Relations for Bankfull Hydraulic Geometry of Sinuous Channels in Submarine and Subaerial Settings*

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Abstract

The bankfull hydraulic geometry of river channels has typically been characterized in terms of mean bankfull width Hbf, mean bankfull depth Bbf, and mean downchannel bed slope S as functions of bankfull discharge Qbf. In the case of rivers, these parameters, as well as bed grain size, can be directly measured. General relations for rivers characterizing hydraulic geometry have been developed in both dimensioned and dimensionless form. A corresponding analysis is difficult to perform in the submarine case because the parameters that are directly measurable are generally limited to channel width, depth, and slope (and bed grain size when cores are available). Neither the characteristic bankfull discharge nor the characteristic volume concentration C of suspended sediment that drives the channel-forming turbidity currents that construct the channels are known in advance. Here we use the following information and tools to reconstruct these parameters: 1) a data set consisting of 250 reaches/cross-sections for (mostly) meandering, sand-bed rivers for which all the relevant parameters are known; 2) a data set for consisting of 180 reaches/cross-sections for meandering submarine channels in which only Hbf, Bbf, and S are known; 3) relations for momentum balance, bed shear stress, and interfacial shear stress for turbidity currents and rivers. We then back-calculate a single characteristic concentration C necessary for the turbidity currents to follow the same trend in driving force/area versus channel size as observed for rivers. We in turn use this value to calculate the bankfull discharge for each submarine channel. The back-calculated value of C that brings the submarine data into accord with the fluvial data is around 0.0017. The analysis yields a common set of relations for hydraulic geometry for the submarine and subaerial cases. While the submarine channels of our data set tended to be much larger than the subaerial channels in the corresponding data set, the two cases do show a zone of overlap. While it is likely that the channel-forming value of C differs from channel to channel, the analysis a) provides a characteristic estimate of this parameter that has proved otherwise inaccessible until now

and b) allows estimation of bankfull discharge for each submarine channel. The relations so derived should provide useful tool in the interpretation of channels in outcrops and seismics.

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Parker, G., T. Muto, Y. Akamatsu, W.E. Dietrich, and J.W. Lauer, 2008b, Unravelling the conundrum of river response to rising sea-level from laboratory to field, Part I, Laboratory experiments: Sedimentology, v. 55/6, p. 1643-1655.

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Wilkerson, G., and G. Parker, 2011, Physical basis for Quasi-Universal relationships describing bankfull hydraulic geometry of sand-bed rivers: Journal of Hydraulic Engineering, v. 137/7, p. 739-753.

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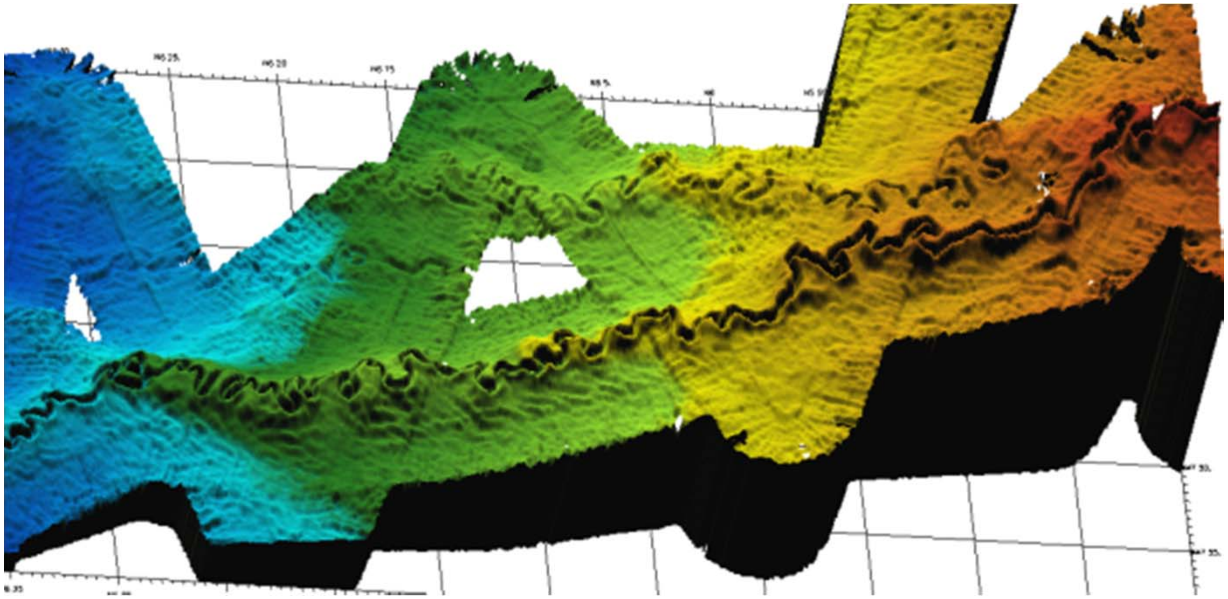
University of Leeds, School of Earth and Environment: Web accessed 14 September 2012.
http://homepages.see.leeds.ac.uk/~earjp/bends.shtml

RELATIONS FOR BANKFULL HYDRAULIC GEOMETRY OF SINUOUS CHANNELS IN SUBMARINE AND SUBAERIAL SETTINGS



Channels on Amazon Submarine Fan: homepages.see.leeds.ac.uk

Strickland River, Papua New Guinea

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April 23, 2012

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Just back from the Loess Plateau, China

BANKFULL (CHANNEL-FORMING) HYDRAULIC GEOMETRY FOR RIVERS

Wabash River, USA

Just above

and below

bankfull stage

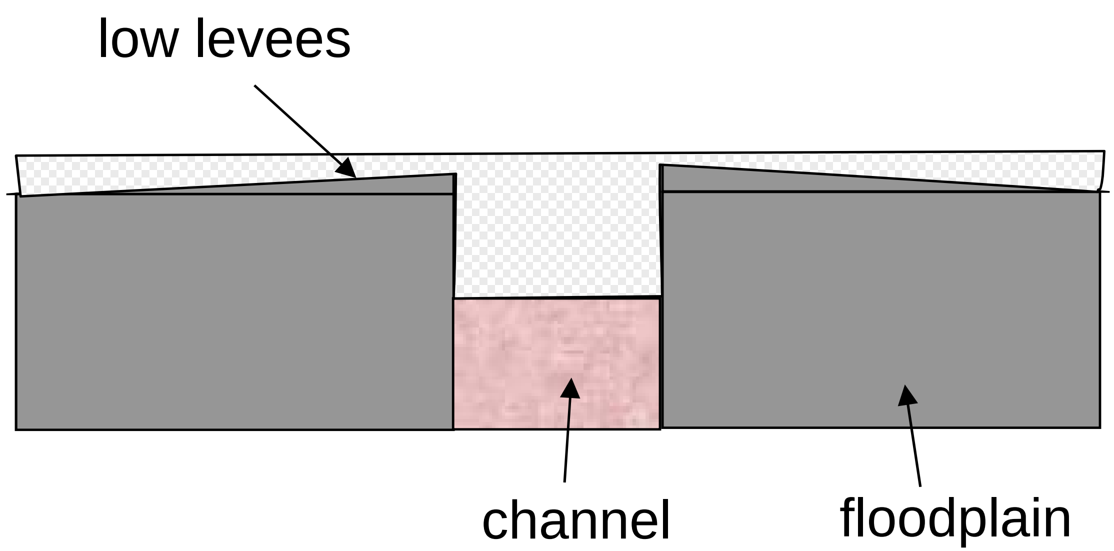
CHARACTERIZATION OF HYDRAULIC GEOMETRY OF RIVERS AT BANKFULL (~ CHANNEL-FORMING) DISCHARGE

Relate

Bankfull width	B
Bankfull depth	H
Channel slope	S

to

Bankfull discharge	Q
Characteristic bed size	D



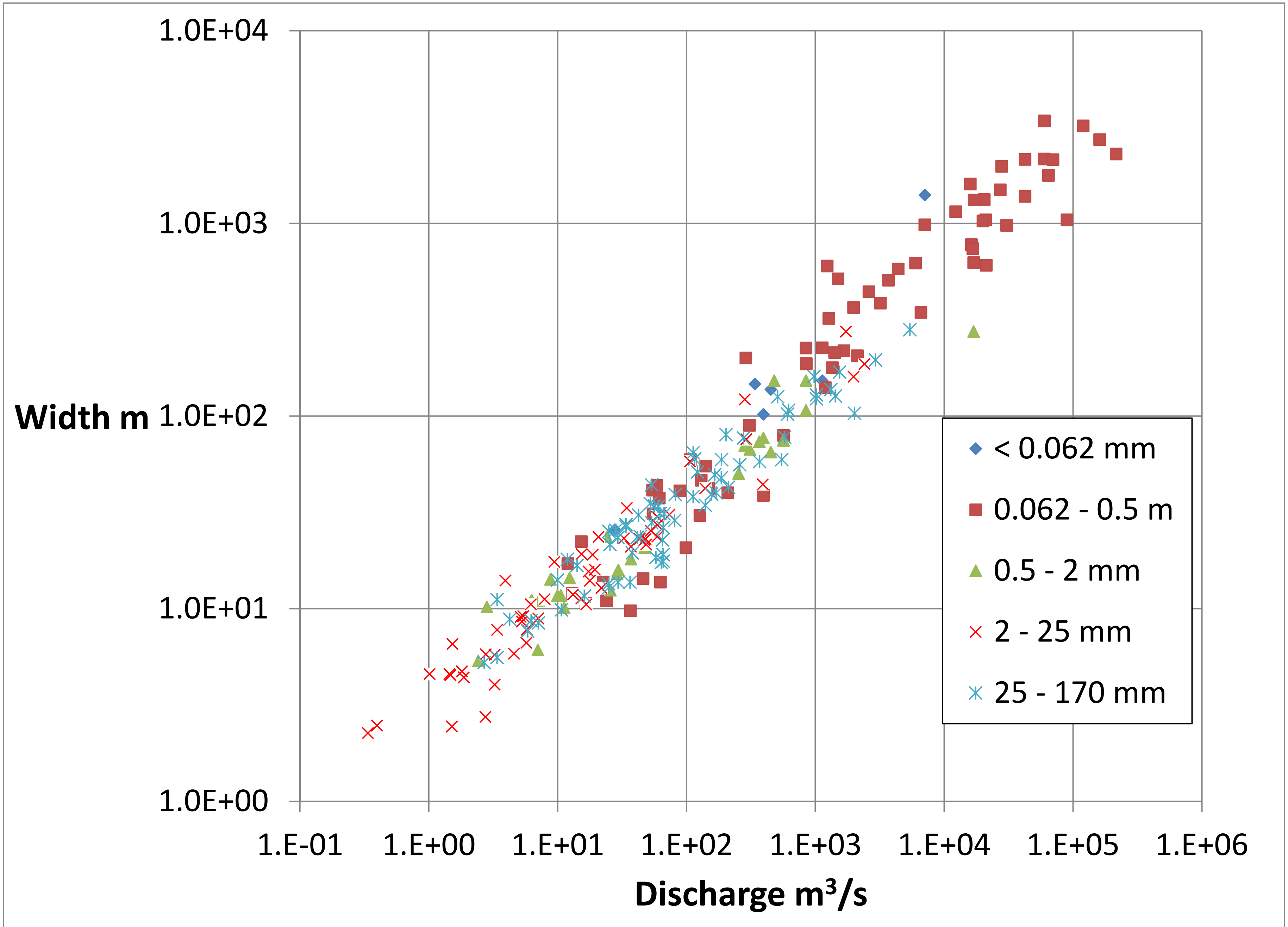
RIVER DATA BASE FOR BANKFULL CHARACTERISTICS

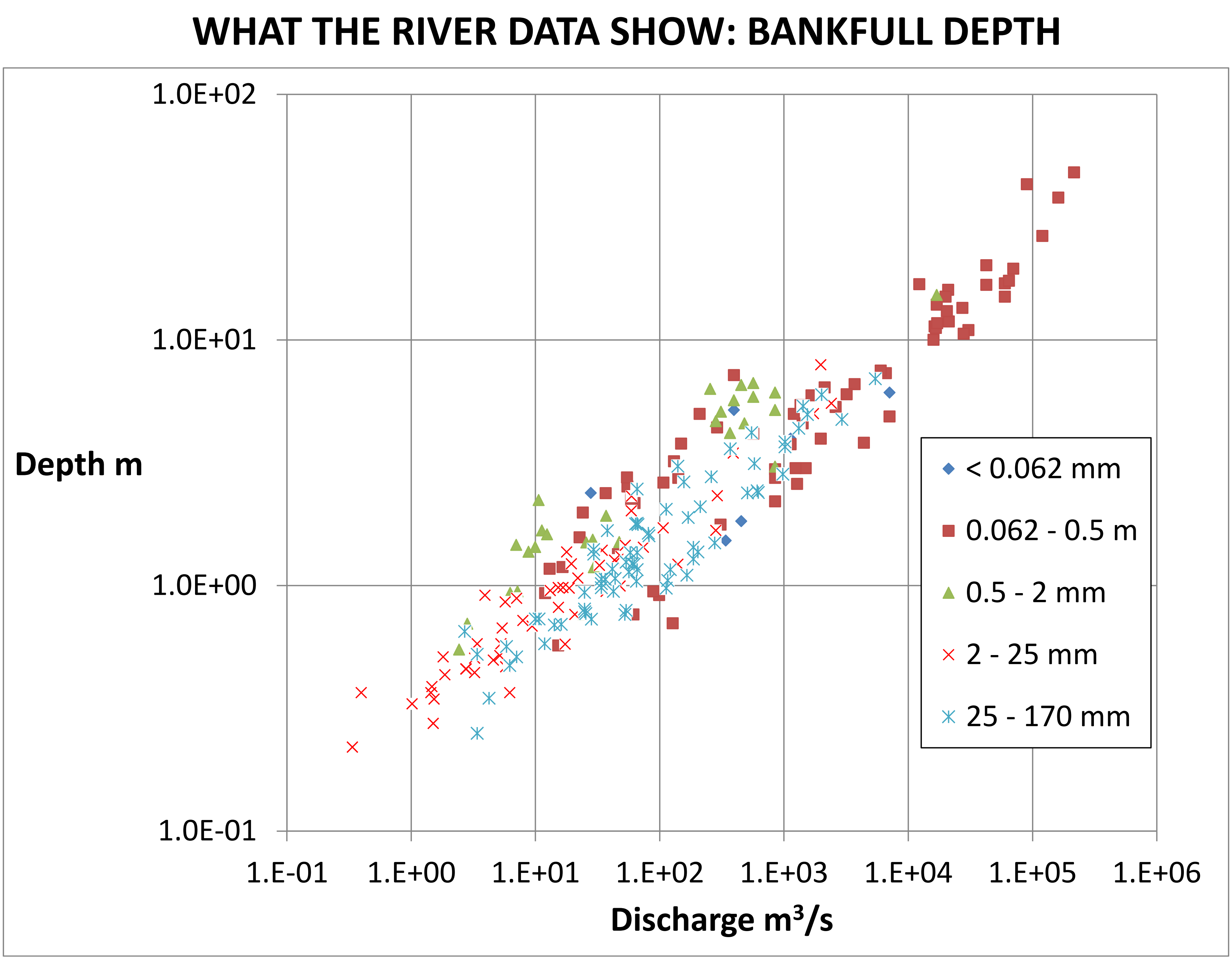
Parker et al., 2008
Wilkerson and Parker, 2011

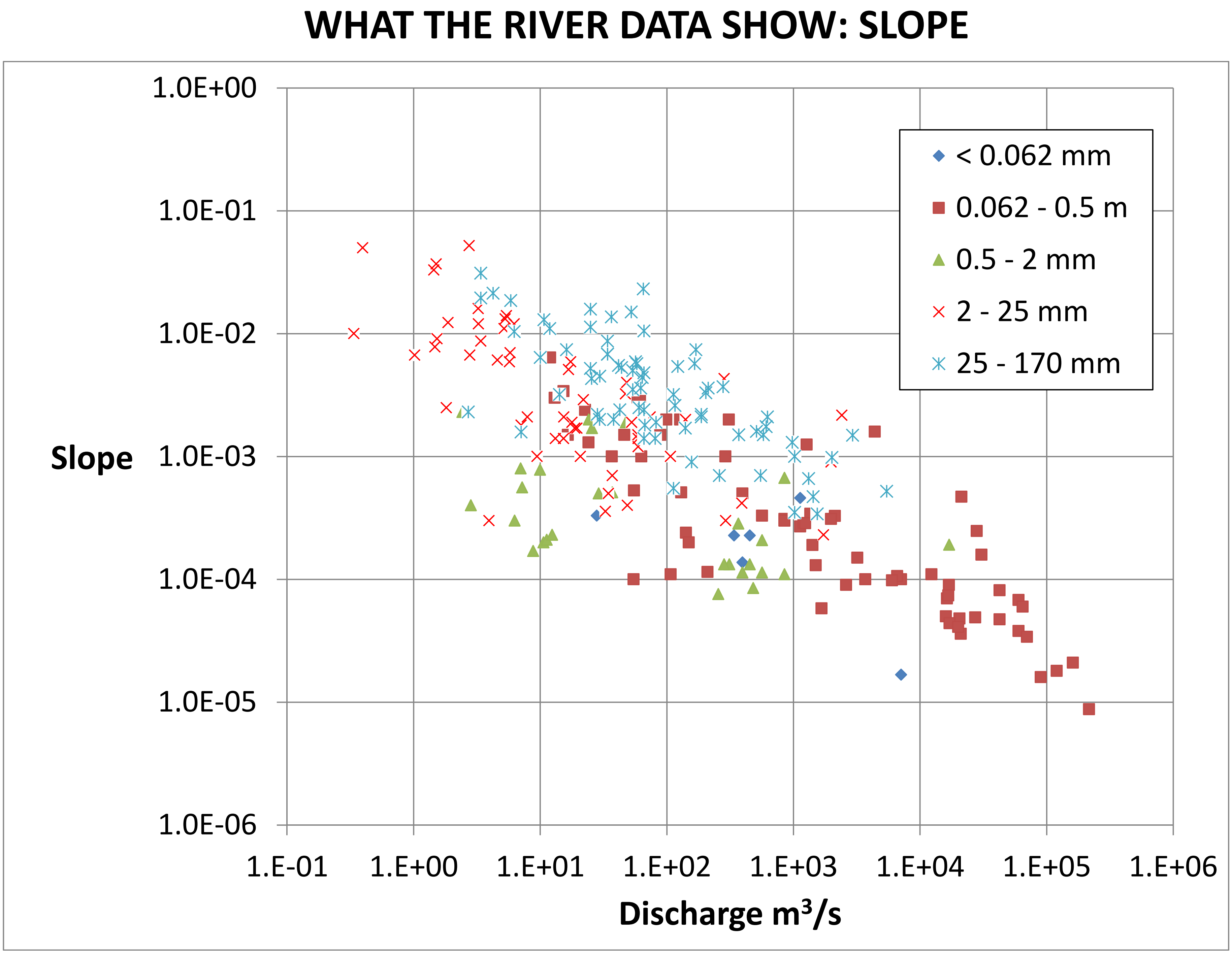
231 River Cross-Sections

	Minimum	Maximum
Discharge (m^3/s)	0.34	2.3×10^5
Bed grain size (mm)	0.04	170
Width (m)	2.3	3400
Depth (m)	0.2	48
Slope	1.0×10^{-5}	5.2×10^{-2}

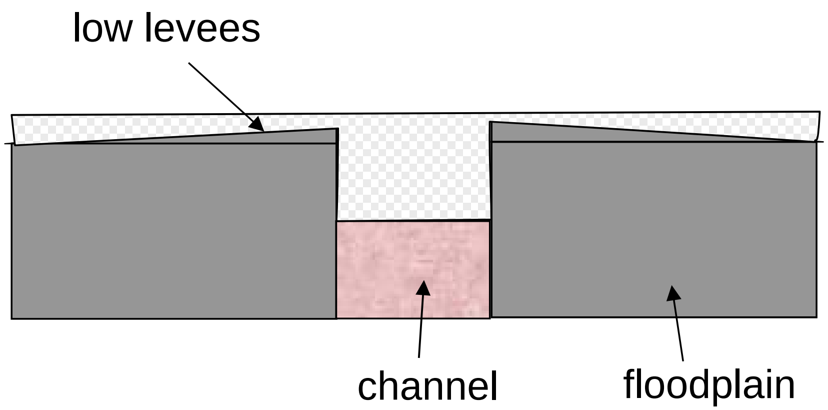
WHAT THE DATA SHOW: BANKFULL WIDTH



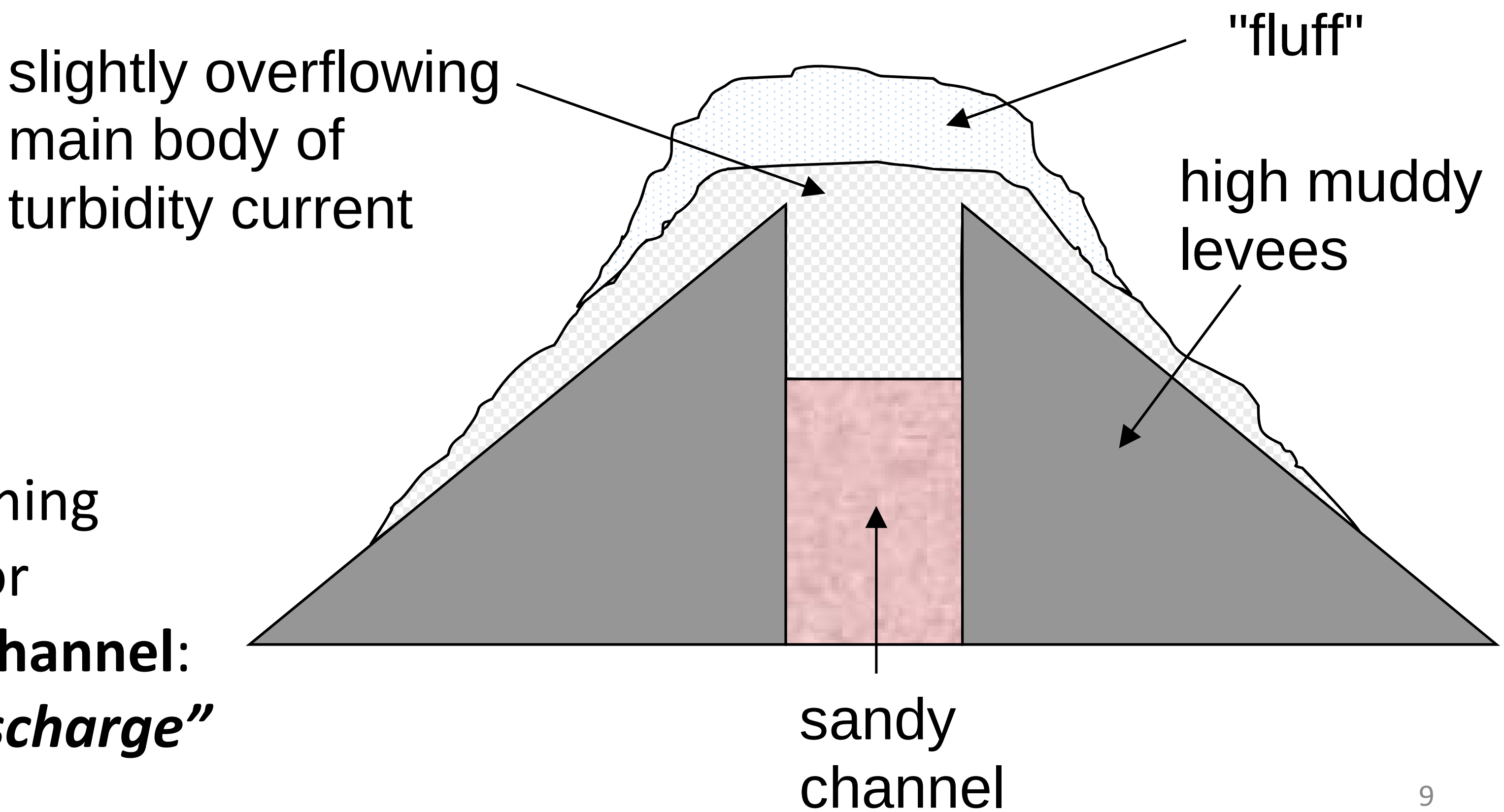

WHAT THE RIVER DATA SHOW: BANKFULL DEPTH
1.0E+02
1.0E+01
1.0E+00
1.0E-01
Depth m
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
Discharge m³/s
< 0.062 mm
0.062 - 0.5 m
0.5 - 2 mm
2 - 25 mm
25 - 170 mm


WHAT THE RIVER DATA SHOW: SLOPE
Slope
1.0E+00
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
Discharge m³/s
< 0.062 mm
0.062 - 0.5 m
0.5 - 2 mm
2 - 25 mm
25 - 170 mm

WHAT ABOUT SUBMARINE CHANNELS?



Channel forming conditions for **river**



Channel forming conditions for **submarine channel**: ***"bankfull discharge"***

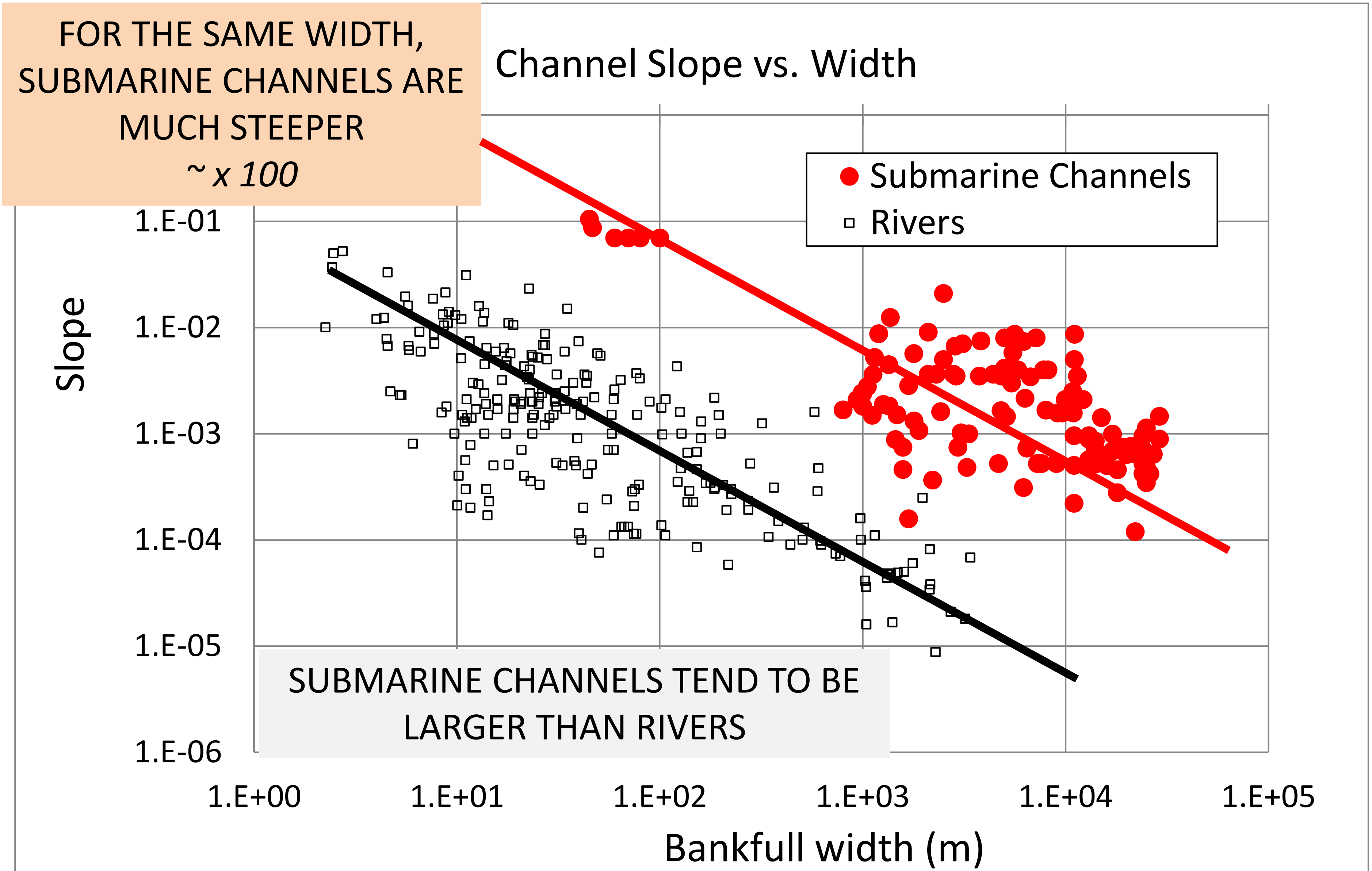
BUT WHAT DO WE KNOW ABOUT SUBMARINE CHANNELS?

178 cross-sections

All we know are width, depth, slope

	Width (m)		Depth (m)		Slope	
	Submarine Channels	Rivers	Submarine Channels	Rivers	Submarine Channels	Rivers
Min	26.7	2.3	3.4	0.2	0.00012	0.00001
Max	60000.0	3400.0	700	48.1	0.10510	0.05200

DO THE DATA TELL US ANYTHING?



REDUCED GRAVITY IN THE SUBMARINE ENVIRONMENT

Unit downstream driving force per unit weight in a river:

$$F_D = S$$

Unit downstream driving force per unit weight of a turbidity current:

$$F_D = RCS$$

$C << 1$

where

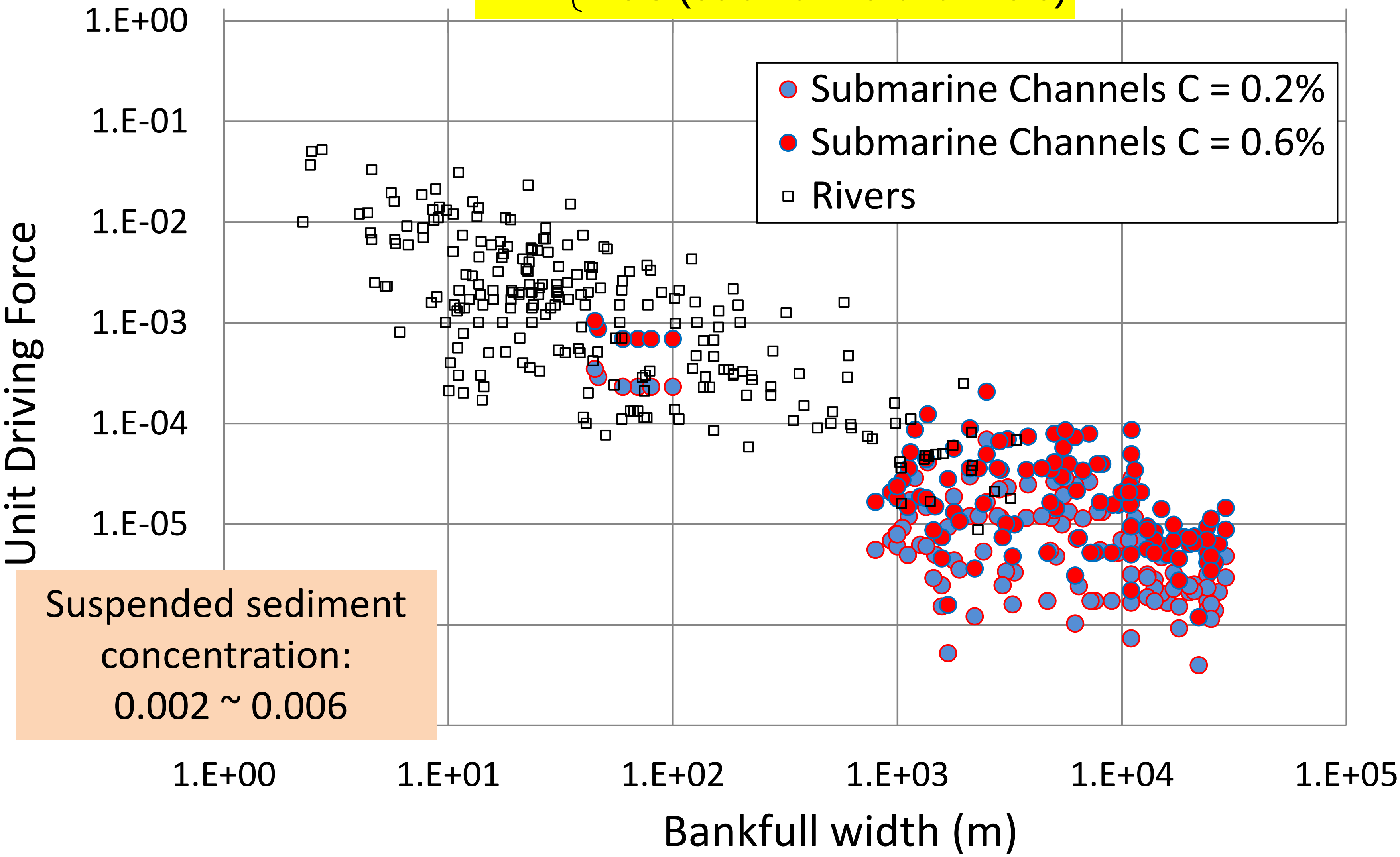
C = volume suspended sediment concentration
R = submerged specific gravity of sediment ~ 1.65 for quartz

HYPOTHESIS 1: RIVERS AND SUBMARINE CHANNELS BEHAVE SIMILARILY WHEN NORMALIZED ACCORDING TO UNIT DRIVING FORCE

To bring turbidity currents into line, lower C until the driving force of turbidity currents fall into line with the river data

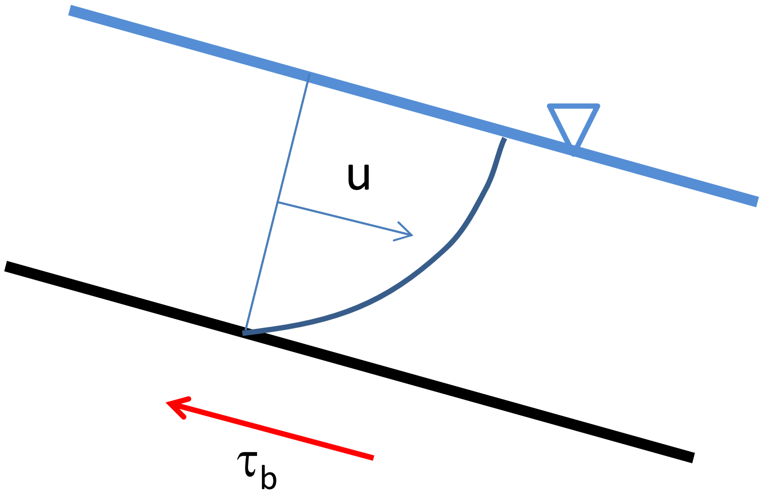
THIS HYPOTHESIS GIVES A BROAD-BRUSH ESTIMATE OF VOLUME SUSPENDED SEDIMENT CONCENTRATION OF FORMATIVE FLOWS

$$F_D = \begin{cases} S \text{ (rivers)} \\ RCS \text{ (submarine channels)} \end{cases}$$



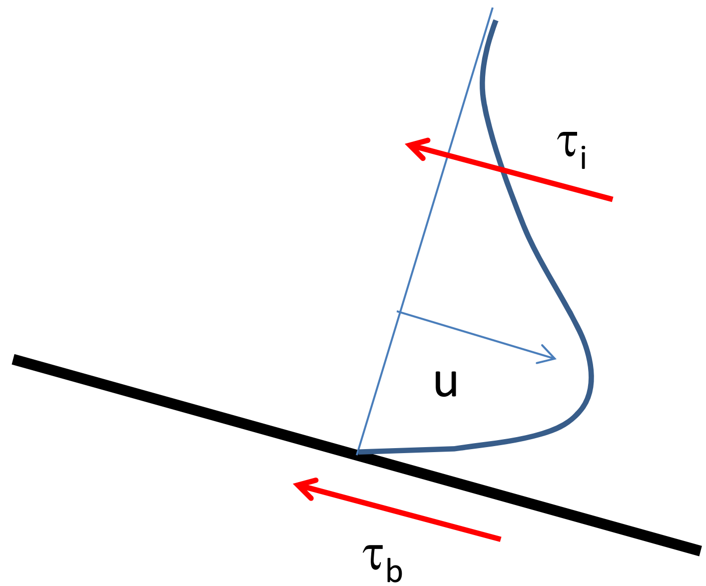
Suspended sediment concentration: 0.002 ~ 0.006

EVEN AFTER NORMALIZATION THERE SHOULD BE SOME UPWARD OFFSET OF THE SUBMARINE DATA



River:
bed friction only

Turbidity current:
bed + interfacial friction



SO WE CHOOSE C = 0.006 AS THE BEST ESTIMATE

ESTIMATE BANKFULL DISCHARGE Q FROM MOMENTUM BALANCE FOR RIVERS AND TURBIDITY CURRENTS

"Normal", i.e. steady, uniform flow approximation:
Balance between downstream pull of gravity and resistance

C_{fb} = coefficient of bed resistance
C_{fi} = coefficient of interfacial resistance
g = gravitational acceleration
$\mathbf{Fr}_d$ = densimetric Froude number
U = flow velocity

$$(C_{fb} + C_{fi})U^2 = \begin{cases} gHS & , \quad \text{rivers} \\ RCgHS & , \quad \text{turbidity currents} \end{cases}$$

or

$$C_{fb} + C_{fi} = \mathbf{Fr}_d^{-2} S$$

where

$$\mathbf{Fr}_d = \begin{cases} \dfrac{U}{\sqrt{gH}} & , \quad \text{rivers} \\ \dfrac{U}{\sqrt{RCgH}} & , \quad \text{turbidity currents} \end{cases}$$

SOLVE FOR CHANNEL-FORMING DISCHARGE Q

$$\mathbf{Fr}_d^{-2} S = C_{fb} + C_{fi}$$

River:

$$C_{fi} = 0$$

$$\mathbf{Fr}_d = \frac{U}{\sqrt{gH}}$$

Turbidity Current:

$$C_{fi} = e_w \left(1 + \frac{1}{2}\mathbf{Fr}_d^{-2}\right)$$

$$e_w = \frac{0.0075}{\sqrt{1 + 718\,\mathbf{Fr}_d^{-4.8}}}$$

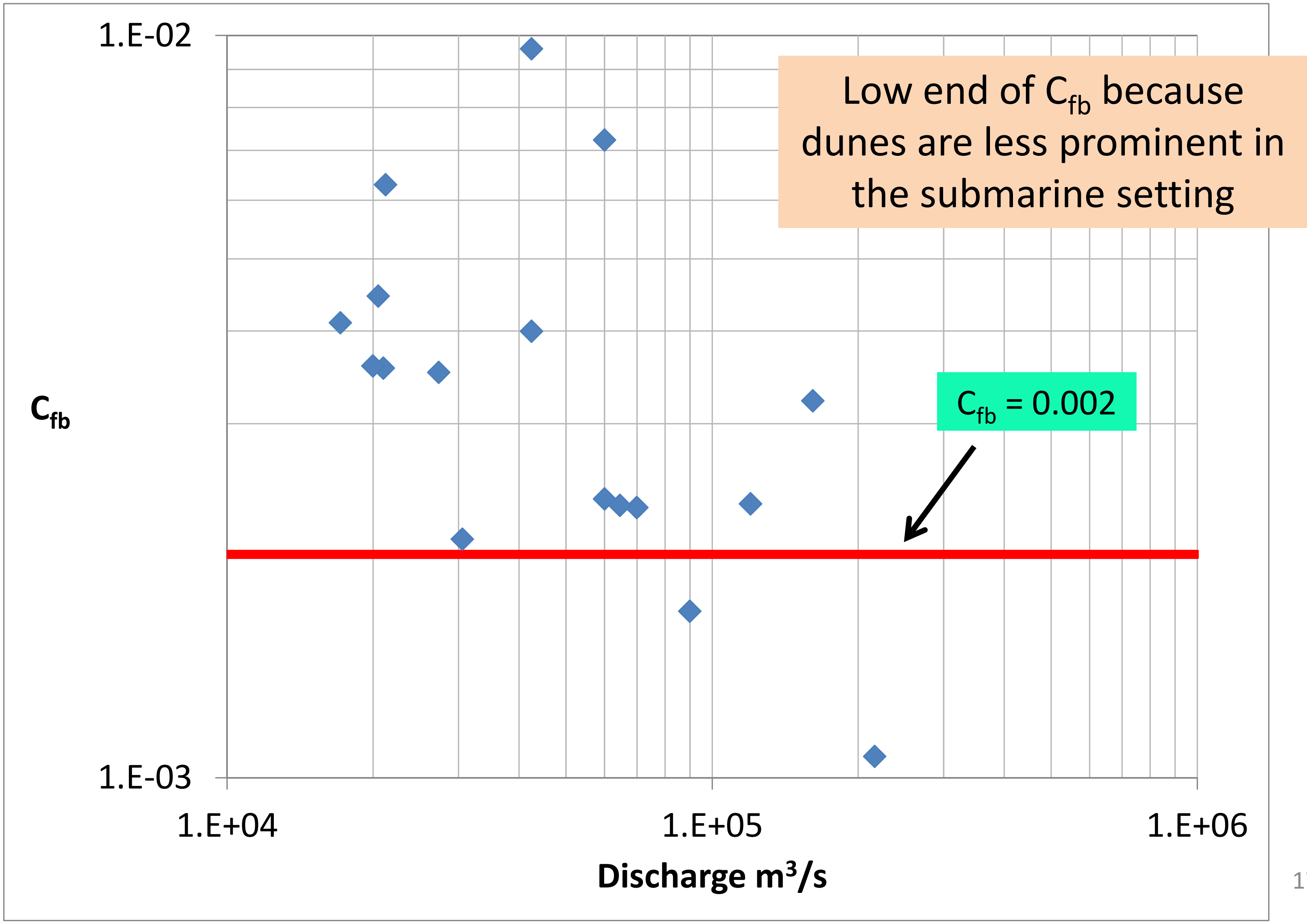
$$\mathbf{Fr}_d = \frac{U}{\sqrt{RCgH}}$$

For given S and C_{fb}, solve for $\mathbf{Fr}_d$. From $\mathbf{Fr}_d$ and given H, find U
For U and given B,

$$Q = UBH$$

BED FRICTION COEFFICIENT CHANNEL-FORMING TURBIDITY CURRENTS

HYPOTHESIS 2: THE BED FRICTION COEFFICIENT CAN BE ESTIMATED FROM THE LOW END OF DATA FOR THE LARGEST RIVERS



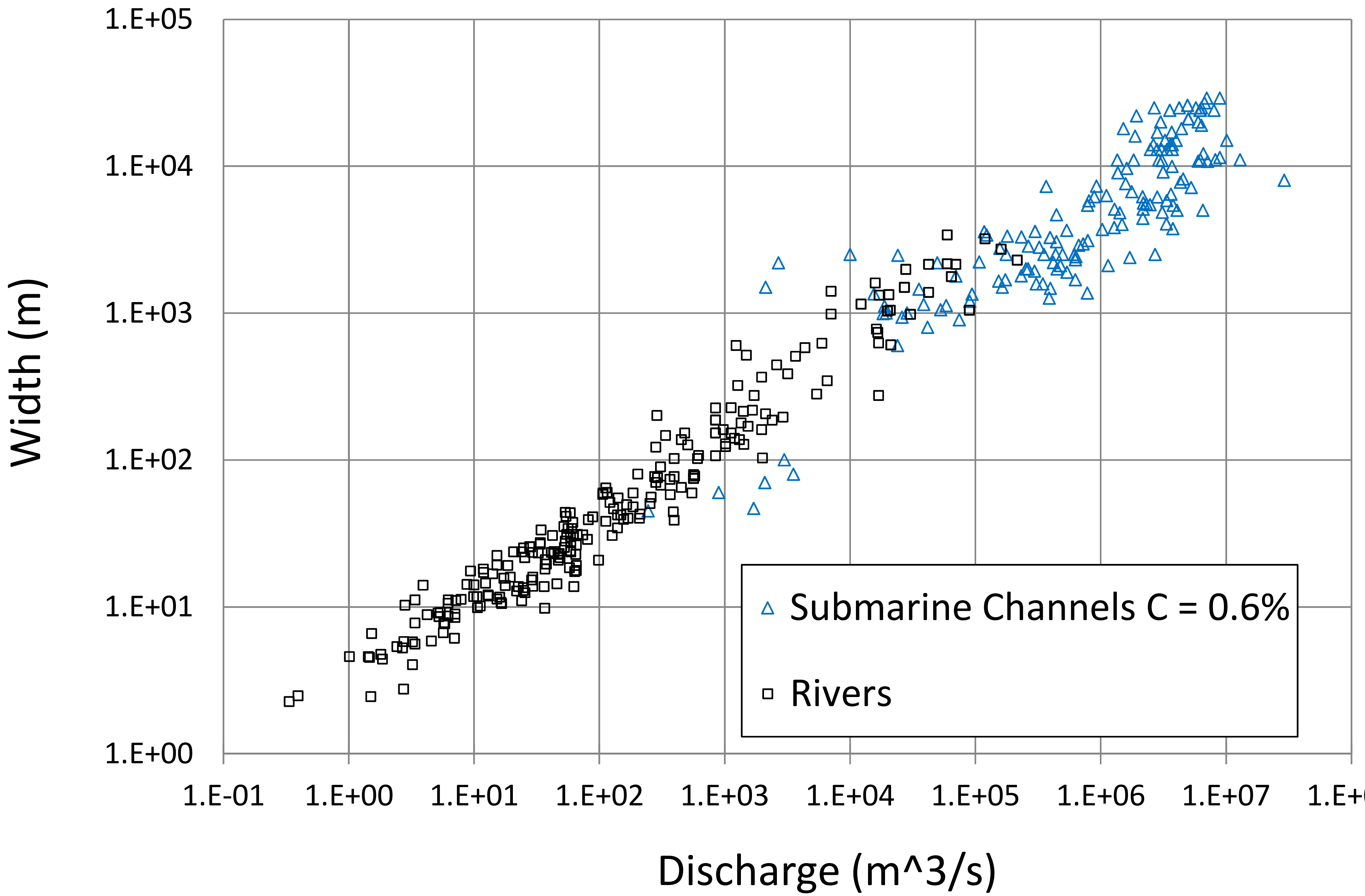
FORMATIVE DISCHARGE OF SUBMARINE CHANNELS

	Width (m)		Depth (m)		Slope	
	Submarine Channels	Rivers	Submarine Channels	Rivers	Submarine Channels	Rivers
Min	26.7	2.3	3.4	0.2	0.00012	0.00001
Max	60000.0	3400.0	700	48.1	0.10510	0.05200

	Discharge (m^3/s)	
	Submarine Channels	Rivers
Min	250	0.34
Max	2.7×10^7	2.2×10^5

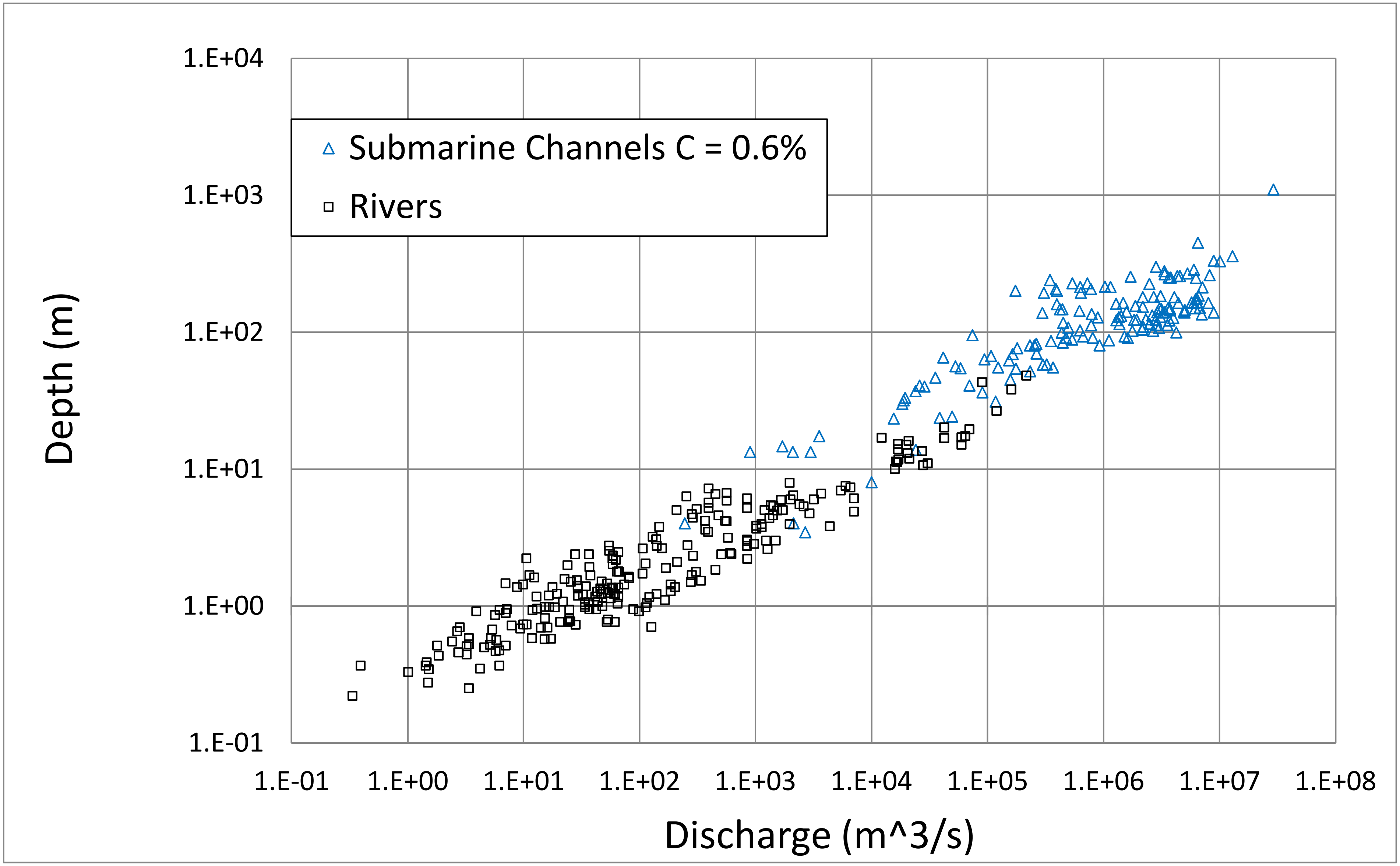
Discharge of turbidity currents ~ 100 times higher than rivers!

WIDTH



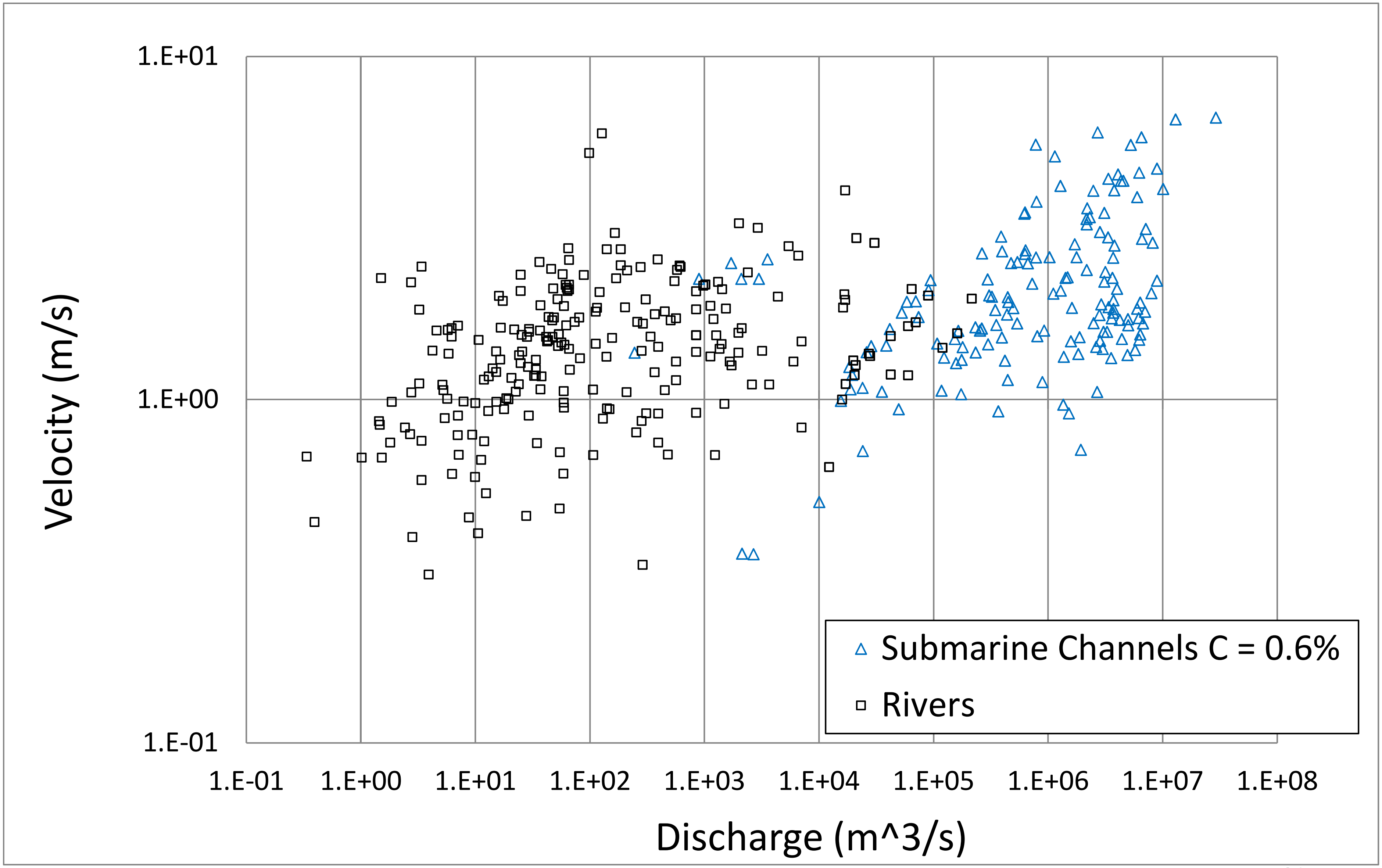
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
Width (m)
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
1.E+08
Discharge (m^3/s)
Submarine Channels C = 0.6%
Rivers

DEPTH



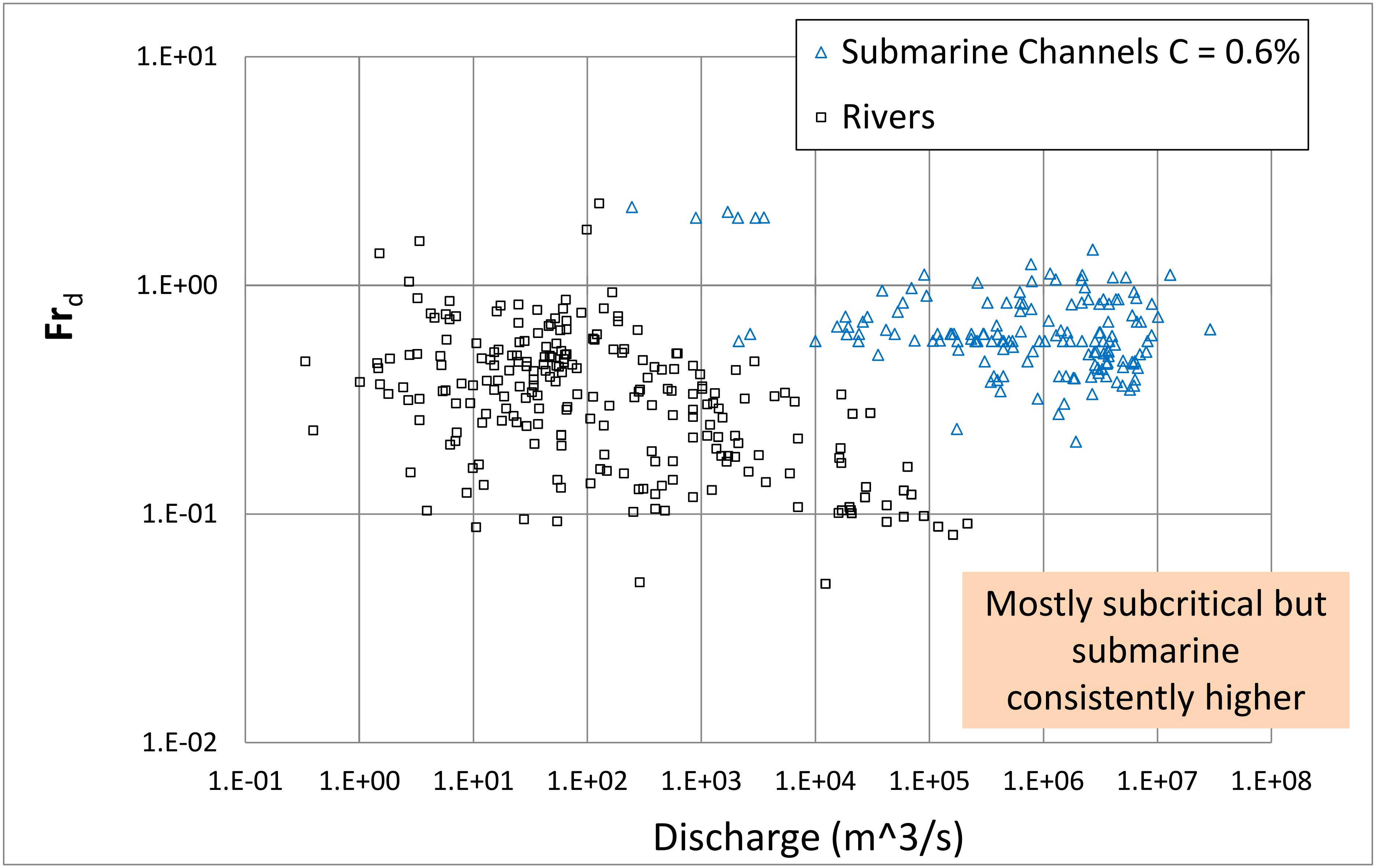
Submarine Channels C = 0.6%
Rivers
Depth (m)
1.E+04
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
1.E+08
Discharge (m^3/s)

VELOCITY



1.E+01
1.E+00
1.E-01
Velocity (m/s)
1.E-01
1.E+00
1.E+01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
1.E+08
Discharge (m^3/s)
Submarine Channels C = 0.6%
Rivers

FROUDE NUMBER VERSUS DISCHARGE



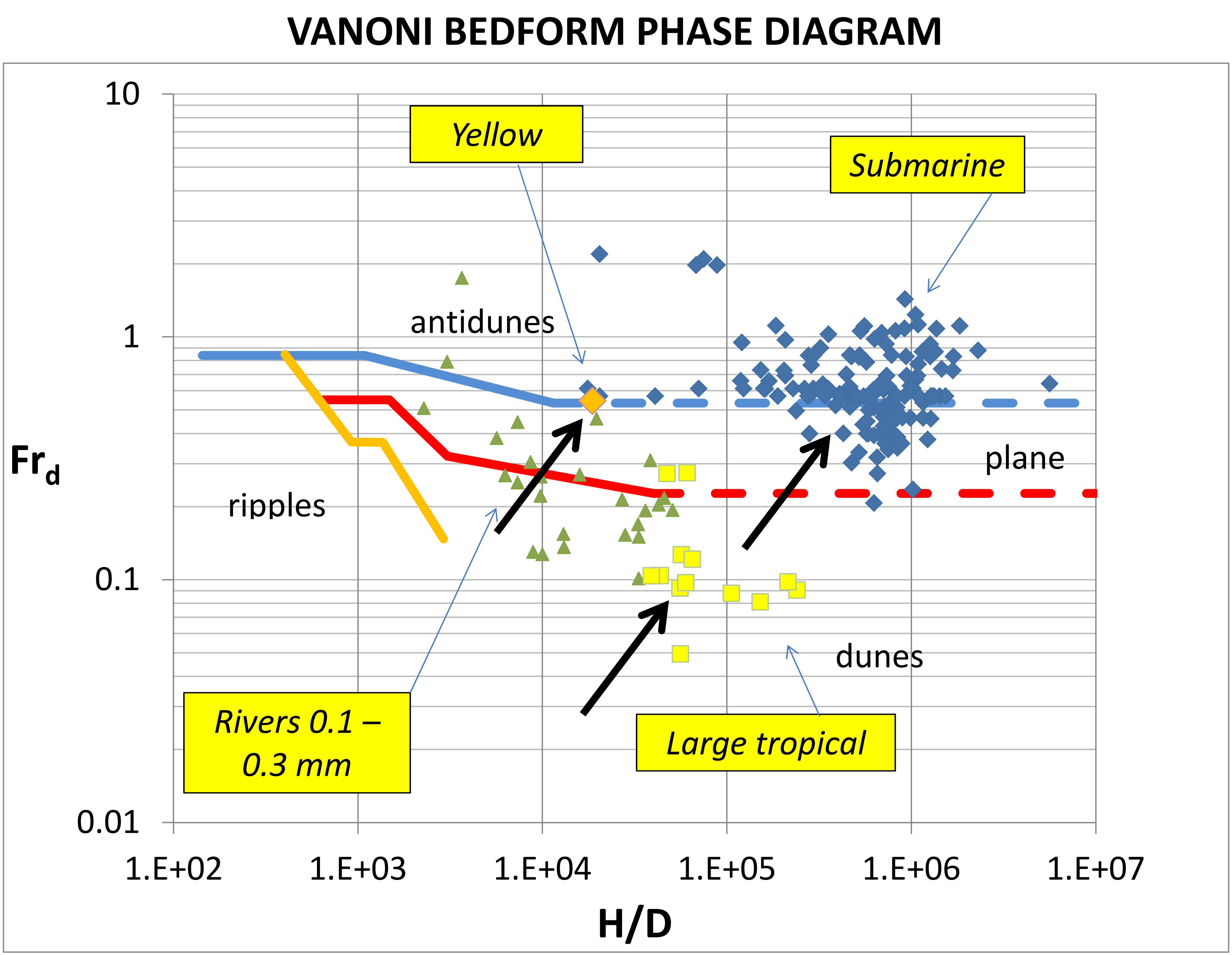
DUNES IN RIVERS AND SUBMARINE CHANNELS

Braided Reach, Yellow River

DUNES IN RIVERS AND SUBMARINE CHANNELS

Turbidite underlying Loess Plateau, Yellow River Basin

For turbidites , we assume 0.12 mm < D < 0.2 mm, and use Vanoni (1974) bedform phase diagram



VANONI BEDFORM PHASE DIAGRAM
Yellow
Submarine
antidunes
plane
ripples
dunes
Rivers 0.1 – 0.3 mm
Large tropical
Fr_d
10
1
0.1
0.01
1.E+02
1.E+03
1.E+04
1.E+05
1.E+06
1.E+07
H/D

THANK YOU FOR LISTENING