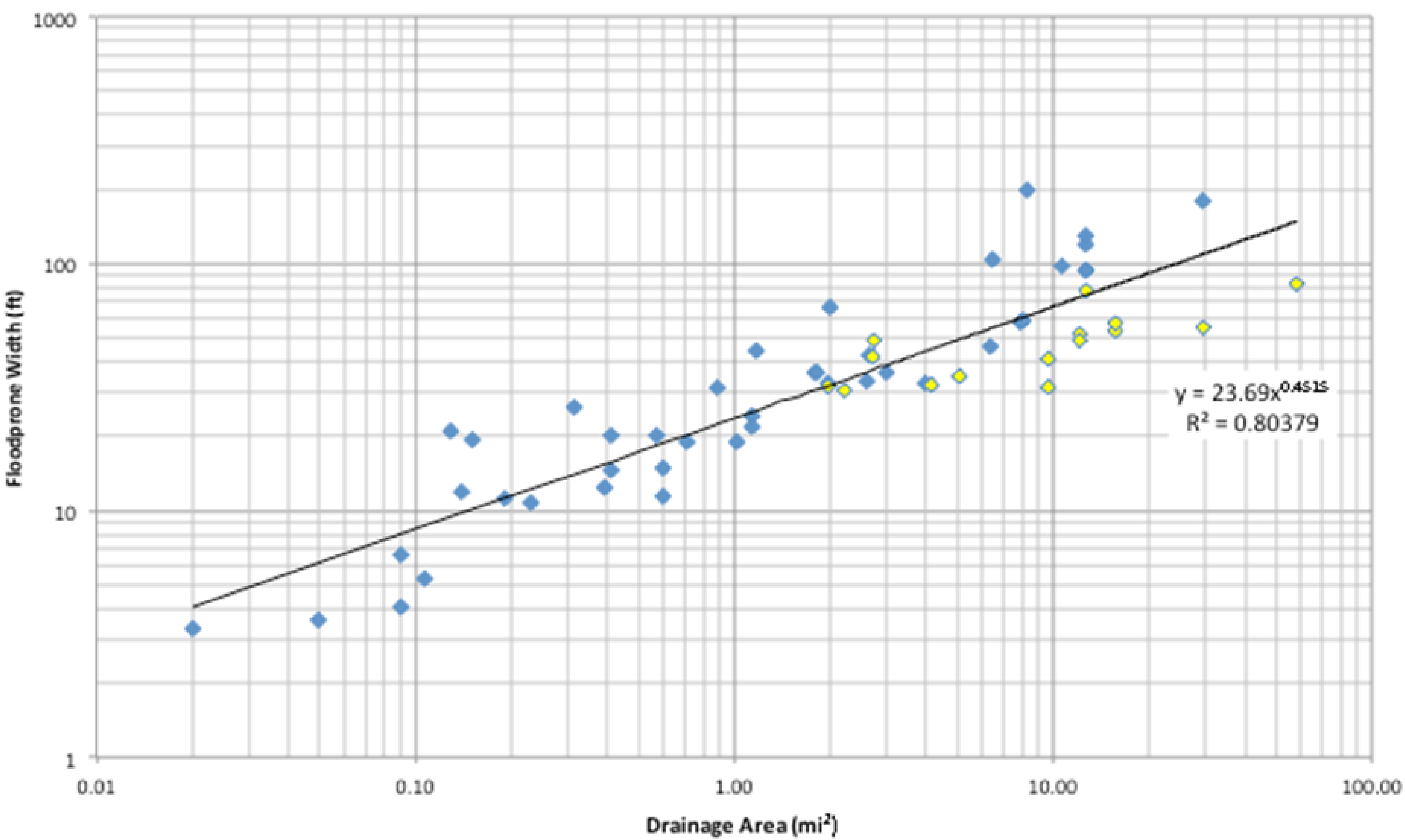


Regional Curve – Bankfull Depth

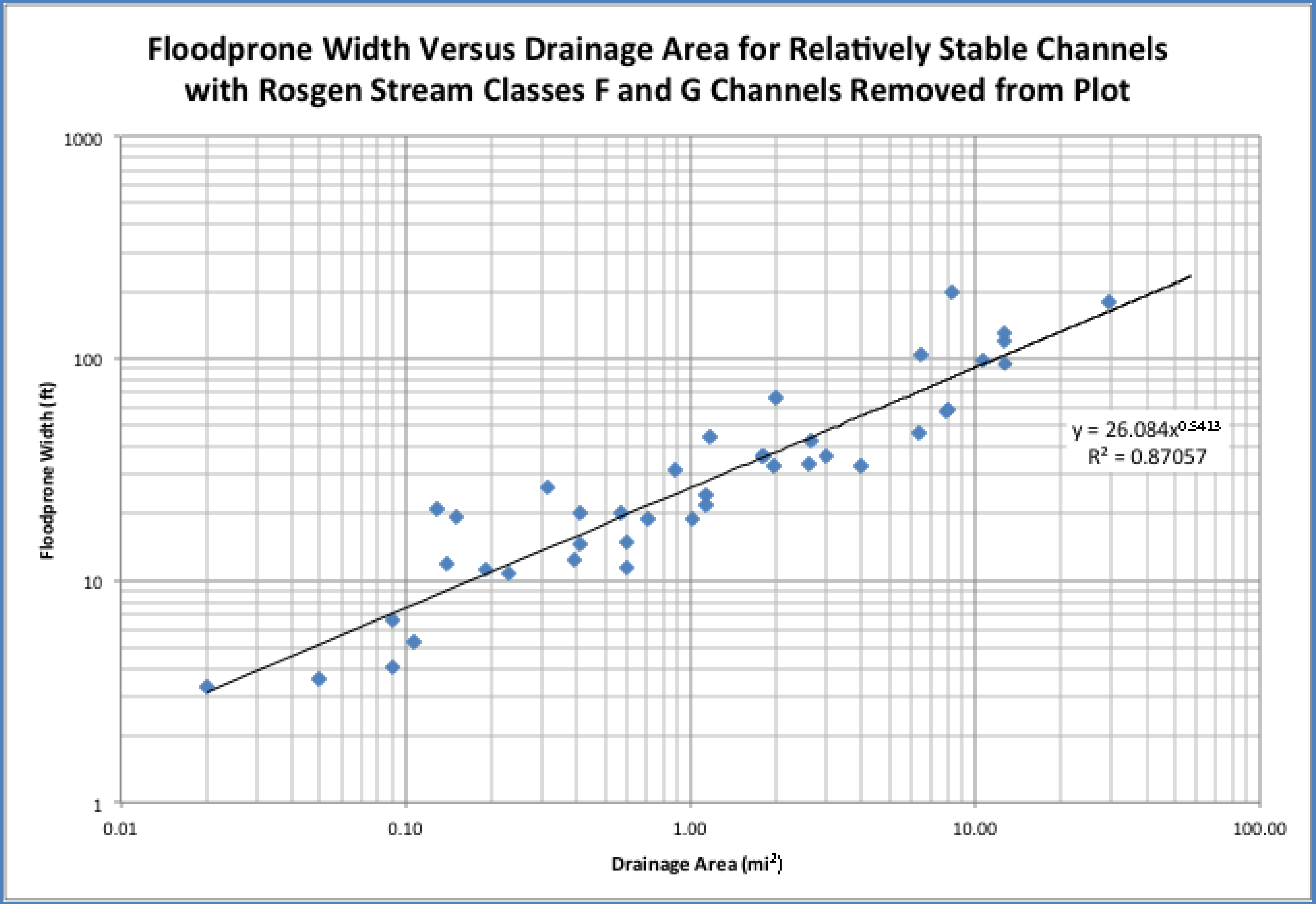


Regional Curve – Flood-Prone Width (all points)

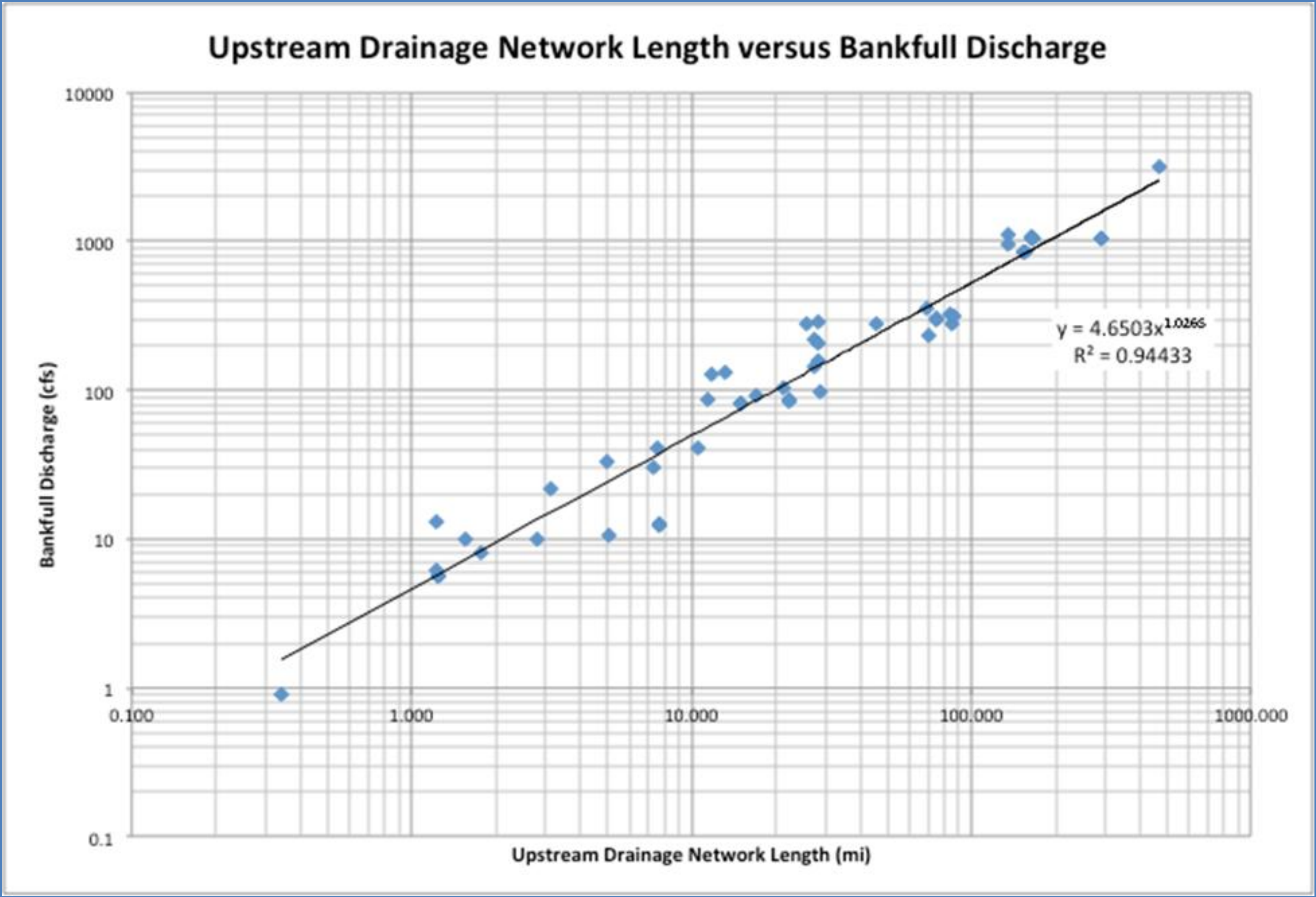
Floodprone Width Versus Drainage Area for All Data including Unstable Rosgen Stream Classes F and G

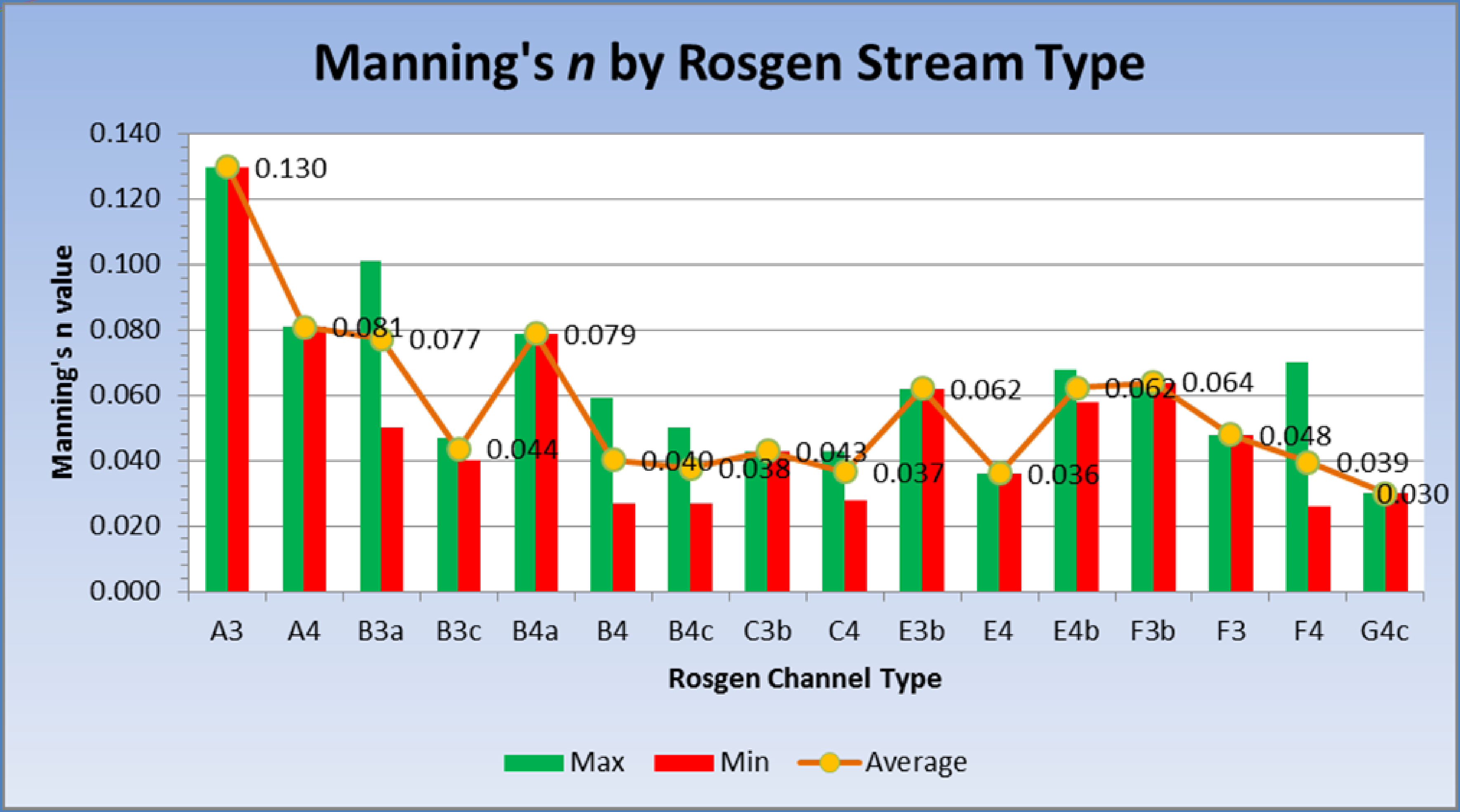


Regional Curve – Flood-Prone Width



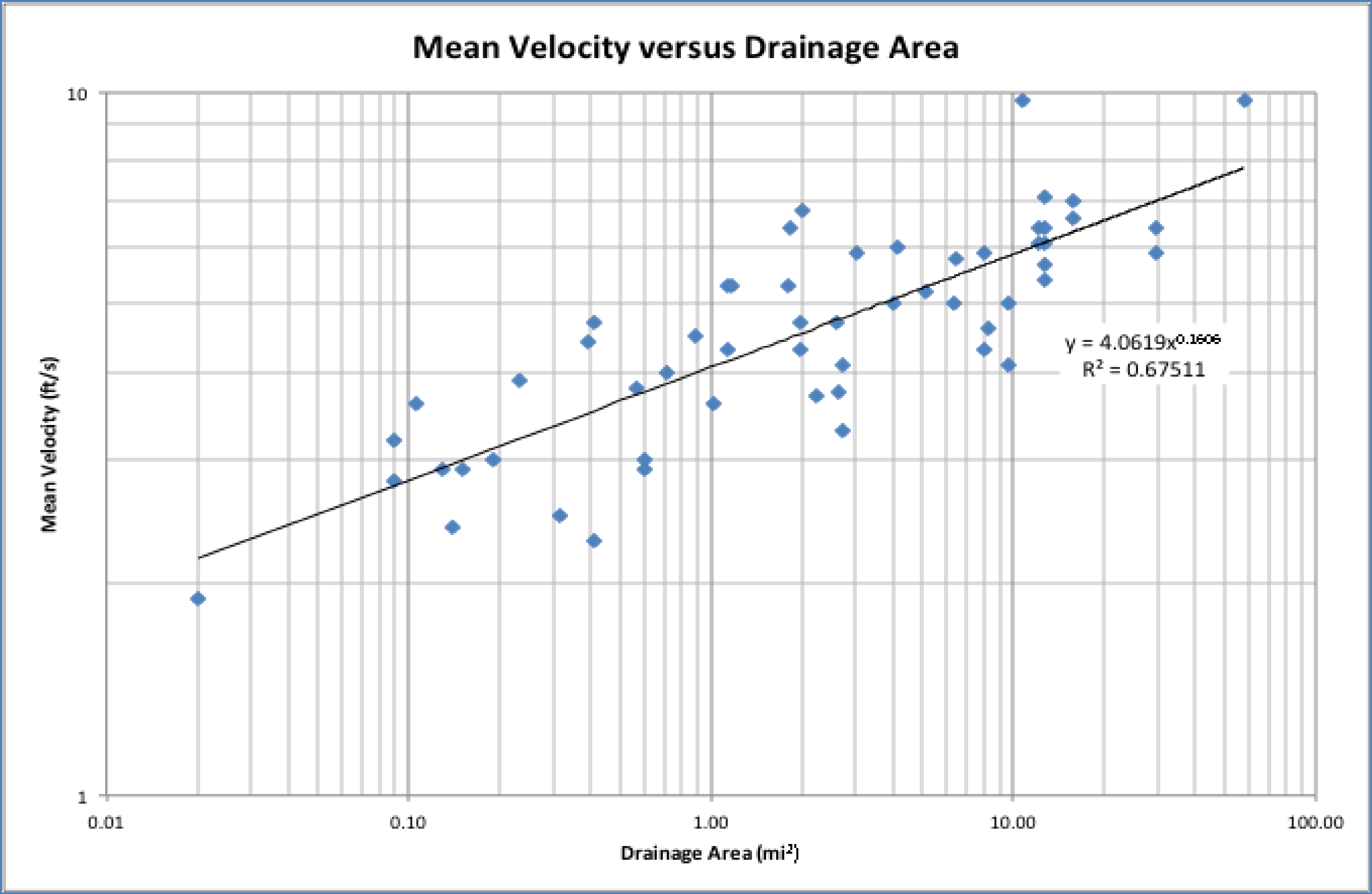
Degree of Channelization





Note: Many ways to calculate n values (only one way shown here). Further explored in Phase II

Mean velocity versus DA



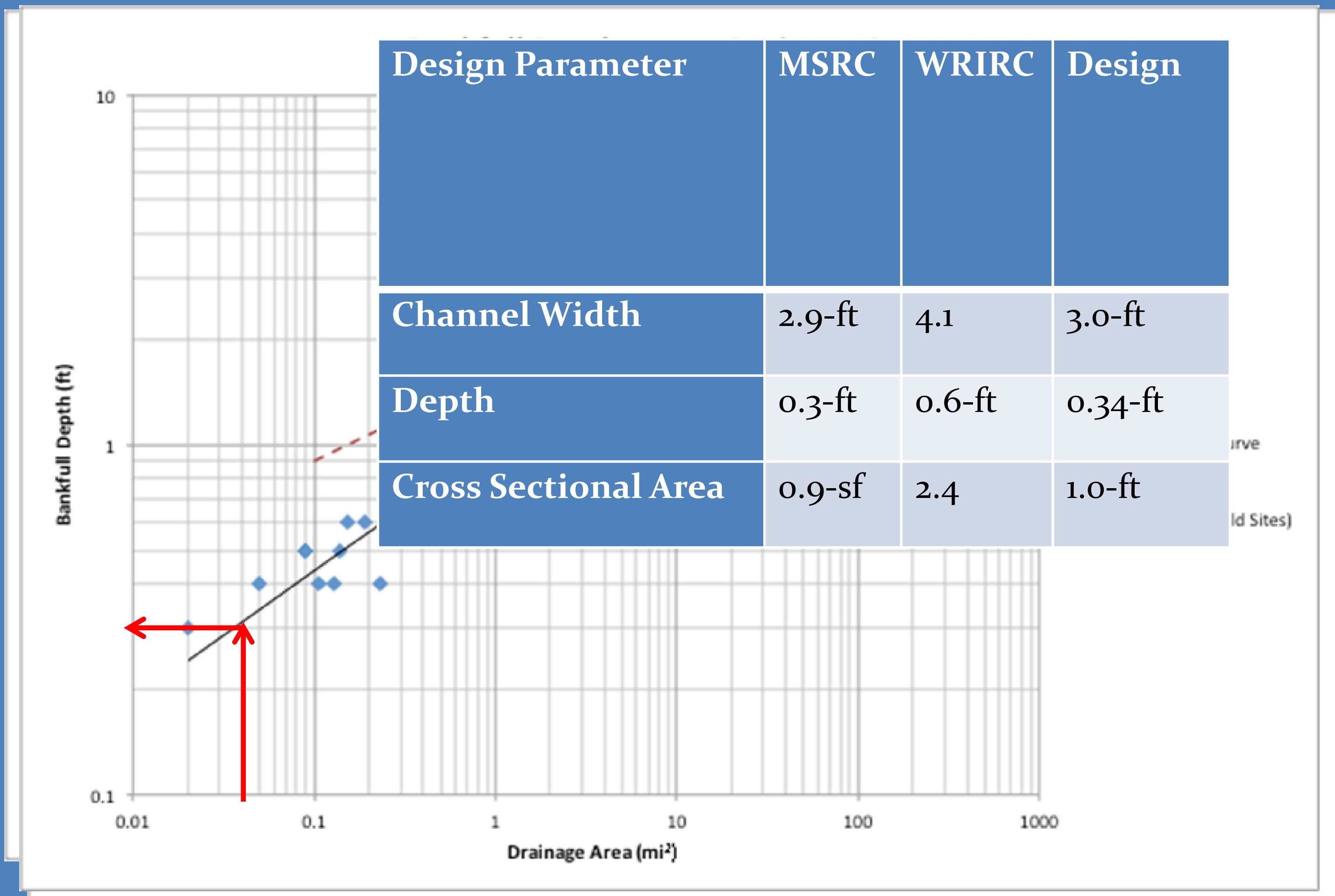
Limitations and Controversies

- Applicable to arid and semi-arid region?
  - Two scales of morphologic events?
- What is stable?
- Process versus Form debate – The "Rosgen wars"
- Regional curves are a design <u>tool</u> not a design end – must understand the current system and history!
  - Sediment inputs
  - Upstream diversions
  - Land use changes
  - Drivers of instability

Application 1 - Creek Restoration

Boyle Park Restoration Design

DA = 0.0375 square miles

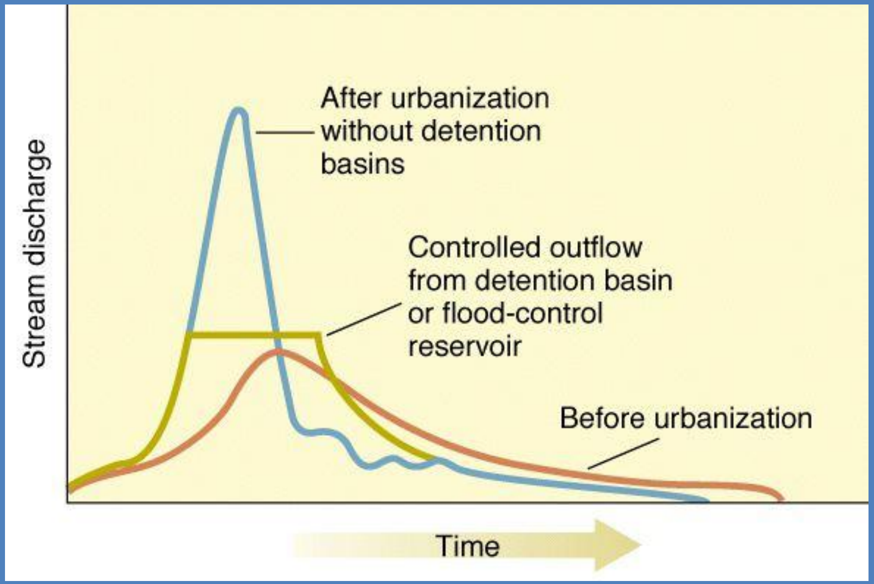


Design Parameter	MSRC	WRIRC	Design
Channel Width	2.9-ft	4.1	3.0-ft
Depth	0.3-ft	0.6-ft	0.34-ft
Cross Sectional Area	0.9-sf	2.4	1.0-ft

Curves and LID Design

- Curves can inform current LID limitations:
  - Need to differentiate geomorphic conditions within receiving channels.
  - sediment supply -limited and transport-limited stream regimes
  - recognize scour as a natural and important part of stream function (buildup of fines and a loss of new riparian vegetation
  - ignores the geomorphic importance of larger magnitude events in channel morphology and ecosystem health especially in semi-arid areas

- In practice, LID design often results in a “dam” hydrology, i.e. reduction of peak flow, increase in recession flow and removal of coarse sediment



From ASCE LID conference in SF 2010

The Bay Area Regional Curves Project: Fluvial Geomorphology and LID Design

Roger Leventhal, P.E. FarWest Restoration Engineering
Laurel Collins, Watershed Sciences

Background

This poster presents the goals of an on-going three-year effort started in 2009 and funded by the EPA through the San Francisco Estuary Project to develop a series of sub-regional curves of hydraulic geometry (bankfull width, depth, and cross sectional area) for various "stable" streams around the Bay Area. The need for reference conditions for various stable stream types has been identified as a major need in LID design by the State.

Although this project is primarily intended to help provide data for stream channel restoration design, the Bay Area Curves project fits directly with many LID design goals and requirements to minimize negative development impacts to our creeks. In some cases, in-stream modifications identified as a part of LID design require information on stable channel characteristics, yet this information is sub-regionally specific and generally not available.

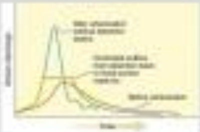
The Bay Area Regional Curves Project began in 2009 and the first phase will be completed in 2012. The project conducts intensive geomorphic surveys at sites that are as "equilibrium" as possible. A variety of data is collected to test whether sites can be stratified by geology, rainfall, or other factors to improve correlations between dimensions and drainage area and/or watershed factors that impact hydrology and sediment supply and transport.

Issues with LID Design and Geomorphology

Current LID practice doesn't differentiate between the geomorphic conditions within different creek types of receiving channels.

- Current LID design guidelines don't differentiate between sediment supply-limited and transport-limited stream regimes
- LID design guidelines do not differentiate by the geomorphic differences between creeks
- Scour is a natural and important part of stream function that can be lost with some LID approaches. Without stream scour, streams experience a buildup of fines and a loss of new riparian vegetation – important stream functions
- The focus on smaller storm events (i.e. less the 2 year), although significant for bankfull alluvial channels, ignores the geomorphic importance of larger magnitude events in channel morphology and ecosystem health especially in semi-arid areas
- Empirically derived parameters (e.g. dimensionless critical shear stress values) are presented as constants across all stream types rather then as variables depending on several factors (i.e., critical shear stress can vary greatly)
- Overuse of in-channel detention ponds removes coarse grained sediments while allowing the fine-grained sediments more commonly associated with pollutants to flow downstream

In practice, LID design often results in a "dam" hydrology i.e. reduction of peak flow, increase in recession flow and removal of coarse sediment



Regional Curves and Hydraulic Geometry

Regional curves are essentially plots of stream channel bankfull parameters plotted against drainage area. These curves were originally developed by Luna Leopold and form the basis of the natural channel design approach.

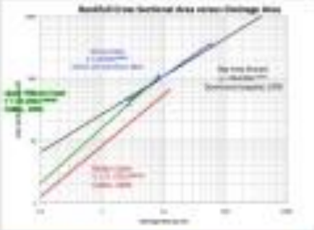
$$W = aQ^b$$

$$d = cQ^f$$

$$v = kQ^m$$

where: w = bankfull width, d = bankfull depth, v = bankfull velocity, Q = bankfull discharge, and a, c, and k are constants that reflect local. Because Q is a product of wdv -> Q = (aQb)(cQf)(kQm) or Q = ack Q b+f+m. Therefore ack and b+f+m must = 1. Exponents and constants change with location, climate, channel properties and discharge conditions.

The graph below presents early results of a local regional curve of bankfull cross sectional area versus drainage area for various Bay Area streams. Data for this project is based upon field indicators at a sub regional level. Ultimately the project goal is to develop regional curves on a variety of channel types and use multi-variate statistical analysis to determine primary controls on stream channel morphology in various Bay Area streams.



Bay Area Regional Curves Project – Beyond Traditional Regional Curves

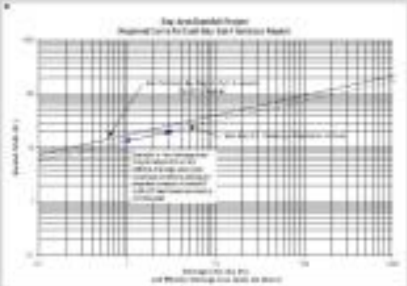
Our project is collecting data on multiple other factors that may have an impact on creek morphology. For each data collection site, the following parameters will be measured or calculated, where possible, and tracked separately in a database. The goal is to use multivariate statistical analysis to assess the control on channel morphology.

- Effective drainage area DA eff – total drainage area normalized by directly connected impervious areas
- Estimate of Area that impact Sediment Supply - ponded & piped drainage area as well as erosive areas that impact watershed sediment supply function
- Drainage network length
- Bed sediment sizes (D50/D84)
- Channel gradient
- Flood prone width, width depth ratio, and entrenchment ratio.
- Roughness/friction factor/Manning's n
- Mean annual precipitation
- Bank strength estimates
- Dominant vegetation assemblage
- Abundance, size and influence of large woody debris
- Presence of upstream diversions and alterations (ponds, dams that function as sediment retention basins)
- Local geology
- Stream slope-drainage area product
- Bed morphology
- Dominant geomorphic setting i.e., alluvial fan, narrow alluvial valley

Extension to Non-Equilibrium Channels –> Our goal is to evaluate the value of extending regional curves as a tool to estimate channel morphology in regimes that have been altered by upstream modifications. We hope to correlate measured channel morphology parameters against altered drainage areas. By developing correlations between various factors such as effective drainage areas or areas of reduced sediment supply or transport, we hope to assess geomorphic channel changes from LID detention basins that produce lower peak flows, longer recession flows and reduced coarse bedload (i.e. dam hydrology).

[illegible]

The Bay Area Curves Project will be assessing if regional curves can assist with predication in the geomorphic channel changes based on changes in flow and sediment load.



Data to Support LID Design

Field geomorphic surveys and regional curves of hydraulic geometry can provide the following information that has been identified as be critical to proper LID design:

- ✓ Provides stable channel reference design parameters (bankfull width, depth, area, slope) for a variety of stream types over a range of watershed conditions
- ✓ Develops correlations of grain size by stable stream type to allow for back calculation of critical shear stress values based on locally derived values by designers
- ✓ Allows for analysis of anticipated creek morphology changes due to implementation of LID design
- ✓ Provides a data base to understand the complex correlations between a variety of factors and creek morphology

Conclusions and Next Steps

The Bay Area Regional Curves Project can provide useful and important data to LID designers and others assessing channel conditions. To-date, the project has collected data at approximately 32 sites in Marin and Sonoma Counties and expects to have at least 100 sites in other selected Bay Area watersheds upon completion. The data will be analyzed and collated and made available to creek restoration designers through SFEP and the RWQCB.

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Thank You!

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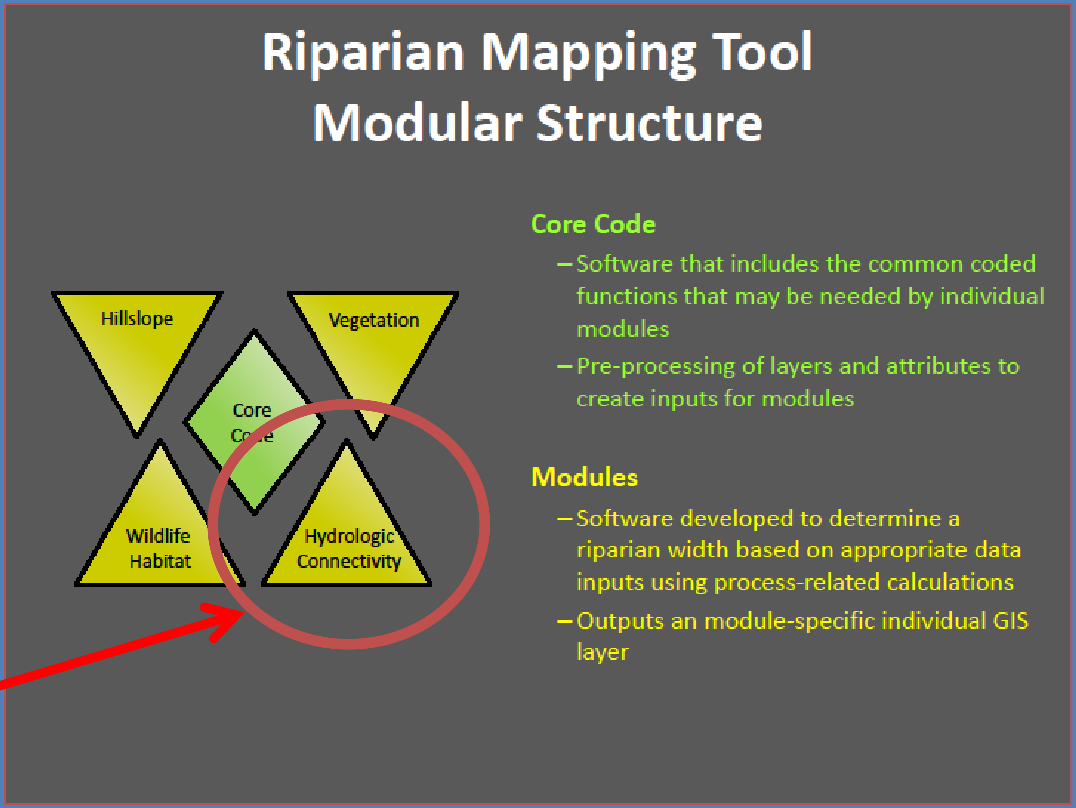
San Francisco Estuary Institute-Statewide Riparian Buffer Width Tool

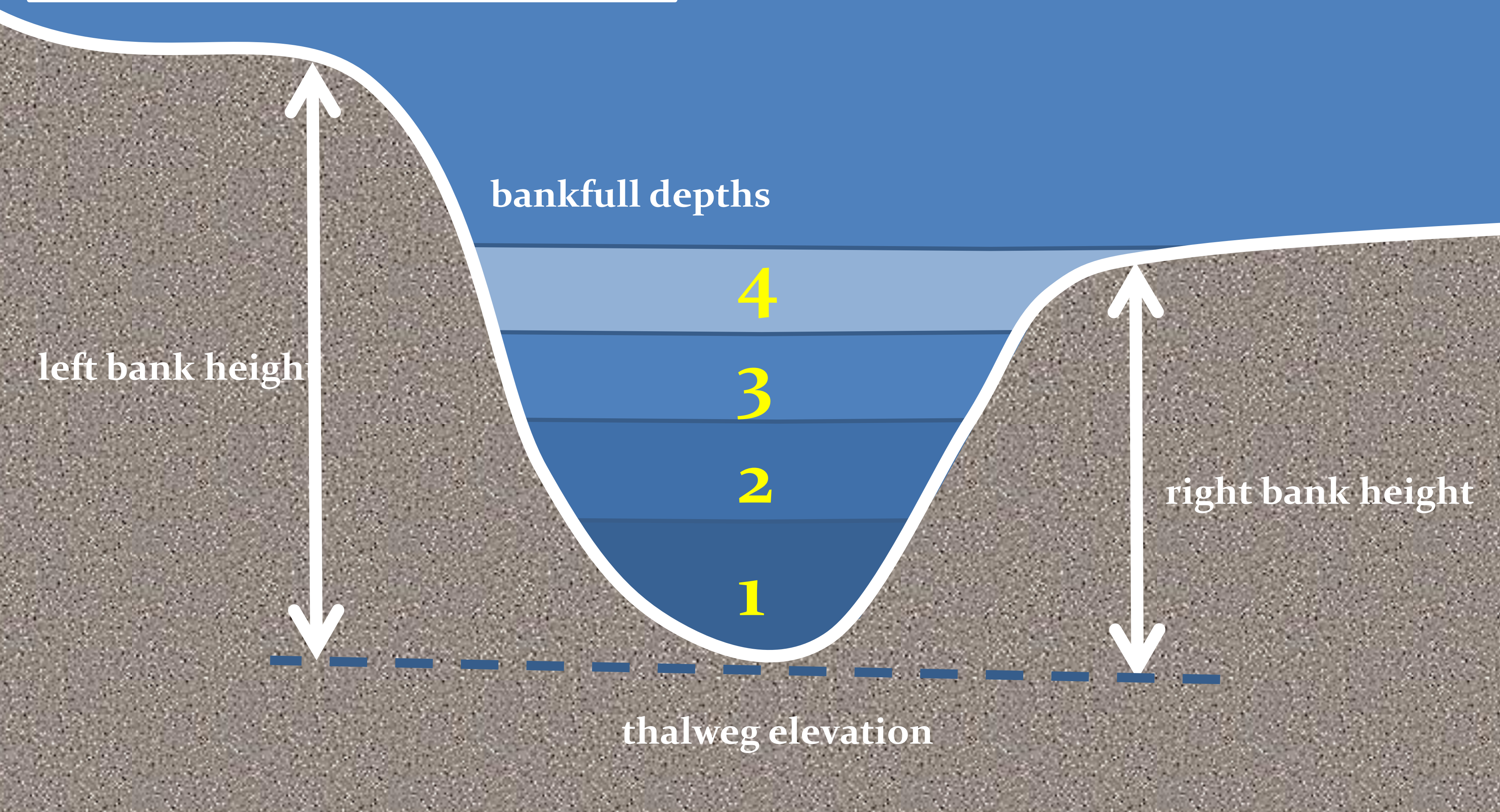
- In-progress with State of Ca agencies DFW, RWQCB others
- Create a web-based tool to set buffer widths for riparian function
- Using regional curves for hydrologic connection module (uses our curves for SF North Bay)



Hydrologic Connectivity Buffer

<u>Example</u>:
right bank height = 18 m
drainage area = 2,000 mi^2
bankfull depth = $0.9(DA)^{0.389}$
no. bankfull depths to get to top of bank = 4

- different stream geometries pose different flood risks
- each side may require unique numbe of bankfulls to flood



Next Steps

Looking for Phase II funding to:

- Perform more field survey at focus sites
- Statistical data analysis and segregation
- Look for riparian signature on floodplain (part of SFEI team) – focus on required floodplain width
- Assess water quality impacts of sediment production from channel erosion
- Prepare a formal methods and procedures guidance document
- Publish findings and prepare presentations of findings and use regional curves for creek restoration design and watershed analyses

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