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Lecture Note

Collecting sediment data for studying sediment-based ecological problems

Mengzhen XU.

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Collecting sediment data for studying sediment-based ecological problems

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Introduction

Measurement of river sediment has been among the challenges of river research. For instances, bed load transport rate could be measured with a variation of 1000 times at different time steps; soil erosion and intensive sediment movement would destroy river ecology; river restoration also requires water and sediment data for strategy making and technical design. Collecting water and sediment data are critical for the provision of safety to the people dwelling by the river and sustainable use of the land and water. It also important for making river use economically productive, socially equitable, and environmentally sustainable. It is attractive to concentrate on a hydrographically coherent region such as a river basin, catchment, or drainage or polder area, as all key actors and all decision-making can be brought under one purview. For integrated river management, one has to understand the whole river system very well, including all issues of a river, and all aspects of the natural and human-impacted system and their interconnections. On the basis of summing up the practice of scientific research, a systematic review is made of the sediment movement, bed evolution, dammed river management and other traditional river sediment disciplines. At the same time, the important research directions of the emerging river sediment discipline, such as the dynamic model and application of vegetation-erosion, the evolution and management of rivers in mountain areas, the methods of river ecological evaluation and ecological restoration, and the strategy of integrated river management, are also expounded.

Content

1. Basic concepts & sediment data collecting
2. Interaction between sediment and river ecology
3. Water-sediment-ecology integrated management

1. Basic concepts & sediment data collecting

- **Explain basic concepts in river management:**
  - ✓ Watersheds, alluvial river, perennial streams, levees, flood defense, estuary, red tide, eutrophication, algal blooms, river-uses, integrated river management, etc.

- **Explain the major issues of river management:**
  - ✓ The main functions of rivers are draining floods, supplying drinking water,

maintaining ecology, irrigating farmland, transporting sediment, supplying power, providing habitat for fish, assimilating wastewater, and providing navigation. Humans exploit the resources of rivers by constructing dams and water-diverting channels, developing navigation channels, and harvesting fish, which result in changes in the river hydrology, runoff, sediment transport, riparian and stream habitats, and water quality.

- ✓ The major issues of river management are associated to the variety of river uses:
- ✓ **Water resources** refer to available or possibly available water sources that possess adequate quantity and utilizable quality and may be utilized in a specific location for a specific purpose.
- ✓ **Flooding** - Several devastating floods have occurred worldwide in the 1990s, with a long list of flood events each killing more than a thousand people or causing material losses in excess of one billion U.S. dollars.
- ✓ **Soil erosion** - Various types of erosion occur naturally and they are classified according to the main agents causing erosion, including water erosion, wind erosion, gravity erosion, and glacier erosion.
- ✓ **Riverbed incision** is defined as continuous bed erosion and bed-level lowering. Mountain rivers either were or are incised rivers. Alluvial rivers may also experience a short period of bed incision.
- ✓ **Pollution and eutrophication** - Most rivers are also used to carry wastewater discharged from communities and industry. The river water is polluted and the river environment is damaged.
- ✓ **Reservoir management** - Impoundment of rivers causes many problems.
- ✓ **River uses** - Hydro-Power, Irrigation, Inland Navigation.
- ✓ **Ecological Restoration** - Environmental protection and ecological restoration have become very popular in China. Restoration of impaired stream ecosystems is necessary for most of the world's rivers. Ecological restoration involves the return of a given ecosystem to a state approximating that in which it existed prior to disturbance and ecological protection implies maintaining the organisms and their environment unchanged.

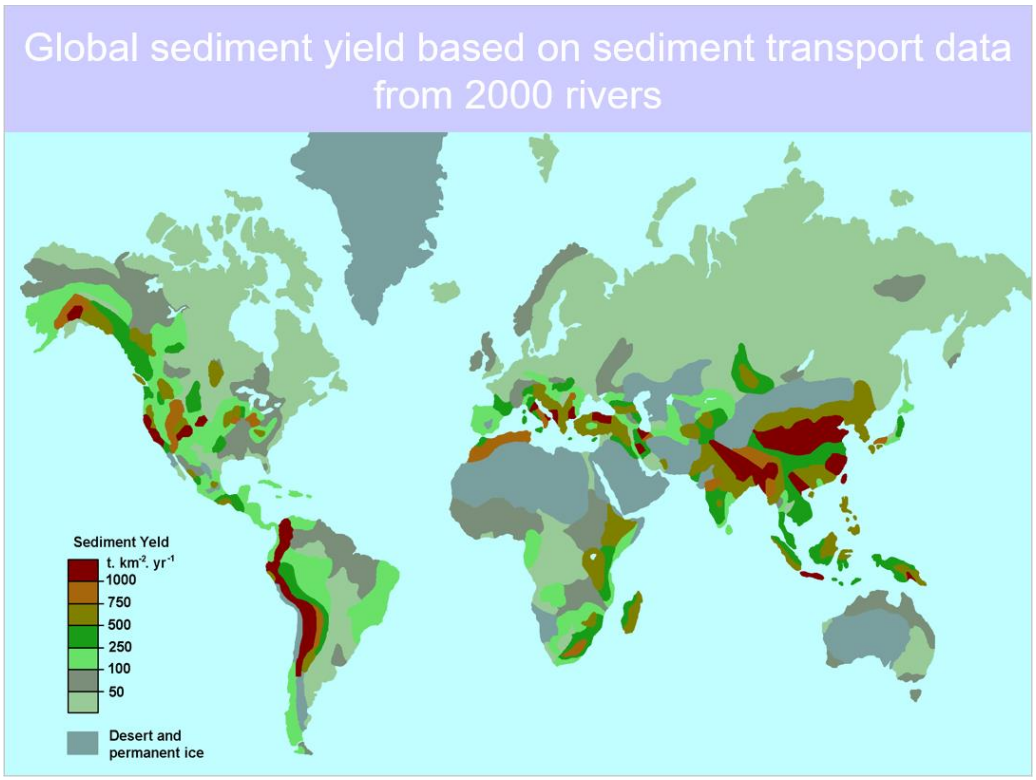
- **Shed light of integrated river management and case study:**
  - ✓ What is **integrated river basin management**?
  - ✓ "Integrated river basin management (IRBM) is the process of coordinating conservation, management and development of water, sediment, land and related resources across sectors within a given river basin, in order to maximise the economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary, restoring freshwater ecosystems." Adapted from Integrated Water Resources Management, Global Water Partnership Technical Advisory Committee Background Papers, No. 4, 2000.)
  - ✓ Many countries have taken an increasing interest in **integrated river management** coordinating various sectors of river issues. A developing country, like China, now strongly emphasizes the goal of flood control, water resources development, and environmental protection in addition to reducing poverty by supporting efficient

and sustainable development of agriculture and light industries.

- **Summary**
  - ✓ Invite students to share their understanding of river uses and integrate river management
  - ✓ Invite students to give example about major issues of rivers in different regions in China
  - ✓ Arrange homework

2. Interaction between sediment and river ecology

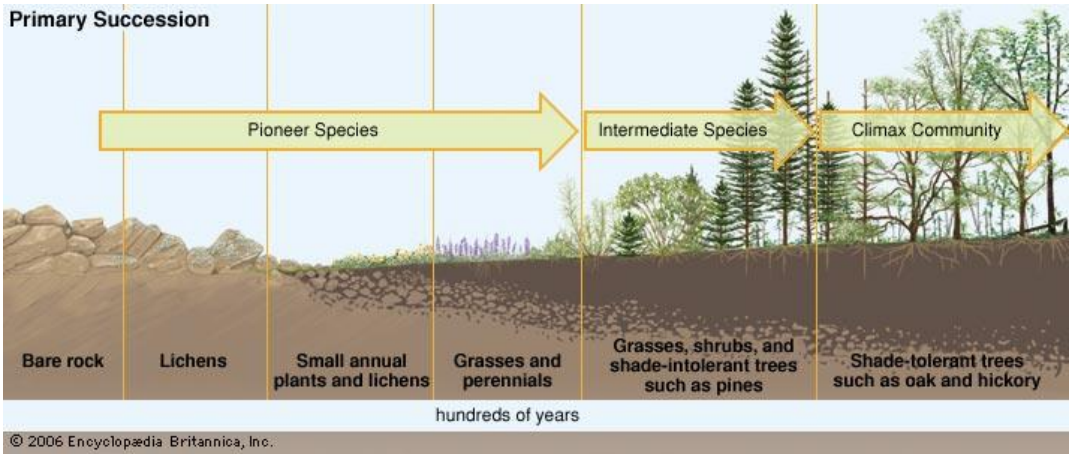
- **Explain agents of erosion:**
  - ✓ Erosion is the processes by which the surface of the earth is constantly being worn away. In other words, erosion means the detachment and removal of solid particles from their original place.
  - ✓ Weathering is the process of chemical or physical breadkdown of minerals, and which involves no movement.
  - ✓ Erosion may be classified according to the agents as water erosion, gravity erosion, glacial erosion and wind erosion (aeolian erosion).



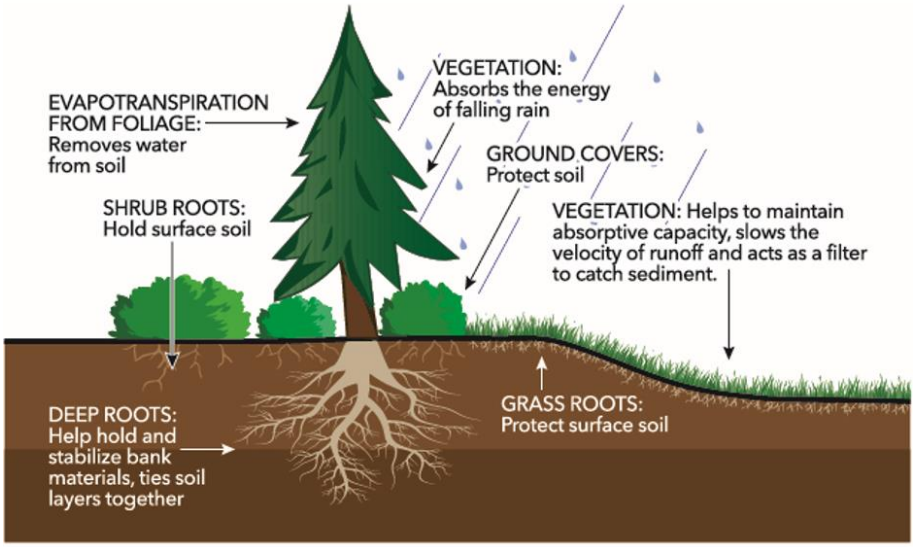
- **Explain various vegetations and vegetation succession:**
  - ✓ Primitive vegetation, such as virgin forest, has not been disturbed by human activities. The floral community usually consists of complex species composition.
  - ✓ Reforested vegetation- To accelerate development of new vegetation human plant trees in these areas. The dominant species of wood is planted by humans, but the understory community develops under the natural conditions and consists of local

species, which is complex.

- ✓ Domestic vegetation - In the process of urbanization, people plant and acclimate various plants to beautify their living environment. Such kinds of vegetation have adjusted to the human stresses and it will not sustain if humans discontinue the artificial stress.
- ✓ Riparian vegetation and watershed vegetation.



- **Explain how does vegetation mitigate water erosion:**



Role of vegetation in reducing erosion and stabilizing slopes

https://shorestewards.cw.wsu.edu/guidelines/guideline-5/

- **Explain stresses on vegetation:**
  - ✓ Ecological stress is defined as any kind of disturbance on the vegetation, which may change the vegetation cover or affect the vegetation development.
  - ✓ Tectonic motion, landslide, drought, salinization, debris flow, flood, catastrophic wind, insect and disease are natural stresses.
  - ✓ The human-induced stresses may be cited as land use change, agriculture, urbanization, air pollution, sewage and industrial waste contamination, husbandry,

logging, reclamation, mining, road construction, and afforestation.

- ✓ Classification of stresses: long-term (life period of trees or decades), short-term (years) and instant stresses (days); mortality stress and vigor stress, resilicence of the vegetation

- **Explain vegetation dynamics model:**
  - ✓ The ecological functions of vegetation are a function of vegetation cover, vigor, and function index: F=V*Vgξ, F: functional capacity of vegetation, V: vegetation cover, Vg: vigor of vegetation, ξ: the functional index
  - ✓ Dynamic balance between soil erosion and vegetation development
  - ✓ The dynamical responses of vegetation to various ecological stresses are modeled in two parts:
  - ✓ Variation in vegetation cover due to mortality stresses and reforestation;
  - ✓ Vigor reduction caused by vigor stresses

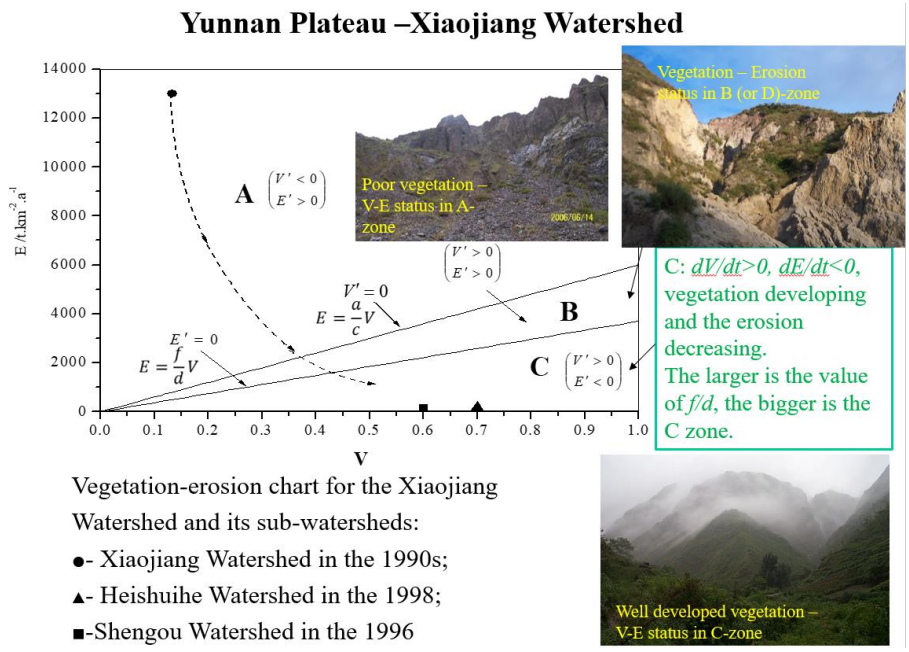
Differential Equations:

The dynamics of the vegetation under the action of various ecological stresses follows the differential equation:

$$\frac{dV}{dt} = aV - cE - K_{inst}\delta(t_0) + V_R$$

- E is the rate of erosion with dimension [mass/area.time] and unit (ton/km^2 yr);
- a, K_{inst} are coefficients of dimension [time^{-1}] and unit (yr^{-1});
- c is a coefficient of dimension [area/mass] and unit (km^2/ton); and V_R is the rate of the reforestation of unit (yr^{-1})
- $\delta(t_0)$ is instant stress

- **Explain application of vegetation-erosion dynamics:**
  - ✓ The vegetation-erosion dynamics model was first applied to the Loess Plateau and Yunnan-Guizhou Plateau in west China:

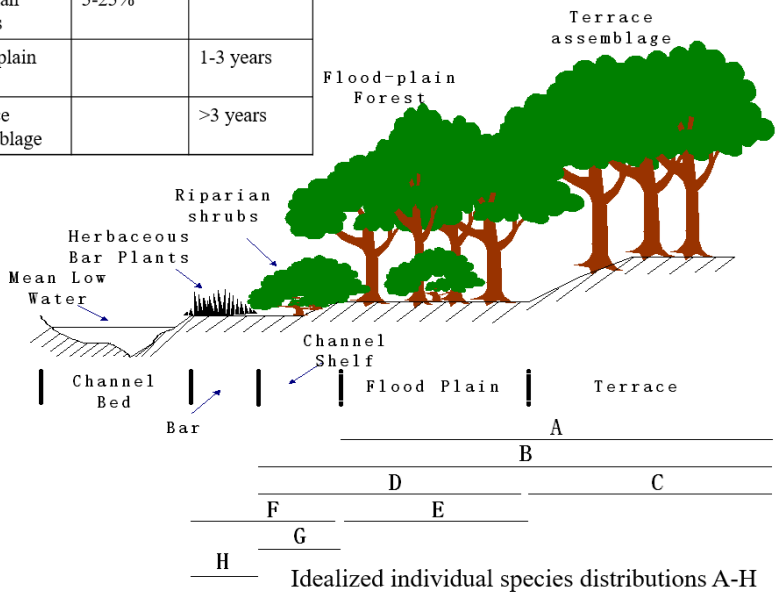


Vegetation-erosion chart for the Xiaojiang Watershed and its sub-watersheds:
●- Xiaojiang Watershed in the 1990s;
▲- Heishuihe Watershed in the 1998;
■-Shengou Watershed in the 1996

- **Explain riparian vegetation:**
  - ✓ Riparian vegetation is affected in both form and species distribution by fluvial-geomorphic forms and processes.
  - ✓ Riparian vegetation affects and is affected by the river development.
  - ✓ Invasive or ruderal plants may play an important and sometimes critical role in the re-establishment of equilibrium conditions.

Fluvial landform	Vegetation type	Inundated duration	Flood frequency
Channel bar	Largely absent	About 40%	
Channel shelf	Riparian shrubs	5-25%	
Floodplain	Floodplain forest		1-3 years
Terrace	Terrace assemblage		>3 years

Fluvial-landforms and their relations with vegetation type, flow duration (i.e. percentage of time the landforms is inundated), and flood frequency.

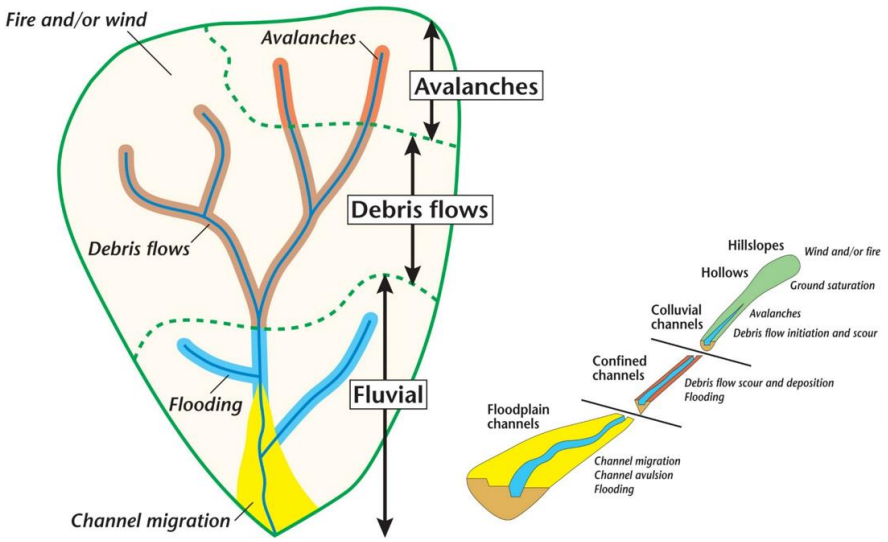


(after Hupp, 1992)

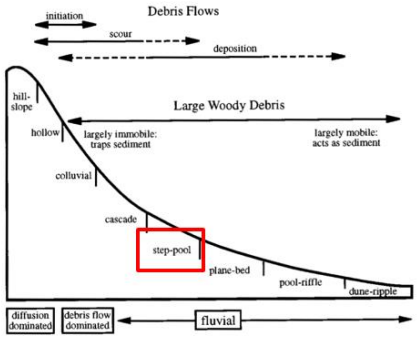
Idealized individual species distributions A-H

- **Explain incised rivers:**
  - ✓ An incised river is defined as a river that is experiencing bed-level lowering

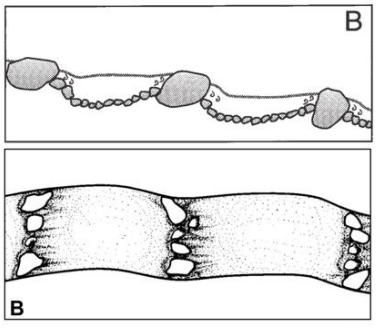
- ✓ River incision is common after tectonic uplift of the landscape.
- ✓ River Incision is the natural process by which a river cuts downward into its bed, deepening the active channel. It can be accelerated rapidly by human factors including land use changes such as timber harvest, mining, agriculture, and road and dam construction.

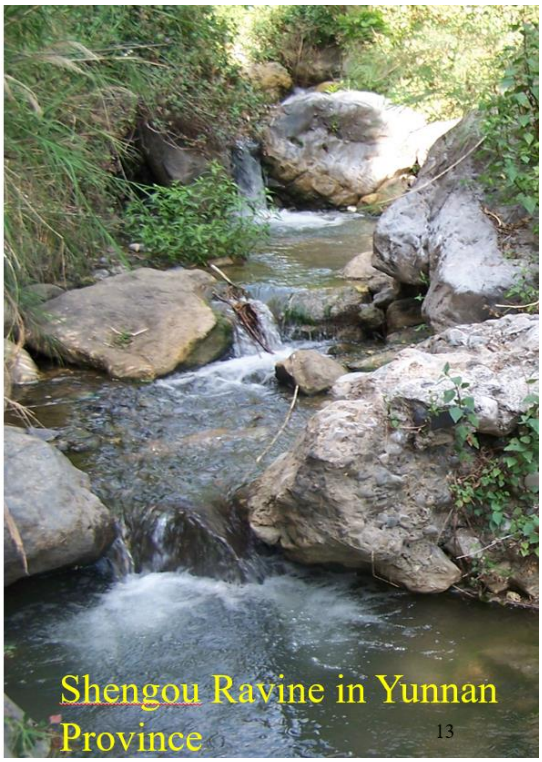


Geomorphic process domains and landscape evolution



(Montgomery and Buffington 1997)





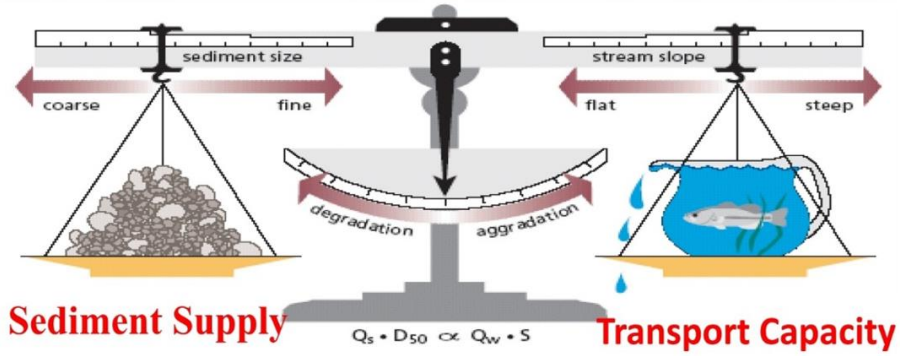
- **Evolution Process of Incised Rivers:**
  - ✓ The incision of the river channel indicates a period of vertical instability or

unequilibrium by degradation.

- ✓ River Incision is the natural process by which a river cuts downward into its bed, deepening the active channel. Though it is a natural process, it can be accelerated rapidly by human factors including land use changes such as timber harvest, mining, agriculture, and road and dam construction.
- ✓ The essential cause of channel incision is high slope and non-equilibrated stream flow and bed roughness.
- ✓ Specific causes: geologic causes; geomorphic causes; climatic causes; hydrologic causes; animal and human activities

- Degradation occurs if

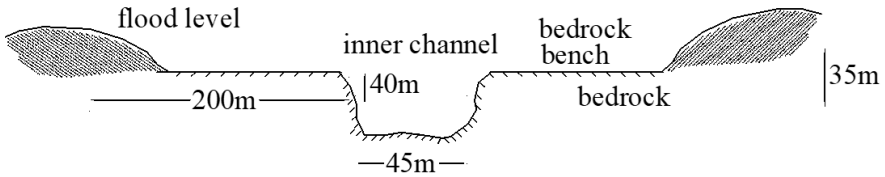
$$Qs > kQ_sD_{50}$$

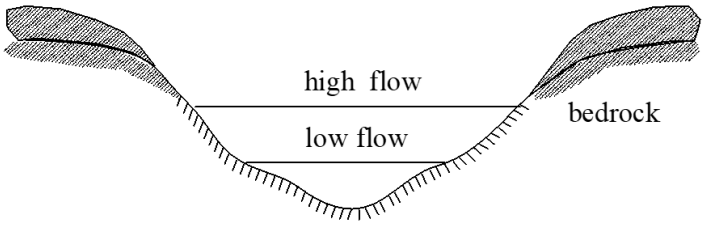


Factors affecting channel degradation or aggradation

- **Explain bedrock channels:**
  - ✓ A bedrock channel may be defined as a channel for which morphology and gradient are directly controlled by bedrock
  - ✓ Incised bedrock channels: Some bedrock channels have low-flow and high-flow portions; Some bedrock channel have a bedrock surface into which a low-flow inner channel is incised, thus have in-channel flow in dry season and high flow in flood season; The exposed bedrock implies that the channels may be particularly sediment-starved during floods
  - ✓ Incision rate of bedrock channels: Because bedrock channel incision commonly occurs over the course of centuries to millennia, channel instability resulting from bed incision is not as widespread a problem among bedrock channels as among alluvial channels.
  - ✓ Incision processes of bedrock channels: The bedrock channel is eroded by three processes: corrosion, corrasion, and cavitation; Corrosion is chemical weathering and solution. Generalized estimates range from 0.005 - 0.2 mm yr-1 for carbonates; Corrasion is abrasive weathering of bedrock by clusters moving along the channel as bed load. Channels incised by corrasional erosion have numerous potholes, longitudinal grooves and knickpoints; Cavitation occurs in a flow induce pressure fluctuations, and implosion of vapor bubbles.

- ✓ Knickpoint: Knickpoint is a point of slope changing or short and steep sections of channel, such as a waterfall or lake; Knickpoints are the sites of the greatest concentration of energy dissipation along the course of a stream.





Knickpoints on the tributaries of the Dadu River

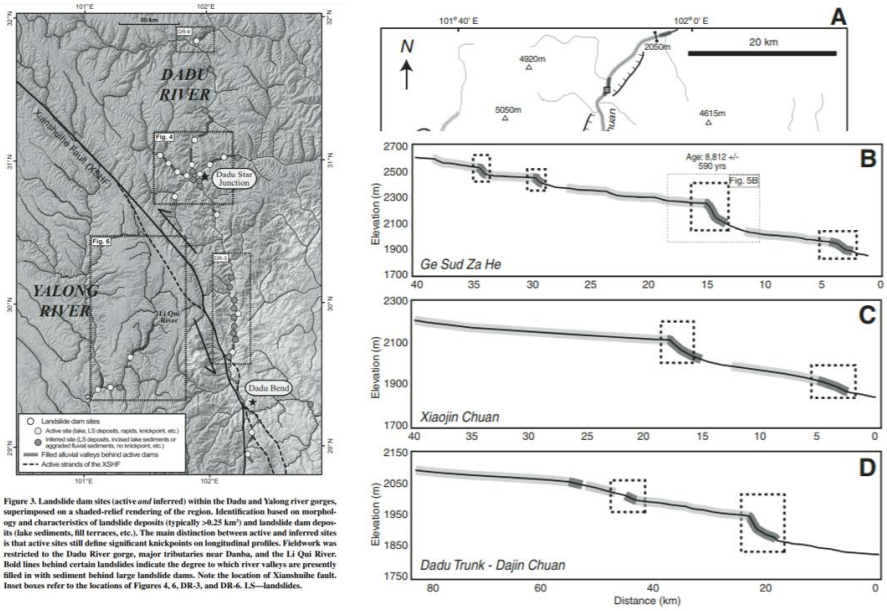
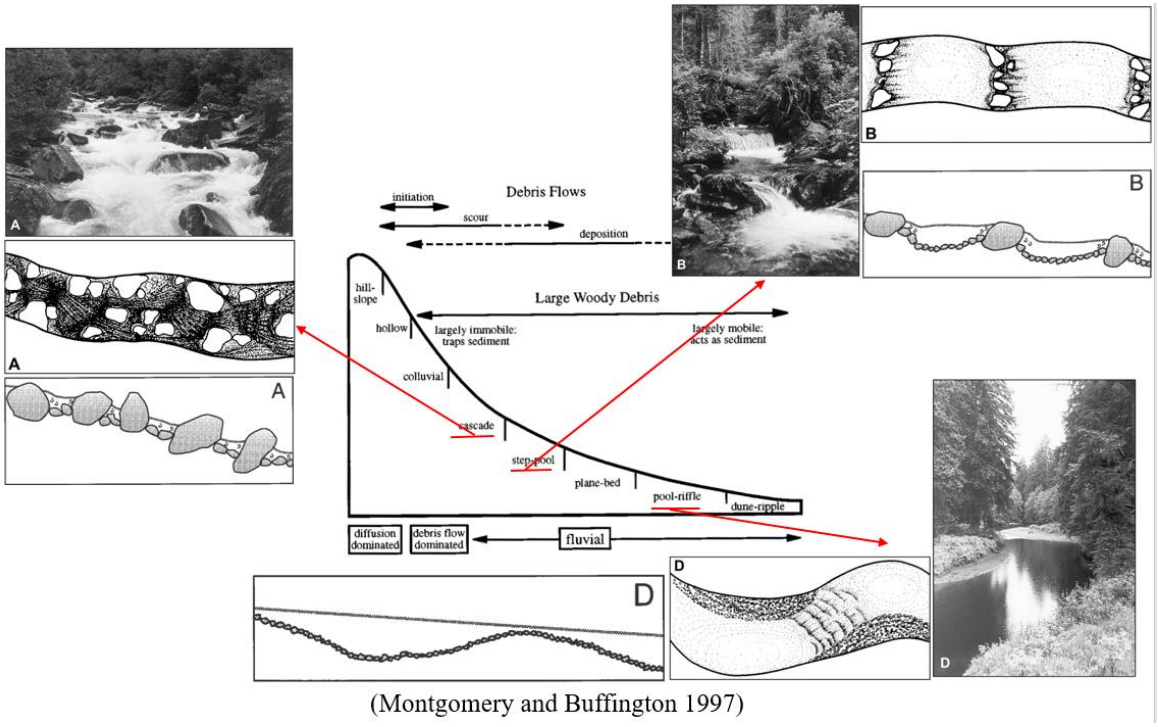


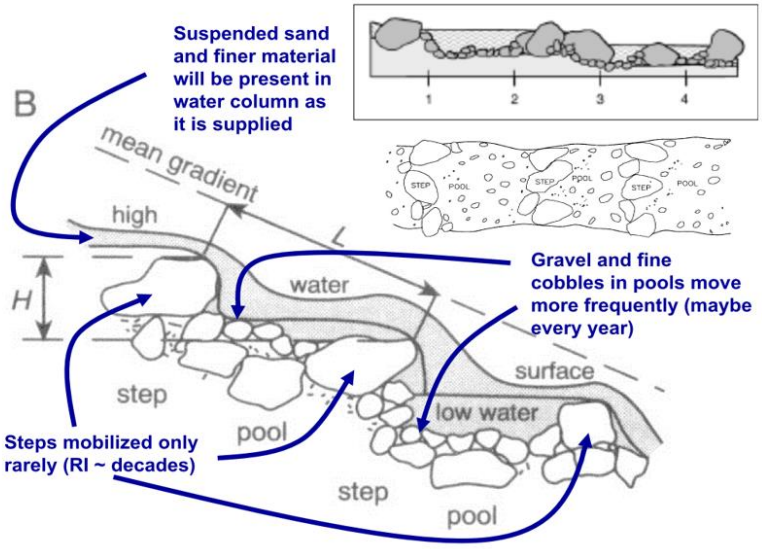
Figure 3. Landslide dam sites (active *and* inferred) within the Dadu and Yalong river gorges, superimposed on a shaded-relief rendering of the region. Identification based on morphology and characteristics of landslide deposits (typically >0.25 km³) and landslide dam deposits (lake sediments, fill terraces, etc.). The main distinction between active and inferred sites is that active sites still define significant knickpoints on longitudinal profiles. Fieldwork was restricted to the Dadu River gorge, major tributaries near Danba, and the Li Qui River. Bold lines behind certain landslides indicate the degree to which river valleys are presently filled in with sediment behind large landslide dams. Note the location of Xianshuihe fault. Inset boxes refer to the locations of Figures 4, 6, DR-3, and DR-6. LS—landslides.

- **Bed structures resisting incision:**
  - ✓ Bed structures are structures on streambeds of boulders and cobbles rearranged by flood flow to reach high resistance and high bed stability.
  - ✓ The step-pool system is the most important bed structure.
  - ✓ Step-pool system - alternating steps and pools having a stair-like appearance are a characteristic feature of mountain streams flowing over slopes greater than 3%.
  - ✓ Ecological effects of step-pool system
  - ✓ provide high diversity of habitats and therefore supports high species diversity of animals
  - ✓ stabilize the stream bed and benefit to the community of long term life

- ✓ allow species migration between downstream and upstream habitats
- ✓ Other bed structures are
- ✓ Ribbing structure – middle gradient
- ✓ Bank stones – middle gradient
- ✓ Star-studded boulders – middle and low gradient
- ✓ Cobble clusters – middle and low gradient
- ✓ Fire rocks – high gradient



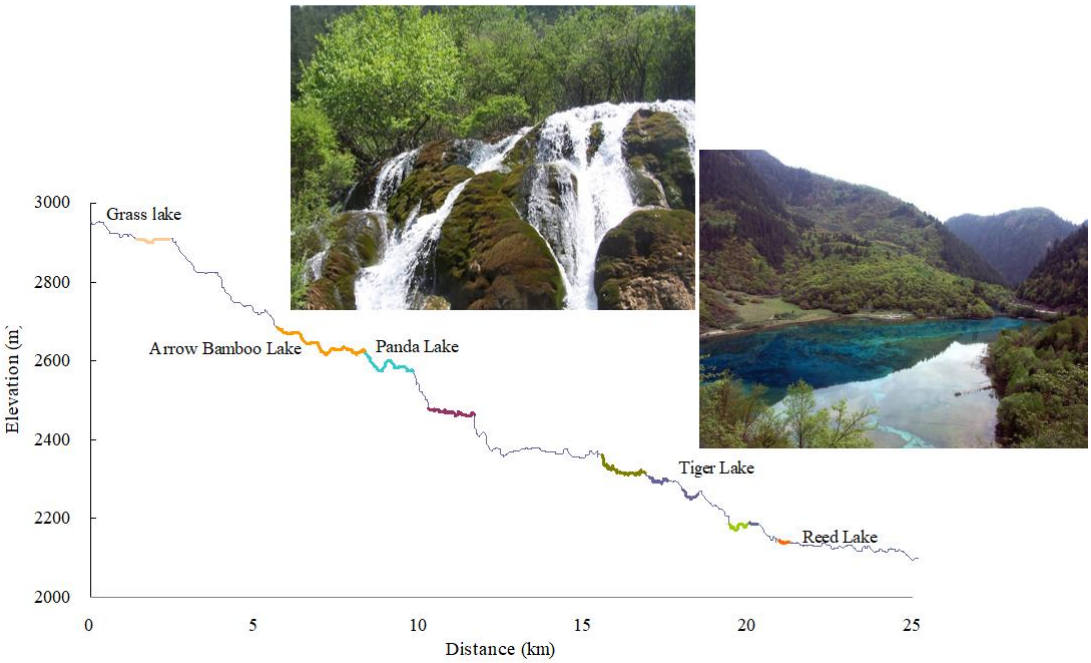
(Montgomery and Buffington 1997)



- **Environmental Impacts and Control Strategies of Riverbed Incision:**
  - ✓ The most disastrous consequence of riverbed incision is causing bank failure, landslides and avalanches

- ✓ The most far-reaching influence of channel incision is soil erosion
- ✓ Furthermore, landslide dam, increased soil erosion and sediment yield may cause a new cycle of fluvial process of the river
- ✓ The process may last for a century or a longer period of time.
- ✓ Other environmental impacts of incision
- ✓ Damage to bridges
- ✓ Loss of gravel bars and, consequently, the loss of habitat and biodiversity, and damage to riparian vegetation
- ✓ Stream bed incision caused great wetland loss in Ruergai swamp land
- ✓ Incision lowers the water table and causes loss of groundwater storage
- ✓ Incision control strategies:
- ✓ Morphologically riverbed incision is controlled by knickpoints, such as landslide dams.
- ✓ Stabilization of natural dams may stop incision.
- ✓ Human constructed dams, after filling with sediment, may be regarded as knickpoints as well and control stream bed incision.
- ✓ Mechanically streambed incision is essentially due to high flow velocity and insufficient bed load.
- ✓ Therefore, two strategies to control incision: 1) enhance the bed resistance and reduce flow velocity; 2) increase bed load.

Profile of the Jiuzhaigou Creek - Numerous landslides resulted in several Knickpoints and control the riverbed incision



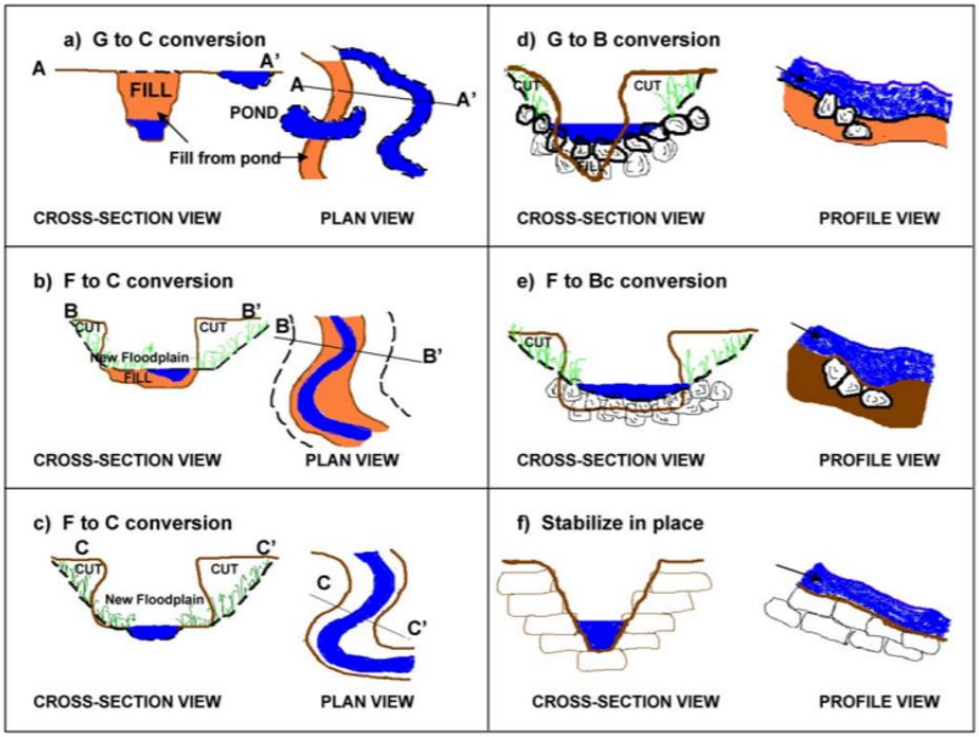


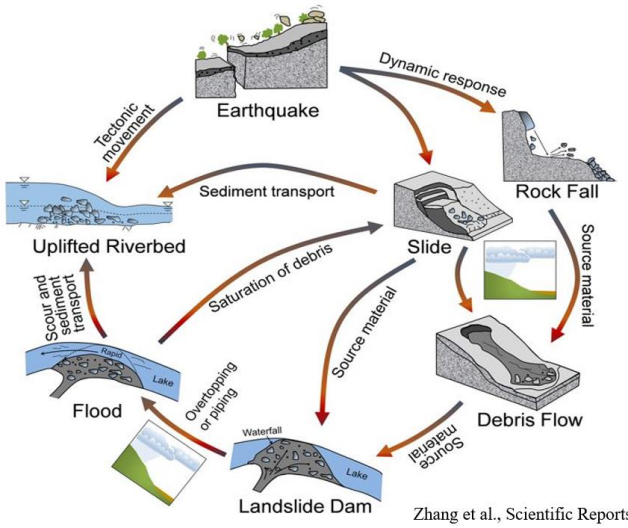
Figure 5. Various restoration/stabilization options for incised channels.

David L. Rosgen. A geomorphological approach to restoration of incised rivers. Proceedings of the Conference on Management of Landscapes Disturbed by Channel Incision, 1997 S.S.Y. Wang, E.J. Langendoen and F.D. Shields, Jr. (eds.) ISBN 0-937099-05-8

- **Landslide**
  - ✓ Disasters caused by landslides and debris flows
  - ✓ Classification of landslide: according to movement, slide surface, slide materials
  - ✓ What causes landslides?
  - ✓ Where landslides occur?

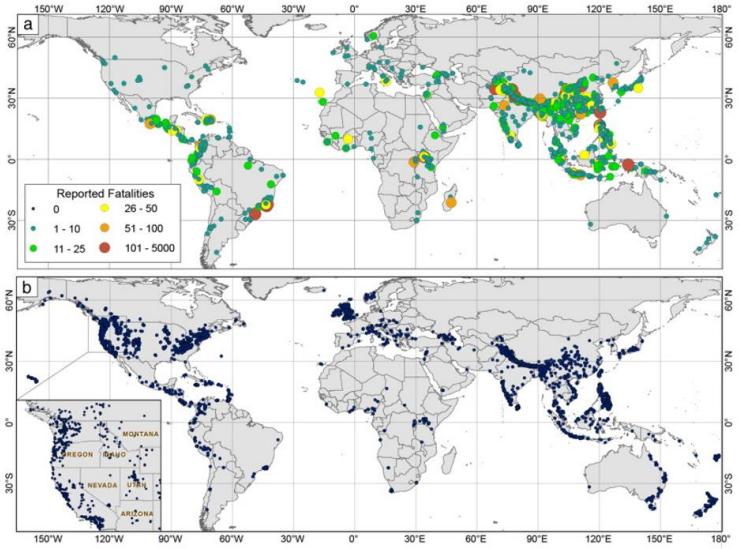
Earthquake caused Landslides

- **Many huge and large landslides were caused by earthquake**



Zhang et al., Scientific Reports, 2016: 36154

Rainfall-triggered landslide events from 2007–2013

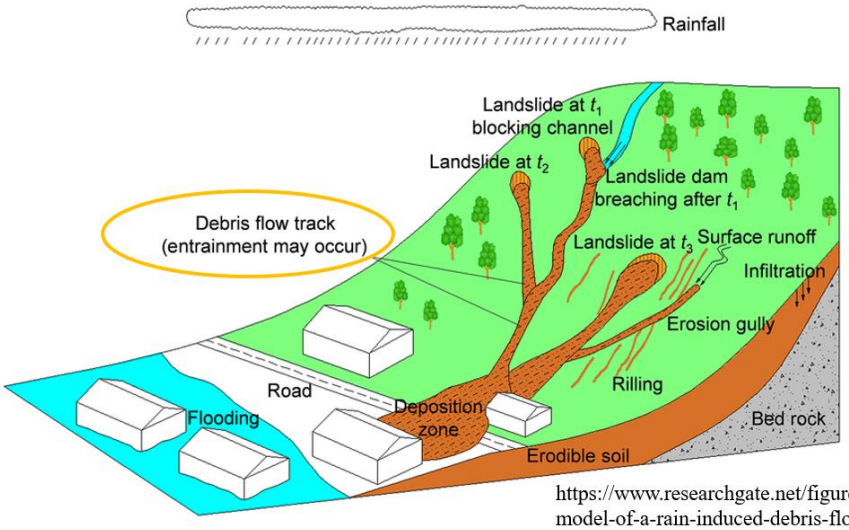


a) landslides with fatalities and b) landslides with no fatalities

Kirschbaum et al., 2015. Geomorphology, 249(15): 4-15

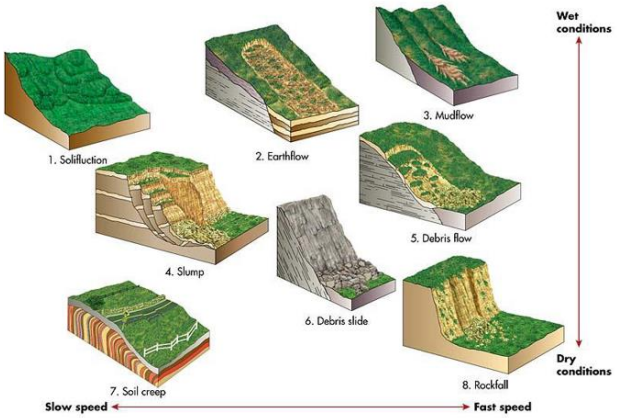
- **Debris Flows**
  - ✓ Classification of Debris Flows
  - ✓ Difference between landslide and debris flow
  - ✓ What causes debris flows?
  - ✓ Distribution of debris flows

- **Debris flow is mass movement of soil rock and water mixture triggered by runoff due to intense rainfall and/or melting snow in steep gullies or ravines.**



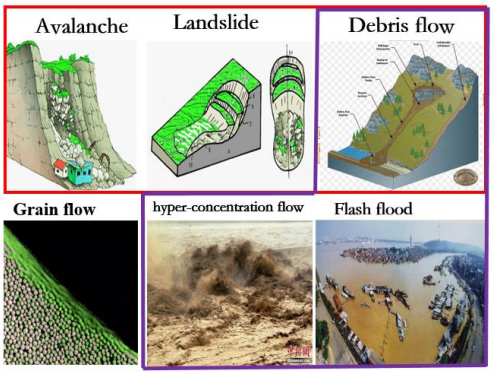
https://www.researchgate.net/figure/Conceptual-model-of-a-rain-induced-debris-flow-and-three-typical-initiation-mechanisms-of_fig2_326382991

Difference between landslide and debris flow



- **Debris flow differs from landslide in its "flowing" feature**
- Flow means relative movement in numerous layers of the medium but slide means only along one or several interfaces or beds

- **Water content in landslide (0-40%) is lower than in debris flow (35-80% by volume)**
- **Landslide slope is higher than debris flow**
- **As a result of their high sediment concentrations and mobility, debris flows can be very destructive**



Comparison of avalanche, landslide and debris flow

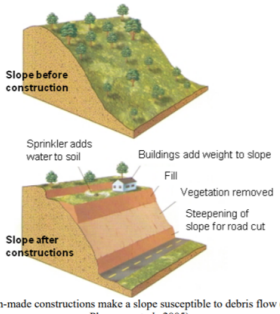
Type	Formation condition	Movement mechanism	Force mechanism
Avalanche	slope>30° no sliding surface	Free falling body, rolling, collision	Failure at peak strength
Landslide	slope<30° sliding surface	Sliding	Failure at residual strength
Debris flow	slope: 10° - 30° inside gulley	Intermittent flowing	> yield stress

Comparison of flash flood, hyperconcentrated flow and debris flow

Type	Sediment concentration	Sediment transport rate	Flow mechanism	Force mechanism
Flash flood	<20%	Low ↓ High	Turbulence	Collision force ↓ Friction Force
Hyperconcentrated flow	20%~60%		Turbulence → laminar flow	
Debris flow	>60%		Intermittent flow	

What causes debris flows?

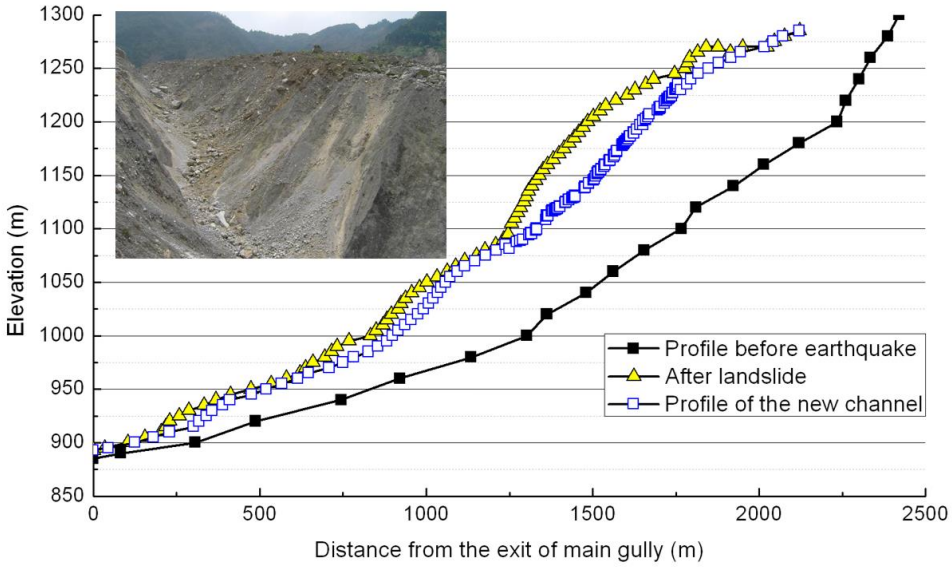
- **Factors influencing the occurrence of debris flow**
  - ✓ **Morphological factors** (Slope angle, Slope aspect , Other morphological factors)
  - ✓ **Geological, geotechnical factors** (Geology, Geotechnical factors)
  - ✓ **Hydrological factors** (Drainage network, Ground water and Hydrogeological conditions)
  - ✓ **Meteorological factors**
  - ✓ **Vegetation cover**
  - ✓ **Land use**
  - ✓ **Landslides**
  - ✓ **Earthquakes and Volcanoes**



Man-made constructions make a slope susceptible to debris flow (modified by Plummer *et al.*, 2005).

- **Landslide disasters**
  - ✓ Cause casualties
  - ✓ Cut off transportation
  - ✓ Dam rivers and create barrier lakes
  - ✓ Cause chain disasters

Chain 1: Landslide - Dam Failure Flood - Intensive Fluvial Process - Loss of Habitats



Profiles of Wenjiagou before the earthquake, after the landslide in May 2008, and after the new drainage development in 2009

- **Debris flow disasters**
  - ✓ Buried towns and caused casualties
  - ✓ Damaged railways and highways
  - ✓ Dammed rivers
  - ✓ Sevier erosion and fast sedimentation
  - ✓ Caused reservoir sedimentation
  - ✓ Detrimental to the environment

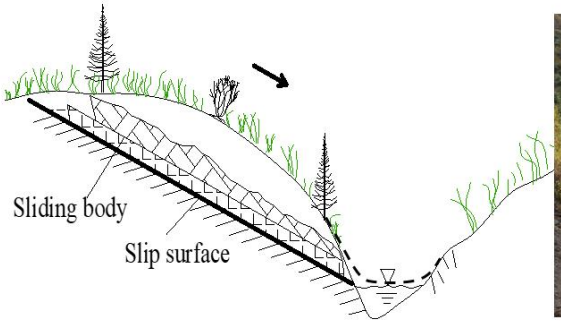
About 1800 people were killed by the debris flow

Extremely high competence

A debris flow buried and scoured farmland by the Jiangjia Ravine in southern China in 2008

- **Effects of landslide on rivers**
  - ✓ Impacts of landslide occurrence
  - ✓ Essential Cause of Landslides
  - ✓ Landslide dams
  - ✓ Stability of landslide dam
  - ✓ Fluvial process induced by landslide dams

- The **essential cause** of avalanches and landslides is the **riverbed incision** no matter they are triggered directly by earthquake or rainstorm.
- If a sliding surface of mountain slope is cut off by stream, landslide will occur by tremor or rainfall.

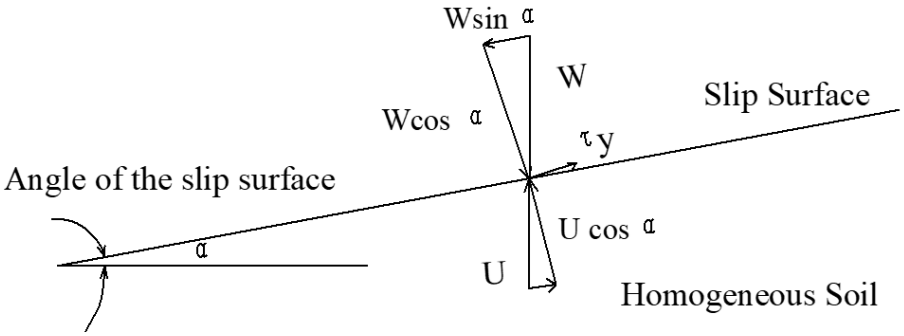


A stream cutting the bed below the slip surface and causing a lands

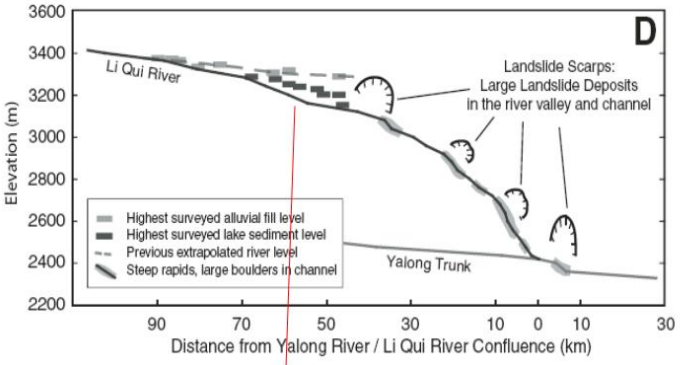
A Simple Model of Landslides

$$W\sin\alpha > \tau_y + (W - U)\cos\alpha\tan\phi'$$

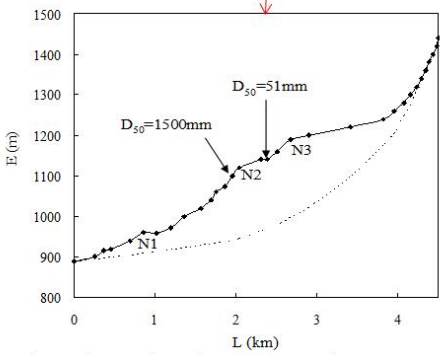
in which W is the weight of the loading per area of the slip surface, U stands for the uplift force resulting from groundwater pressure in the soil, α is the angle of the inclined slip surface, $\tan\phi'$ is the frictional coefficient, and τ_y is the yield strength of the material.



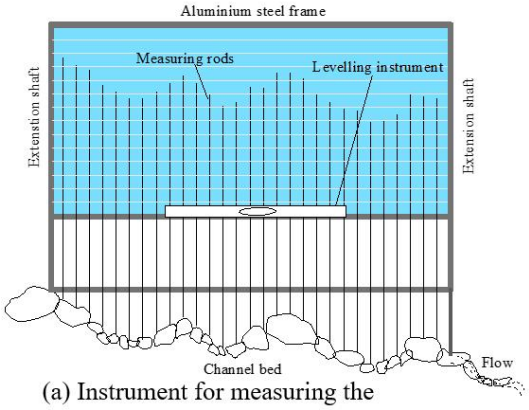
1) Removal or preservation



Knickpoints developed from landslide dams on the Li Qui River – a tributary of the Yalong River.



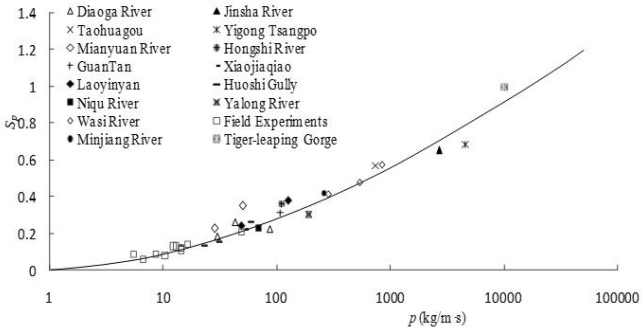
The Shenxi Ravine is on the epicenter. No landslide occurred on the ravine because of the preserved landslide dam reduced the potential.



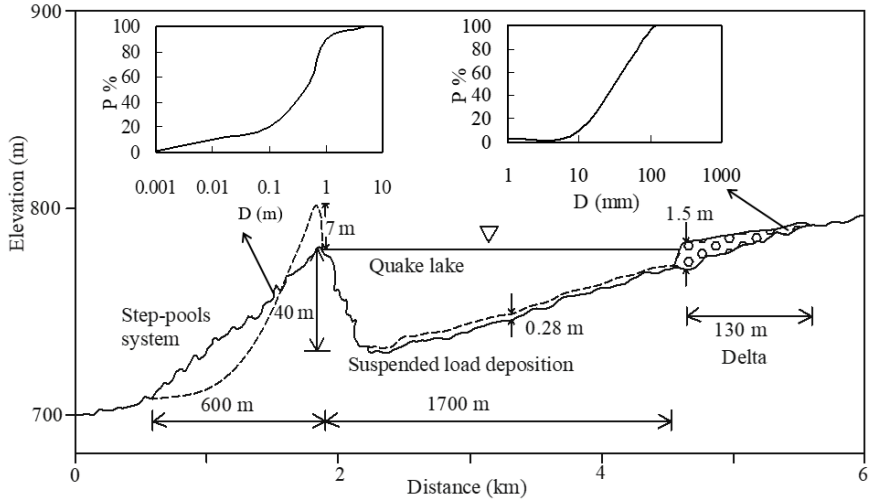
(a) Instrument for measuring the development degree of step-pool system

(b) step-pool formed on the landslide dam

Development degree of step-pool system as a function of unit stream power for stabilized channels on landslide dams



- Sedimentation occurs in the quake lake. The lake may finally filled with sediment.
- Step-pool system develops on the spillway channel of landslide dams.



3. Sediment-based ecological problems

- **River Ecology**
  - ✓ River Continuum Concept (RCC)
  - ✓ Dimensions of Rivers and Streams
  - ✓ River Ecosystem Components
  - ✓ Spatial Elements of River Ecosystem
  - ✓ Biological Community
  - ✓ Aquatic Ecosystem
  - ✓ River Continuum Concept Model (Revised)
  - ✓ Ecological Conditions
  - ✓ Ecological Functions of Rivers

What & how we study in river ecology

Morphological changes

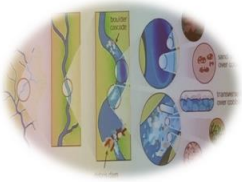
•Changes due to natural dynamics, events

•Anthropogenic influences

Ecology

•Aquatic Flora

•Fauna (aquatic and floodplains)



Scales

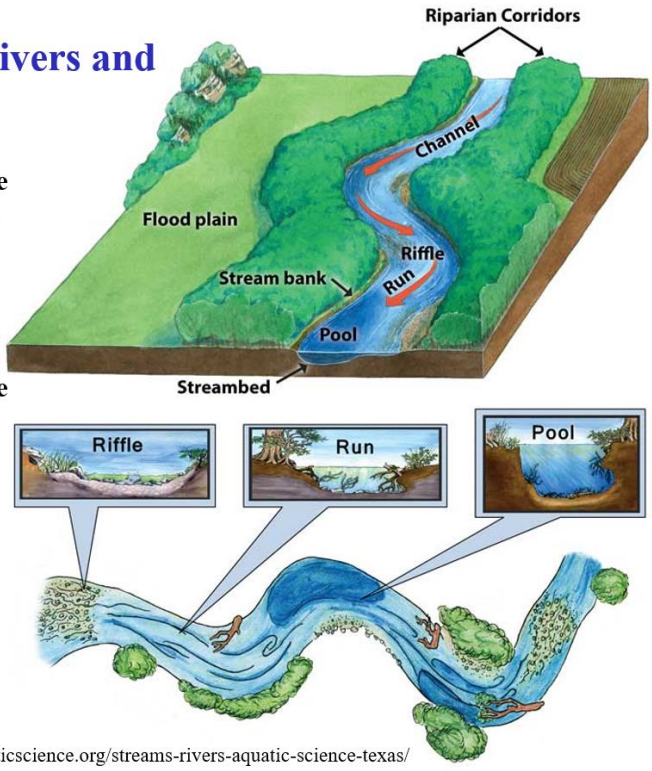
•Macro→ catchment

•Meso→ river system

•Micro→ grain structure

•Pico→ single particle

- **Dimensions of Rivers and Streams**
  - **Rivers and streams are longitudinally divided into**
    - **Riffle, run, and pool**
  - **Rivers and streams are transversely divided into**
    - **Channel, riparian zone, and flood plain**



http://texasaquaticscience.org/streams-rivers-aquatic-science-texas/

- **Disturbances of River Ecology**
  - ✓ Ecological Stresses
  - ✓ Natural Ecological Stresses
  - ✓ Human-Induced Stresses
  - ✓ Fragmentation of habitat
  - ✓ Harmful algal bloom species

✓ Introduction of Exotic Species

Measuring Human Impacts

Changes in land use affect watershed resources:

- Changes in hydrology
- Changes in water quality
- Changes in stream morphology
- Changes in stream ecology

Large dams cause cutoff of the natural flow, artificial fluctuation of discharge, morphological changes, and cutoff of the migration path of fishes;
Channelization and hardened banks and channel bed in urban streams cause fragmentation and isolation of habitats;
Gold mining, sediment mining, and removal of large boulders often cause instability of the channel and loss of habitat;
Reclamation and land use change disturb the eco-system;
Point pollution may kill many lives in the system;
Disturbances can also be introduced through agriculture (pesticides and nutrients), urban activities (municipal and industrial waste contaminants), and mining (acid mine drainage and heavy metals).

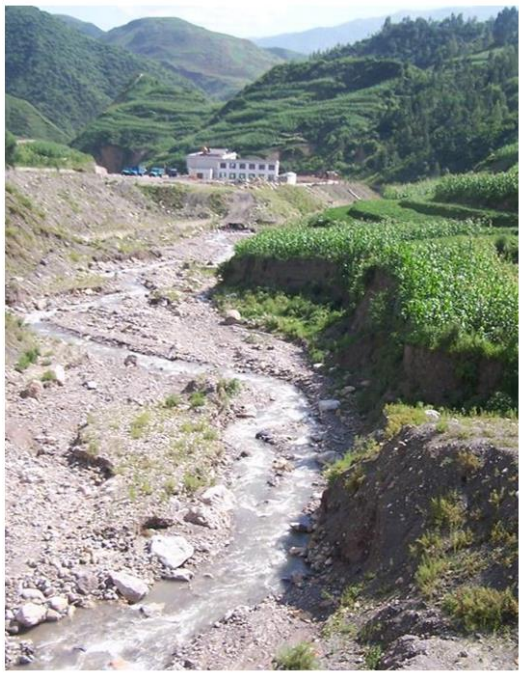
- **Assessment of River Ecosystems**
  - ✓ Biological indicator
  - ✓ Biological monitoring
  - ✓ Biological assessment

How to Measure Biological Integrity?

Biological indicator: groups or types of biological resources that can be used to assess environmental condition.

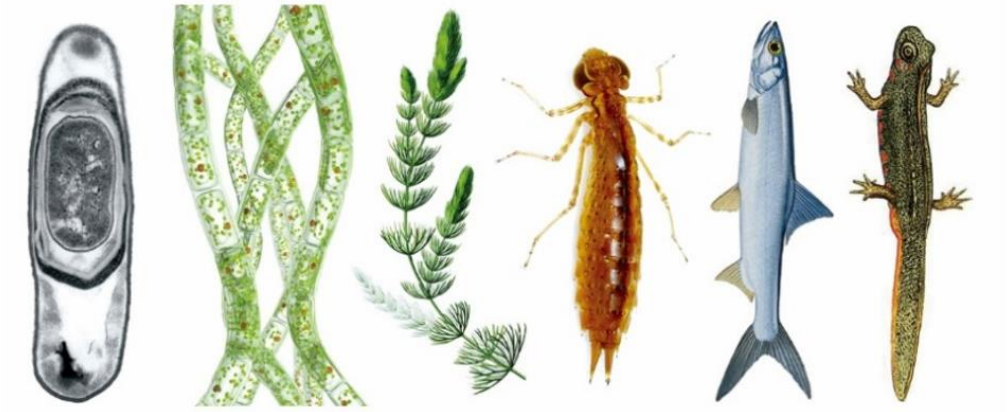
Biological monitoring: the study of organisms and their responses to environmental condition

Biological assessment: an evaluation of the biological condition of a water body using biological monitoring data and other direct measurements of resident biota in surface waters



Indicators Candidates for aquatic ecology

Biological Complexity

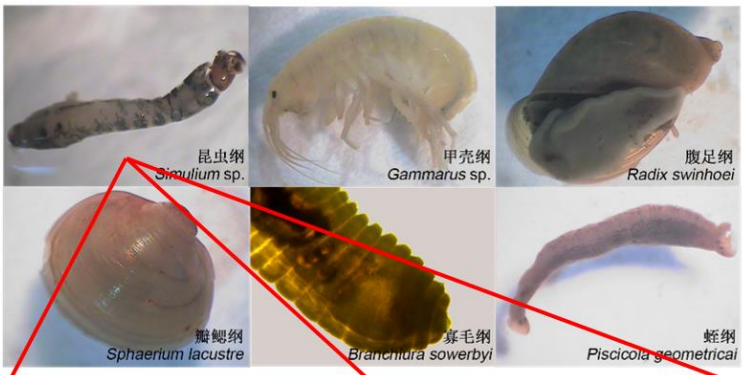


Indicating Integrity

Quantifiability &
Response Speed

Benthic Macroinvertebrates

(bottom-dwelling) (animals w/o backbones visible to naked eye)

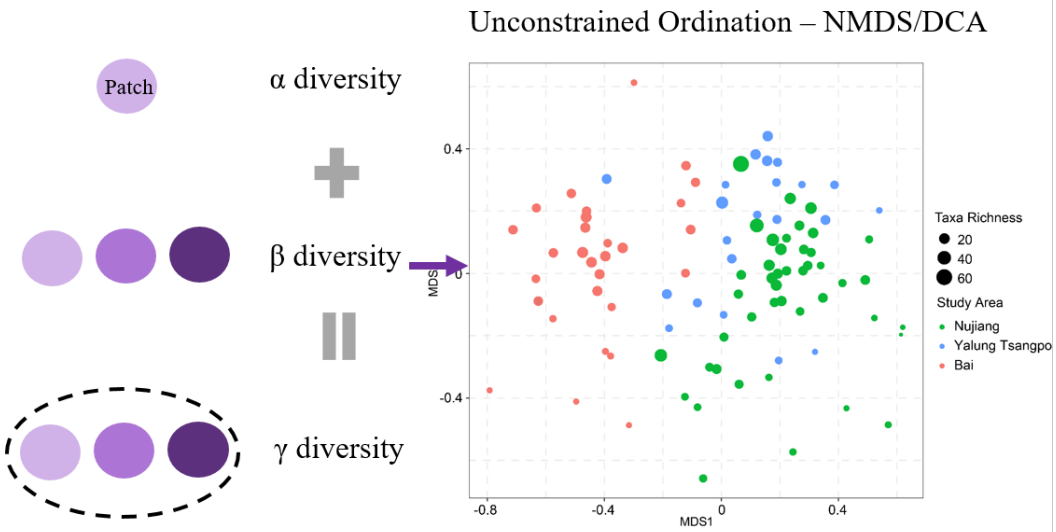


Heptageniidae sp.
(Mayfly larva)

Hydropsyche sp.
(Caddisfly larva)

Perlodidae sp.
(Stonefly larva)

Calculation - diversity



Calculation - FFGs & FHGs

FFG	Examples	Diet	Characteristics
Predators	Dragonflies, damselflies, stoneflies	Other insects	Toothy jaws, larger in size
Shredders	Stoneflies, beetles, caddisflies	CPOM, leaves, woody debris	Streamlined, flat
Grazers / Scrapers	Mayflies, caddisflies, true flies, beetles	Periphyton, diatoms	Scraping mandibles
Gathering Collectors	Mayflies, worms, midges, crayfish	BFPOM, settled particles, bacteria	Filtering hairs, hemoglobin
Filtering Collectors	Black flies, net-spinning caddisflies, mayflies	SFPOM, phytoplankton, floating particles	Some build cases (caddisflies)

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