SPECIFIC DEGRADATION AND RESERVOIR SEDIMENTATION

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Outline

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  - Defining Sediment Degradation
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Sediment deposits in the upper catchment of the Indus River.

Image: http://www.innovationresearchfocus.org.uk/Issues/91/IRF91_HR1.html

Erosion vs. Sediment Yield

- (Gross) Erosion (E) is the total amount of erosion that occurs in a watershed
- All erosion does not however reach the outlet and gets entrained elsewhere in the basin (i.e deposited on the floodplain, deposited in channel pools, trapped behind vegetation on hillslopes, permanently trapped in lakes and reservoirs)
- Sediment Yield (Y) is the total amount of sediment that is delivered to the outlet of a watershed
- The Sediment Delivery Ratio (S_{DR}) relates gross erosion to sediment yield

$$S_{DR} = Y/E$$

Sediment Yield Variables

- Characteristics of a river basin will affect sediment yield (Y)
- Function of:
  - Precipitation
  - Surface runoff
  - Vegetation (V)
    - More V will decrease Y
  - Lithology
    - Easily erodible rocks will increase Y
  - Soil type
  - Slope (S)
    - Steeper S will increase Y
  - Watershed Size
    - Smaller basin will increase Y
  - Land use

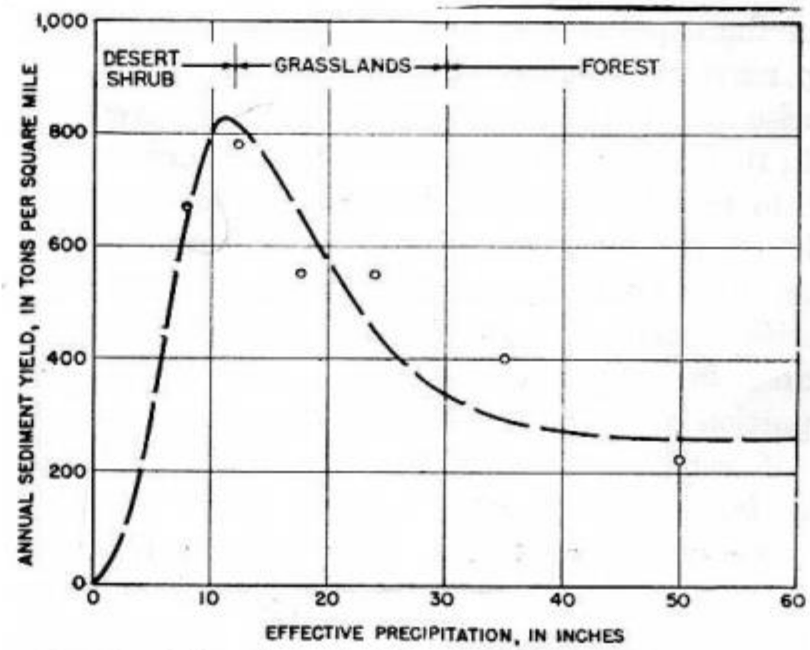


FIG. 2 – Climatic variation of yield of sediment as determined from records at sediment stations

(Langbein and Schumm 1958)

General shape of the curve known as the **Langbein-Schumm Curve** and has been modified to include some regions that experience monsoons and a secondary peak in sediment yield.

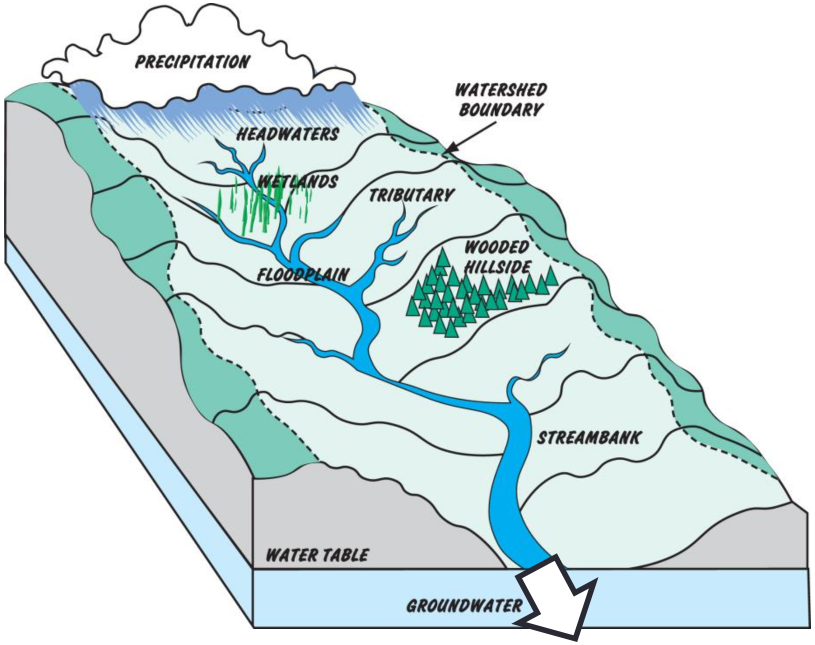
Note other models exist to predict sediment yield as a function of precipitation (effective and actual) including the **Wilson Model** and the **Fournier Model**

Sediment Yield

Can be calculated by:

- Empirical Methods
- Direct Measurements

- Wash load ($d_s < d_{10}$) typically comprises the majority of a basin's sediment yield



$$Y = \frac{metic\ tons\ of\ sediment}{time}$$

Image: http://fergusonfoundation.org/btw-students/what-is-a-watershed/

Empirical Methods

1. Determine total watershed erosion (E) through empirical equations such as the Universal Soil Loss Equation (USLE)

$$\hat{E} = \hat{R}\hat{K}\hat{L}\hat{S}\hat{C}\hat{P}$$

$\hat{R} = rainfall\ erosivity\ factor$
$\hat{K} = soil\ erodibility\ factor$
$\hat{L} = field - length\ factor$
$\hat{S} = field - slope\ factor$
$\hat{C} = cropping - management\ factor$
$\hat{P} = conservation\ practice\ factor$

2. Estimate the sediment-delivery ratio from a S_{DR} vs $Drainage\ Area$ plot (From *River Mechanics* by Pierre Julien, 2002)

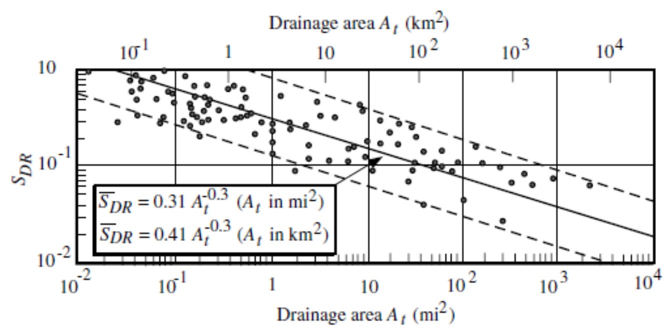


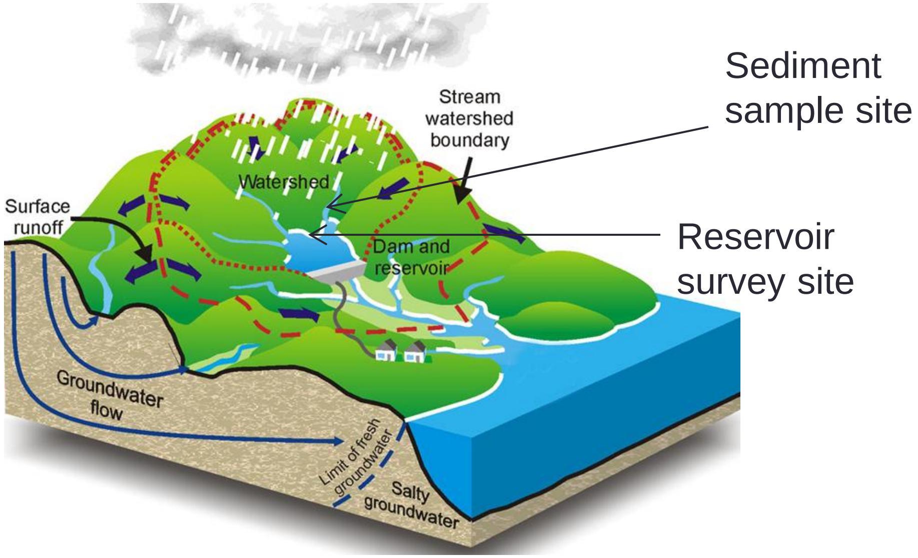
Figure 3.28. Sediment–delivery ratio (modified after Boyce, 1975).

3. Determine Sediment Yield:

$$Y = S_{DR}E$$

Direct Measurements

- Direct measurement of sediment in channels (i.e. suspended sediment load+ bedload)
- Reservoir sedimentation rates
    1. Determined from surveys on reservoir deltas over time
    2. Determined from comparing LiDAR data over time



http://www.vpcfiberglass.com/watershed.shtml

Specific Degradation

- Specific degradation equals Sediment Yield divided by drainage area.

$$SD = \frac{Y}{A} \quad \left[\frac{Vol}{Area * Time}\right]$$

- Provides a volume per unit area per time of sediment degradation from a watershed
- Naturally, we live in a geologic time period where most river basins are degrading
- However, human activities have increased the sediment degradation of watersheds through deforestation, farming, and urbanization

Specific Degradation Equations

- Attempts have been made to quantify specific degradation as a function of one or more variables
- Kane (2003), performed an analysis of the existing models and developed new regression equations to improve estimates of specific degradation (in order of author recommendation)

$SD = VA^{-0.09}R^{1.7}e^{-0.0036R-0.13S}$ (function of vegetation factor V, rainfall R, and slope S)

$SD_{95} = 0.026A^{-0.09}R^{1.7}e^{-0.0017R} \pm 1.96\sigma$ (function of area A and rainfall R)

$SD_{95} = 0.02R^{1.7}e^{-0.0017R} \pm 1.96\sigma$ (function of rainfall R)

$SD_{95} = 410.44A^{-0.09} \pm 1.96\sigma$ (function of area A)

$SD_{95} = 402.55e^{-0.13S} \pm 1.96\sigma$ (function of slope S)

Timeframe of Watershed Sediment Yield

Case Study: In 1969 in Tunisia, 3 consecutive floods with return intervals of 40, 46 and 60 years, delivered 20 years of sediment to the nearby rivers in 13 days causing significant channel aggradation and flooding (Frenette and Julien, 1996). 542 people drowned during the flood and hundreds of thousand were homeless (*Natural Disasters* by Lee Allyn Davis).

Case Study: On the Indus River in Pakistan, surface runoff and sediment load are a function of the time of the year (due to melting snow) and the sediment load is found to vary by month (Frenette and Julien, 1996)

Case Study: In mountain rivers in Taiwan, over 75% of the long-term sediment yield occurs during typhoon floods that occur less than 1% of the time (Kao and Milliman, 2008)

Specific Degradation Importance

- Determining reasonable estimates of specific degradation (that account for annual sediment variability) are important in order to assess life spans of reservoirs

Case Study: On the Oldman River in Alberta, about 60% of the total sediment volume into a reservoir was measured in 3 years and one year the sediment load was 350% the mean annual sediment load (for the recorded 12 years of sediment data). Using the upper limit of this data, the life expectancy of the reservoir would be underestimated by 200-300%. When neglecting the extreme values of the sediment load, the life expectancy of the reservoir was 200-300% overestimated (Frenette and Julien, 1996).

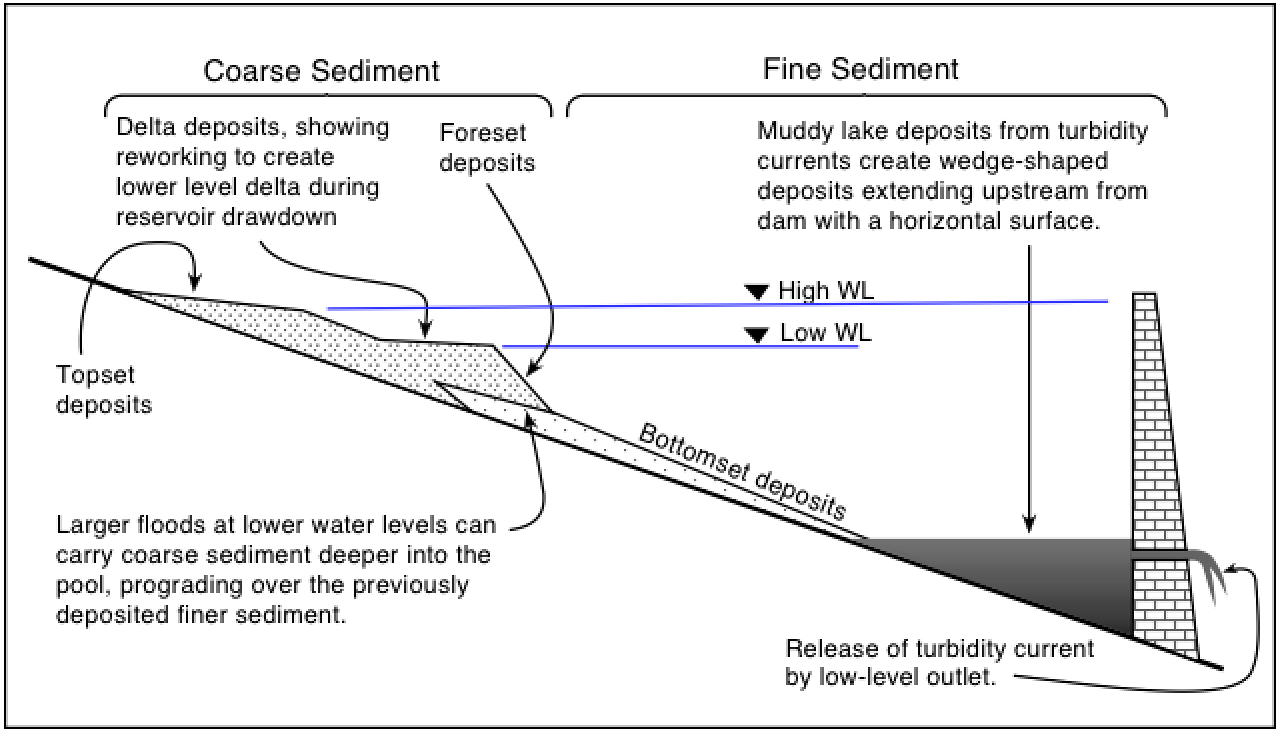
- Changes in climate and land use which modify the hydrologic and hydraulic regimes can change sediment yields and ultimately reduce life expectancies of reservoirs over time.

Reservoir Sedimentation

- Loss of storage capacity and reduced firm yield
- Can interfere with water supply intakes and gates
- Interferes with navigation
- Reduced ecological & recreational benefits

Generalized Sediment Deposition Patterns

Longitudinal Profile



Life Expectancy of Reservoirs

- Life expectancy T_R

$$T_R = \frac{\forall_R \gamma_{mdT}}{\sum_i T_{Ei} \Delta P_i Q_{ti}}$$

$$\gamma_{mdT} = \text{dry specific weight after } T_c \text{ years}$$

$$T_{Ei} = 1 - e^{-\frac{X\omega_i}{hV}}$$

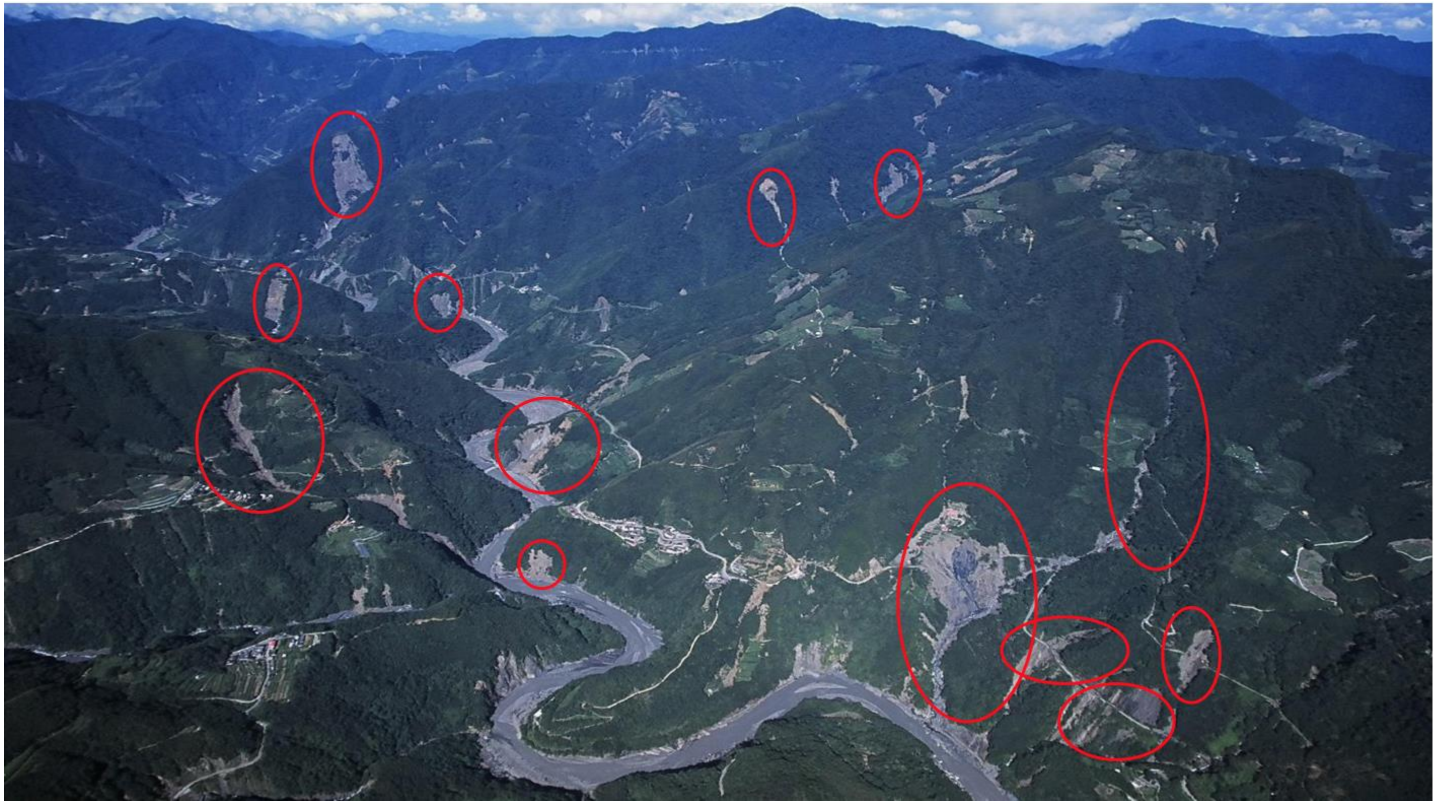
Control Measures

- Watershed control
  - Soil conservation
  - Vegetation
- Inflow control
  - Sediment-retarding structures
  - Sabo dam
  - Off-channel reservoirs
  - By-pass canal
- Deposition control
  - Proper design of reservoir
  - Sluicing/Flushing
  - Dredging

Shihmen Reservoir in Taiwan

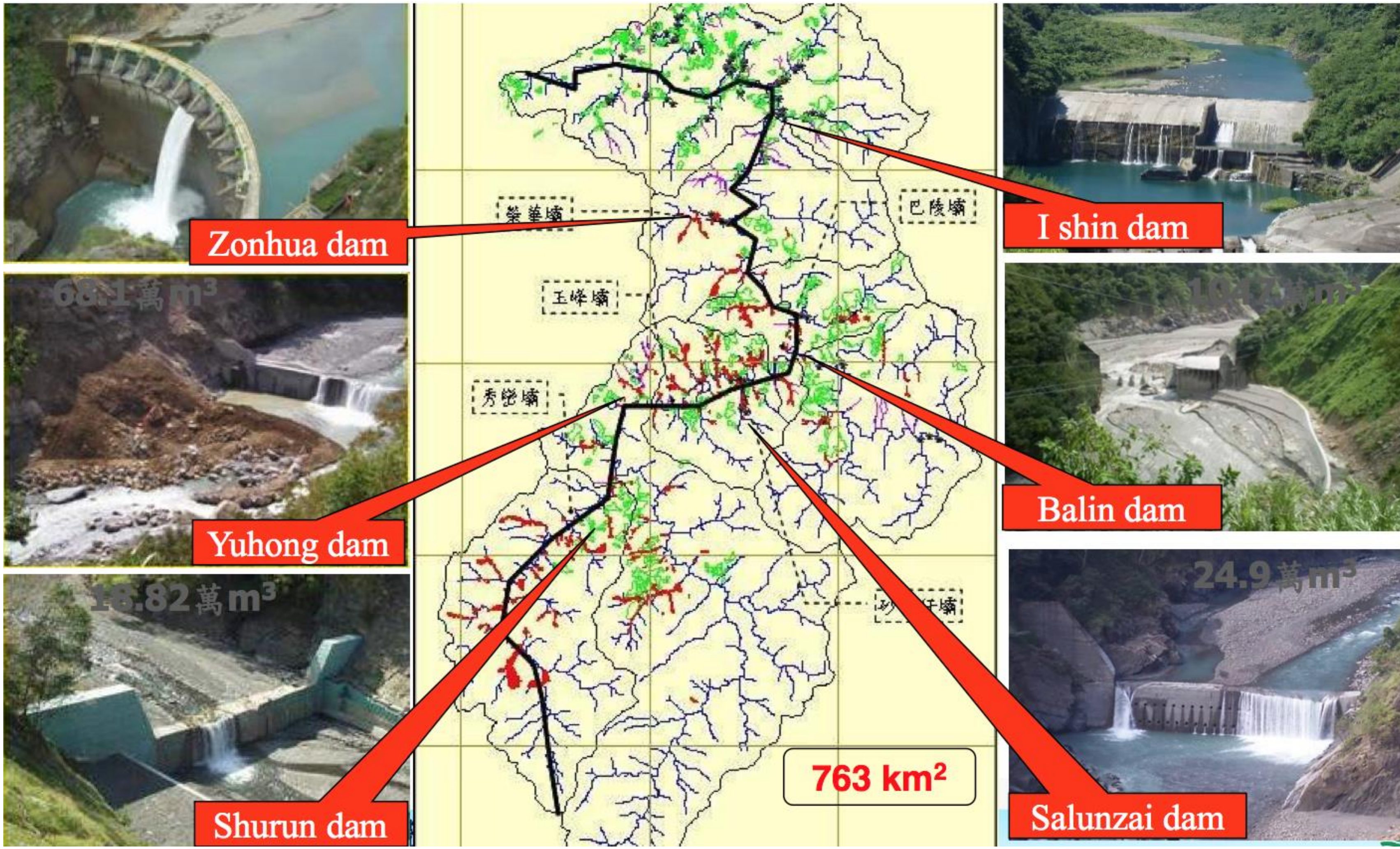
- Embankment dam
  - Dahan Creek
  - h : 133 m
  - w : 360 m
  - Catchment area: 763 km^2
  - Capacity : 252 millions m^3
- Flood control
  - Spillway : 12,400 cms
- Water supply
  - 221 millions m^3
- Hydroelectricity generation
  - 200 millions kwh/year

Sedimentation Issues in Shihmen Reservoir



Rate of capacity decreasing: 1,840,000 m^3/year

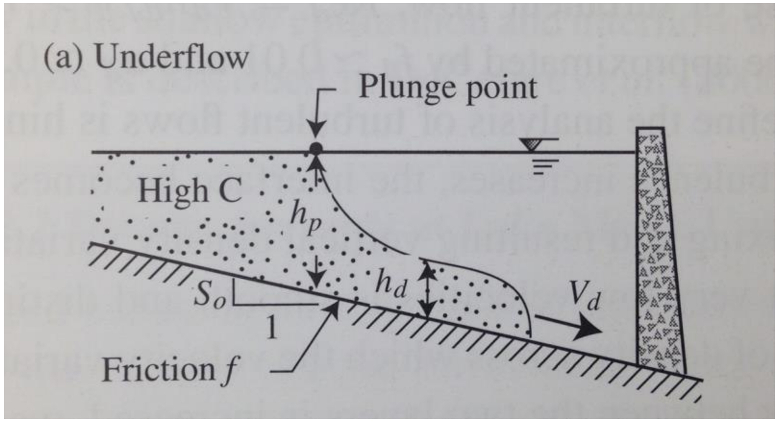
Check dams



Zonhua dam
68.1萬m³
Yuhong dam
16.82萬m³
Shurun dam
I shin dam
Balin dam
24.9萬m³
Salunzai dam
榮華壩
巴陵壩
玉峰壩
秀巒壩
763 km²

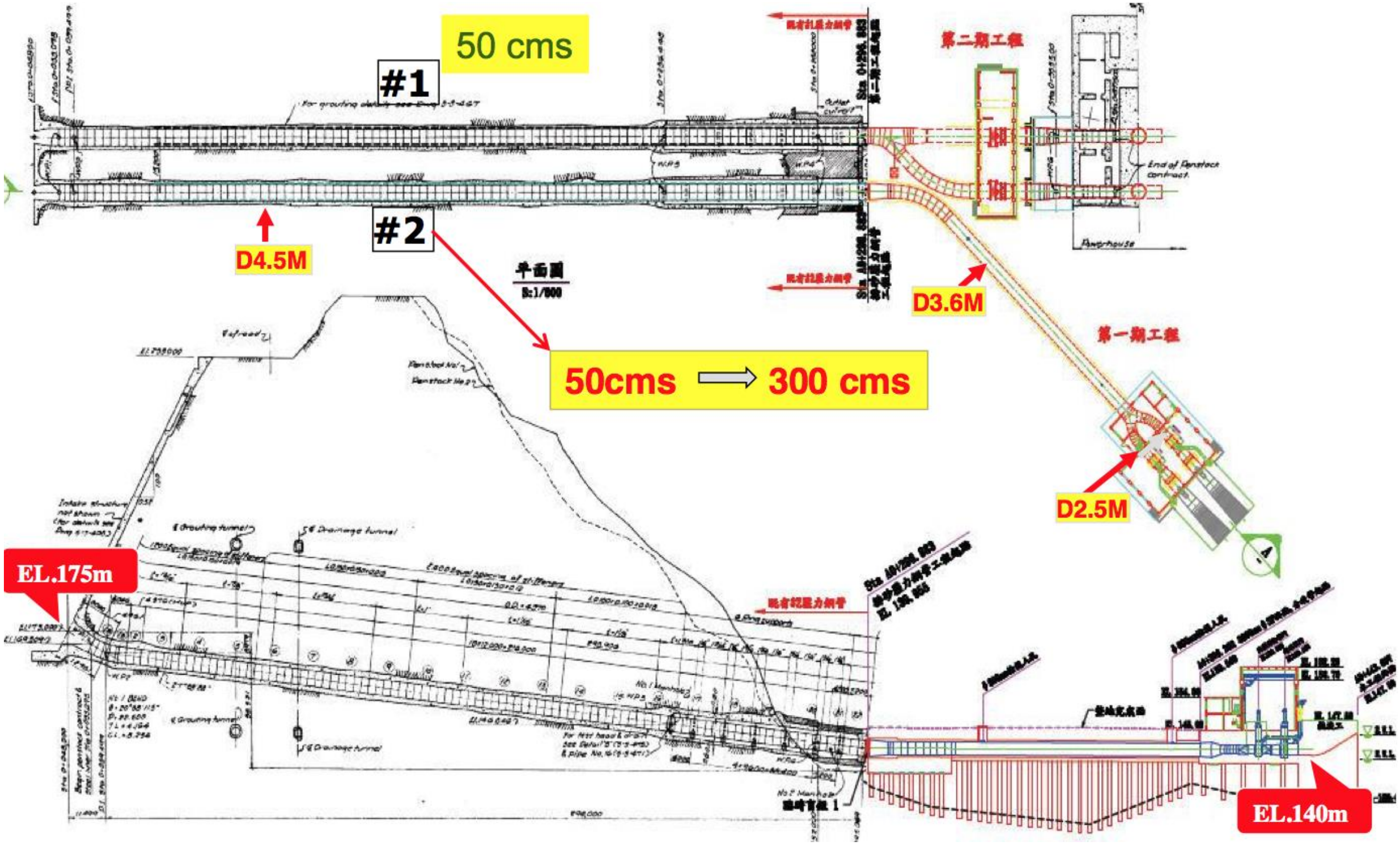
Sedimentation Issues in Shihmen Reservoir

Density currents



Modification

Modify power plant penstock to sluicing tunnel



Sluicing Operation During Typhoon Soulik (2013)

Conclusions

- Sediment yields vary over a given year (due to climatic influences such as snow) so it is important to know the range when performing estimates
- A large portion of a watershed’s sediment yield may occur in a short amount of time due to extreme events (rather than gradually over time)
- Sediment yield observations are important during high events, however many measurements are not available when the events are extreme (Frenette and Julien, 1996)
- Identifying accurate predictions of sediment yield can be difficult but is necessary in order to properly size reservoirs and determine lifespans.
- Dam construction requires the consideration of sedimentation for the storage and release of sediment over its lifetime.