Surface Erosion Type of Sediment Yield Model used to upstream of Yangtze River Catchment
Sedimentation in dam reservoir

Transparency before and after dam site
Sedimentation problems at Three Gorges Dam

The dam reservoir
   600-km-long lake
   sediment load inflow: $5 \times 10^8$ tons per year

Sediment problem
   • sedimentation behind the dam
   • diminish of capacity for hydropower and flood control
   • damage of ecosystems
Location of the Jialingjiang watershed (Area: 160,000km²) in the Changjiang River Basin
- System for a Combination of Water, Sediment, Land and Human Activities
- Dynamic System in which natural factors and an artificial factor interact, leading to their mutual changes

**Interactions that characterize a system of hydrological and geomorphological processes**
Sediment Yield Features in Monsoon Asia region

1. Geo-morphological Factors
   Zones with Active Mountain-building Movement

2. Climate Factors
   temperate
   heavy-rainfall climate
   too much water

3. Human Activity
   active, intense, wide and dense land uses
   usages of steep mountain slope
Global Distribution of the Tectonic Zones
Hydrological characteristics similar to those of Asian pluvial temperate tectonic zones
Predicting Sediment Yield in Monsoon Asia
- Jialingjiang watershed upstream Yangtze river -

1. difficult to predict unsteady and discreet sediment yield caused by mass movement
   
   diving forces $\neq$ sediment yield
   
   driving forces:
   
   rainfall intensity, surface runoff discharge,
   slope gradient, flow velocity, stream power of flow

2. finding the possible method to predict
   
   surface erosion type of sediment yield model
   
   diving forces = sediment yield
Surface erosion type of sediment yield model

1. Raindrop impact – sediment yield
   - USLE type,
   - modification of USLE in many areas and country

2. Surface flow discharge – sediment yield
   - bed shear stress type
   - stream power type
Surface erosion type of sediment yield model

Basic Expression of equation

\[ q_B = \varepsilon \cdot \pi \cdot \gamma \cdot q_{B0} \]

- \( q_B \) = computed transport rate
- \( \varepsilon \) = vegetation cover factor
- \( \pi \) = cropping and management factor
- \( \gamma \) = countermeasure and anti-erosion works factor
- \( q_{B0} \) = transport rate on bare land:
  - estimated on the basis of rainfall intensity type
  - estimated on the basis of rainfall intensity type
Raindrop impact erosion type

Modified USLE used to Japan
  hydro-geo-morphological features in Japan
  too much water and heavy rainfall
  devastated soil structure

Kusaka model (1986)

\[ q_B = a \ K_e \ (L/19.7)^\alpha \ (\sin\theta)^\beta \cdot f \cdot r \]

a, \ \alpha, \ \beta = \text{empirical constants, } \sin\theta = \text{slope gradient,}
\ f = \text{runoff ration}
\ r = \text{rainfall intensity}
Application of USLE type (Kusaka model)

- Dahou test site (upstream Yantze river catchment)
- area 9000m$^2$, slope angle $\theta = 37.5^\circ$
- mass movement: high possibility
Surface flow erosion type of sediment yield model

- Requires rainfall runoff model to estimate surface runoff discharge

- long-term rainfall and intermittent heavy rainfall
  long-term watershed runoff model
  → Stanford Watershed model

- outputs of runoff model
  surface flow discharge
  → unit stream power type

Proposed model: unit stream power type
Surface flow erosion type of sediment yield model

unit stream power type

\[ q_{B0*} = A_0 \left\{ q^* I^* - (q^* I^*)_c \right\}^m \]

\[ q_{B0*} = q_{B0}/\{(\sigma/\rho-1)gd^3\}^{0.5}, \]
\[ q^* = q/\{(\sigma/\rho-1)gd^3\}^{0.5}, \]
\[ I^* = I/(\sigma/\rho-1), \]
\[ d = \text{representative diameter}, \ I = \text{slope gradient}, \]
\[ q = \text{unit discharge of surface flow at the end of slope} \]
\[ A_0, \ m, \ (q^* I^*)_c = \text{empirical constants}. \]
Experimental result of sediment erosion rate with respect to unit stream power

\[ q_{B*} = 1.01(q_*I_* - 0.008)^{\frac{5}{3}} \]
Sediment-yield sources area in watershed

1. Watershed slopes
   (1) raindrop impact type of model
   (2) surface flow type of model

2. Riverbank and flood plain
   pick-up type model
   : bed shear, flow discharge, stream power
Riverbank erosion type of sediment yield model

Supply of fine sediment from riverbank and flood plain

**Sediment erosion expression**

\[
Q_{wl} = L \cdot q_{WL} = L \cdot A_1 d \cdot p_s \cdot \Delta B
\]

- \( Q_{WL} \): sediment erosion from riverbank and flood plain
- \( q_{WL} \): sediment yield per unit length
- \( A_1 d \): sand diameter
- \( p_s \): sediment erosion rate
- \( \Delta B \): width of eroded riverbank
- \( L \): length of deposited fine sediment reach
sediment erosion rate $p_s$ in terms of bed shear

\[
\frac{p_s}{\sqrt{\tau_{*c}}} = F_0 \sqrt{\frac{\tau_*}{\tau_{*c}}} (1 - 0.4 \frac{\tau_{*c}}{\tau_*})^3
\]

- Patheniades (1965, 1970)
- Otubo (1985)
- Ashida & Sawai (1978)
Use of surface erosion model to predict sediment yield to Jialingjiang watershed

- typical sediment yield source in monsoon Asia -

• Possible or not whether we can use surface erosion model?

• How extent can this model estimate sediment yield?
  spatial scale
  temporal scale (yearly, monthly, daily)

• Period: 1987
  Data: Changjiang Water Resources Commission
Location of hydrological stations used for the validation of the sediment runoff model in the Jialingjiang watershed

Hydrologic station
A: Lijie on the Bailongjiang
B: Haoping on the Baishuijiang
C: Zhaojiaci on the Lizixi
D: Donglin on the Zhouhe
Selection of sub-watershed

1. Applicability of surface erosion type

2. Limitation of surface erosion type

3. Criterion
   possibility of mass movement

4. Peltier’s mass movement diagram
   • mechanical weathering       : annual mean precipitation
   • chemical weathering         : annual mean temperature

5. Selecting watersheds with from low to high possibilities on Peltier’s Diagram
## Topographic properties of sub-catchments I to IV

<table>
<thead>
<tr>
<th>Basin</th>
<th>A(km²)</th>
<th>H(m)</th>
<th>θ(°)</th>
<th>L(km)</th>
<th>Movement</th>
<th>i_b</th>
<th>B_{max}(m)</th>
<th>B_{min}(m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>8403</td>
<td>1540</td>
<td>12.9</td>
<td>167.9</td>
<td>Low</td>
<td>0.0098</td>
<td>50.3</td>
<td>21.4</td>
</tr>
<tr>
<td>II</td>
<td>8148</td>
<td>898</td>
<td>16.2</td>
<td>177.9</td>
<td>Low</td>
<td>0.0096</td>
<td>51.1</td>
<td>35.3</td>
</tr>
<tr>
<td>III</td>
<td>464</td>
<td>17</td>
<td>0.0</td>
<td>30.0</td>
<td>Medium</td>
<td>0.0006</td>
<td>178.0</td>
<td>0.8</td>
</tr>
<tr>
<td>IV</td>
<td>6374</td>
<td>287</td>
<td>8.4</td>
<td>162.4</td>
<td>High</td>
<td>0.0074</td>
<td>143.0</td>
<td>35.5</td>
</tr>
</tbody>
</table>
Mass movement possibility diagram (modification of Peltier’s original diagram)
Digital elevation data for the Jialingjiang catchment
Land cover distribution in the Jialingjiang catchment
Land use of watershed slope according to slope gradient
Application of Stanford Watershed model (1)

1. DEM with a spatial resolution of 1 km
   Global Land One-km Base Elevation (GLOBE) Project

2. River network
   Institute of Geographical Science and Natural Resources Research
   Chinese Academy of Sciences

3. Land cover into seven types
   forest, bush and shrub, grassland, farmland, paddy field,
   urban area, and wasteland
Application of Stanford Watershed model (2)

1. Daily precipitation in 1987
   431 observatories (Changjiang Water Resources Commission)

2. Universal kriging method
   distributed data with a spatial resolution of 0.5° × 0.5°

3. 6-hour data with a regular spacing of 1° (ISLSCP)
   Spatially distributed potential evaporation (Penman’s equation)

4. Conversion from 6 hours to 1 hour precipitation
Number of Sub-Watersheds for Simulation: 738
Simulation results in Yichang: Hydrological process model

- Observed daily data
- Simulated data

Underestimation of peak flowrates
## Important parameters for hydrologic component

<table>
<thead>
<tr>
<th>Identification</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>INFILT</td>
<td>Index zone nominal storage</td>
<td>mm/h</td>
</tr>
<tr>
<td>IRC</td>
<td>Interflow recession parameter</td>
<td>d⁻¹</td>
</tr>
<tr>
<td>INTFW</td>
<td>Interflow inflow parameter</td>
<td>—</td>
</tr>
<tr>
<td>UZSN</td>
<td>Upper zone nominal storage</td>
<td>mm</td>
</tr>
<tr>
<td>LZSN</td>
<td>Lower zone nominal storage</td>
<td>mm</td>
</tr>
<tr>
<td>LZETPᵇ</td>
<td>Lower zone ET parameter</td>
<td>—</td>
</tr>
<tr>
<td>AGWRC</td>
<td>Basic ground-water recession rate</td>
<td>d⁻¹</td>
</tr>
<tr>
<td>KVARY</td>
<td>Ground-water recession flow</td>
<td>mm⁻¹</td>
</tr>
<tr>
<td>INFEXP</td>
<td>Exponent in the infiltration</td>
<td>—</td>
</tr>
<tr>
<td>INFILD</td>
<td>Ratio between the maximum and mean infiltration capacities</td>
<td>—</td>
</tr>
</tbody>
</table>

ᵃ Dimensionless.
ᵇ The values of this coefficient vary with each month.
## Selected hydrologic calibration parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sub-catchment I</th>
<th>Sub-catchment II</th>
<th>Sub-catchment III</th>
<th>Sub-catchment IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>INFILT</td>
<td>0.420-0.950*</td>
<td>0.420-0.950</td>
<td>0.200-0.580</td>
<td>0.275-0.775</td>
</tr>
<tr>
<td>IRC</td>
<td>0.20-0.25</td>
<td>0.20-0.25</td>
<td>0.10-0.18</td>
<td>0.10-0.18</td>
</tr>
<tr>
<td>INTFW</td>
<td>0.85-1.00</td>
<td>0.85-1.00</td>
<td>1.00-1.35</td>
<td>1.15-1.60</td>
</tr>
<tr>
<td>UZSN</td>
<td>9.00</td>
<td>9.00</td>
<td>4.22</td>
<td>4.30</td>
</tr>
<tr>
<td>LZSN</td>
<td>230</td>
<td>230</td>
<td>205</td>
<td>275</td>
</tr>
<tr>
<td>LZETP</td>
<td>0.00-0.39</td>
<td>0.00-0.39</td>
<td>0.00-0.25</td>
<td>0.00-0.45</td>
</tr>
<tr>
<td>AGWRC</td>
<td>0.97</td>
<td>0.97</td>
<td>0.90</td>
<td>0.96</td>
</tr>
<tr>
<td>KVARY</td>
<td>0.035</td>
<td>0.035</td>
<td>0.045</td>
<td>0.027</td>
</tr>
<tr>
<td>INFEXP</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>INFILD</td>
<td>1.0-1.8</td>
<td>1.0-1.8</td>
<td>1.0-1.8</td>
<td>1.0-1.8</td>
</tr>
</tbody>
</table>

*Ranges of values for each parameter represent the differences in land cover type within each segment.*
Simulated results by Stanford watershed model and observed data - daily river flow discharge -
Number of Sub-Watersheds for Simulation: 738
Effect of land-uses on estimation sediment yield

\[ Q_{B^*} = \sum_{i} q_{B^*i} \cdot L_{ri} \]

\[ = \sum_{i} \varepsilon_i \cdot \pi_i \cdot \gamma_i \cdot A_0 \cdot \{(q_i I_i)_i - (q_i I_i)_c\}_i \cdot 5/3 \cdot L_{ri} \]

\[ = \sum_{i} \varepsilon_i \cdot \pi_i \cdot \gamma_i \cdot a K_e (L_i / 19.7)^\alpha (\sin \theta)^\beta \cdot f_i \cdot r_i \cdot L_{ri} \]

Factors with respect to sediment yield
: conditioned according to each land-use
\( \varepsilon = \) vegetation cover factor
\( \pi = \) cropping and management factor
\( \gamma = \) countermeasure and anti-erosion works factor
\( f = \) runoff ratio

\( \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \) and so on
Application of sediment erosion/yield model

1. Estimation of sediment yield
   product of flow discharge and sediment concentration at hydrological stations in first-order streams

2. Driving force
   raindrop impact type: $f=0.5$
   stream power $= q \cdot I$ at the end of watershed slope

3. Effects of sediment erosion
   vegetation factor, protection works, management factor

4. Parameters
   $d=0.25\,(cm)$, $A_0 = 1.01$, $F_0 = 8 \times 10^{-3}$,
   $(q*I)_c : \text{min. } Q_{Bc} = 10\,\text{kg/s}$
## Reduction Rate by forest, vegetation and protection

<table>
<thead>
<tr>
<th>Tree Type</th>
<th>Reduction Rate</th>
<th>Vegetable</th>
<th>Reduction Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pine (30 old)</td>
<td>0.0084</td>
<td>Potato</td>
<td>0.301</td>
</tr>
<tr>
<td>Conifer tree</td>
<td>0.0073</td>
<td>Sweet Potato</td>
<td>0.433</td>
</tr>
<tr>
<td>Deciduous tree</td>
<td>0.0160</td>
<td>Corn</td>
<td>0.747</td>
</tr>
<tr>
<td>Beech</td>
<td>0.0069</td>
<td>Beans</td>
<td>0.756</td>
</tr>
<tr>
<td>Afforested tree</td>
<td></td>
<td>Protection</td>
<td></td>
</tr>
<tr>
<td>Pine (5 old)</td>
<td>0.0140</td>
<td>Terrace</td>
<td>0.200</td>
</tr>
<tr>
<td>Pine (32 old)</td>
<td>0.0051</td>
<td>Terrace+grass</td>
<td>0.052</td>
</tr>
<tr>
<td>Conifer tree</td>
<td>0.0045</td>
<td>Terrace+wood</td>
<td>0.002</td>
</tr>
<tr>
<td>Japan cedar</td>
<td>0.0049</td>
<td>Green belt</td>
<td>0.007</td>
</tr>
<tr>
<td>Cedar (young)</td>
<td>0.0120</td>
<td>Mulching</td>
<td>0.100</td>
</tr>
<tr>
<td>Cypress</td>
<td>0.0050</td>
<td>Straw mat</td>
<td>0.017</td>
</tr>
</tbody>
</table>
Mass movement possibility diagram
(modification of Peltier’s original diagram)
Comparison between calculated and observed values annual sediment yields in each sub-watershed
Comparison between calculated and observed monthly sediment yields in each sub-catchment
Simulated results and observed data
daily surface runoff depth in sub-catchment II
Calculated results and observed data
Daily sediment concentration in each sub-catchment
Calculated Results

Applicability of surface erosion models?

**diving forces = sediment yield**

<table>
<thead>
<tr>
<th>Type</th>
<th>Annual yield</th>
<th>Monthly yield</th>
<th>Daily yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raindrop impact</td>
<td>○</td>
<td>?</td>
<td>×</td>
</tr>
<tr>
<td>Surface flow</td>
<td>○</td>
<td>?</td>
<td>×</td>
</tr>
<tr>
<td>Pick-up in riverbank</td>
<td>○</td>
<td>○</td>
<td>?</td>
</tr>
</tbody>
</table>

Further research

- Combination of watershed erosion model with riverbank/floodplain mode
- Continuous sediment routing from slope to river
Next research

Combination of sediment runoff model with sub-catchment based hydrologic model for the response of the whole Jialingjiang basin
First step towards combination of sediment runoff model with hydrologic model

Flowrate at Beibei

Suspended solid Concentration at Beibei