# AN INTRODUCTION TO THE RIVER STYLES FRAMEWORK

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**Auckland, New Zealand**

Squamish River, British Columbia

Cooper Creek, western Qld

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# Schedule for the workshop

| Time | Topic |
|---|---|
| 8.30-8.45 | Registration |
| 8.45-9.00 | Introductions and welcome |
| 9.00-9.30 | Presentation 1: Underlying principles and applications of the River Styles Framework |
| 9.30-10.30 | Presentation 2: Stage One of the River Styles Framework: River character, behaviour, pattern and controls. |
| | |
| 10.30-11.00 | **MORNING TEA** |
| | |
| 11.00-11.15 | Exercise 1: River Styles Quiz |
| 11.15-12.30 | Exercise 2: Mapping geomorphic units and interpreting river behaviour, and determining boundaries between river reaches (50 mins for exercises, 25 mins for discussion of answers). |
| | |
| 12.30-13.30 | **LUNCH** |
| | |
| 13.30-13.50 | Presentation 3: Stage Two of the River Styles Framework: Catchment framed assessment of geomorphic river condition |
| 13.50-14.15 | Exercise 3: Selecting appropriate geoindicators of condition for different River Styles. |
| 14.15-14.35 | Presentation 4: Stage Three of the River Styles Framework: Assessing the evolutionary trajectory and geomorphic recovery potential of rivers |
| 14.35-15.00 | Exercise 4: Scenario building and assessing river recovery potential |
| | |
| 15.00-15.30 | **AFTERNOON TEA** |
| | |
| 15.30-16.15 | Presentation 5: Stage Four of the River Styles Framework: Implications for river management (setting geomorphic visions, identifying target conditions for river management, prioritisation based on geomorphic river condition and recovery potential, monitoring and auditing improvement in condition) and uses of information bases derived from using the River Styles Framework. |
| 16.15-17.00 | Discussion session: Prioritisation, identifying target conditions for river rehabilitation, levels of intervention required, river management practice. |
| 17.00 | Closing remarks |

## Presentation 1:
## The River Styles Framework: A catchment approach to guide coherent, geomorphologically informed river management practices

**Gary Brierley and Kirstie Fryirs**

Thanks: Jon, Ian, IPENZ Rivers Group

www.riverstyles.com
Email: info@riverstyles.com

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## Outline and aims of the day

Show how the River Styles framework presents a coherent, scaffolded approach to develop process-based, catchment-scale geomorphic understandings of river systems.

Demonstrate its application to river management.

Show how emerging technologies can support the uptake of this tool.

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## Geomorphology as a biophysical template

Fluvial geomorphology

vegetation

habitat/ecology

water quality/ nutrient flux

rehabilitation

hydrology

SOCIETY FOR ECOLOGICAL RESTORATION INTERNATIONAL

River Futures

*An Integrative Scientific Approach to River Repair*

Edited by Gary J. Brierley and Kirstie A. Fryirs

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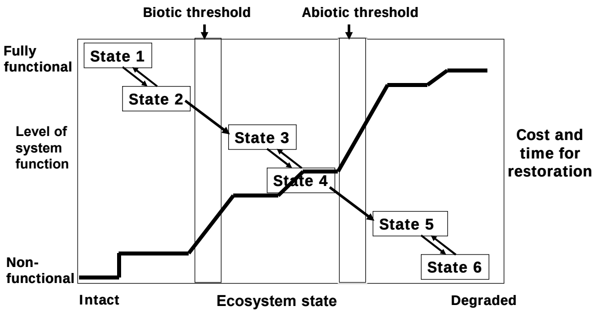
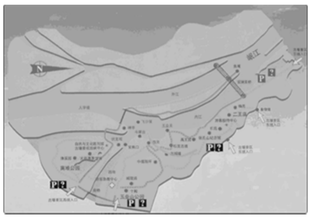
## An economic case for uptake of geomorphology as a basis for environmental protection



(Hobbs, 2001)

## Working with nature: Lessons from history
## Dujiangyan (near Chengdu), Sichuan, China



- c250BC Governor Li Bing: channeling and dividing the Min River
- Flood prevention and irrigation source on the Chengdu Plain for more than 2000 years
- Importance of sediment maintenance!
- cf., Sanmenxia, dam along lower Yellow River built 1957-1960

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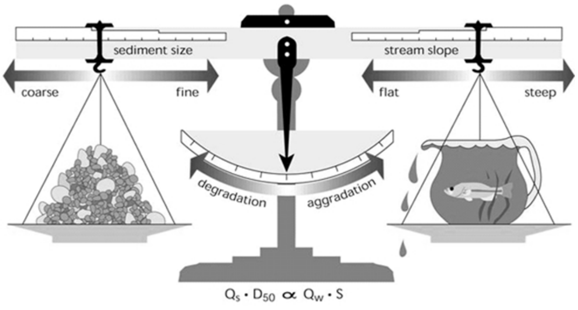
## Sediment regime: Maintaining the balance …



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## So, what can we do about it?

- ➢ Geomorphology & river management
- ➢ Describe, Explain, Predict
- ➢ Work with managers, work with nature
- ➢ But, we need a coherent framework to do this …

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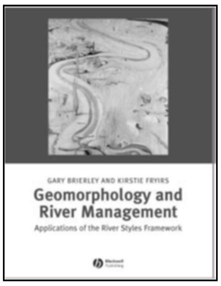
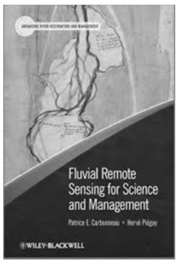
A new dawn is upon us: The use of emerging technologies in river science and management … Merging worlds …





# Emerging geomorphologies

*Geomorphology is simultaneously developing in diverse directions: on one hand, it is becoming a more* ***rigorous geophysical science*** *– a significant part of a larger earth science discipline; on another, it is becoming more concerned with* ***human social and economic values****, with environmental change, conservation ethics, with the human impact on environment, and with issues of social justice and equity.*

Michael Church, 2010, p. 265

# Questions of perspective & training

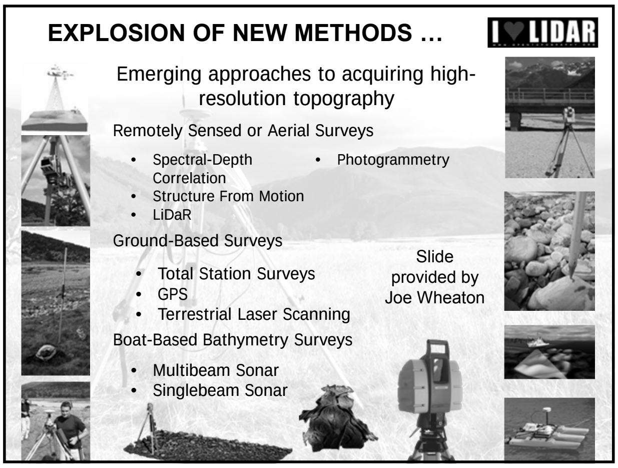
Engineering, Mathematics, Computing, Geophysics applications
- Development & testing of theories
- Programming skills (R, Python, C++, Matlab, etc)

Geographic skillsets
- An ability to develop and apply contextualized understandings
- The specialist-generalist synthesis
- Place-based applications … situated knowledges

Not Either/Or … we need both!

# James Brasington (University of Waikato): Emerging technologies for river science & management – Big Data & Extreme Science

NZ as a test ground … Brasington & Wheaton short courses



## EXPLOSION OF NEW METHODS …

Emerging approaches to acquiring high-resolution topography

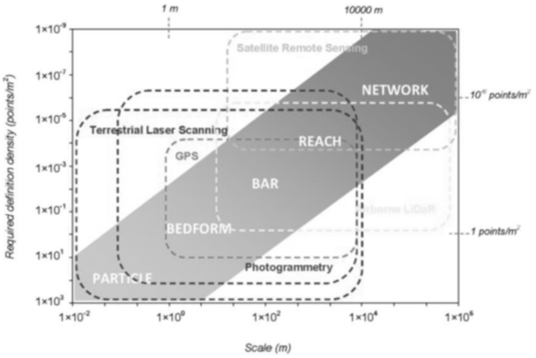
Remotely Sensed or Aerial Surveys
- Spectral-Depth Correlation
- Structure From Motion
- LiDaR
- Photogrammetry

Ground-Based Surveys
- Total Station Surveys
- GPS
- Terrestrial Laser Scanning

Boat-Based Bathymetry Surveys
- Multibeam Sonar
- Singlebeam Sonar

Slide provided by Joe Wheaton

# Options across scales



# So, why is this different from LENZ, REC & FRENZ?

- Resolution
- Change detection – adjustment … insight into formative process
- Concern for evolutionary trajectory

# Automated mapping

Making riverscapes real (Carbonneau et al., 2012; Wheaton et al., 2015) … cross-scalar applications

- Grain size (e.g. Marchetti et al., in prep.)
- Habitat mapping (e.g. Demarchi et al., 2016 a, b; *Remote Sensing*, *ESPL*; Wheaton et al.)
- Channel geometry & classification work (e.g. Leviandier et al. (2012, Geomorphology; Bizzi et al., in review)
- Automated reach delimitation work (Fluvial Corridor toolbox; e.g. Notebaert & Piegay, 2013; Alber & Piegay, 2011, *Geomorphology*; Roux et al., 1014, *Geomorphology*)
- Regional-scale comparative work

Management implication: "*Respect Diversity*"

# Detecting patterns

- Long profile and stream power (Bizzi & Lerner, 2015)
- Automated delineation of valley width (Gilbert et al., 2016)
- Connectivity relationships (Schmitt et al., 2016)
- Drainage network configuration and geomorphic hotspots (Czuba & Foufoula-Georgiou, 2015)
- 3D Visualization of landscapes – virtual field trips

Management application: "*Know your Catchment*"

## Automated change detection

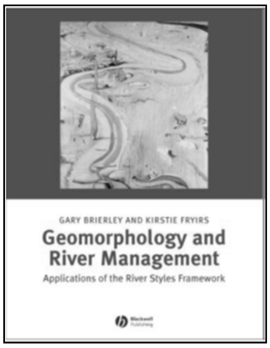
- Geomorphic unit assemblages – the fuzzy bits! Process-based understandings of what happens where, at what rate
- Grain size work = sediment transport (morphological budgets)
- Bathymetric surveys …
- Analysis of behaviour, change, range of variability
- Development and use of process archetypes (Cullum et al., 2016)
- Explanation of controls and drivers … from channel processes to valley evolution … rivers are products of their valleys!

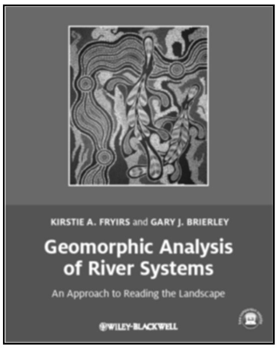
Management application: "*Work with Change*"

## Things we are now able to do

- Evolutionary trajectories
  - Quantification of process relationships
  - Tracking sediment pulses
  - Modelled landscapes 'come alive' in front of our eyes
    - Merging of geomechanical properties of materials with tectonic principles to account for long term landscape evolution
    - Terrace evolution models
- Retrofitting and testing of theories - equilibrium notions and magnitude-frequency relations
- Regional-scale comparisons and prioritization of management endeavours
  - What do we seek to protect; working with recovery
- Guide transferability of understandings (framing reaches in their catchment context)

## This workshop builds on 2 books





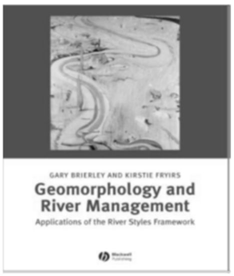
## The River Styles Framework

Stage 1: Baseline survey of river character **and** behaviour, patterns & controls

Stage 2: River evolution and geomorphic river condition

Stage 3: River recovery potential

Stage 4: Management applications



River Styles$^{®}$ framework is a package of steps and a learning tool.

## The River Styles Framework

A way of thinking about rivers …

An ecosystem approach to river science and management

A scaffolded package of interpretative steps that is cross-scalar, adaptable and flexible … importance of open-ended thinking … 'Engage thy Brain!

## FUNDAMENTAL PREMISE

**Geomorphology ≠ Answer in itself**, but management practices may be compromised without appreciation of geomorphic considerations

Dangers of overly generalised and inappropriate information ….

- Importance of place-based knowledge
- Grounded (field-based) interpretations tied to desk-top information, linked to local understandings

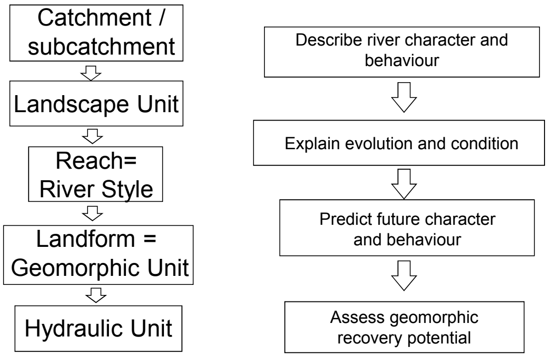
## Key attributes of the River Styles Framework

- Work *with* nature … and trajectory of change
  - Appreciation of river diversity (open-ended, generic framework, channel and floodplain, regulated and non-regulated)
  - Process-based framework (behavioural regime, capacity for adjustment, evolutionary not static)
  - Comparing like with like – 'open-ended'; new variants can be added
  - Nested hierarchical framework
  - Catchment-framed assessment
  - Linkages and change in space and time – connectivity, fragmentation, response gradient, treatment response
- 'Causes not symptoms
- Generic – can be adapted for use in any landscape setting (e.g regulated versus non-regulated, rural versus urban)

## KNOW YOUR CATCHMENT

- Importance of place-based applications: Geography & History Matter
- Nested hierarchical framework: Proactive management tool: Looking forwards, informed by the past

## A nested hierarchy of spatial and temporal linkages



Catchment / subcatchment

Landscape Unit

Reach= River Style

Landform = Geomorphic Unit

Hydraulic Unit

Describe river character and behaviour

Explain evolution and condition

Predict future character and behaviour

Assess geomorphic recovery potential

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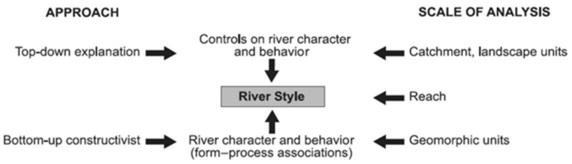
## Top-down, bottom-up framing of River Style analysis



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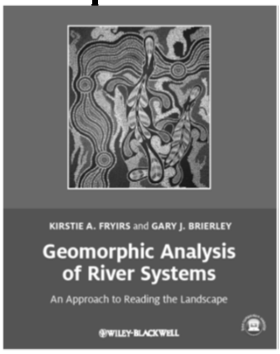
## NEVER forget the importance of fieldwork



- Things must make sense ‘on the ground’
- Read the landscape, relating place-based knowledge to generalized (theoretical) principles
- The importance of context

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# SUMMARY

- Importance of catchment-scale thinking: Know Your Catchment
  - Identify what we are trying to protect, and why
  - Don’t fight the site: Respect diversity & work with change
  - Identify key attributes, species and controls on ecosystem functionality
  - Proactive, future focus: Concern for evolutionary trajectory and threatening processes (e.g. threshold-induced changes)
- Informing the future: Effective use of emerging tools and technologies
  - Linking desk-top techniques with field-based measurement and analytical procedures (representativeness, transferability, etc)
  - Use of modelling applications
  - Working with managers and river practitioners to inform geomorphic assessments of river systems (e.g. Catchment Action Plans)

## Presentation 2:

## Stage One of the River Styles Framework: Analysis of river character, behaviour, patterns and controls

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## Analysing river character

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## Identifying River Styles

- River Styles are differentiated on the basis of:
  - Valley-setting
  - Channel planform
  - Channel and floodplain geomorphic units
  - Bed material texture
- Each River Style has a distinctive set of attributes

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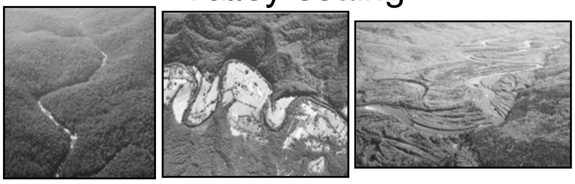
## Valley-setting



- **Confined** … Absent or isolated pockets of floodplain
  - **Partly-confined** … Discontinuous pockets of floodplain
- **Laterally-unconfined** ... Continuous floodplains along both banks
  - With continuous channels
  - With discontinuous/absent channels

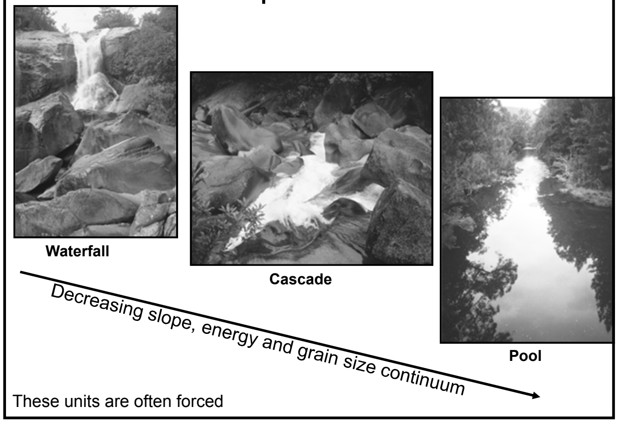
## Channel planform

- number of channels
  - single, multichannelled or no channel
- sinuosity
  - the amount of meandering exhibited by a stream channel, i.e. channel ‘bendiness’
  - $\boxed{S = L/\lambda}$ L = length of stream along thalweg, $\lambda$ = length of valley along axis
- lateral adjustment of channel
  - ability of the channel to adjust its position on the valley floor (lateral migration, thalweg shift, avulsion)

## Geomorphic units

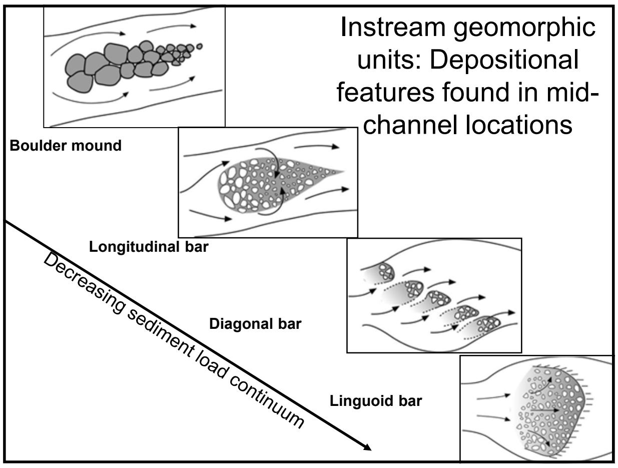
- The building blocks of rivers
- Form-process associations
  - specific relationship between individual landforms and the set of processes that produces them
  - means to interpret river behaviour, evolution and condition
- Categories:
  - instream sculpted (pg 83, B&F 2005)
  - instream depositional (mid-channel) (pg 87, B&F 2005)
  - instream depositional (bank-attached) (pg 94, B&F 2005)
  - fine-grained sculpted (pg 148, F&B 2013)
  - floodplain (pg 110, B&F 2005)
- Distinct channel and floodplain assemblages for different River Styles$^{®}$

## Instream sculpted or erosional units

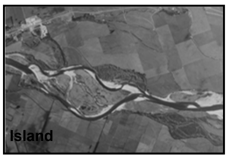


These units are often forced

## Instream geomorphic units: Depositional features found in mid-channel locations



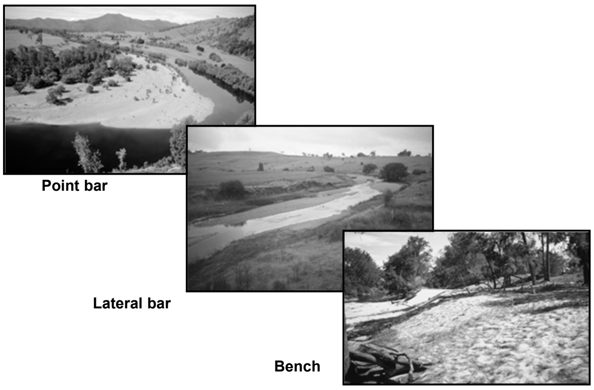
## Other mid-channel geomorphic units


Island


Bedrock core bar

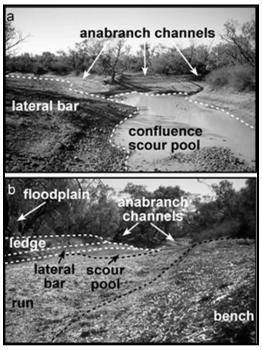

Sand or gravel sheet

## Instream geomorphic units: Depositional features found in bank-attached locations



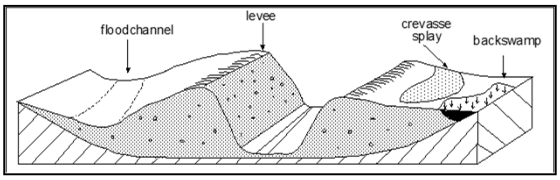
## Instream geomorphic units: Sculpted fine grained geomorphic units

- Geomorphic units found in fine grained river systems that have been scoured from the surrounding sediment.
- Resemble depositional forms – but really should be noted as erosional.



Pg148 F&B

## Floodplain geomorphic units



# Bed material texture

Grain size (Wentworth scale)

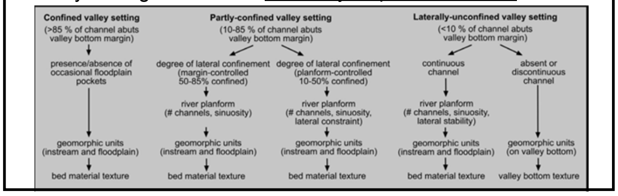
| Class name | Grain size (mm) | Grain size (phi (Ø) |
|---|---|---|
| Bedrock | | |
| Boulder | ≥ 256 | ≤ -9 |
| Cobble | 64 - 256 | -6 to -9 |
| Gravel | 2 - 64 | -1 to -6 |
| Sand | 0.062 - 2 | 4 to -1 |
| Silt | 0.004 – 0.062 | 8 to 4 |
| Clay | ≤ 0.004 | ≥ -8 |

Termed fine-grained

Other considerations:
Bedload versus mixed load versus suspended load rivers

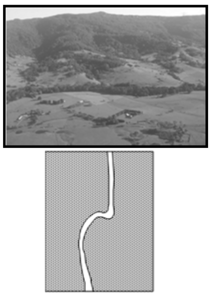
# Identification of River Styles

- ➢ Entry level:
  - Valley-setting (channel-valley margin relationship)
- ➢ Then, mix of:
  - River planform (number and sinuosity of channels, lateral stability of channel)
  - Instream and floodplain geomorphic units
  - Bed material texture
- ➢ Specific procedures are used to identify River Styles in each valley setting – this is the River Styles procedural tree

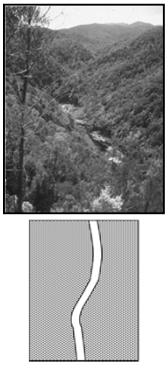


# Confined valley setting

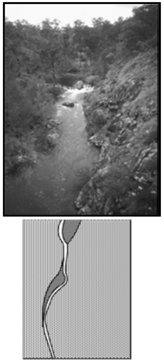
Steep headwater



Gorge

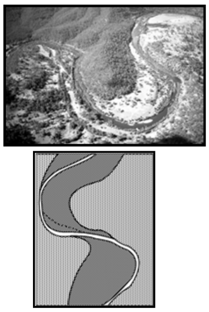


Confined with occasional floodplain pockets

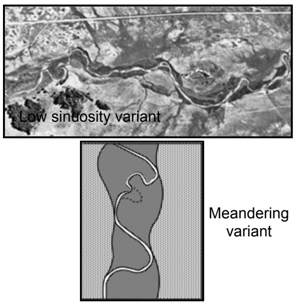


# Partly-confined valley setting

Partly-confined, bedrock-controlled discontinuous floodplain



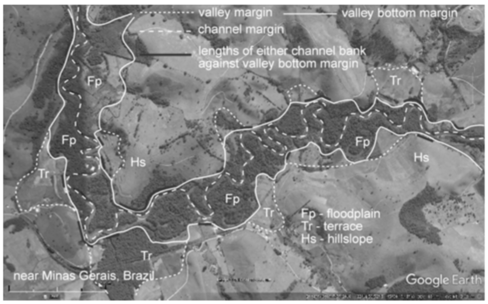
Partly-confined, planform-controlled discontinuous floodplain



The role of terraces and other constraining (e.g. terraces and fans), and confining features (stop banks, river works etc.) should also be considered............

# Partly confined

## (planform-controlled and terrace constrained)



Partly confined, planform-controlled, meandering, terrace constrained’ discontinuous floodplain, sand bed

PC_PC_meandering_terrCS_dcfp_Sbed

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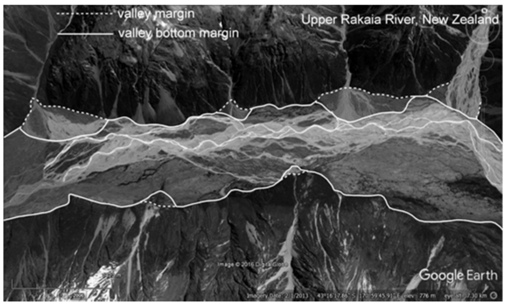
# Partly confined

## (planform-controlled and fan constrained)



Partly confined, planform-controlled, braided, fan constrained, discontinuous floodplain, gravel bed

PC_PC_braided_fanCS_dcfp_Gbed

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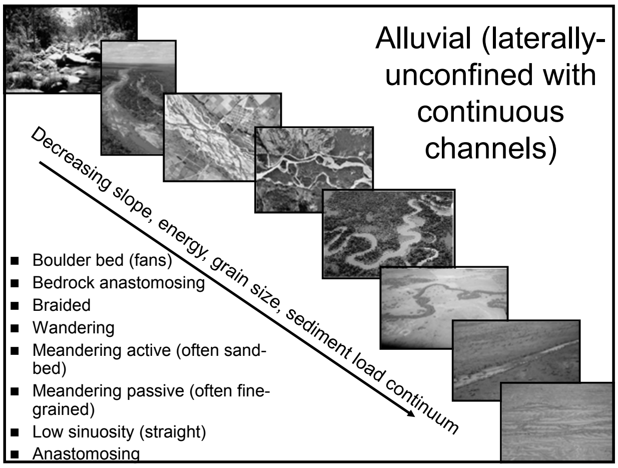
# Alluvial (laterally-unconfined with continuous channels)



- Boulder bed (fans)
- Bedrock anastomosing
- Braided
- Wandering
- Meandering active (often sand-bed)
- Meandering passive (often fine-grained)
- Low sinuosity (straight)
- Anastomosing

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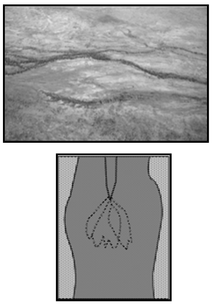
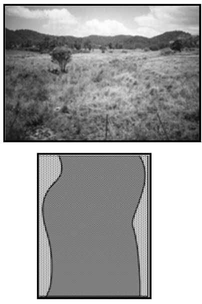
# Laterally-unconfined valley setting (discontinuous channel)

Chain-of-ponds

Floodout

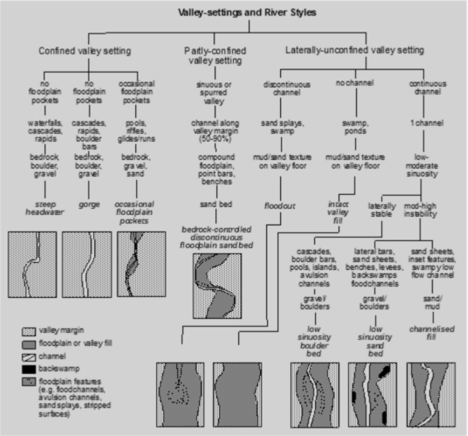


Intact valley fill (swamp)



# Producing a River Styles tree

- Using the procedural tree produce a flow diagram representing how each River Style was identified
- Remember:
  - Methods for identification are **valley-setting specific**
  - River Styles are identified on a **mix of parameters** (geomorphic units assemblage, river planform, bed material texture)
- Each River Style is given a diagnostic name
- Each River Style has a distinctive set of attributes



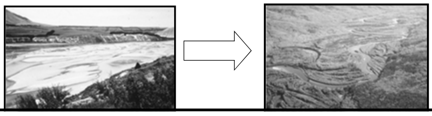
Catchment specific River Styles tree (Bega catchment)

# Interpreting river behaviour

# River behaviour vs change

- River behaviour refers to 'natural' adjustments that occur for a particular river type (e.g. meander migration occurs along meandering rivers). Brierley and Fryirs (2005) (p143): "Adjustments to river morphology induced by a range of erosional and depositional mechanisms by which water moulds, reworks and reshapes fluvial landforms, producing characteristic assemblages of landforms at the reach scale".

- River change occurs with a shift in the assemblage of landforms along a river resulting in a wholesale change in river type and behavioural regime (e.g. from braided to meandering).



- River behaviour is assessed at three flow stages, reflecting how a river behaves under different flow magnitudes.
  - low flow stage
  - bankfull stage
  - overbank stage
- The ***capacity for river adjustment*** (behaviour) measures the degree to which a river has the ability to adjust in the vertical, lateral and wholesale dimensions at different flow stages.

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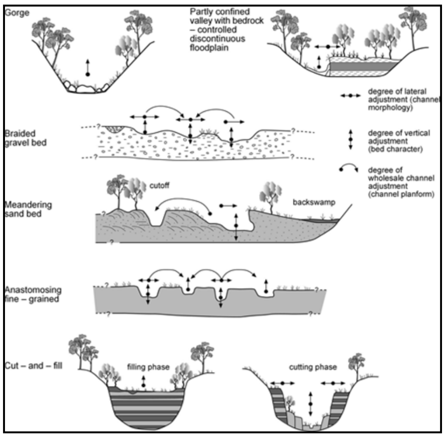
Forms of adjustment

Natural capacity for adjustment

Differing mixes of formative processes

Variable rates of activity (sensitivity)



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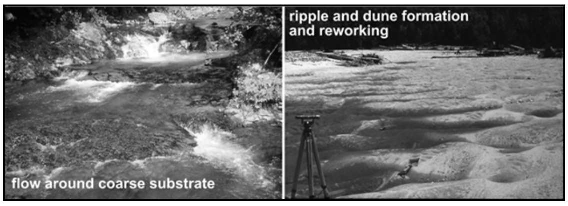
## Low flow stage river behaviour

- Involves the organisation of sediments on the channel bed (i.e. adjustments to substrate and bedform organisation and flow alignment around geomorphic units).



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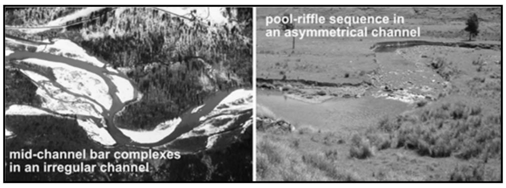
## Bankfull stage river behaviour

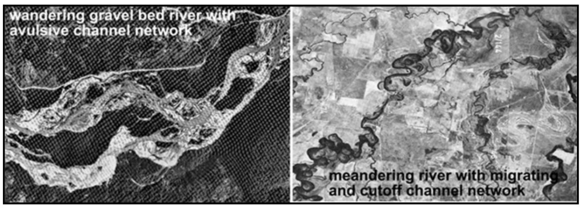
- Processes responsible for channel bed and bank adjustments (inc bank erosion).
- Processes responsible for the size and shape of channels.
- Processes responsible for the formation and reworking of instream geomorphic units.



•Different types of river have distinct instream geomorphic unit assemblages and hence bankfull behaviour …….

## Overbank stage river behaviour

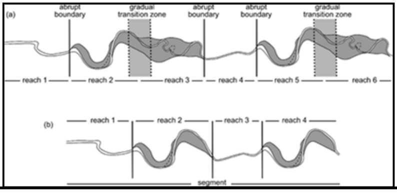
- Involves the formation and reworking of floodplains and their associated geomorphic units.
- There are 2 dominant forms of floodplain formation:
  - Overbank vertical accretion
  - Lateral accretion
- Multiple forms of floodplain reworking such as:
  - Catastrophic floodplain stripping, cutoffs, floodchannels, palaeochannels etc.



## Downstream patterns and controls

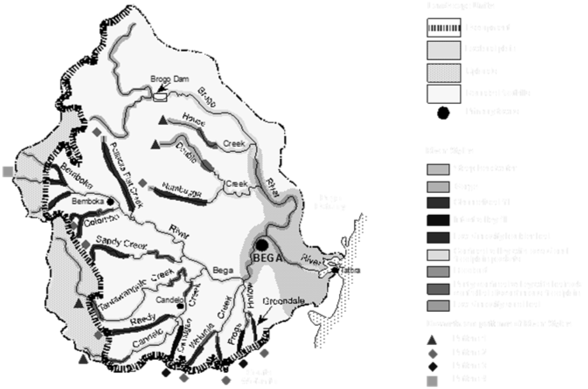
## Boundaries between River Styles (reaches)

- Identify boundaries between River Styles and put them on maps and longitudinal profiles
  - wherever a wholesale change in river character occurs
  - may be distinct or gradual
- May coincide with:
  - tributary confluences, changes in slope, changes in valley confinement
- Splitting versus clumping

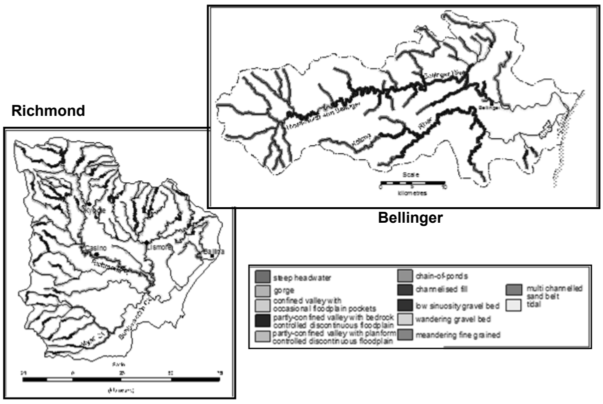


## Downstream pattern of River Styles

(Bega catchment)



## Catchment-wide River Styles maps and patterns



## Assessing controls on character, behaviour and downstream patterns of River Styles

### Imposed boundary conditions

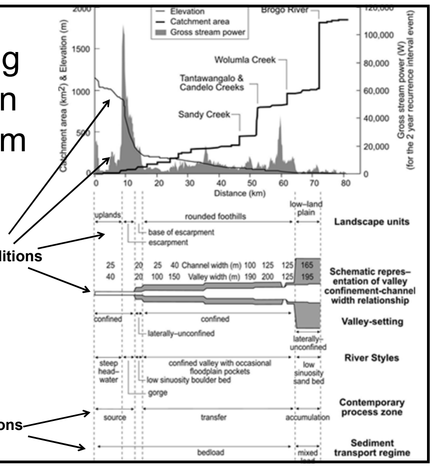
- Imposed boundary conditions – controls that over geomorphic timeframes (centuries to thousands of years) are largely set/imposed and do not change.
- Examples:
  - valley slope,
  - valley confinement,
  - valley shape,
  - sediment calibre (linked to geology)
- These controls determine the maximum potential energy conditions within which river can operate (i.e. they set outer ranges of behaviour).
- Essentially set the type of valley-setting.

## Assessing controls on character, behaviour and downstream patterns of River Styles

### Flux boundary conditions

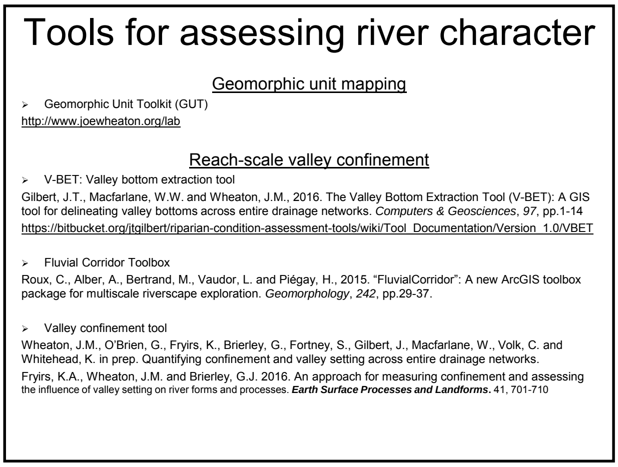
- Flux boundary conditions - conditions that over geomorphic timeframes (centuries to thousands of years) are able to change.
- Examples:
  - flow regime – discharge and flow variability
  - sediment transfer regime – volume and rate of supply of sediment
  - vegetation associations – function of climate
- These conditions determine the specific energy conditions under which rivers operate.
- Determine the range of types of river that can be found within imposed boundary conditions (i.e. valley-setting).

## Interpreting controls on downstream patterns



**Imposed boundary conditions**

**Flux boundary conditions**



# Tools for assessing river character

## Geomorphic unit mapping

- Geomorphic Unit Toolkit (GUT)

http://www.joewheaton.org/lab

## Reach-scale valley confinement

- V-BET: Valley bottom extraction tool

Gilbert, J.T., Macfarlane, W.W. and Wheaton, J.M., 2016. The Valley Bottom Extraction Tool (V-BET): A GIS tool for delineating valley bottoms across entire drainage networks. *Computers & Geosciences*, *97*, pp.1-14

https://bitbucket.org/jtgilbert/riparian-condition-assessment-tools/wiki/Tool_Documentation/Version_1.0/VBET

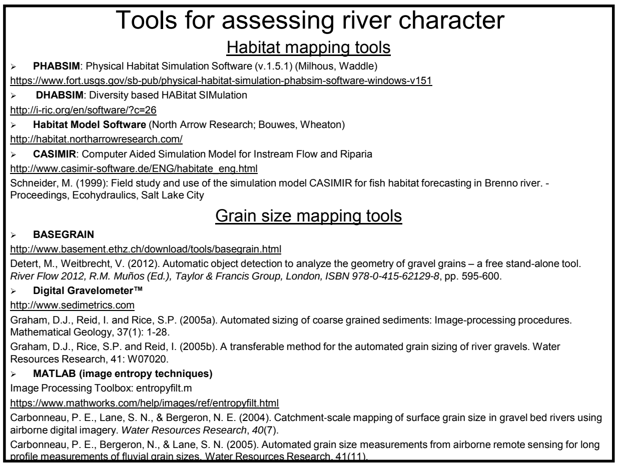
- Fluvial Corridor Toolbox

Roux, C., Alber, A., Bertrand, M., Vaudor, L. and Piégay, H., 2015. "FluvialCorridor": A new ArcGIS toolbox package for multiscale riverscape exploration. *Geomorphology*, *242*, pp.29-37.

- Valley confinement tool

Wheaton, J.M., O'Brien, G., Fryirs, K., Brierley, G., Fortney, S., Gilbert, J., Macfarlane, W., Volk, C. and Whitehead, K. in prep. Quantifying confinement and valley setting across entire drainage networks.

Fryirs, K.A., Wheaton, J.M. and Brierley, G.J. 2016. An approach for measuring confinement and assessing the influence of valley setting on river forms and processes. ***Earth Surface Processes and Landforms*.** 41, 701-710



# Tools for assessing river character

## Habitat mapping tools

- **PHABSIM**: Physical Habitat Simulation Software (v.1.5.1) (Milhous, Waddle)

https://www.fort.usgs.gov/sb-pub/physical-habitat-simulation-phabsim-software-windows-v151

- **DHABSIM**: Diversity based HABitat SIMulation

http://i-ric.org/en/software/?c=26

- **Habitat Model Software** (North Arrow Research; Bouwes, Wheaton)

http://habitat.northarrowresearch.com/

- **CASIMIR**: Computer Aided Simulation Model for Instream Flow and Riparia

http://www.casimir-software.de/ENG/habitate_eng.html

Schneider, M. (1999): Field study and use of the simulation model CASIMIR for fish habitat forecasting in Brenno river. - Proceedings, Ecohydraulics, Salt Lake City

## Grain size mapping tools

- **BASEGRAIN**

http://www.basement.ethz.ch/download/tools/basegrain.html

Detert, M., Weitbrecht, V. (2012). Automatic object detection to analyze the geometry of gravel grains – a free stand-alone tool. *River Flow 2012, R.M. Muños (Ed.), Taylor & Francis Group, London, ISBN 978-0-415-62129-8*, pp. 595-600.

- **Digital Gravelometer™**

http://www.sedimetrics.com

Graham, D.J., Reid, I. and Rice, S.P. (2005a). Automated sizing of coarse grained sediments: Image-processing procedures. Mathematical Geology, 37(1): 1-28.

Graham, D.J., Rice, S.P. and Reid, I. (2005b). A transferable method for the automated grain sizing of river gravels. Water Resources Research, 41: W07020.

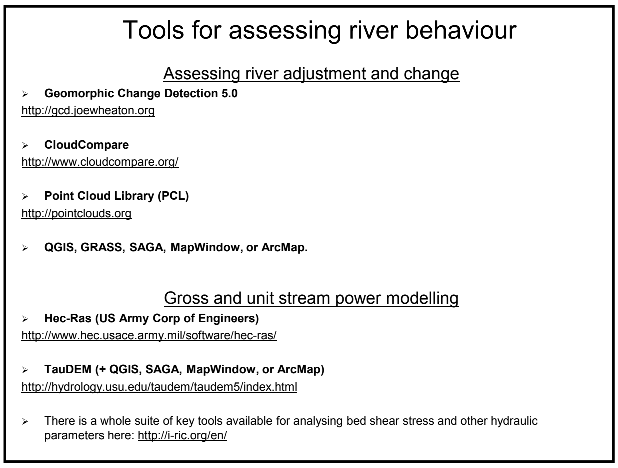
- **MATLAB (image entropy techniques)**

Image Processing Toolbox: entropyfilt.m

https://www.mathworks.com/help/images/ref/entropyfilt.html

Carbonneau, P. E., Lane, S. N., & Bergeron, N. E. (2004). Catchment-scale mapping of surface grain size in gravel bed rivers using airborne digital imagery. *Water Resources Research*, *40*(7).

Carbonneau, P. E., Bergeron, N., & Lane, S. N. (2005). Automated grain size measurements from airborne remote sensing for long profile measurements of fluvial grain sizes. Water Resources Research, 41(11).



# Tools for assessing river behaviour

## Assessing river adjustment and change

- **Geomorphic Change Detection 5.0**

http://gcd.joewheaton.org

- **CloudCompare**

http://www.cloudcompare.org/

- **Point Cloud Library (PCL)**

http://pointclouds.org

- **QGIS, GRASS, SAGA, MapWindow, or ArcMap.**

## Gross and unit stream power modelling

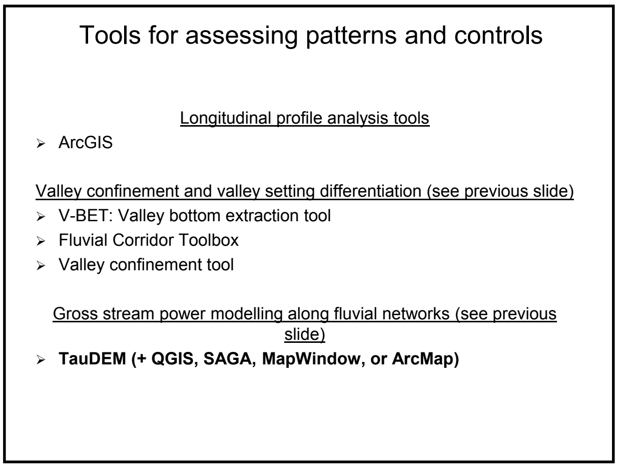
- **Hec-Ras (US Army Corp of Engineers)**

http://www.hec.usace.army.mil/software/hec-ras/

- **TauDEM (+ QGIS, SAGA, MapWindow, or ArcMap)**

http://hydrology.usu.edu/taudem/taudem5/index.html

- There is a whole suite of key tools available for analysing bed shear stress and other hydraulic parameters here: http://i-ric.org/en/



# Tools for assessing patterns and controls

## Longitudinal profile analysis tools

- ArcGIS

## Valley confinement and valley setting differentiation (see previous slide)

- V-BET: Valley bottom extraction tool
- Fluvial Corridor Toolbox
- Valley confinement tool

## Gross stream power modelling along fluvial networks (see previous slide)

- **TauDEM (+ QGIS, SAGA, MapWindow, or ArcMap)**

**Exercise 1: River Styles quiz**

You will be shown a number of Google Earth© images. Put the photo number next to the river type.

| **River Style** | **Photograph #** |
|---|---|
| Laterally-unconfined, chain of ponds | |
| Confined, gorge | |
| Laterally-unconfined, braided | |
| Laterally-unconfined low-moderate sinuosity sand bed | |
| Laterally-unconfined, anastomosing | |
| Laterally-unconfined, wandering gravel-bed | |
| Partly-confined, bedrock-controlled discontinuous floodplain pockets | |
| Partly-confined, low-moderate sinuosity planform-controlled discontinuous floodplain pockets | |

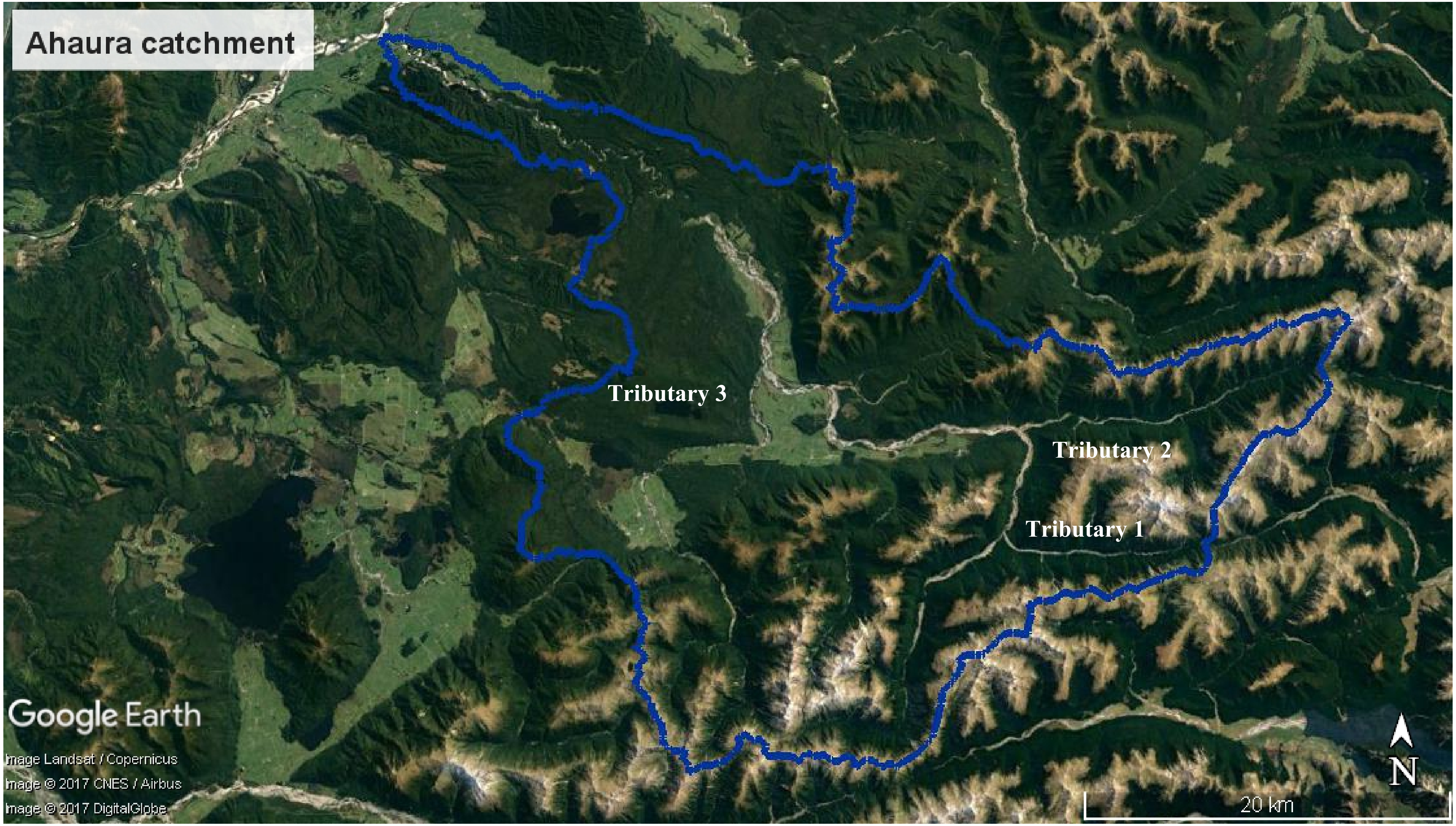
**Exercise 2: Part A) Identifying boundaries between reaches. Part B) Mapping geomorphic units and making interpretations of river behaviour.**

**PART A)**

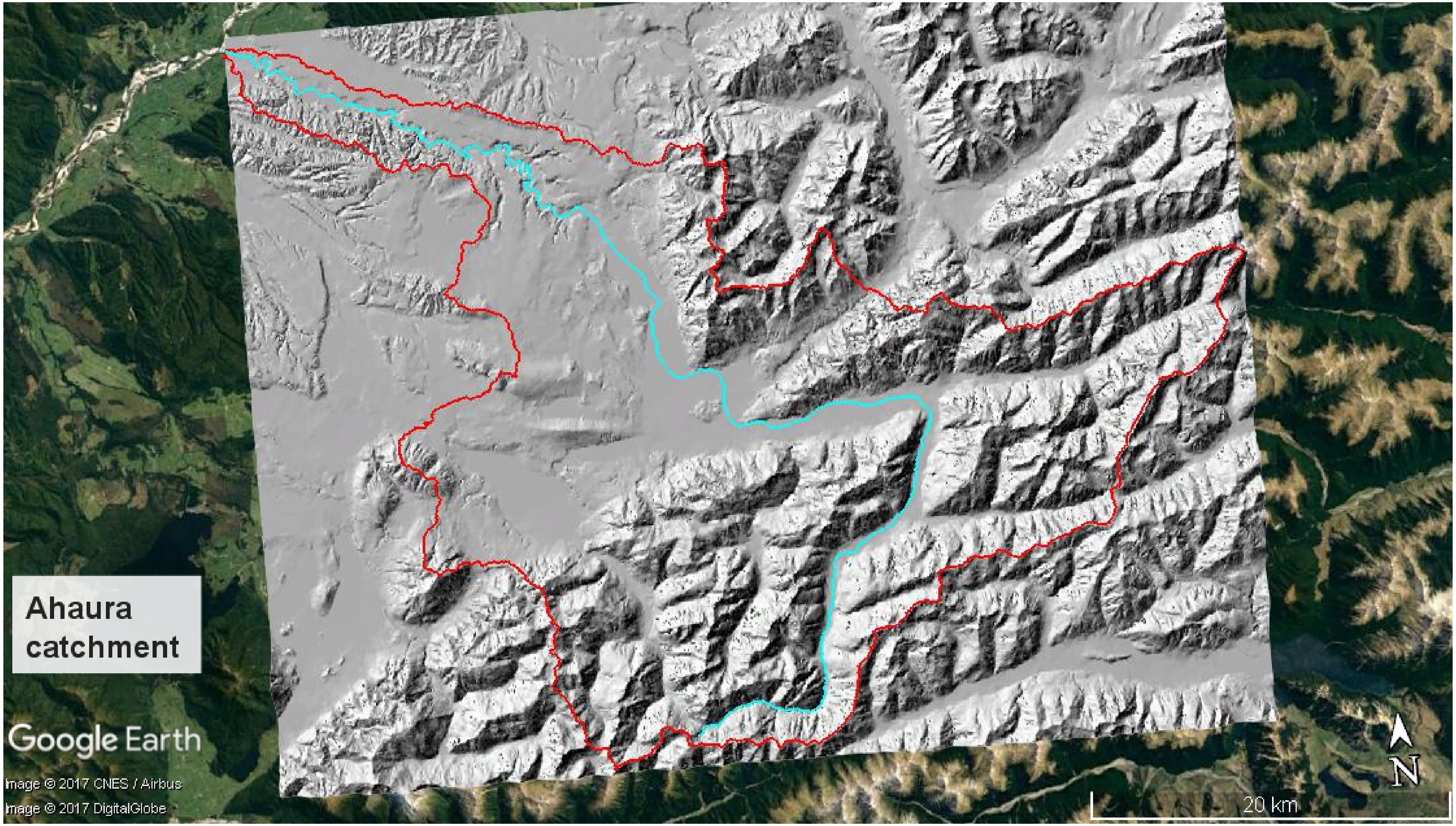
You have been given Google Earth© image of the Ahaura Catchment.

As a group, place reach boundaries on this map and along the longitudinal profile. Identify the River Styles you see along this river.

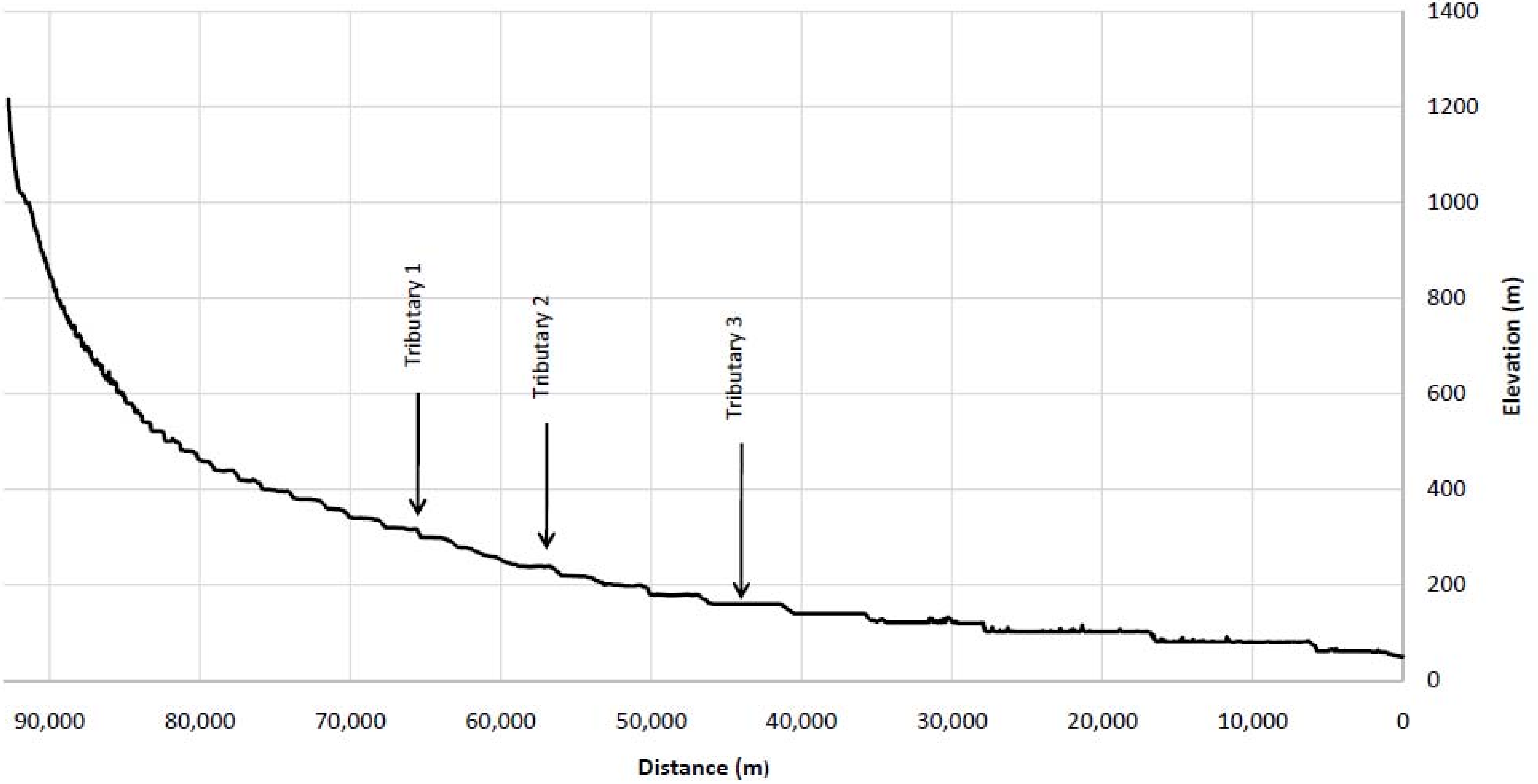
The streamline you should follow is on the hillshade DEM. Are you a splitter or a clumper?



**Hillshade DEM with Ahaura River streamline noted**



**Longitudinal profile of the Ahaura River. Streamline noted of the hillshade DEM.**



**Note what are some of the key controls on this downstream pattern. Why do you get the type of river you do at the position that you do along the longitudinal profile?**

**PART B)**

For one of the River Styles identified in the quiz, you will be given a Google Earth© image.

- Map and identify/label geomorphic features directly onto the image (valley margin, channel planform, instream and floodplain geomorphic units, inferred bed material size)

In the tables below, list the types of geomorphic units you have mapped and make an interpretation of river behaviour at low flow, bankfull, overbank stages.

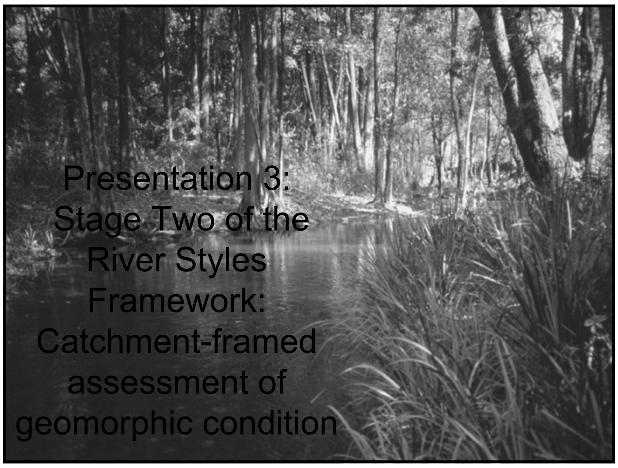
**Valley setting:**
**River Style name:**

**GEOMORPHIC UNITS**

| **Instream geomorphic units** |
|---|
| |
| **Floodplain geomorphic units** |
| |

**RIVER BEHAVIOUR**

| **Low flow stage behaviour** |
|---|
| |
| **Bankfull stage behaviour** |
| |
| **Overbank stage behaviour** |
| |



# Presentation 3: Stage Two of the River Styles Framework: Catchment-framed assessment of geomorphic condition

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**River condition**
What is the present geomorphic condition of River XX vs River YY?

**River recovery**
What is the likelihood of River XX recovering towards something like River YY over the next 50-100 years?

---

## Deriving a meaningful procedure to assess geomorphic river condition

**Definition:**

- Geomorphic river condition is defined as the state of the river reach as it is today.
- Assessing whether river structure is appropriate for its environmental/landscape setting
- Links to ‘health’ in ecological terms

**Must be:**

- Framed in terms of river type…. Compare like-with-like
- Process based….Measure relevant parameters for different River Styles
- Framed in terms of river  evolution … identify an ‘expected reference condition’ against which to make assessment
- Linked to ecology for diagnostic indicators of river condition

---

## Stage Two: Assessing geomorphic river condition

Step One: Interpret river evolution to identify whether change has been irreversible

⇩

Step Two: Identify a reference reach for the River Style

⇩

Step Three: Determine appropriate measures of geomorphic condition for that River Style, based upon its capacity for adjustment

⇩

Step Four: Relate your reach to the reference reach

## Step One: Interpret river evolution to identify whether change has been irreversible

- Assessments of river evolution are used to examine how the river had adjusted in the past and to explain how the river is adjusting today (future trajectory is used to assess river recovery – Stage 3).
- Basis for examining the causes of ‘condition’ rather than just the symptoms.
- If change has been irreversible – identify reference reach for the contemporary River Style, not its pre-disturbance type.

## Step Two: Identify a reference reach for the River Style

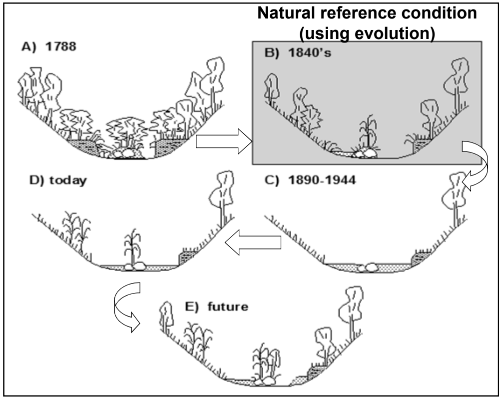
**Two key concepts:**

1) Determine what is ‘expected’ for that type of river.
2) Identify a reference condition (good condition reach) for that type of river as it is today.

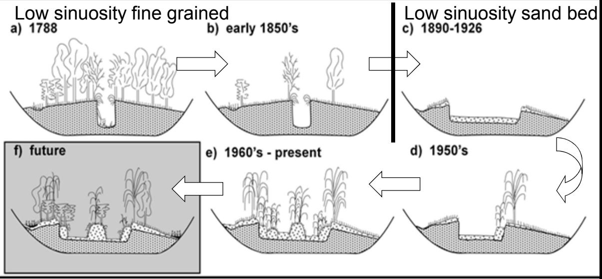
Identify the best available version of the contemporary River Style against which to compare other reaches.

- may be available in the catchment (remnants)
- identify them from the evolutionary sequence
- use geomorphic insights about how we would expect the river to look and adjust

## Step 2: Determine the evolution and natural reference condition (Confined with occ. fplain. pockets)



## Step 2: Determine the evolution and natural reference condition (Laterally unconfined, low sinuosity, sand bed)



**Natural reference condition (using geomorphic insight)**

## Step Three: Determine appropriate measures of geomorphic condition for that River Style, based upon its capacity for adjustment

- Identify ‘desirability criteria’ based on parameters that will give a meaningful signal about the condition for a reach.
- Measure parameters that are relevant for the river type under investigation.
- Essentially asking: How can this river adjust and what measures can be used to indicate the rate and extent of those adjustments?

---

## Using capacity for adjustment to identify geoindicators

- Measure those geoindicators that are relevant for the river type under investigation.
- **Capacity for adjustment**
  - Channel attributes
  - River planform
  - Bed character
- **Numerous geoindicators**, for example:
  - Channel attributes - size, shape, bank morphology, vegetation structure
  - River planform - # of channels, sinuosity, lateral stability, geomorphic unit assemblage
  - Bed character – grain size, sorting, sediment regime

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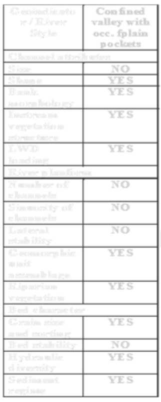
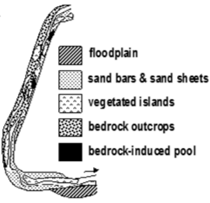
## Confined with occasional floodplain pockets



| Geoindicator / River Style | Confined valley with occ. fplain pockets |
|---|---|
| Channel attributes | |
| Size | NO |
| Shape | YES |
| Bank morphology | YES |
| Instream vegetation structure | YES |
| LWD loading | YES |
| River planform | |
| Number of channels | NO |
| Sinuosity of channels | NO |
| Lateral stability | NO |
| Geomorphic unit assemblage | YES |
| Riparian vegetation | YES |
| Bed character | |
| Grain size and sorting | YES |
| Bed stability | NO |
| Hydraulic diversity | YES |
| Sediment regime | YES |



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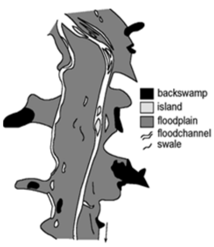
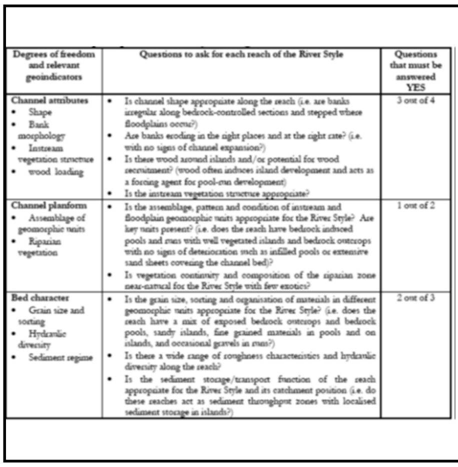
## Laterally unconfined, low sinuosity, sand bed

| Geoindicator / River Style | Low sinuosity sand bed |
|---|---|
| Channel attributes | |
| Size | YES |
| Shape | YES |
| Bank morphology | YES |
| Instream vegetation structure | YES |
| LWD loading | YES |
| River planform | |
| Number of channels | YES |
| Sinuosity of channels | YES |
| Lateral stability | YES |
| Geomorphic unit assemblage | YES |
| Riparian vegetation | YES |
| Bed character | |
| Grain size and sorting | YES |
| Bed stability | YES |
| Hydraulic diversity | YES |
| Sediment regime | YES |





| Degrees of freedom and relevant geoindicators | Questions to ask for each reach of the River Style | Questions that must be answered YES |
|---|---|---|
| **Channel attributes**<br>• Shape<br>• Bank morphology<br>• Instream vegetation structure<br>• wood loading | • Is channel shape appropriate along the reach (i.e. are banks irregular along bedrock-controlled sections and stepped where floodplains occur?)<br>• Are banks eroding in the right places and at the right rate? (i.e. with no signs of channel expansion?)<br>• Is there wood around islands and/or potential for wood recruitment? (wood often induces island development and acts as a forcing agent for pool-run development)<br>• Is the instream vegetation structure appropriate? | 3 out of 4 |
| **Channel planform**<br>• Assemblage of geomorphic units<br>• Riparian vegetation | • Is the assemblage, pattern and condition of instream and floodplain geomorphic units appropriate for the River Style? Are key units present? (i.e. does the reach have bedrock induced pools and runs with well vegetated islands and bedrock outcrops with no signs of deterioration such as infilled pools or extensive sand sheets covering the channel bed)?<br>• Is vegetation continuity and composition of the riparian zone near-natural for the River Style with few exotics? | 1 out of 2 |
| **Bed character**<br>• Grain size and sorting<br>• Hydraulic diversity<br>• Sediment regime | • Is the grain size, sorting and organisation of materials in different geomorphic units appropriate for the River Style? (i.e. does the reach have a mix of exposed bedrock outcrops and bedrock pools, sandy islands, fine grained materials in pools and on islands, and occasional gravels in runs?)<br>• Is there a wide range of roughness characteristics and hydraulic diversity along the reach?<br>• Is the sediment storage/transport function of the reach appropriate for the River Style and its catchment position (i.e. do these reaches act as sediment throughput zones with localised sediment storage in islands?) | 2 out of 3 |

Desirability criteria for Confined valley with occasional floodplain pockets River Style – Bega catchment

(from Fryirs and Brierley e-book at www.riverstyles.com)

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## Step Four: Relate your reach to the reference reach and explain geomorphic condition

- Relate contemporary river condition to the expected reference reach.
- Essentially asking about the ‘appropriateness’ of the geomorphic structure of a reach based on the relevant geoindicators for each River Style.
- Does the river have a character and behaviour that is ‘expected’ for that River Style?
- Highlights how far from the reference condition the reach has adjusted, and which attributes are not functioning appropriately.
- Explains the causes not the symptoms of change.

---

## Reaches in a **good** condition

- River character and behaviour are appropriate for the River Style, given its valley-setting and within-catchment position.
- Native riparian vegetation associations occur.
- Answer yes to all the desirability criteria.

---

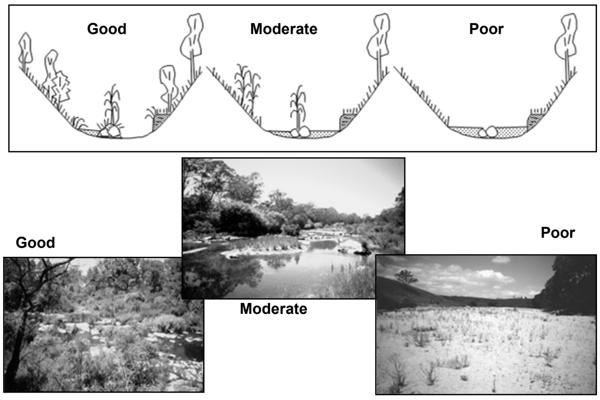
## Reaches in a **moderate** condition

- Locally, geomorphic structures are in the wrong places and there are some anomalous processes and/or vegetation associations.
- Answer yes to most of the desirability criteria.

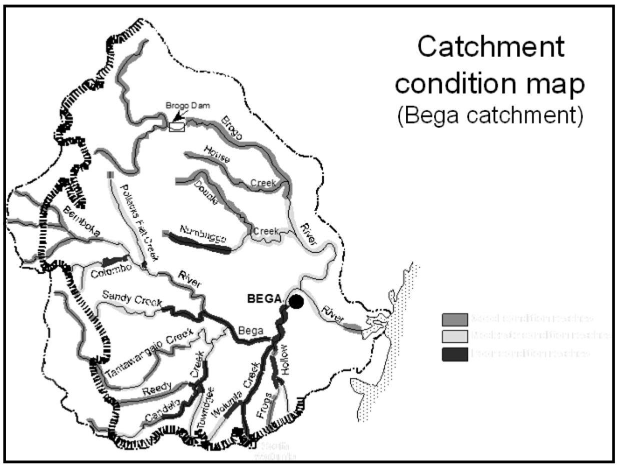
## Reaches in a **poor** condition

- Accelerated geomorphic instability occurs.
- Breaching a threshold could push the reach into a new River Style or cause irreversible geomorphic change.
- Geomorphic forms are found in inappropriate places.
- Processes are out-of-balance or anomalous.
- Vegetation is non-existent or exotic in composition.
- Answer no to all of the desirability criteria.

Example 1: Confined with occ. fp. pockets River Style



## Catchment condition map
(Bega catchment)



## Take home messages

- Compare like with like, measuring appropriate (diagnostic) indicators of river condition for any given river type.
- This should be framed in relation to ‘what is expected’ for that type of river.

## Tools for assessing river evolution and geomorphic condition

River evolution

- **Geomorphic Change Detection 5.0**

http://gcd.joewheaton.org

- **CloudCompare**

http://www.cloudcompare.org/

- **Point Cloud Library (PCL)**

http://pointclouds.org

- **QGIS, GRASS, SAGA, MapWindow, or ArcMap**

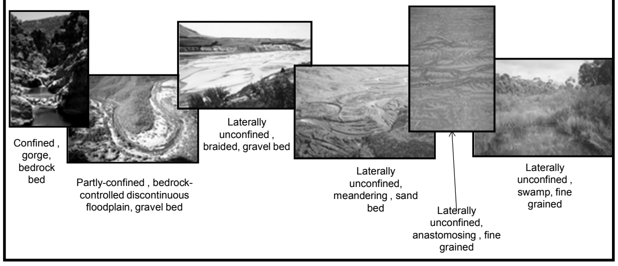
River condition and geoindicators

- n/a yet

---

## Exercise: Selecting appropriate indicators of geomorphic river condition

- Channel attributes (size, shape, bank morphology, riparian vegetation)
- Planform attributes (number of channels, sinuosity, lateral stability, geomorphic unit assemblage)
- Bed characteristics (grain size, sorting, bed stability, hydraulic diversity)



## Exercise 3: Selecting appropriate geoindicators and designing desirability criteria for measuring the condition of different River Styles.

For the **Partly confined valley with bedrock-controlled discontinuous floodplain** and **Laterally unconfined valley, low-moderate sinuosity sand bed** River Styles from previous exercises, and an extra example (**Laterally unconfined valley, swamp**), identify geoindicators that could be used to assess the geomorphic condition of the reaches pictured. Put yes or no next to each geoindicator in the tables below.

Remember:

- Ask the question: How can this river adjust and what measures will give me a signal about the rate and extent of those adjustments?
- Chose geoindicators that are relevant for the river type under investigation.

### PARTLY CONFINED, BEDROCK-CONTROLLED DISCONTINUOUS FLOODPLAIN, GRAVEL BED

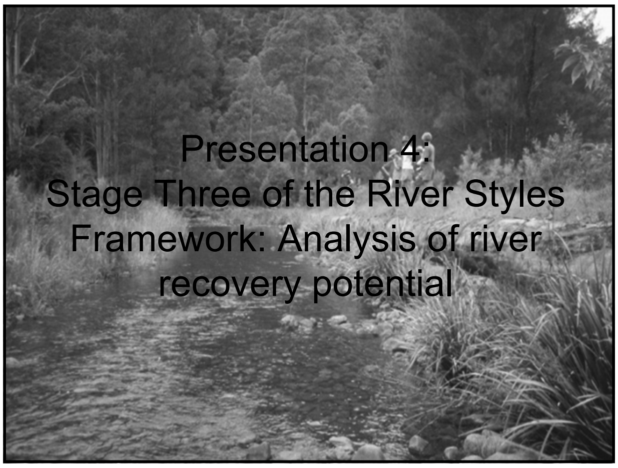
| Geoindicator | Relevant or not? | Desirability criteria (What question would you ask?) |
|---|---|---|
| Channel attributes | | |
| Size | | |
| Shape | | |
| Bank morphology | | |
| Instream vegetation structure | | |
| Wood loading | | |
| **River planform** | | |
| Number of channels | | |
| Sinuosity of channels | | |
| Lateral stability | | |
| Geomorphic unit assemblage | | |
| Riparian vegetation | | |
| **Bed character** | | |
| Grain size and sorting | | |
| Bed stability | | |
| Hydraulic diversity | | |
| Sediment regime | | |

**LATERALLY UNCONFINED, LOW-MODERATE SINUOSITY, SAND BED**

| Geoindicator | Relevant or not? | Desirability criteria (What question would you ask?) |
|---|---|---|
| Channel attributes | | |
| Size | | |
| Shape | | |
| Bank morphology | | |
| Instream vegetation structure | | |
| Wood loading | | |
| **River planform** | | |
| Number of channels | | |
| Sinuosity of channels | | |
| Lateral stability | | |
| Geomorphic unit assemblage | | |
| Riparian vegetation | | |
| **Bed character** | | |
| Grain size and sorting | | |
| Bed stability | | |
| Hydraulic diversity | | |
| Sediment regime | | |

### LATERALLY UNCONFINED, SWAMP, FINE GRAINED

| **Geoindicator** | **Relevant or not?** | **Desirability criteria (What question would you ask?)** |
|---|---|---|
| Channel attributes | | |
| Size | | |
| Shape | | |
| Bank morphology | | |
| Instream vegetation structure | | |
| Wood loading | | |
| **River planform** | | |
| Number of channels | | |
| Sinuosity of channels | | |
| Lateral stability | | |
| Geomorphic unit assemblage | | |
| Riparian vegetation | | |
| **Bed character** | | |
| Grain size and sorting | | |
| Bed stability | | |
| Hydraulic diversity | | |
| Sediment regime | | |



# Presentation 4: Stage Three of the River Styles Framework: Analysis of river recovery potential

## River recovery potential

- **River recovery** determines the **trajectory** of change a reach is likely to take (3 pathways; degradation, creation, resstoration).
- Determines the **potential** for a reach to move towards a restored or created condition.

**River condition**
What is the present geomorphic condition of River XX vs River YY?

**River recovery**
What is the likelihood of River XX recovering towards something like River YY over the next 50-100 years?

## Deriving a meaningful procedure to assess geomorphic river recovery potential

- Determining the recovery potential of a reach is a **predictive process**. Predicting what the likelihood is of a river improving its geomorphic condition over the next 50-100 years.
- Must integrate spatial/temporal linkages throughout a catchment (e.g. sediment delivery).
- Must be framed in terms of **limiting factors** (internal to the system) and **pressures** (external to the system) that impact on rivers in the catchment.

## Stage Three: Assessing geomorphic river recovery potential

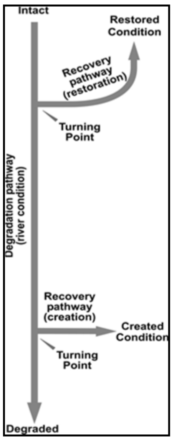
Step One: Determine the trajectory of river change over the next 50-100 years

⇩

Step Two: Assess river recovery potential … place each reach in its catchment context and assess limiting factors to recovery

---

## Trajectories of change



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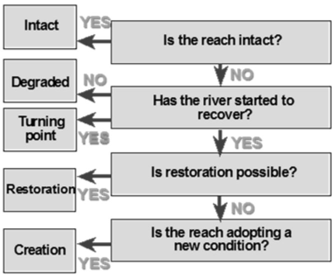
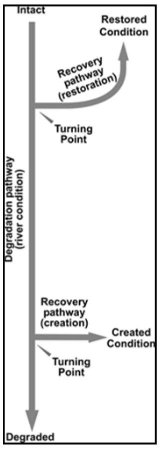
## Stage One: Determining the trajectory of change of a reach … positioning reaches on the recovery diagram





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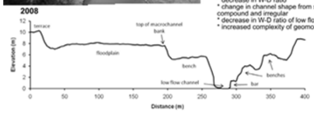
## Measuring river recovery (different measures for different rivers)

**Upper Hunter River @ Key's Bridge**
Laterally-unconfined, meandering gravel bed

**Reach-scale measures**
- decrease in percent of banks affected by bank erosion and mass bank failure
- increased complexity of geomorphic unit assemblage
- decrease in percent of channel bed covered with gravel sheets
- well defined low flow channel
- decrease in number of low flow channels
- increase in percentage of vegetated islands
- decrease in percent coverage of bars
- decrease in percent coverage of ledges
- increase in percent coverage of benches
- decreased ratio of bars to benches
- increase in number of compound bars
- increase in number of pools and riffles in reach
- deeper, more elongate pools and well defined riffles
- greater continuity and coverage of bank and bench vegetation
- greater ratio of native to exotic vegetation
- greater number of wood structures in reach

**Cross-sectional measures**
- decrease in (macro)channel capacity
- decrease in W-D ratio
- change in channel shape from symmetrical to compound and irregular
- decrease in W-D ratio of low flow channel
- increased complexity of geomorphic unit assemblage

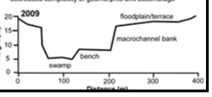


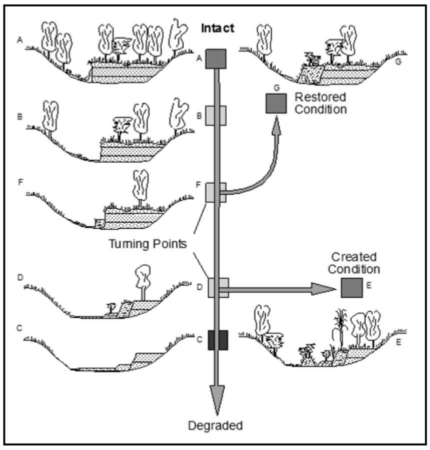
From Fryirs et al. subm. LDD

**Wolumla Creek**
Laterally-unconfined, channelised fill, sand bed

**Reach-scale measures**
- decrease in percent of banks affected by bank erosion and mass bank failure
- decreased complexity of geomorphic unit assemblage
- decrease in percent of channel bed covered with sand sheets
- decrease in percentage coverage of ledges
- increase in percent coverage of benches
- increase in swamp coverage on macrochannel bed
- increased discontinuity of low flow channel on macrochannel be
- greater continuity and coverage of bank and bench vegetation
- greater ratio of native to exotic vegetation

**Cross-sectional measures**
- decrease in (macro)channel capacity
- decrease in W-D ratio
- change in channel shape from symmetrical to compound and irregular
- decreased complexity of geomorphic unit assemblage





Trajectories of change for reaches of a bedrock-controlled discont. floodplain River Style

---

## Step Two: Assessing river recovery potential

- Based on (dis)connectivity of reaches in the catchment and whether limiting factors and pressures will be manifest or suppressed and whether this enhances or inhibits river recovery.
- Based on mix of river condition and position in catchment for each reach (i.e. the limiting factors and pressures in the catchment).

---

## Determine pressures and limiting factors to recovery

### Pressures

**(imposed from outside the system)**

- land use change
- climate change
- water management
- AND ?????

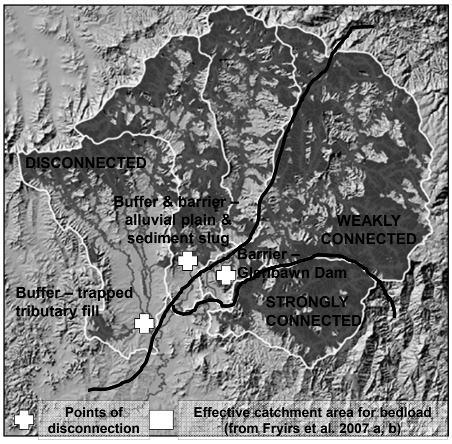
### Limiting factors

**(imposed from inside the system)**

- sediment transfer
- water transfer
- vegetation associations (native & exotic)
- seed sources
- AND ????

***CATCHMENT-SPECIFIC***

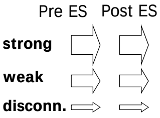
---



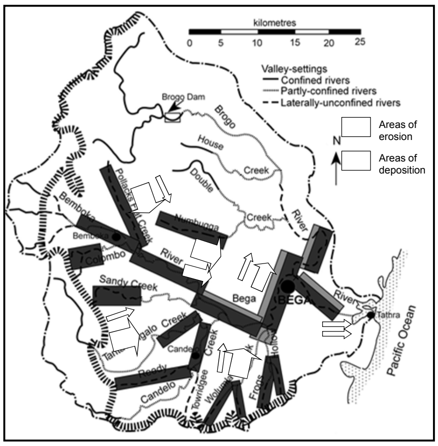
Bedload sediment (dis)-connectivity

- Pattern (spatial variability) of (dis)connectivity is controlled by position of natural and anthropogenic blockages (buffers & barriers).
- Use this information to make assessments of the extent to which disturbances within the catchment will have off-site impacts (either positive or negative).

## Landscape connectivity in Bega catchment (changes over time)



Enhanced connectivity since European settlement

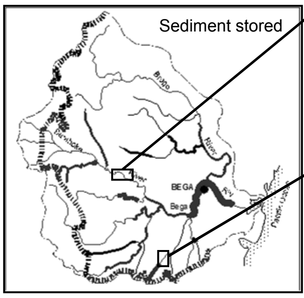


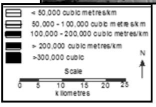
## Future focus: Scenario building

- What happens if sediment supply remains *as is?*
- What happens if sediment supply is *reduced?*
- What happens if sediment supply is *increased?*

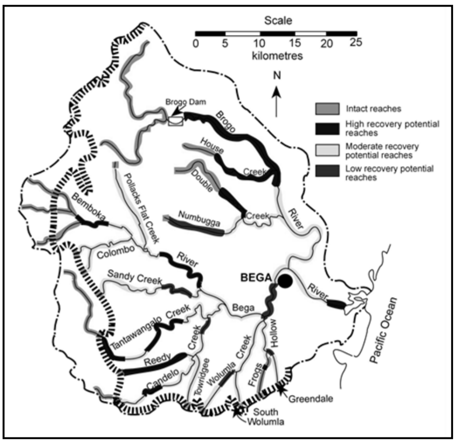
- Modelling applications tied to real world data

## Bega sediment budget Predicting geomorphic responses (recovery potential)





**Description + Explanation = PREDICTION**



## Catchment recovery potential map

(Bega catchment)

# Take home messages

- Assess how past evolutionary traits fashion likely river futures (possible states, and their likelihood of being achieved).
- Address causes, not symptoms, of river degradation (i.e. process-based management is vital).

---

# Tools for analysis of river trajectory and recovery potential

## Analysis of trajectory

- **Geomorphic Change Detection 5.0**

http://gcd.joewheaton.org

## (Dis)connectivity in catchments

- Buffers, barriers and blankets (3Bs)

Lisenby, P. and Fryirs, K. 2017. 'Out with the Old?' Why coarse spatial datasets are still useful for catchment-scale investigations of sediment (dis)connectivity. ***Earth Surface Processes and Landforms***. 42, 1588-1596. DOI: 10.1002/esp.4131

Fryirs, K., Brierley, G. J., Preston, N. J. and Spencer, J. 2007 (b). Catchment-scale (dis)connectivity in sediment flux in the upper Hunter catchment, New South Wales, Australia. ***Geomorphology***, 84, 297-316.

- CASCADE

Schmitt, R.J., Bizzi, S. and Castelletti, A., 2016. Tracking multiple sediment cascades at the river network scale identifies controls and emerging patterns of sediment connectivity. *Water Resources Research*, *52*(5), pp.3941-3965.

- 'Hotspots'

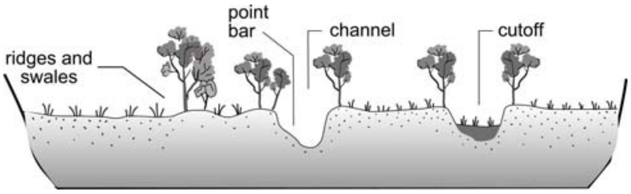
Czuba, J.A. and Foufoula-Georgiou, E., 2015. Dynamic connectivity in a fluvial network for identifying hotspots of geomorphic change. *Water Resources Research*, *51*(3), pp.1401-1421.

**Exercise 4: Assessing river recovery potential through scenario building.**

For the **Laterally unconfined, low-moderate sinuosity, sand bed** River Style from previous exercises, you are now given a range of scenarios.

This river reach is located in the middle-reaches of a catchment.
The upstream catchment area is 1000 km$^2$.
The reach is in moderate geomorphic condition.
The reach is strongly connected to its upstream sediment sources.

**Cross-section**



**Scenario 1) The upstream catchment has had extensive forest clearance and a large sediment slug now sits 3 km upstream of your reach and is expected to enter your reach over the next 10 years.**

| | |
|---|---|
| Describe how your reach will adjust over the next 10 years? | |
| Draw a cross-section of what you think the reach will look like in 10 years time. | |
| Will the condition of the reach improve or deteriorate over the next 10 years? Why? | |
| What is the recovery potential of your reach over the next 10 years? | |

**Scenario 2) The upstream catchment has a national park in its headwaters and a mix of low-intensity agriculture elsewhere. The riparian corridor along the majority of the river length has a good buffer strip of local and exotic vegetation. In the reach immediately upstream direct planting and weed management has been occurring for the last 10 years as part of a river rehabilitation initiative.  A balance of sediment supply and transfer occurs throughout the catchment.**

| | |
|---|---|
| Describe how your reach will adjust over the next 10 years? | |
| Draw a cross-section of what you think the reach will look like in 10 years time. | |
| Will the condition of the reach improve or deteriorate over the next 10 years?  Why? | |
| What is the recovery potential of your reach over the next 10 years? | |

# Presentation 5:
# Stage Four of the River Styles Framework:
# Implications for river management

## Stage Four: River management applications

Step One: Create a catchment framed physical vision...
What do we want the river to be like?

⇩

Step Two: Identify target conditions for river conservation and rehabilitation and determine the level of intervention required

⇩

Step Three: Prioritise efforts based on geomorphic condition and recovery potential

⇩

Step Four: Monitor and audit improvement in river condition

## Step 1: Develop a catchment framed physical vision

- Physical vision … determining and working towards the best-attainable catchment-wide river structure and function given the contemporary boundary conditions under which the river operates.
- Proactive … provides the basis for prioritisation of management efforts

## What is achievable?

- Contemporary diversity and patterns of river types, and their condition are framed in relation to their evolutionary trajectory to provide a physical platform to determine what is realistically achievable in geomorphic terms over a definable timeframe (e.g. 50-100 years).
- Scientific platform to link with socio-economic and cultural values.
- Consider the range of possible outcomes:
  - What happens if you leave it alone (the do nothing option)?
  - Objectives must be measurable and evidence-based.
  - What are the criteria for success or failure?

# Principles that underpin a catchment-framed physical vision

- Identify and maintain good bits
- Target unique attributes and assets
- Identify key drivers and stressors that limit system functionality (state-pressure-response)
- Identify and rectify problems (causes not symptoms)
- Minimise off-site impacts

# Examples of simple visions …

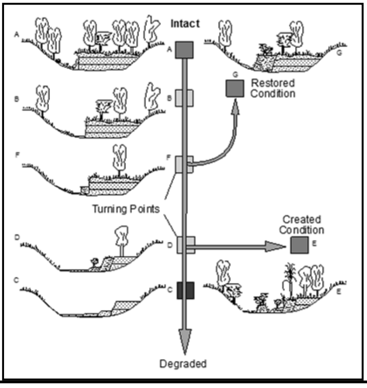
- Watershed (Toronto Harbour)
- Chesapeake Bay: Can I see my toes?
- Mersey Basin campaign: Fish
- Brisbane River: Swimming in the river

- Broadly-based (truly catchment-framed), socially-inclusive, generative

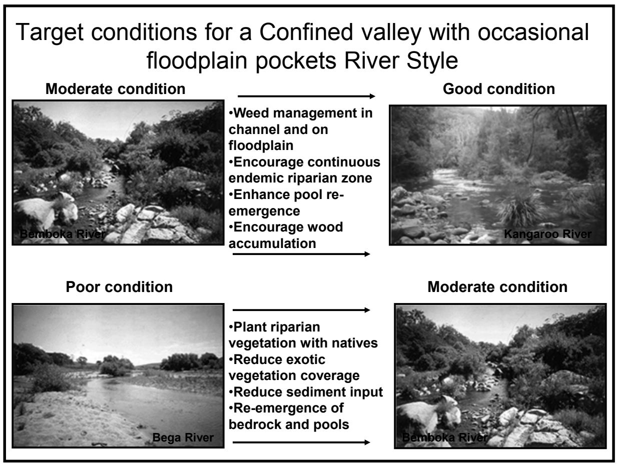
# Step 2: Identify target conditions for river conservation / rehabilitation

- As River Styles are characterized in terms of their character and behaviour, differing ‘problems’ & ‘treatments’ can be determined for particular River Styles
- Each River Style has its own capacity for (sensitivity to) adjustment
- Focus upon those *geoindicators* of *river condition* that can be addressed
- Address *causes not symptoms* - framework to consider rehabilitation options
- Focus on those attributes/reaches that are manageable (i.e. target programs in areas with meaningful prospects for management success)
  - What is the optimal river character and behaviour that can be achieved?
  - Based on reaches of River Styles in different geomorphic condition

# Assessing target conditions for the bedrock-controlled discont. floodplain River Style



Aim for the restored or created condition as long-term goals



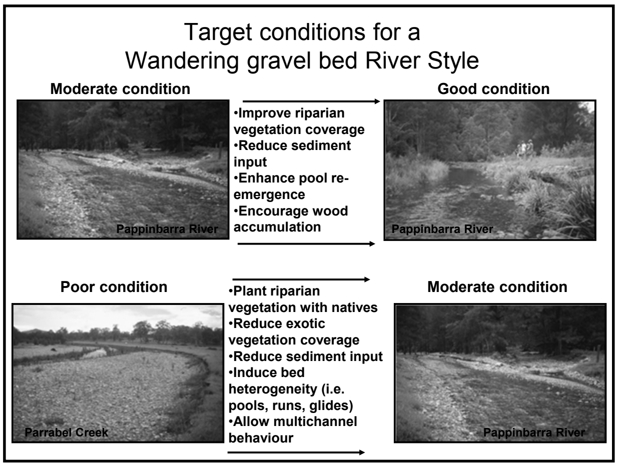
## Target conditions for a Confined valley with occasional floodplain pockets River Style

**Moderate condition** → **Good condition**

- •Weed management in channel and on floodplain
- •Encourage continuous endemic riparian zone
- •Enhance pool re-emergence
- •Encourage wood accumulation

**Poor condition** → **Moderate condition**

- •Plant riparian vegetation with natives
- •Reduce exotic vegetation coverage
- •Reduce sediment input
- •Re-emergence of bedrock and pools



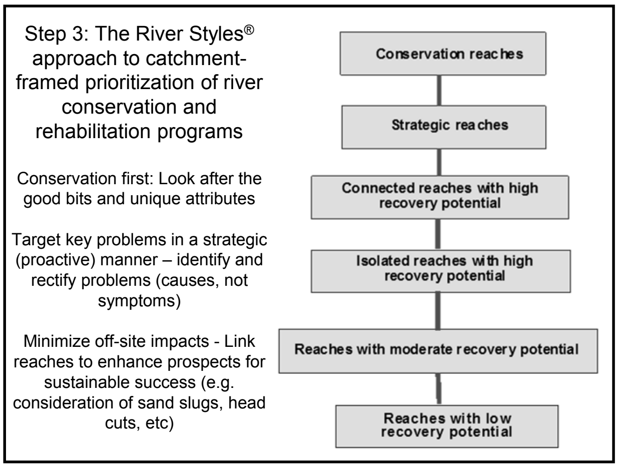
## Target conditions for a Wandering gravel bed River Style

**Moderate condition** → **Good condition**

- •Improve riparian vegetation coverage
- •Reduce sediment input
- •Enhance pool re-emergence
- •Encourage wood accumulation

**Poor condition** → **Moderate condition**

- •Plant riparian vegetation with natives
- •Reduce exotic vegetation coverage
- •Reduce sediment input
- •Induce bed heterogeneity (i.e. pools, runs, glides)
- •Allow multichannel behaviour



## Step 3: The River Styles® approach to catchment-framed prioritization of river conservation and rehabilitation programs

Conservation first: Look after the good bits and unique attributes

Target key problems in a strategic (proactive) manner – identify and rectify problems (causes, not symptoms)

Minimize off-site impacts - Link reaches to enhance prospects for sustainable success (e.g. consideration of sand slugs, head cuts, etc)

Conservation reaches

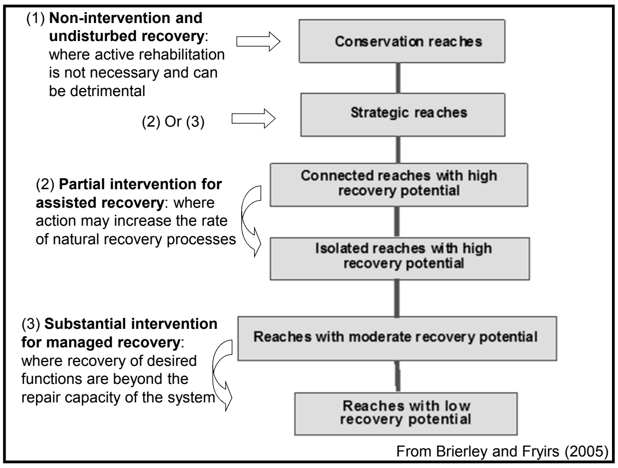
Strategic reaches

Connected reaches with high recovery potential

Isolated reaches with high recovery potential

Reaches with moderate recovery potential

Reaches with low recovery potential



(1) **Non-intervention and undisturbed recovery**: where active rehabilitation is not necessary and can be detrimental

(2) Or (3)

(2) **Partial intervention for assisted recovery**: where action may increase the rate of natural recovery processes

(3) **Substantial intervention for managed recovery**: where recovery of desired functions are beyond the repair capacity of the system

Conservation reaches

Strategic reaches

Connected reaches with high recovery potential

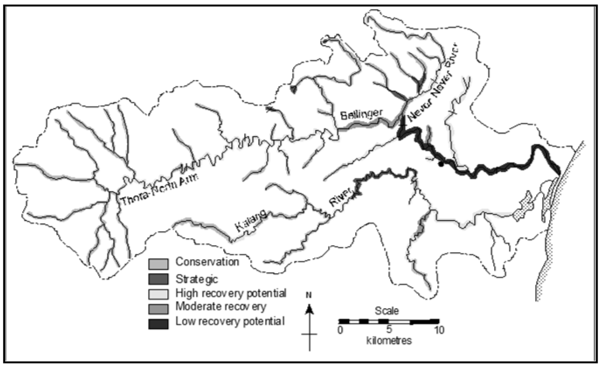
Isolated reaches with high recovery potential

Reaches with moderate recovery potential

Reaches with low recovery potential

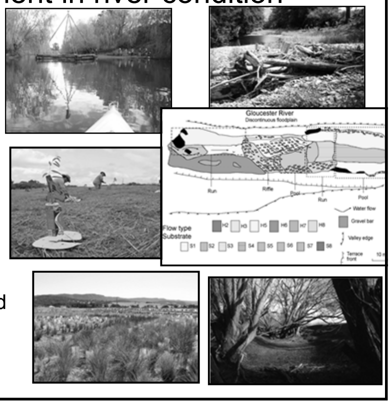
From Brierley and Fryirs (2005)

## Prioritisation in the Bellinger catchment, North Coast, NSW



## Step Four: Monitor and audit improvement in river condition

- Conservation planning
- On-the-ground rehabilitation design: e.g. wood and revegetation designs & effectiveness
- Monitoring: Habitat assessment
- Flow management: Maintaining the geomorphological and ecological sustainability of different river types



## How is the River Styles Framework being used?

## Extensions & applications of the River Styles Framework

- Coherent information base (cross-scalar, differing timeframes, including evolutionary trajectory)
- Physical template
  - Link physical to ecological integrity and measures of ecosystem functionality (i.e. process-based)
  - Management of flow regimes and water quality
  - Habitat associations (fish, macroinvertebrates, etc)
  - Riparian vegetation planning (differing associations on differing surfaces)
- Link to coherent (integrative) policy
  - Visioning and prioitisation
  - Catchment action plans
  - Flow management
  - Riparian vegetation management
- Platform to link to community values (relation to place)
- Basis to design and apply representative monitoring programs

NSW GOVERNMENT | Department of Primary Industries Water

CHaMP Columbia Habitat Monitoring Program

NSW GOVERNMENT | Local Land Services

REFORM
REstoring rivers FOR effective catchment Management

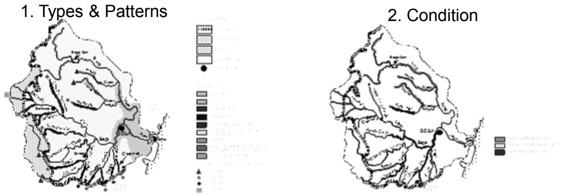
Australian Government
Department of the Environment and Energy

European Commission

ISPRA
Italian National Institute for Environmental Protection and Research

1. Types & Patterns

2. Condition



RIVER STYLES OF BEGA CATCHMENT, AUSTRALIA
MANAGERS LOVE MAPS!

3. Recovery potential

4. Management actions & prioritizatio

---

# Translation into policy applications

- Sustained collaborations with river managers (around 15 years after initial discussions).
- Ownership and enactment by managers themselves.

- Brierley et al. 2011. Geomorphology in action: Linking policy with on-the-ground actions through applications of the River Styles framework. *Applied Geography*.
- Fryirs & Brierley. 2009. Naturalness and place in river rehabilitation. *Ecology and Society*.
  - River diversity, Heterogeneity/homogeneity, 'Common' versus 'Unique'
- Brierley & Fryirs. 2009. Don't fight the site: Three geomorphic considerations in catchment-scale river rehabilitation planning. *Environmental Management*.
  - River character and behaviour, Catchment-scale relationships, Evolutionary trajectory

---

**NSW Government: Tool for coherent land & water management (Brierley et al., 2011)**

- Strategic planning of river conservation and rehabilitation activities
- Concerns for asset protection and risk management (fragility)
- Now being transformed into a toolkit to support efforts to increase agricultural productivity

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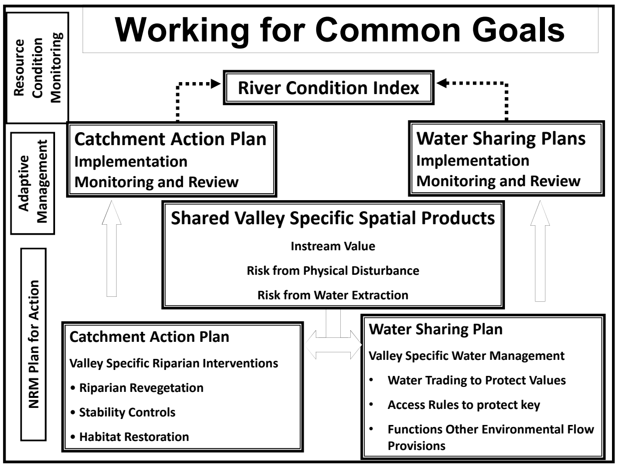
# Working for Common Goals



Resource Condition Monitoring

Adaptive Management

NRM Plan for Action

**River Condition Index**

**Catchment Action Plan**
**Implementation**
**Monitoring and Review**

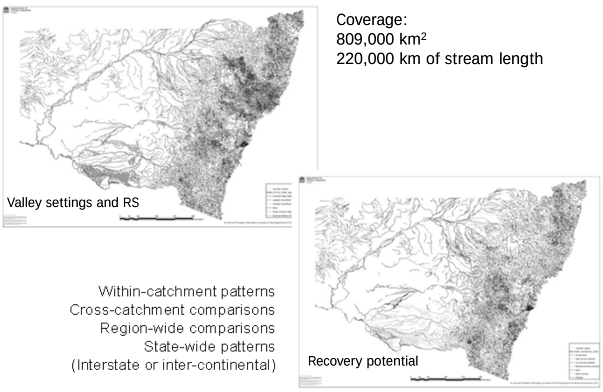
**Water Sharing Plans**
**Implementation**
**Monitoring and Review**

**Shared Valley Specific Spatial Products**
Instream Value
Risk from Physical Disturbance
Risk from Water Extraction

**Catchment Action Plan**
Valley Specific Riparian Interventions
- Riparian Revegetation
- Stability Controls
- Habitat Restoration

**Water Sharing Plan**
Valley Specific Water Management
- Water Trading to Protect Values
- Access Rules to protect key
- Functions Other Environmental Flow Provisions

## River types, condition, recovery, prioritisation in New South Wales



Coverage:
809,000 km$^2$
220,000 km of stream length

Valley settings and RS

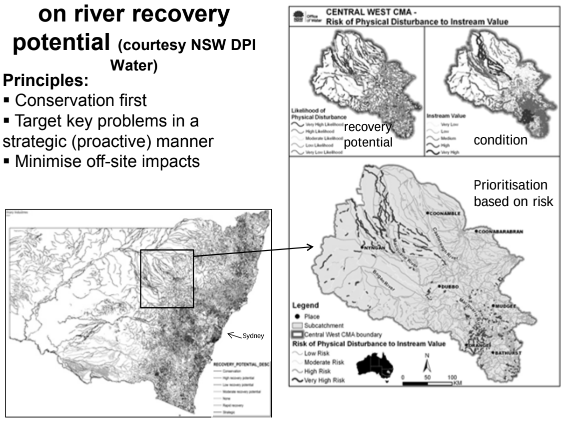
Within-catchment patterns
Cross-catchment comparisons
Region-wide comparisons
State-wide patterns
(Interstate or inter-continental)

Recovery potential

## Prioritorisation based on river recovery potential (courtesy NSW DPI Water)

**Principles:**

- Conservation first
- Target key problems in a strategic (proactive) manner
- Minimise off-site impacts



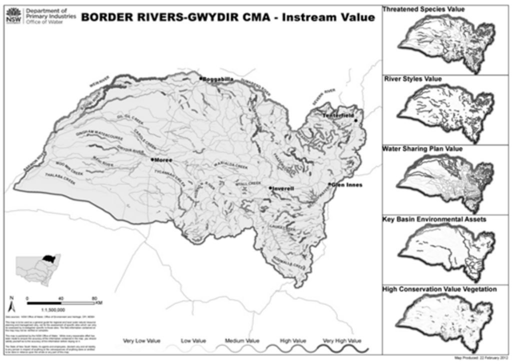
recovery potential

condition

Prioritisation based on risk

Sydney

## River Value – for trading / dealing rules in Water Sharing Plans



## Risk assessment

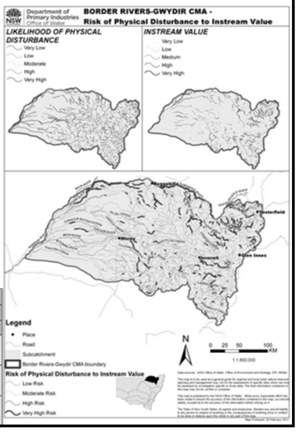
**Risk = Likelihood** (of irreversible change from physical disturbance)

x

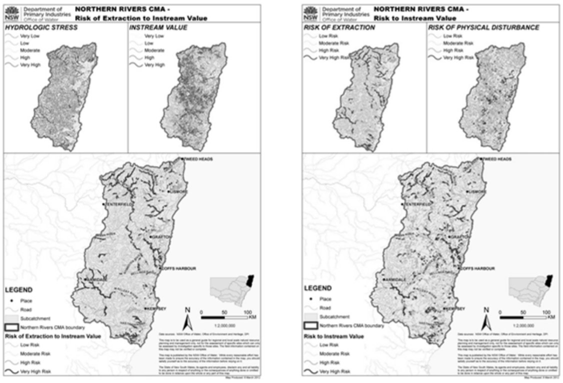
**Consequence** (instream value)

Likelihood matrix:

| | | | THREAT<br>River Styles Recovery Potential – based on Condition | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Conservation | Strategic | Rapid | High | Moderate | Low |
| | | | 6 | 5 | 4 | 3 | 2 | 1 |
| River Styles Fragility | High | 3 | 18 | 15 | 12 | 9 | 6 | 3 |
| | Medium | 2 | 12 | 10 | 8 | 6 | 4 | 2 |
| | Low | 1 | 6 | 5 | 4 | 3 | 2 | 1 |



# Risk to Instream Value Outputs

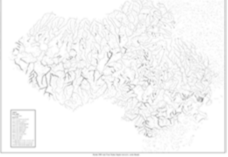


# Identifying natural reference reaches and 'rare' River Styles for conservation

- Measuring or observing condition indicators at appropriately contextualised reference reaches for each River Style in NSW.

- Identification of rare River Styles for protection in policy at State level and Federal Bioregional Plans.


Low sinuosity cobble bed

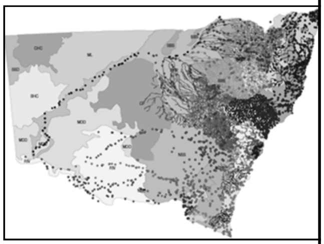

Rare River Styles, Hunter NSW


Chain of ponds


THPSS

# Linking River Styles to biodiversity Chessman et al. (2006)

"Protection of reaches that are in *good geomorphic condition* is critical to maintenance of *indigenous biodiversity and ecological function*. Once the process of deterioration in geomorphic condition begins, it is often difficult and costly to arrest. For reaches that are already in moderate or poor geomorphic condition, any rehabilitation works should aim to achieve good geomorphic condition in order to engender *a high level of biological recovery*".

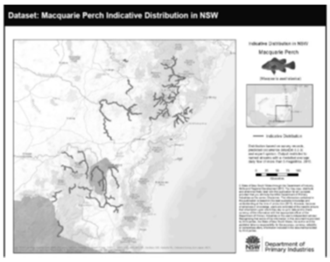

River Styles and AUSRIVAS databases
Source: Fryirs & Hose

# Fish communities and threatened species distributions and habitat mapping across NSW

- To assess distribution and status of fish communities at the reach scale.

- Support strategic planning frameworks to ensure integration of biodiversity considerations in planning.

- Monitor improvements in habitat condition and status.


Dataset: Macquarie Perch Indicative Distribution in NSW

## River Styles and riverworks design

Upper Hunter – 517 riverworks installed since 1950 on almost every river course.


Piles & mesh grid bays
Kingdon Ponds 1968


Groynes
Pages River 1954


Pool jams ('Fish cabins') – Habitat - 2006

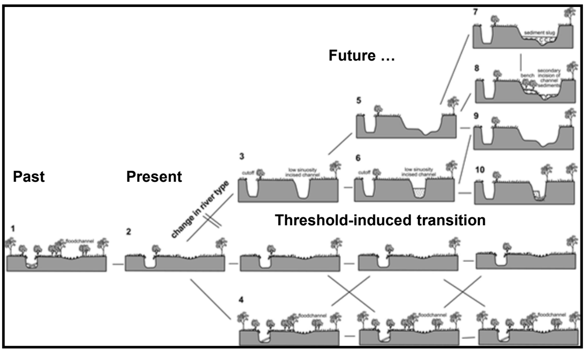

revegetation

- Same types of works applied to different River Styles and different forms of river adjustment.
- Lack of understanding of causes (bed instability) and recovery potential of reaches.
- Now designing river-type appropriate plans and structures that work with recovery potential.

## On-ground with agencies and community

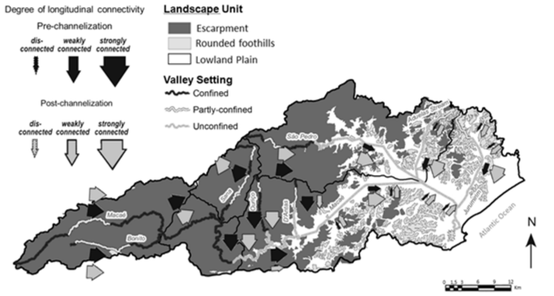
- Sustained collaborations with river managers (around 15 years after initial discussions).
- Ownership and enactment by managers themselves.

## Evolutionary trajectories: Prospective future adjustments of Wollombi Brook (Fryirs et al., 2012; Brierley & Fryirs, 2016; Fryirs & Brierley, 2016)



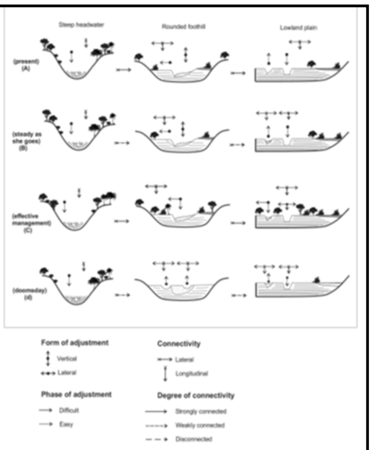
Moving targets …

## Changes to landscape connectivity in the Macaé Catchment, Brazil



Marcal et al. (2017)

## Scoping prospective futures in the Macaé Catchment



Marcal et al. (2017)

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## Restoring salmon stocks in the Columbia Basin

Joe Wheaton & his mini-army, Watershed Sciences, Utah State University

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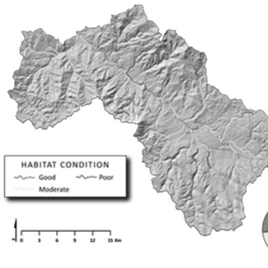
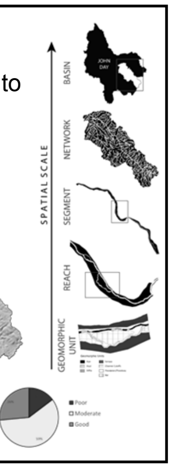
## CATCHMENT-SCALE THINKING & ACTIONS

'A continuous view of the river is needed to understand how processes interacting among scales set the context for stream fishes and their habitat' – Fausch et al. (2002)





**Wheaton et al.**

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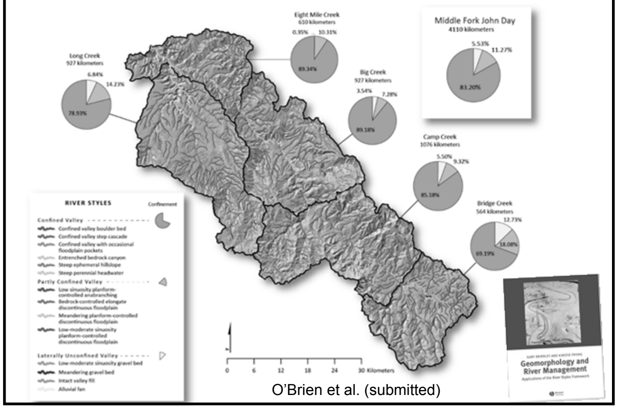
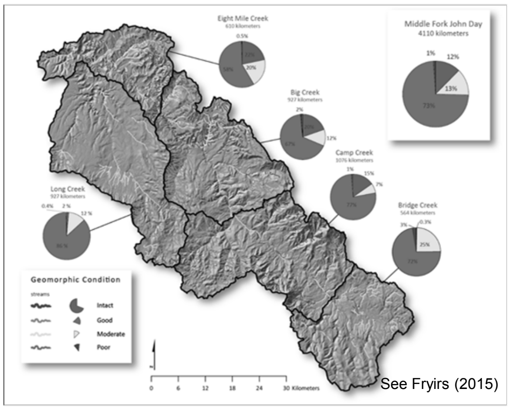
## GEOMORPHIC REACH TYPES (O'Brien et al., 2017)

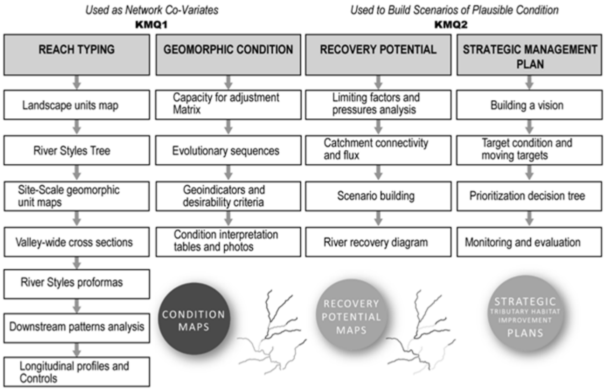


O'Brien et al. (submitted)

## GEOMORPHIC CONDITION (O'Brien et al., 2017)

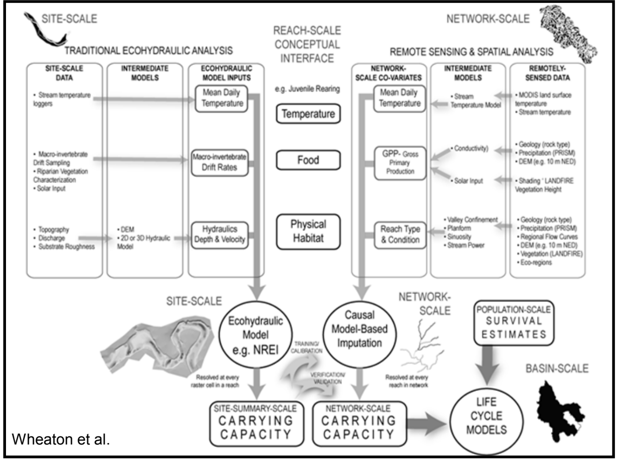


See Fryirs (2015)



| *Used as Network Co-Variates* KMQ1 | | *Used to Build Scenarios of Plausible Condition* KMQ2 | |
|---|---|---|---|
| **REACH TYPING** | **GEOMORPHIC CONDITION** | **RECOVERY POTENTIAL** | **STRATEGIC MANAGEMENT PLAN** |
| Landscape units map | Capacity for adjustment Matrix | Limiting factors and pressures analysis | Building a vision |
| River Styles Tree | Evolutionary sequences | Catchment connectivity and flux | Target condition and moving targets |
| Site-Scale geomorphic unit maps | Geoindicators and desirability criteria | Scenario building | Prioritization decision tree |
| Valley-wide cross sections | Condition interpretation tables and photos | River recovery diagram | Monitoring and evaluation |
| River Styles proformas | CONDITION MAPS | RECOVERY POTENTIAL MAPS | STRATEGIC TRIBUTARY HABITAT IMPROVEMENT PLANS |
| Downstream patterns analysis | | | |
| Longitudinal profiles and Controls | | | |

Wheaton et al.



SITE-SCALE

TRADITIONAL ECOHYDRAULIC ANALYSIS

REACH-SCALE CONCEPTUAL INTERFACE

NETWORK-SCALE

REMOTE SENSING & SPATIAL ANALYSIS

| SITE-SCALE DATA | INTERMEDIATE MODELS | ECOHYDRAULIC MODEL INPUTS | e.g. Juvenile Rearing | NETWORK-SCALE CO-VARIATES | INTERMEDIATE MODELS | REMOTELY-SENSED DATA |
|---|---|---|---|---|---|---|
| • Stream temperature loggers | | Mean Daily Temperature | Temperature | Mean Daily Temperature | • Stream Temperature Model | • MODIS land surface temperature<br>• Stream temperature |
| • Macro-invertebrate Drift Sampling<br>• Riparian Vegetation Characterization<br>• Solar Input | | Macro-invertebrate Drift Rates | Food | GPP- Gross Primary Production | • Conductivity)<br>• Solar Input | • Geology (rock type)<br>• Precipitation (PRISM)<br>• DEM (e.g. 10 m NED)<br>• Shading ' LANDFIRE Vegetation Height |
| • Topography<br>• Discharge<br>• Substrate Roughness | • DEM<br>• 2D or 3D Hydraulic Model | Hydraulics Depth & Velocity | Physical Habitat | Reach Type & Condition | • Valley Confinement<br>• Planform<br>• Sinuosity<br>• Stream Power | • Geology (rock type)<br>• Precipitation (PRISM)<br>• Regional Flow Curves<br>• DEM (e.g. 10 m NED)<br>• Vegetation (LANDFIRE)<br>• Eco-regions |

SITE-SCALE

Ecohydraulic Model e.g. NREI

TRAINING/ CALIBRATION

VERIFICATION/ VALIDATION

Causal Model-Based Imputation

NETWORK-SCALE

POPULATION-SCALE SURVIVAL ESTIMATES

BASIN-SCALE

Resolved at every raster cell in a reach

Resolved at every reach in network

SITE-SUMMARY-SCALE CARRYING CAPACITY

NETWORK-SCALE CARRYING CAPACITY

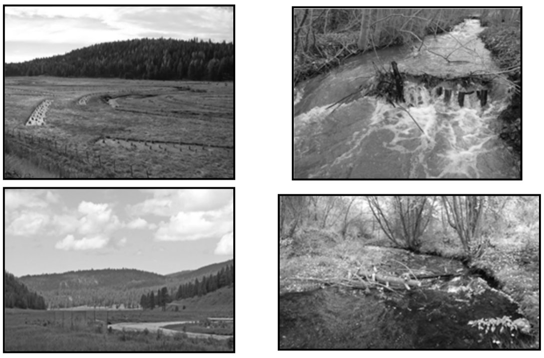
LIFE CYCLE MODELS

Wheaton et al.

## MODELLING RESTORATION SCENARIOS

Riparian shading

Wood structures



# Primary results (Wheaton et al.)

- Steelhead population continues to warrant conservation attention (i.e. continued restoration activities are necessary)
- Riparian vegetation measures are more important than large-scale wood re-introduction in this system

Note: Long-term schemes that enhance riparian vegetation will increase wood in the system over the long-term

Joe Wheaton & his mini-army

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## REFORM Project: REstoring rivers FOR effective catchment Management
## (EU FP7 Project – 26 partner organizations)

River Styles connections

- Geomorphic template … tied to instream and floodplain vegetation (Gurnell et al., 2015, 2016)
- Direct collaboration with terrestrial and aquatic ecologists
- Condition assessment (Rinaldi et al., 2013, 2015)
- Evolutionary perspectives
- Special Issue of Aquatic Sciences (January 2016)

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# REFORM CONTRIBUTIONS

- Assessment and rehabilitation of hydromorphological processes in rivers
- Discerning the impact of hydromorphological modification from other stressors
- Achievements by restoration and mitigation practices
- How to improve the (cost-)effectiveness of river rehabilitation?
- Benefits of river rehabilitation and synergies with other uses (flood protection, navigation, agriculture, hydropower)
- Linking science to practice: tools to assess river status and guide rehabilitation to optimize river basin management

Superb resource base at: www.reformrivers.eu

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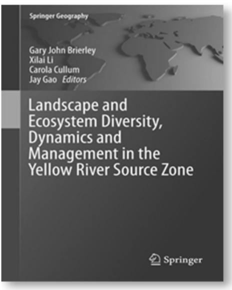
## River diversity atop the Qinghai-Tibetan Plateau: The Sanjiangyuan

Upper Yellow River at Dari



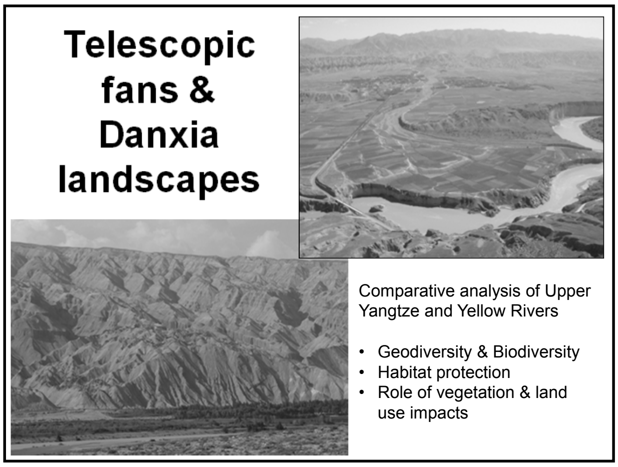
Springer Geography

Gary John Brierley
Xilai Li
Carola Cullum
Jay Gao *Editors*

Landscape and Ecosystem Diversity, Dynamics and Management in the Yellow River Source Zone

Springer

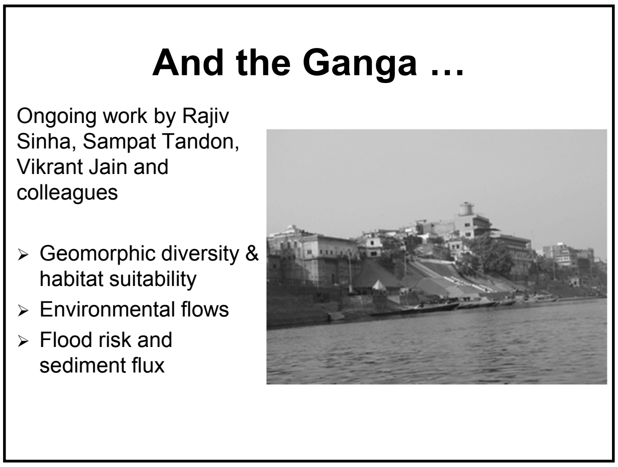
Brierley et al. (2017). Use of a landscape platform as a platform for integration in an international research collaboration project. *Journal of Geography in Higher Education*.



## Telescopic fans & Danxia landscapes

Comparative analysis of Upper Yangtze and Yellow Rivers

- Geodiversity & Biodiversity
- Habitat protection
- Role of vegetation & land use impacts

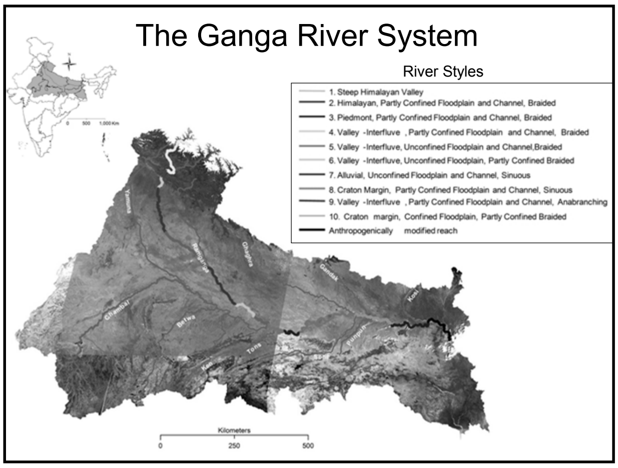


## And the Ganga …

Ongoing work by Rajiv Sinha, Sampat Tandon, Vikrant Jain and colleagues

- Geomorphic diversity & habitat suitability
- Environmental flows
- Flood risk and sediment flux

## The Ganga River System



Moves towards effective uptake of emerging technologies to inform river management

## Work collectively/collaboratively

- Work with managers at the outset … If struggling to translate, it's too late!
- Unless tools and frameworks are co-developed with practitioners who will use them, they are likely to be either ignored or mis-applied.

## Ask the right questions

In a world of information and data overload, asking the right questions is a vital ingredient in efforts not to be overwhelmed.

Don't re-invent the wheel or throw the baby out with the bathwater. In many instances we are simply doing conventional things in better ways.

## (Re)training and professional development

Moving forward collectively
- Professional Accreditation for geomorphologists
- Professional short courses

Learn effectively
- Apply open-ended, flexible and adaptive learning tools
- Use structured (scaffolded) frameworks to generate and apply new knowledges
- Monitor and update in a meaningful way
- Ensure appropriate commitment to reporting and information management

## Interpretation in geomorphology

Technology will not necessarily provide all the answers.

A multiple knowledges, multiple lines of evidence approach to enquiry will always be important.

Local stories/narratives and quirky pieces of field insight are often critical in working out why a river looks and behaves as it does.

How do we relate case studies to 'generalized' principles?

# On a cusp – lots of choices

- Don't let technology drive questions – use it carefully and effectively to answer questions
- Incorporate emerging technologies alongside field analyses
- Be ready!
  - Be prepared – importance of strategic, proactive planning
  - Although simple solutions are often attractive, they are not always right
- Science and politics … All power to the writer of the algorithms … the politics of modelling!

# Take home messages

- The River Styles framework provides a coherent (scaffolded) package of geomorphic principles to inform river management.
- This must be used alongside 'textbook' and modelled (virtual) realities. It is an adaptive framework … a flexible approach to learning and information management.
- Proactive, prioritized scientific understandings provide a basis for negotiation in appraising likely (and desirable) river futures and management options.
- Emerging technologies offer enormous prospect for place-based applications in river science and management.

## Take home messages – Introduction to the River Styles framework workshop

**Presentation 1: Underlying principles of the River Styles framework**

- The River Styles® framework builds upon long-standing principles in fluvial geomorphology (i.e. it builds directly upon principles outlined yesterday).
- It integrates (pulls together) our best available understandings as a conceptually coherent whole

**Presentation 2: Stage One of the River Styles Framework: Analysis of river character, behaviour, patterns and controls**

Work out contemporary process-form linkages and patterns for YOUR catchment

- Articulate key formative processes that fashion the range of river behaviour (erosion and deposition processes, channel and floodplain processes) for each reach.
- Determine the type and ease of geomorphic adjustment framed in relation to the capacity for adjustment (and associated sensitivity) for a range of flow stages.

**Presentation 3: Stage Two of the River Styles Framework: Catchment-framed assessment of geomorphic condition**

- Compare like with like, measuring appropriate (diagnostic) indicators of river condition for any given river type.
- This should be framed in relation to 'what is expected' for that type of river.

**Presentation 4: Stage Three of the River Styles Framework: Analysis of river recovery potential**

- Assess how past evolutionary traits fashion likely river futures (possible states, and their likelihood of being achieved).
- Address causes, not symptoms, of river degradation (i.e. process-based management is vital).

**Presentation 5: Stage Four of the River Styles Framework: Implications for river management and Take home messages for the day**

- The River Styles Framework provides a coherent (scaffolded) package of geomorphic principles that can be used to inform management applications.
- This must be used alongside 'textbook' and modelled (virtual) realities. It is an adaptive framework for adaptive management … a flexible framing (approach to learning) that can be adapted for a range of applications.
- Geomorphology cannot be taught in a day or a week. Hopefully we have shown that a range of skill sets and levels of expertise are evident.
- Proactive, prioritized scientific understandings provide a basis for negotiation in appraising likely (and desirable) river futures and management options (including the 'do nothing' option = passive rehabilitation)