SPECIFIC DEGRADATION AND RESERVOIR SEDIMENTATION

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  - Defining Sediment Degradation
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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

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

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.
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

\[
Y = \frac{\text{metic tons of sediment}}{\text{time}}
\]
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)

![Diagram of Sediment Delivery Ratio vs Drainage Area](image)

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.

\[ SD = \frac{Y}{A} \left[ \frac{Vol}{Area \times Time} \right] \]

• 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.
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):

\[
SD = VA^{-0.09} R^{1.7} e^{-0.0036R-0.13S}
\]

\[
SD_{95} = 0.026A^{-0.09} R^{1.7} e^{-0.0017R} \pm 1.96\sigma
\]

\[
SD_{95} = 0.02R^{1.7} e^{-0.0017R} \pm 1.96\sigma
\]

\[
SD_{95} = 410.44A^{-0.09} \pm 1.96\sigma
\]

\[
SD_{95} = 402.55e^{-0.13S} \pm 1.96\sigma
\]
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

- **Coarse Sediment**
  - Delta deposits, showing reworking to create lower level delta during reservoir drawdown
  - Topset deposits
  - Larger floods at lower water levels can carry coarse sediment deeper into the pool, prograding over the previously deposited finer sediment.

- **Fine Sediment**
  - Muddy lake deposits from turbidity currents create wedge-shaped deposits extending upstream from dam with a horizontal surface.
  - Foreset deposits
  - Bottomset deposits
  - Release of turbidity current by low-level outlet.

- **Water Levels**: High WL, Low WL
Life Expectancy of Reservoirs

- Life expectancy $T_R$

\[
T_R = \frac{\bigwedge R \gamma_{mdT}}{\sum_i T_{Ei} \Delta P_i Q_{ti}}
\]

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

- **Embarkment dam**
  - Dahan Creek
  - h : 133 m
  - w : 360 m
  - Catchment area: 763 km²
  - Capacity : 252 millions m³
- **Flood control**
  - Spillway : 12,400 cms
- **Water supply**
  - 221 millions m³
- **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

I shin dam

Yuhong dam

Balin dam

Shurun dam

Salunzai dam

763 km²
Sedimentation Issues in Shihmen Reservoir

Density currents
Modification

Modify power plant penstock to sluicing tunnel
Sluicing Operation During Typhoon Soulik (2013)

Q = 300 cms
C = 37,400 ppm
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.