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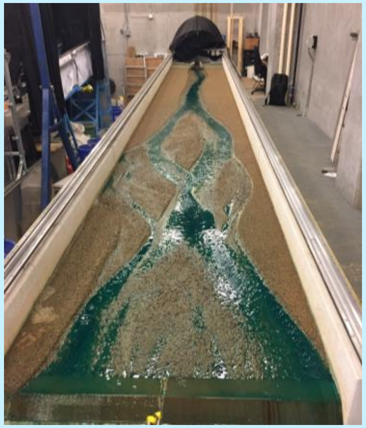
Concepts Related to Sediment Entrainment, Transport Continuity, and Floodplain Seeding: Opportunities for Increased Resilience in River Restoration



Dr. Paul Villard, P.Geo., CISEC-CAN
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Mitacs

GEO MORPHIX

UBC Geography

TRIECA Conference • March 20-21, 2019

Restored Equilibrium Channels and Sediment Continuity

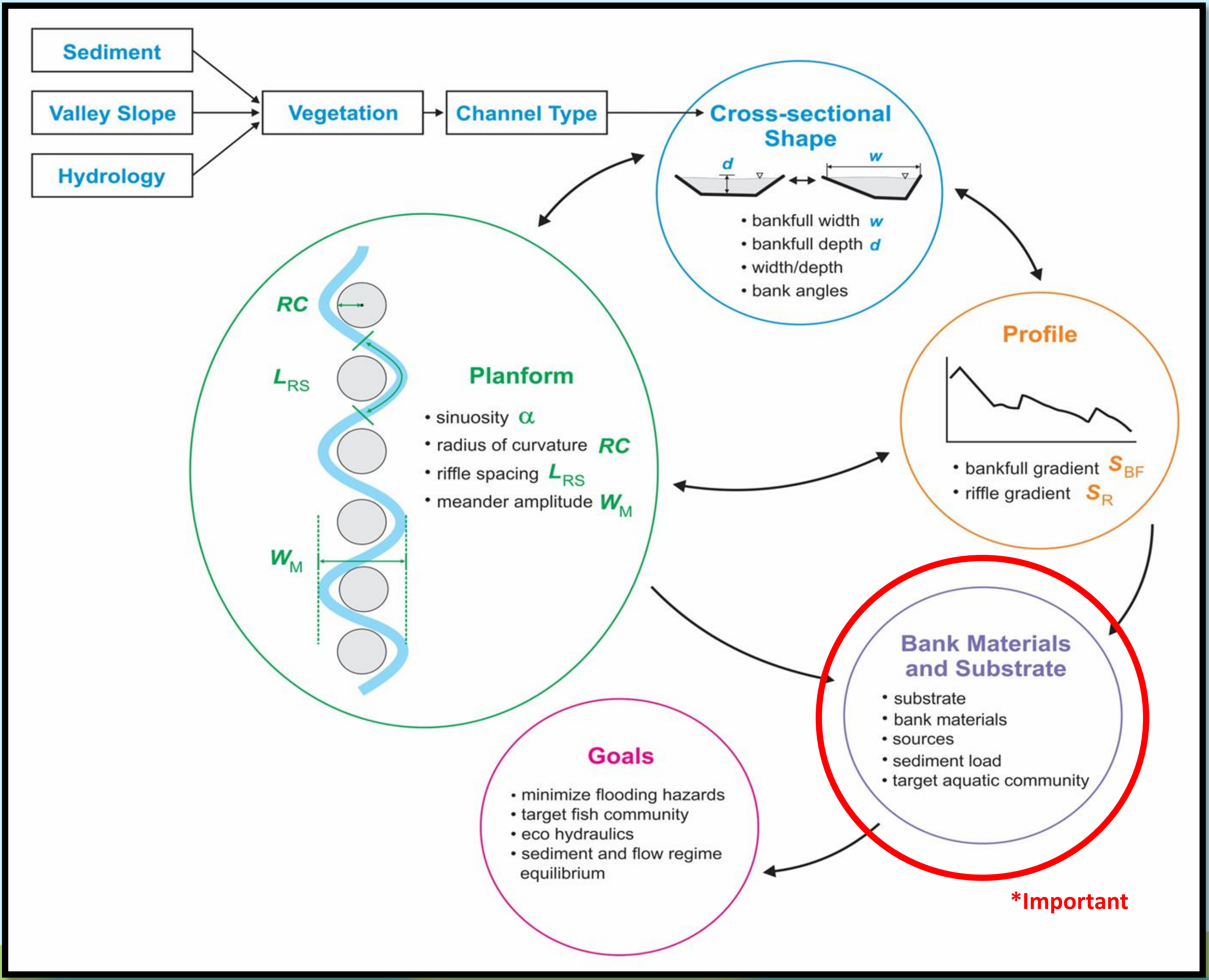
- Questions we should ask ourselves:
  - Where is the sediment coming from?
  - Where is it going?
  - Do we have enough sediment?
  - Is there a way to make sediments more stable while retaining channel dynamics?

Sediment Entrainment, Transport Continuity, and Floodplain Seeding

- Resilient channel designs are required in the face of hydrological and sediment regime changes associated with urbanization and climatic change
- Adaptive management is advertised to address unforeseen adjustments but relies heavily on monitoring and expenditure of future resources to address issues
- A better approach is to implement designs that allow the channel to adjust naturally
- Several concepts are presented that offer greater resiliency for constructed corridors to adjust to changes in hydrology and sediment regime

Spoilers

- Many design approaches match channel form but ignore active processes and sediment transport
- To improve long-term stability and resiliency in large scale channel realignments, we need to:
  - Identify and provide for long-term sediment sources
  - Focus on sediment size distributions
  - Acknowledge sediment continuity



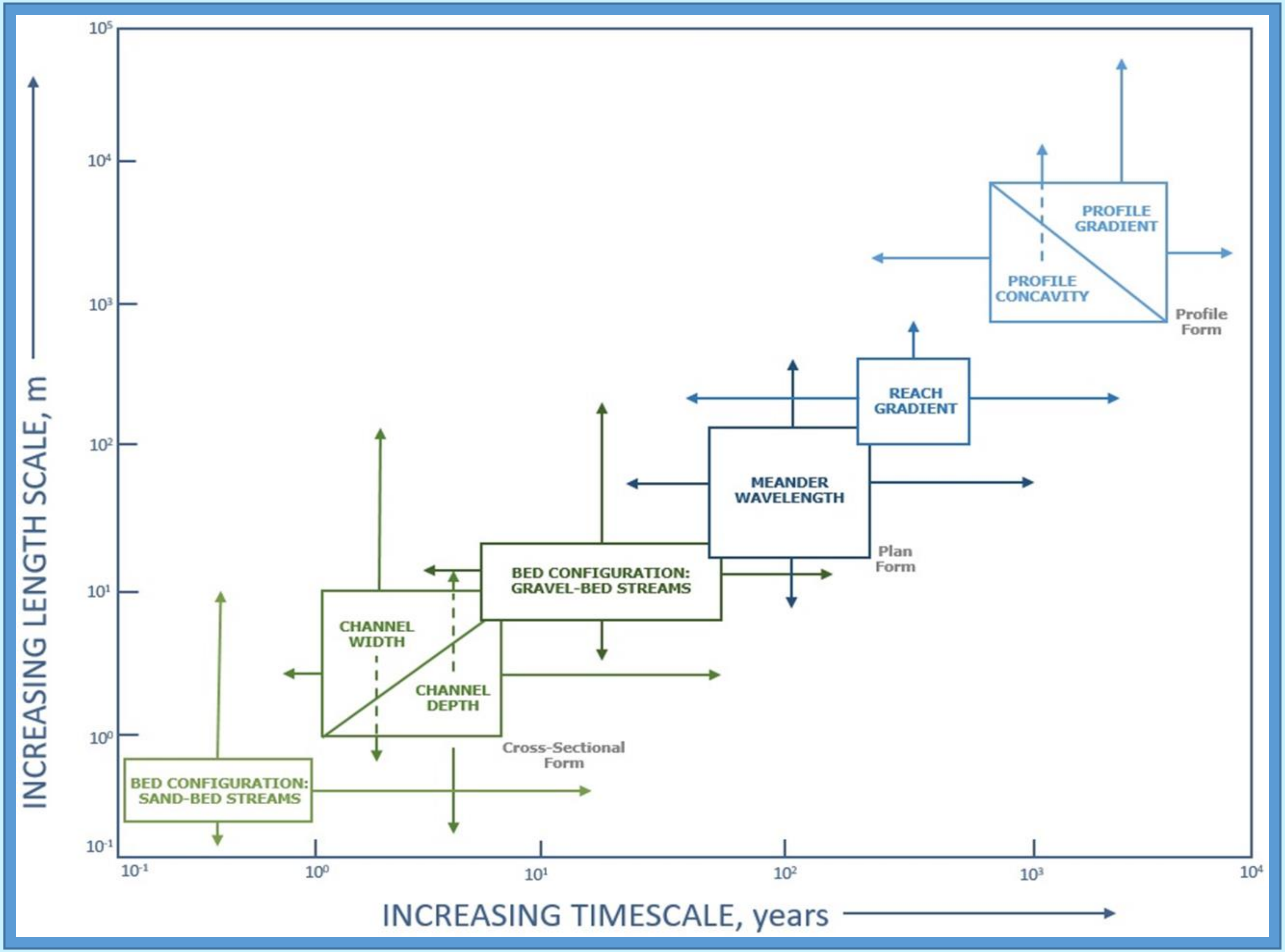
Sediment
Valley Slope
Hydrology
Vegetation
Channel Type
Cross-sectional Shape
d
w
• bankfull width w
• bankfull depth d
• width/depth
• bank angles
RC
L_{RS}
W_M
Planform
• sinuosity α
• radius of curvature RC
• riffle spacing L_{RS}
• meander amplitude W_M
Profile
• bankfull gradient S_{BF}
• riffle gradient S_R
Bank Materials and Substrate
• substrate
• bank materials
• sources
• sediment load
• target aquatic community
Goals
• minimize flooding hazards
• target fish community
• eco hydraulics
• sediment and flow regime equilibrium
*Important

Dependent Channel Parameters and Controlling Variables in Alluvial Streams

- Degrees of freedom describe a channel's capacity for change by the number of physical attributes that can adjust
- Degrees of freedom define the system's ability to assimilate and recover from perturbations

Degree of freedom (dependent variable)	Process driver (controlling variable)
Mean velocity	Flow regime
Channel slope	Sediment load
Hydraulic radius (mean and max depth)	Bed material characteristics
Wetted perimeter (channel width)	Bank material properties
Planform sinuosity	Valley slope
Meander bend arc length	Riparian vegetation

Data taken from Hey et al., 1982 (Sear et al., 2010)



Developed from a diagram by Knighton (1998)


Organics/Compost
Alluvium
Local Soil
Native Material

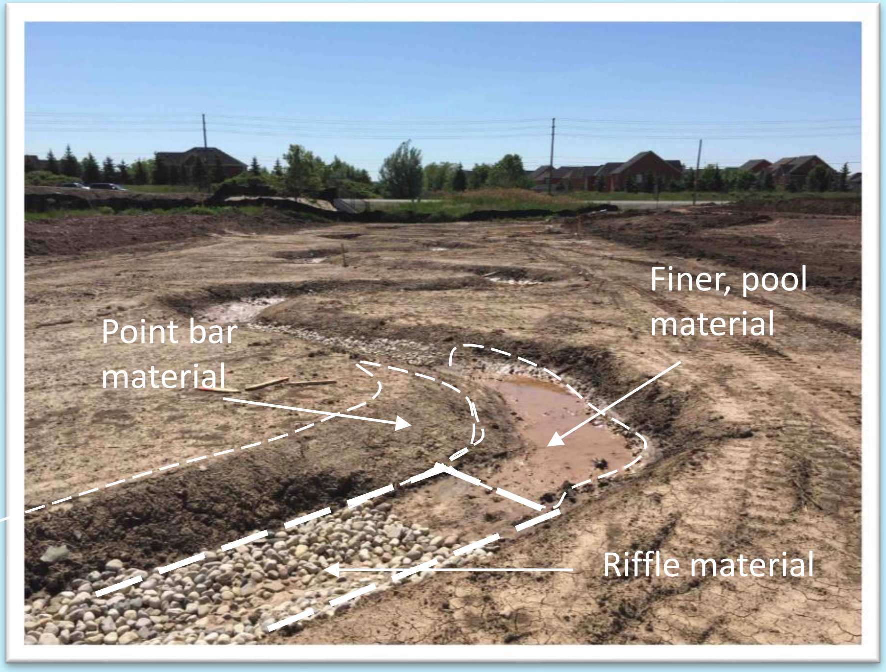
Shale Excavation

Reinstall native, non-organic sediments

Native parent material

Material Stockpiles – Riffle Stone

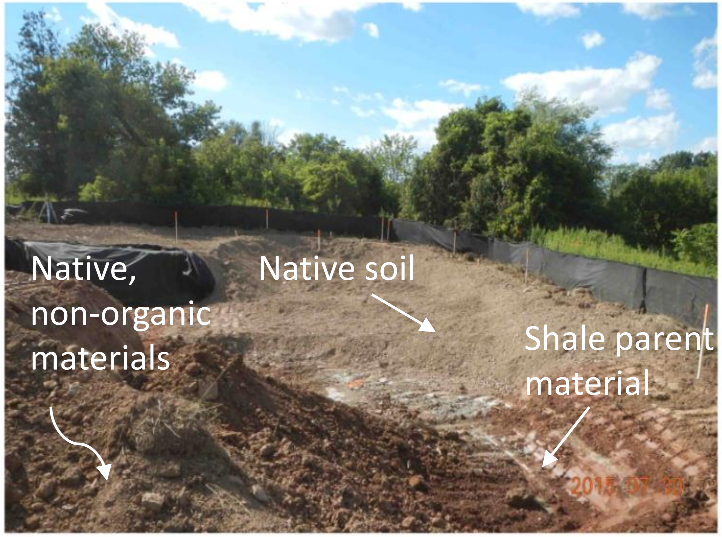
Point Bar



Constructed Point Bar Formation

Natural Point Bar Formation

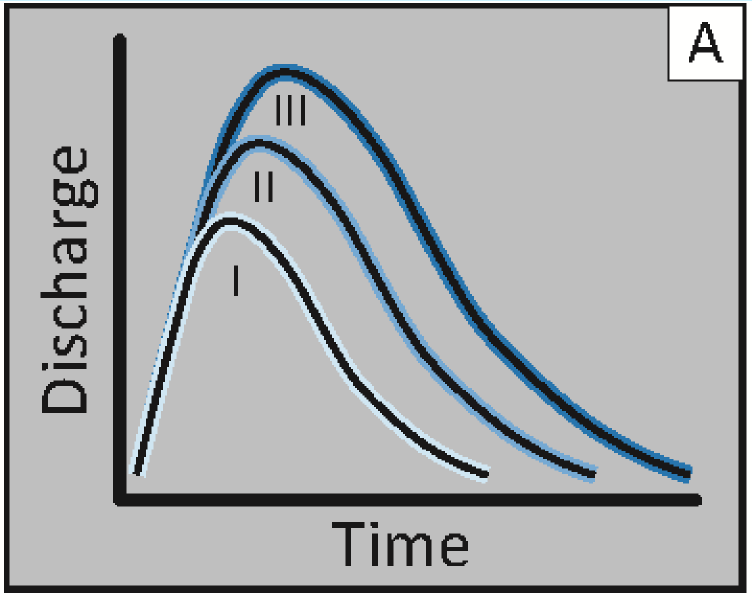
Wetland Installation - Sediment Banks



Wetland Installation - Sediment Banks

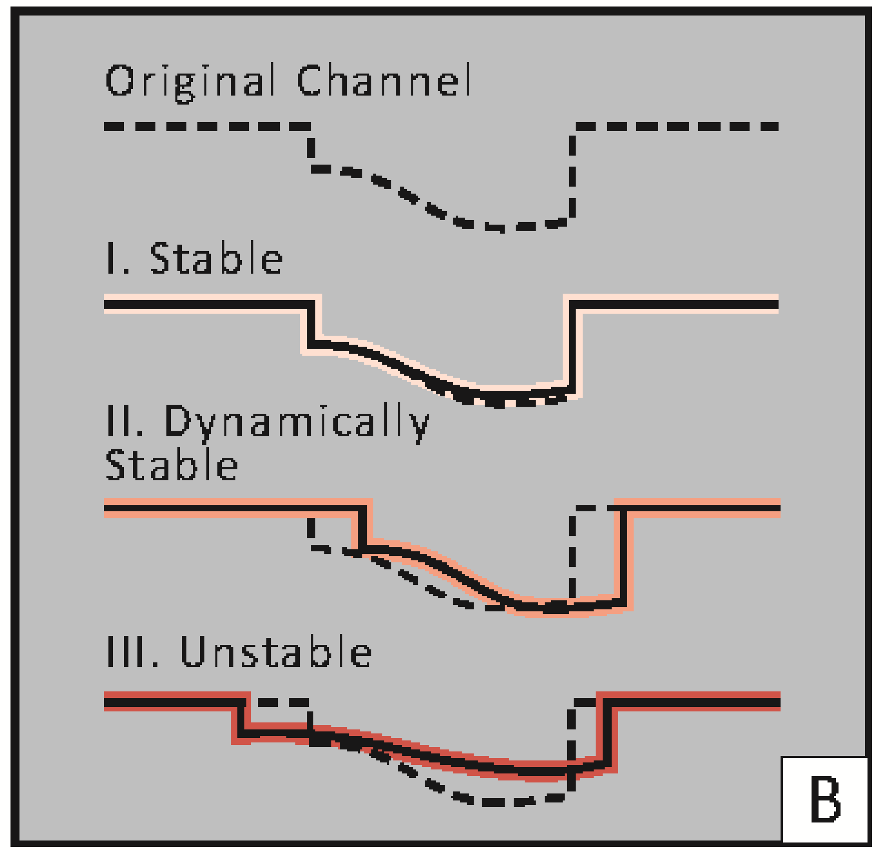
What is Channel Stability?

Conceptualize channel stability as having three phases:



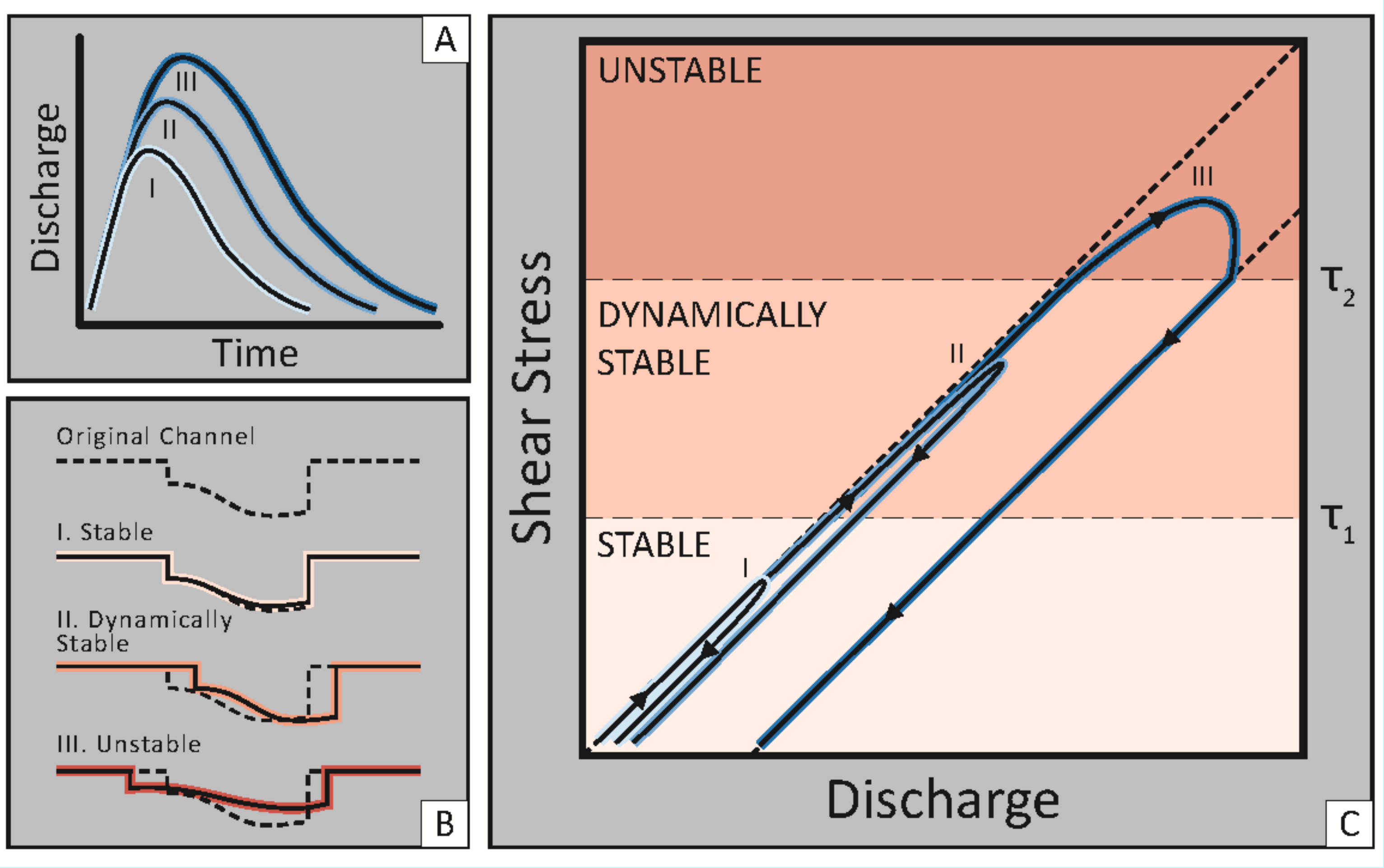
Based on evidence from Ashworth and Ferguson 1989, Warburton 2002, Eaton and Church 2004 and others

Figure from MacKenzie et al 2018



What is Channel Stability?

Figure from MacKenzie et al 2018



What Governs these Thresholds?

$$\text{Relative Bank Stability (RBS)} = \frac{\text{Critical shear stress}}{\text{Shear stress on bed}}$$

e.g. Jowett 1989; Gordon 1992; Olsen 1997

Channel stability is lost
when RBS < 1

(i.e. Shear stress on bed > Critical shear stress)

Existing literature and models use the

critical shear stress of the median grain size of the bed surface

Weaknesses of RBS Approach

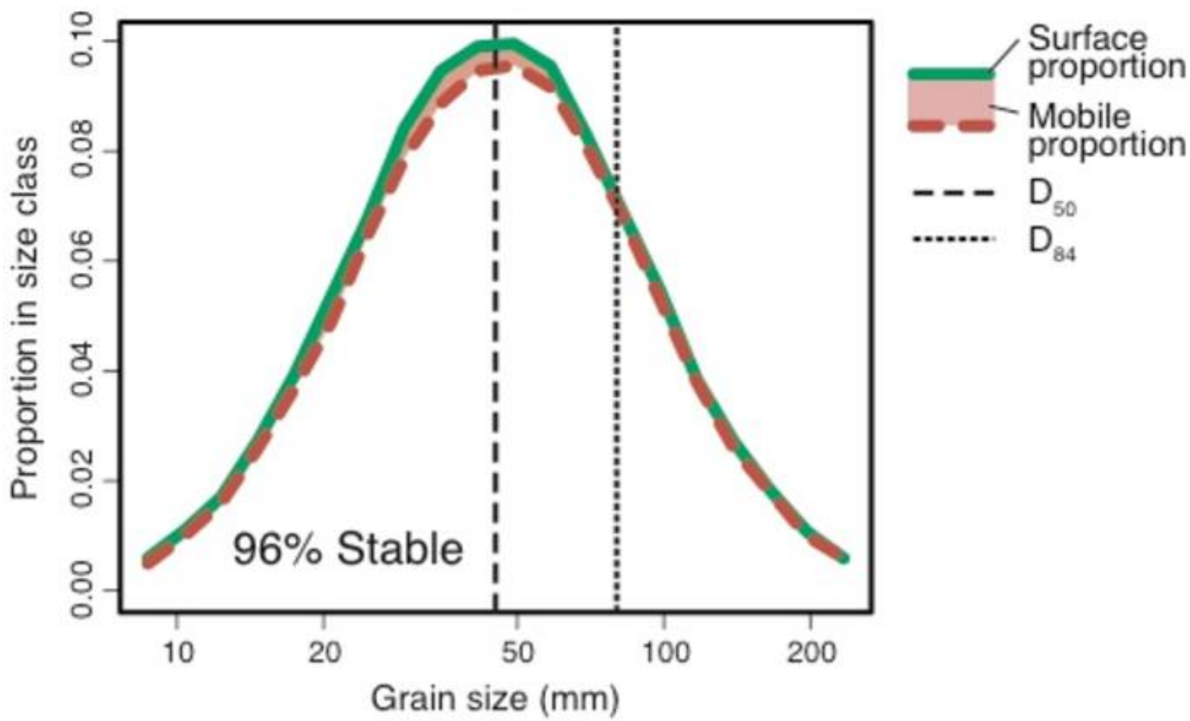
- Entrainment of bed material $\neq$ bank erosion
- Bank erosion $\neq$ channel instability
  - Stability is a phased process
- **Building evidence shows channel stability is more closely related to mobility of large grains**

(e.g. Ashworth and Ferguson 1989, Warburton 2002, Eaton and Church 2004)

What governs channel stability?

$$\text{Relative Bank Stability (RBS)} = \frac{\text{Critical shear stress of } D_{50}}{\text{Shear stress on bed}}$$

Jowett 1989; Gordon 1992; Olsen 1997

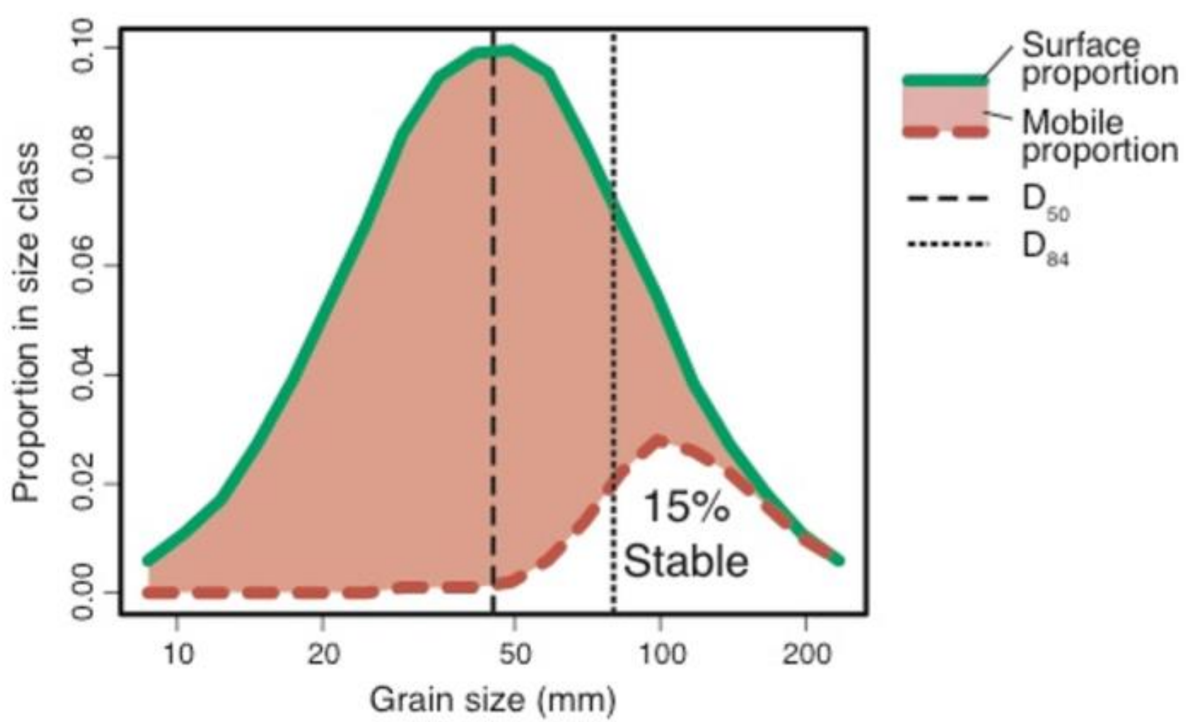


Based on Wilcock and McArdell 1997

What governs channel stability?

Mobility of largest grains?

Evidence from Ashworth and Ferguson 1989, Warburton 2002, Eaton and Church 2004,



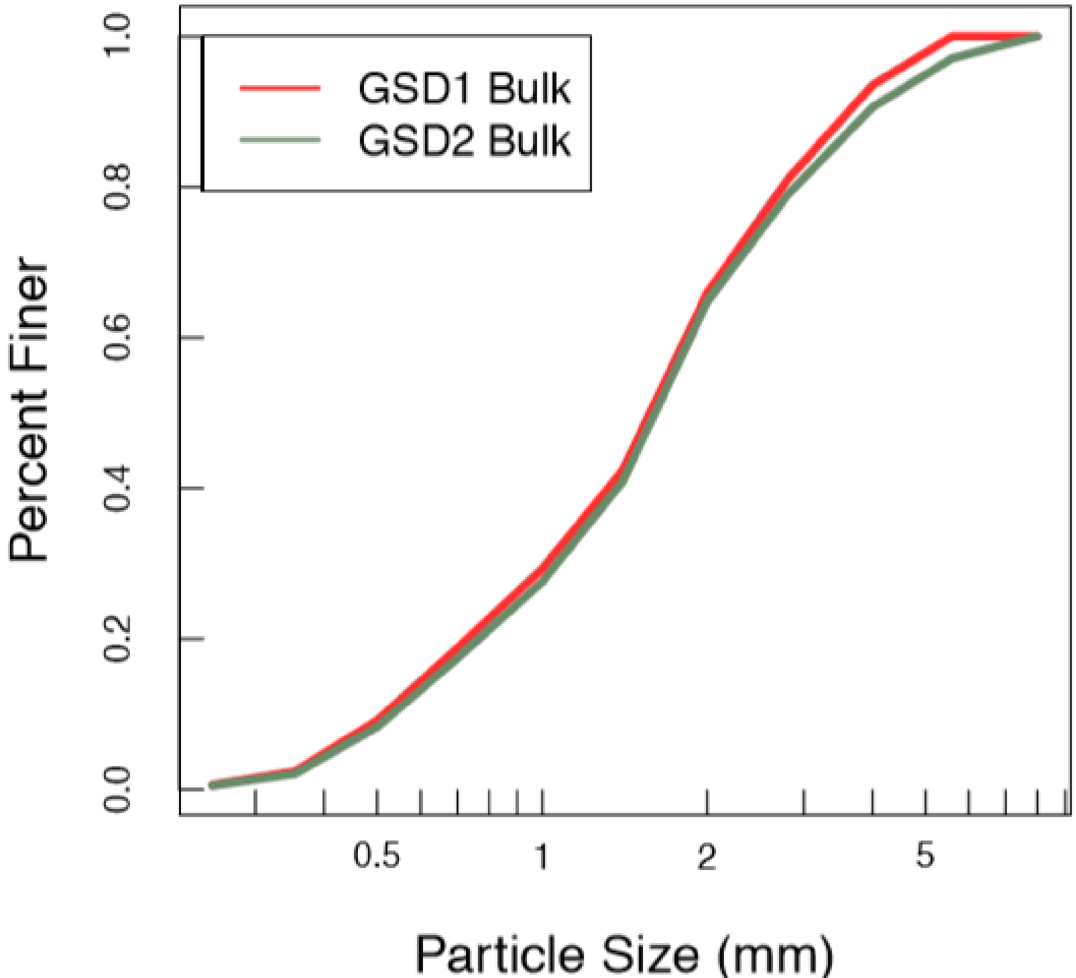
Based on Wilcock and McArdell 1997

UBC Geography Stream Table

- 12 long, 1.5 m wide
- Variable slope (currently at 2%)
- Data capture:
  - 2 mm resolution DEMs
  - 15 min sediment output
  - Surface texture

Generic model of a gravel-bed channel

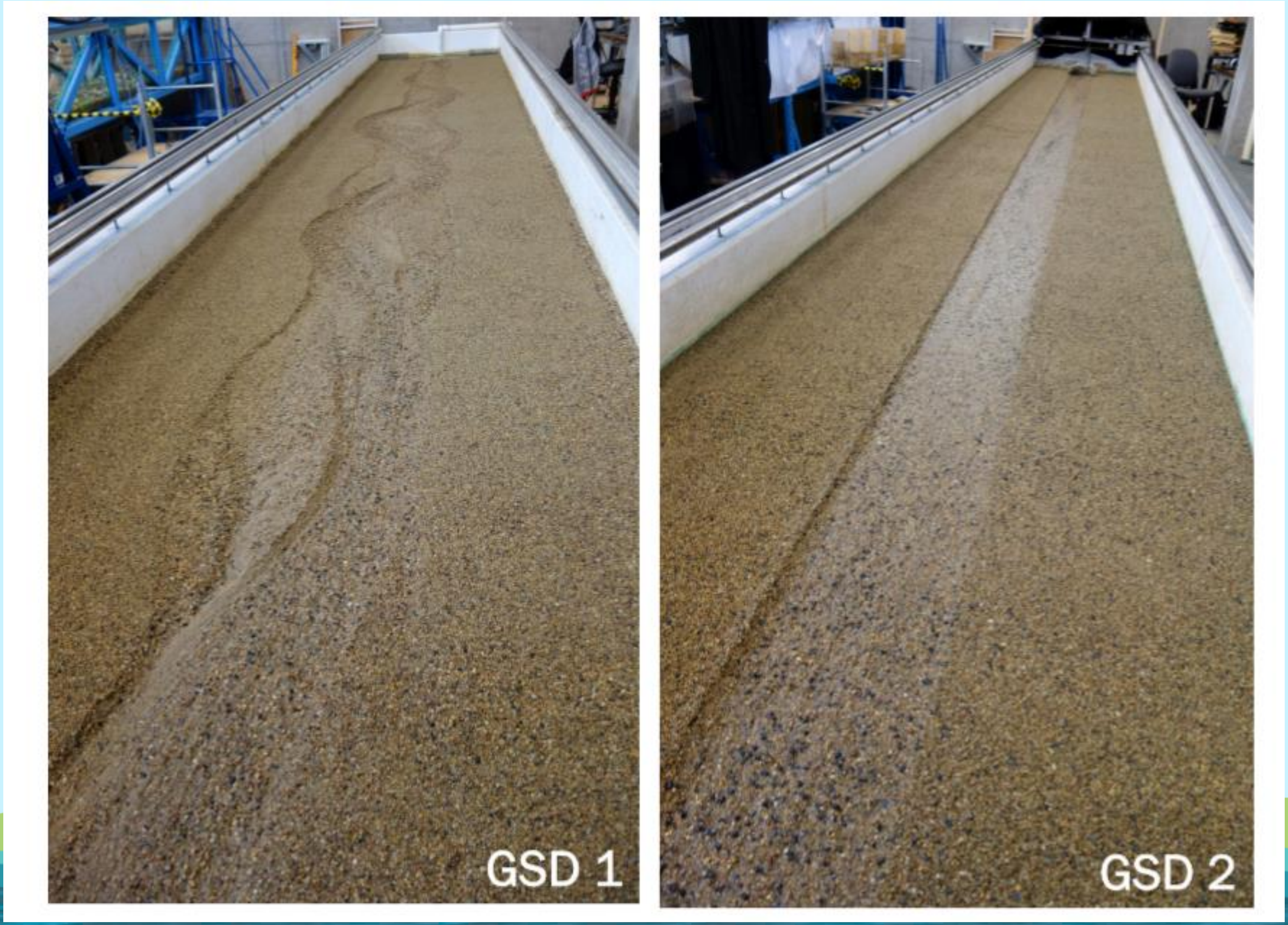
Foundational Experiments



Mackenzie & Eaton (2017)

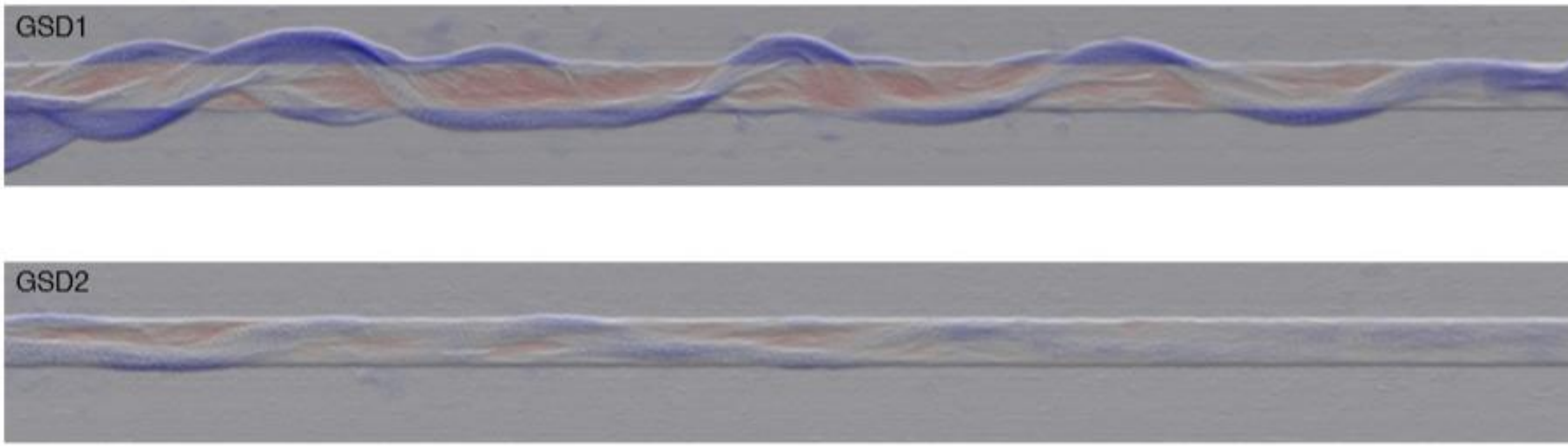
	GSD 1	GSD2
D_{50}	1.60 mm	1.63 mm
D_{84}	3.09 mm	3.23 mm
D_{90}	3.66 mm	3.95 mm

Foundational Experiments



Mackenzie & Eaton (2017)

Foundational Experiments



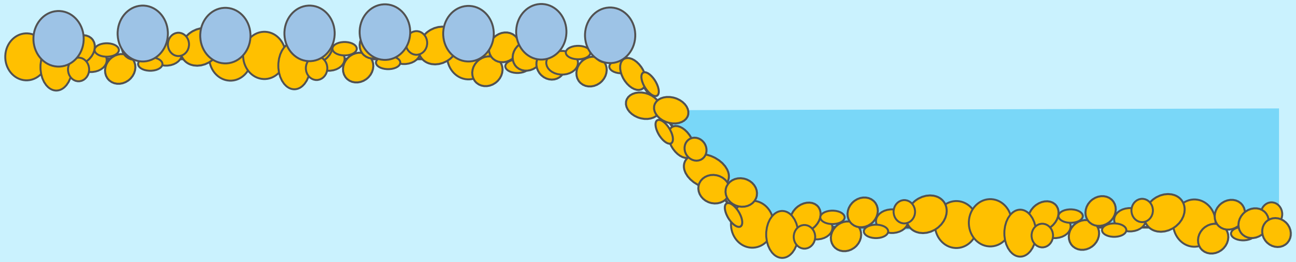
Can the addition of a small amount of coarse material stabilize a channel in the context of hazard mitigation?

Mackenzie & Eaton (2017)

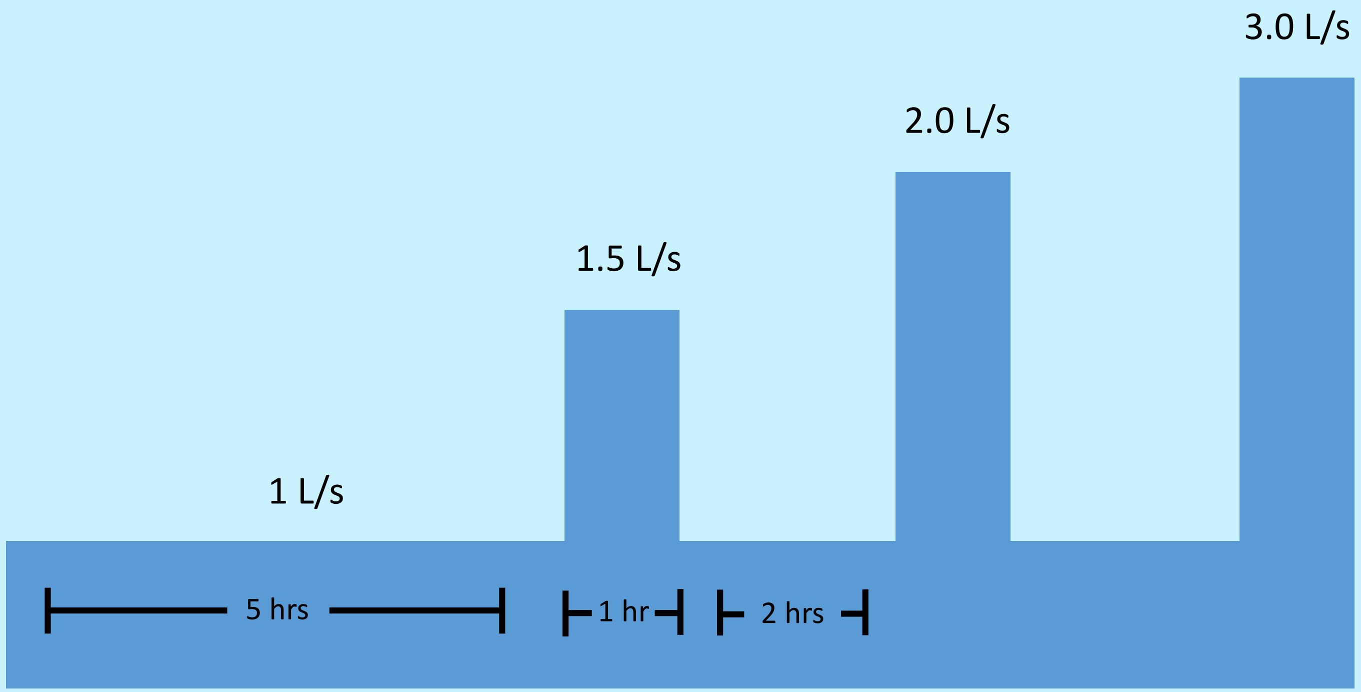
Real World Applications

How can these results inform natural channel design?

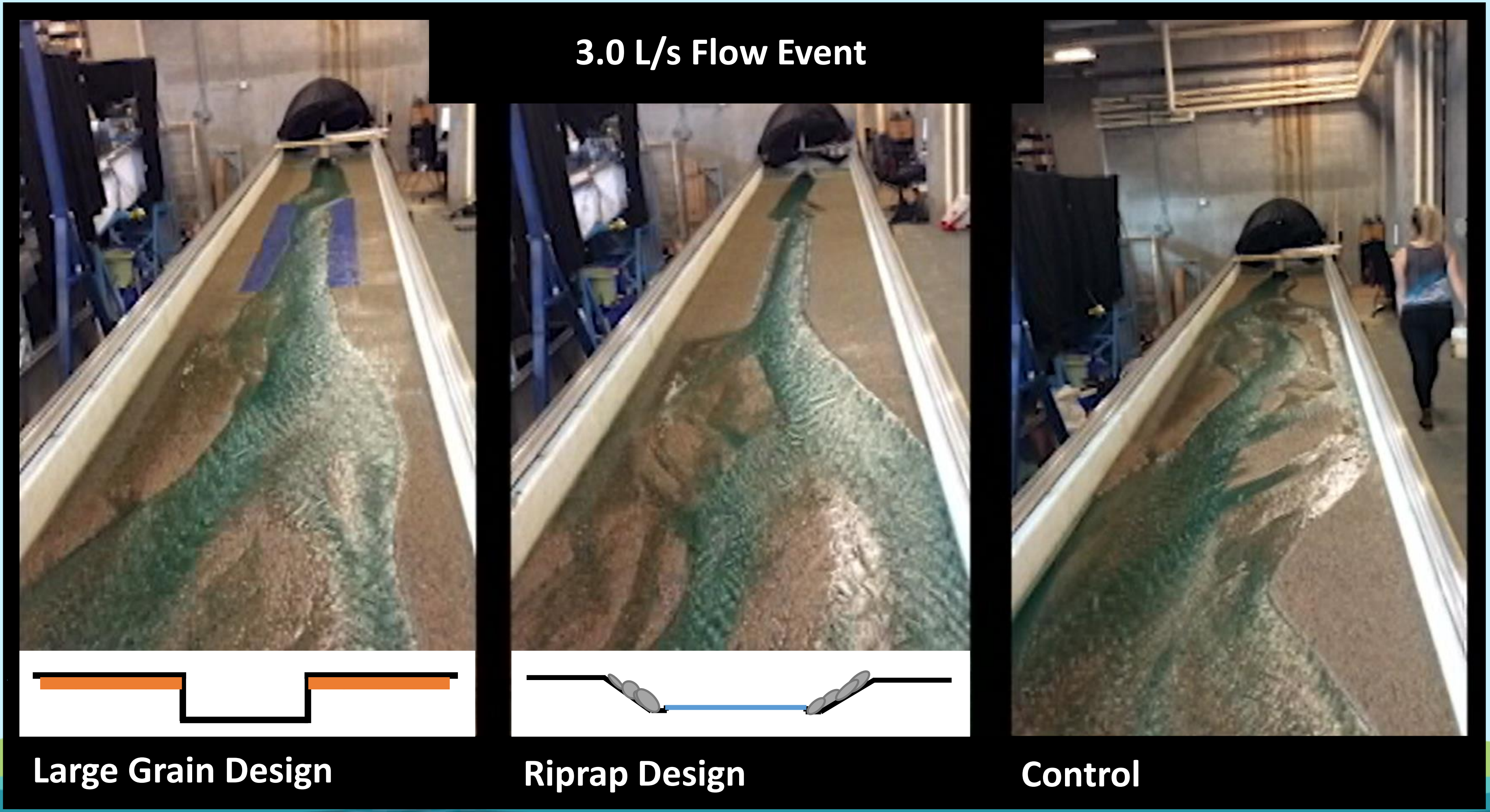
Floodplain seeding
of large grains



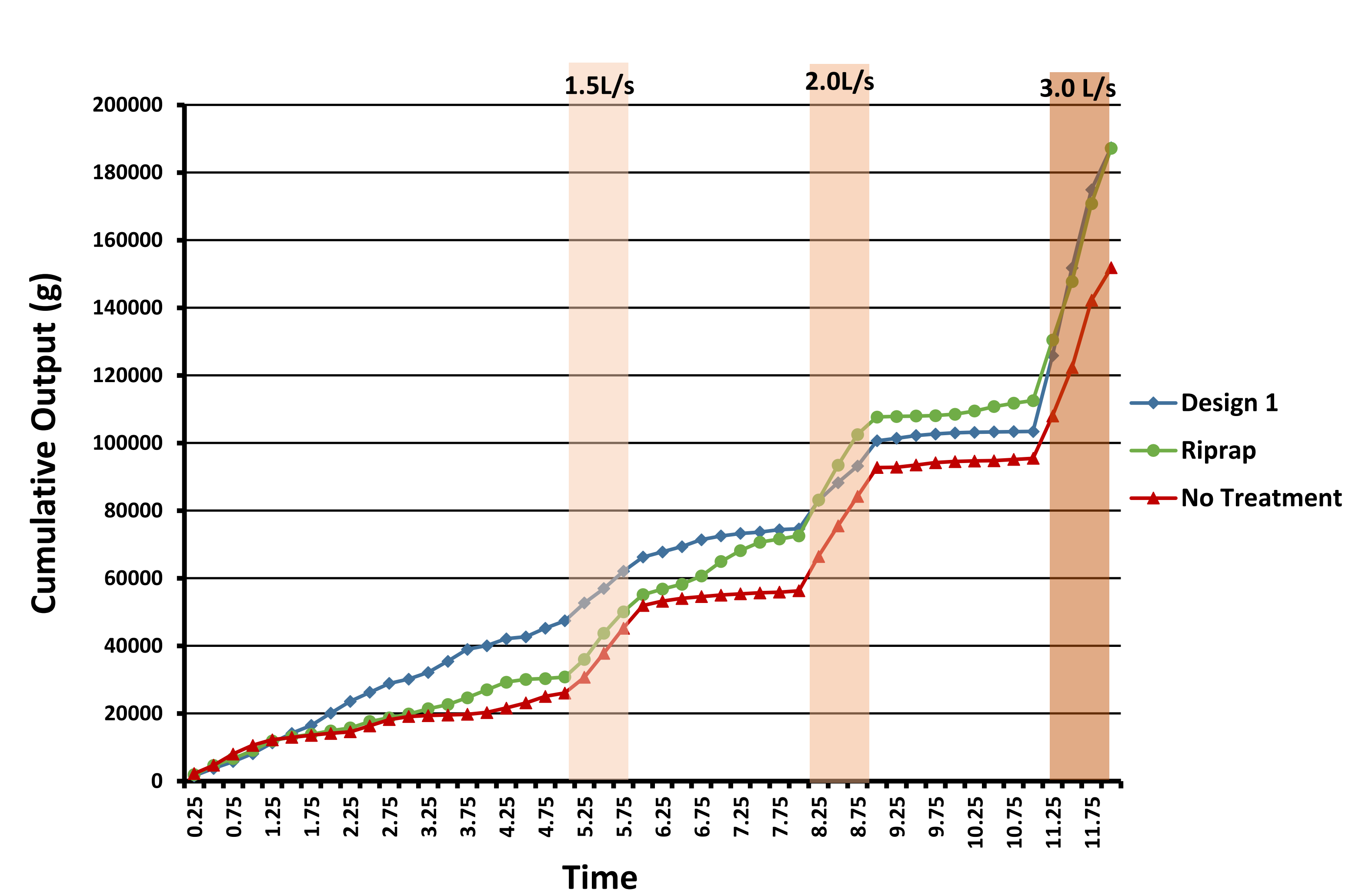
Flood Testing



- Sediment feed
- Treatment installed in the middle 4-8m of the channel



Preliminary Results



Floodplain Seeding

Bank erosion

↓

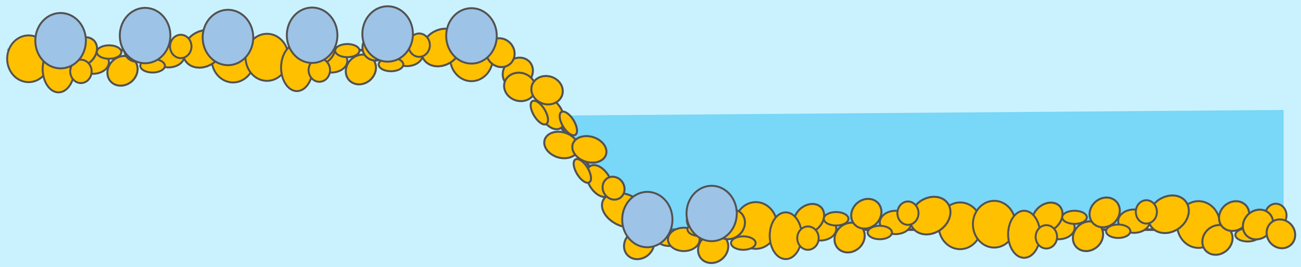
Large grains fall into channel

↓

Relative roughness increases (+ other processes?)

↓

Bank erosion slowed/stopped



Negative feedback process

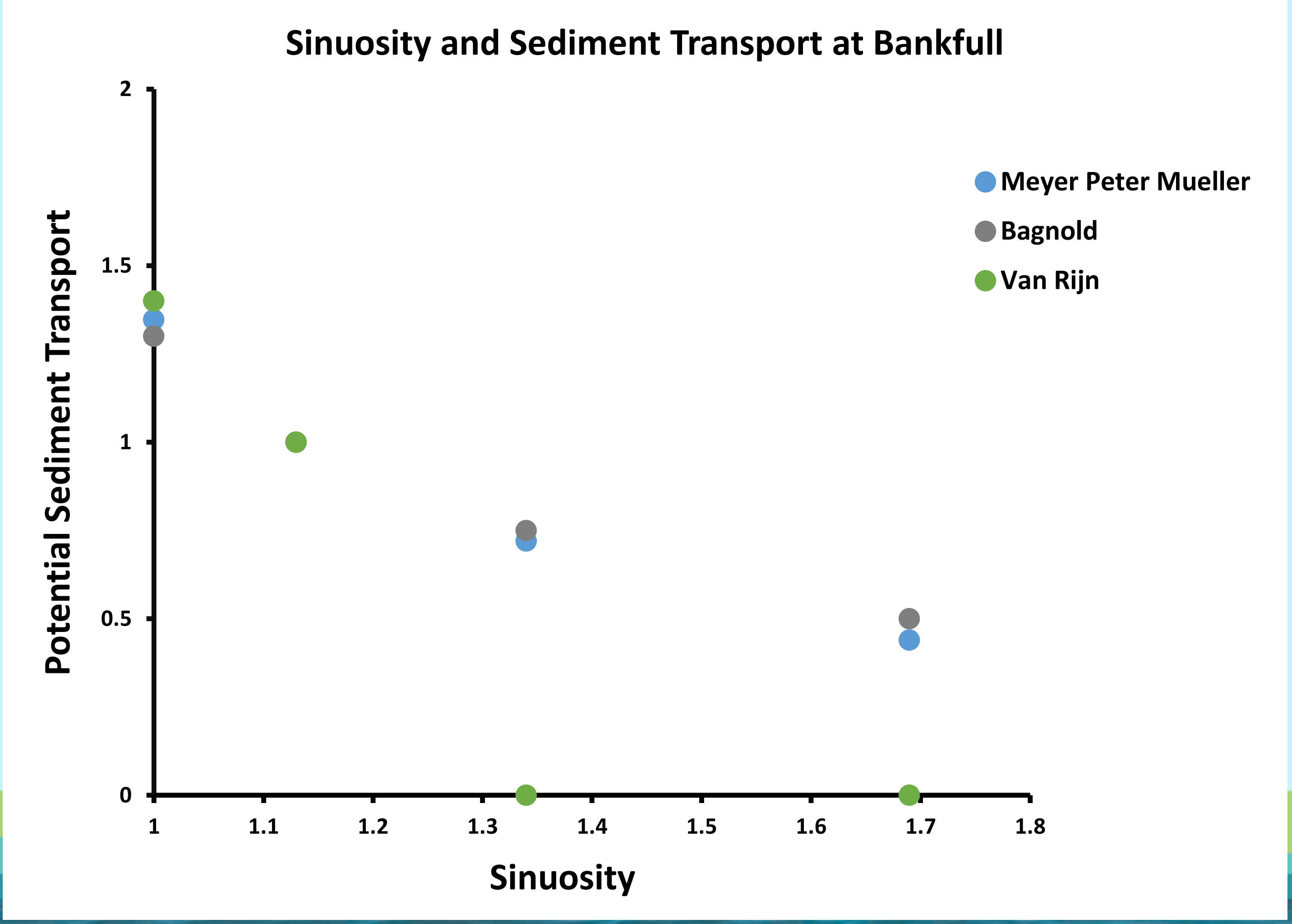
Continuity and Sediment Transport Modelling

- Long-term dynamic equilibrium of the channel assumes that same volume of sediment entering re-constructed channel leaves the system
    - In = Out
- Sediment transport models can be applied where there are questions related to sediment continuity
- The following slides examine sediment volumes potentially leaving a reference reach in a range of design scenarios
- Changes to slope based on design sinuosity and bankfull widths and depths based on different width to depth ratios
- Reference channel had slope of 0.79%, median grain size of 2.0 cm, and width to depth ratio of 10:1

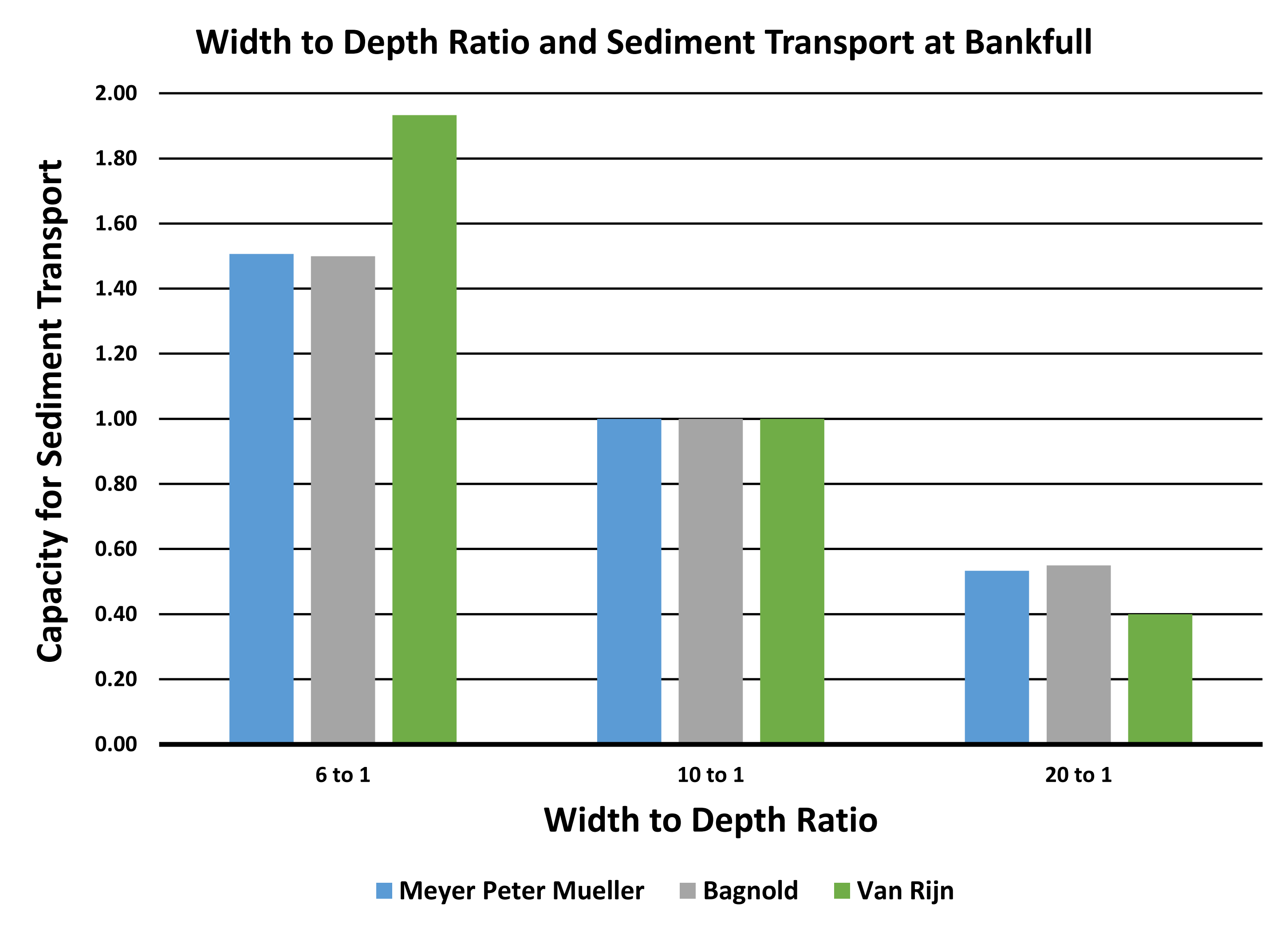
Continuity and Sediment Transport Modelling

- Meyer-Peter and Mueller (MPM, 1948)
  - Empirical bedload transport relation based on experiments with well sorted fine gravel materials (grain size between 0.4 and 30 mm)
  - A function of Shields number, a dimensionless value used to calculate initiation of motion of sediment
- Bagnold (1963)
  - Originally designed for coarse sands and fine gravels. Predicts bedload transport as function of stream power above threshold value of median grain size
  - Model takes into account angle of repose and channel slope
- Van Rijn (1984)
  - Modification of Bagnold formula based on gravel bed experiments with constant flow
  - Equation uses roughness coefficient based on ratio of grain size to water depth

Continuity and Sediment Transport Modelling



Continuity and Sediment Transport Modelling



Summary and Conclusions

- Future sediment banks need to be considered and provided for in corridor designs
- Current academic research suggests that D_{84} (the coarse tail) is a better indicator of entrainment/stability than the traditional D_{50} (median grain size)
- Seeding the floodplain with a coarse tail may provide a novel approach to further stabilize channels
- Sediment transport models can assess continuity through proposed channels and can predict long-term trends such as aggradation or degradation
- We learn from past restoration projects, but we should also look to current research to inform our designs and reduce our reliance on intervention

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