

# WATS 5150 – Fluvial Geomorphology

## River Behavior



# Reading for this Module

## • Chapter 11: River behaviour

### CHAPTER ELEVEN

## *River behaviour*

#### Introduction

Analysis of river systems is not only concerned with what they look like, it also emphasises how they behave and why they adjust in the way that they do. Morphodynamic relationships fashion mutual interactions between river morphology and the processes that create and rework that form. This means that the processes shape the form, while the form influences the type and effectiveness of processes. Analysis of river behaviour entails consideration of how different types of rivers are able to adjust, the rate at which adjustment takes place and the permanence (or irreversibility) of those adjustments. These considerations determine the behavioural regime of a river reach.

Rivers are forever adjusting to disturbance events and prevailing flow and sediment fluxes. Vegetation conditions on valley floors greatly influence these interactions through their impact upon flow resistance. These relationships vary markedly in differing environmental settings. In addition, all river systems have a history of past disturbance events, whereby geologic, climatic or anthropogenic activities continue to influence contemporary river behaviour. Critically, adjustments in one part of a catchment affect reaches elsewhere within that system.

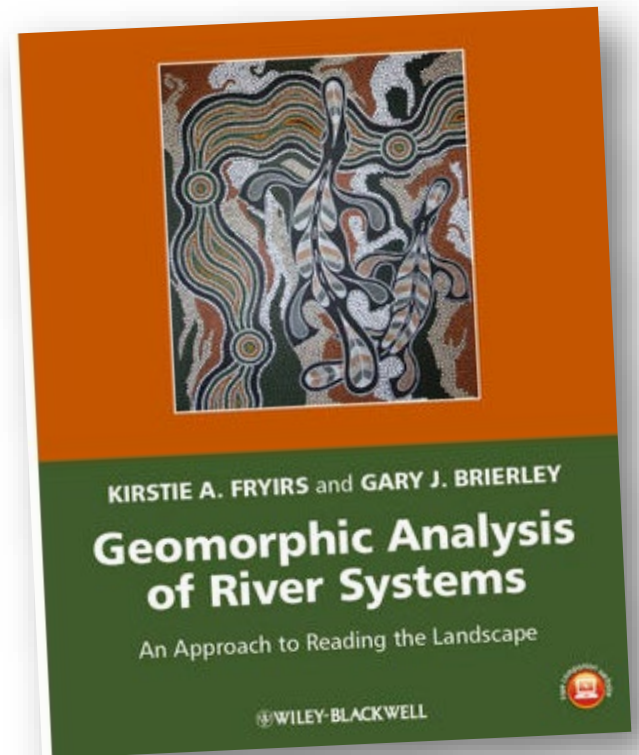
Any given reach is made up of a set of landforms (geomorphic units) that are created and reworked by a particular set of processes. Marked differences are evident for a confined river such as a gorge relative to a braided river or a swamp. For these rivers, different types of adjustments occur in different ways over different timeframes, in response to events of differing magnitude and frequency. The rate and extent of adjustment reflect the inherent sensitivity or resilience of a reach. These factors determine the 'natural capacity for adjustment' of a reach. This reflects the range of forms that reach may adopt in its given setting, and its associated behavioural regime.

Chapter 10 highlighted the remarkable range of river diversity in the natural world. The range of river behaviour

and system adjustments to disturbance events is similarly broad. This reflects inherent variability in the capacity for adjustment of different types of rivers (i.e. their erodibility) on the one hand, and pronounced variability in the range of driving forces that promote river adjustment on the other hand (i.e. the erosivity of any given landscape). These factors determine how a river adjusts, how often it adjusts, what it adjusts towards and the likelihood that the river will be able to adjust back towards its previous state (i.e. whether these adjustments fall within the behavioural regime for that type of river or whether change has occurred).

Rivers adjust in vertical, lateral and wholesale dimensions. Vertical adjustment refers to the stability of the bed. Lateral adjustment refers to the ability of the channel to alter its banks. Wholesale adjustment refers to the manner and rate of alterations to channel position on the valley floor. Analysis of the package of vertical, lateral and wholesale adjustments defines the behavioural regime of a river. The capacity for river adjustment determines the ease with which a reach is able to adjust its form in these three dimensions. This is dictated by the relationship between available erosive flow energy and the nature/distribution of resistance elements along a reach. This is fashioned by, and in turn reflects, the texture and cohesiveness of channel boundary materials and the inherent roughness of the river (determined largely by channel geometry/planform, riparian vegetation and the loading of wood within the reach). The erosivity of a reach is determined largely by the nature of disturbance events, especially the magnitude, frequency and duration of flood events.

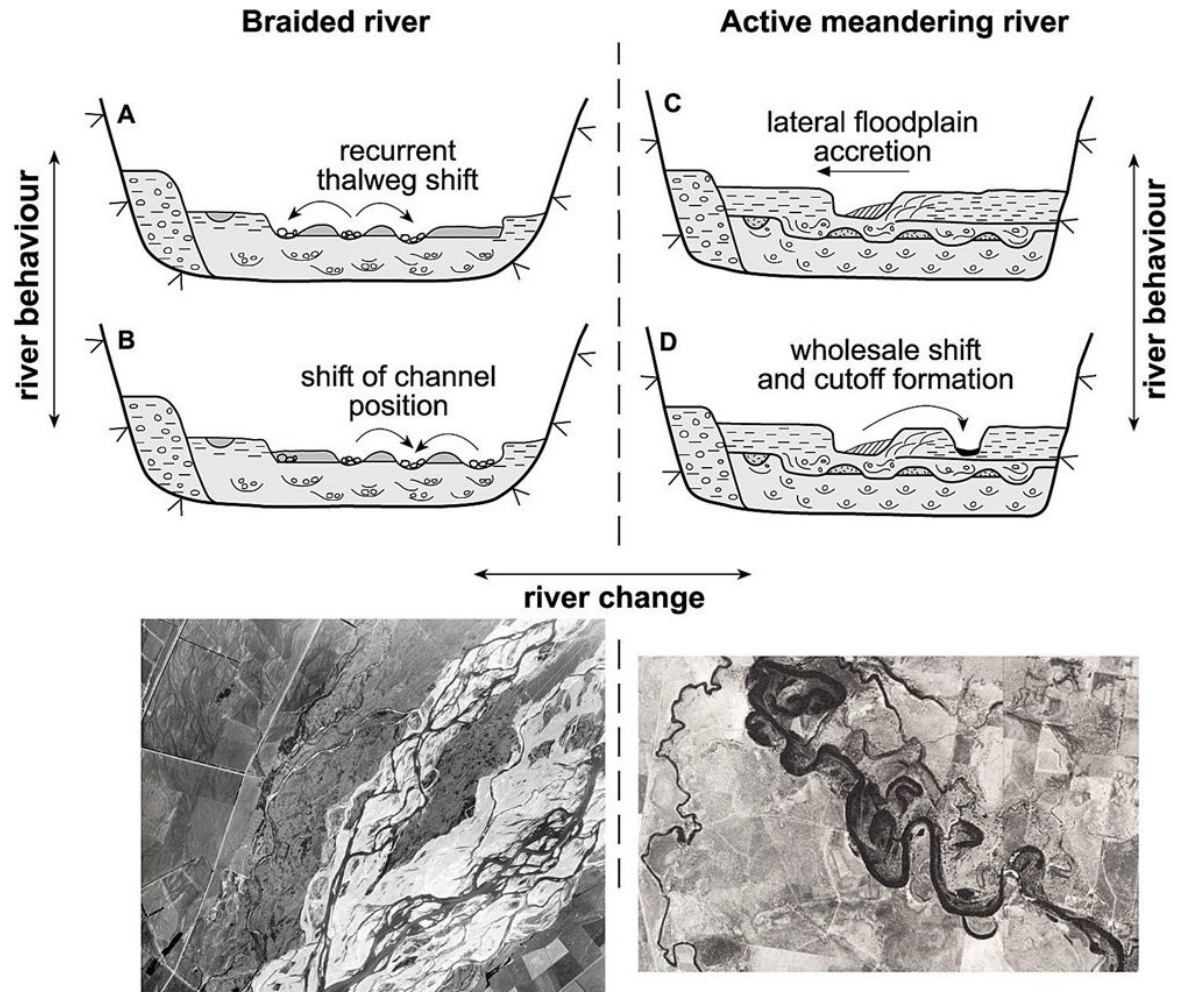
In general terms, different types of rivers are subjected to different forms of adjustment and have variable capacity to adjust. Rivers that can adjust in vertical, lateral and wholesale dimensions have greatest capacity to adjust. Hence, channels with non-cohesive bed and bank materials are particularly prone to adjustment. These rivers are considered to be sensitive to adjustment.



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

# Behavior vs. Change

- **Behavior** encompasses the contemporary processes that are at play
- **Change** is reserved for the conversion from one "River Style" to another, reflecting a shift in both **character** (form) and **behavior** (process)



**River behaviour** - natural adjustments that occur for a particular river type (e.g. lateral migration and cutoff formation along the meandering river; thalweg shift for the braided river)

**River change** - when a wholesale change in river type occurs (e.g. change from braided to active meandering)

**Figure 11.1** Differentiating river behaviour from river change. Behaviour is expressed by thalweg shift and redistribution of bars in a braided river, and by progressive lateral migration of an active meandering river. Change is expressed by the transformation of a braided river to a meandering river. From Brierley and Fryirs (2008). © Island Press, Washington, DC. Reproduced with permission.

# Dimensions of River Adjustment

- Adjustment is behavior

Form of adjustment



form of vertical  
adjustment  
(bed character)



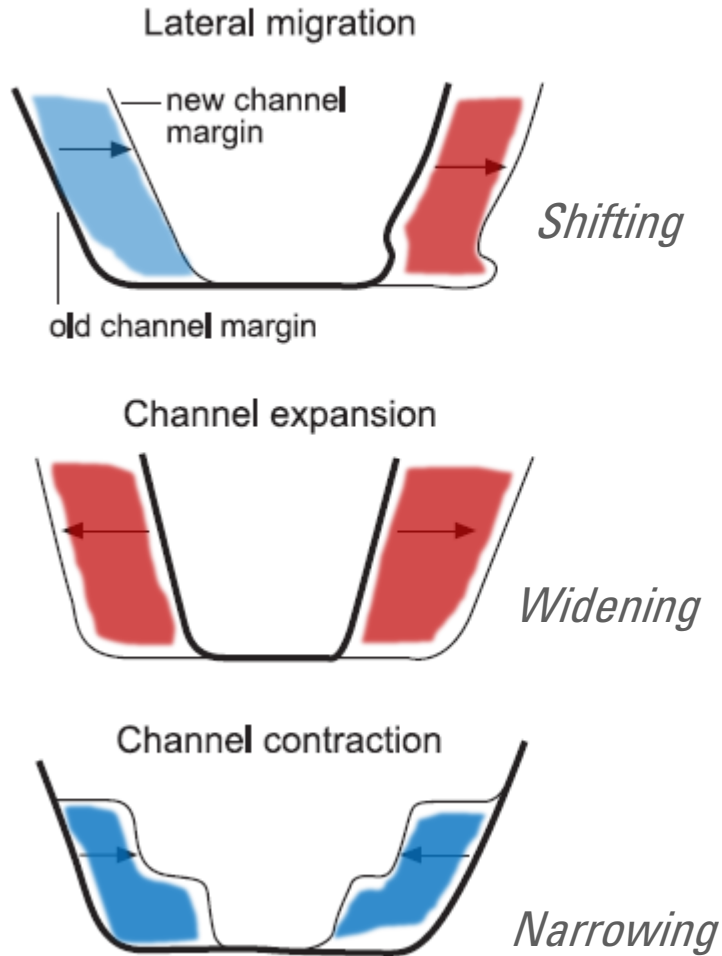
form of lateral  
adjustment (channel  
morphology)



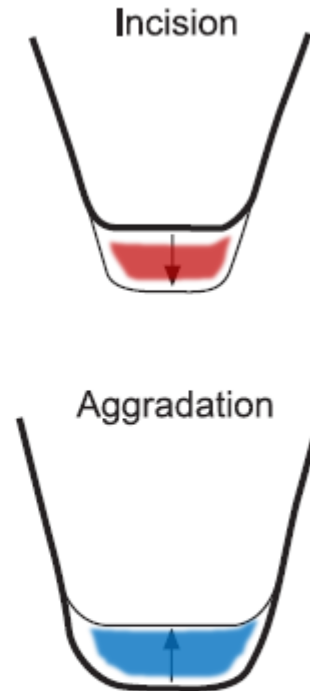
form of wholesale  
channel adjustment  
(channel planform)

# Recall Forms of Adjustment to Channel Shape

## Lateral adjustment processes



## Vertical adjustment processes



- Geomorphologists have lots of special names for things...
- Basically, all expressions or special cases of **erosion** or **deposition**
- Other forms of topographic adjustment:
  - Isostatic rebound ( $\frac{\partial z}{\partial t} > 0$ )
  - Tectonic uplift ( $\frac{\partial z}{\partial t} > 0$ )
  - Fault displacement ( $0 > \frac{\partial z}{\partial t} > 0$ )
  - Settling ( $\frac{\partial z}{\partial t} < 0$ )
  - Compaction ( $\frac{\partial z}{\partial t} < 0$ )
  - Bulge ( $\frac{\partial z}{\partial t} > 0$ )
  - Deflation ( $\frac{\partial z}{\partial t} < 0$ )
  - Chemical weathering ( $\frac{\partial z}{\partial t} < 0$ )
  - Precipitation – e.g. travertine growth ( $\frac{\partial z}{\partial t} < 0$ )

# Recall Vertical Adjustments of Channels

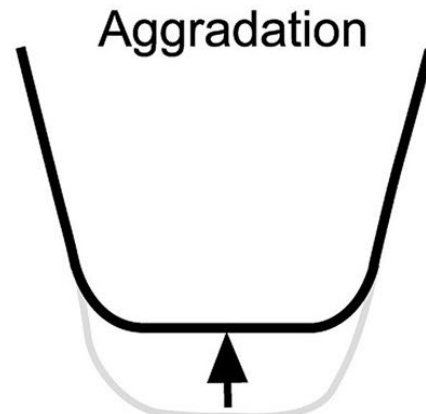
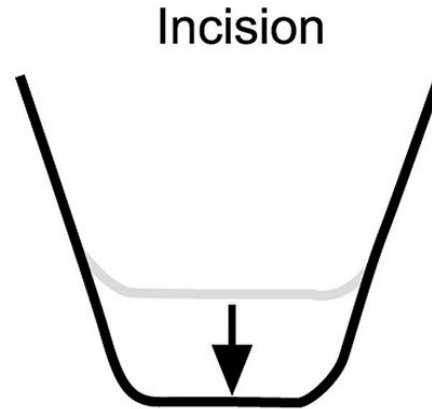
Vertical adjustment of  
“channel bed” or  
topography...

Other terms:

- Scour
- Erosion (or  
sediment/topography)

Terms that tend to  
describe net:

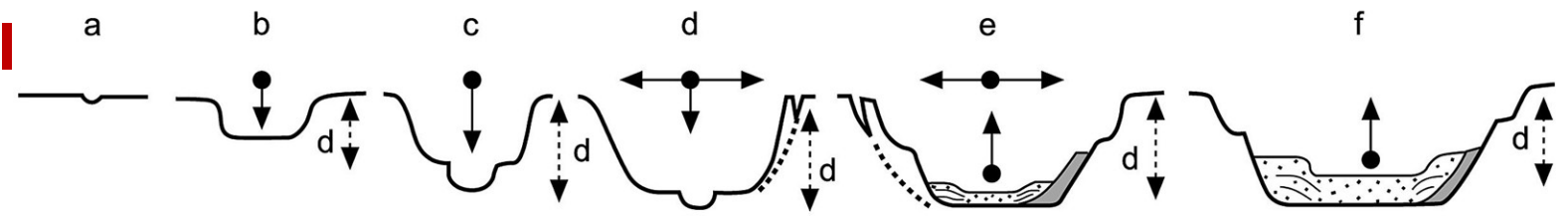
- Degradation
- Incision\*



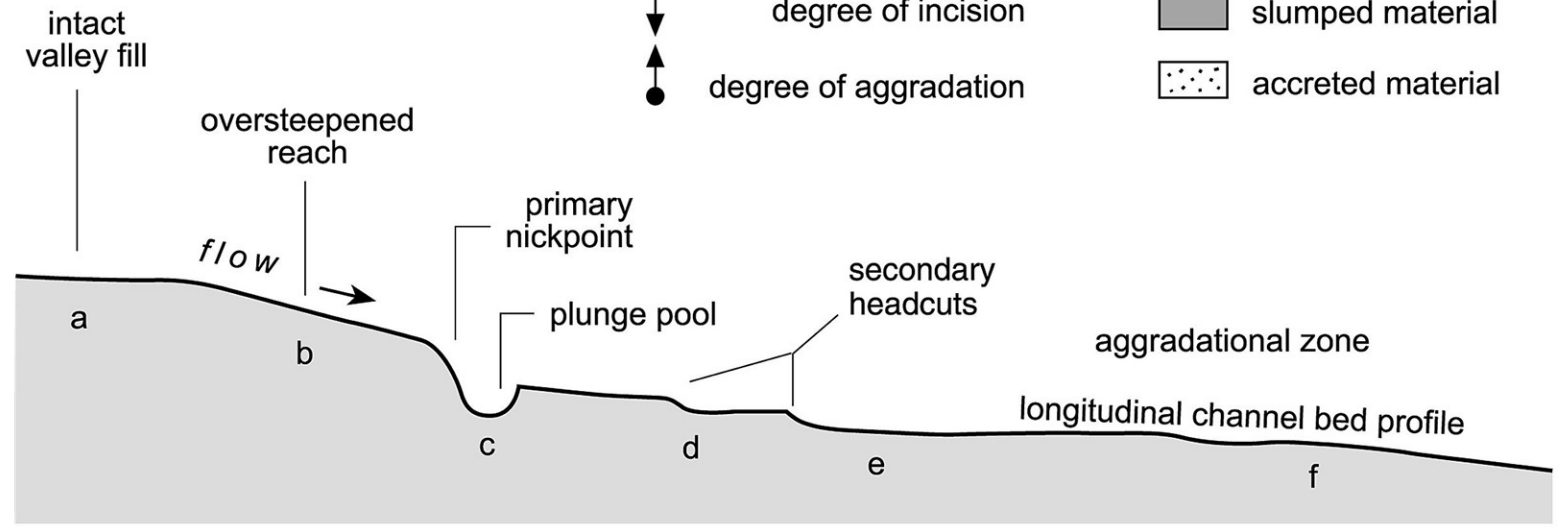
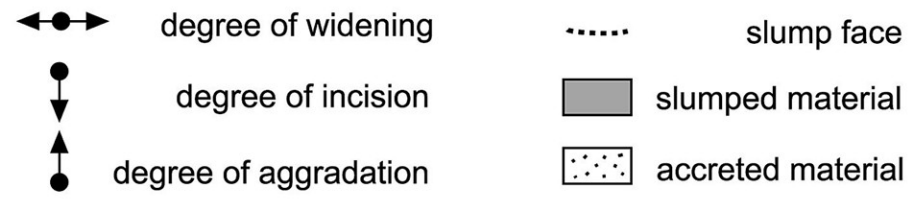
— new channel bed  
— old channel bed

**Figure 7.1** Vertical adjustments in channels. Incision and aggradation induce bed-level instability, lowering the bed via erosion and raising the bed through deposition respectively. The photographs are from the Tardale gully site, Waipaoa Catchment, New Zealand, where recurrent cutting and filling of tributary networks (top photograph) supplies sediment to the trunk stream that aggrades (lower photograph). Photographs (K. Fryirs).

# Recall



Some reserve "incision" for those profile adjustments



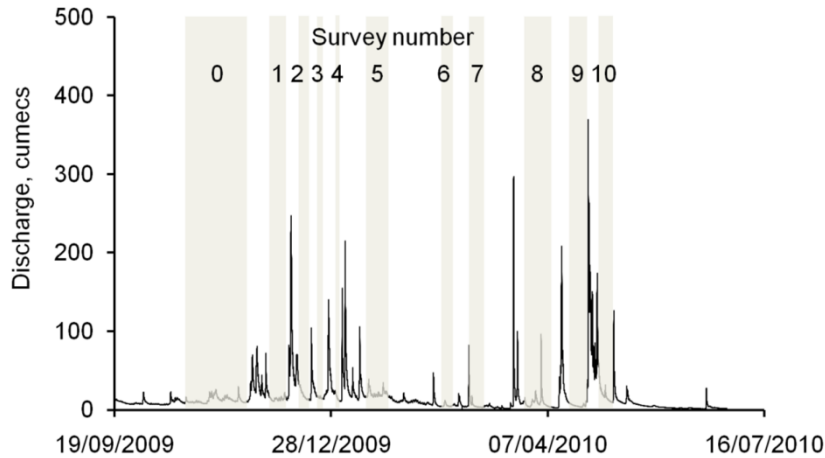
Geomorphic Analysis of River Systems: An Approach to Reading the Landscape, First Edition. Kirstie A. Fryirs and Gary J. Brierley. © 2013 Kirstie A. Fryirs and Gary J. Brierley. Published 2013 by Blackwell Publishing Ltd.

**Figure 4.9** Incised channel development via incision and headward retreat. Incision into intact valley floors occurs due to factors such as lowering of base level or oversteepening of the valley floor. A preferential drainage line is developed on the surface (section a). Once a primary headcut develops, channels incise into the surrounding alluvium and become narrow and deep (sections b and c). A plunge pool develops at the base of the headwall (section c). To accommodate the increased discharge, the channel expands laterally through sidewall and bank erosion processes, producing a wide, deep channel (section d). Once the transport capacity of the channel to carry sediment is exceeded, sediment is deposited on the channel bed and aggradation occurs (section e). Eventually, channel expansion ceases and bank-attached, inset floodplains may develop (section f). Modified from Schumm *et al.* (1984). © Water Resources Publications. Reproduced with permission.

Figure 4.9 Fryirs & Brierley (2013)

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

# Recall High Frequency Dynamics



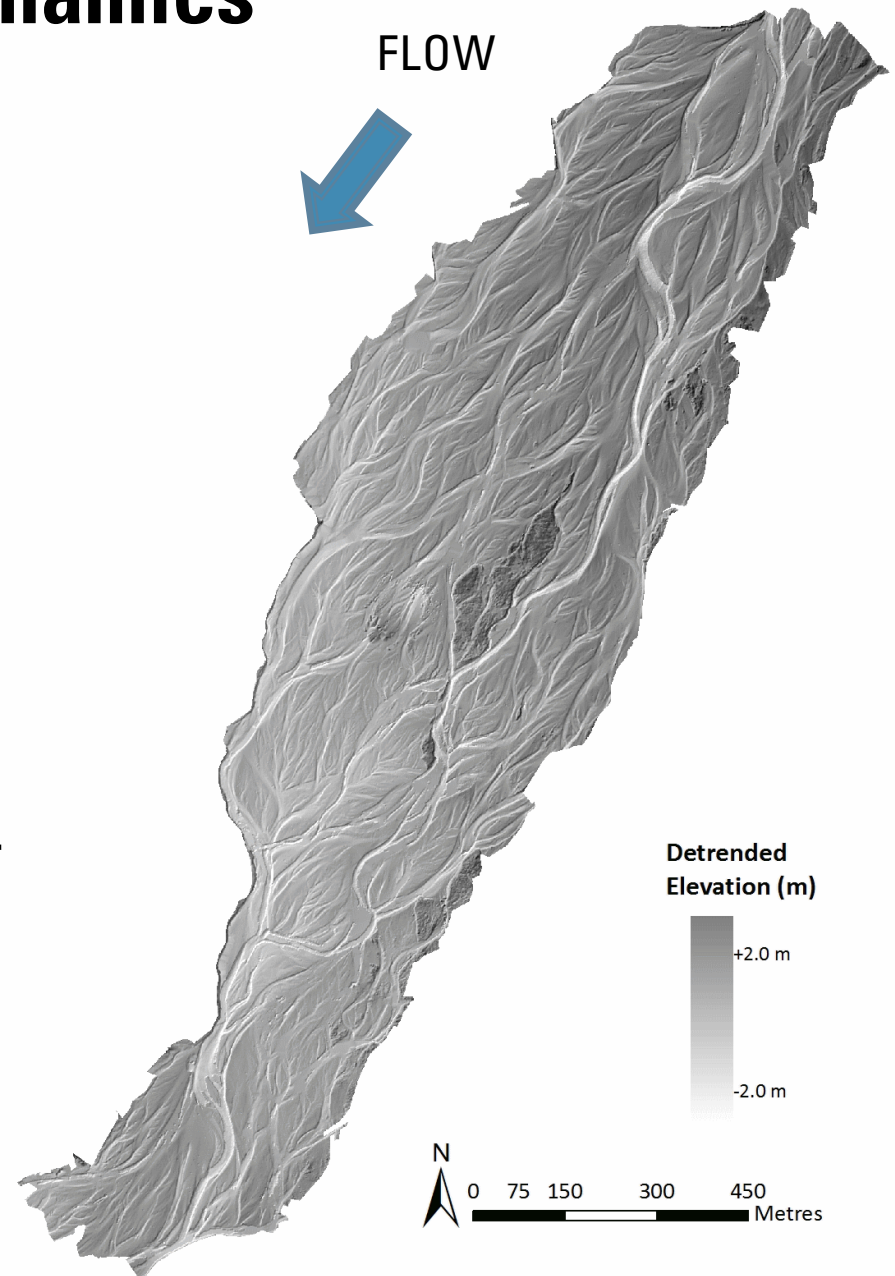
**BOTH SPACE AND TIME**

10 cm resolution models

Timeseries of DEMs of Rees River

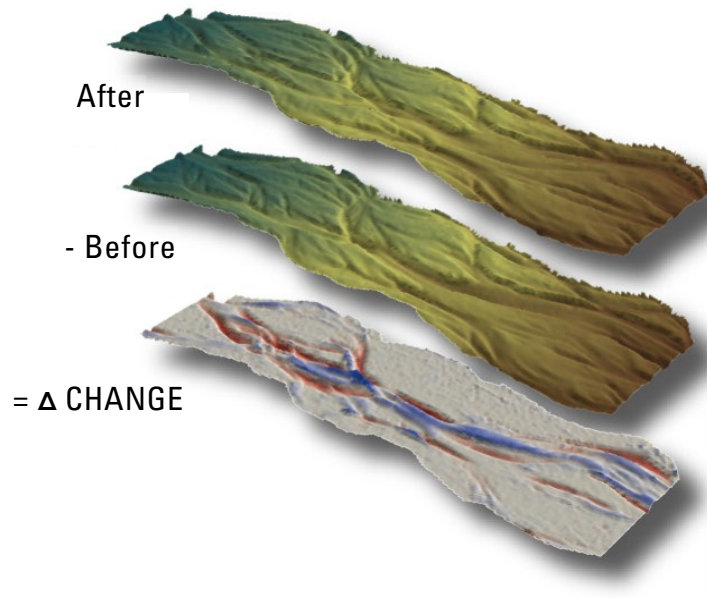
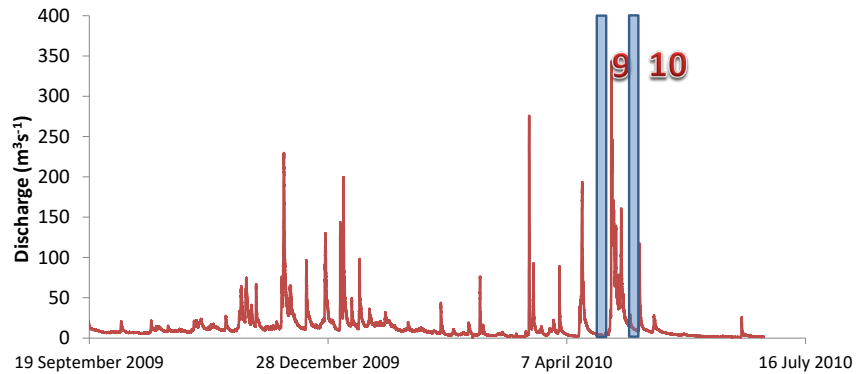
Nov 2009 - May 2010

Before/after consecutive events

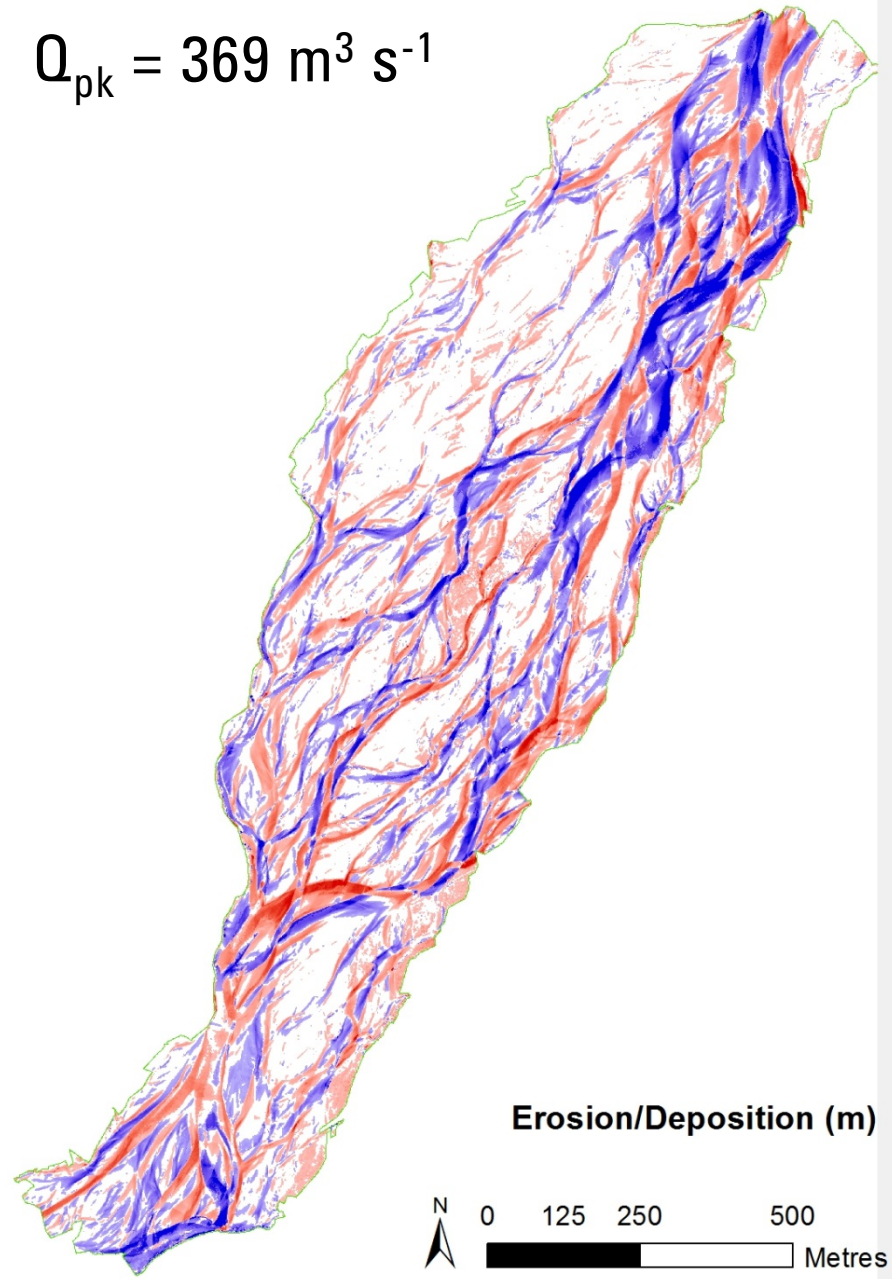




# Recall DEM of DIFFEREN



$$Q_{pk} = 369 \text{ m}^3 \text{ s}^{-1}$$

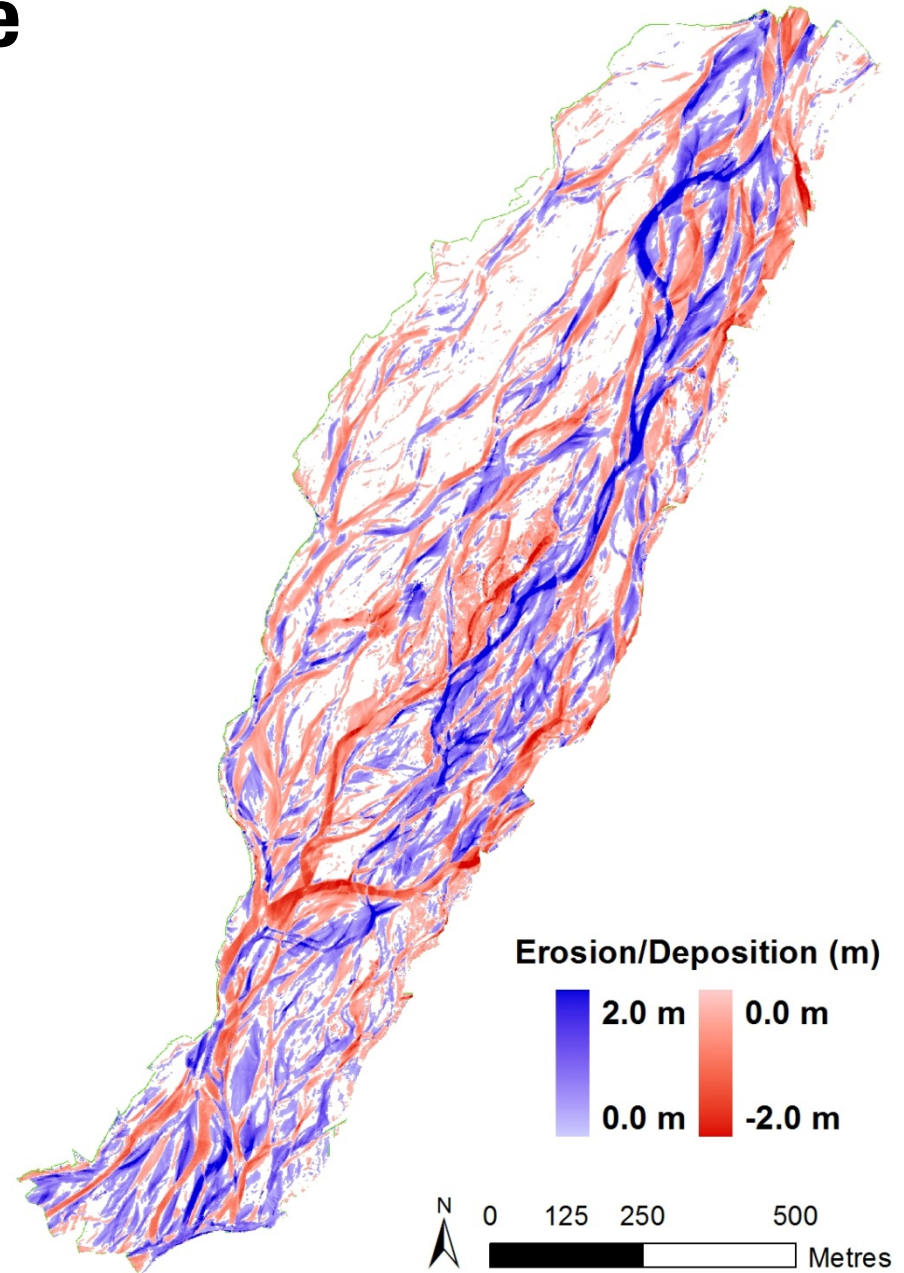


# Recall Quantifying Change

C.I.	70%	80%	90%
$V_e$ (m <sup>3</sup> )	128,841	124,442	117,587
$V_d$ (m <sup>3</sup> )	85,757	82,463	77,145
$\Delta Z$ (m)	-0.035	-0.036	-0.034
$\bar{d}_e$ (m)	-0.368	-0.395	-0.395
$\bar{d}_d$ (m)	0.307	0.328	0.329
Mobile %	52.5	47.3	40.7




Account for data uncertainty .... & propagate into estimates of change

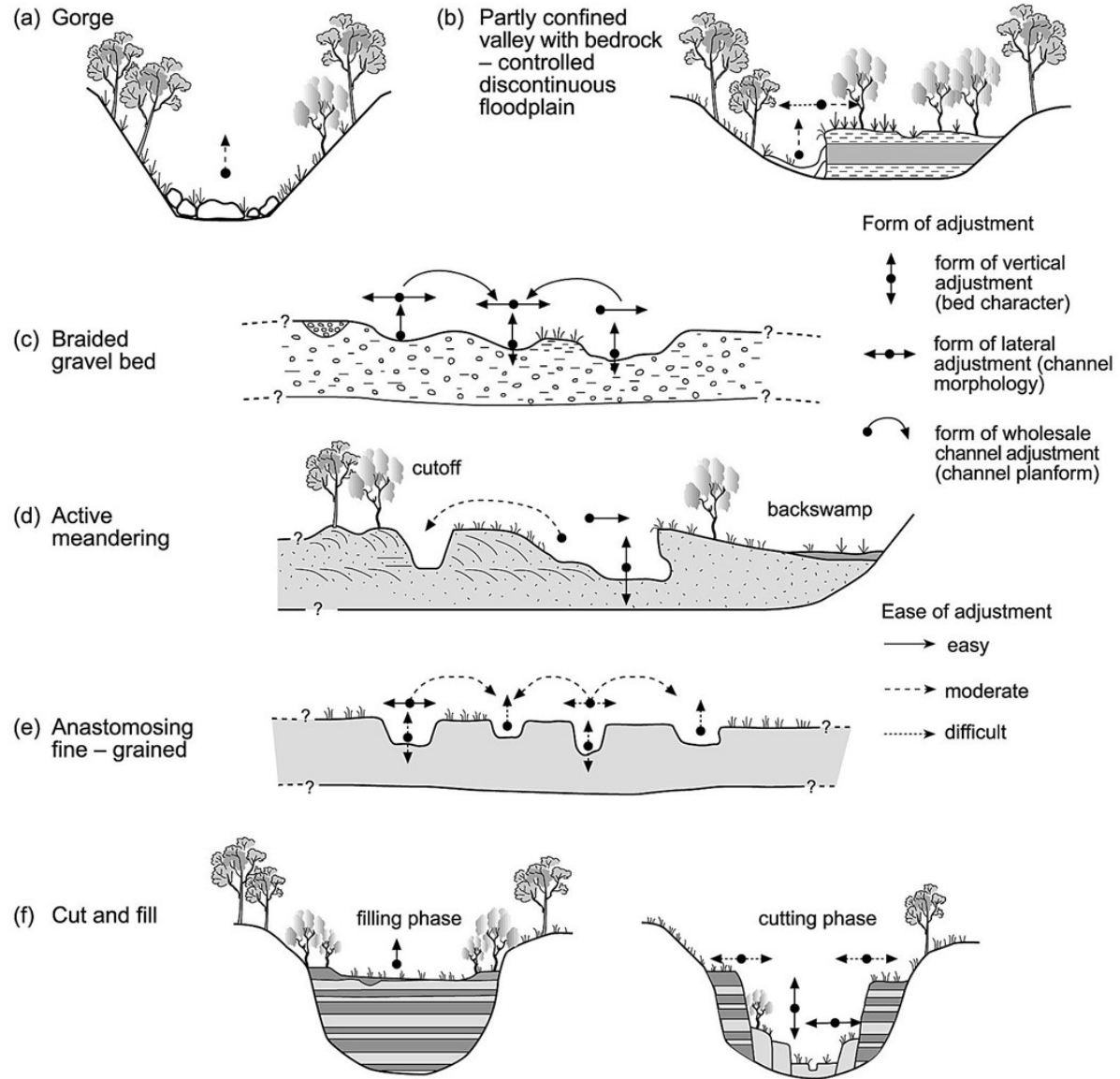
> robust presentation of data



# Recall

## Form of adjustment


- 
 form of vertical adjustment (bed character)
- 
 form of lateral adjustment (channel morphology)
- 
 form of wholesale channel adjustment (channel planform)



**Figure 11.2** The capacity for vertical, lateral and wholesale adjustment of various river types. Arrows portray the forms of adjustment that can take place for different river types. These may be adjustments in bed character (the vertical dimension), channel morphology (the lateral dimension) and channel planform (the wholesale dimension). Some rivers have significant capacity to adjust in all three dimensions, while others adjust in one or two dimensions. The ease with which these adjustments take place is shown by the 'strength' of the arrows. Modified from Brierley and Fryirs (2005). © Wiley–Blackwell Publishing. Reproduced with permission.

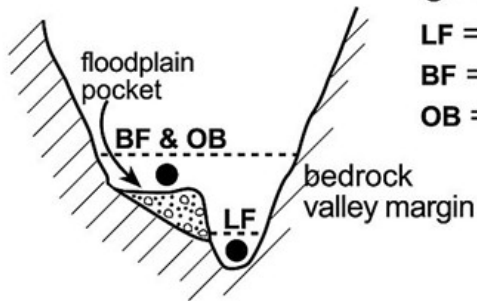
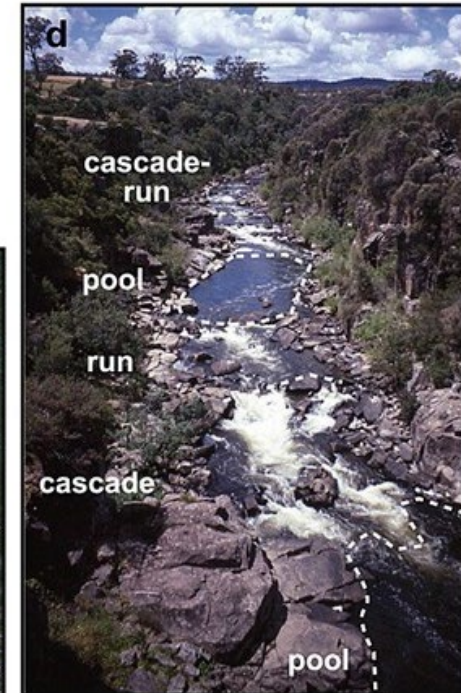
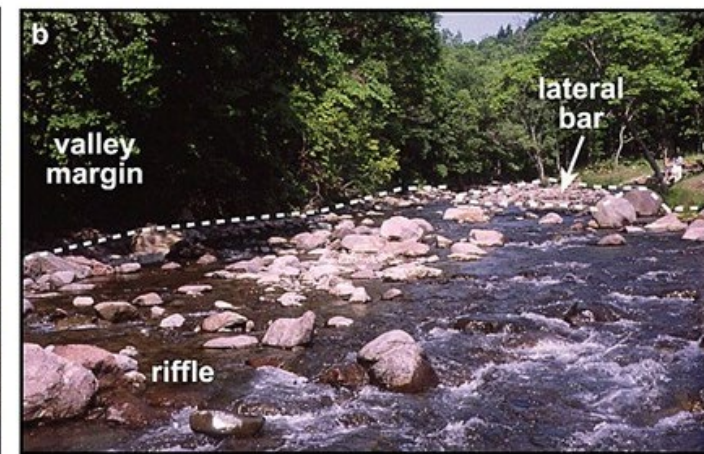
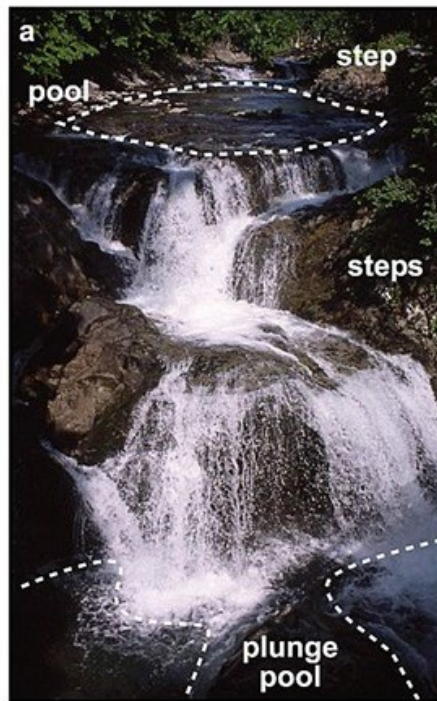
# Behavior in Bedrock Confined Rivers

## Form of adjustment


 form of vertical adjustment  
 (bed character)


 form of lateral adjustment  
 (channel morphology)

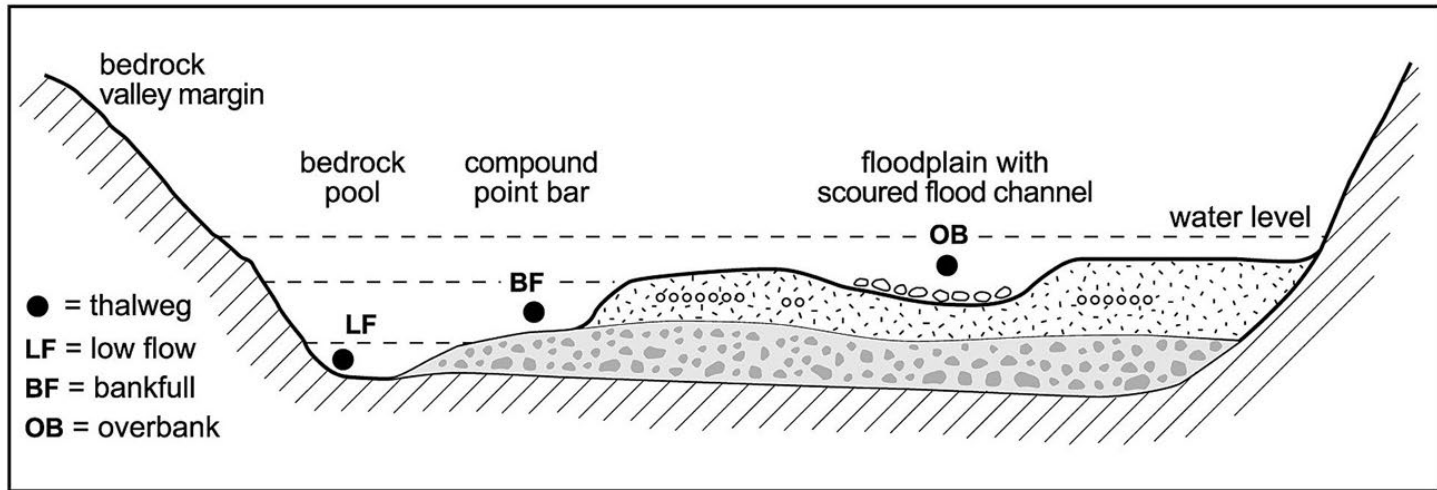
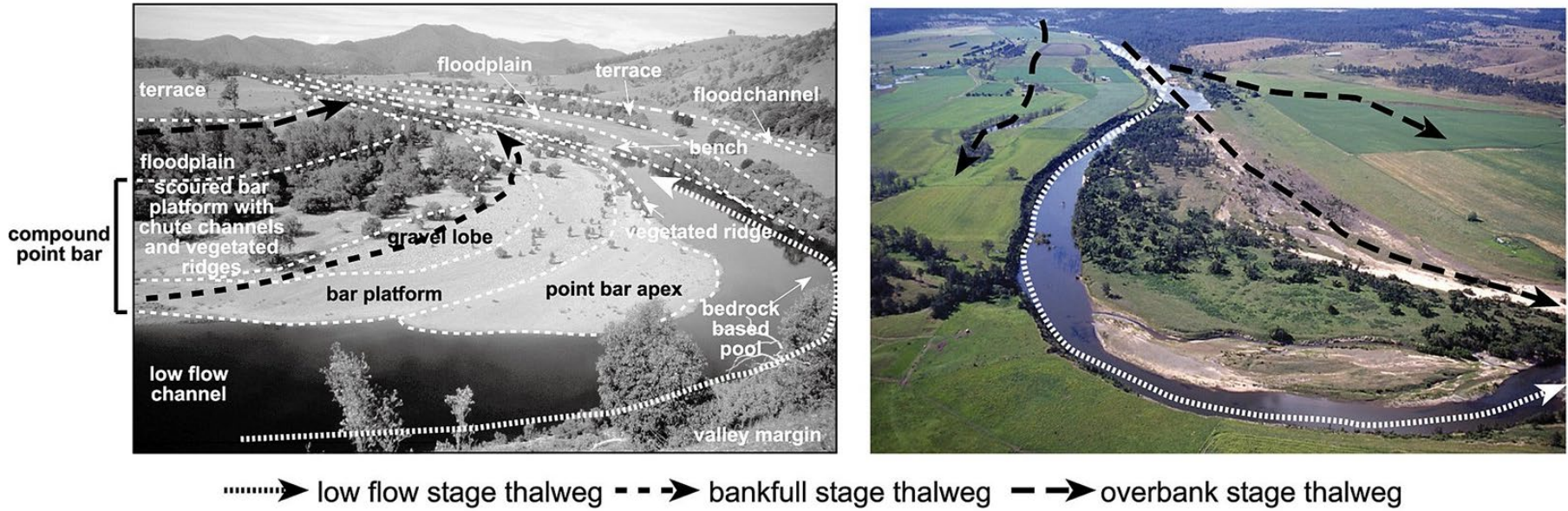

 form of wholesale channel adjustment  
 (channel planform)



● = thalweg  
 LF = low flow  
 BF = bankfull  
 OB = overbank

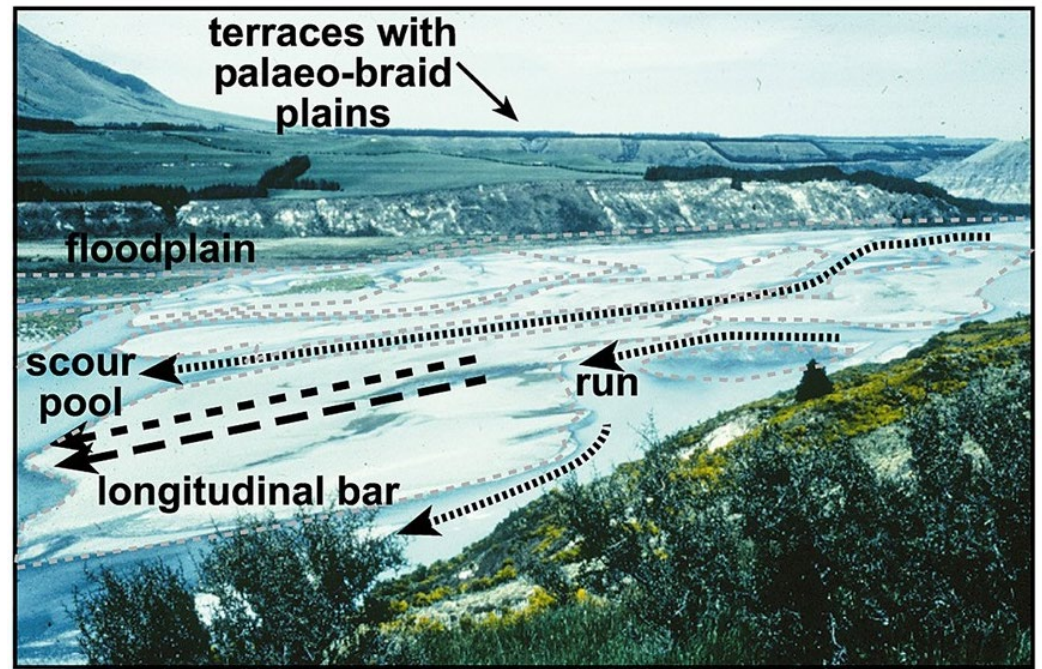
**Figure 11.3** River behaviour in bedrock-confined rivers. Instream geomorphic units are only activated at high flow stage. A forced morphology prevails. Photographs: (a, b) Sangainotaki River (Three Steps of Waterfall), Japan; (c) upper Kangaroo River, NSW; (d) gorge near Launceston, Tasmania (K. Fryirs). Modified from Brierley and Fryirs (2005). © Wiley–Blackwell Publishing. Reproduced with permission.

# Behavior in Partly-Confined Rivers

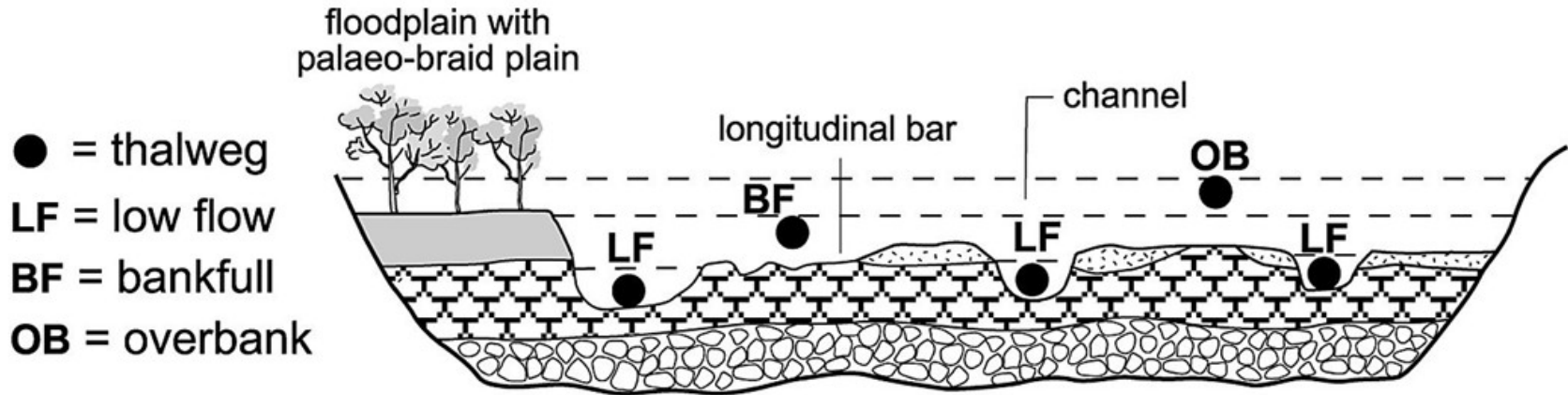


**Figure 11.4** River behaviour in a partly confined valley. As flow alignment varies with flow stage over this bedrock-controlled floodplain pocket, differing phases of erosion and deposition generate and rework an array of channel and floodplain forms. Photographs: left, Macleay River, NSW; right, Clarence River, NSW (R. Ferguson).

# Behavior in Laterally-Unconfined Rivers



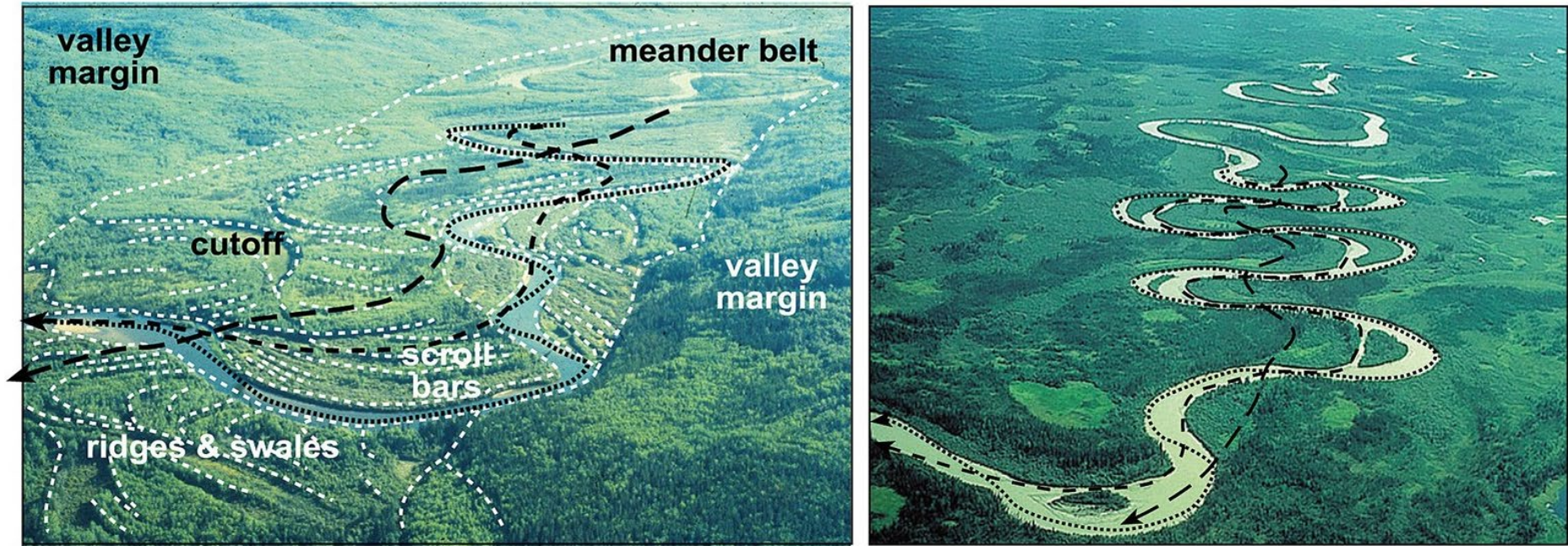
.....> low flow stage thalweg - - -> bankfull stage thalweg  
 - - -> overbank stage thalweg



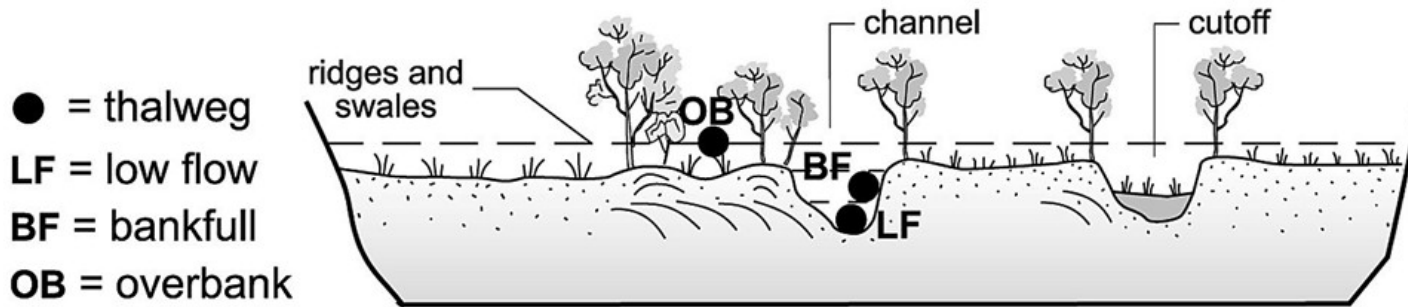
**Figure 11.5** River behaviour in laterally unconfined, high-energy rivers – braided river type. Inundation of bar surfaces instigates erosion, reworking and redeposition, via both bar extension and thalweg shift. Photograph: Rakaia River, New Zealand (G. Brierley).

Fryirs & Brierley (2013)

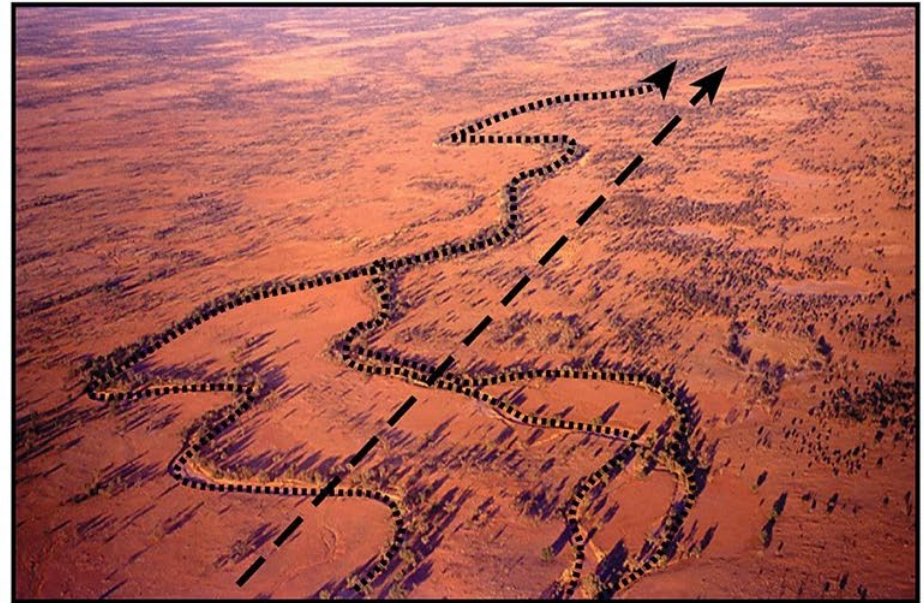
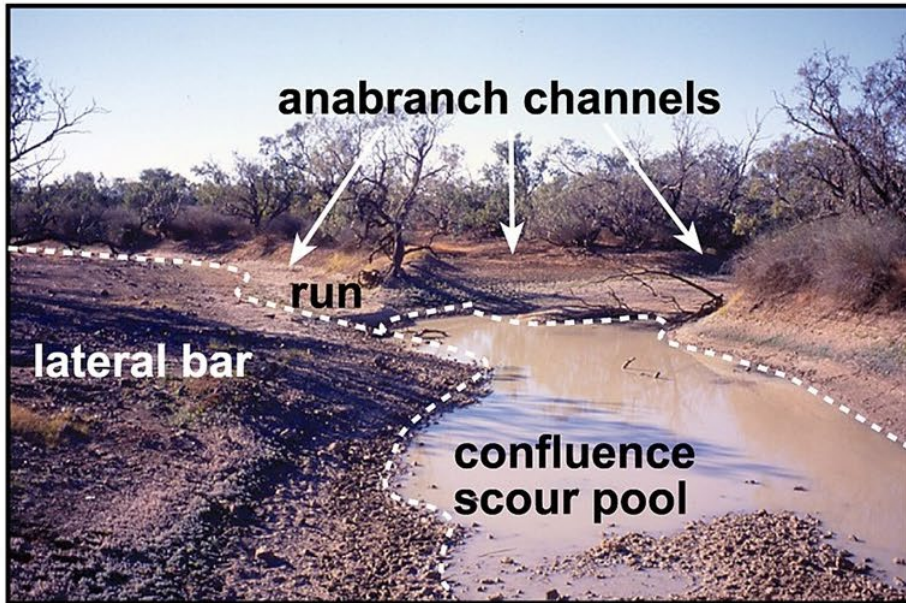
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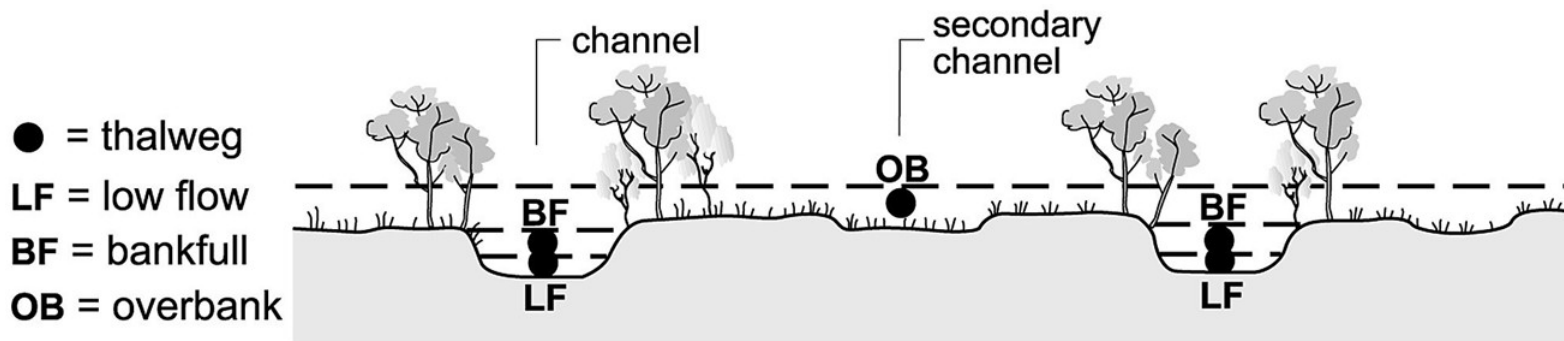
.....➔ low flow stage thalweg - - ➔ bankfull stage thalweg - ➔ overbank stage thalweg



**Figure 11.6** River behaviour in laterally unconfined, medium-energy rivers – active meandering river type. Helicoidal flow promotes deposition of scroll bars on the inner (convex) slope and erosion of the outer (concave) bank within asymmetrical channels of this mixed-load river. Ridge and swale topography demarcates phases of lateral migration, capped by overbank deposits (thereby creating composite floodplain sediments and associated banks). Cut-offs may be generated. Photographs: left, British Columbia (G. Brierley); right, Williams River, Alaska (N.D. Smith from [http://lessen.museon.nl/generated/s900x600\\_1196c8e6add0dd0005daa11f5ae3bc8f.jpg](http://lessen.museon.nl/generated/s900x600_1196c8e6add0dd0005daa11f5ae3bc8f.jpg)).

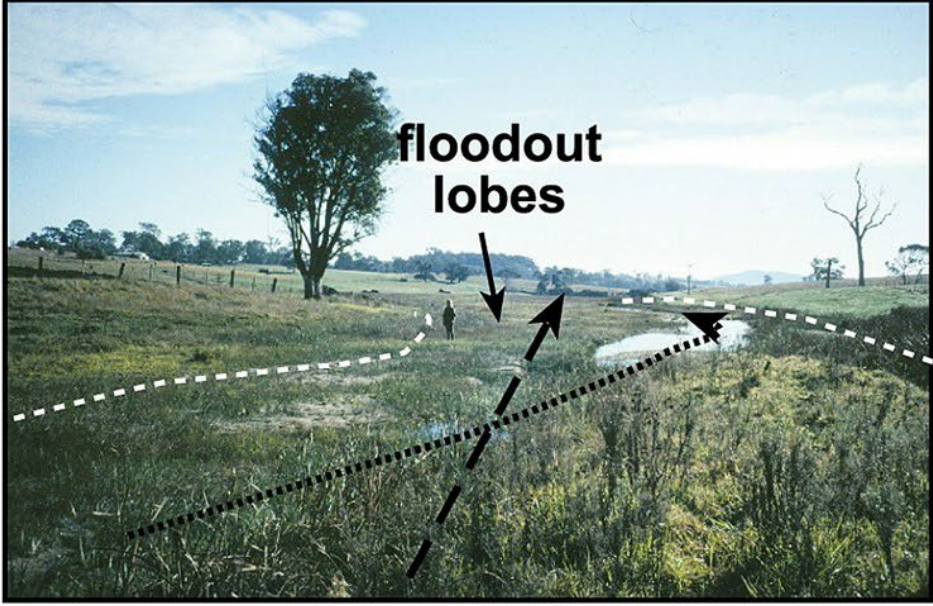
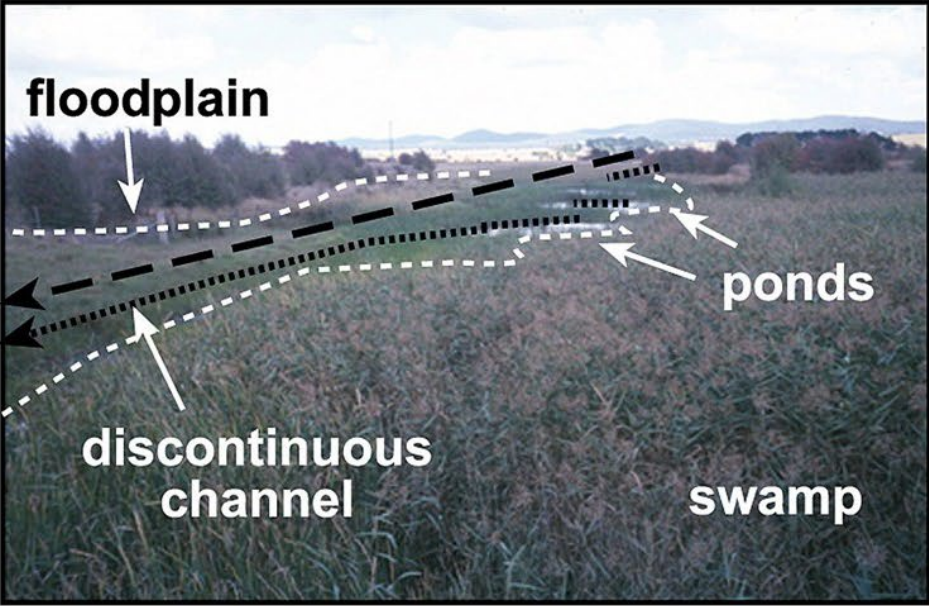


.....➔ low flow stage thalweg - - ➔ bankfull stage thalweg - - ➔ overbank stage thalweg



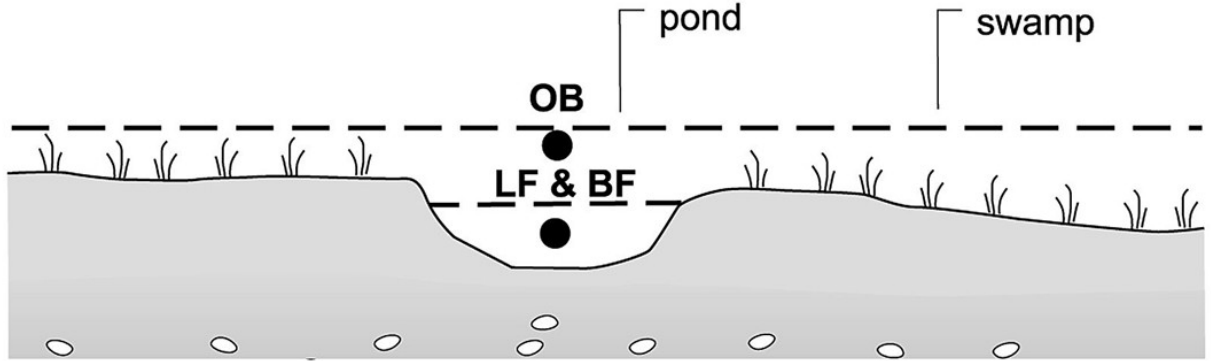
**Figure 11.7** River behaviour in laterally unconfined, low-energy rivers with continuous channel(s) – anastomosing (anabranching) river type. Low flow stages deposit fine-grained sediments, partially infilling scoured pools. Erosion sculpts fine-grained instream geomorphic units at bankfull stage. Overbank flows inundate the floodplain, promoting vertical accretion. The channel banks of this suspended-load river are laterally stable as they are comprised of fine-grained cohesive sediment. Photographs: Cooper Creek, central Australia (K. Fryirs).



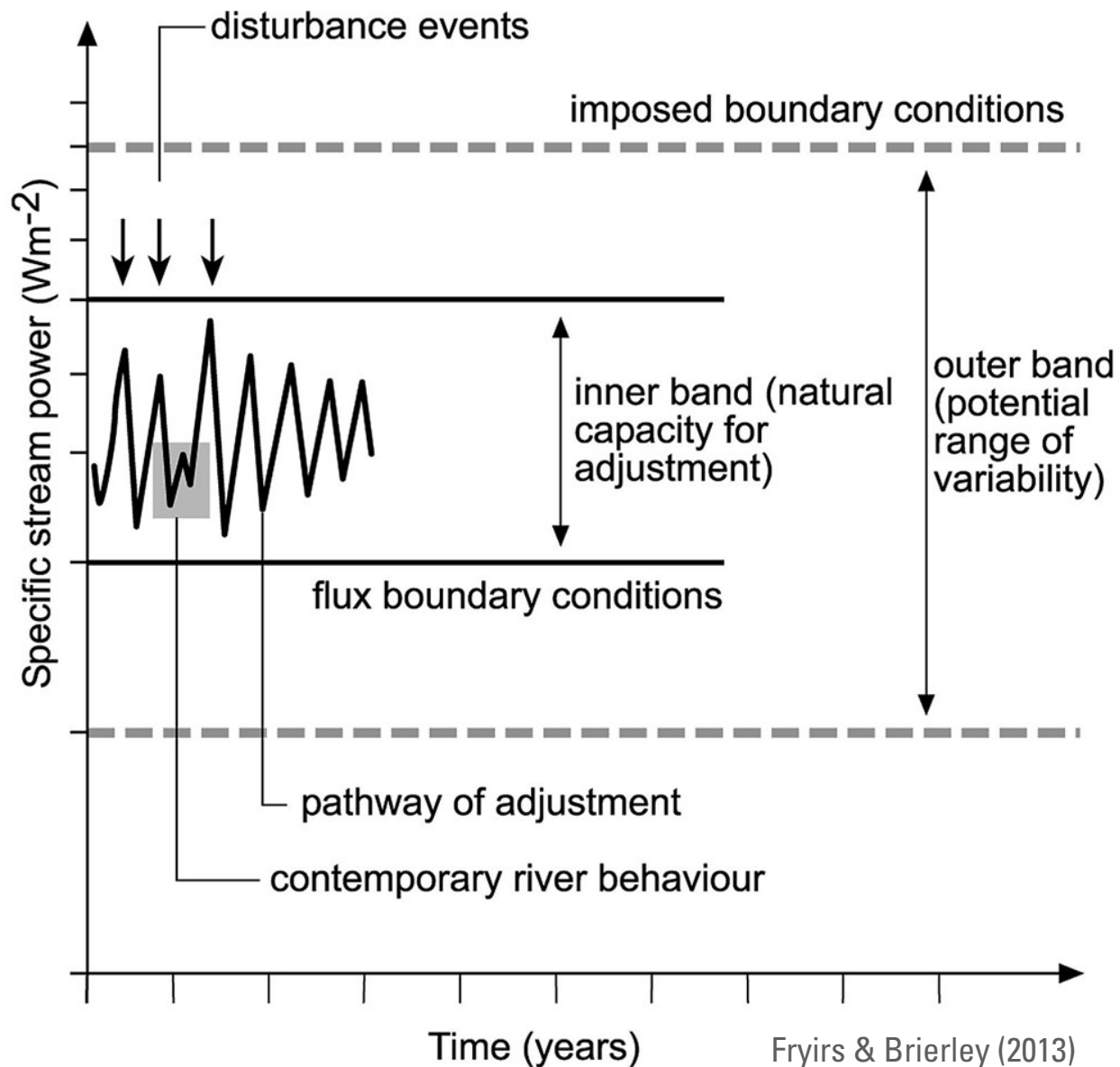


.....➔ low flow & bankfull stage thalweg    - - ➔ overbank stage thalweg

- = thalweg
- LF = low flow
- BF = bankfull
- OB = overbank

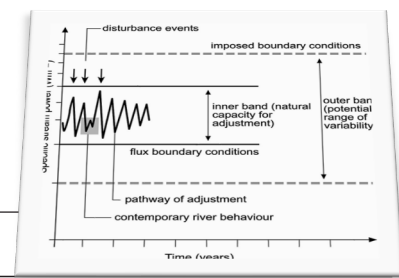


**Figure 11.8** River behaviour in laterally unconfined, low-energy rivers with discontinuous channels – chain-of-ponds and floodout types. Unconfined flows dissipate energy over the valley floor, promoting vertical accretion of valley fills. At lower flow stages, virtually all flows are subsurface. Floodout deposits may occur as splay-like features immediately downstream of discontinuous channels. Photographs: left, Mulwaree River, NSW; right, Frogs Hollow Creek, NSW (K. Fryirs).



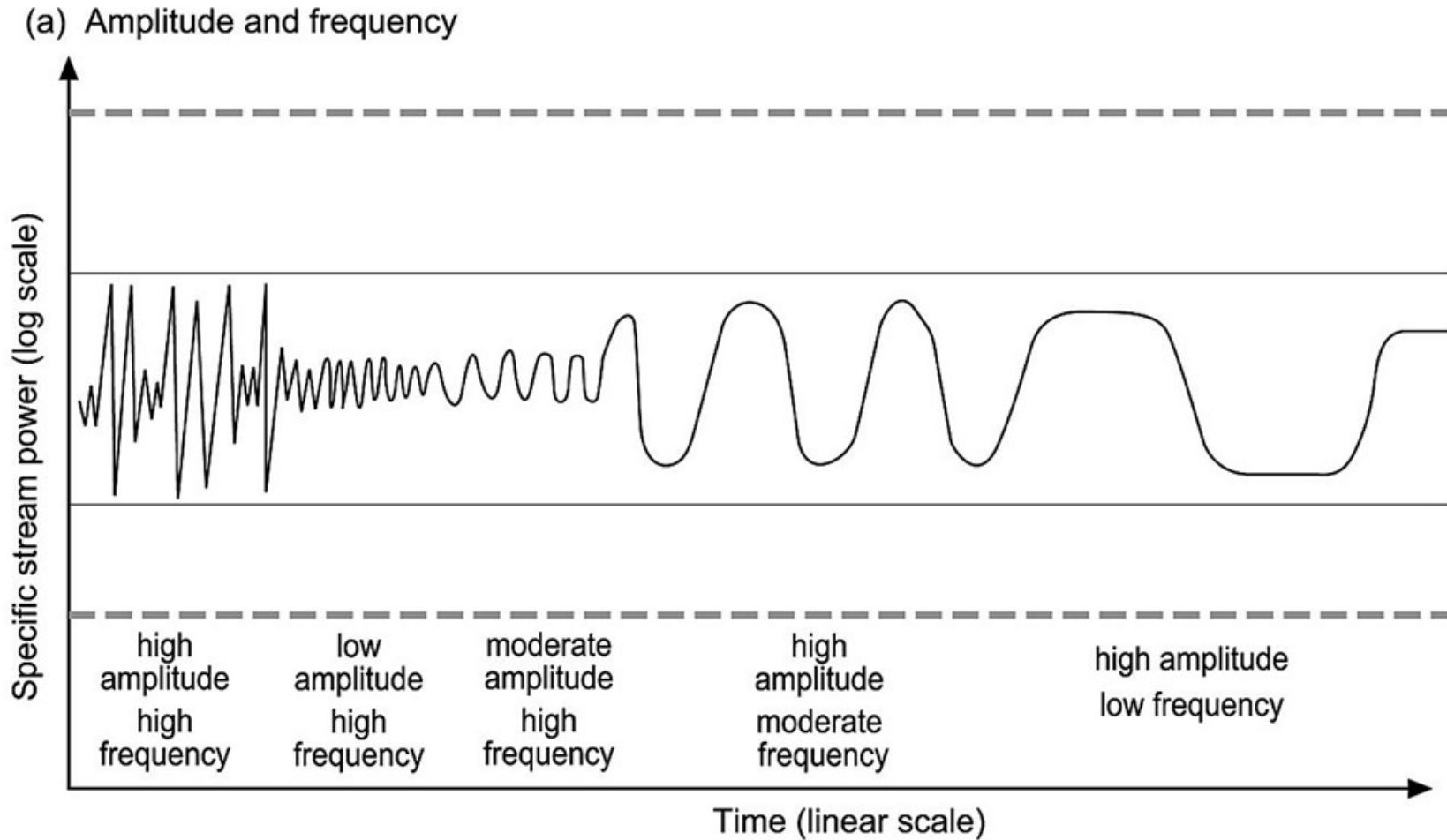
**Figure 11.9** Components of the river evolution diagram. This conceptual scheme provides a framework to examine how rivers adjust over time. Energy settings are determined by imposed boundary conditions (outer band) and prevailing flux boundary conditions (i.e. flow and sediment regimes; inner band). When subjected to differing forms of disturbance events, the river adopts a pathway of adjustment (the jagged line within the inner band). This records the pattern and rate of morphological variability that is characteristic for that type of river. From Brierley and Fryirs (2005). © Wiley–Blackwell Publishing. Reproduced with permission.

# River Evolution Diagram Components

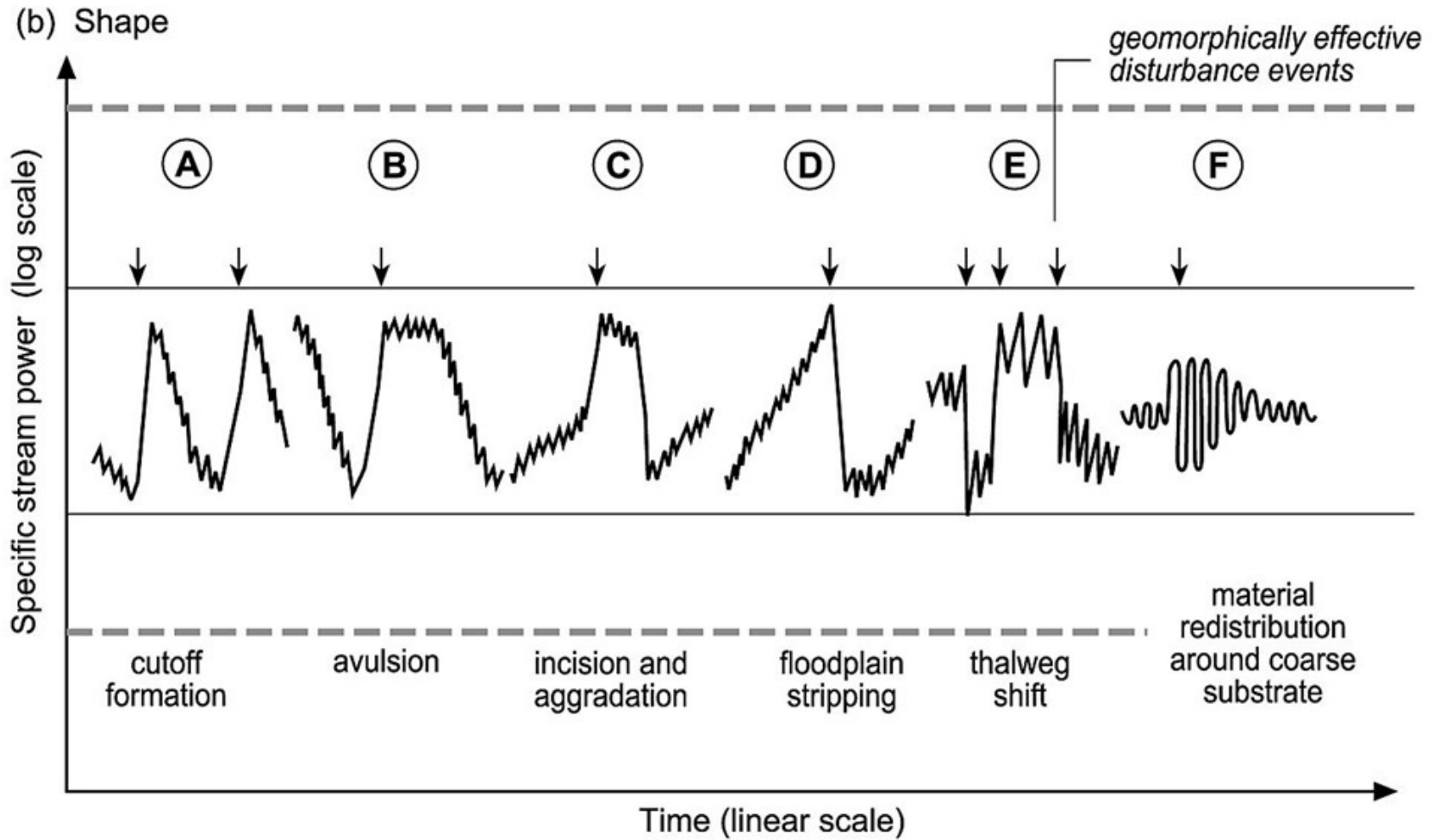


**Table 11.1** Definition of components of the river evolution diagram<sup>a</sup>

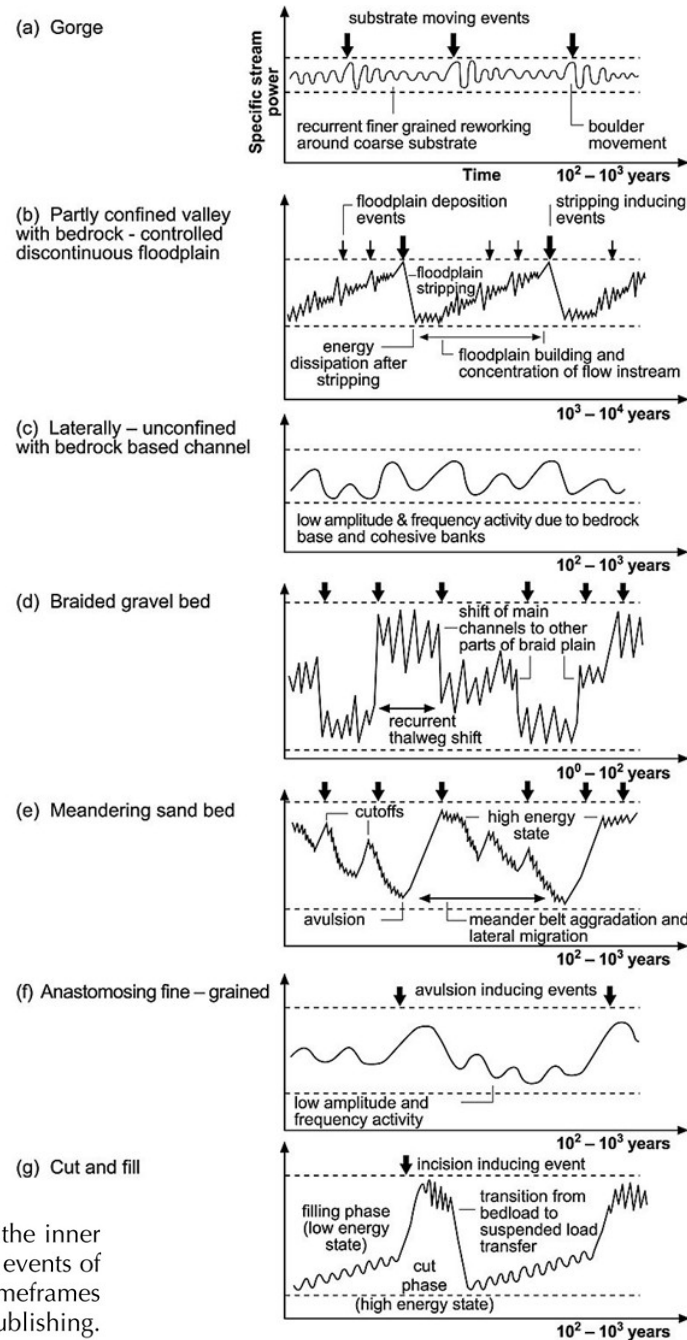
Component	Definition
Specific stream power (see Chapter 4)	Total stream power is calculated as the product of discharge acting in any given cross-section multiplied by channel slope. Specific stream power determines the energy acting on a given area (e.g. per unit channel width). Hence, as channel geometry adjusts, so does the use of available energy. Specific stream power is represented on the y-axis of the river evolution diagram using a logarithmic scale. Geomorphic work reflects the ability of a flow to induce adjustment in bed character, channel morphology, the assemblage of geomorphic units and channel planform without inducing change to a different river type.
Time	Represents the timeframe over which the full suite of behaviour occurs for a particular river type. Shown using a linear scale on the x-axis of the river evolution diagram.
Outer band	Reflects the <i>potential range of variability</i> in the types of rivers that can form under a certain set of <i>imposed boundary conditions</i> (i.e. valley setting, slope and lithology).
Inner band	Reflects the <i>natural capacity for adjustment</i> for a particular river type which represents the degree to which vertical, lateral and wholesale adjustments can occur for that type. The width of the inner band is defined by the <i>flux boundary conditions</i> , i.e. the range of flow and sediment fluxes and vegetation dynamics that dictate the potential extent of adjustment in the assemblage of geomorphic units, channel planform, channel morphology and bed character for that type.
Pathway of adjustment	Defined by the frequency and amplitude of system responses to disturbance events. The shape of the pathway reflects the variability in the trajectory and timeframe of recovery in response to disturbance events. This records the behavioural regime of a river. Some rivers may adjust among multiple states.
Disturbance event	Formative events that induce geomorphic adjustments to a river type. The size of the arrows represents the relative magnitude of the event that induced adjustment. The sequence of events may be a significant determinant of geomorphic response.
Contemporary river behaviour	Adjustments that take place under contemporary flux boundary conditions while maintaining the river type.



**Figure 11.10** Components of the pathway of adjustment as used in the river evolution diagram. Significant variability in the form and rate of adjustment occurs for different types of rivers. Three components are considered in appraisal of pathways of adjustment, namely (a) amplitude, frequency and (b) shape. From Brierley and Fryirs (2005). © Wiley-Blackwell Publishing. Reproduced with permission.



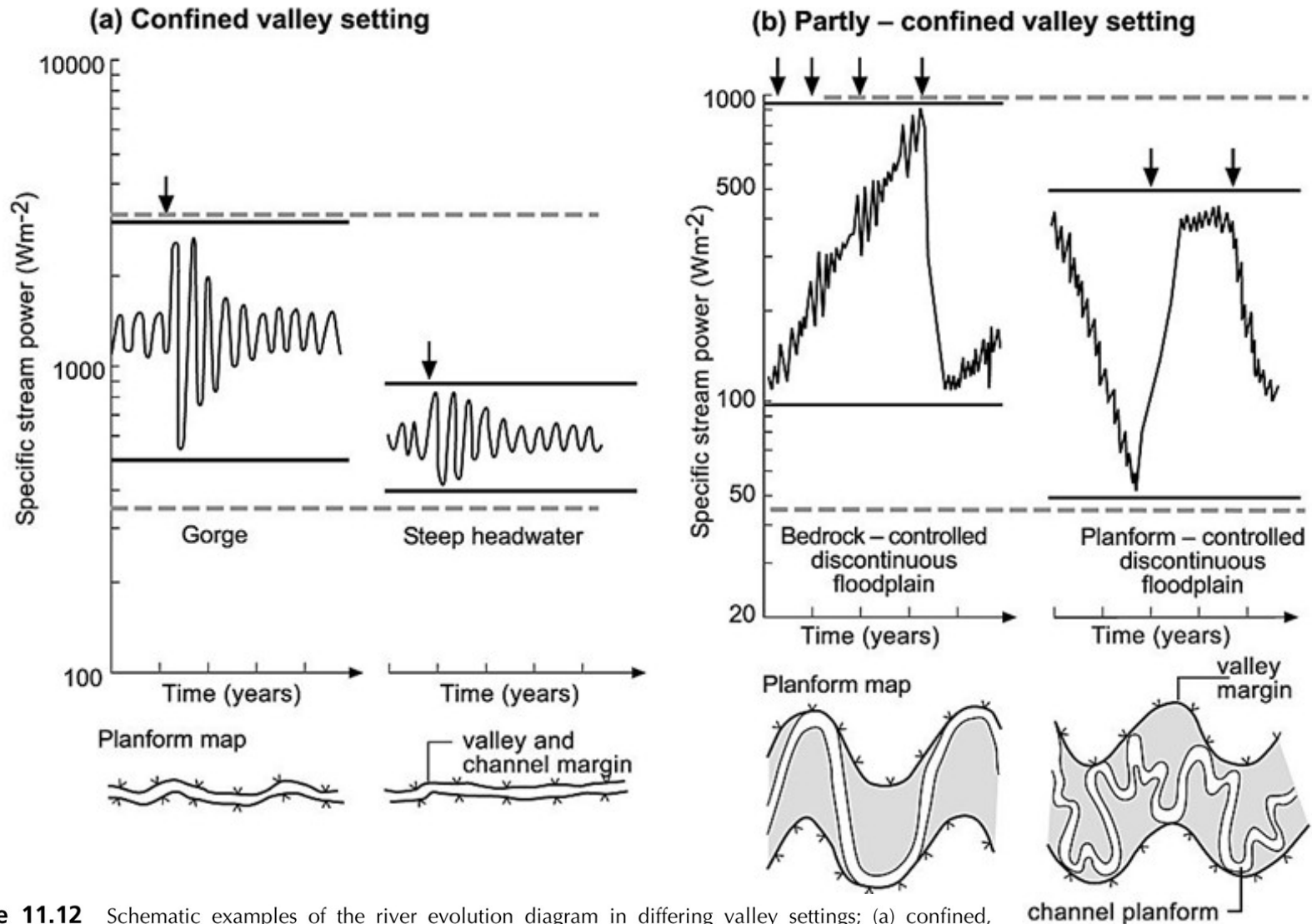
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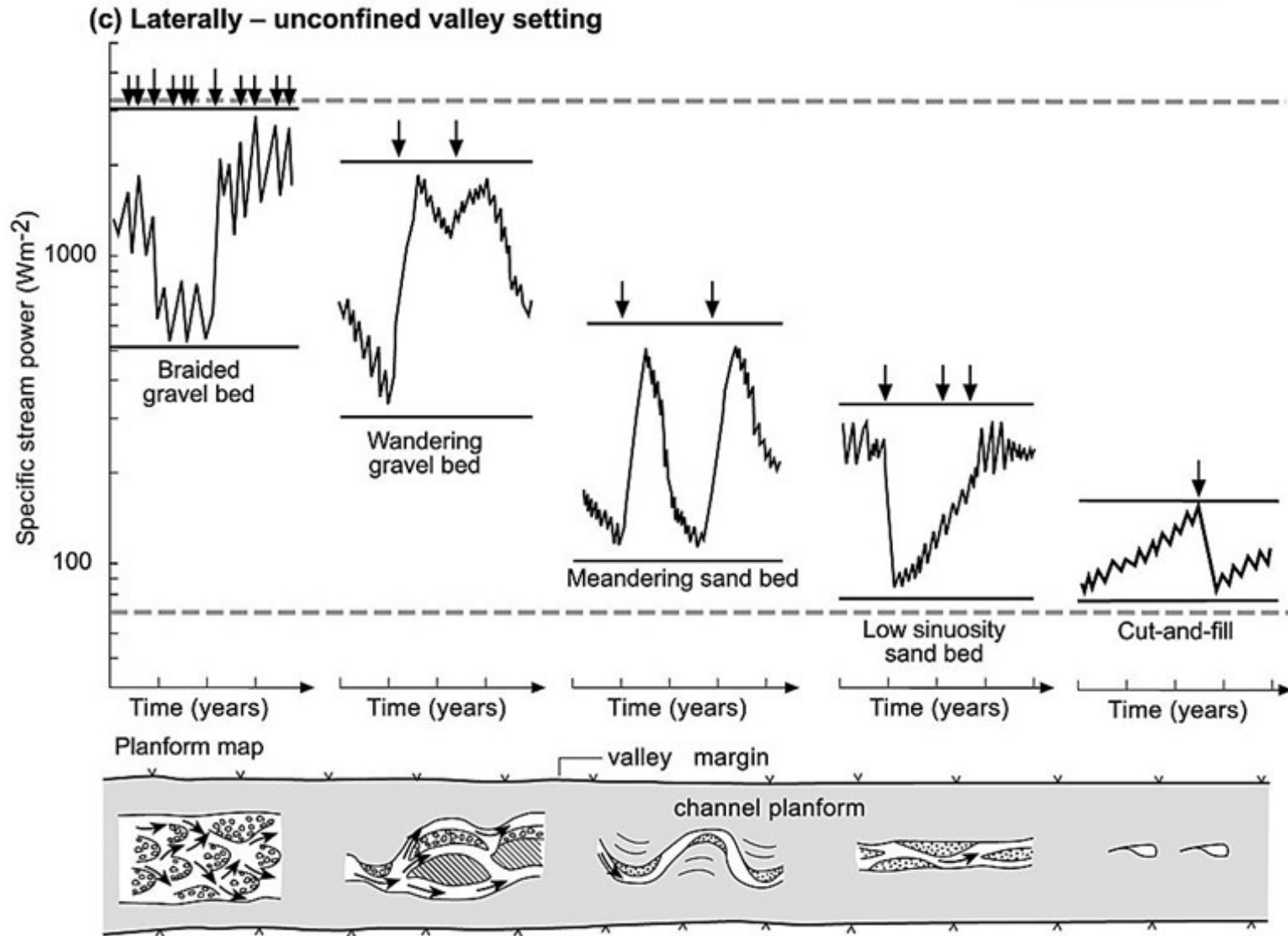
Fryirs & Brierley (2013)

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

**Figure 11.11** Pathways of adjustment for different types of rivers. This diagram, which only conveys the inner band of the river evolution diagram, indicates different pathways of adjustment in response to disturbance events of variable recurrence for different types of rivers. Profound differences in the ranges of variability and the timeframes of adjustment are indicated (see text for details). From Brierley and Fryirs (2005). © Wiley-Blackwell Publishing. Reproduced with permission.

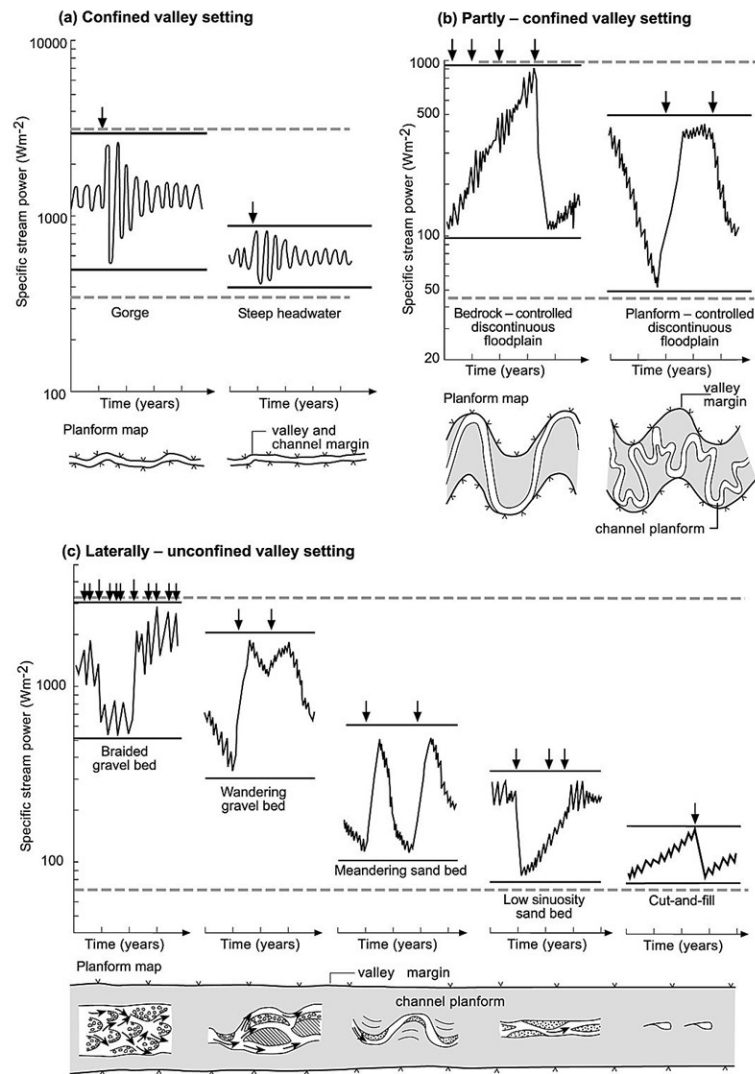


**Figure 11.12** Schematic examples of the river evolution diagram in differing valley settings; (a) confined, (b) partly-confined, (c) laterally-unconfined. Note the variability in specific stream power estimates for these differing behavioural pathways of adjustment. See text for details. From Brierley and Fryirs (2005). © Wiley–Blackwell Publishing. Reproduced with permission.



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Sediment  
Transport Limited



capacity-limited channel

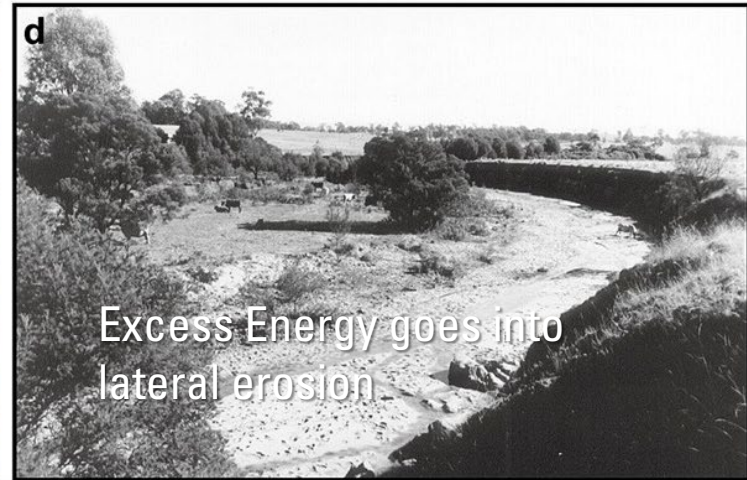


competence-limited channel

Sediment  
Supply Limited



supply-limited channel where incision has occurred



supply-limited channel where channel expansion has occurred

**Figure 6.15** Sediment-supply- and transport-limited systems. Sediment transport-limited systems occur when sediment volume or size exceeds the capacity of the flow to transport it, resulting in sediment deposition and storage. Transport-limited systems can be competence (grain size is too large) or capacity (volume is too large) limited. Sediment-supply-limited systems occur when the flow is able to carry more sediment than is made available to it, resulting in erosion of sediment. Photographs: (a) Waiapu River, New Zealand (K. Fryirs), (b) Sangainotaki River, Japan (K. Fryirs), (c) Latrobe River, Victoria (G. Brierley), (d) Greendale Creek, NSW (K. Fryirs).