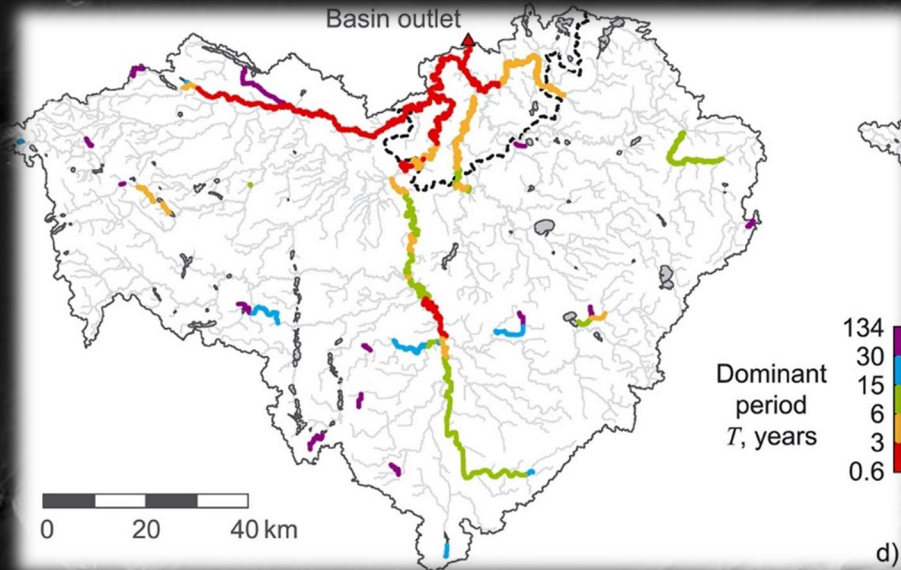


WATS 5150 – Fluvial Geomorphology

Sediment Flux @ Catchment Scale



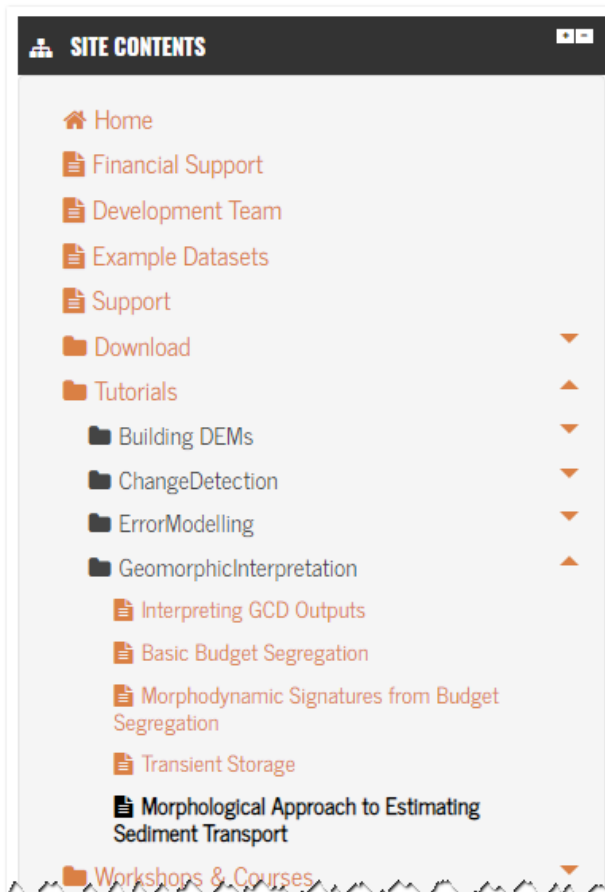
Housekeeping




- Projects: Due Friday, April 30 @ Midnight
 - Please come to office hours Wednesday if you need any help on your projects
 - Post questions
- Grades: End of next week
- Can I share your websites with future classes?
- Feedback on Class
 - Please take the IDEA survey (we do make changes based on them)
 - If you have suggestions for ways to improve the class in future, please get in touch
 - What about an overnight float trip next time?
 - Spring or Fall?
- Today's Plan
 - Fun from Saturday
 - Chapter 14 – Whole Afternoon (sorry)
 - Quick Synthesis
- Follow Ups
 - Lots of Classes
 - Just keep reading those landscapes!

Get Ready...

- Start ArcGIS now
- Download from:
- <http://gcd.riverscapes.xyz/Tutorials/Geomorphic Interpretation/morphological-approach.html>



River Rees, New Zealand

- 2km of braided river near  Queenstown, New Zealand
- Two LiDAR surveys
- 0.5m cell resolution

 Exercise Data (DEMs & Shapefile)

 Exercise Data (Shapefile Mask Only)

Lots of Follow Up Courses @ USU

- WATS 6900 – Sed Transport w/ Open Channel Flow
- CEE 3500 – Fluid Mechanics
- CEE 3510 – Eng. Hydraulics

- WATS 4490/6490 Watershed Hydrology
- CEE 3430 – Eng. Hydrology
- CEE 55

Hydrology
(water regimes)

Biology
(vegetation & seedbank characteristics)

Ecology (faunal composition & evolution)

Hydraulics
(vel & depth)

Chemistry
(turbidity, nutrient & contaminant cycling)

River geomorphology - character, behaviour & evolution

- CEE 6740 – Water Quality Modelling
- WATS 4530/6530 – Water Quality and Pollution

Social science
(connection & place)

Management
(rehabilitation & conservation planning)

- CEE 5470 – Sedimentation Engineering
- WATS 6900 – Sediment Transport in Stream Assessment & Design
- WATS 6850 – Geomorphologic Change Detection
- GEO 6800 – OSL Short Course
- GEO 6900 – Fluvial Geomorph Seminar

- ENVS 6320 - Water Law & Policy
- ENVS 6530 – Natural Resources Administration
- ENVS 4110 – Fisheries & Wildlife Policy & Administration

- WATS 5620-5625 – LTPBR Series
- WATS 5300 – Principles of Aquatic Ecosystem Restoration
- WATS 5330 – Large River Management
- WATS 5340-5350 – MRAE Capstone
- WATS 6310 – Wetland Ecology & Management
- WATS 6700 – Restoration Ecology

LTPBR Website

<http://lowtechpbr.restoration.usu.edu>

The screenshot shows the LTPBR website homepage. At the top, there is a navigation menu with links for RIVERSCAPES, RC TOOLS, RC SCIENCE, RC DATA, and RC HELP. The main header features the title "LOW-TECH PROCESS-BASED RESTORATION OF RIVERSCAPES DESIGN MANUAL, RESOURCES, WORKSHOPS" and the Utah State University Restoration Consortium logo. A yellow callout bubble points to the "Workshops" link in the site contents menu, stating "Click here to get to the workshop pages right away." Another yellow callout bubble points to the "Manual" section, stating "Click here for manual... and pocket guide". Below the header, there is a banner for a virtual workshop registration. The main content area includes a "Manual" section with a description of the design manual's purpose and a list of resources. A QR code is located in the bottom right corner of the website screenshot.

Process Based Restoration

LOW-TECH PROCESS-BASED RESTORATION OF RIVERSCAPES DESIGN MANUAL, RESOURCES, WORKSHOPS

Utah State University RESTORATION CONSORTIUM

Click here to get to the workshop pages right away.

Register for Virtual LTPBR Workshop - FREE August 11-14, 2020

SITE CONTENTS

- Home
- Design Manual
- PBR Resources
- Low-Tech PBR Workshops

Subscribe to the Low-Tech PBR mailing list

Email Address

First Name

Last Name

Subscribe

Manual

The purpose of this **design manual** is to provide restoration practitioners with guidelines for implementing a subset of low-tech process-based restoration (LT-PBR) in riverscapes. While the concept of process-based restoration in riverscapes has been advocated for at least two decades, details and specific examples on how to implement it remain sparse. Here, we describe 'low-tech process-based restoration' (LT-PBR) as a practice of using simple, low unit-cost, structural additions (e.g. wood and beaver dams) to riverscapes to mimic functions and initiate specific processes. Hallmarks of this approach include:

- An explicit focus on the processes that a low-tech restoration intervention is meant to promote
- A conscious effort to use cost-effective, low-tech treatments (e.g. hand-built, natural materials).

LOW-TECH PROCESS-BASED RESTORATION OF RIVERSCAPES DESIGN MANUAL

Edited by: Joseph M. Wheaton, Stephen N. Bennett, Nicolaas Bouwes, Jeremy D. Maestas & Scott M. Shahverdian

Find:

- Design Manual
- Pocket Guide
- Other Resources
- Workshop Slides
- Links/Videos/Literature



We offer University Courses (Spring)



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Utah State University Administered Courses

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Professional Continuing Education Units

Make sure you have an A Number

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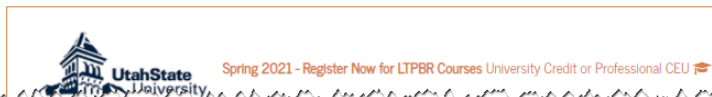
In Spring 2021, we began offering a sequence of five, short-courses, that parallel the modularized workshop curriculum (available for free, self-pacing [here](#)). These short-courses differ from the workshop curriculum in that:

- These courses are taken for University Credit (for matriculated USU students) or University Continuing Education Units
- These courses use the same curriculum as the free self-paced modules, but are augmented by more in-depth class discussions, quizzes and homework assignments
- These courses are assessed, and you will receive feedback and a letter grade based on your assessed work.

The LTPBR Spring Series of courses meet weekly on Tuesdays from 13:30 to 15:30 (hybrid F2F), and the Design and Implementation have mandatory Saturday Field Trips in addition (see [Spring 2021 for dates](#)).

Course #	Course Title	Number of Meetings	Pre-Requisite
WATS/CEWA 5620♣	Introduction to Low-Tech Process-Based Restoration of Riverscapes	Meets 3 times remotely	NA
WATS/CEWA 5621♣	Science and Case Studies of Low-Tech Process-Based Restoration of Riverscapes	Meets 3 times remotely	WATS 5620
WATS/CEWA 5622♣	Planning Low-Tech Process-Based Restoration of Riverscapes	Meets 3 times remotely	WATS 5620
WATS/CEWA 5623♣	Designing Low-Tech Process-Based Restoration of Riverscapes	Meets 3 times remotely, with mandatory Saturday Design Field Trip	WATS 5620 & 5622
WATS/CEWA 5624♣	Implementing Low-Tech Process-Based Restoration of Riverscapes	Meets once remotely, with mandatory Construction Field Trip on a Saturday	WATS 5620

♣ Course numbers pending: Note for [Spring 2021](#), these were offered as WATS 6900 and CEWA 5700 Special Topics

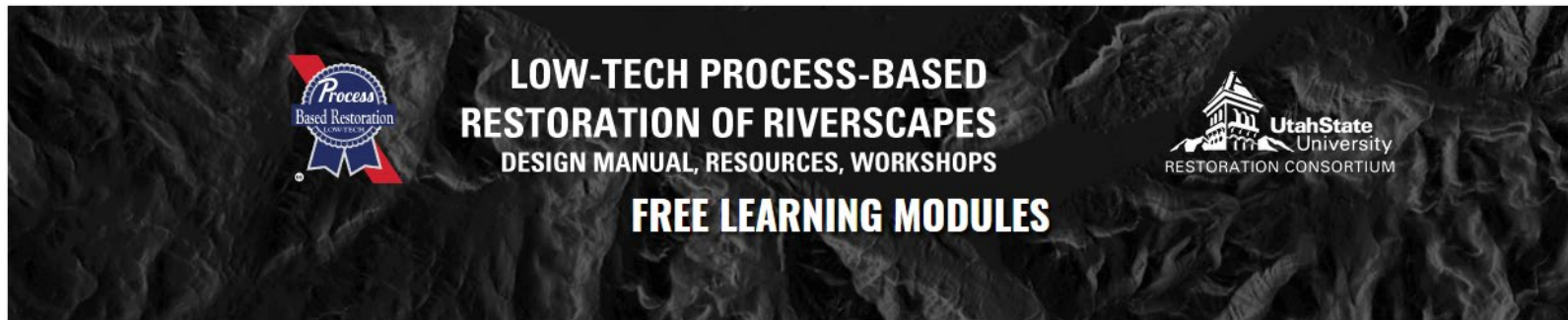


We also offer:

- Graduate Restoration Certificate
- BS in Management, Restoration of Aquatic Ecosystems / Fisheries
- +1 MoER - Masters of Ecological Restoration
- Many other short courses

For Professional CEU Credit or University Credit: <http://lowtechpbr.restoration.usu.edu/workshops/uni>

More in-Depth, **FREE**, Self-Paced Modules



PAGE CONTENTS

Free Learning Modules

Introductory PBR Workshop Modules

Modules

- Bonus Resources & Exercises by Module Topic
- Free Resources Made Possible By
- Want to Take Above for Credit?
- Subscribe to the Low-Tech PBR mailing list

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- Home
- Design Manual
- PBR Resources
 - Pocket Guide
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 - LT-PBR in News
 - Free Learning Modules**
 - Introductory LTPBR Topics
 - SEM Quiz

Introductory PBR Workshop Modules

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Modules

Module 1 - Intro

Slides Recorded Lectures and Exercises

Module 2 - Science

Slides Recorded Lectures and Exercises

Module 3 - Planning

Slides Recorded Lectures and Exercises

Module 4 - Design

Slides Recorded Lectures and Exercises

Module 5 - Implementation

Slides Recorded Lectures and Exercises

Or take these modules as actual university courses and be paced and assessed:

Spring 2021- Register Now for LTPBR Courses University Credit or Professional CEU

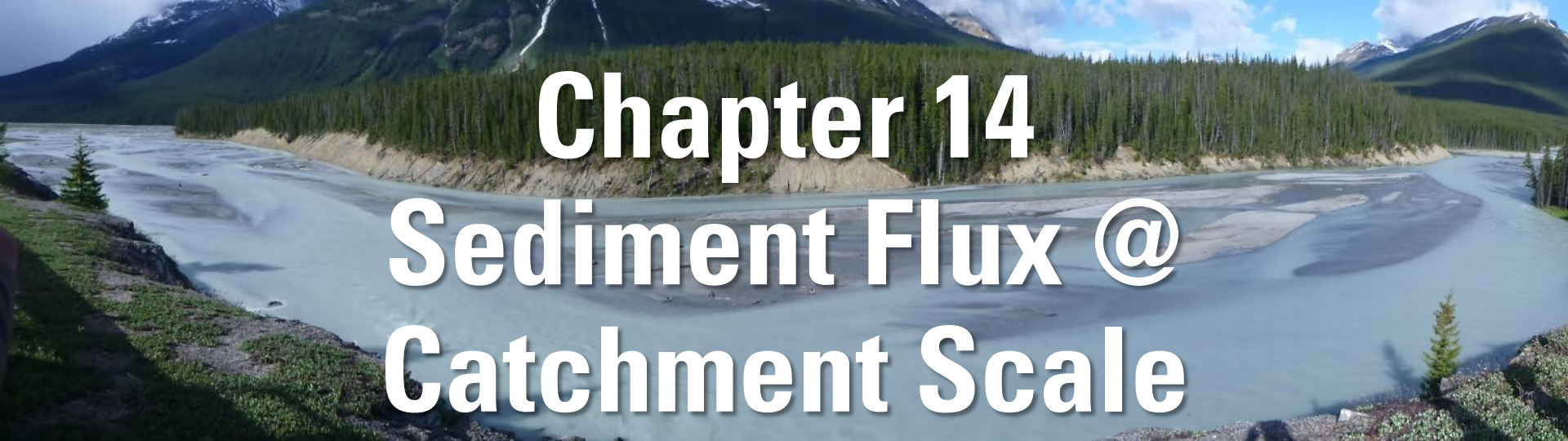
Bonus Resources & Exercises by Module Topic

All Free! <http://lowtechpbr.restoration.usu.edu/resources/Topics/>

Thanks to our Awesome Fluvial Volunteers on Saturday!



<https://photos.app.goo.gl/EZ8xnKEveNrLkeWr9>



Chapter 14 Sediment Flux @ Catchment Scale



A good synthesis chapter

Reading for this Module

- Chapter 14: Sediment flux at the catchment scale: source-to-sink relationships

CHAPTER ONE

Geomorphic analysis of river systems: an approach to reading the landscape

Introduction

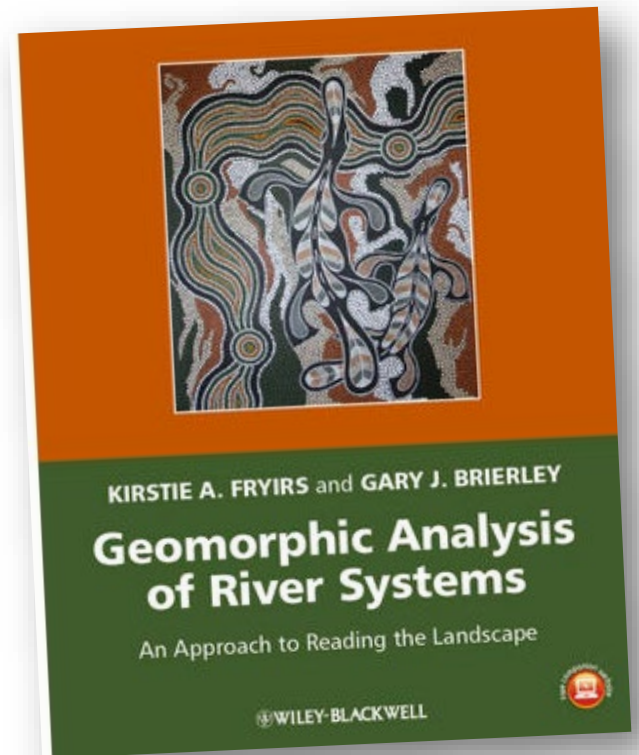
Landscapes have been a source of fascination and inspiration for humans for thousands of years. Sensory responses to landscapes vary markedly from person to person. To many, spiritual associations evoke a sense of belonging, perhaps tinged with nostalgic sentiments. To others, a sense of awe may be accompanied by alienation or innate fear. Artists strive to capture the essence of landscapes through paintings, prose, poetry or other media. Our experiences in life are often fashioned by the landscapes in which we live and play. Relationships and associations vary from place to place and over time. New experiences may generate new understandings, wherein observations are compared with experiences elsewhere. These collective associations not only reflect the bewildering range of landscapes in the natural world, they also reflect the individual consciousness with which we relate to landscapes, and the influences/experience that fashion our way of thinking, whether taught or intuitive. No two landscapes are exactly the same. Each landscape is, in its own way, 'perfect'. Different sets of controls interact in different ways in different settings, bringing about unique outcomes in any particular landscape. Just as importantly, interactions change over time, such that you cannot step in the same river twice (Heraclitus, 535-c. 475 BCE). Sometimes it seems a shame to formalise our understandings of landscapes within the jargonistic language of scientific discourse, but that is what geomorphologists do!

In simple terms, geomorphology is the scientific study of the characteristics, origin and evolution of landscapes. Geomorphic enquiry entails the description and explanation of landscape forms, processes and genesis. Implicitly, therefore, it requires both a generic understanding of the physics and mechanics of process and an appreciation of the dynamic behaviour of landscapes as they evolve through time. The key to effective use of geomorphic knowledge is the capacity to place site-specific insights and relationships in their broader landscape context, framing contemporary

process-form linkages in relation to historical imprints. Theoretical and modelling advances are pivotal in the development and testing of our understanding. However, the ultimate test of geomorphological knowledge lies in field interpretation of real-world examples.

This book outlines general principles with which to interpret river character, behaviour and evolution in any given system. Emphasis is placed upon the development of field-based skills with which to read the landscape. Field-based detective-style investigations appraise the relative influence of a multitude of factors that affect landscape-forming processes, resulting patterns of features and evolutionary adjustments. Interactions among these factors change over time. Inevitably, such investigations are undertaken with incomplete information. Information at hand has variable and uncertain accuracy. Some facets of insight may be contradictory. Individual strands of enquiry must be brought together to convey a coherent story. Significant inference may be required, drawing parallels with records elsewhere. Unravelling the inherent complexities that fashion the diversity of the natural world, the assemblages of features that make up any given landscape and the set of historical events that have shaped that place is the essence of geomorphic enquiry. Just as importantly, it is great fun!

Although this book emphasises process-form relationships on valley floors, it is implicitly understood that rivers must be viewed in their landscape and catchment context. Rivers are largely products of their valleys, which, in turn, are created by a range of geologic and climatic controls. Hillslope and other processes exert a primary control upon what happens on valley floors. Sediment delivery from river systems, in turn, exerts a major influence upon coastal-zone processes. Source-to-sink relationships are a function of catchment-scale controls on sediment supply, transport and delivery. Efforts to read the landscape place site-specific observations, measurements and analyses in an appropriate spatial and temporal context. Understanding of this dynamic landscape template provides a coherent platform for a wide range of management applications.



- Brierley G and Fryirs K. 2005. *Geomorphology and River Management: Applications of the River Styles Framework*. Blackwell Publishing: Victoria, Australia, 398 pp.

Get Global Flux Out of Way



Global Distribution of Mean Annual Discharge (Q)

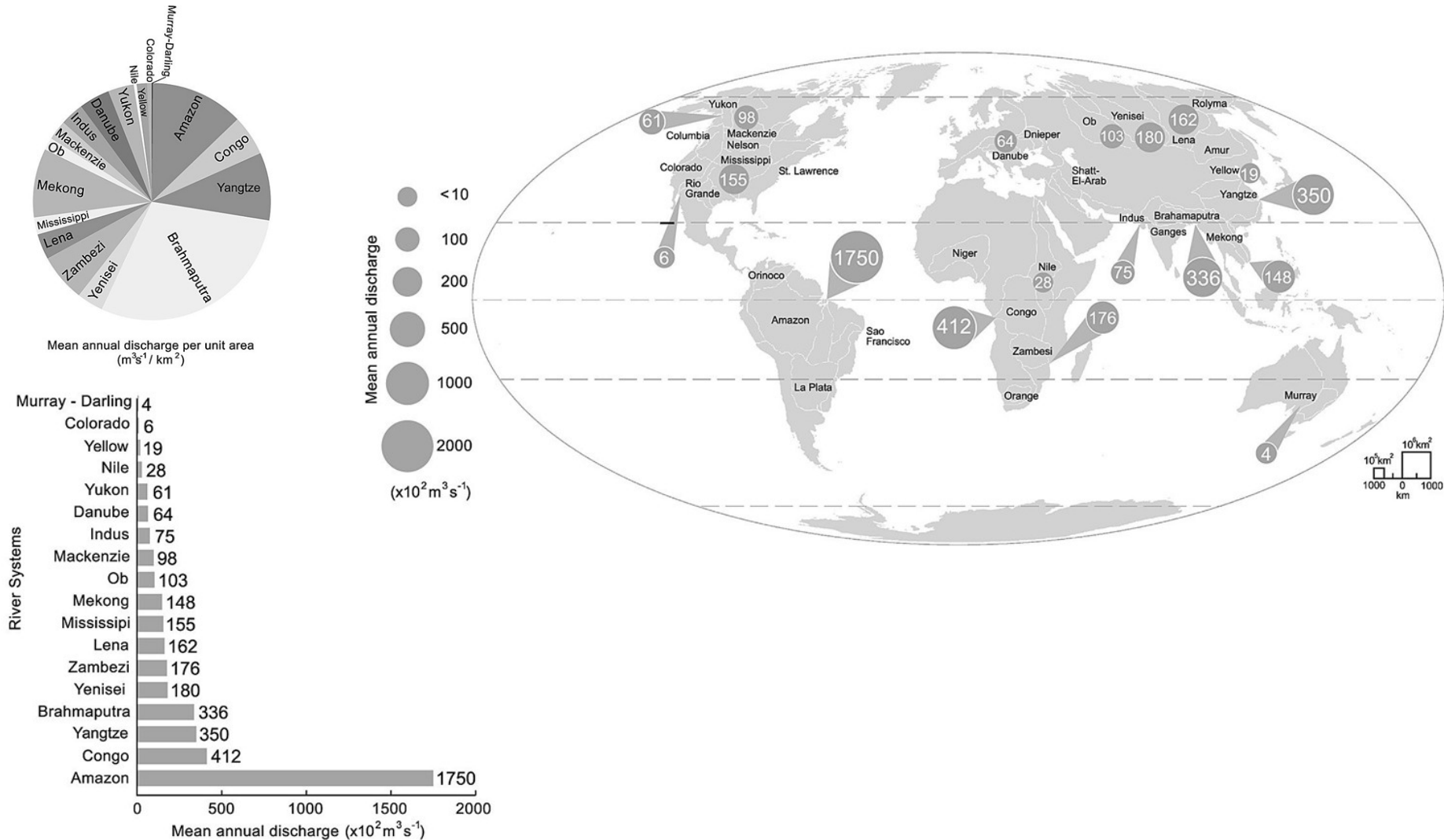
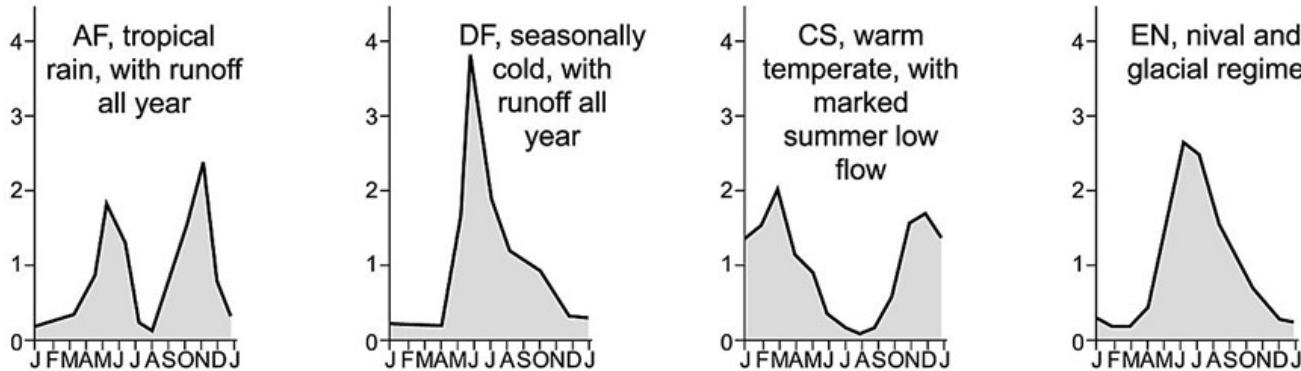


Figure 14.10 Global variability in mean annual discharge and mean annual discharge per unit area. In volumetric terms, the highest discharge is generated by the Amazon Basin. However, the highest yield is generated by the Brahmaputra, which has the highest mean annual discharge per square kilometre of catchment area in the world. Data from Wohl (2007).

Global Distribution of Seasonal Flow Variability

Flow regime

F = appreciable runoff all year, W = marked winter low flow, S = marked summer low flow, EN/EG = nival and glacial



Note: examples are from Northern Hemisphere

Climate region

A = tropical, B = dry, C = warm temperate, D = seasonally cold

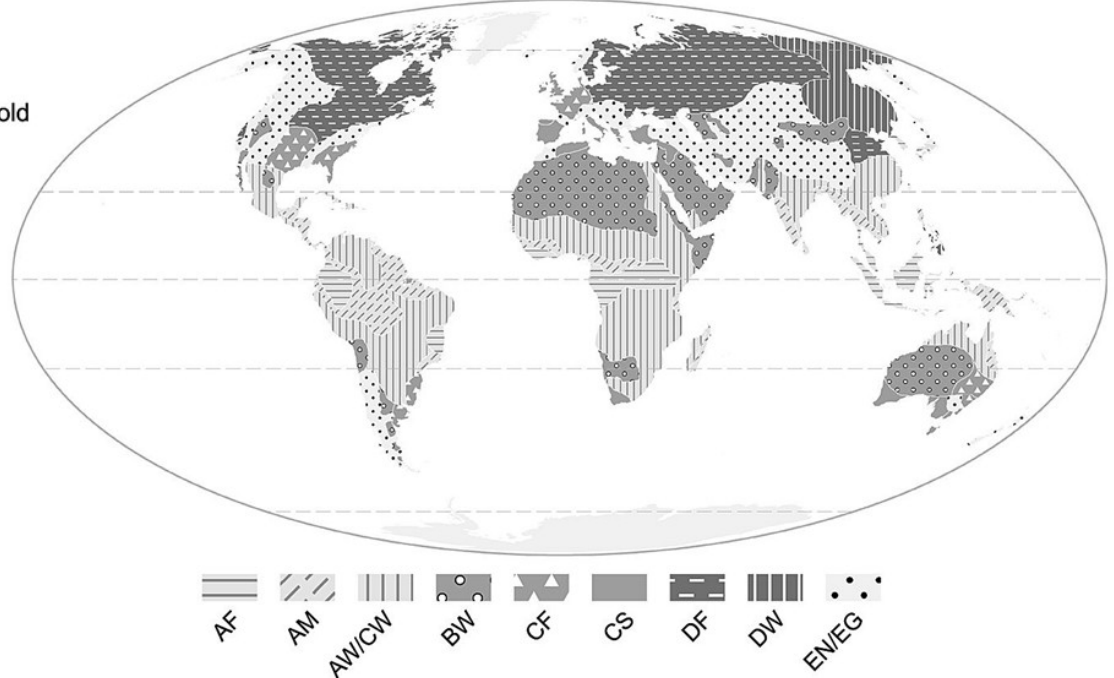
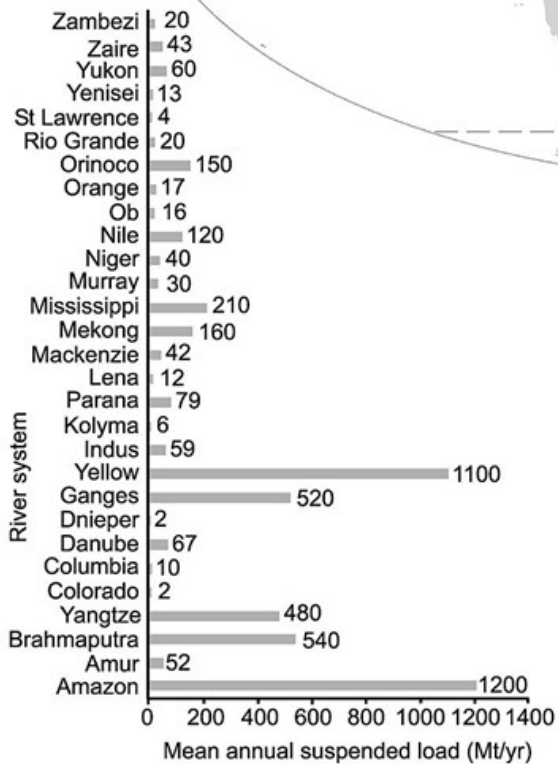
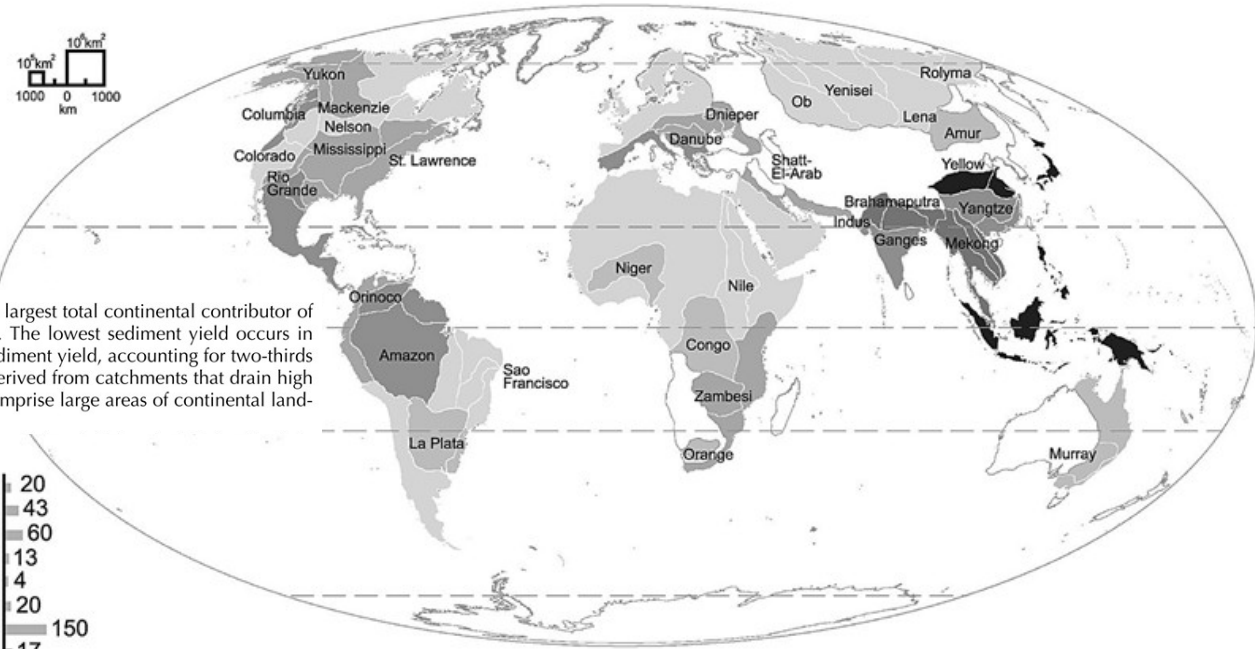


Figure 14.11 Seasonal flow variability for climate regions across the globe. In general terms, *interannual variability* in peak discharge correlates with mean annual runoff, such that more arid basins have much greater interannual variability than drainage basins with greater precipitation and runoff totals. From Burt (1996). © Wiley–Blackwell. Reproduced with permission.

Fryirs & Brierley (2013)

DOI: [10.1002/9781118305454](https://doi.org/10.1002/9781118305454)

Global Distribution of Suspended Sediment Load (Q_s)



Mean annual suspended load per unit area ($t/yr/km^2$)

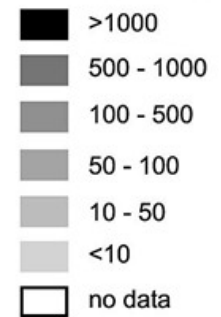


Figure 14.12 Global distribution of suspended-sediment load. Asia is the largest total continental contributor of fluvial sediment to oceans, followed by South America and North America. The lowest sediment yield occurs in polar regions, while tropical and warm temperate regions have the highest sediment yield, accounting for two-thirds of the global sediment delivery. Almost 60% of global sediment delivery is derived from catchments that drain high mountainous terrain (>5000 m asl). Low mountains (1000–3000 m asl) that comprise large areas of continental land-mass contribute the second largest amount.

**Okay... Back to a
Catchment / System Scale**



Landscape Evolution to Start



Timeframes of Sediment (re)Generation

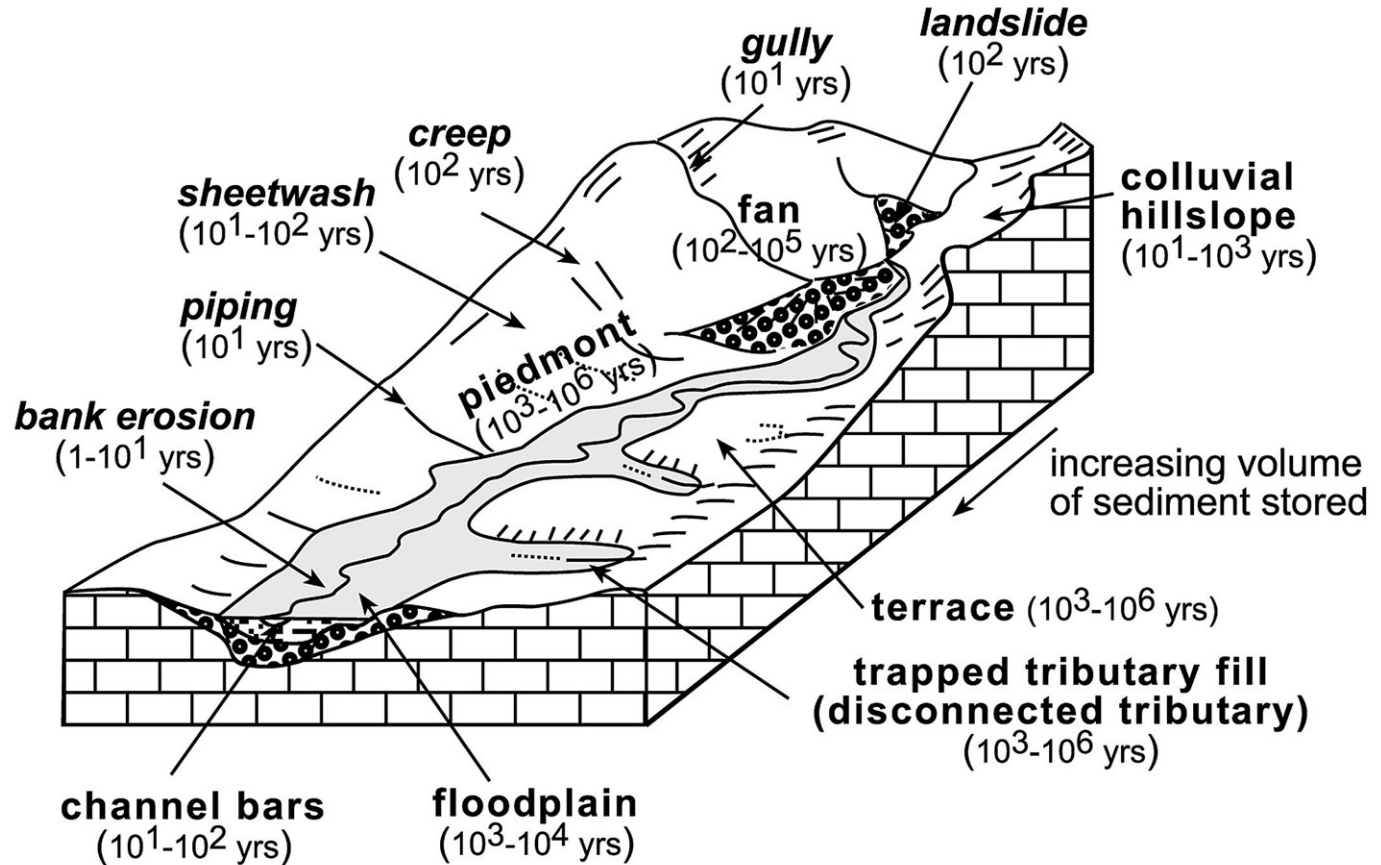


Figure 14.1 Timeframes of sediment (re)generation for differing sediment sources and residence times for sediment stores in river systems. Differing colluvial and alluvial landforms operate as sediment sources and stores/sinks over variable timeframes, ranging from years to many thousands of years. The recurrence with which sediments are sourced or stored is largely dependent on position in a catchment and the recurrence of geomorphically effective disturbance events.

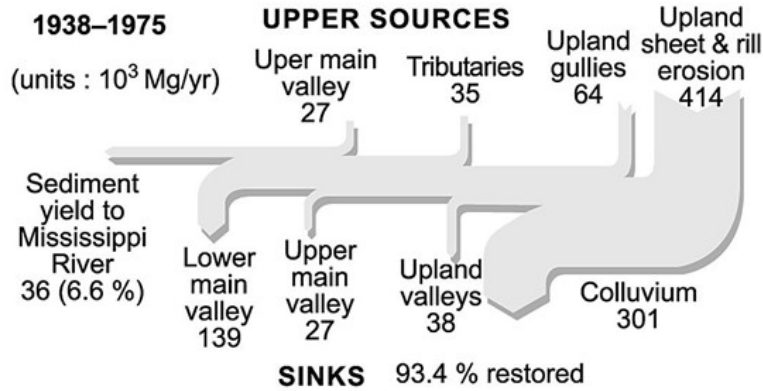
Sediment Budgets

Everyone's doing them
(or talking about them at least)

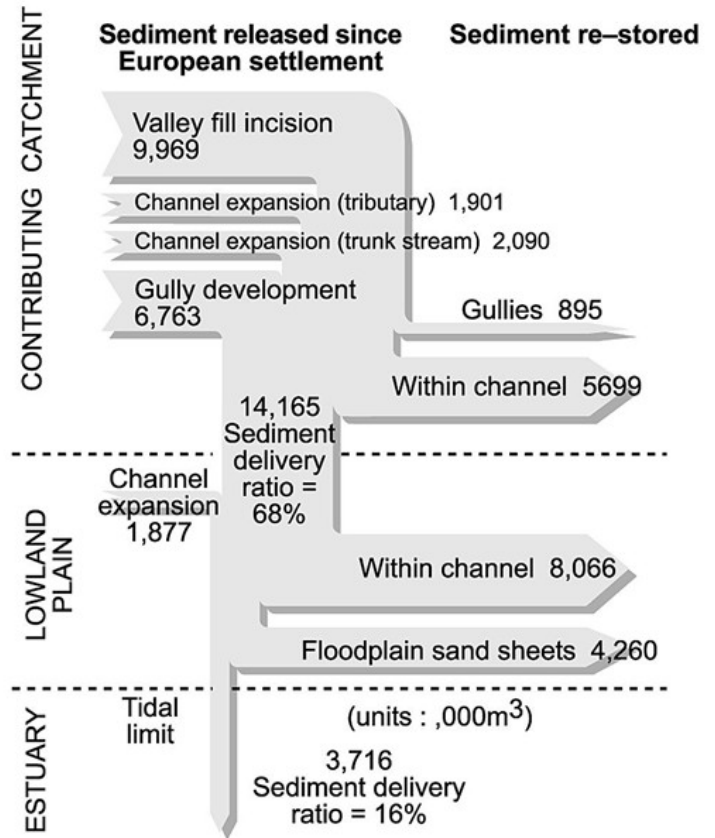


Sediment Budget Diagrams

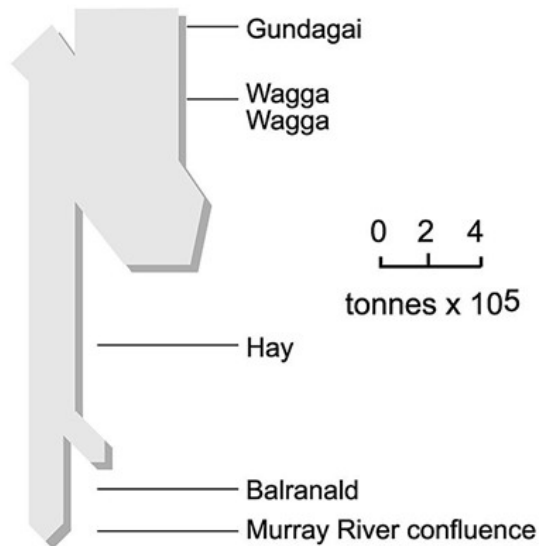
(a) Coon Creek



(b) Bega catchment



(c) Murrumbidgee catchment



Constructing a Sediment Budget

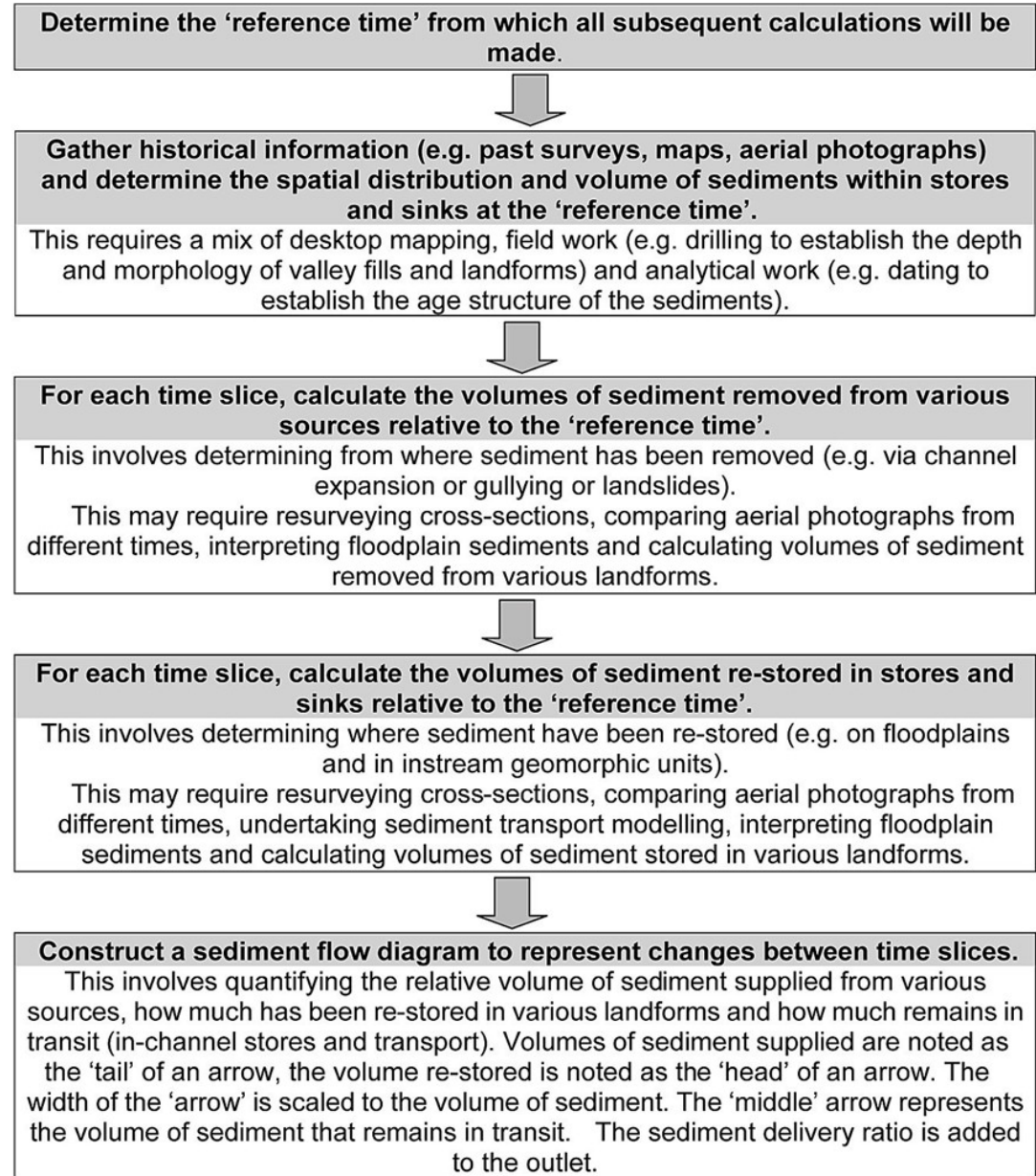


Figure 14.3 Flow chart of generic tasks undertaken to construct a sediment budget.

Sediment Budget Terms from DoDs

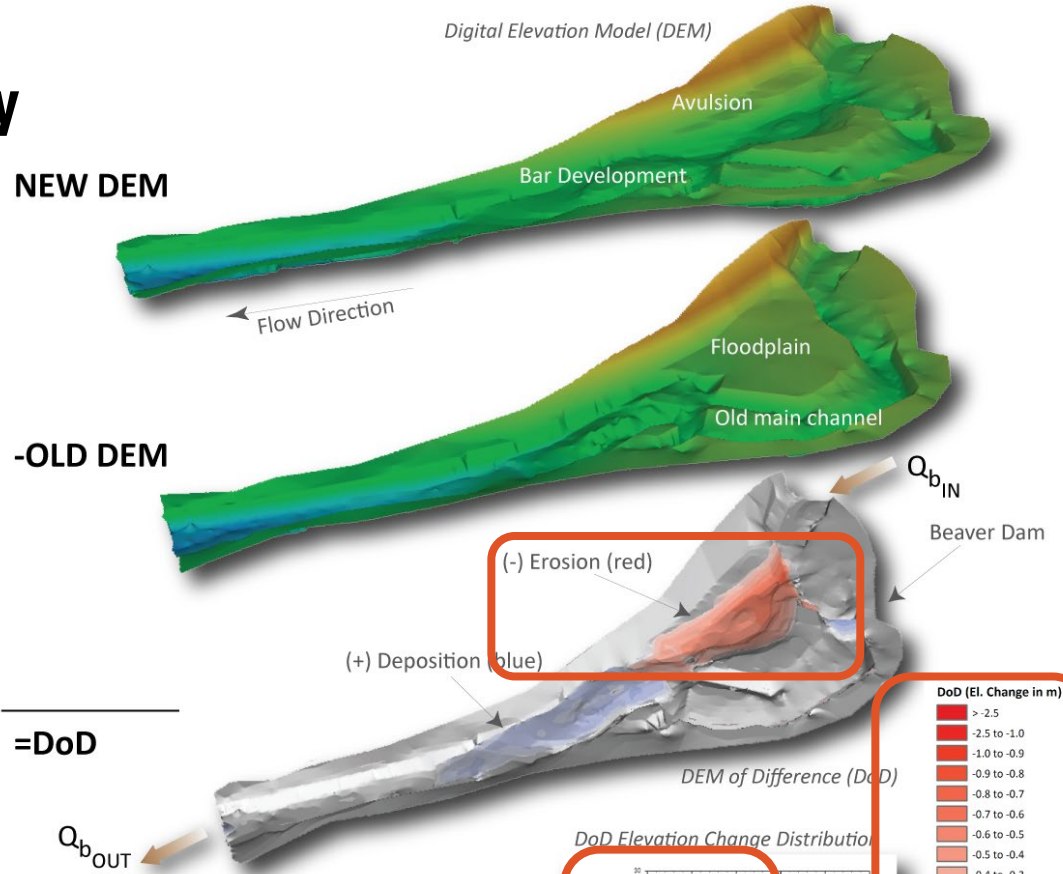
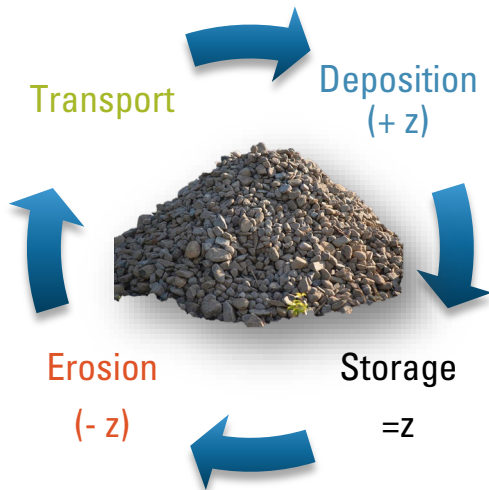
Fluvial Geomorphic Processes _____ Topography

- Erosion
- Transport
- Deposition
- Storage

Shape

Reflect

Reflect



=DoD

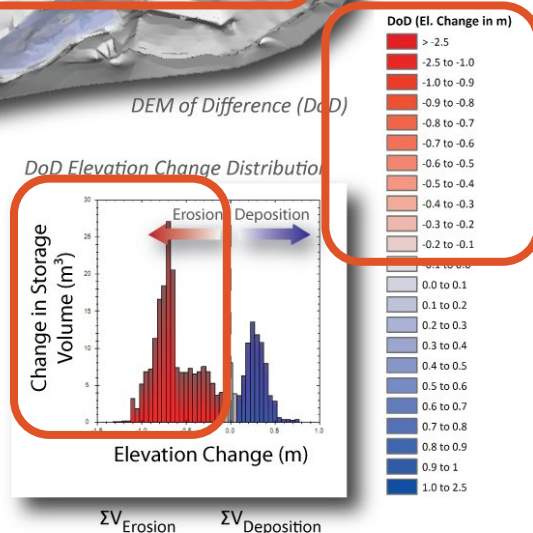
$Q_{b\text{OUT}}$

Morphological Sediment Budget:

$$Q_{b\text{IN}} - Q_{b\text{OUT}} = \frac{\Delta V_{\text{DoD}}}{\Delta t}$$

Bedload Flux Difference Change in Storage

$$\Delta V_{\text{DoD}} = \Sigma V_{\text{Deposition}} - \Sigma V_{\text{Erosion}}$$



$\Sigma V_{\text{Erosion}}$ $\Sigma V_{\text{Deposition}}$

Recall: Aggradation vs. Degradation

- Net erosion vs. Net Deposition
- Not necessary to “isolate” the bed (more generically, this is a topography change)
- Talk about “localized” changes in bed material availability (supply) and sediment transport flux
- Don’t talk about localized hydraulics
- Part of problem with “net” is whether this is at a point /cell or over a larger control volume (i.e. riverscape segment / reach of bed)

Morphological Sediment Budget:

$$Q_{b_{IN}} - Q_{b_{OUT}} = \frac{\Delta V_{DoD}}{\Delta t}$$

Bedload Flux Difference Change in Storage

$$\Delta V_{DoD} = \Sigma V_{Deposition} - \Sigma V_{Erosion}$$

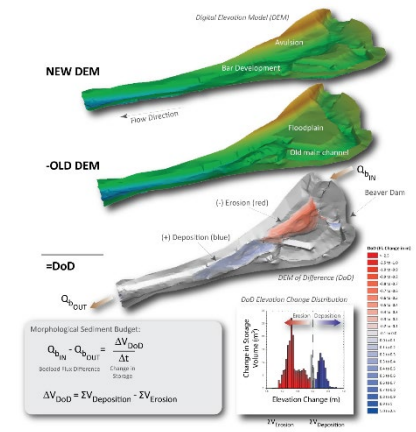
Bed processes that influence channel shape: incision and aggradation

The channel bed can adjust in two primary ways. **Vertical adjustments** reflect either **bed degradation** (i.e. channel incision/lowering of the channel bed) or channel **aggradation** (i.e. accumulation of sediment on the channel bed) (Figure 7.1). Channel incision occurs where the bed is destabilised, or scoured, resulting in bed lowering and

channel deepening (see Chapter 4). Elsewhere, degradation entails accentuated erosion of sculpted geomorphic units such as potholes (see Chapter 8). **Incision is commonly initiated by a reduction in the availability of bed material.** As noted by the Lane balance and Exner equation (Chapter 5), a delicate balance is required here, as bed materials provide the erosional tools that promote incision. If there are too many materials, the bed is protected. In contrast, if there are too few materials, rates of erosion are inhibited. Degradation may occur through downstream- or upstream-progressing mechanisms. **Downstream-progressing degradation is typically associated with a decrease in bed material load or increase in water discharge.** Alternatively, **upstream-progressing degradation typically reflects a fall in base level.** Upstream-progressing degradation generally proceeds at a much faster pace than its downstream counterpart, because the former mechanism increases slope while the latter mechanism decreases slope. In contrast, channel aggradation results in shallower channels with an array of depositional geomorphic units on the channel bed (Figure 7.1; see Chapter 8).

Recall What is difference between net change, total change sums & net total?

- **Net change** (@ x,y), is inferred from the net result (after – before; $\frac{\partial z}{\partial t} = z_{t2} - z_{t1}$)
- **Total change sums** ($\sum V$) all the erosion and deposition over the Δt duration between surveys.
- **Net** (e.g. reach) **Total** is difference of total change sums ($\Delta V_{DoD} = \sum V_{Dep} - \sum V_{Ero}$)



$$\int_{t_2}^{t_1} \sum V_{\text{Deposition}} dt$$

$$\int_{t_2}^{t_1} \sum V_{\text{Erosion}} dt$$

Morphological Sediment Budget:

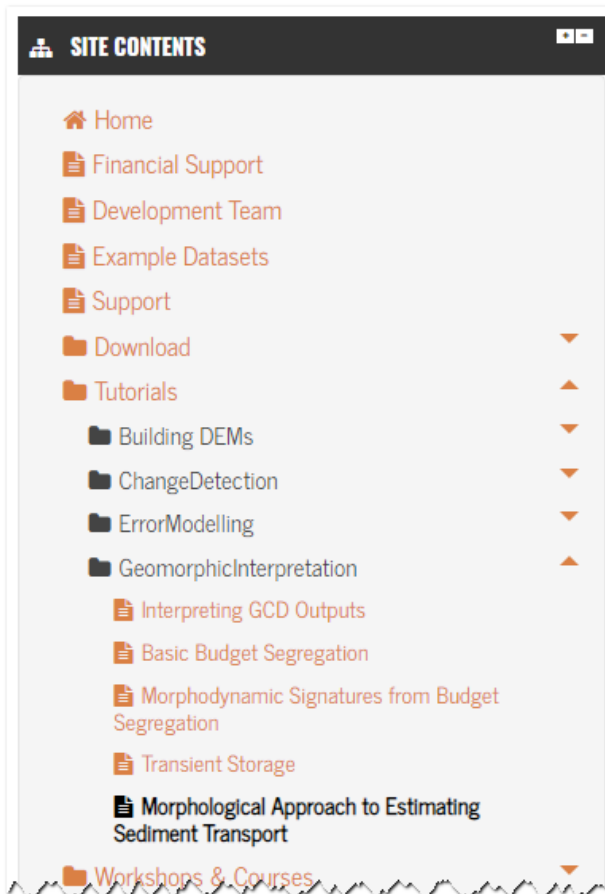
$$Q_{b_{IN}} - Q_{b_{OUT}} = \frac{\Delta V_{DoD}}{\Delta t}$$

Bedload Flux Difference Change in Storage


$$\Delta V_{DoD} = \sum V_{\text{Deposition}} - \sum V_{\text{Erosion}}$$

We'll Do This

- Start ArcGIS now
- Download from:
- [http://gcd.riverscapes.xyz/Tutorials/Geomorphic Interpretation/morphological-approach.html](http://gcd.riverscapes.xyz/Tutorials/Geomorphic%20Interpretation/morphological-approach.html)



River Rees, New Zealand

- 2km of braided river near  Queenstown, New Zealand
- Two LiDAR surveys
- 0.5m cell resolution

 Exercise Data (DEMs & Shapefile)

 Exercise Data (Shapefile Mask Only)

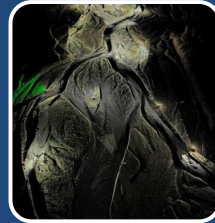
WHAT IS THE MORPHOLOGICAL APPROACH?

- Based on the sediment continuity equation (Exner's, 1925);
- Original approach (early XX century!) related to bed material discharge explicitly to the celerity bedforms (Wittmann, 1927 and Hubell, 1964);
- Application of the morphometric method (after Ashmore and Church, 1989) implies repeat measurements of channel topography;
- ... an inverse-solution to estimating bed material transport, in contrast to direct measurements and hydraulically-based predictions of sediment transport ...

Prerequisites To Morphological Approach

- Three main data components are required to solve it
- Methods in each component can be diverse
- These methods have been evolved; more advances in topographic changes

FEEDING THE MORPHOLOGICAL APPROACH: PRIMARY DATA



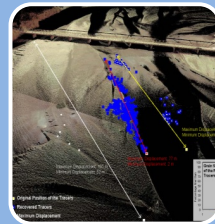
TOPOGRAPHIC CHANGES

- PLANFORM DATA
- SCOUR-CHAINS
- CROSS-SECTIONS (1D)
- DIGITAL ELEVATION MODELS (2D)
- POINT CLOUDS (2.5D)



REFERENCE SEDIMENT FLUX

- BEDLOAD MEASUREMENTS
- ZERO TRANSPORT ASSUMPTION
- BEDLOAD FORMULAE



PARTICLE STEP-LENGTHS

- TRACERS
- LOCI OF EROSION/SEDIMENTATION
- EROSIONAL/DEPOSITIONAL FEATURES

The Basics: Two Way To Solve It

- Budgeting

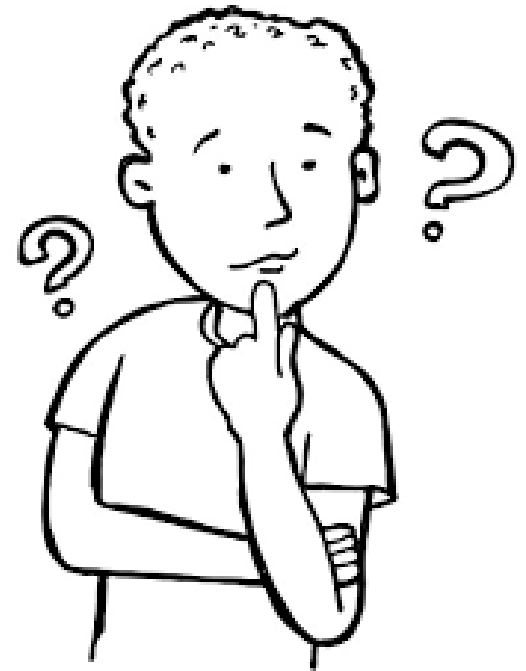
$$(Q_{b_{in}} - Q_{b_{out}})\Delta t = (1 - p)\Delta V$$

- Flux in/out
- Porosity
- Volumetric changes

- Step length

$$Q_b = (v_b \Sigma V_e (1 - p) \rho_s) / L_c$$

- Virtual velocity (L/T; step length/time)
- Erosion
- Porosity
- Density
- Streamwise channel length

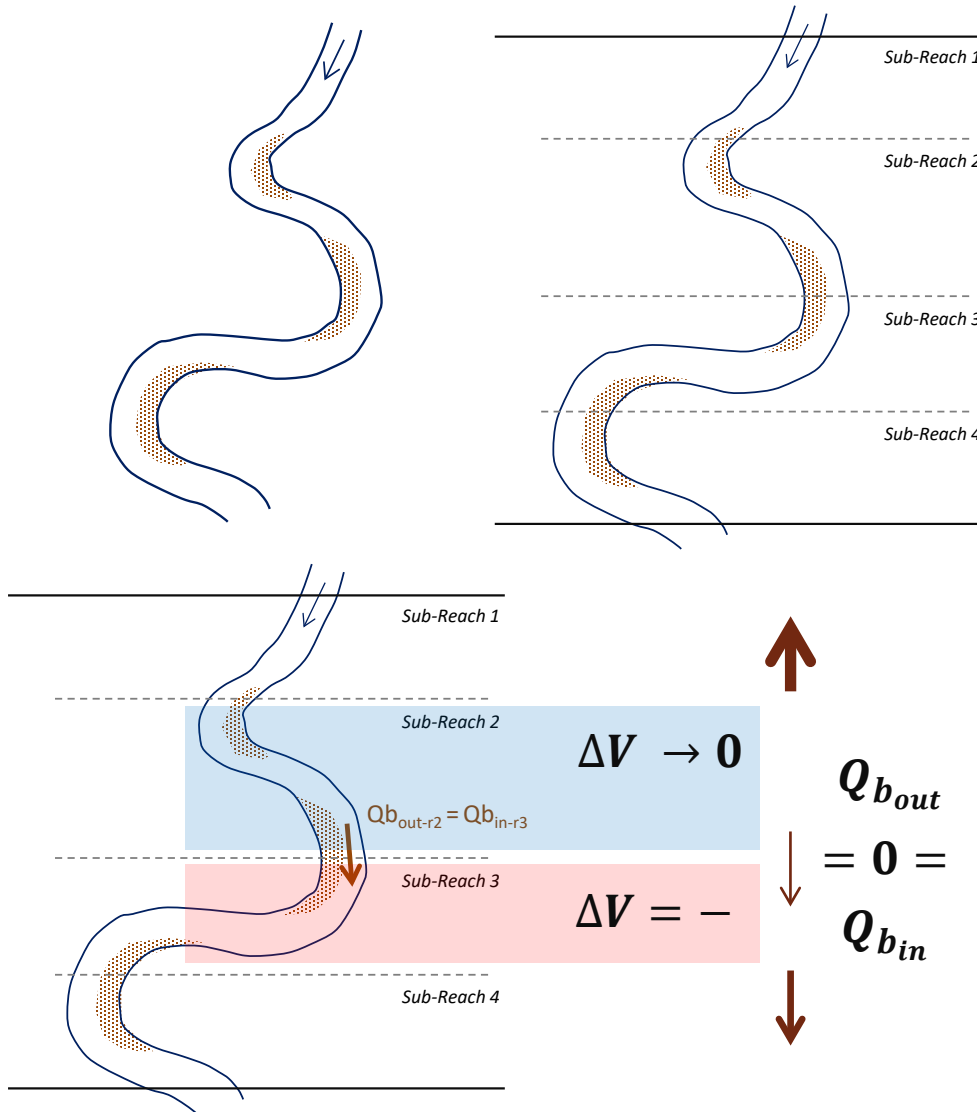


Budgeting

$$(Q_{b_{in}} - Q_{b_{out}})\Delta t = (1 - p)\Delta V$$

Transport Rate from DoD

- (1) Discretize the study-reach into a streamwise series of sub-reaches
- (2) $Q_{b_{out}}$ from a section i is the same $Q_{b_{in}}$ next section $i+1$
- (3) Assume a zero-flux boundary into a net erosional reach form a net depositional (or compensated) reach
- (4) Back calculate $Q_{b_{in/out}}$ (lower-bound estimates)



Budgeting

$$(Q_{b_{in}} - Q_{b_{out}})\Delta t = (1 - p)\Delta V$$

MORPHOLOGICAL SEDIMENT BUDGET:

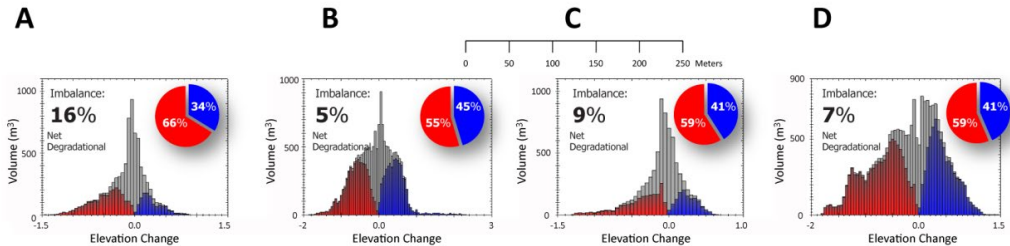
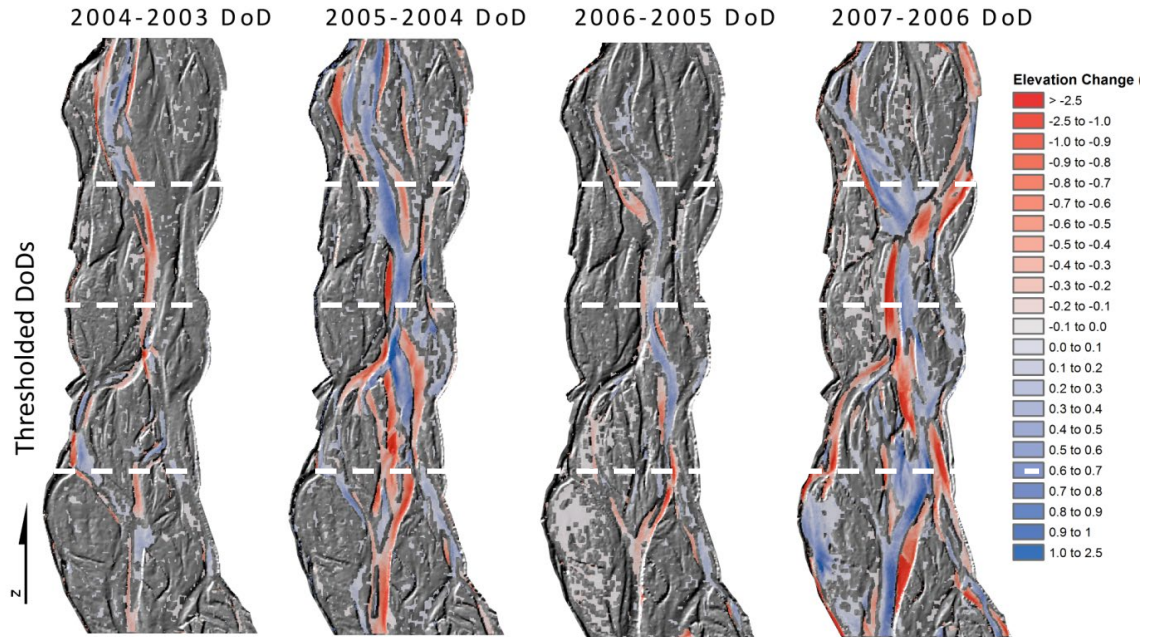
$$V_{in} - V_{out} = \Delta V_{DoD}$$

Volumetric Flux Difference Change in Storage

$$\Delta V_{DoD} = \sum V_D - \sum V_E$$

DoD Measured

Best estimate of gross reach-scale sediment budget



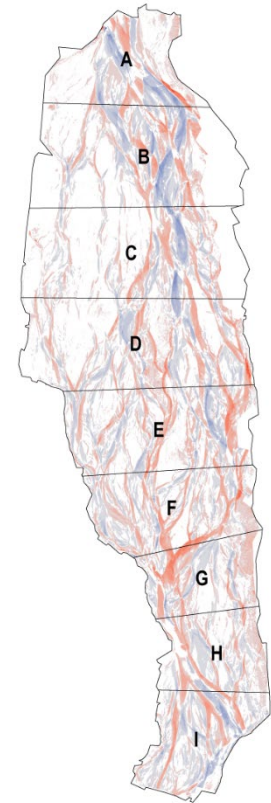
Volumetric Elevation Change Distributions

Where in the reach is contributing the most?

EXERCISE 0- PART 1A: PERFORM BUDGET SEGREGATION

C:\0_GCD\Excercises\O_MorphologicalApproach

1. In new project as C, perform another change detection at 2σ (i.e. 95%)
2. Now perform a budget segregation using sub-reach mask shapefile→
3. Explore results... look at longitudinal variation...

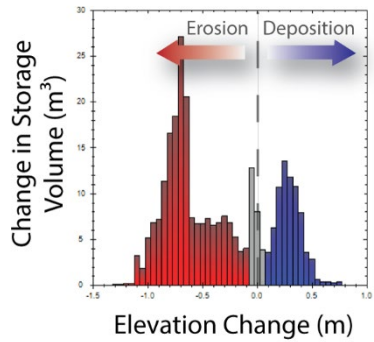


0 100 200 300 400 500 Meters



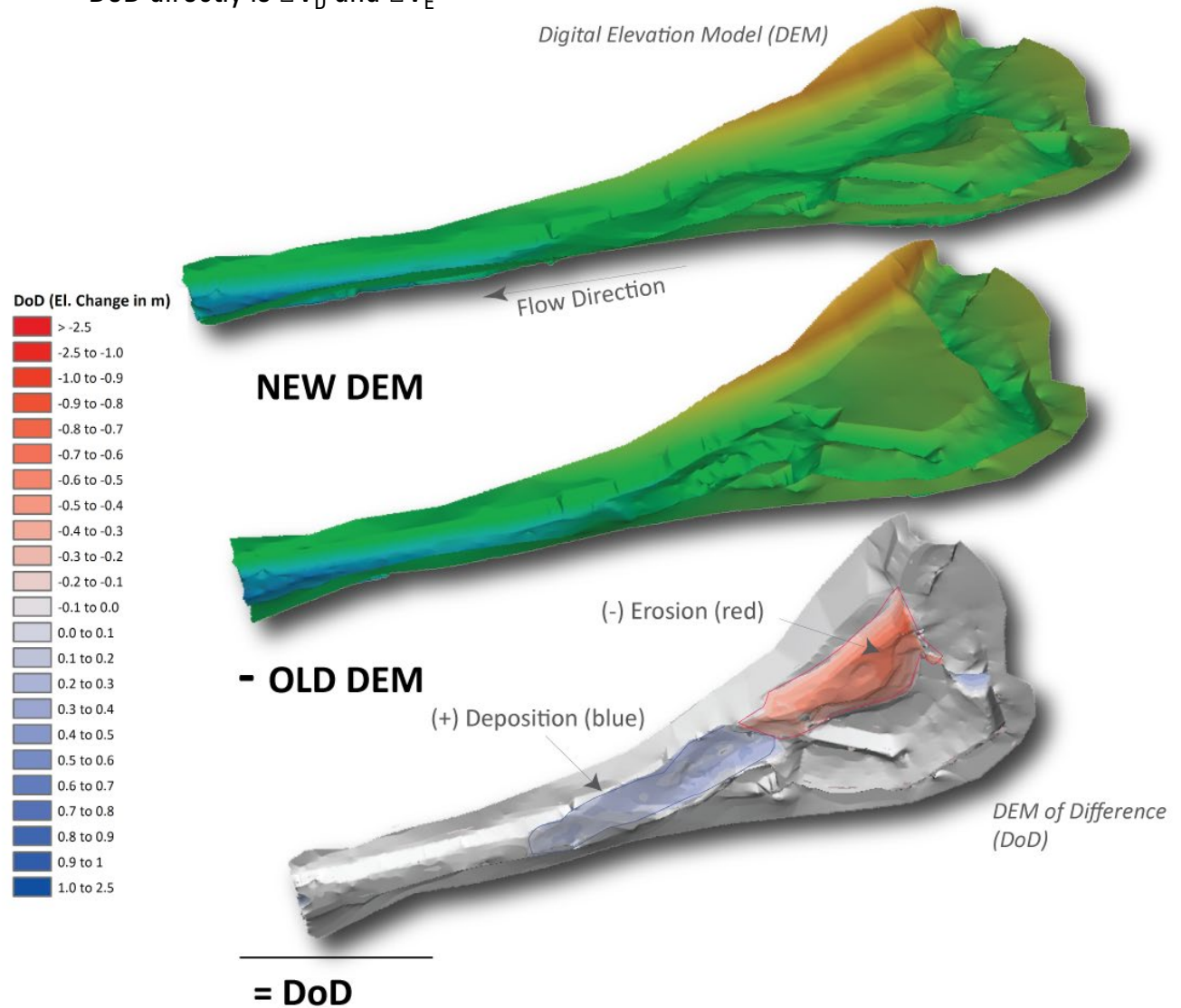
What terms are you getting?

DoD Elevation Change Distribution



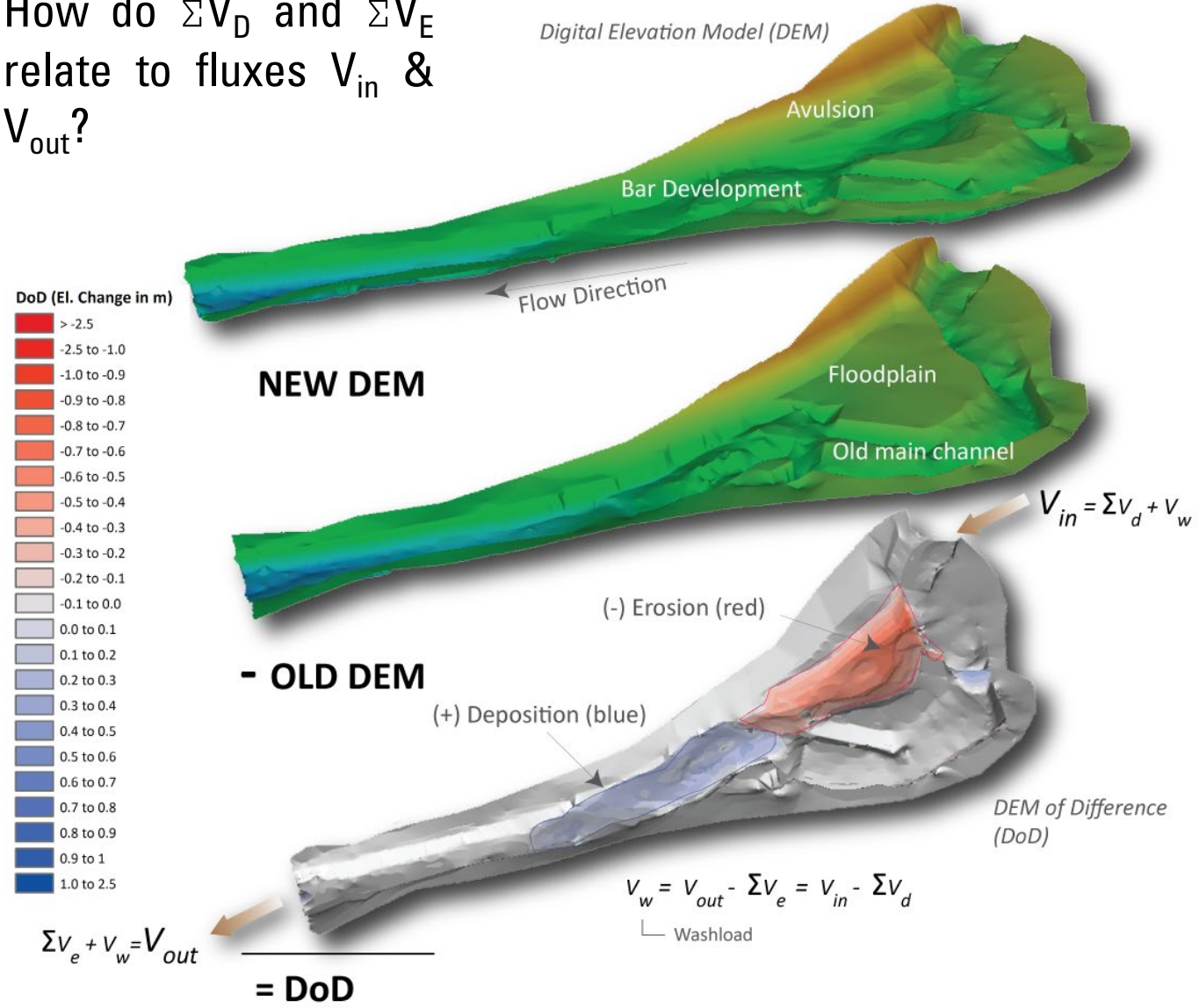
ΣV_e = Erosion Volume ΣV_d = Deposition Volume

What you actually get of use from a DoD directly is ΣV_D and ΣV_E



Morphological Approach

How do ΣV_D and ΣV_E relate to fluxes V_{in} & V_{out} ?



The Morphological Sediment Budget

MORPHOLOGICAL SEDIMENT BUDGET:

$$V_{in} - V_{out} = \Delta V_{DoD}$$

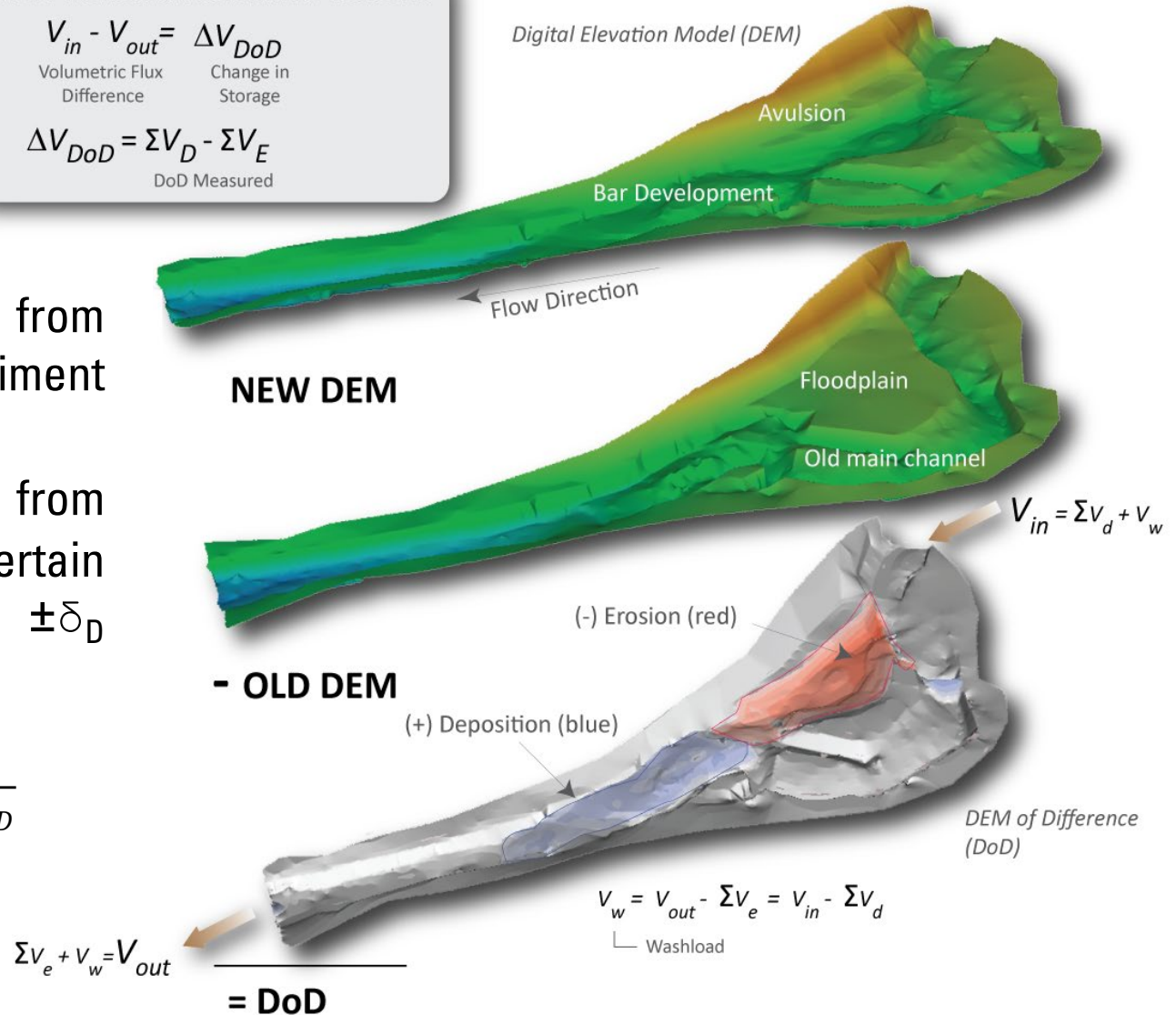
Volumetric Flux
Change in
Difference
Storage

$$\Delta V_{DoD} = \Sigma V_D - \Sigma V_E$$

DoD Measured

- The only term from HRT in a sediment budget is ΔV_{DoD}
- ΔV_{DoD} is derived from two uncertain quantities: $\Sigma V_D \pm \delta_D$ and $\Sigma V_E \pm \delta_E$
- Thus,

$$\delta_{DoD} = \sqrt{\delta_E + \delta_D}$$

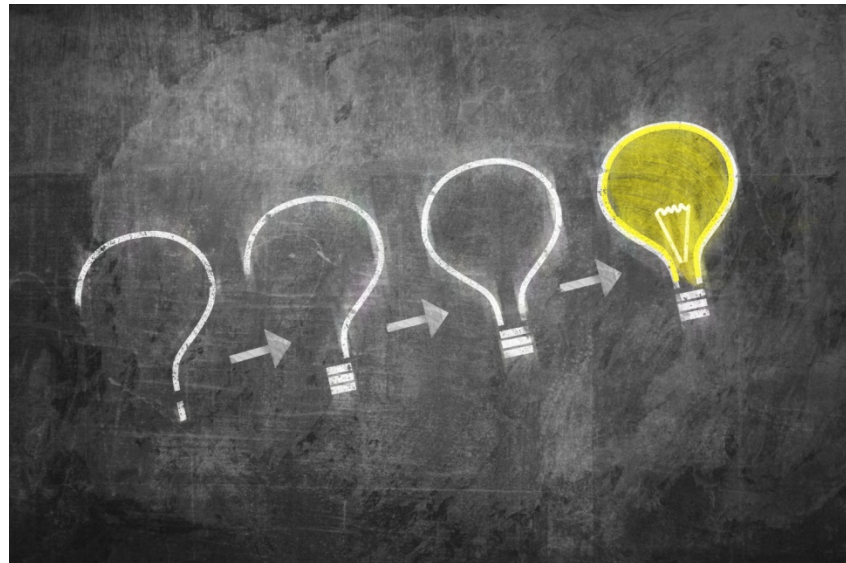


Estimating Bed Material Fluxes

- Budgeting

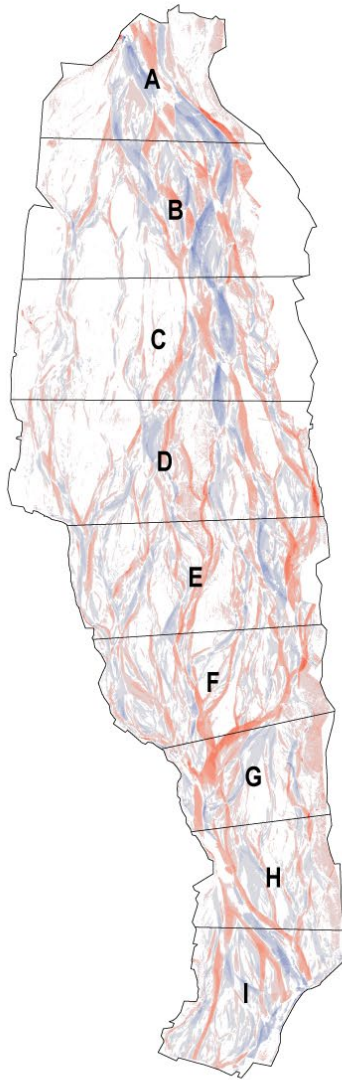
$$(Q_{b_{in}} - Q_{b_{out}})\Delta t = (1 - p)\Delta V$$

- Flux in/out
- Porosity
- Volumetric changes



The River Rees

1. Start with DoD
2. Break up into sub-reaches



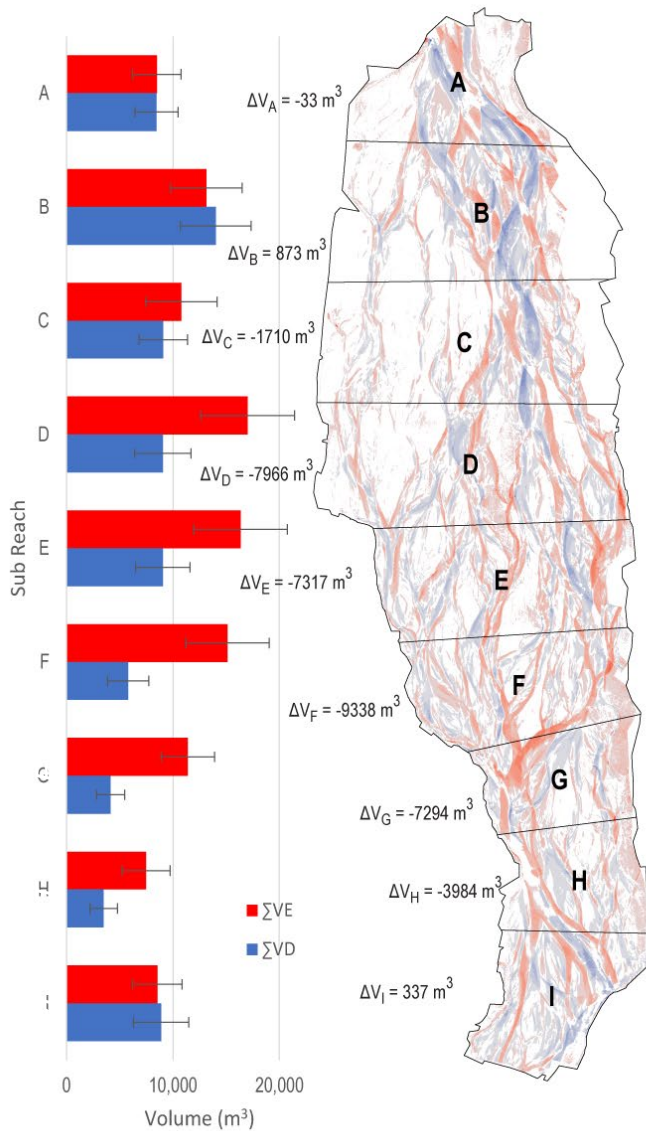
0 100 200 300 400 500 Meters



March 28, 2010 to May 1, 2010
Duration above Q_{crit} : 8.6 days
 Q_{crit} : 30 cumecs
Peak Q_s : 226 & 403 cumecs
Porosity: 0.26

The River Rees

1. Start with DoD
2. Break up into sub-reaches
3. Using DoD, calculate ΔV_{DoD} for each sub-reach



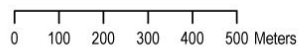
MORPHOLOGICAL SEDIMENT BUDGET:

$$V_{in} - V_{out} = \Delta V_{DoD}$$

Volumetric Flux Difference
Change in Storage

$$\Delta V_{DoD} = \Sigma V_D - \Sigma V_E$$

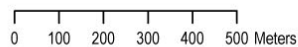
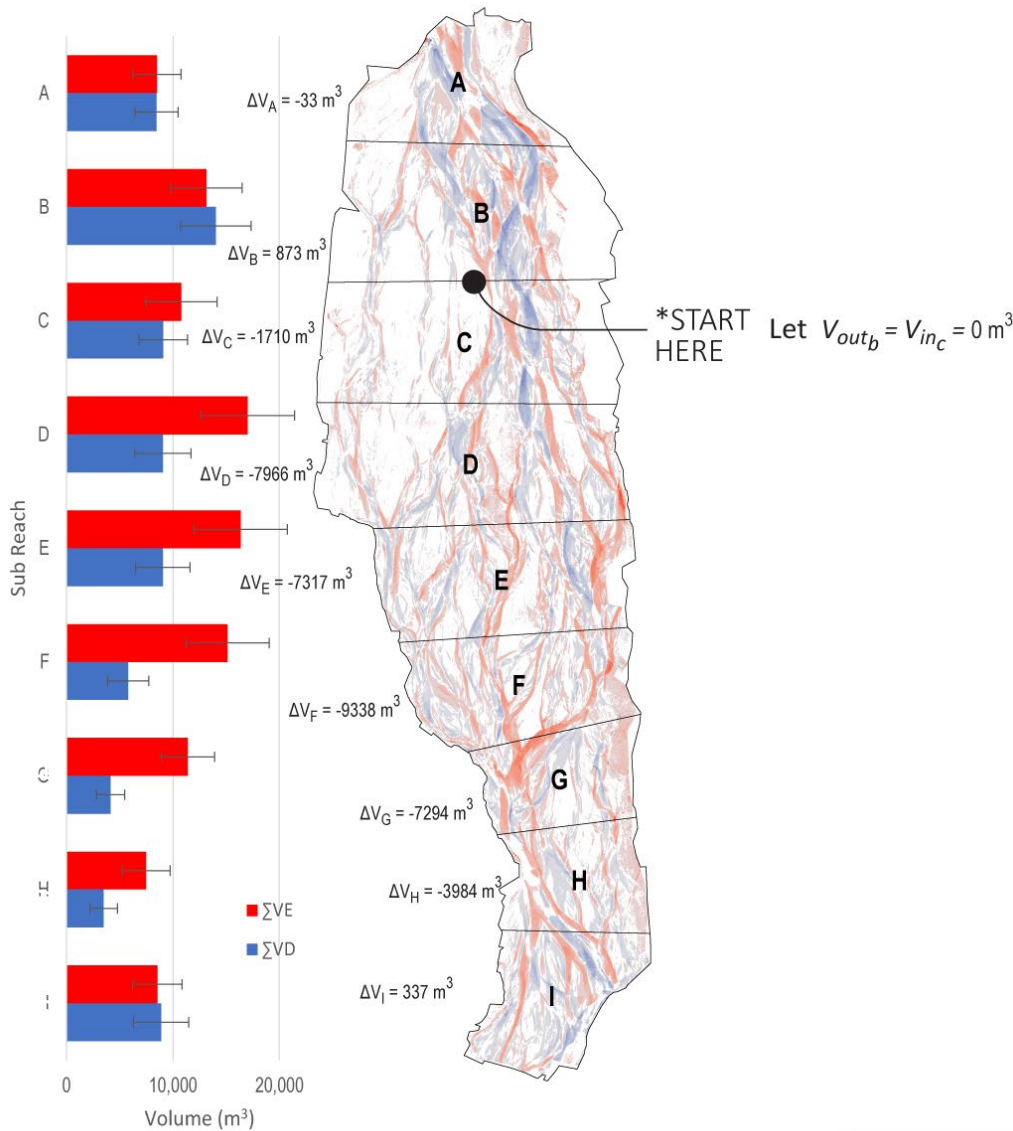
DoD Measured



March 28, 2010 to May 1, 2010
 Duration above Q_{crit} : 8.6 days
 Q_{crit} : 30 cumecs
 Peak Qs: 226 & 403 cumecs
 Porosity: 0.26

The River Rees

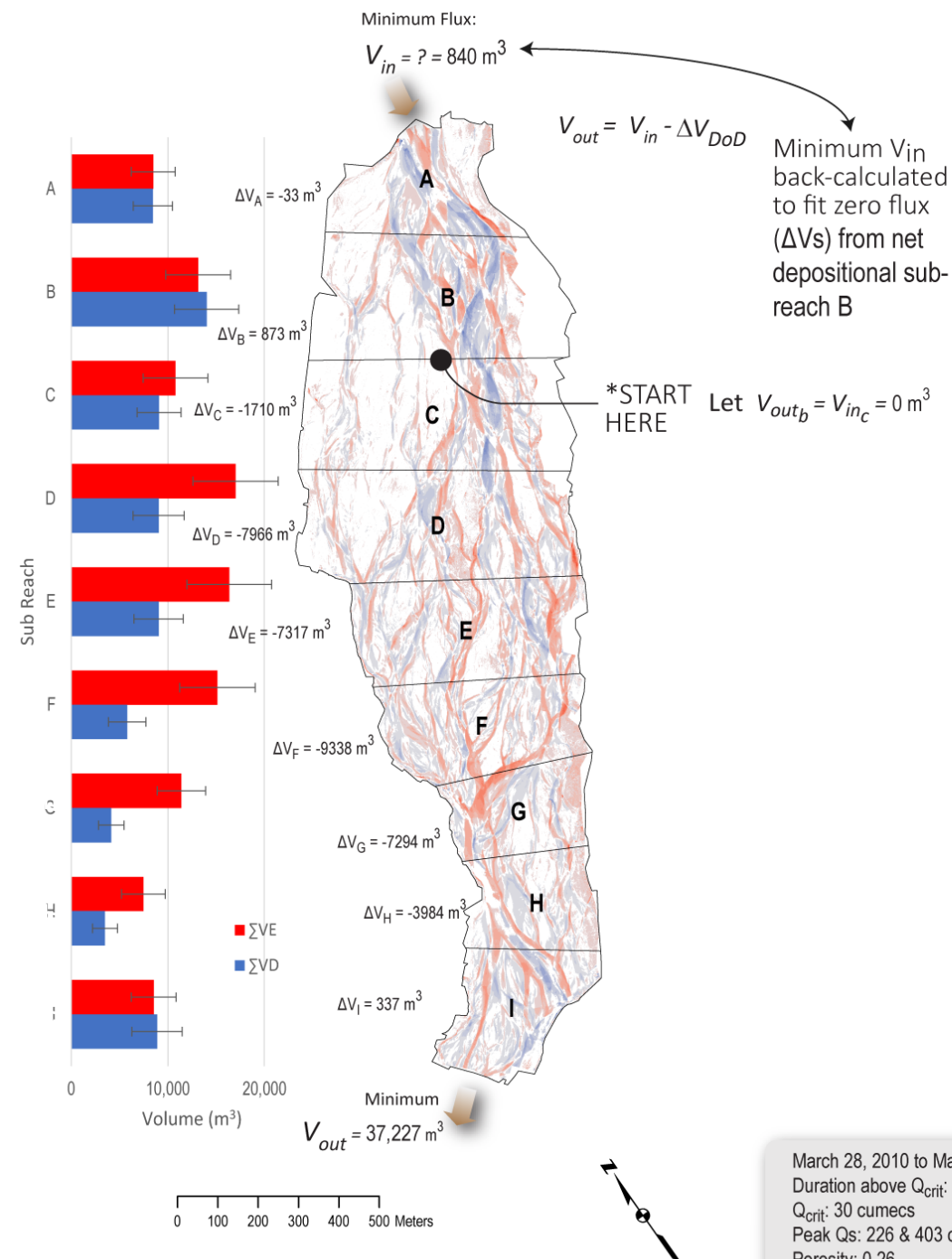
1. Start with DoD
2. Break up into sub-reaches
3. Using DoD, calculate ΔV_{DoD} for each sub-reach
4. Choose a no flux boundary at outlet of one of sub-reaches



March 28, 2010 to May 1, 2010
 Duration above Q_{crit} : 8.6 days
 Q_{crit} : 30 cumecs
 Peak Qs: 226 & 403 cumecs
 Porosity: 0.26

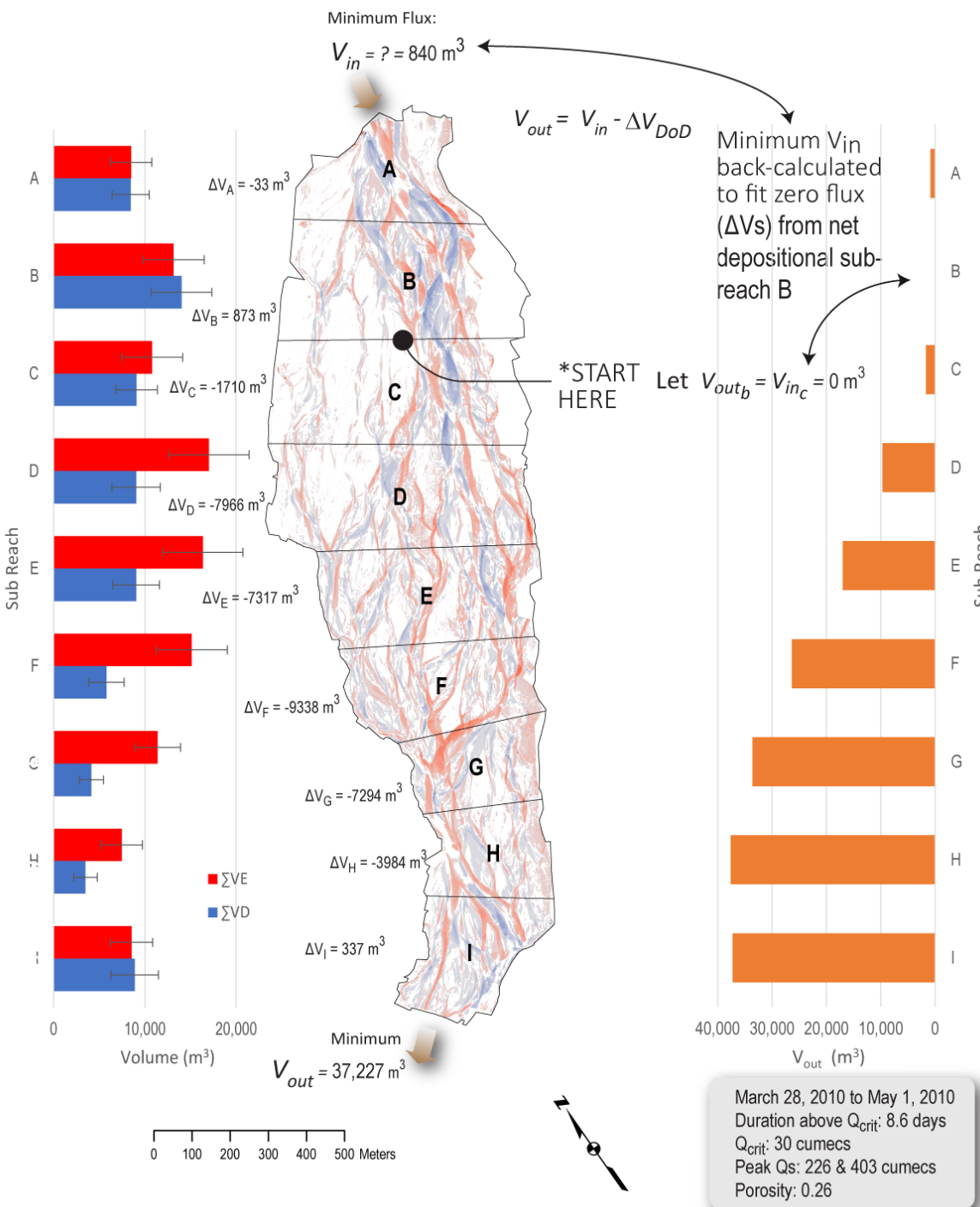
The River Rees

1. Start with DoD
2. Break up into sub-reaches
3. Using DoD, calculate ΔV_{DoD} for each sub-reach
4. Choose a no flux boundary at outlet of one of sub-reaches
5. Back out the minimum flux V_{in} to support that no flux boundary



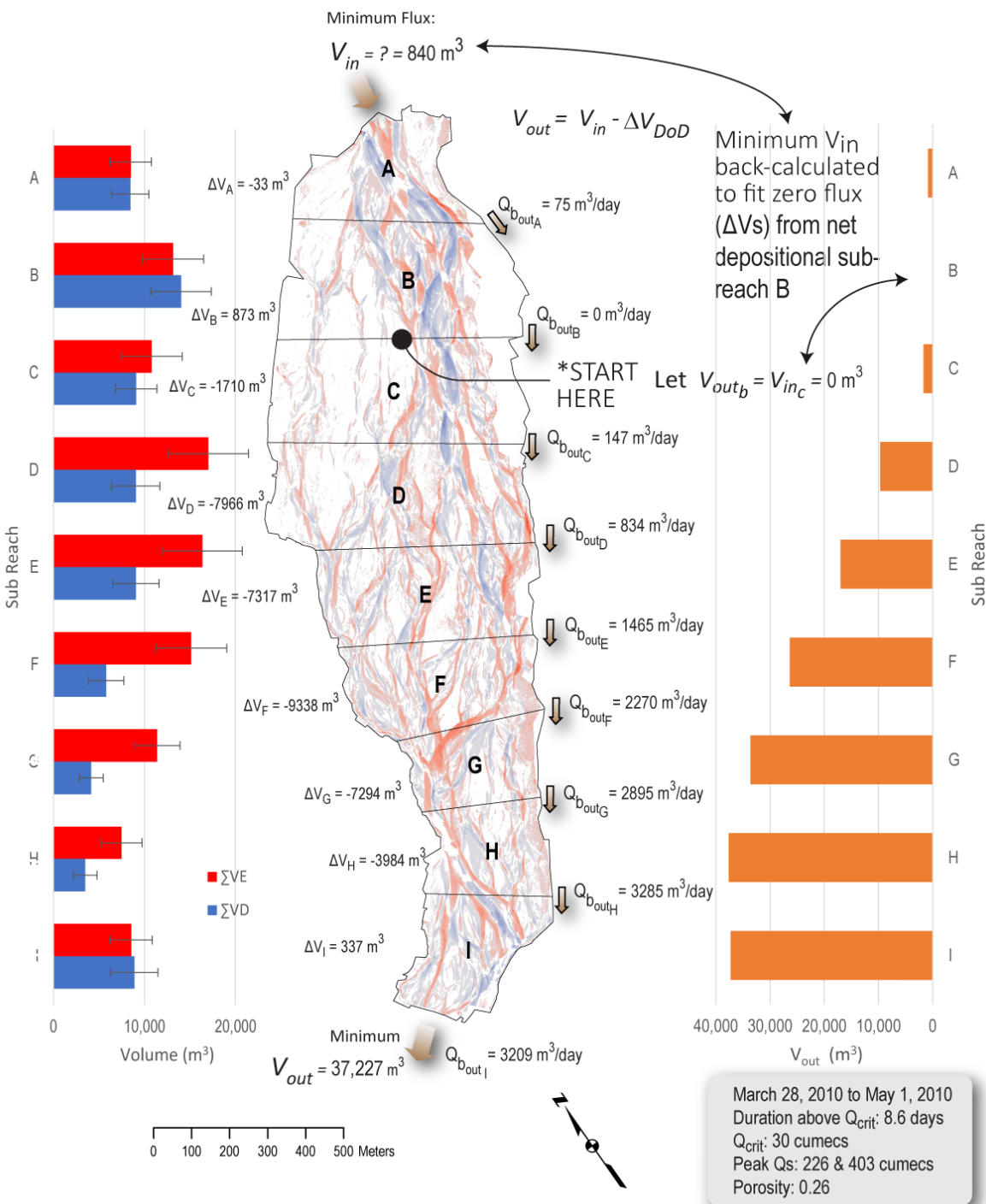
The River Rees

1. Start with DoD
2. Break up into sub-reaches
3. Using DoD, calculate ΔV_{DoD} for each sub-reach
4. Choose a no flux boundary at outlet of one of sub-reaches
5. Back out the minimum flux V_{in} to support that no flux boundary
6. Propagate through each sub-reach to get V_{out}



The River Rees

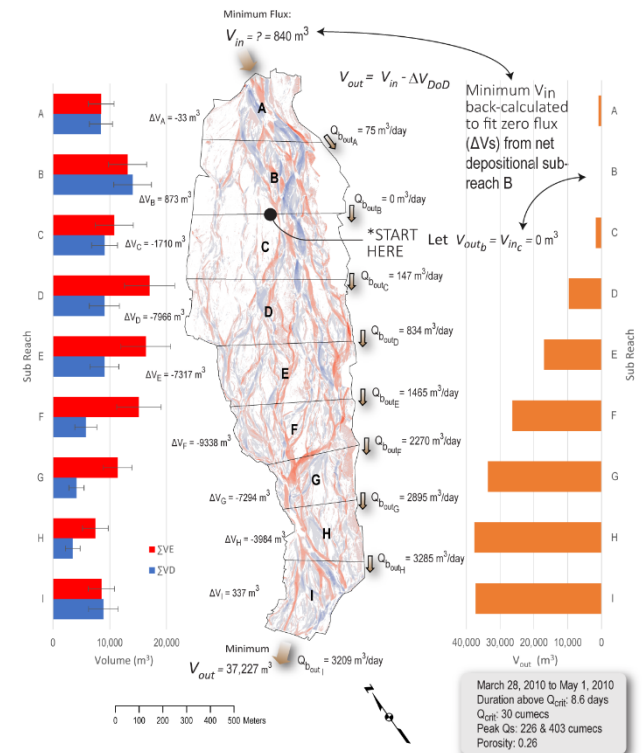
1. Start with DoD
2. Break up into sub-reaches
3. Using DoD, calculate ΔV_{DoD} for each sub-reach
4. Choose a no flux boundary at outlet of one of sub-reaches
5. Back out the minimum flux V_{in} to support that no flux boundary
6. Propagate through each sub-reach to get V_{out}
7. Using duration, convert V_{out} to rate to get Q_b

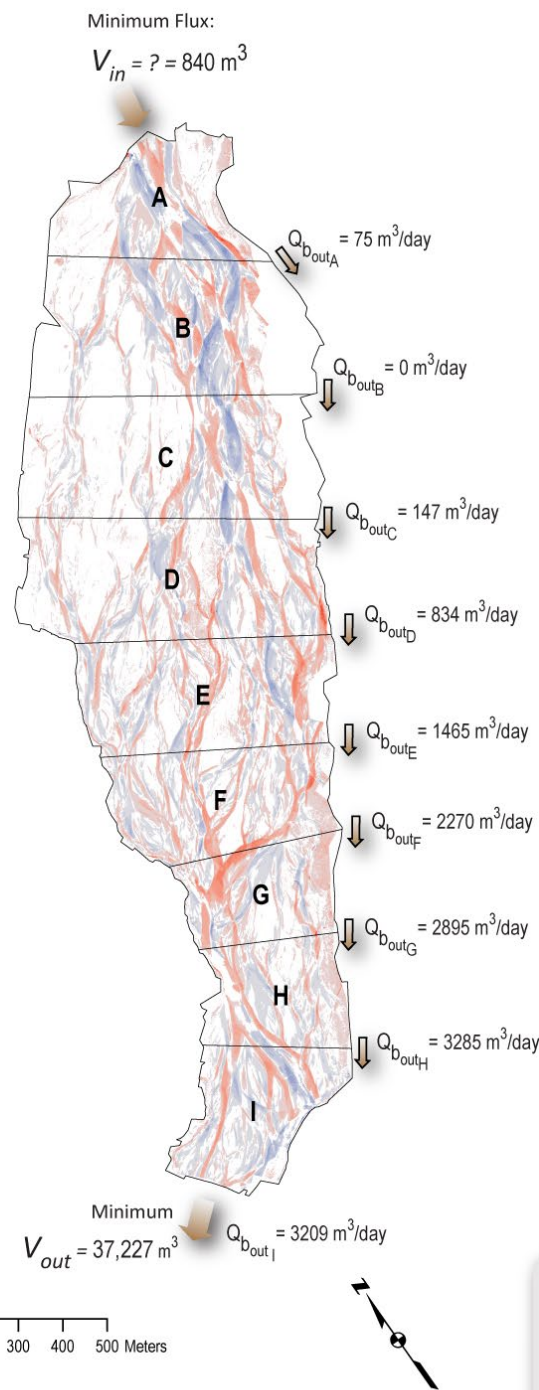


EXERCISE D- PART 1B: MORPHOLOGICAL APPROACH

C:\0_GCD\Excercises\0_MorphologicalApproach

1. Use results to populate spreadsheet (Budget) and calculate V_{out}
2. Use event duration to back out a Q_B





THE RIVER REES

- Longitudinal patterns and transfer between reaches.
- All this without actually having any reference flux measurement.
- This is only a minimum flux.
- Better if you have an actual reference flux at one point.
- Choosing a site with a real zero flux boundary can help

March 28, 2010 to May 1, 2010
 Duration above Q_{crit} : 8.6 days
 Q_{crit} : 30 cumecs
 Peak Qs: 226 & 403 cumecs
 Porosity: 0.26

Key Sediment Flux Concepts



Conceptualization of Controls on Sediment Flux

- Hmmm...

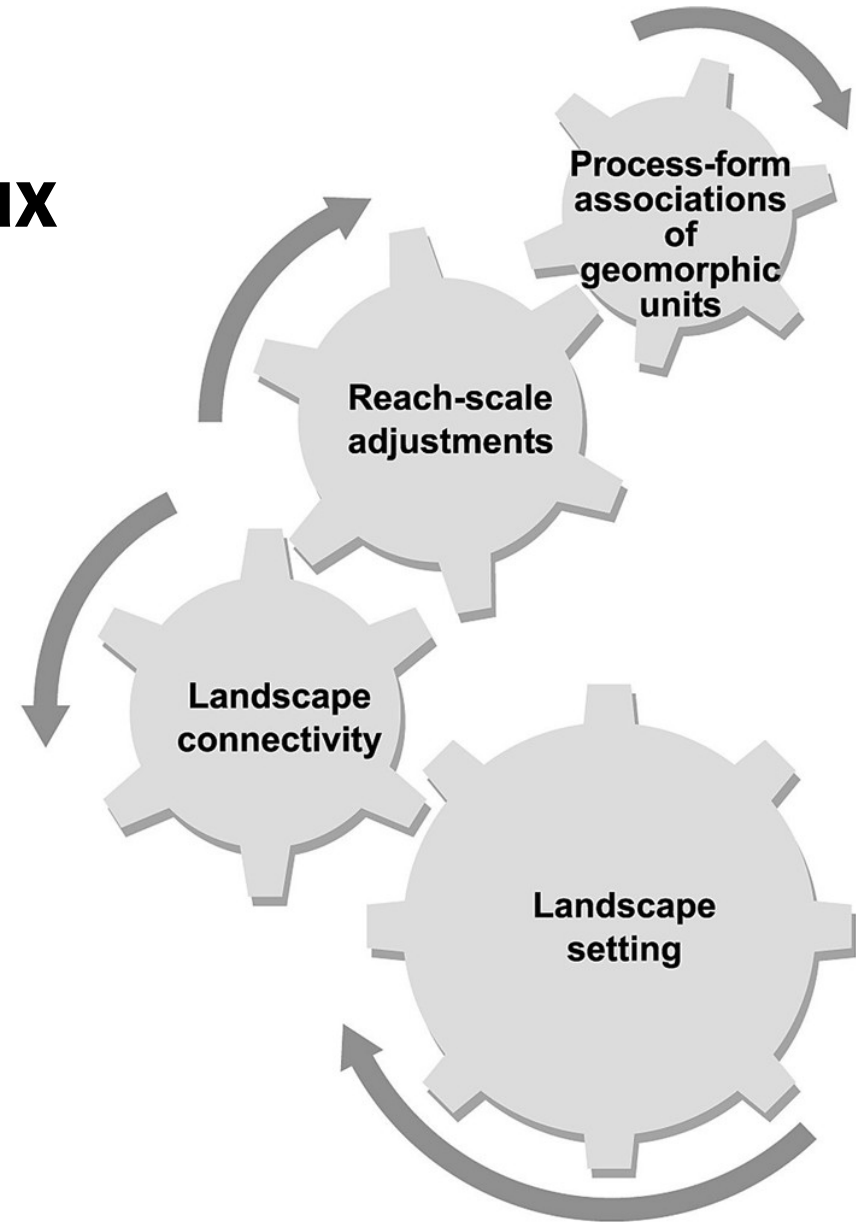


Figure 14.4 Conceptualisation of controls upon sediment flux at the catchment scale.

Fryirs & Brierley (2013)

DOI: [10.1002/9781118305454](https://doi.org/10.1002/9781118305454)

Hillslope-Channel Coupling (Connectivity)

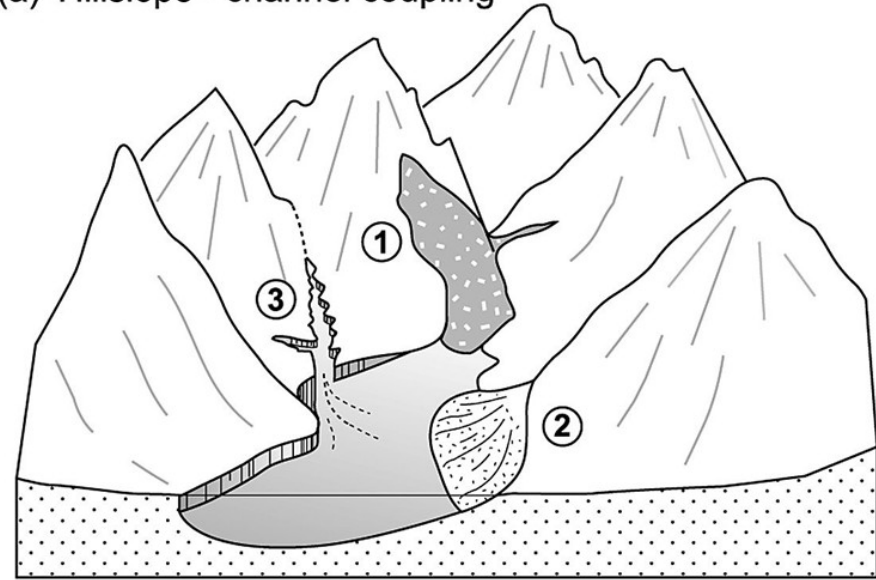
Phrases like:

- Tightly coupled
- Weakly coupled
- Decoupled

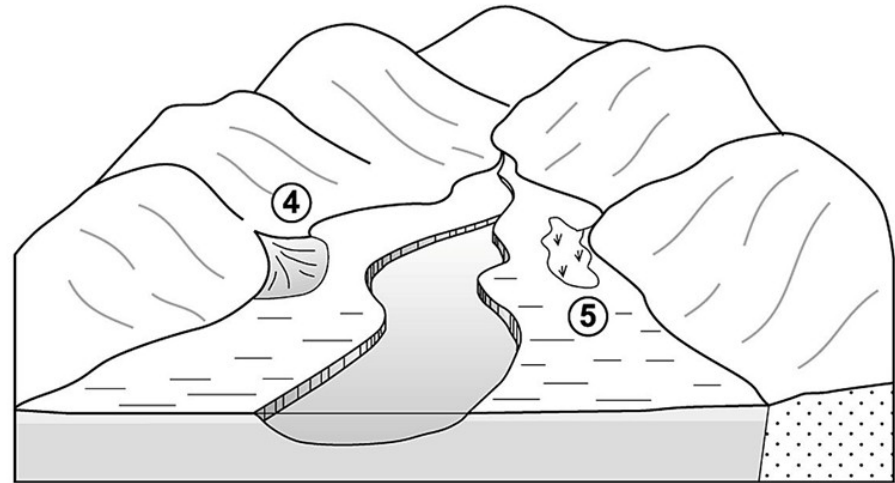
All just proxies for degree of connectivity

Figure 14.5 Hillslope–valley floor (de)coupling. (a) In coupled landscapes, hillslope materials are efficiently transferred to the valley floor, where they are prone to be readily reworked. Landslide deposits, fans and gully networks (numbered 1–3 respectively) transfer materials to channels. (b) In decoupled landscapes, sediments released from hillslopes at valley margins may be stored further down-slope (i.e. within the catena) or they may be stored atop extensive floodplains (numbers 4 and 5 respectively).

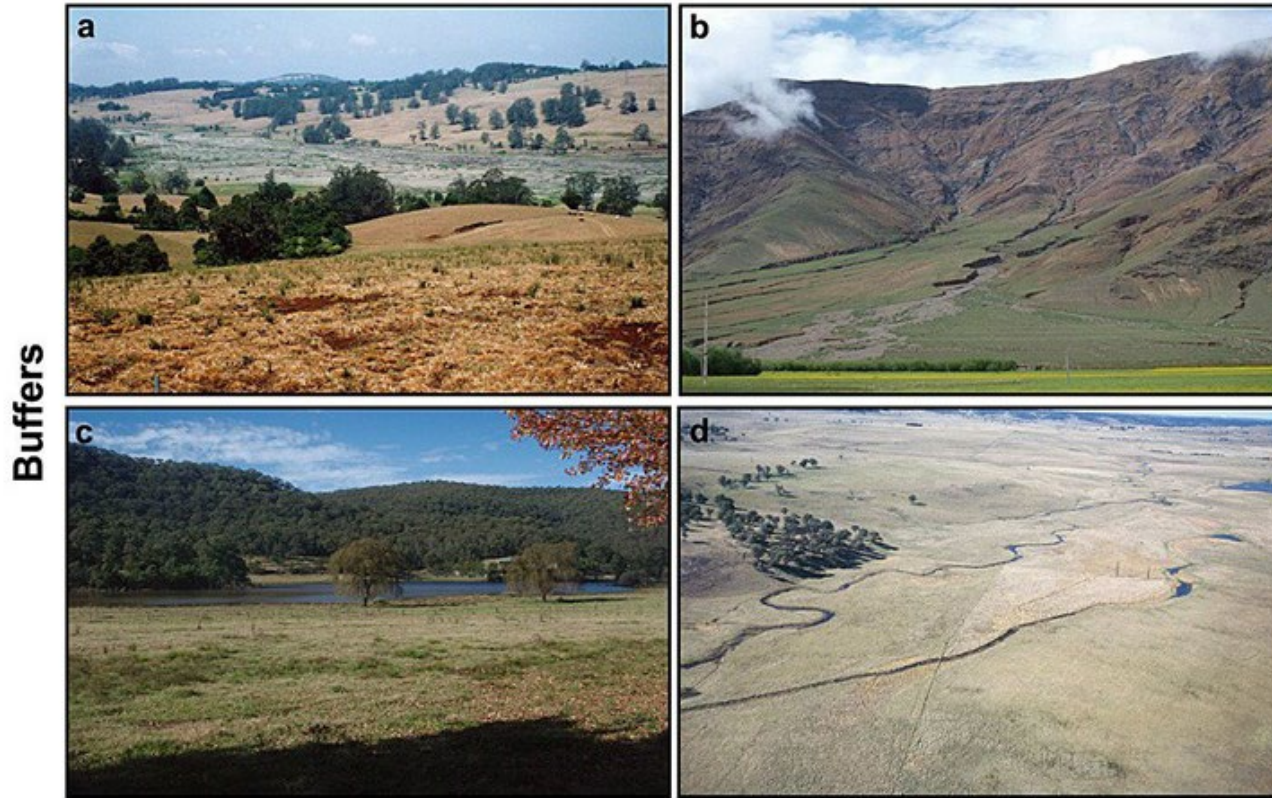
(a) Hillslope - channel coupling



(b) Hillslope - channel decoupling



Buffers



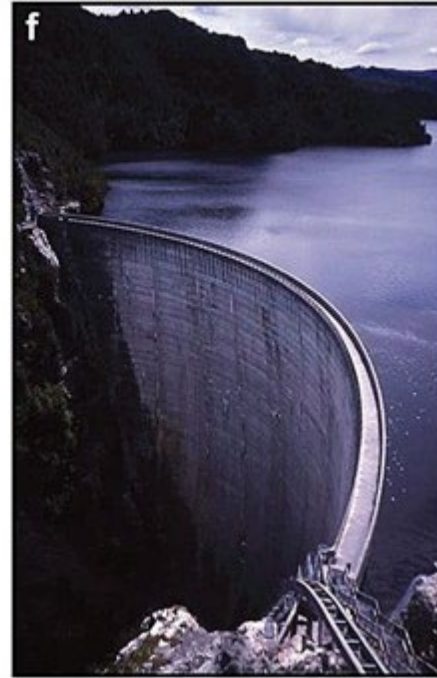
Buffers

- A **buffer disrupts** longitudinal and lateral linkages, preventing sediment from entering a channel
- Geomorphic units like:
 - Valley bottom swamps (a)
 - Alluvial fans (b)
 - Trapped tributaries (c)
 - Open alluvial plains (d)

Figure 14.6 Buffers, barriers and blankets. These landforms impede lateral, longitudinal and vertical connectivity of sediment flux in landscapes. They promote sediment storage, thereby reducing the efficiency of sediment transfer through a catchment. *Buffers*. (a) Valley-bottom swamps, Wingecarribee swamp, NSW. Photograph: K. Fryirs. (b) Alluvial fans in steep terrain, Tibet. Photograph: G. Brierley. (c) Trapped tributary fill, Macdonald River, NSW. Photograph: K. Fryirs. (d) Broad, open alluvial plains, North Coast, NSW. Photograph: R. Ferguson. *Barriers*. (e) Sediment slug, Waiapu River, New Zealand. Photograph: K. Fryirs. (f) Dam, Gordon River, Tasmania. Photograph: K. Fryirs. *Blankets*. (g) Floodplain sediment sheet, King River, Tasmania. Photograph: K. Fryirs. (h) Fine-grained materials in the interstices of gravels, King River, Tasmania. Photograph: K. Fryirs.

Barriers

Barriers



- A *barrier* impedes downstream conveyance of sediment already in the network
- Geomorphic units like:
 - Sediment slugs (e)
 - Dams (f)

Figure 14.6 Buffers, barriers and blankets. These landforms impede lateral, longitudinal and vertical connectivity of sediment flux in landscapes. They promote sediment storage, thereby reducing the efficiency of sediment transfer through a catchment. *Buffers*. (a) Valley-bottom swamps, Wingecarribee swamp, NSW. Photograph: K. Fryirs. (b) Alluvial fans in steep terrain, Tibet. Photograph: G. Brierley. (c) Trapped tributary fill, Macdonald River, NSW. Photograph: K. Fryirs. (d) Broad, open alluvial plains, North Coast, NSW. Photograph: R. Ferguson. *Barriers*. (e) Sediment slug, Waiapu River, New Zealand. Photograph: K. Fryirs. (f) Dam, Gordon River, Tasmania. Photograph: K. Fryirs. *Blankets*. (g) Floodplain sediment sheet, King River, Tasmania. Photograph: K. Fryirs. (g) Fine-grained materials in the interstices of gravels, King River, Tasmania. Photograph: K. Fryirs.

Blankets

Blankets



- A **blanket disrupts** vertical linkages by smothering (protecting) deposits and landforms.
- Geomorphic units like:
 - Floodplain sediment sheet (f)
 - Planar channel deposits of fines (g)
- Mechanisms like filling intensities with fines or vegetation

Figure 14.6 Buffers, barriers and blankets. These landforms impede lateral, longitudinal and vertical connectivity of sediment flux in landscapes. They promote sediment storage, thereby reducing the efficiency of sediment transfer through a catchment. *Buffers*. (a) Valley-bottom swamps, Wingecarribee swamp, NSW. Photograph: K. Fryirs. (b) Alluvial fans in steep terrain, Tibet. Photograph: G. Brierley. (c) Trapped tributary fill, Macdonald River, NSW. Photograph: K. Fryirs. (d) Broad, open alluvial plains, North Coast, NSW. Photograph: R. Ferguson. *Barriers*. (e) Sediment slug, Waiapu River, New Zealand. Photograph: K. Fryirs. (f) Dam, Gordon River, Tasmania. Photograph: K. Fryirs. *Blankets*. (g) Floodplain sediment sheet, King River, Tasmania. Photograph: K. Fryirs. (g) Fine-grained materials in the interstices of gravels, King River, Tasmania. Photograph: K. Fryirs.

They Collectively Lead to

- Longer residence time of sediment
- Greater sediment storage (i.e. depositional geomorphic units) manifested in RIVERSCAPES!
- Inefficient conveyance of mass water and sediment!



Figure 14.6 Buffers, barriers and blankets. These landforms impede lateral, longitudinal and vertical connectivity of sediment flux in landscapes. They promote sediment storage, thereby reducing the efficiency of sediment transfer through a catchment. *Buffers*. (a) Valley-bottom swamps, Wingecarribee swamp, NSW. Photograph: K. Fryirs. (b) Alluvial fans in steep terrain, Tibet. Photograph: G. Brierley. (c) Trapped tributary fill, Macdonald River, NSW. Photograph: K. Fryirs. (d) Broad, open alluvial plains, North Coast, NSW. Photograph: R. Ferguson. *Barriers*. (e) Sediment slug, Waiapu River, New Zealand. Photograph: K. Fryirs. (f) Dam, Gordon River, Tasmania. Photograph: K. Fryirs. *Blankets*. (g) Floodplain sediment sheet, King River, Tasmania. Photograph: K. Fryirs. (h) Fine-grained materials in the interstices of gravels, King River, Tasmania. Photograph: K. Fryirs.

Sensitivity to Disturbance

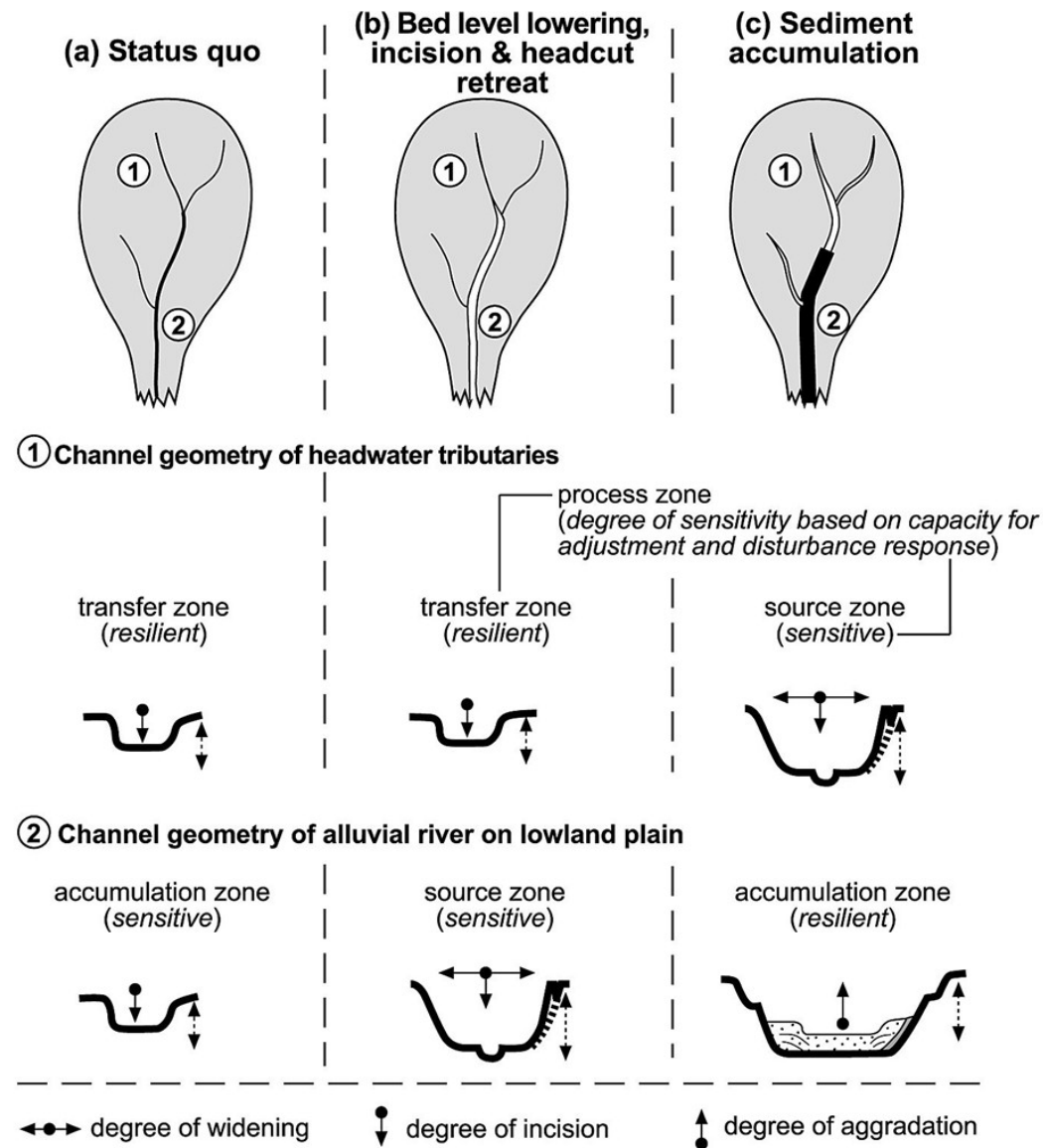


Figure 14.7 The changing nature of process zones and reach sensitivity as a result of disturbance. In this figure bed level lowering and headcut retreat alter the process zone distribution of a catchment. Associated changes to reach sensitivity are noted. (a) In the status quo situation (undisturbed), headwater tributaries act as transfer zones and the lowland plain acts as an accumulation zone. (b) Following bed level lowering, reaches along the lowland plain become sensitive to adjustment. Channel incision and expansion release sediment, transforming the reach into a source zone. Headward retreat and network extension induce incision and expansion of tributary channels, releasing additional sediment. These reaches now act as sensitive source zones. (c) Sediment released from upstream source zones is trapped along the lowland plain, switching this reach back to an accumulation zone.

Managing Riverscapes for **Resilience** of _____, water, wildlife, working lands?

What is resilience?

"The capacity to recover quickly from difficulties, toughness."

The lack of sensitivity to disturbance



Landslides & Tributary Impacts on Trunks

- How big is big?

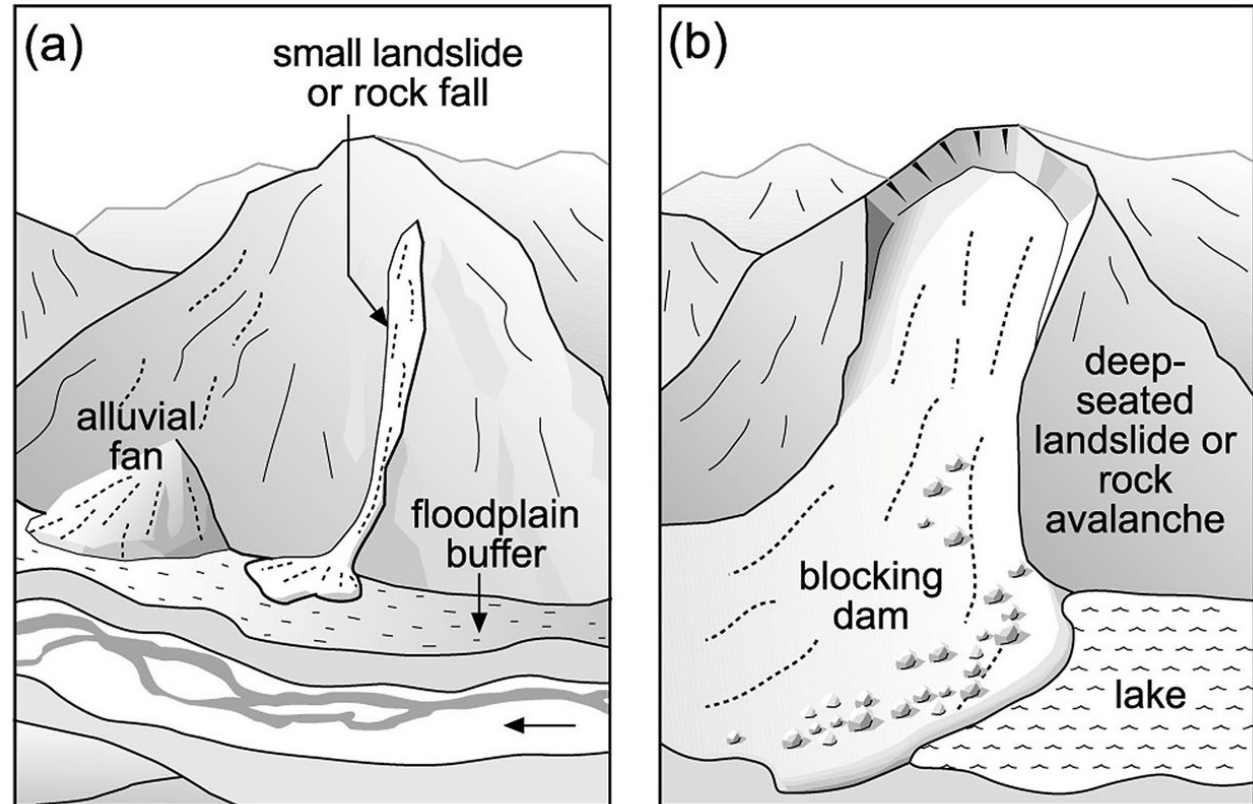


Figure 14.8 Conceptual representation of landslide impacts upon trunk streams. (a) Landslides are too small to reach the drainage network. The ratio of landslide runout to slope length is insufficient, and valley floor buffer width is wide, resulting in no sediment delivery to the channel. (b) Landslides are large enough to form dams, thus disrupting or obliterating the drainage system. Long-term blockage will force backwater sedimentation and trapping behind landslide dams or, in extreme cases, drainage reversal. Landslide size in relation to cross-valley length scale is sufficient to overwhelm the channel and form a stable landslide-dammed lake. From Korup (2005). © John Wiley and Sons. Reproduced with permission.

Buffers, Barriers and Blankets

Effective timescale

Frequent, low magnitude

Less frequent, moderate magnitude

Infrequent, high magnitude

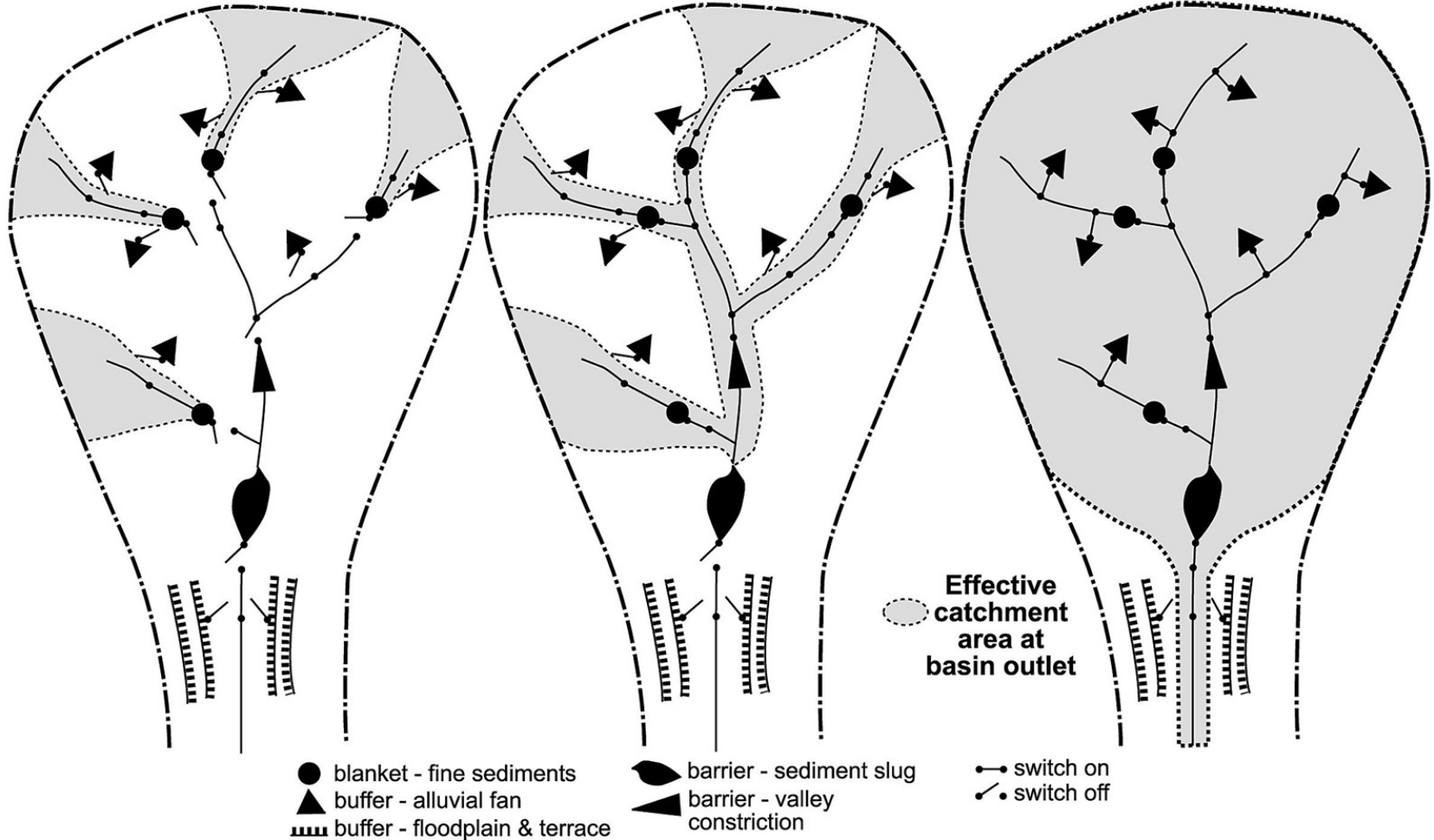


Figure 14.9 Magnitude–frequency relationships that fashion the operation of buffers, barriers and blankets that control effective timeframes and effective catchment areas of sediment flux. Changes to the effective catchment area and effective timescales of (dis)connectivity are depicted as a series of switches that are active or inactive under certain flow conditions. From Fryirs *et al.* (2007a). © Elsevier. Reproduced with permission.



Riverscapes span the network across a watershed

Riverscapes are the part of the landscape (*connected network*) that could **plausibly flood** by their rivers & streams in the contemporary natural flow regime.

... Includes **riparian floodplains** & **wetlands!**

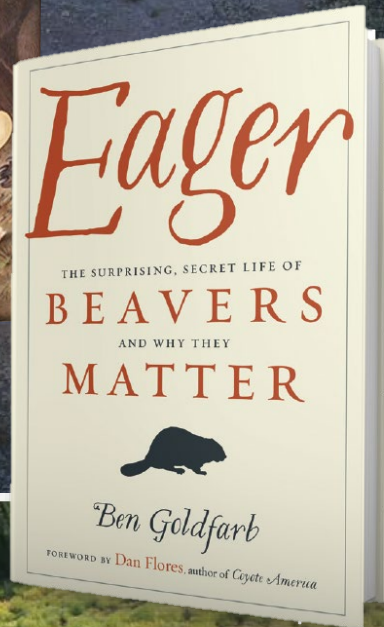
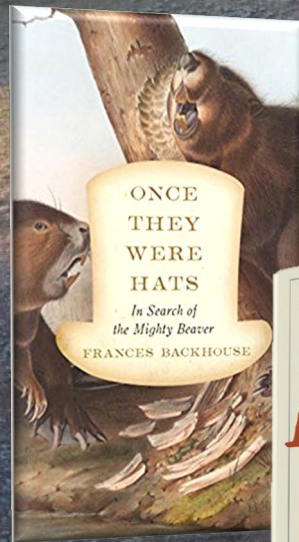
Riverscape (laterally) \approx valley bottom

“Riparian” only makes up 2% to 4% of most landscapes today...

But its potential (valley bottoms) make up 5% to 10% of most landscapes.

A

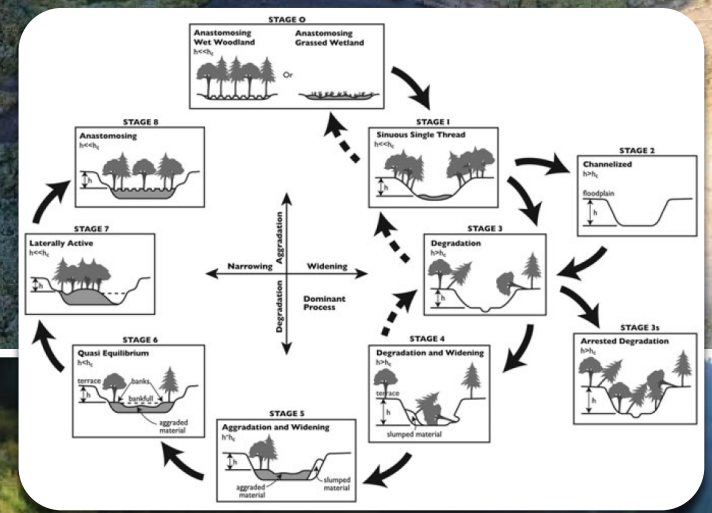
We forgot what valley bottoms could be & that **STAGE 0** was **NOT** an anomaly!



CC Joe Wheaton

E

Stage 0 or 8
Anastomosing



From: Cluer & Throne (2013)
DOI: [10.1002/rra.2631](https://doi.org/10.1002/rra.2631)

Adapted from Figure 1.7 (p 36) of Shahverdian et al. (2019) – Chapter 1 LTPBR Manual DOI: [10.13140/RG.2.2.14138.03529](https://doi.org/10.13140/RG.2.2.14138.03529)

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STAGE 0 ~ A MESS

Helping us articulate messy!

Photo credit: © Johan Hogervorst



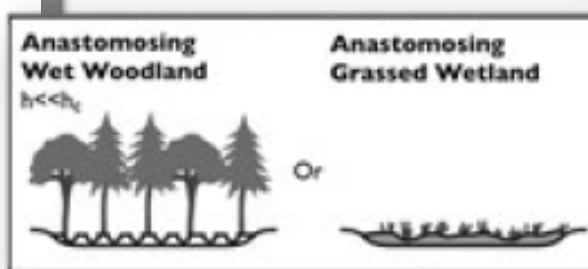
Joe Wheaton
@fluvialwheaton

Follow

Lots of fun #lowtechPBR talks here at #Watersheds2018. Thanks to Scott Gillilan and Mark Beardsley for the awesome Stage 0 riparian reconnect shirt!



© Mark Beardsley



RIVER RESEARCH AND APPLICATIONS
River Res. Applic., 12(1):3
Published online in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/rpa.1201

A STREAM EVOLUTION MODEL INTEGRATING HABITAT AND ECOSYSTEM BENEFITS

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¹Florida Geomorphological Solutions Center, NOAA's National Marine Fisheries Service, Santa Rosa, California, USA
²Chair of Physical Geography, University of Nottingham, Nottingham, UK

ABSTRACT
In decades, Channel Evolution Models have provided useful templates for understanding morphological responses to disturbance associated with lowered base level, channelization or alterations in the flow and/or sediment regimes. The proposed Stream Evolution Model (SEM) is revised and updated in light of recent research and practical experience. The proposed Stream Evolution Model (SEM) is revised and updated in light of recent research and practical experience. The proposed Stream Evolution Model (SEM) is revised and updated in light of recent research and practical experience. The proposed Stream Evolution Model (SEM) is revised and updated in light of recent research and practical experience.

INTRODUCTION
It is now generally accepted that river engineering and management that works with rather than against natural processes is more likely to sustain and sustain the multi-functional goals (e.g. land drainage, flood risk management, fisheries, conservation, biodiversity, and recreation) demanded by local stakeholders and society more widely (Wolff et al., 2005; Thorne et al., 2010). This, coupled with growing recognition that the range and value of ecosystem services provided by rivers increase with the degree to which they are allowed to function naturally, fuels the drive for restoration of fluvial systems degraded by past management and engineering actions that have proven, in the long term, to be unsustainable (Palmer et al., 2005).
However, complete restoration of a river to some former condition is seldom possible, not always desirable (Downs and Gregory, 2004), and deciding whether partial restoration, rehabilitation or environmental enhancement is the best way to treat a damaged stream raises fundamental questions for river managers responsible for achieving increased biodiversity or the protection and recovery of endangered species. Specifically, serious questions arise concerning the nature of the pre-disturbance condition to which a given river should be restored, the likely sequence (and habitat impacts) of channel adjustments associated with post-project evolution and the merits of restoring the river to some former condition rather than facilitating, or even enhancing, its progression to a configuration that, in fact, better adjusted to the prevailing hydrological and sediment regimes and, second, more resilient to the unavoidable impacts of future climate change and/or land use.

In this paper, these questions are addressed by:
1. revisiting well-established Channel Evolution Models (CEMs) for streams that respond to disturbance through incision;
2. updating these CEMs in light of recent research, including on pre-disturbance channel forms in Europe and North America, to propose a more broadly based Stream Evolution Model (SEM);
3. linking the evolutionary stages of channel adjustment to indicators of habitat and lotic ecosystem benefits and

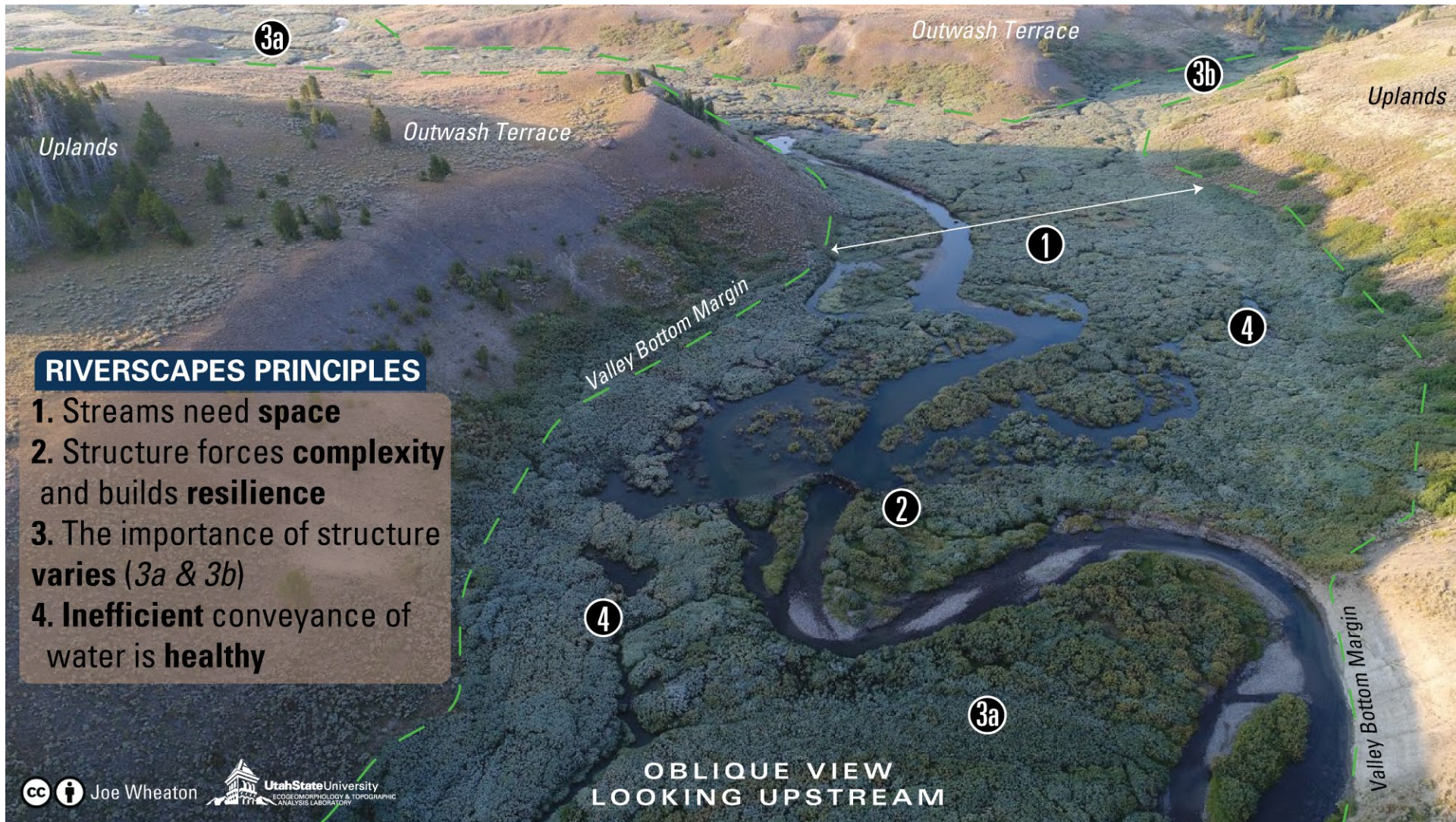
*Correspondence to: B. Cluer, Florida Geomorphological Solutions Center, NOAA's National Marine Fisheries Service, 777 Santa Rosa Ave., Suite 225, Santa Rosa, California 95404, USA.
E-mail: bcluer@noaa.gov

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EcoMetrics
Stream and Riparian Monitoring, Assessment and Restoration

What constitutes a healthy riverscape?



CC i Joe Wheaton



Utah State University
EDGEOMORPHOLOGY & TOPOGRAPHIC
ANALYSIS LABORATORY

From pages 3-4 of Pocket Guide; Wheaton et al. (2019)

DOI: [10.13140/RG.2.2.28222.13123/1](https://doi.org/10.13140/RG.2.2.28222.13123/1)

See Wheaton et al. (2019, p 60): Chapter 2 LTPBR Manual for Principles

DOI: [10.13140/RG.2.2.34270.69447](https://doi.org/10.13140/RG.2.2.34270.69447)

Riverscapes Principles

INEFFICIENT CONVEYANCE OF WATER IS HEALTHY RIVERSCAPES PRINCIPLE 4.

Hydrologic inefficiency is the hallmark of a healthy system. More diverse residence times for water can attenuate potentially damaging floods, fill up valley bottom sponges, and slowly release that water later elevating baseflow and producing critical ecosystem services.

Adapted from figure 2.3 from Wheaton et al.
(2019, p 62)

Chapter 2 LTPBR Manual for Principles

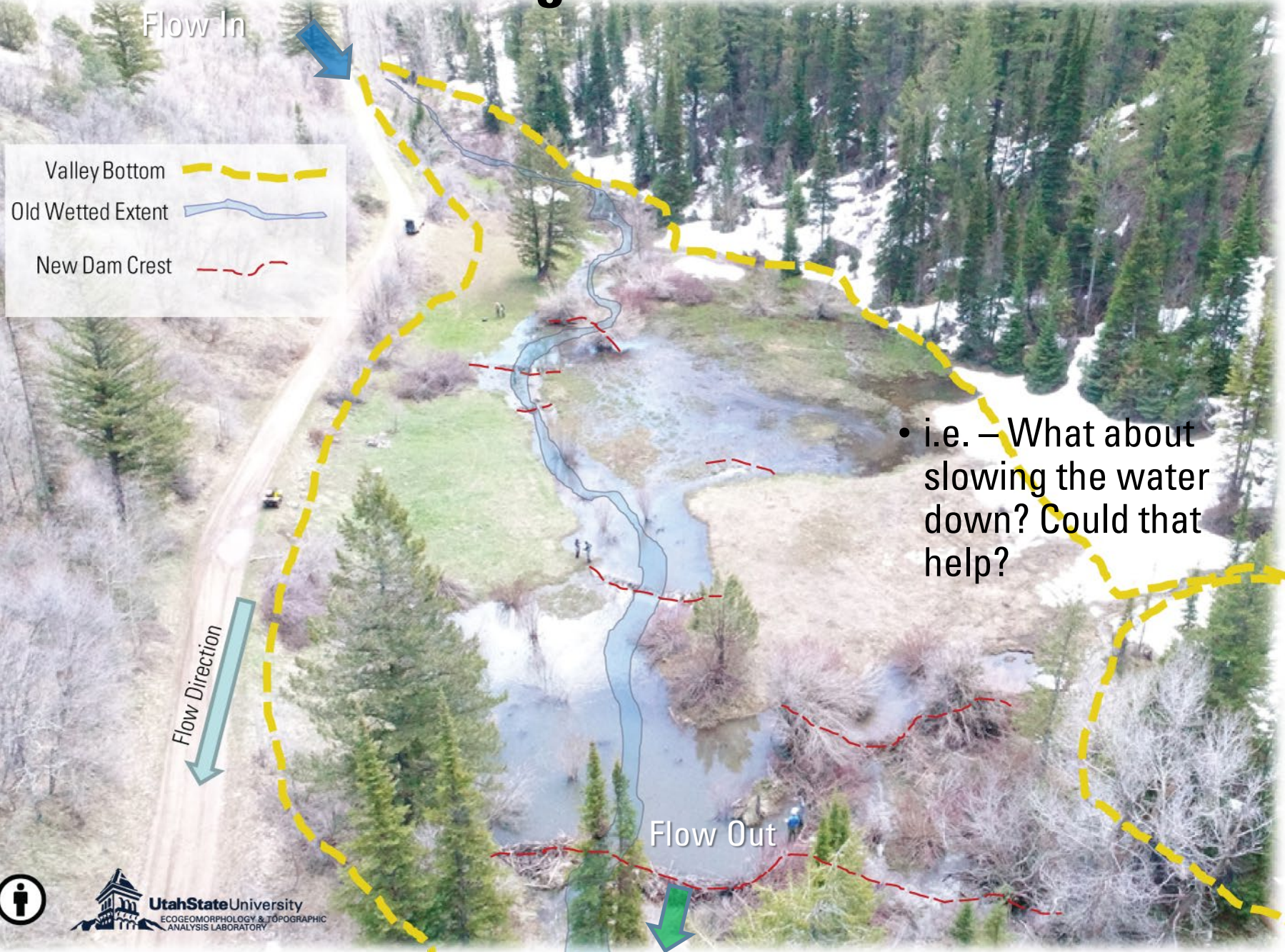
DOI: [10.13140/RG.2.2.34270.69447](https://doi.org/10.13140/RG.2.2.34270.69447)

Which one wins race? Efficient or Inefficient?



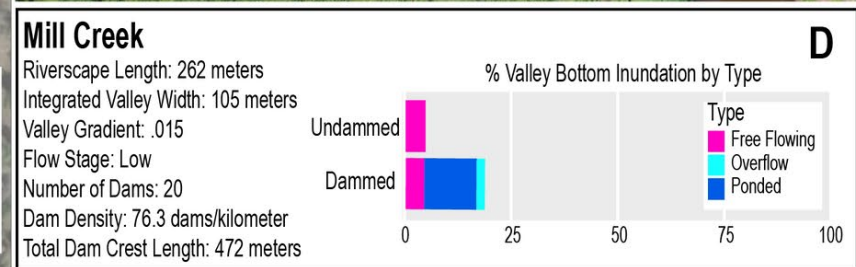
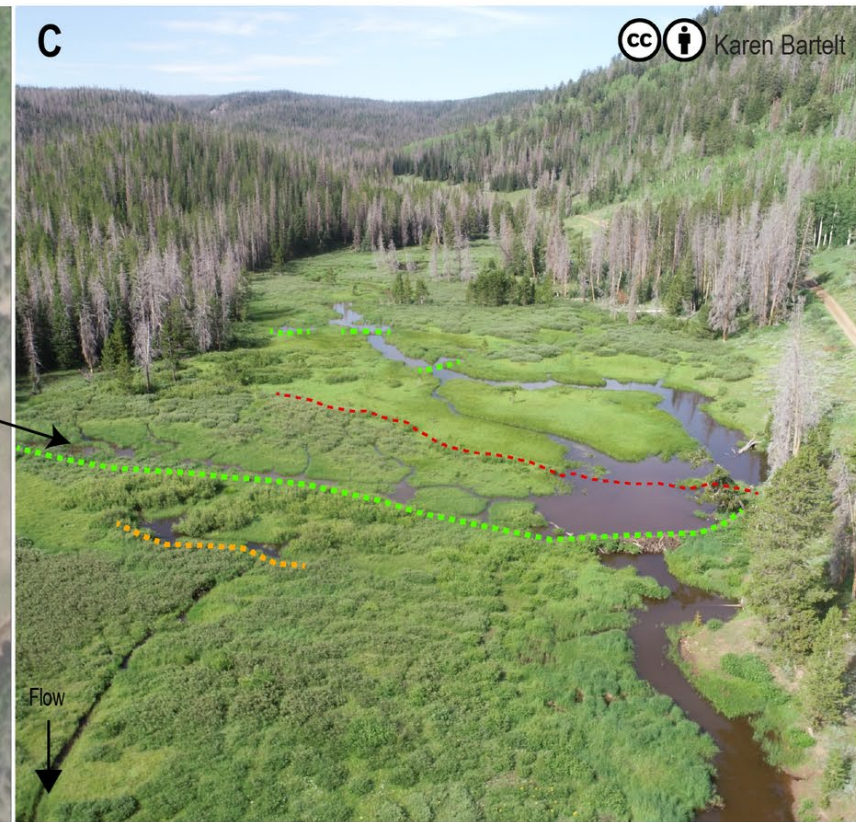
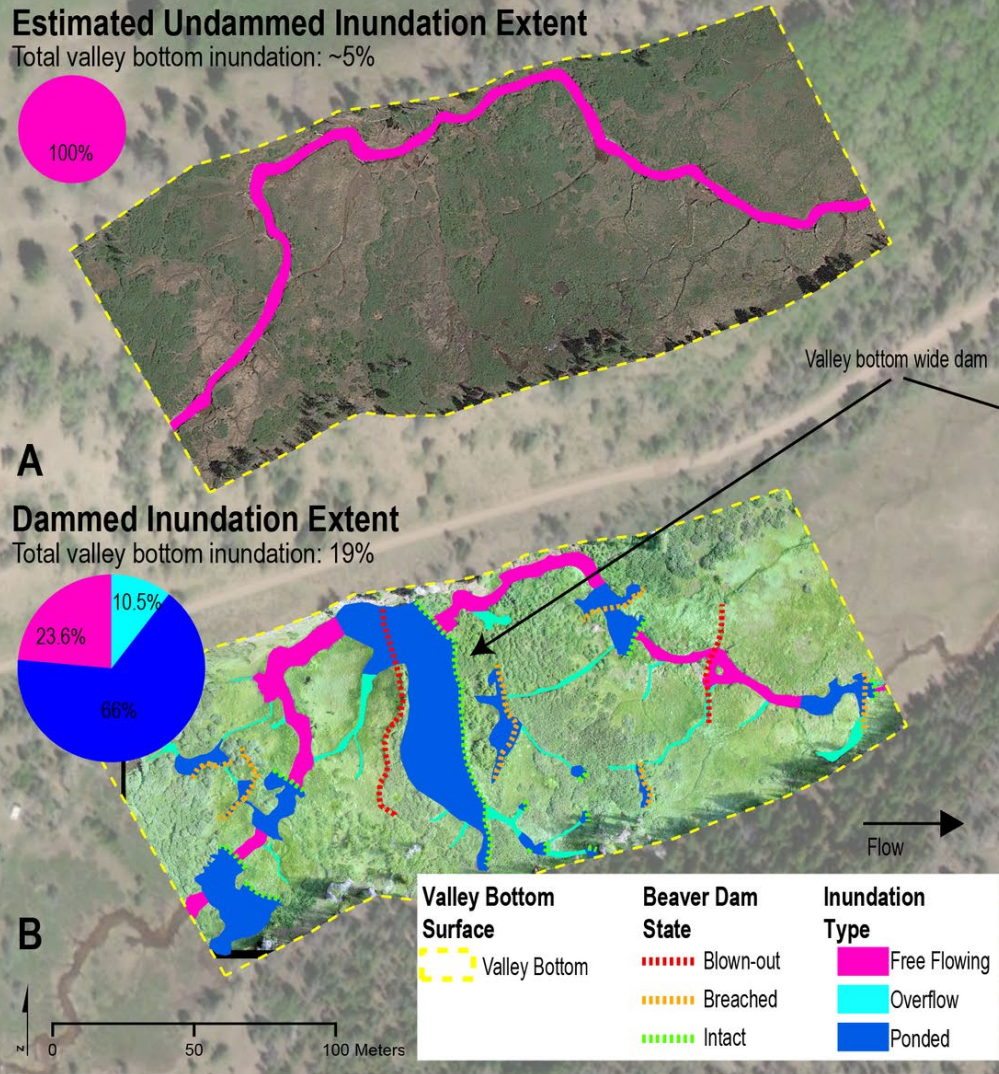
OBLIQUE VIEW
LOOKING UPSTREAM

How Does Flow Change With Dams?



Structural forcing produced most of these wetlands

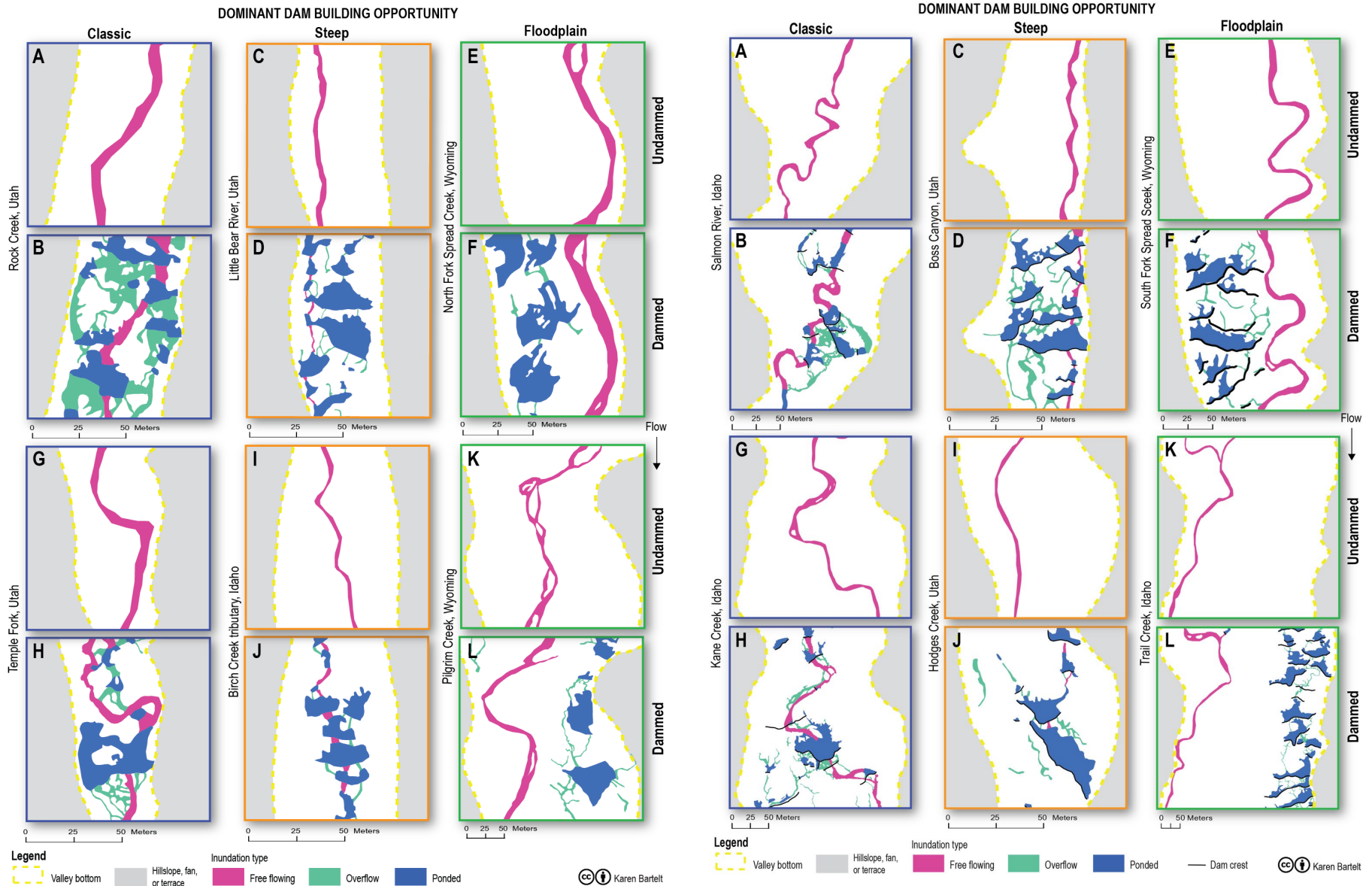
CC BY Karen Bartelt



- Diverse flow types buy greater proportion inundation

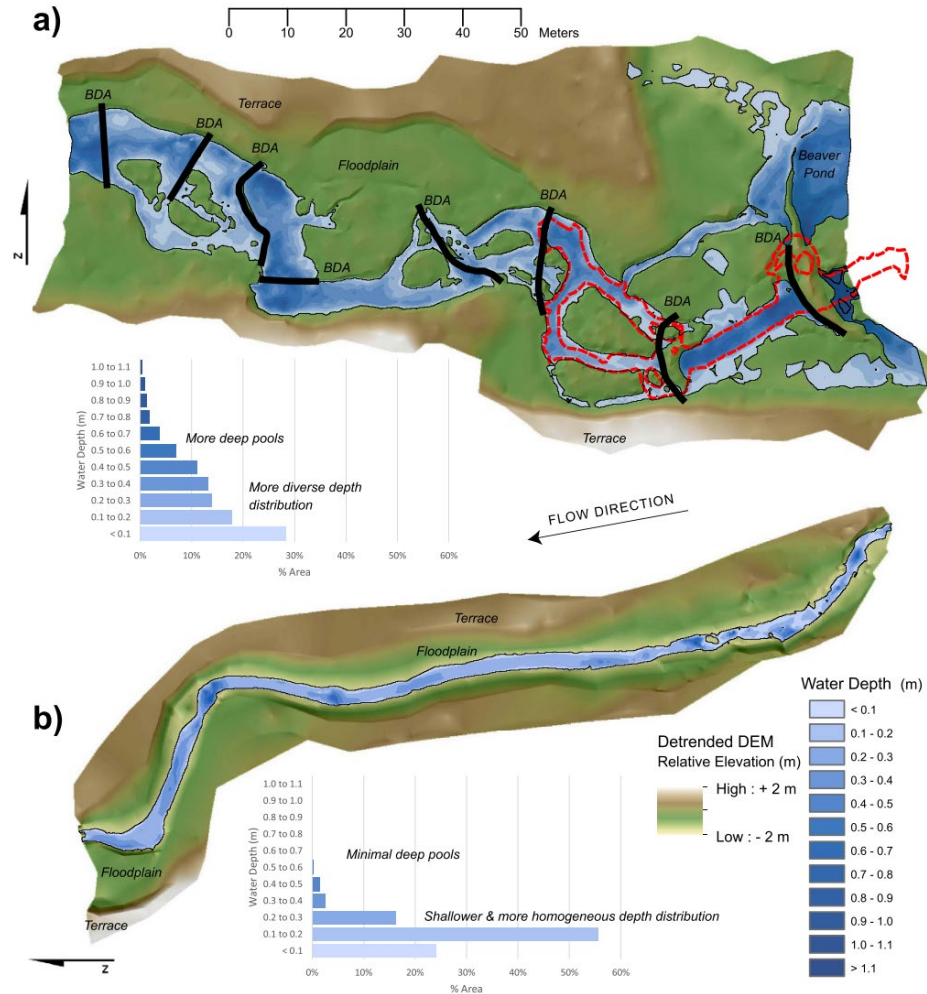
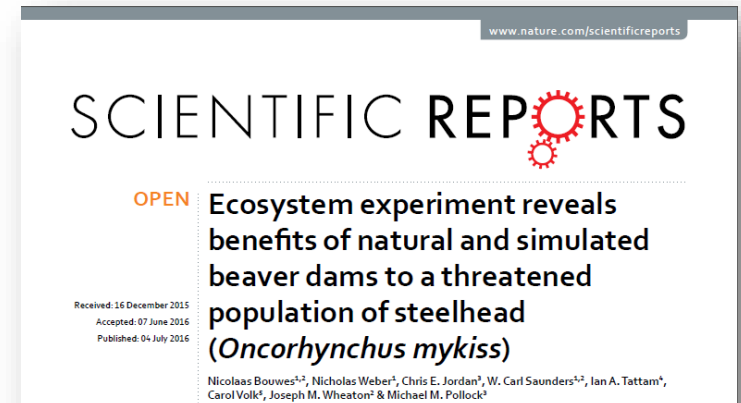
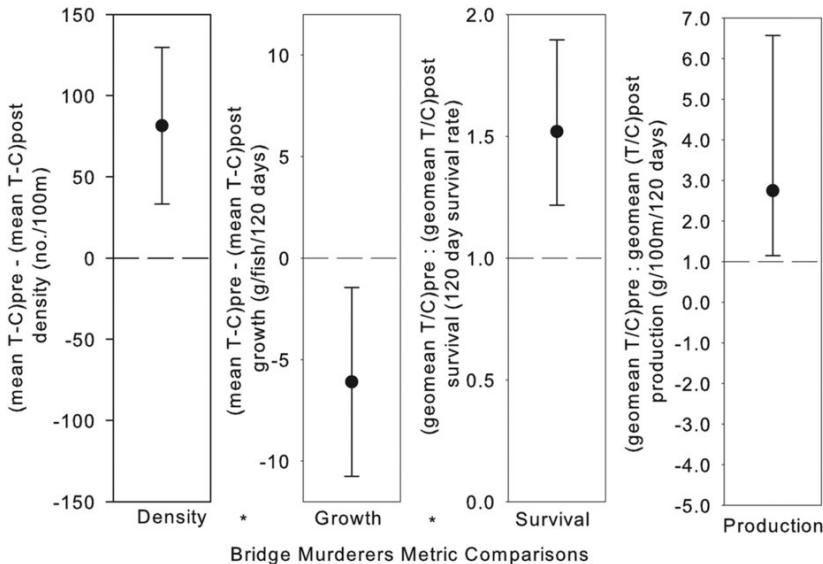
How common?

- On average increase of riverscape inundation from 7% to 23% of valley bottom at same baseflow



Habitat quality matters, but quantity matters more to fish & The Water Magic Trick

- Restoration using BDAs & beaver as restoration agent produced a population level increase in density, survival and production of ESA listed salmon



Contrasting (dis)Connectivity

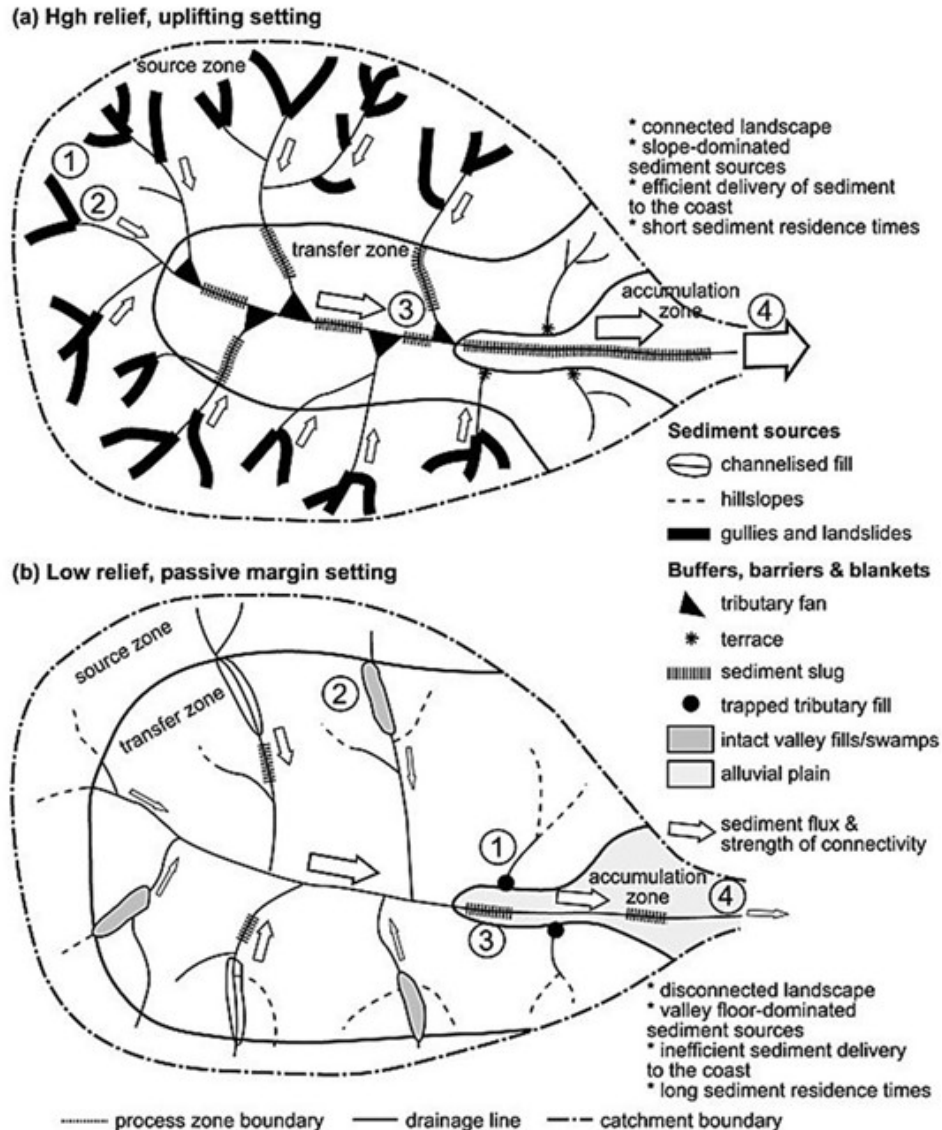
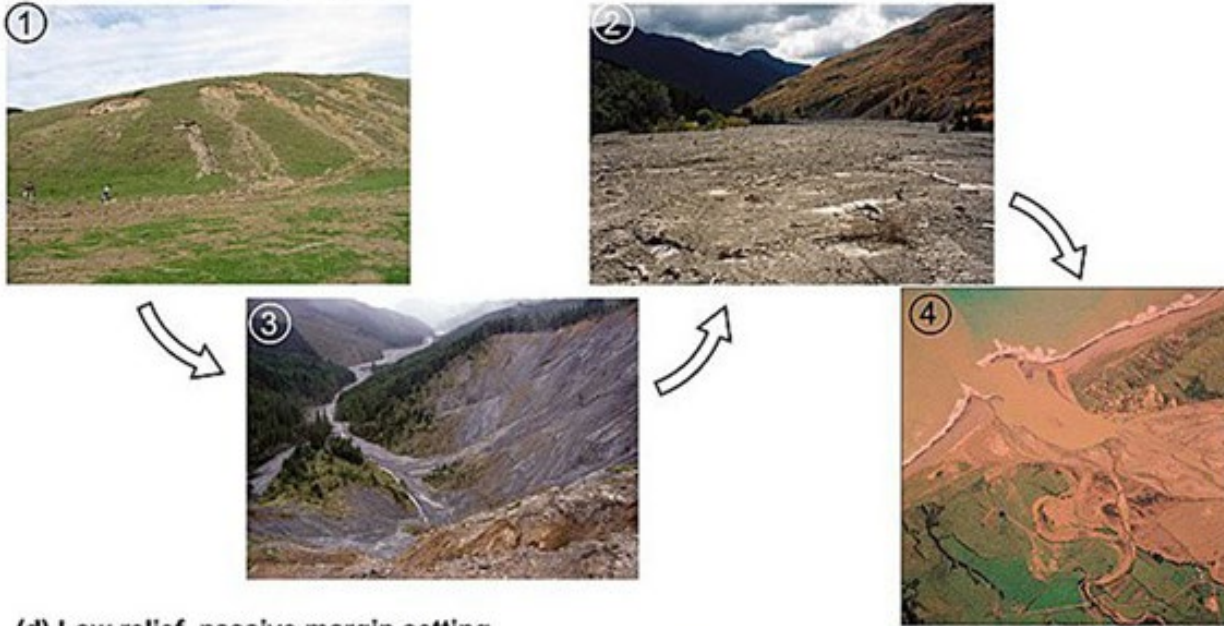


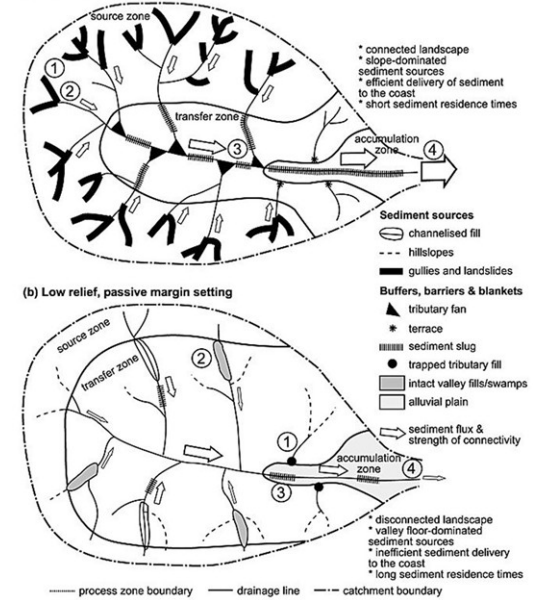
Figure 14.13 Generalised patterns of (dis)connectivity in sediment flux in high-relief, uplifting terrains versus low-relief, passive-margin settings. (a, c) Catchments in high-relief, uplifting terrains such as New Zealand tend to have high drainage densities. Steep headwater (sediment source) zones are transitional to very efficient transfer zones and expansive lowland plains. Within the source zones, significant volumes of material are supplied from hillslope gully complexes and landslides. These materials are transferred as sediment slugs along the tributary and trunk stream network. Along the lowland plains, sediments are effectively evacuated from the catchment. Overall, the degree of catchment connectivity is high and sediment delivery to the river mouth is high. The timeframe of geomorphic recovery is relatively short, as large parts of catchments are recurrently connected. (b, d) Catchments in low-relief, passive-margin settings such as Australia tend to have low drainage densities and subdued topography. Significant sediment stores buffer and disconnect sediment conveyance through the system. Recent sediment flux is dominated by reworking of materials from valley floor stores. Overall, there is significant disconnectivity and sediment delivery ratios at the basin mouth are low. At the continental scale, only 20% of the total load to Australian rivers is exported to the coast. Around 90% of the river sediment load is generated from only 20% of the contributing catchment area; that is, effective catchment areas are small. Once disturbed, timeframes for recovery may be very long (i.e. centuries or millennia) because of sediment exhaustion. Modified from Fryirs *et al.* (2007a). © Elsevier. Reproduced with permission.

Contrasting (dis)Connectivity

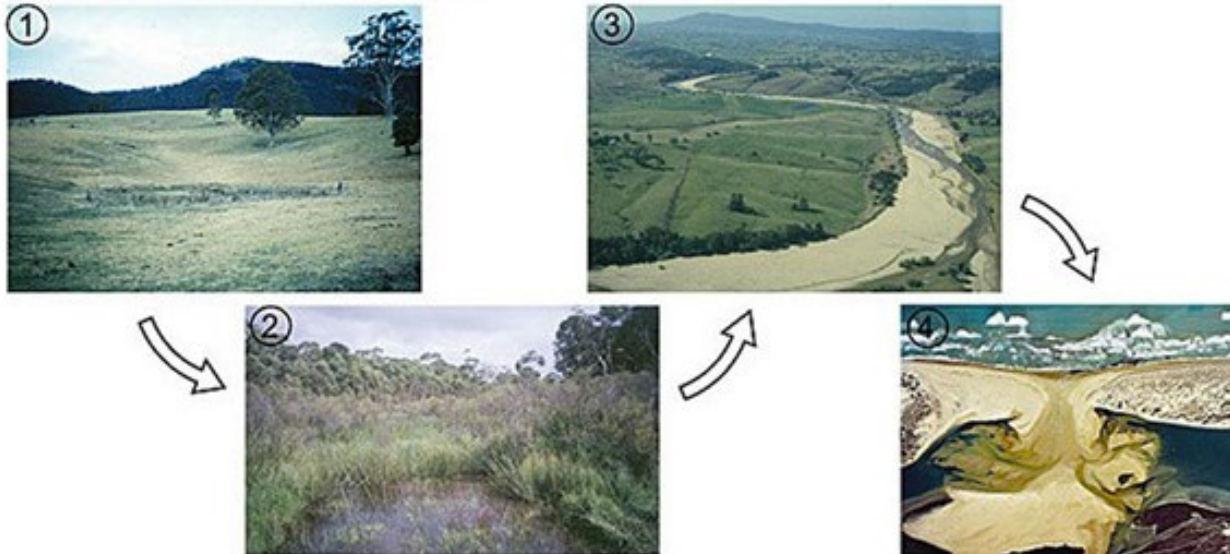
(c) High relief, uplifting setting



(a) High relief, uplifting setting



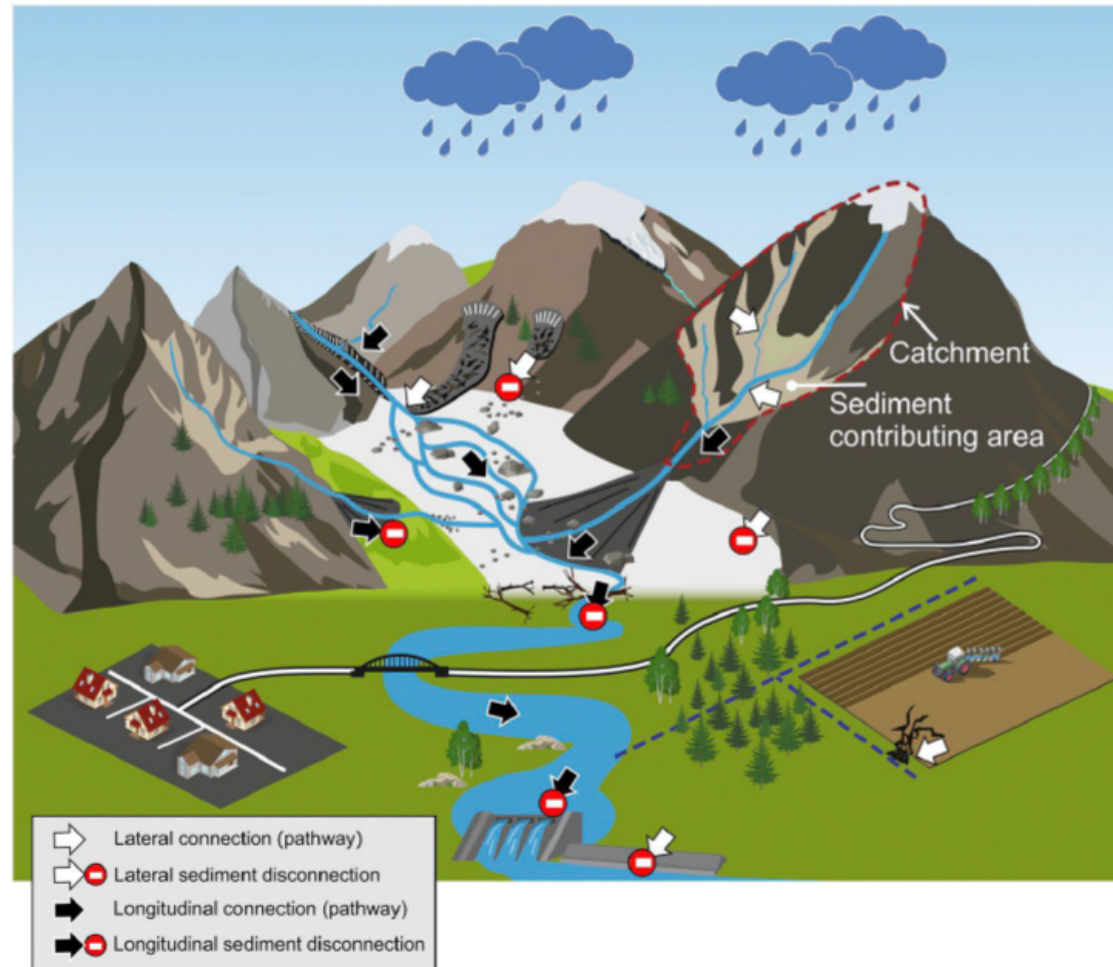
(d) Low relief, passive margin setting



Sediment Connectivity



- ✓ “Hydrological and sediment connectivity: the degree to which a system facilitates the transfer of water and sediment through itself, through coupling relationships between its components. In this view, connectivity becomes an emergent property of the system state, reflecting the continuity and strength of runoff and sediment pathways at a given point in time.” (Heckmann et al., 2018)
- ✓ **Structural connectivity** represents the spatial configuration of system components
- ✓ **Functional connectivity** is inferred from the actual transfer of water and sediment, i.e. the system’s process dynamics



Heckmann T., Cavalli M., Cerdan O., Foerster S., Javaux M., Lode E., Smetanova A., Vericat D., Brardinoni B., 2018. Indices of sediment connectivity: opportunities, challenges and limitations. *Earth-Science Reviews*, 187, 77-108. DOI: 10.1016/j.earscirev.2018.08.004.



In mountain catchments, sediment supply to downstream areas is often due to spatially limited sediment source areas where geomorphic processes occur with high intensity.



Strimm Creek



Geomorphic coupling (linkages between geomorphic system components), and sediment connectivity have become key issues in the study of sediment transfer processes.

Coupling



Decoupling



Geomorphometric approach for the assessment of sediment connectivity

The connectivity index (IC) is computed using two components:

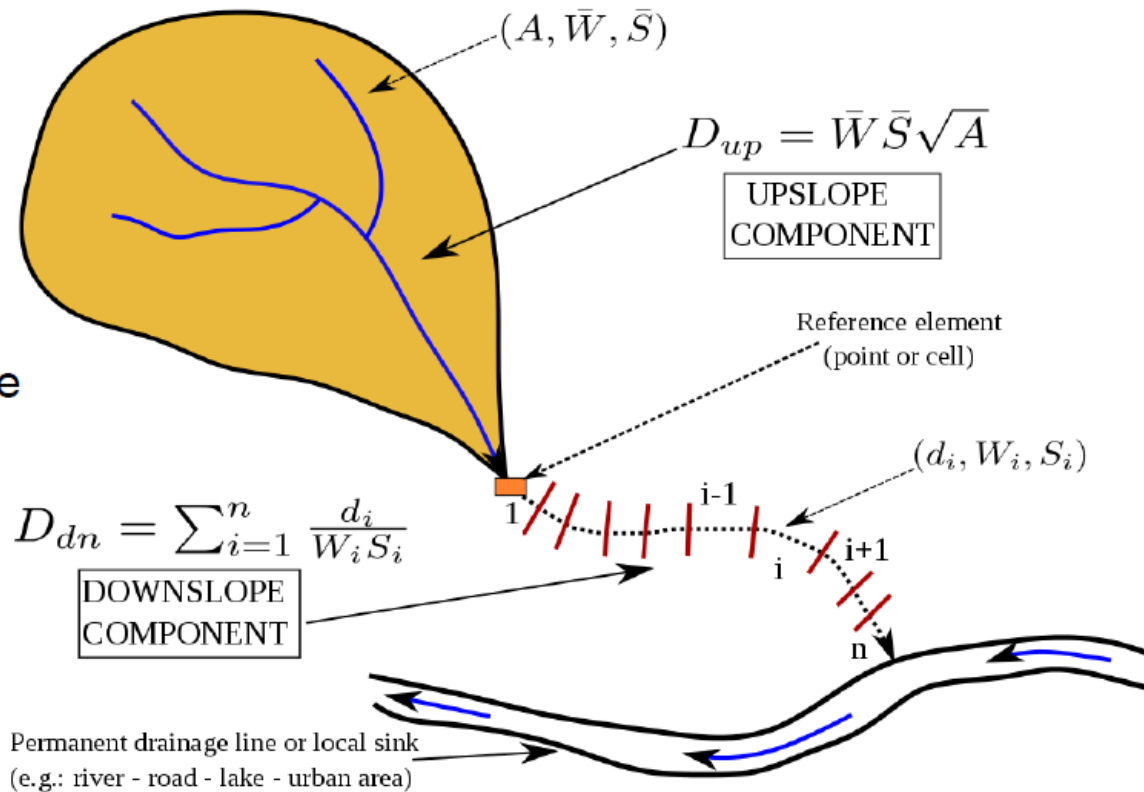
Upslope component D_{up}

potential for downward routing due to upslope area, mean slope and impedance factor.

Downslope component D_{dn}

flow path length that a particle has to travel to arrive to the nearest target or sink.

$$IC = \log_{10} \left(\frac{D_{up}}{D_{dn}} \right)$$



Borselli L., Cassi P., Torri D., 2008. Prolegomena to sediment and flow connectivity in the landscape: a GIS and field numerical assessment. *Catena*, 75(3), 268-277.

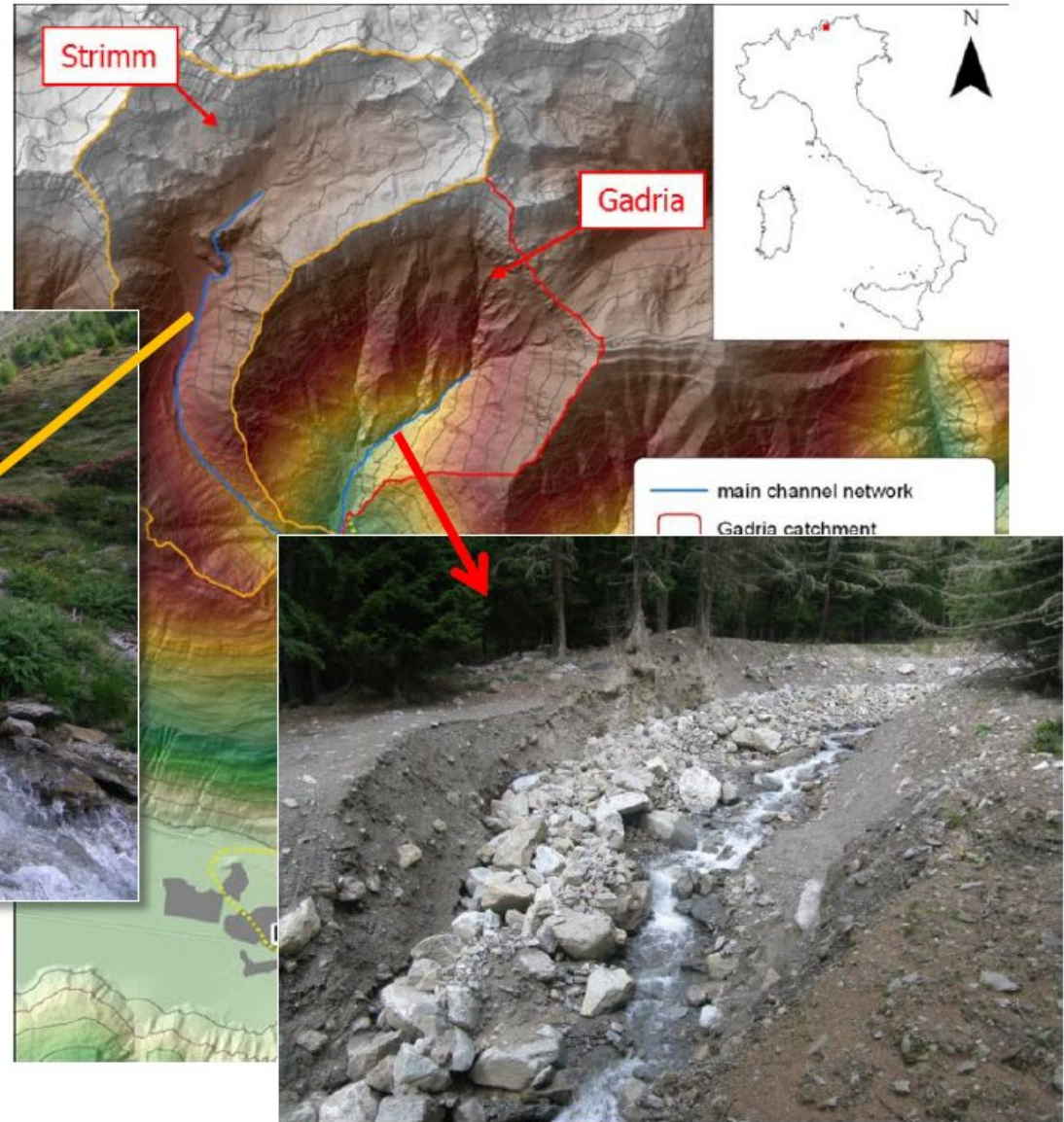
Cavalli M., Trevisani S., Comiti F., Marchi L., 2013. Geomorphometric assessment of spatial sediment connectivity in small alpine catchments. *Geomorphology*, 188, 31-41.

Gadria and Strimm catchments (Eastern Italian Alps)

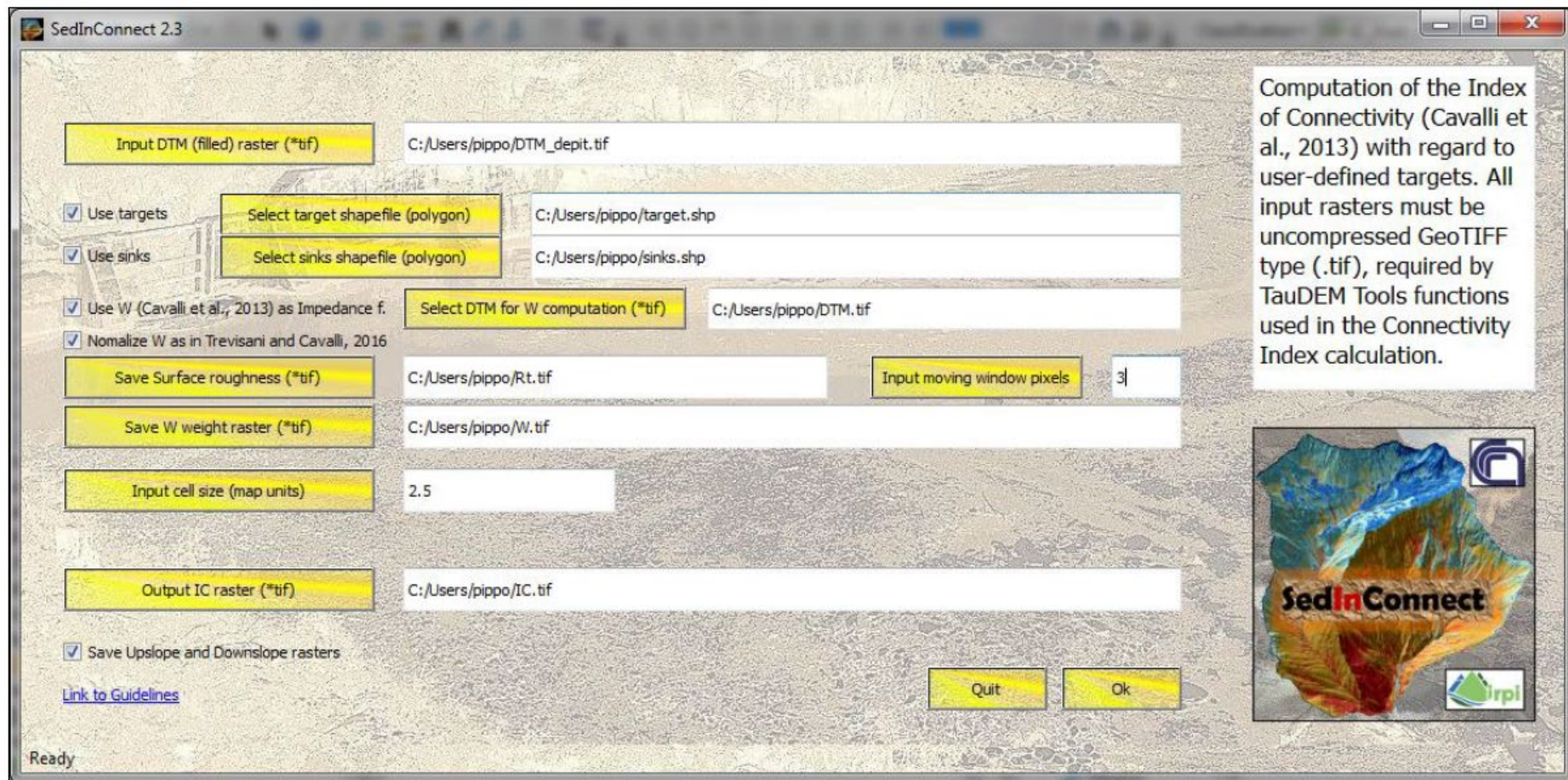
Lithology: mica-schist, gneiss.



range in elevation 1394 – 3197
m.



Open-source implementation (SedInConnect 2.3) (Crema & Cavalli, 2018)

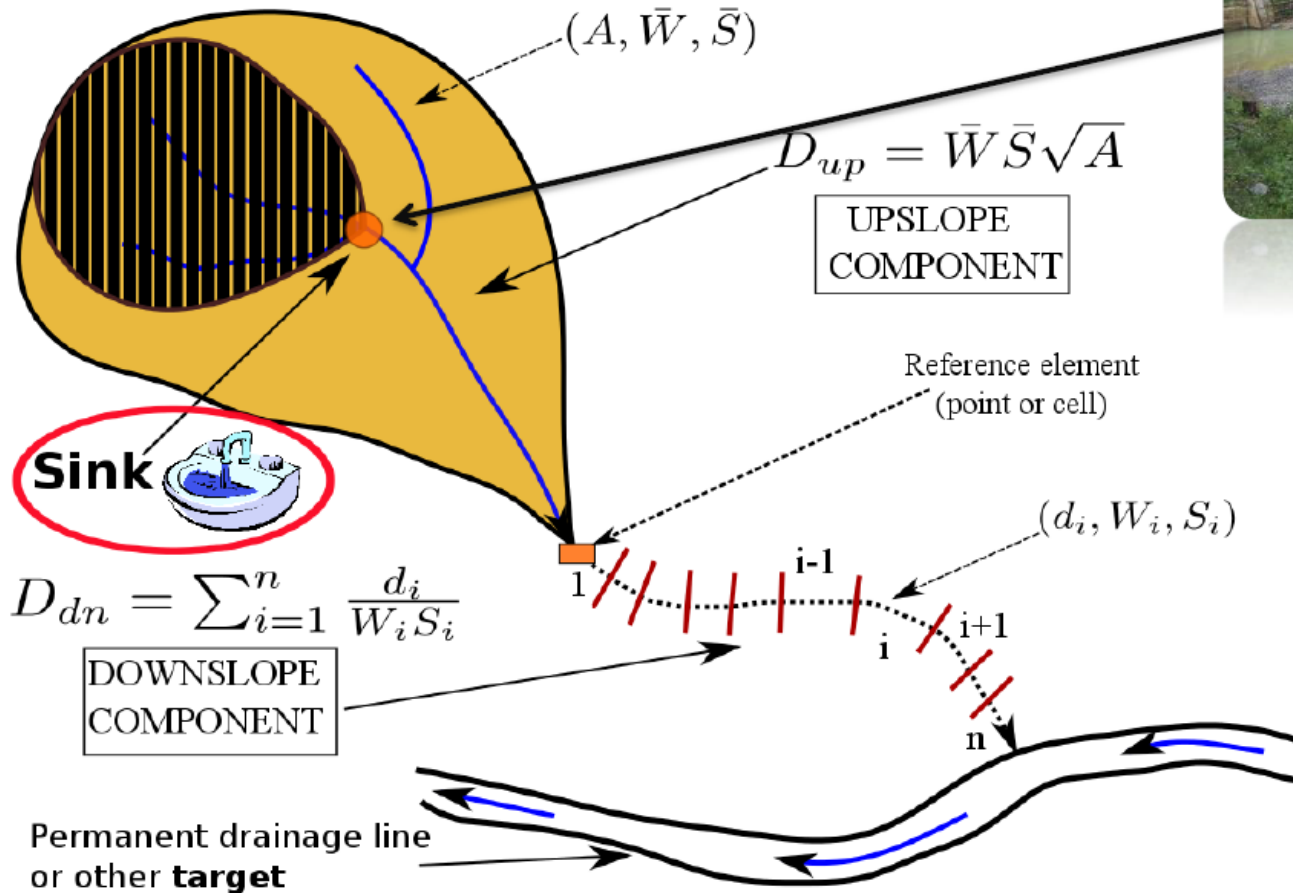


- It avoids the use of commercial GIS;
- It implements the “Sink” function.

https://github.com/HydrogeomorphologyTools/SedInConnect_2.3

<http://www.sedalp.eu/download/tools.shtml>

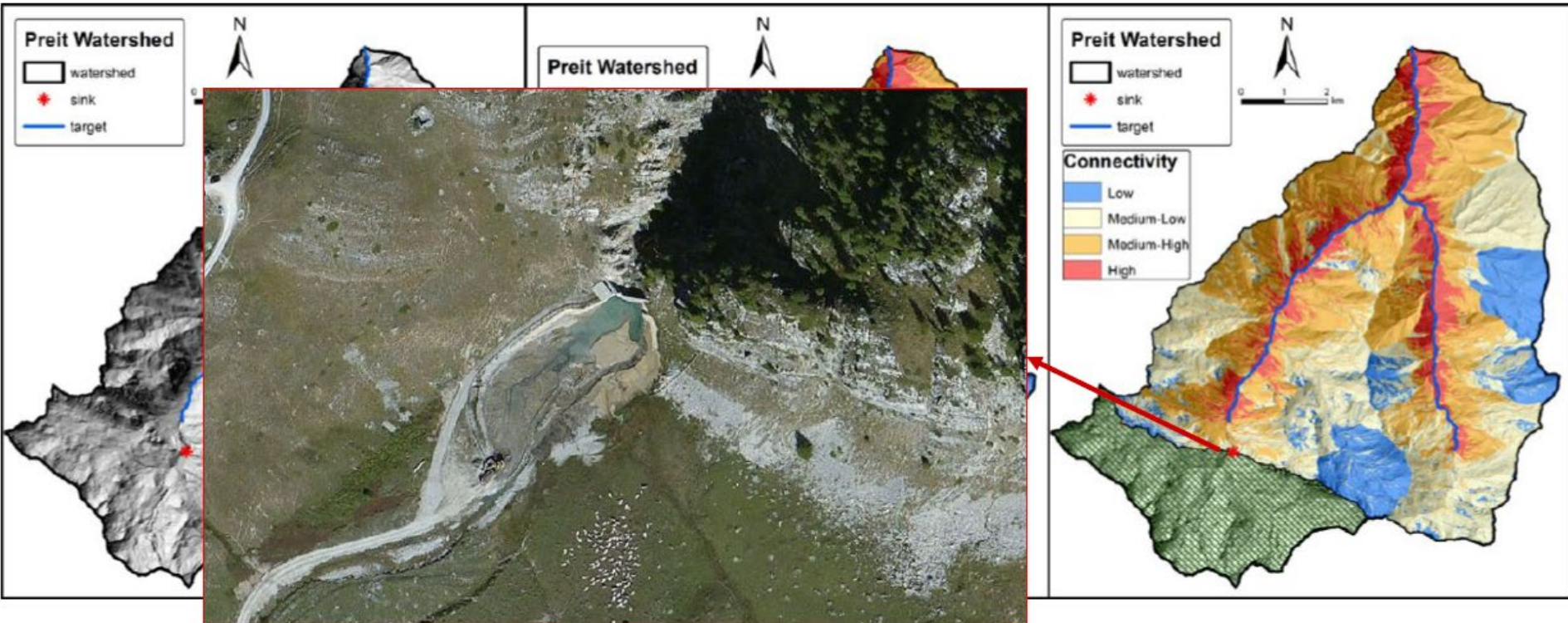
How *sink* feature works?



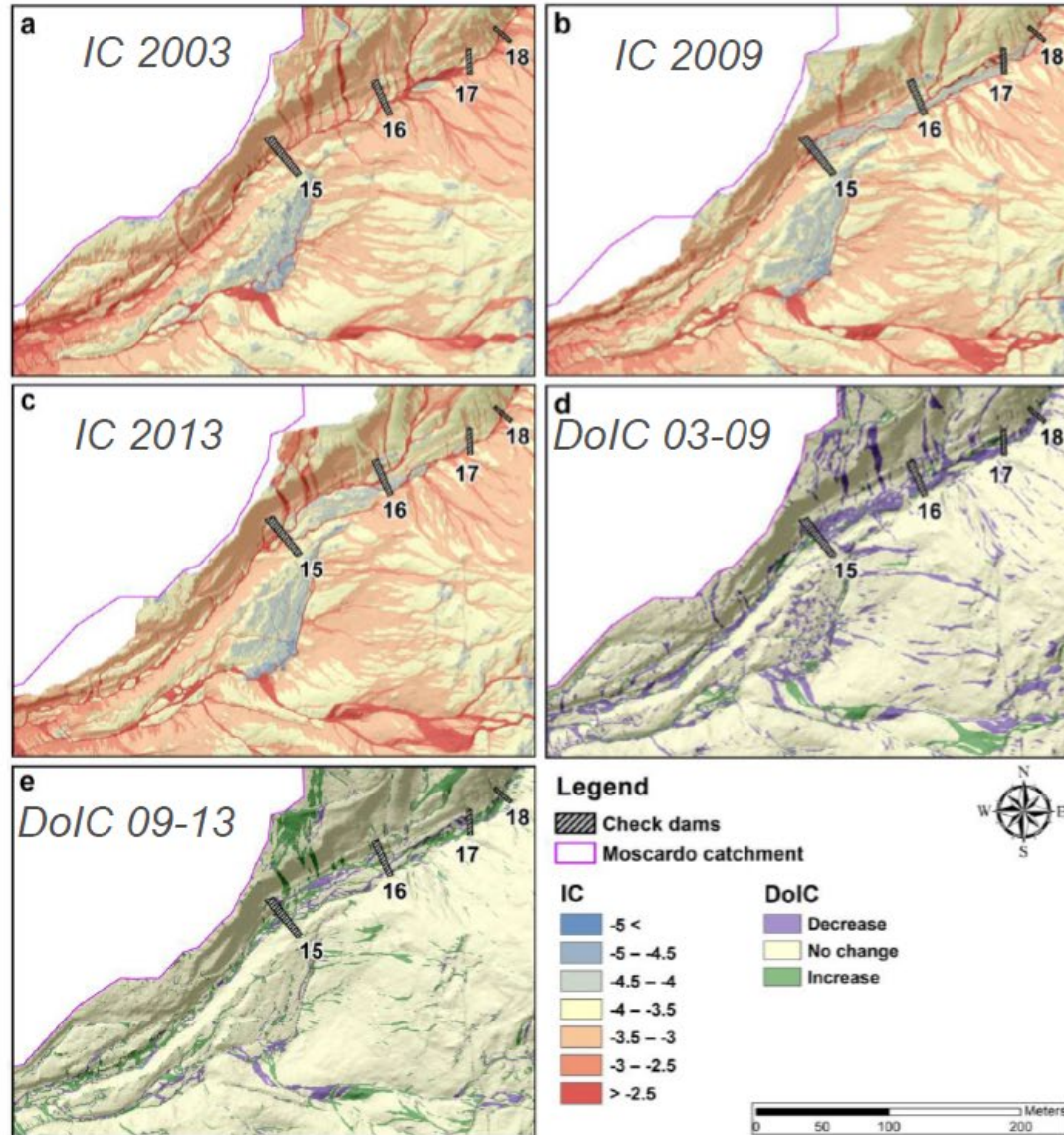
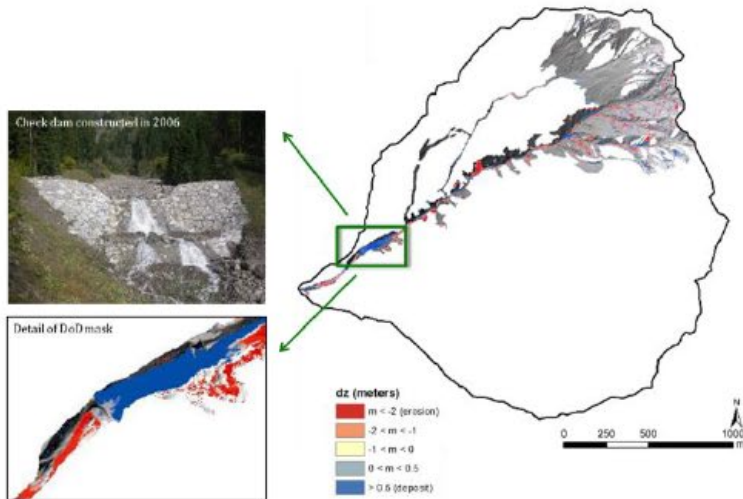
Aim: modeling those features that can act as sink in respect to the sediment connectivity (fluxes)



Sink feature

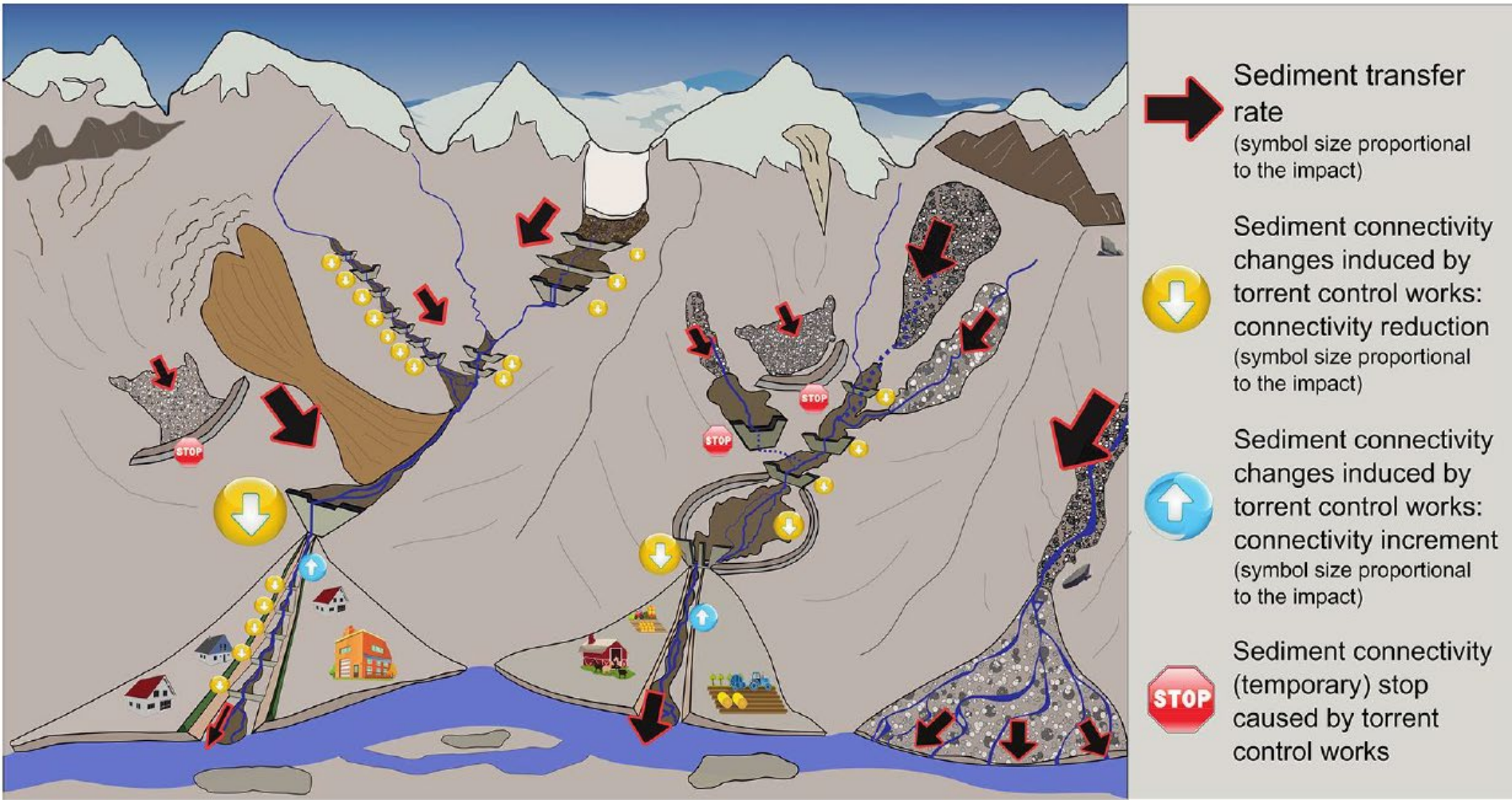


- Understand the check dams' effects on sediment dynamics in a debris flow catchment at different spatial scales;
- Integration of DoD and IC analyses over time.



Cucchiaro S., Cazorzi F., Marchi L., Crema S., Beinat A., Cavalli M., 2019. Multi-temporal analysis of the role of check dams in a debris-flow channel: Linking structural and functional connectivity. *Geomorphology*, 345, 106844.

- Impacts of channel control works on coarse sediment connectivity within catchments and on alluvial fans



Marchi L., Comiti F., Crema S., Cavalli M., 2019. Channel control works and sediment connectivity in the European Alps. *Science of The Total Environment*, 668, 389-399.

Monitoring Sediment Flux



From Simone Bizzi



1222-2022
800
ANNI



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DEGLI STUDI
DI PADOVA



DIPARTIMENTO
DI GEOSCIENZE

Monitoring contemporary channel geomorphological processes and sediment transport at the network scale by the use of low cost drones and satellites

Simone Bizzi, Ph.D.

Assistant Professor,

Department of Geosciences,

University of Padova

Coauthors: Barbara Belletti , Rafael Schmitt, Hervé Piegay , Francesco Asaro , Martina Bussettini , Patrice Carbonneau, Marco Casaioli , Andrea Castelletti , Matt Kondolf, Barbara Lastoria , Giulia Marchetti, Stefano Mariani ,Marco Micotti, Claudio Prati.



POLITECNICO
MILANO 1863

Workshop Regionalized fluvial geomorphology

18th and 19th December

Irstea Lyon-Villeurbanne Center



Stanford
WOODS
INSTITUTE for the
ENVIRONMENT

Berkeley
UNIVERSITY OF CALIFORNIA



ISPRA
Istituto Superiore per lo Studio e la Ricerca Ambientale

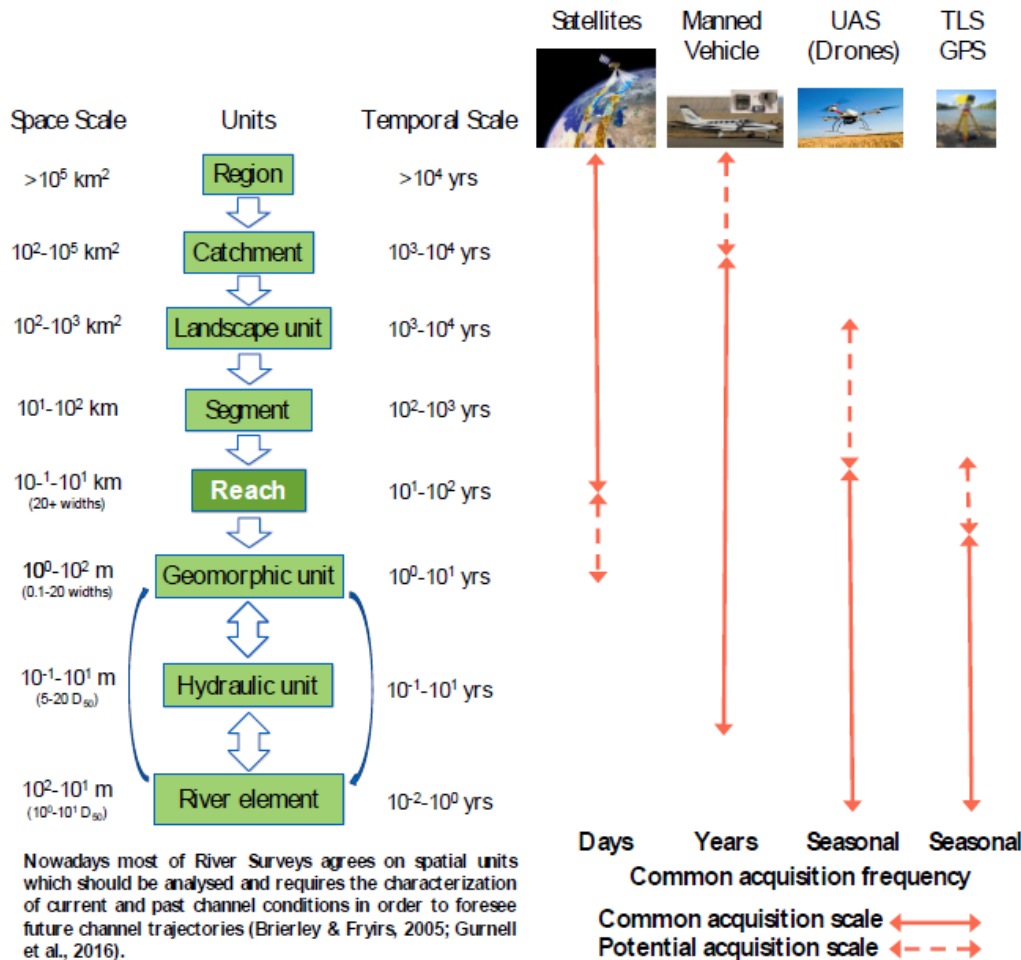


Istituto Nazionale
per la Protezione
dell'Ambiente

Durham
University

We can measure this stuff at multiple spatio-temporal scales

(Emerging) Remote Sensing technology



Article

The trajectory of geomorphology

Michael Church
The University of British Columbia, Canada



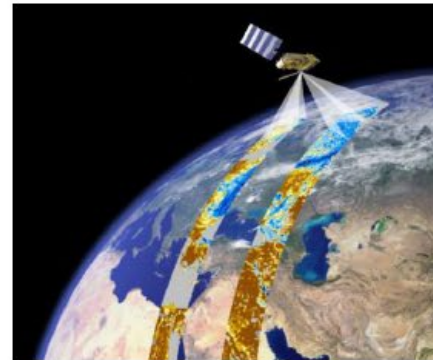
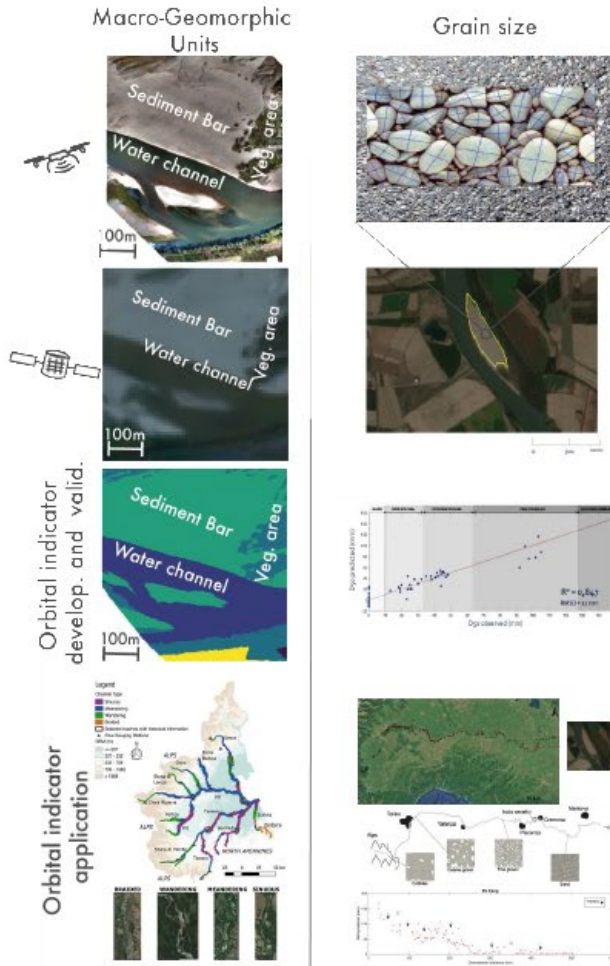
“Toward the end of the twentieth century the subject was dramatically transformed by improved technologies for remote sensing and surveying of Earth’s surface, the advent of personal computation and of large-scale computation, and important developments of absolute dating techniques. These technical innovations in turn promoted recognition of geomorphology as a ‘system science’ ...”

Remotely Sensed Rivers in the Anthropocene:
State of the Art and Prospects

H. Piégay¹, F. Arnaud¹, B. Belletti², M. Bertrand³, S. Bizzi⁴, P. Carboneau⁵, S. Dufour⁶, F. Liebault⁷, V. Ruiz-Villanueva^{1,7}, L. Slater⁸

Becoming Increasingly Cost-Effective

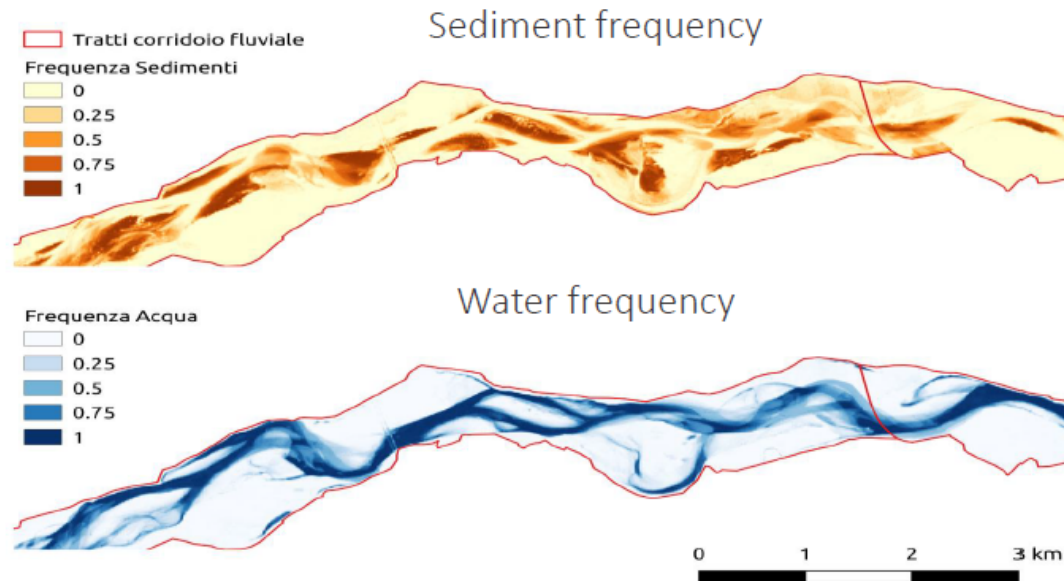
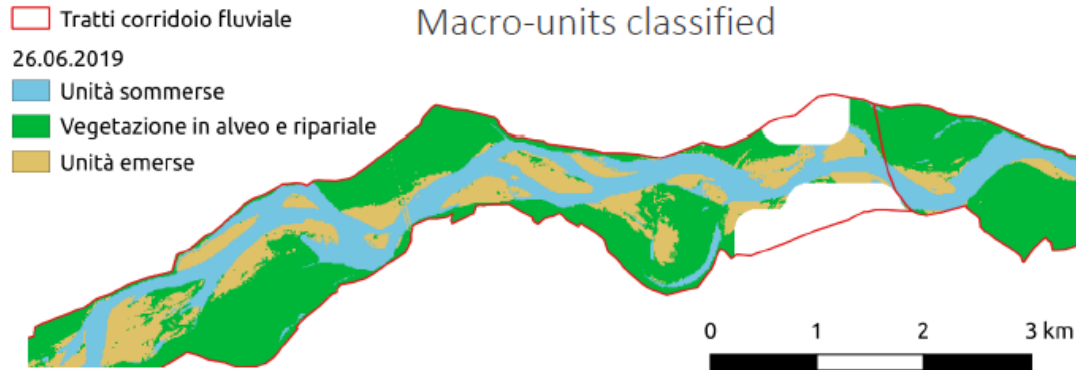
Low cost global river monitoring



From Simoni Bizzi

<http://cascade.deib.polimi.it/>

Your Building Blocks – Gus... through time

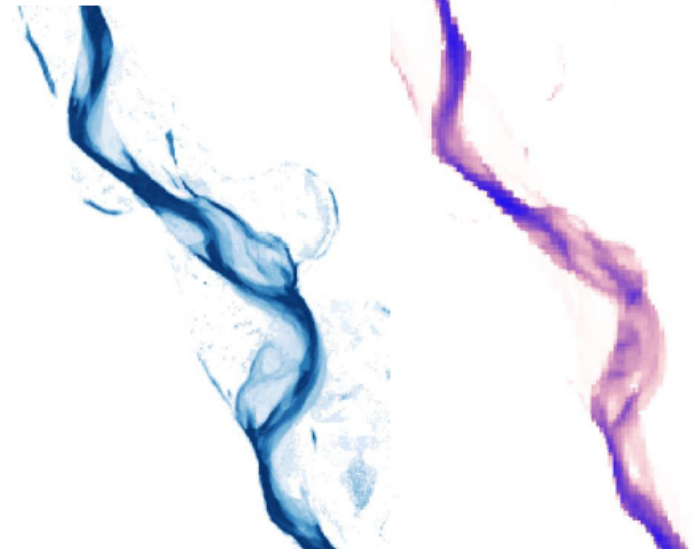


Sentinel 2 Classifier

We classified from Nov 2015 to Oct 2016
macro-units within the river corridor and
generated frequency layers

IRIS Project,
Four years, 10m Resolution

<https://global-surface-water.appspot.com/>
global surface water over the past 32 years
at 30-metre resolution (Landsat)
Peker et al., Nature, 2016

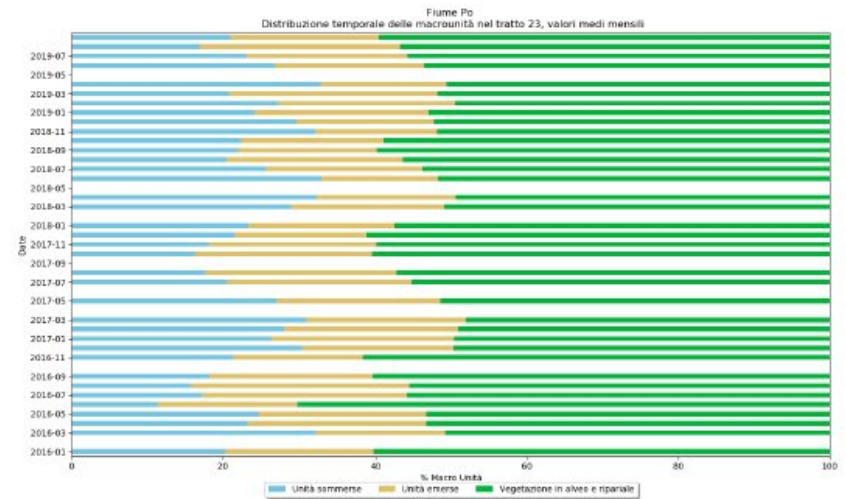
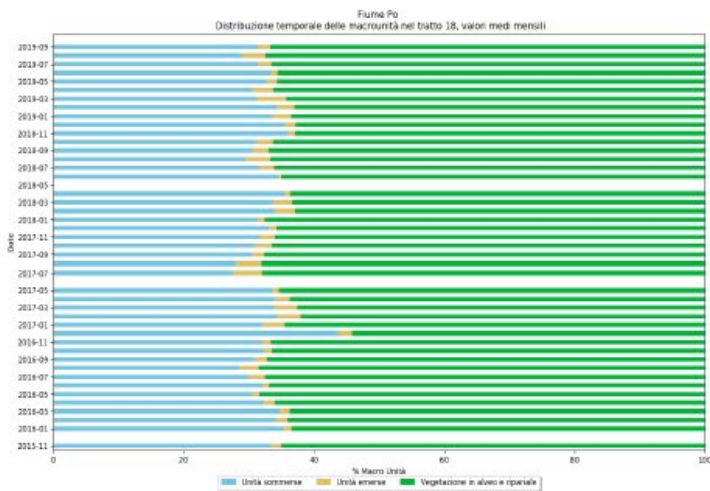
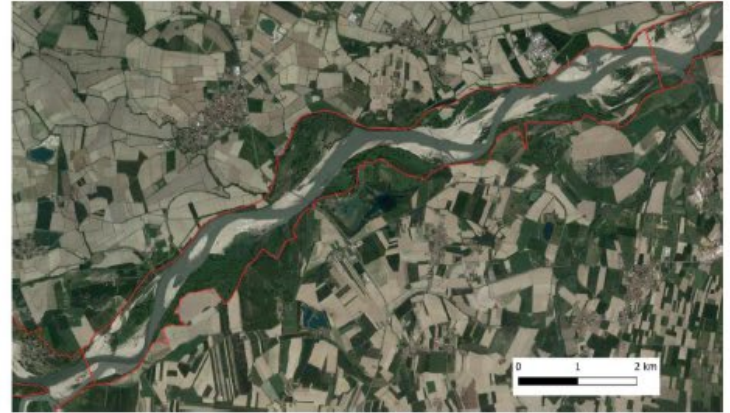


From Simoni Bizzi

<http://cascade.deib.polimi.it/>

Temporal Time Series of Tier 1 GUs

Quantifying river channel geomorphic trajectories



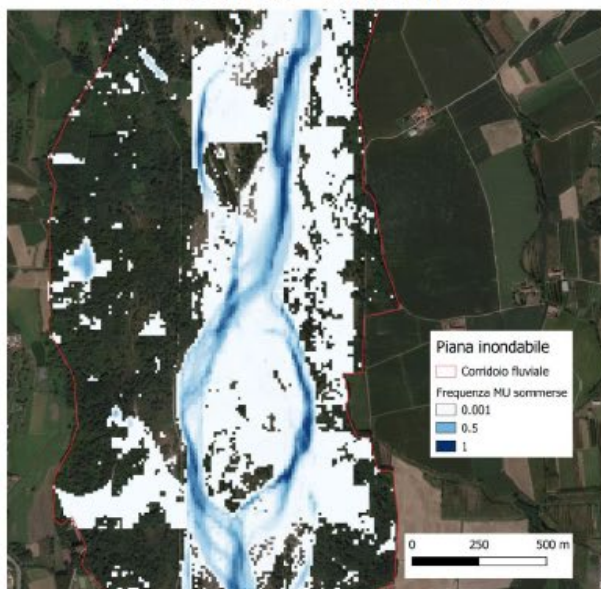
From Simoni Bizzi

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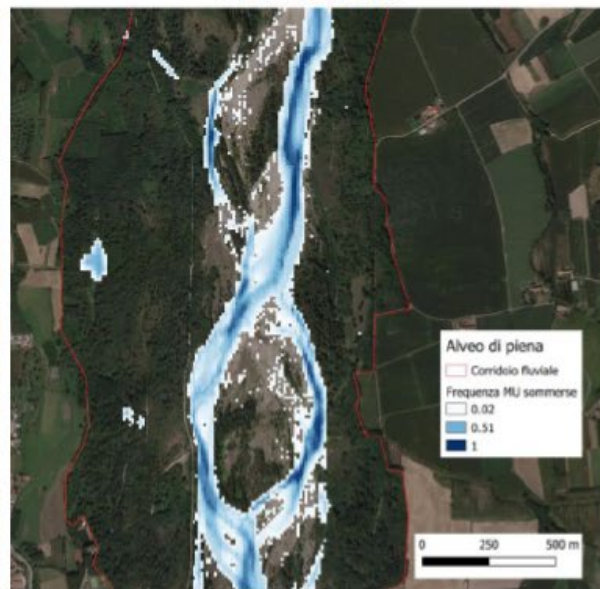
Capturing Flow Dynamics

Mapping channel zones

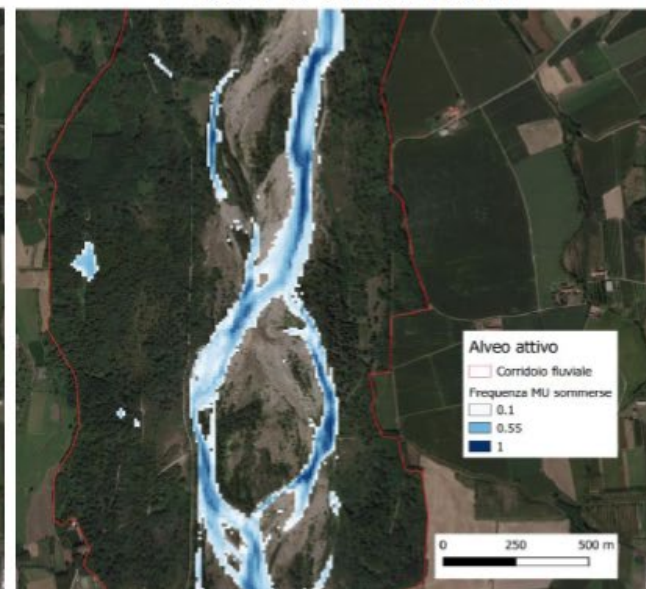
Flooded Channel



Bankfull



Active Channel



From Simoni Bizzi

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For Bigger Rivers...

PNAS

Toward global mapping of river discharge using satellite images and at-many-stations hydraulic geometry

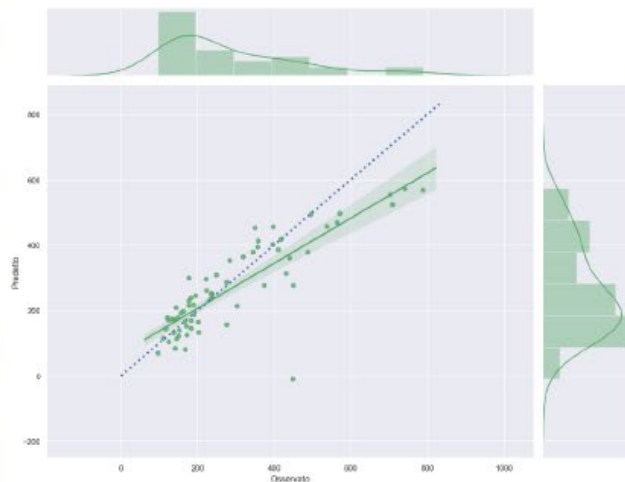
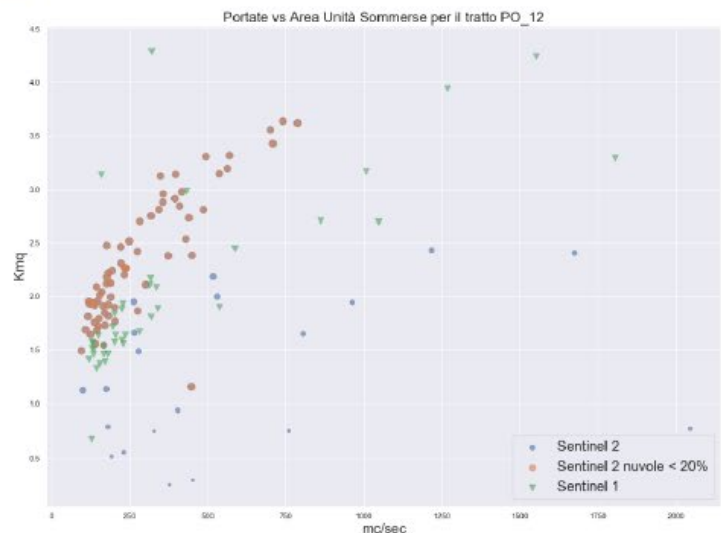
Colin J. Gleason¹ and Laurence C. Smith

Department of Geography, University of California, Los Angeles, CA 90095-1524

Edited by James S. Famiglietti, University of California, Irvine, CA, and accepted by the Editorial Board February 18, 2014 (received for review September 17, 2013)



Predicting river discharge from Space



- For the Po water channel area from Sentinel 2 can predict discharge with an average error of 20% of the measured discharge
- Sentinel 1 detected higher discharge. Integrating S2 and S1 we can have multiple measurements every week.
 - Wandering channels better predict discharge than single channel ones
- It does not work for river water channel width lower than 50m. Other satellites are needed (WorldView, Pleiades)



From Simoni Bizzi

<http://cascade.deib.polimi.it/>

River monitoring in the next years: basin (network) scale is finally possible

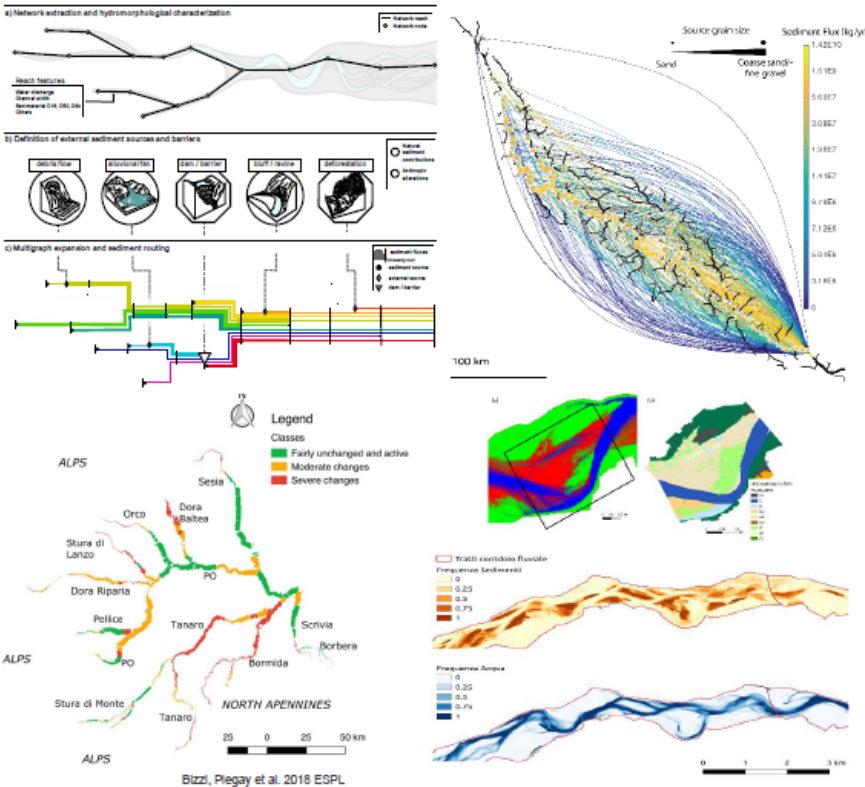
Regional Modeling

Generation of new information/knowledge at regional/network scale

Data Acquisition

- Sentinels plus Drone is a cost effective-solutions for a multi-scale hydromorphological monitoring framework for medium-large river systems: pilot basins can be designed with limited efforts (it is an opportunity!)
- Large scale monitoring and assessment frameworks needs to integrate different sources of remotely sensed data
- The new layers of information allow a exhaustive characterization of fluvial forms and process: geomorphic units, water channels mapping, and then habitat evaluation, monitoring channel evolution trajectories, characterizing grain size and predicting discharges. And on selected sites we can integrated this information with field data on sediment budgets and sediment transport.
- Network scale harmonized databases needs ot be shared (globally) and feed network-scale models (e.g., CASCADE)

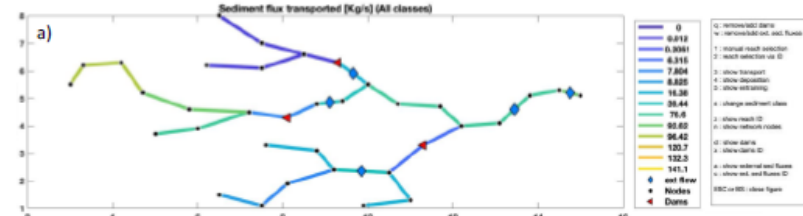
We are on a cusp of something in river science and management... but it still has not happened



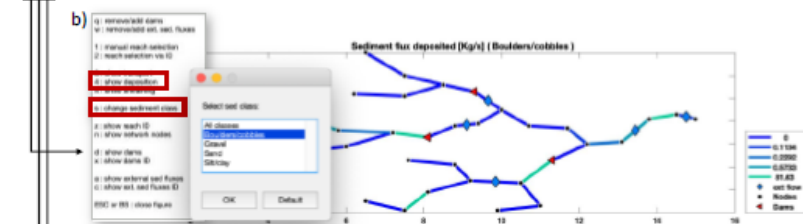
Modeling Sediment Routing

CASCADE toolbox: www.cascademodel.org

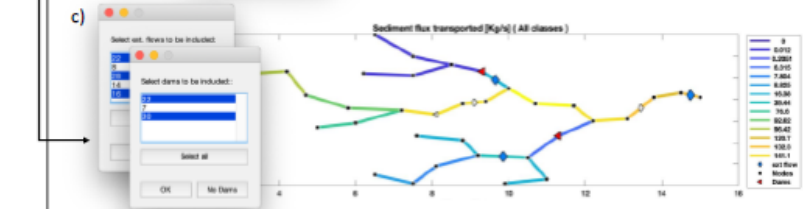
Sediment Fluxes



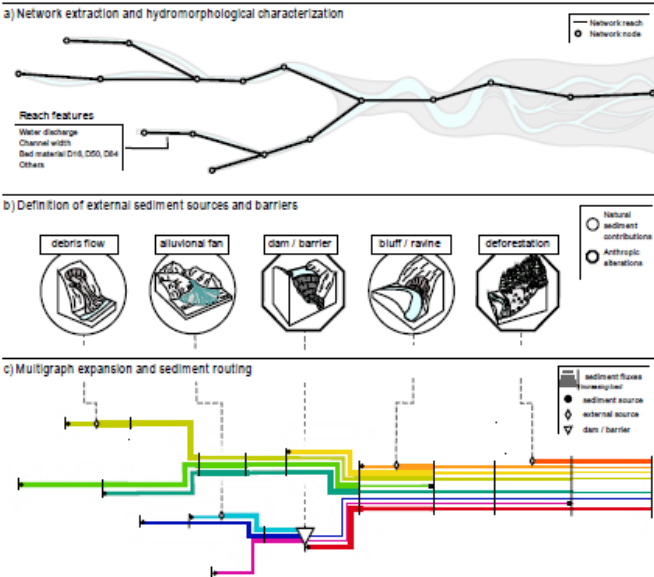
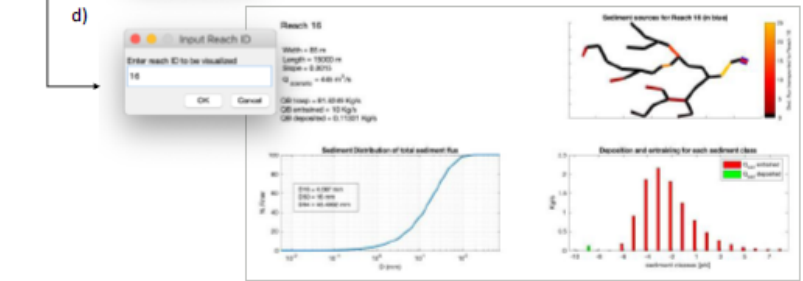
Sediment Eroded/Deposited



Sediment Fluxes for alternative management options

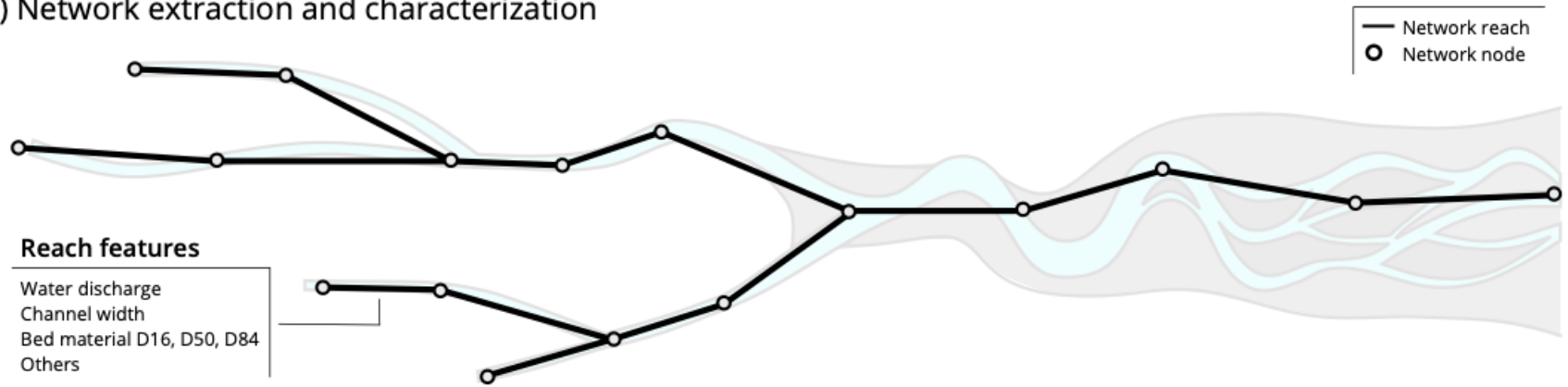


Sediment sizes and sources for a specific reach

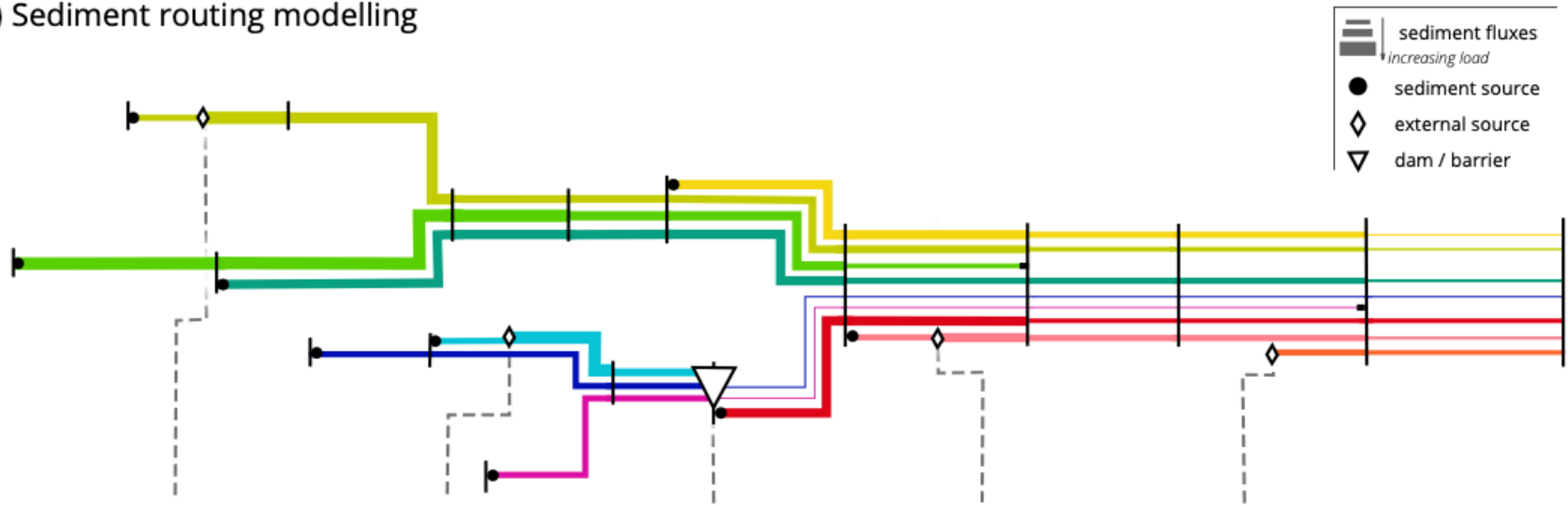


Tangi, M, Schmitt, R, Bizzi, S, Castelletti, A, (2019) Environmental Modelling & Software, Vol. 119, p. 400-406, <https://doi.org/10.1016/j.envsoft.2019.07.008> [online]

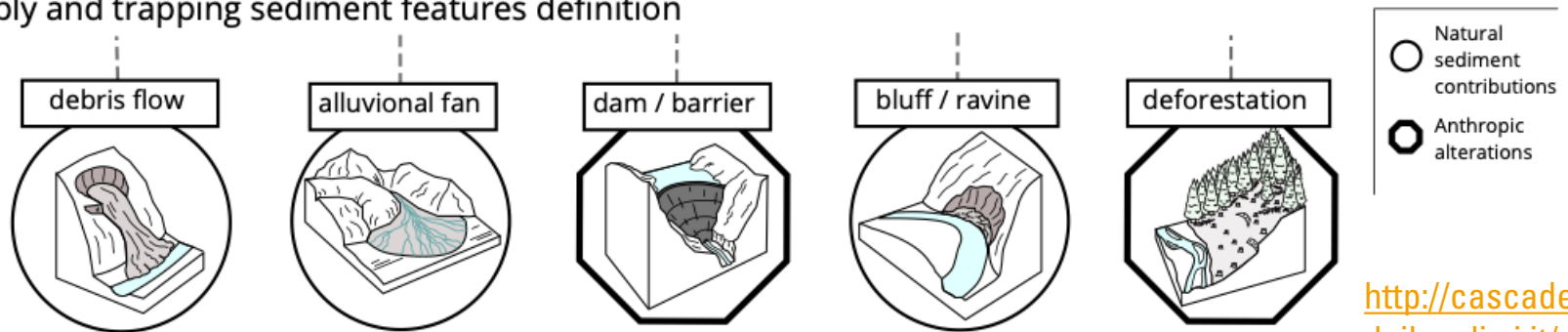
a) Network extraction and characterization



b) Sediment routing modelling



c) Supply and trapping sediment features definition



A Couple Cool Modeling Applications



CASCADE Toolbox Animation



Journal of Geophysical Research: Earth Surface

RESEARCH ARTICLE

10.1002/2016JF003965

Key Points:

- We develop a Lagrangian model of bed material sediment transport and in-channel storage dynamics on a river network
- Pulsing the system with Poisson sediment arrivals allows for analytical insight on bed sediment dynamics
- Emergence of low-transport capacity reaches creates “bottlenecks” which dynamically alter the downstream sediment supply

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Citation:

Czuba, J. A., E. Fofoula-Georgiou, K. B. Gran, P. Belmont, and P. R. Wilcock (2017), Interplay between spatially explicit sediment sourcing, hierarchical river-network structure, and in-channel bed material sediment transport and storage dynamics, *J. Geophys. Res. Earth Surf.*, 122, 1090–1120, doi:10.1002/2016JF003965.





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Interplay between spatially explicit sediment sourcing, hierarchical river-network structure, and in-channel bed material sediment transport and storage dynamics

Jonathan A. Czuba^{1,2} , Efi Fofoula-Georgiou³ , Karen B. Gran⁴ , Patrick Belmont⁵ , and Peter R. Wilcock⁵

¹Department of Civil, Environmental, and Geo-Engineering, St. Anthony Falls Laboratory, and Institute on the Environment, University of Minnesota, Twin Cities, Minneapolis, Minnesota, USA, ²Now at the Department of Earth and Atmospheric Sciences, Indiana University, Bloomington, Indiana, USA, ³Department of Civil and Environmental Engineering, University of California, Irvine, California, USA, ⁴Department of Earth and Environmental Sciences, University of Minnesota, Duluth, Minnesota, USA, ⁵Department of Watershed Sciences, Utah State University, Logan, Utah, USA

Abstract Understanding how sediment moves along source to sink pathways through watersheds—from hillslopes to channels and in and out of floodplains—is a fundamental problem in geomorphology. We contribute to advancing this understanding by modeling the transport and in-channel storage dynamics of bed material sediment on a river network over a 600 year time period. Specifically, we present spatiotemporal changes in bed sediment thickness along an entire river network to elucidate how river networks organize and process sediment supply. We apply our model to sand transport in the agricultural Greater Blue Earth River Basin in Minnesota. By casting the arrival of sediment to links of the network as a Poisson process, we derive analytically (under supply-limited conditions) the time-averaged probability distribution function of bed sediment thickness for each link of the river network for any spatial distribution of inputs. Under transport-limited conditions, the analytical assumptions of the Poisson arrival process are violated (due to in-channel storage dynamics) where we find large fluctuations and periodicity in the time series of bed sediment thickness. The time series of bed sediment thickness is the result of dynamics on a network in propagating, altering, and amalgamating sediment inputs in sometimes unexpected ways. One key insight gleaned from the model is that there can be a small fraction of reaches with relatively low-transport capacity within a nonequilibrium river network acting as “bottlenecks” that control sediment to downstream reaches, whereby fluctuations in bed elevation can dissociate from signals in sediment supply.

Conceptual Framework of Bed-Material Sediment Dynamics across a River Network

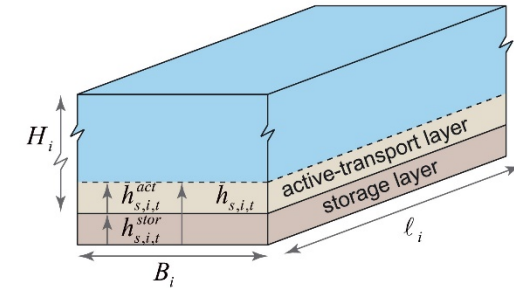
Bed-Material Sediment Dynamics on a Hierarchical River Network

DOI: [10.1002/2016JF003965](https://doi.org/10.1002/2016JF003965)

Spatially-explicit magnitude and frequency of sediment sourcing
(input pulsing; independent exponential interarrival timing)

Hierarchical network structure
(i.e., topology, geometry, and arrangement of channel properties)

a) Physical characteristics of a link



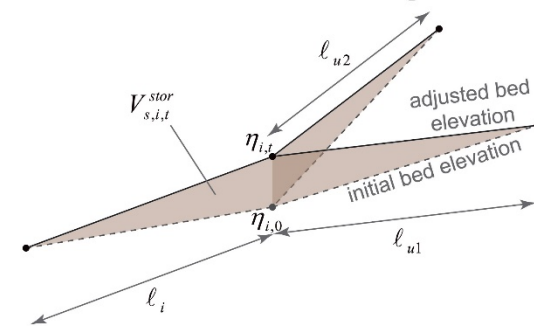
In-channel transport and storage dynamics

Feedbacks between channel slope and transport
(threshold-type modulation of pulsing via storage and release)

Supply limited:
Poisson arrival process of sediment to a link
(bed-sediment thickness pdf is a scaled Poisson distribution)

Transport limited:
non-Poisson arrival process of sediment to a link
(bed-sediment thickness pdf is heavy tailed and a time periodicity emerges)

b) Adjustment of channel slopes via in-channel storage



c) Input and arrival of sediment parcels on a network

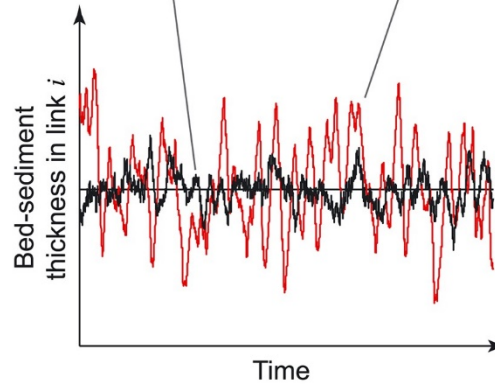
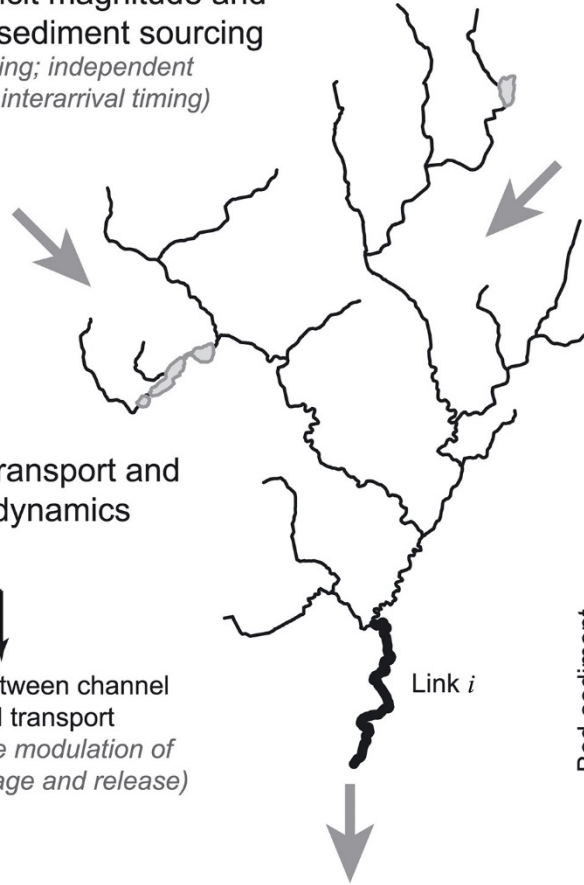
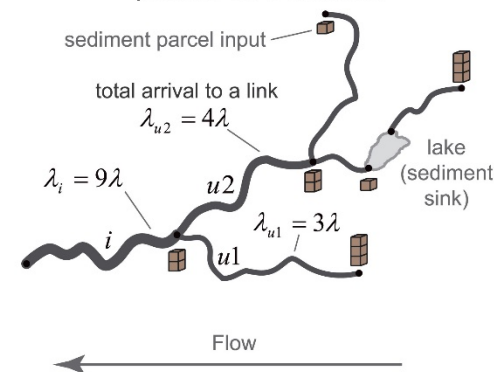


Figure 1. Conceptual overview of bed material sediment dynamics on a hierarchical river network. The combination of spatially explicit magnitude and frequency of sediment sourcing, hierarchical network structure, and in-channel transport and storage dynamics creates a temporal variability in bed sediment thickness. Under supply-limited conditions, the bed sediment thickness probability distribution function (pdf) is a scaled Poisson distribution, which is directly related to the Poisson arrival structure of the inputs. Under transport-limited conditions, the bed sediment thickness pdf is heavy tailed and the temporal dynamics exhibit a characteristic timescale (periodicity).

Greater Blue Earth Study Site

Greater Blue Earth River Basin

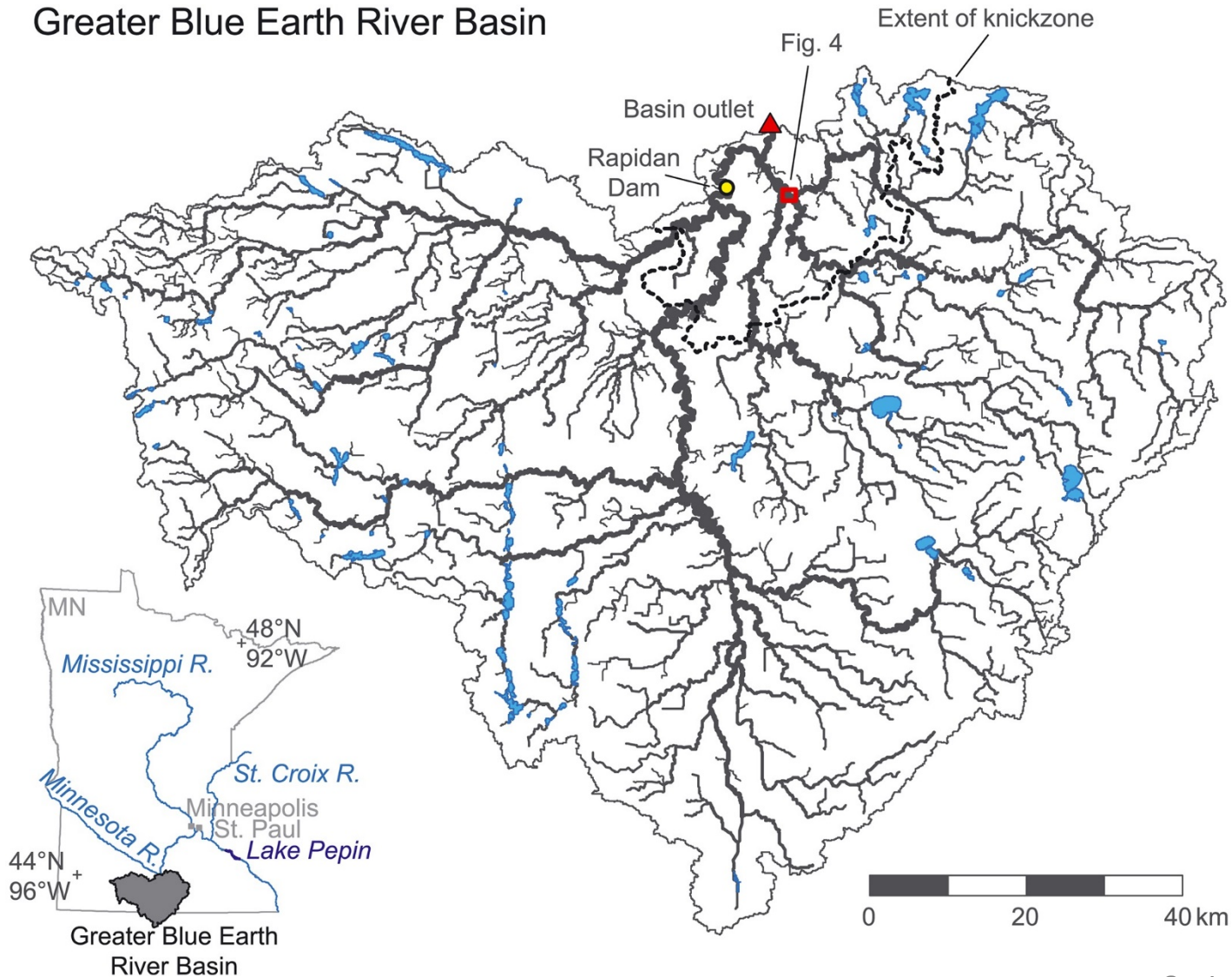


Figure 3. Study area map of the Greater Blue Earth River Basin. A detailed basin map shows the channel network (gray; thicker lines correspond to reaches with larger upstream drainage areas), lakes incorporated into the model (light blue), and the approximate extent of the knickzone (black dashed line). Location and extent of Figure 4 is shown by a small red box. Inset shows a location map of the Greater Blue Earth River Basin relative to the State of Minnesota.

Czuba, Foufloula-Georgiou, Gran, Belmont & Wilcock (2017)

DOI: [10.1002/2016JF003965](https://doi.org/10.1002/2016JF003965)

Sources: Riverscape, Bluffs and Ravines

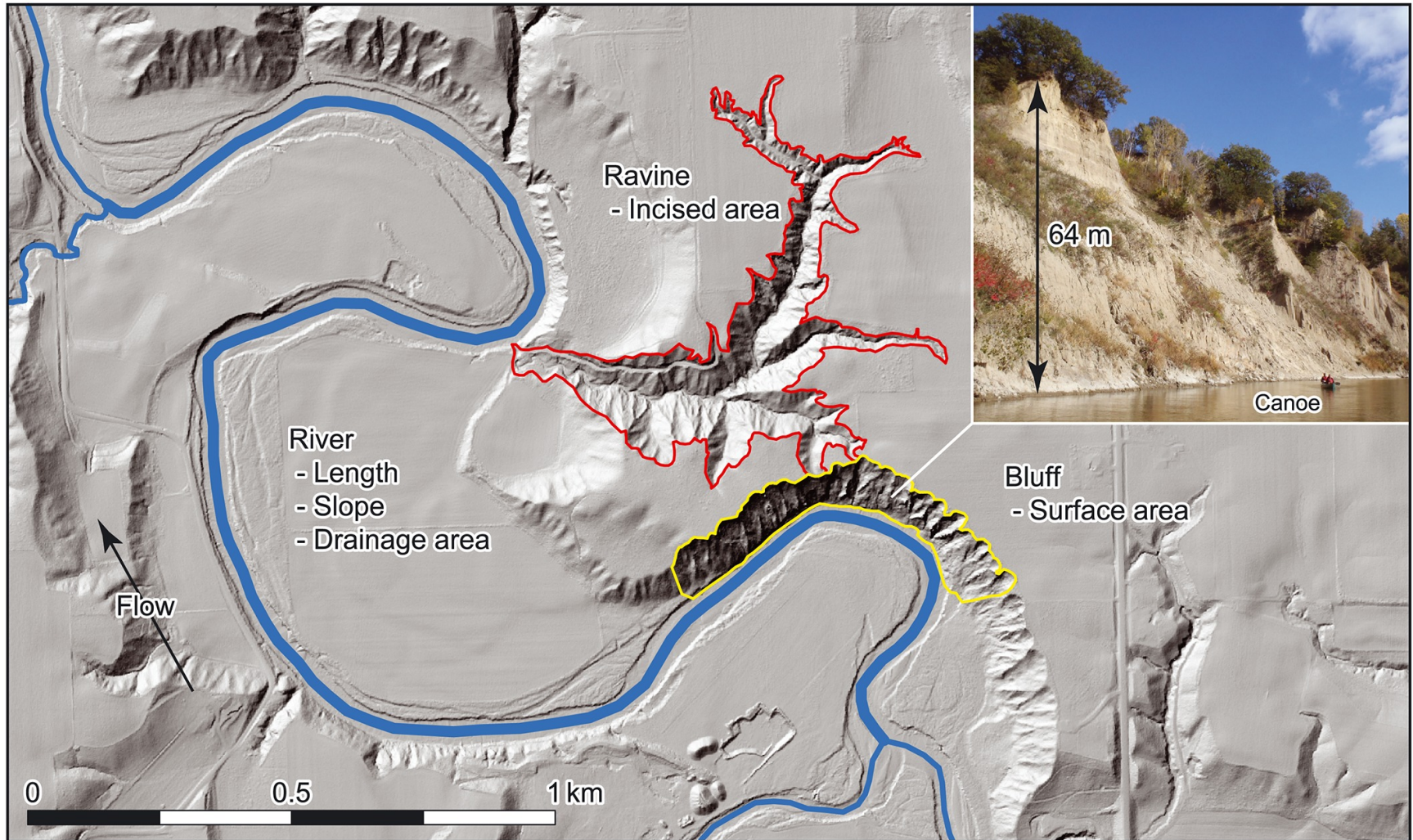
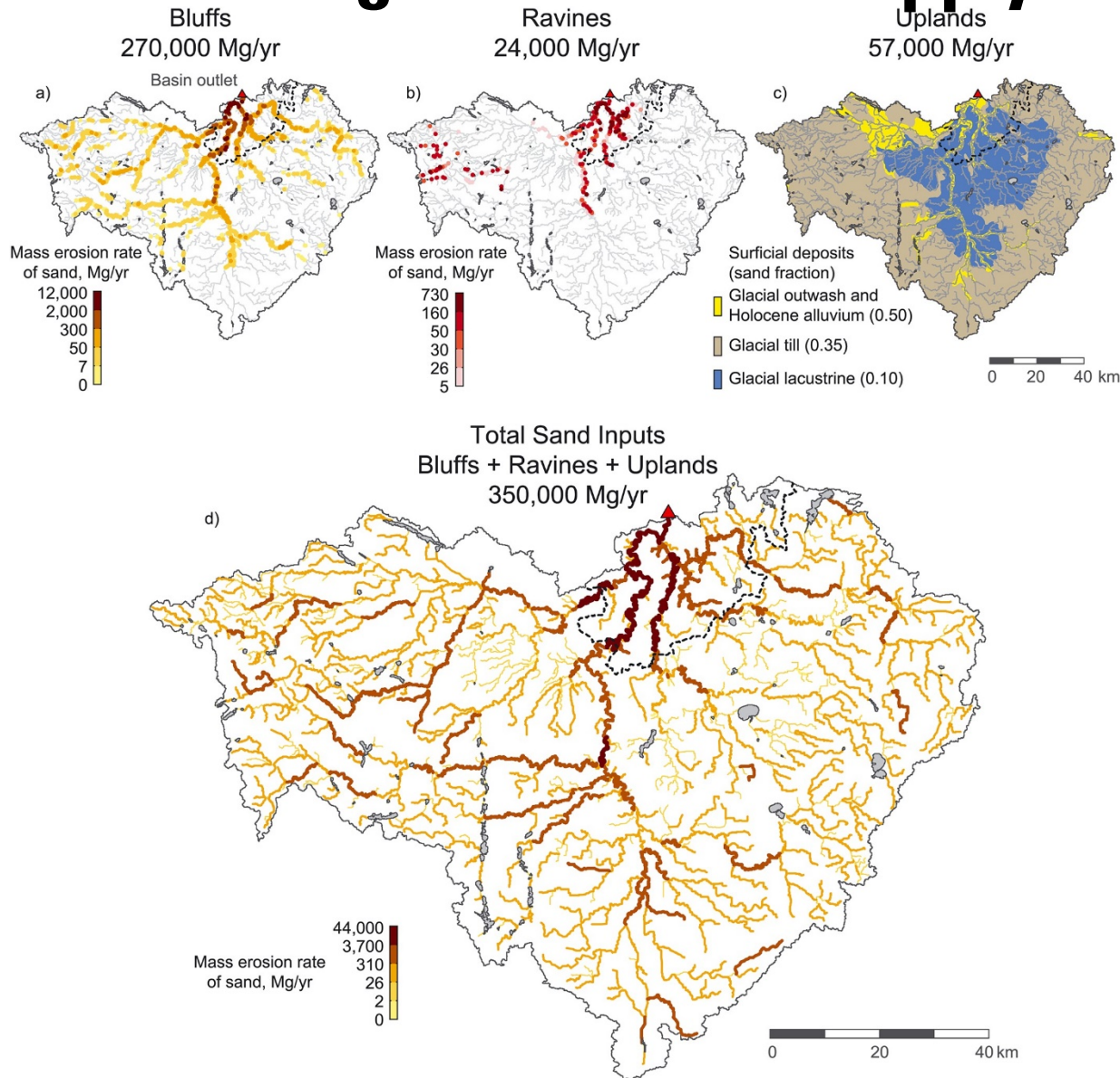


Figure 4. Lidar hillshade highlighting major features (river, bluff, and ravine, each with relevant attributes) incorporated into the model. Inset image shows a 64 m bluff; note the canoe for scale. Location and extent is shown in Figure 3 by a small red box.

Czuba, Foufoula-Georgiou, Gran, Belmont & Wilcock (2017)

DOI: [10.1002/2016JF003965](https://doi.org/10.1002/2016JF003965)

Partitioning of Sediment Supply Sources



Czuba, Foufoula-Georgiou, Gran,
Belmont & Wilcock (2017)

DOI: [10.1002/2016JF003965](https://doi.org/10.1002/2016JF003965)

Figure 5. Spatially variable and temporally Poisson process (independent arrival) of sediment supply. (a) Bluff locations colored by mass erosion rate of sand from each bluff. (b) Ravine locations colored by mass erosion rate of sand from each ravine. (c) Uplands with surficial deposits and sand fraction. (d) Total sand input delivered to each link of the network from bluffs, ravines, and uplands. The approximate extent of the knickzone is shown as a dashed line.

Simulating "Bed Thickness" Through Time

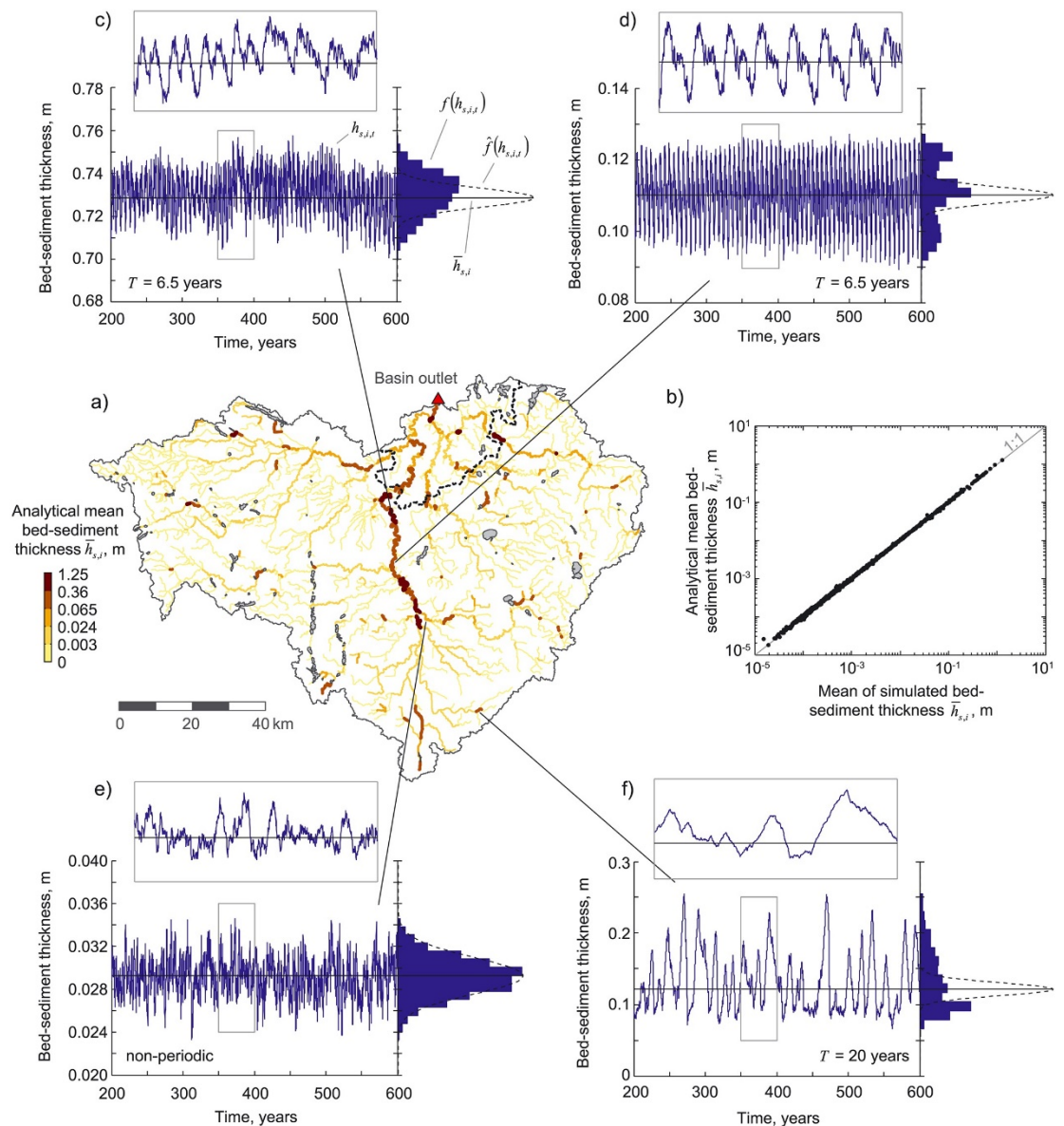
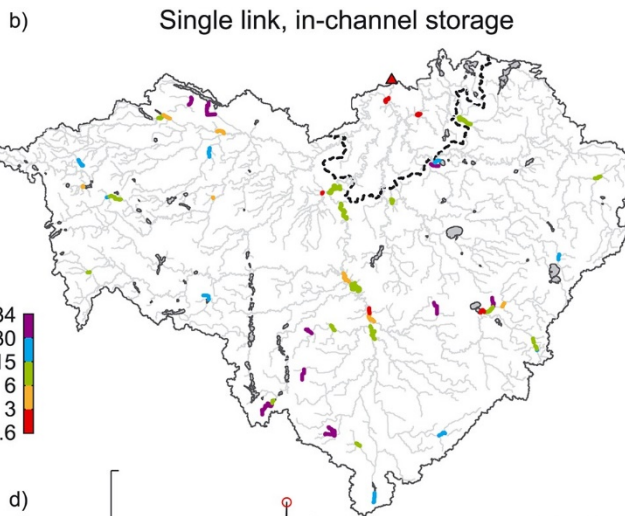
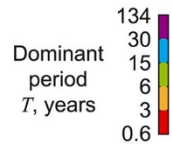
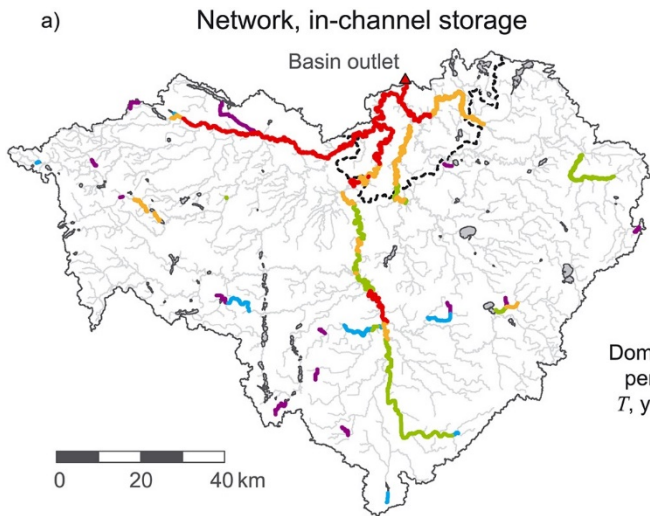


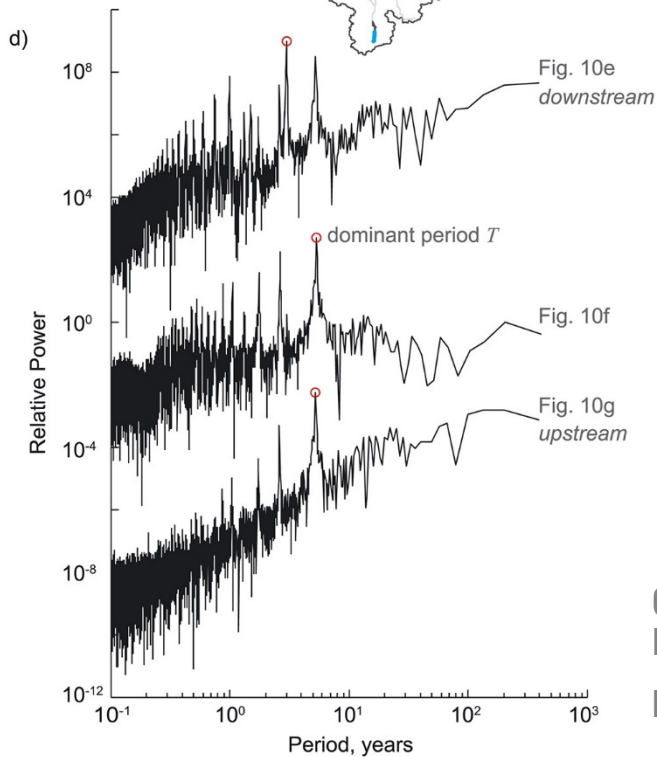
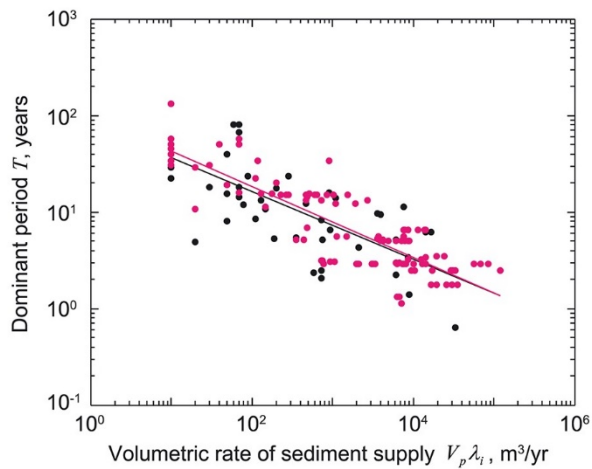
Figure 7. Simulated and analytical bed sediment thickness with in-channel storage. (a) Analytical mean bed sediment thickness $\bar{h}_{s,j}$ (see equation (13)). The color breaks are at the 0.99, 0.95, 0.90, and 0.75 quantiles. The approximate extent of the knickzone is shown as a dashed line. (b) Simulated mean bed sediment thickness averaged from 200 to 600 years versus the analytical mean bed sediment thickness $\bar{h}_{s,j}$. (c–f) Simulated bed sediment thickness $h_{s,j,t}$ with probability distribution function (pdf) $f(h_{s,j,t})$ shown at the right (blue). The solid horizontal line denotes the analytical mean bed sediment thickness $\bar{h}_{s,j}$. The estimated pdf $\hat{f}(h_{s,j,t})$ that assumes the in-channel storage process preserves the structure of a Poisson arrival process is shown at the right (black dashed; see equation (12) and discussion at the end of section 2.5). Inset box zooms in on the simulated bed sediment thickness time series between 350 and 400 years. The dominant period T of the bed sediment thickness time series (i.e., the time period corresponding to the peak of the Fourier transform) is also indicated. See text for definition of symbols.

Czuba, Foufoula-Georgiou, Gran, Belmont & Wilcock (2017)

DOI: [10.1002/2016JF003965](https://doi.org/10.1002/2016JF003965)



- c)
- network, in-channel storage
 $T \sim V_p \lambda_i^{-0.37}$; $R^2 = 0.73$
 - single link, in-channel storage
 $T \sim V_p \lambda_i^{-0.35}$; $R^2 = 0.53$

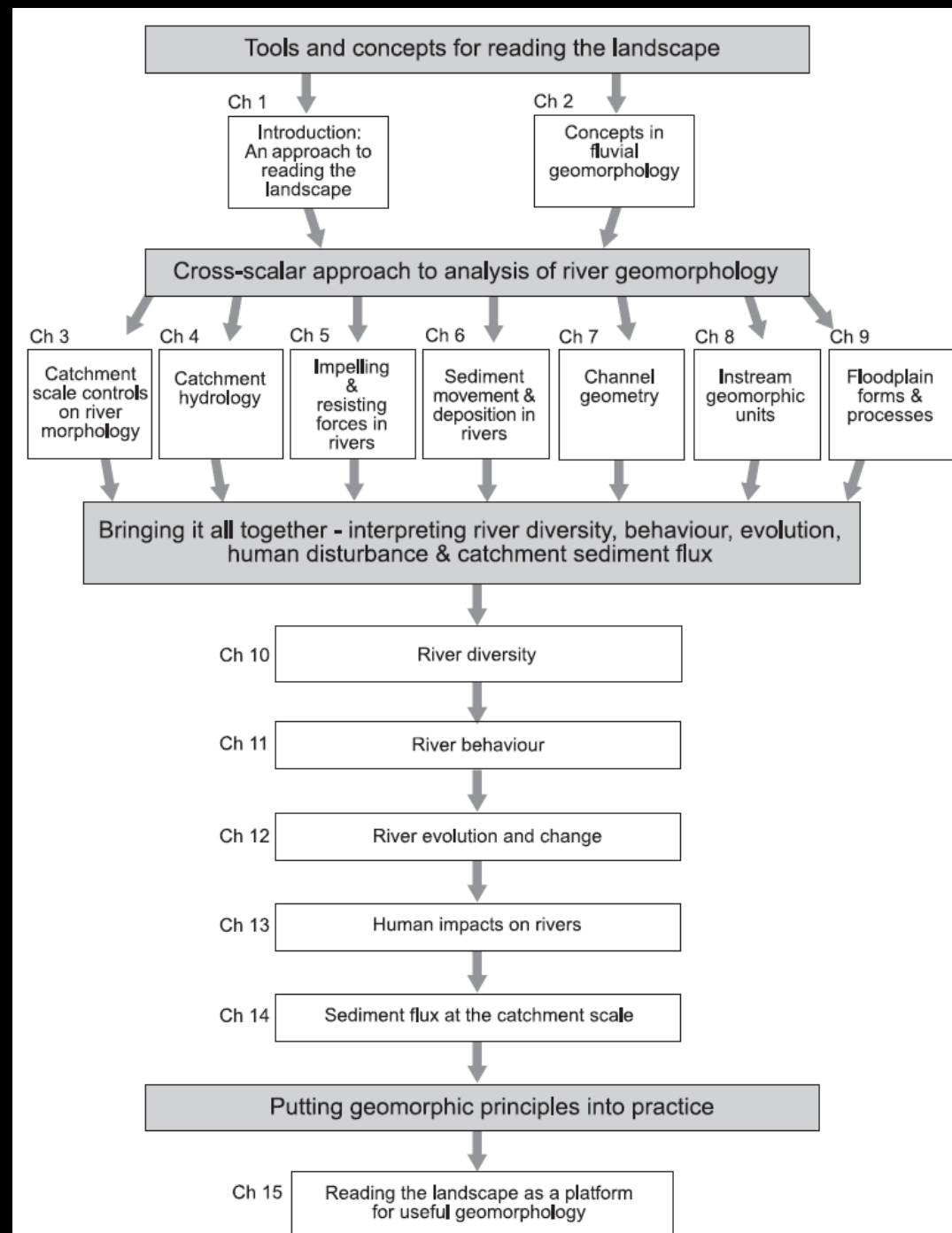
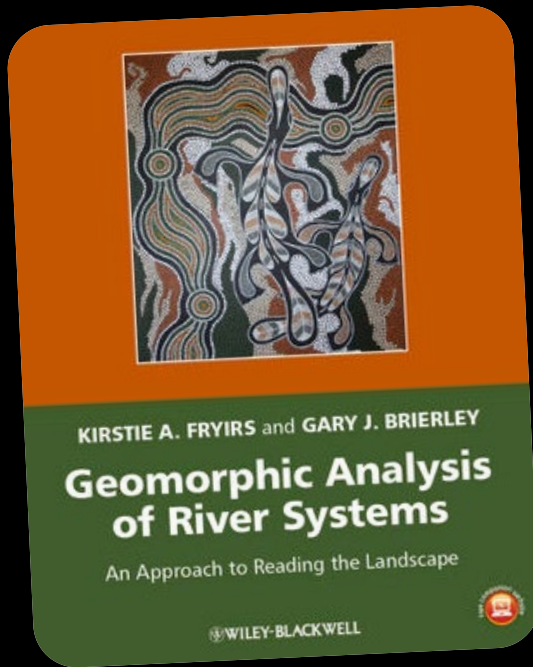


Synthesis of the Class



Organization of Class Mirrored Book

- Modules ~ Chapters

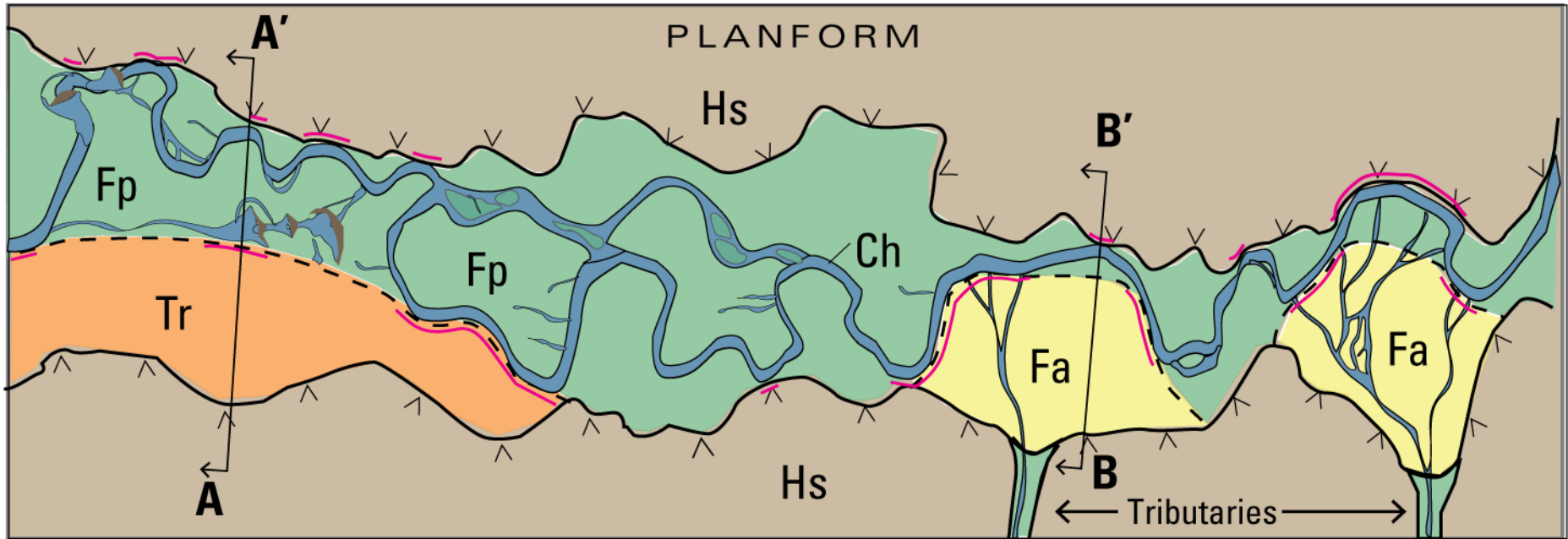


A topographic map of a watershed, showing a network of rivers and streams. The terrain is shaded in light gray and white, indicating elevation. The rivers and streams are shown as blue lines. Several areas along the river channels are highlighted in green, representing riverscapes. The text is overlaid on the map.

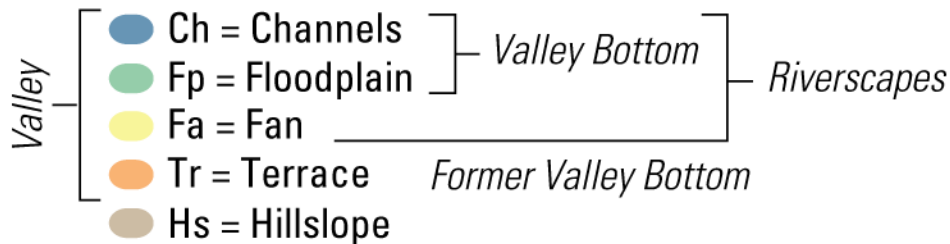
Riverscapes span the network across a watershed

Riverscapes are the part of the landscape that could plausibly flood by their rivers & streams in the natural flow regime.

Reading your riverscape... to look for opportunities



GEOMORPHIC UNIT KEY



The valley bottom is comprised of areas that could plausibly flood in the contemporary flow regime.

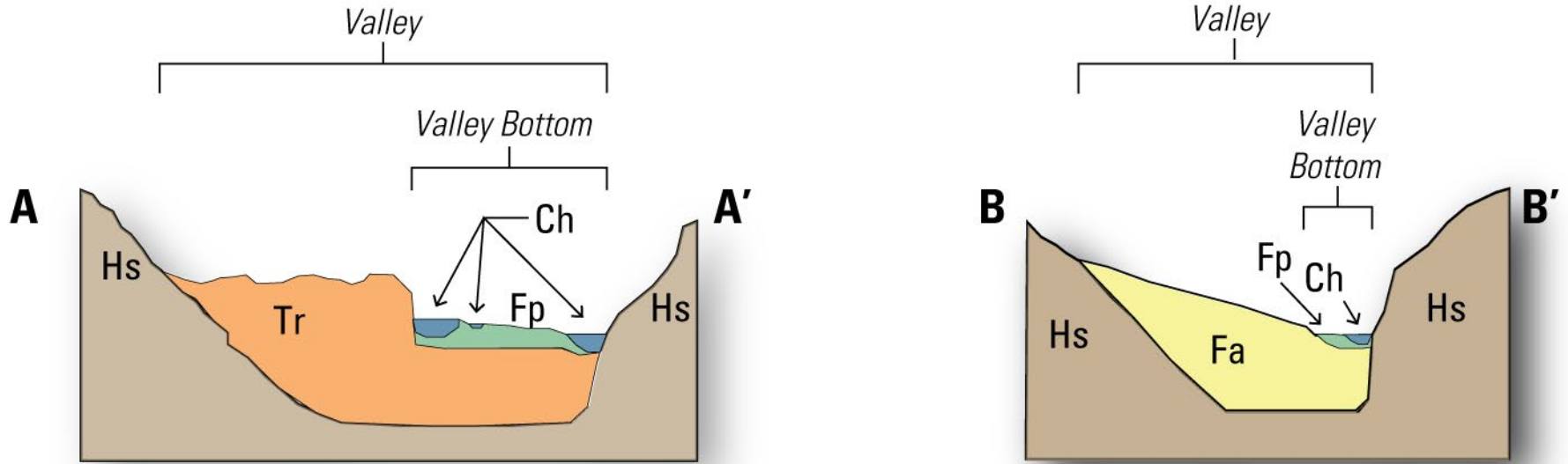
MARGIN TYPES

- ∨ ∨ Valley Margin
- - Valley Bottom Margin
- Active Confining Margin

Where are their mesic/riparian restoration opportunities?

Contrasting Valley Settings Define Reach Breaks

VALLEY CROSS SECTIONS



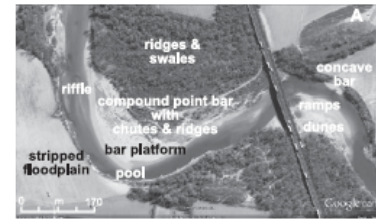
From page 10 of Pocket Guide; Wheaton et al. (2019)

DOI: [10.13140/RG.2.2.28222.13123/1](https://doi.org/10.13140/RG.2.2.28222.13123/1)

Reading Riverscapes

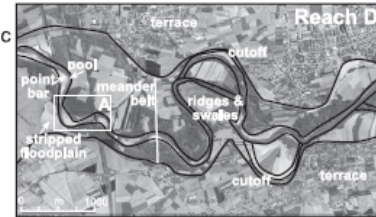


Step 1: Identify individual instream and floodplain geomorphic units and determine their process-form relationships.



Example of interpretation
 *ridges & swales formed by helicoidal flow forming scroll bars, concave bank erosion and channel migration
 *compound point bar formed by deposition of gravel on the inside of a meander bend, flow realignment over the bar at bankfull stage and scour of chute channels. Sediment is deposited around vegetation to form ridges.

Step 2: Analyse and interpret the assemblage of geomorphic units at the reach scale and how they adjust over time.



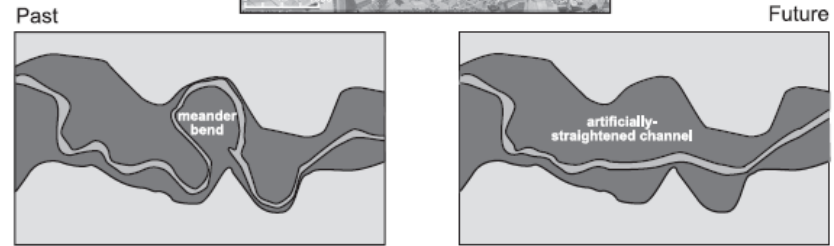
Example of interpretation
 *low flow stage - flow aligned around bars and over riffles. Undercutting of concave bank occurs.
 *bankfull stage - point bars are short-circuited, pools are scoured, riffles are deposited, concave bank erosion and deposition on convex bank leads to channel migration.
 *overbank stage - flow aligned over the neck of meander bends, forming cutoffs

Step One: Identify individual landforms (geomorphic units) and the process-form relationships that determine their process regime.
 Identify the types of units in the channel and on the floodplain. Interpret the morphodynamics of each geomorphic unit based upon its process-form interactions, outlining the erosional and depositional processes that create and rework each feature.

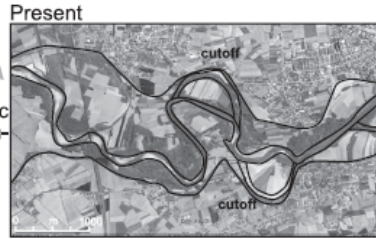
Step Two: Analyse and interpret the package and assemblage of landforms at the reach scale and how they adjust over time.
 Analyse the range of units within a reach as packages of genetically linked assemblages, taking into account their position and their juxtaposition with other units. Appraise interactions between landforms by interpreting the erosional or depositional nature of boundaries (contacts) between units. Assess magnitude-frequency relationships that form and rework the package of landforms. These insights are combined to determine the behavioural regime (natural range of variability) of the reach.

Step Three: Explain controls on the package and assemblage of landforms at the reach scale and how they adjust over time.
 Analyse the range of flux and imposed boundary conditions that control the process relationships that characterize the behavioural regime of a reach. Assess natural (geological, climatic) and human-induced controls upon river behaviour and evolution. Explain contemporary landscape behaviour in relation to longer term evolution, framing system responses to human disturbance in relation to natural variability.

Step Four: Integrate understandings of geomorphic relationships at the catchment scale.
 Place each reach/site in its catchment context and examine linkages between compartments to interpret spatial relationships within that system. Examine downstream patterns of river types to assess why certain rivers occur where they do along longitudinal profiles, interpreting the dominant controls on river character and behaviour. Interpreting the efficiency and effectiveness of sediment flux at the catchment scale determines the strength of linkages (connectivity) in the catchment, and associated natural or human-induced responses to disturbance events (i.e. lagged and offsite impacts).

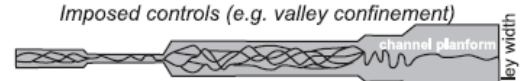
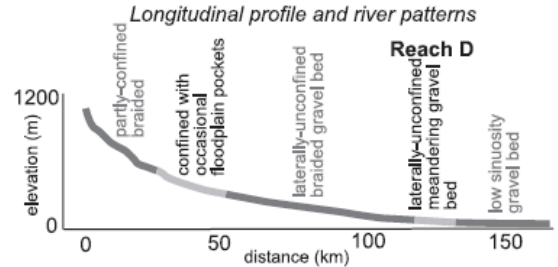


Step 3: Explain controls on the assemblage of geomorphic units, and 'natural' and human-induced impacts.



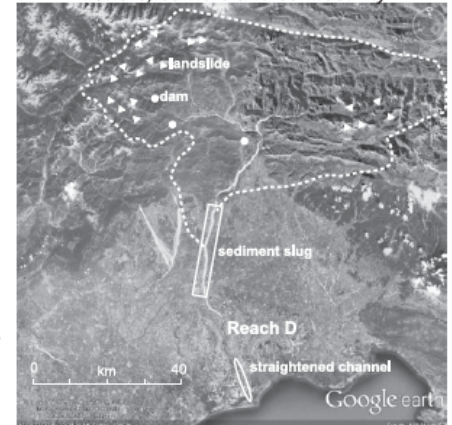
Example of interpretation
 *flux controls - transport-limited river with high sediment supply, Flashy flow regime.
 *imposed controls - tectonic activity resets base level.
 *human impacts - deforestation, cutoff formation and artificial straightening of channel.

Step 4: Integrate understandings of geomorphic relationships at the catchment scale.



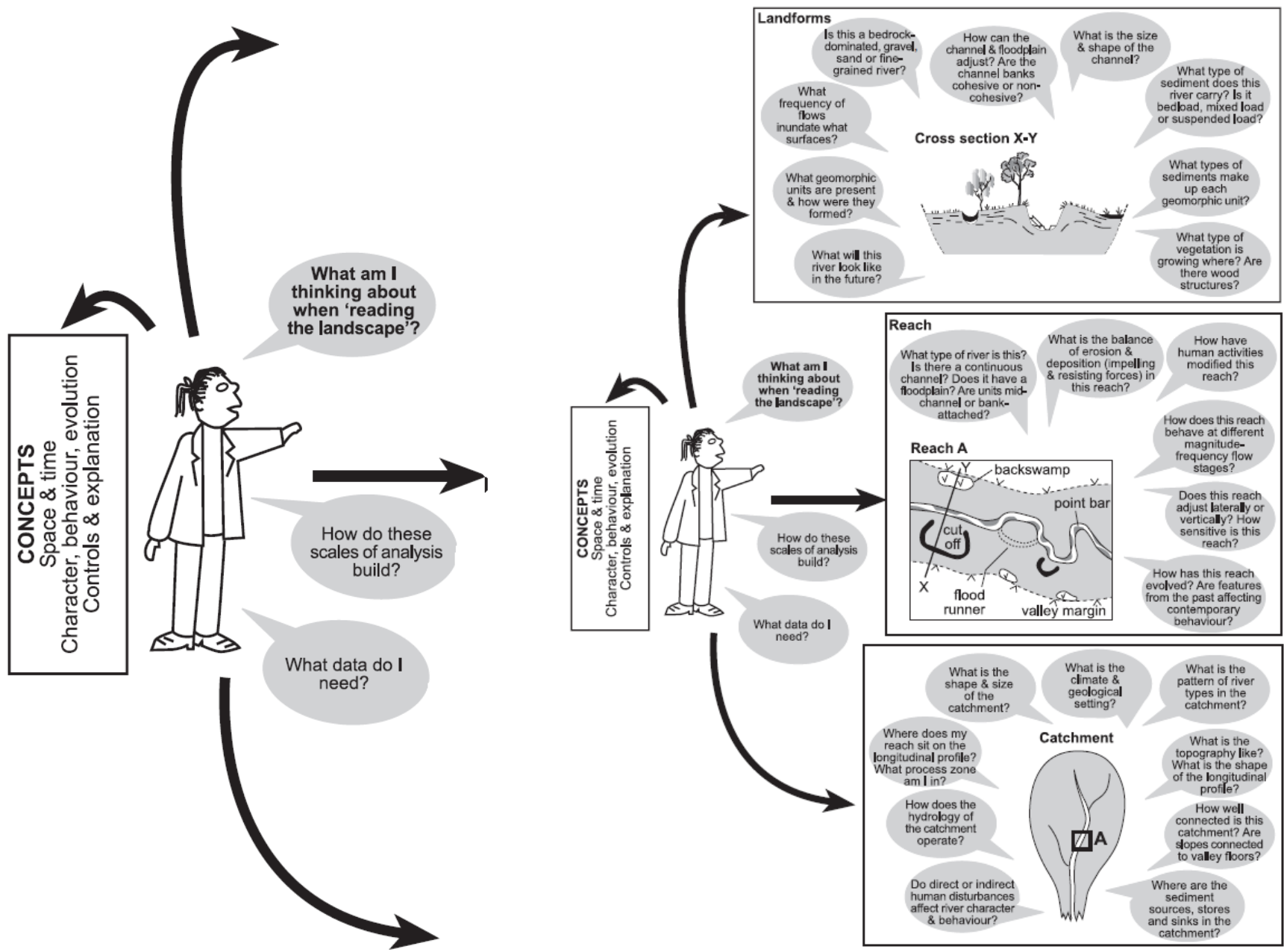
Example of interpretation
 *pattern of river diversity controlled by slope and valley confinement
 *sediment supply is high due to landslide connectivity in headwaters
 *role of disconnected tributaries varies over time (e.g. dams)
 *channelised reaches convey sediment more efficiently

Buffers, barriers and connectivity



• It's a lot... that's why we'll take all semester learning it...

Figure 1.2 Questions you should ask when reading the landscape at the landform, reach and catchment scales.





**Thanks for Being
an Awesome, Patient, &
Engaging Class**

