# A COMBINED MODEL OF SEDIMENT PRODUCTION AND SEDIMENT RUNOFF

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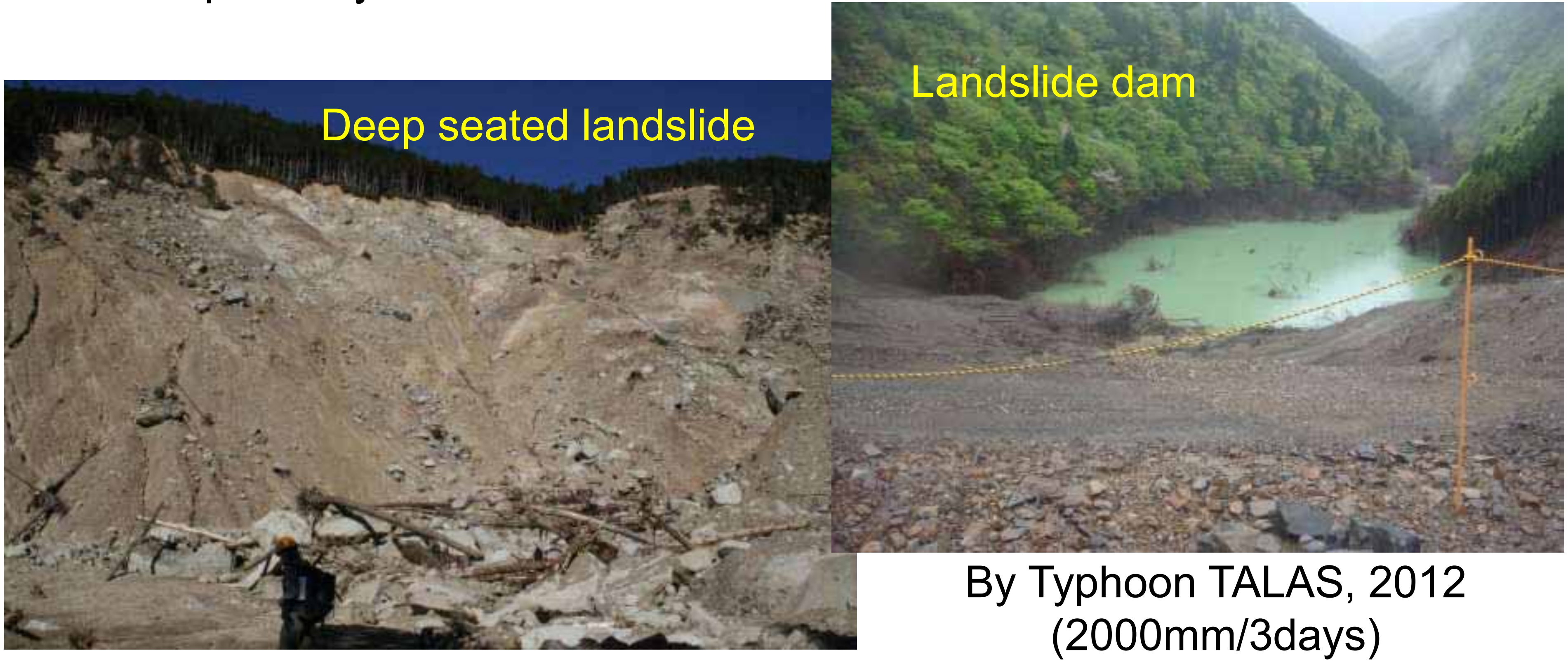
Disaster Prevention Research Institute
Kyoto University
Japan

# Objectives

**Multimodal sediment disaster :**

Sediment disasters could be much severer if various scales of sediment movement happen simultaneously or sequentially.



By Typhoon TALAS, 2012
(2000mm/3days)

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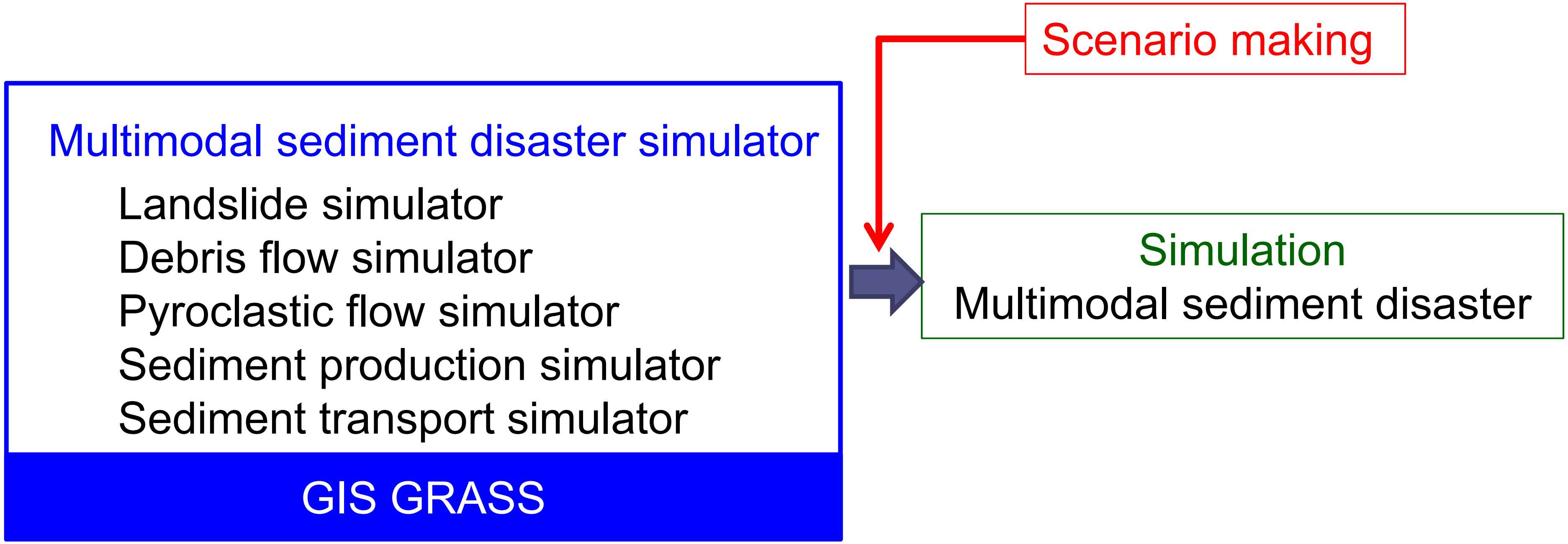

Scenario making

Multimodal sediment disaster simulator

Landslide simulator
Debris flow simulator
Pyroclastic flow simulator
Sediment production simulator
Sediment transport simulator

GIS GRASS

Simulation
Multimodal sediment disaster

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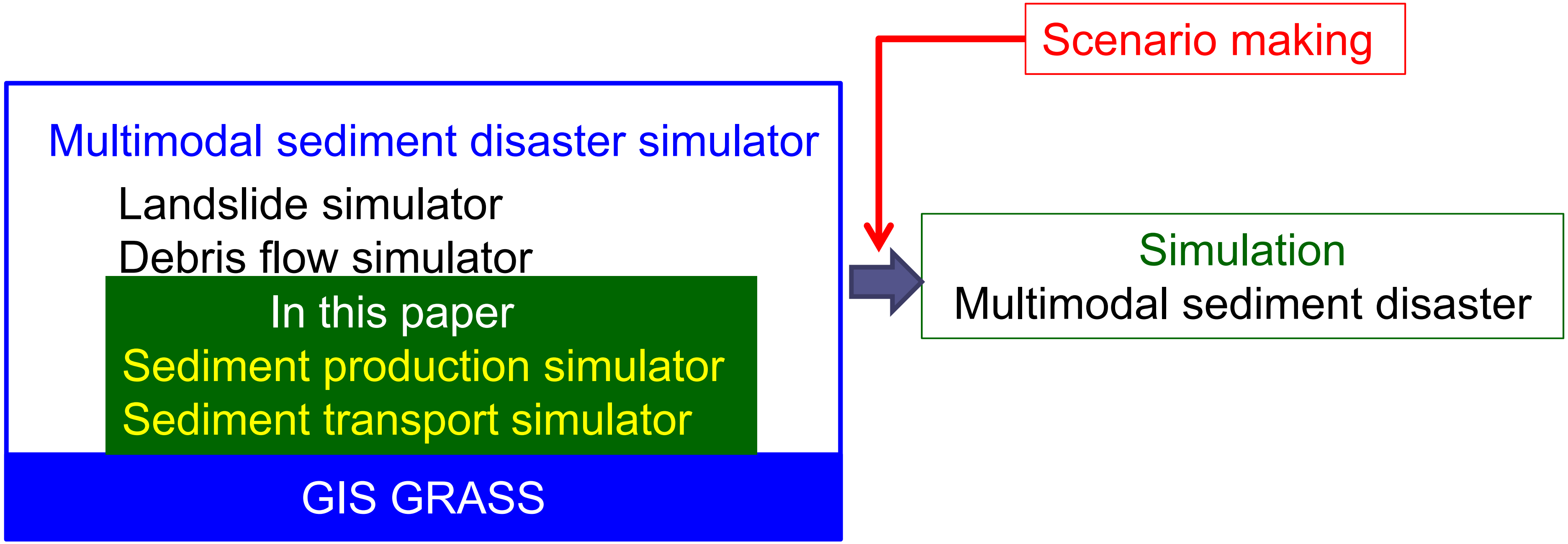

Scenario making

Multimodal sediment disaster simulator

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In this paper

Sediment production simulator

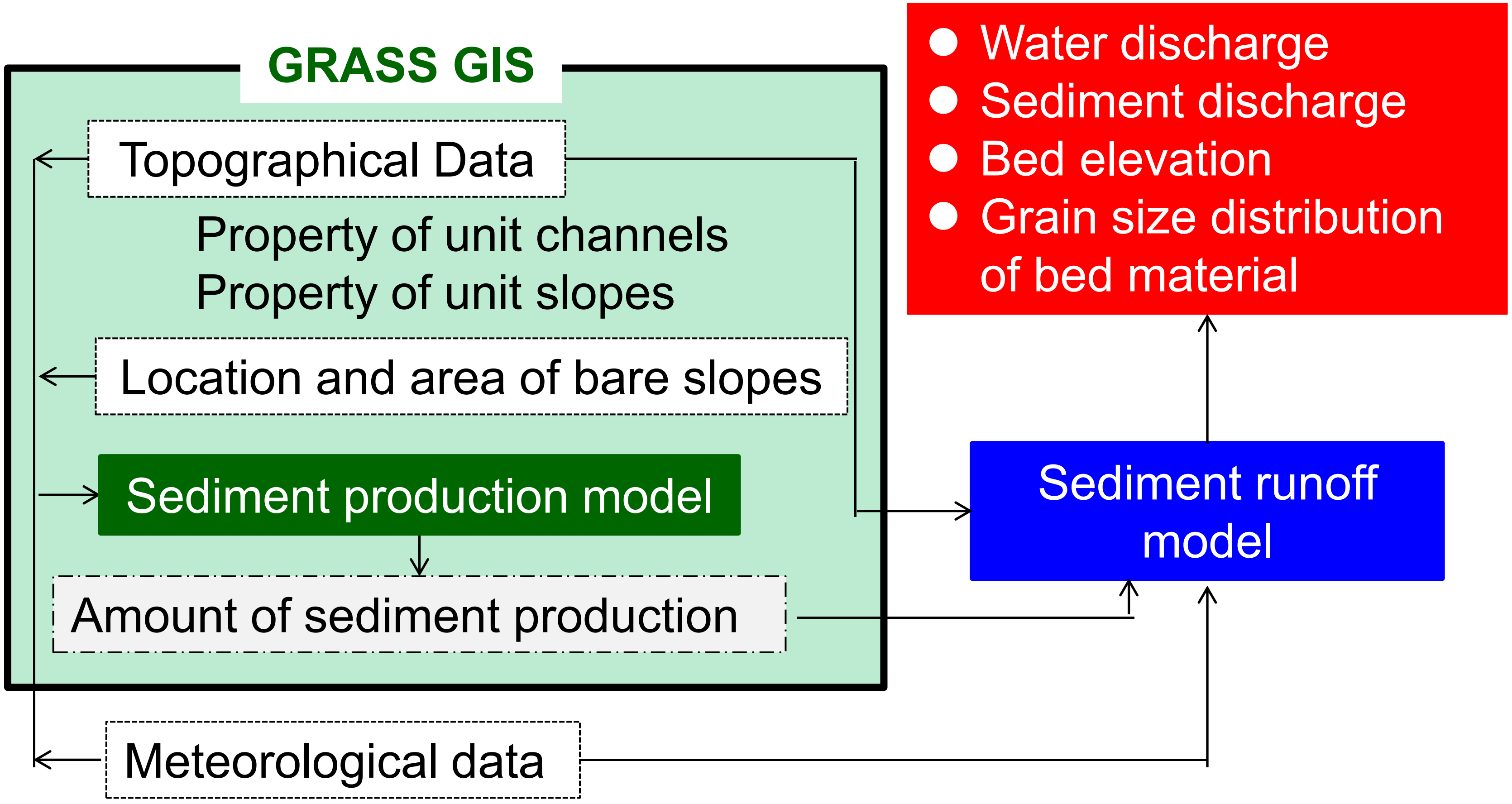
Sediment transport simulator

GIS GRASS

Simulation

Multimodal sediment disaster

# Framework of the Simulator



**GRASS GIS**

Topographical Data

Property of unit channels
Property of unit slopes

Location and area of bare slopes

Sediment production model

Amount of sediment production

Meteorological data

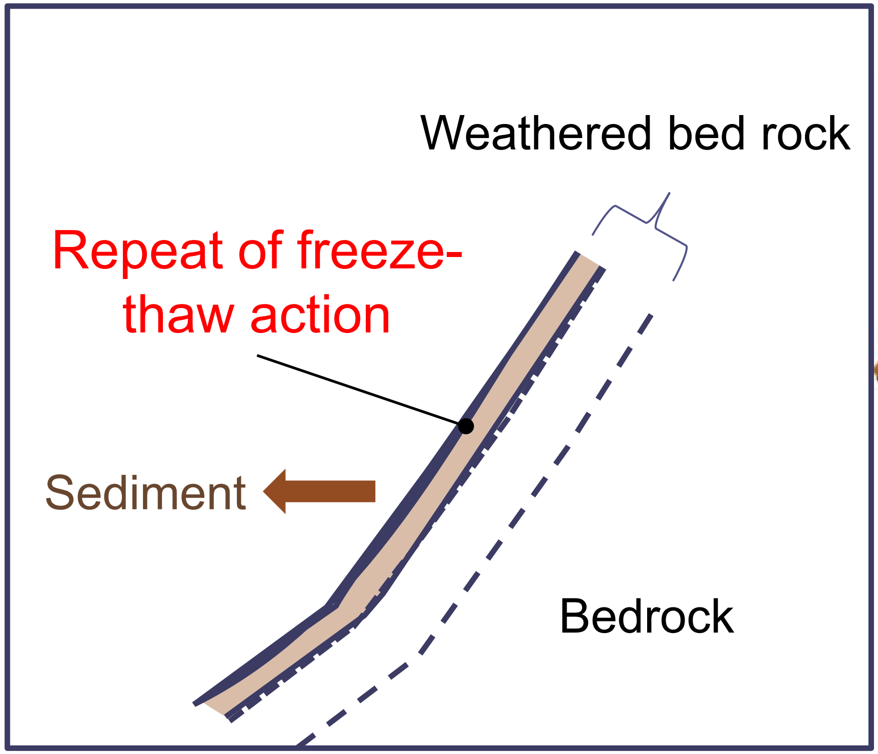
Sediment runoff model

- Water discharge
- Sediment discharge
- Bed elevation
- Grain size distribution of bed material

# Sediment Production Model

What is the dominant process on sediment production ?

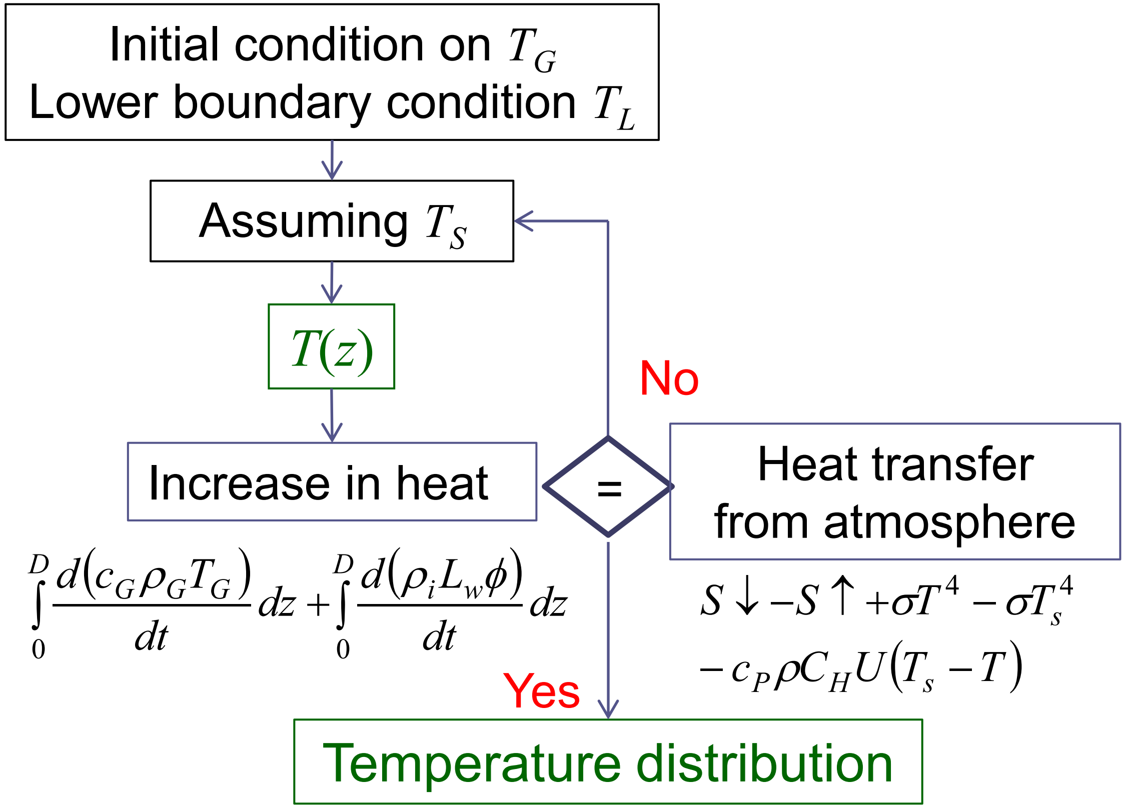
One of the typical sediment production cycle in Japan



# Analysis on Freeze & Thaw Process

## Temperature distribution under ground

$$\rho_G c_G \frac{\partial T_G}{\partial t} = \frac{\partial}{\partial z}\left(\lambda_G \frac{\partial T_G}{\partial z}\right) + \rho_i L_w \frac{\partial \phi}{\partial t}$$



Initial condition on $T_G$
Lower boundary condition $T_L$

Assuming $T_S$

$T(z)$

Increase in heat

$$\int_0^D \frac{d(c_G \rho_G T_G)}{dt} dz + \int_0^D \frac{d(\rho_i L_w \phi)}{dt} dz$$

=

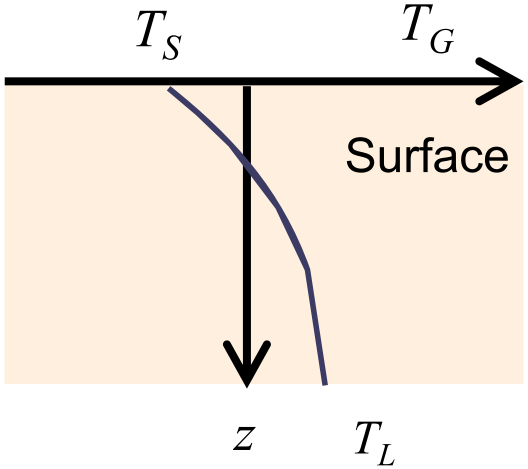
No

Yes

Heat transfer from atmosphere

$$S\downarrow - S\uparrow + \sigma T^4 - \sigma T_s^4 - c_P \rho C_H U(T_s - T)$$

Temperature distribution



$T_G$ = underground temperature;
$\phi$ = ice content;
$c_G$ = thermal capacity of bedrock;
$\rho_G$ = density of bedrock;
$\rho_w$ = density of water;
$\rho_i$ = density of ice;
$\lambda_G$ = thermal conductivity;
$L_w$ = latent heat of ice;
$t$ = time;
$z$ = axis perpendicular to slope surface

# Analysis on Freeze & Thaw Process

## Temperature distribution under ground

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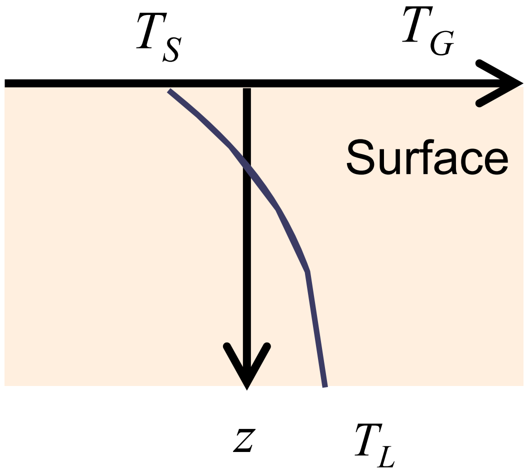

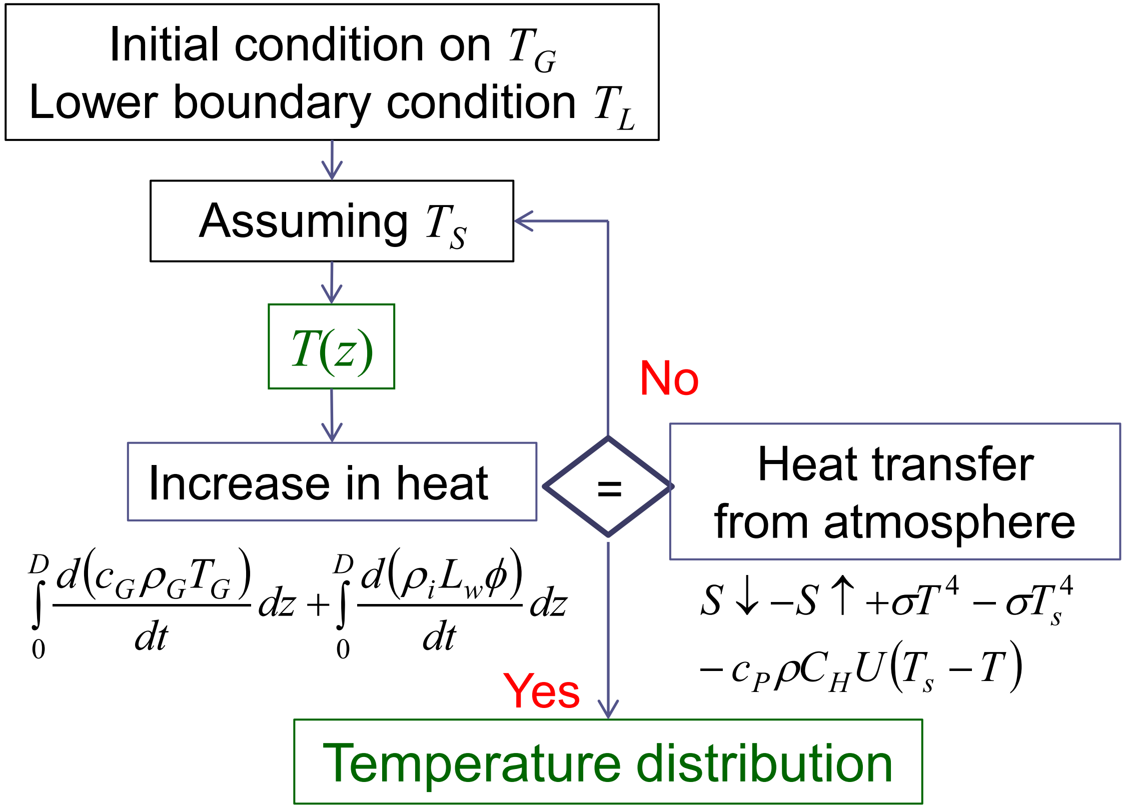

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=

Heat transfer from atmosphere

$$S\downarrow - S\uparrow + \sigma T^4 - \sigma T_s^4 - c_P \rho C_H U (T_s - T)$$

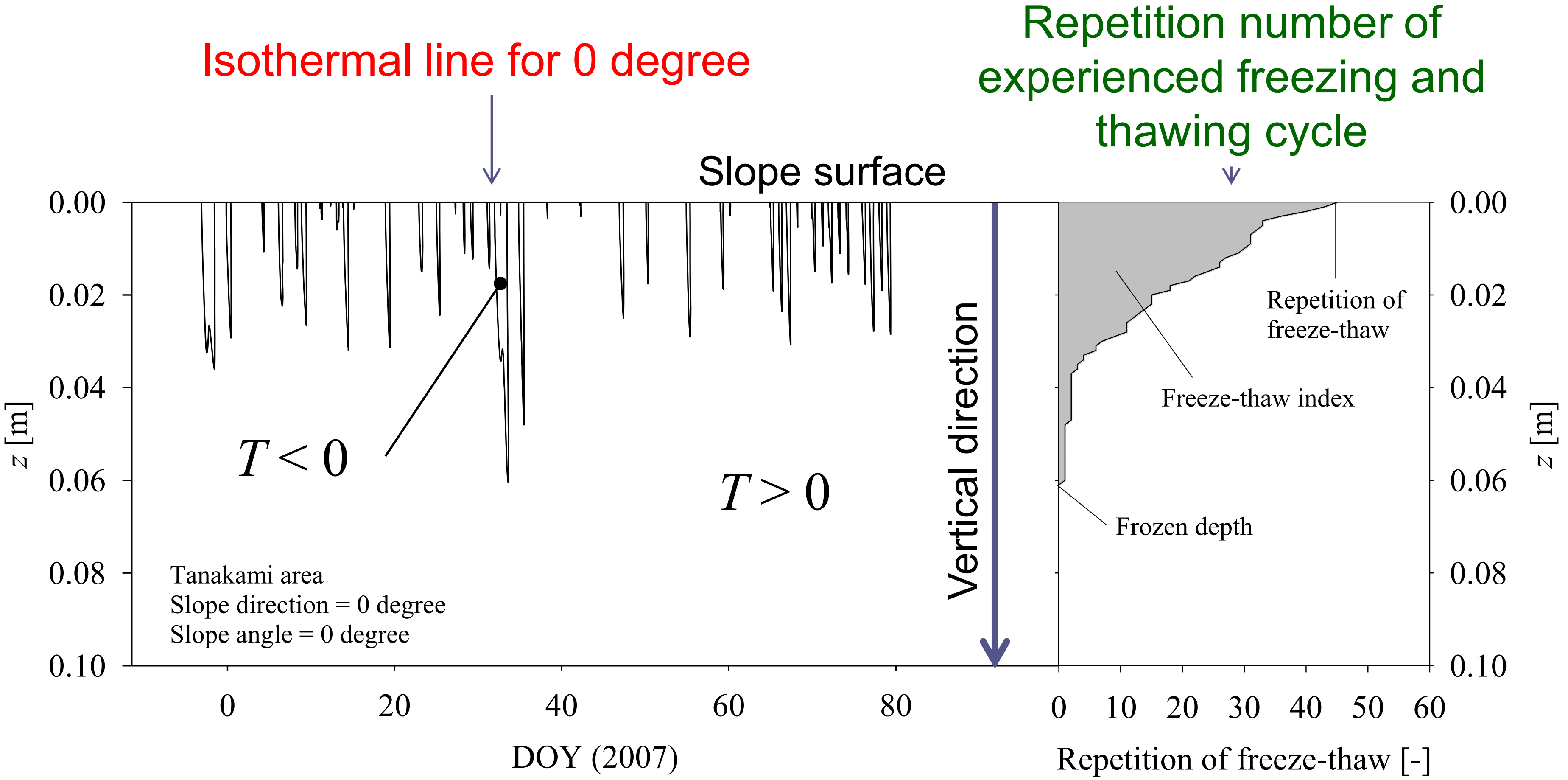
No

Yes

Temperature distribution

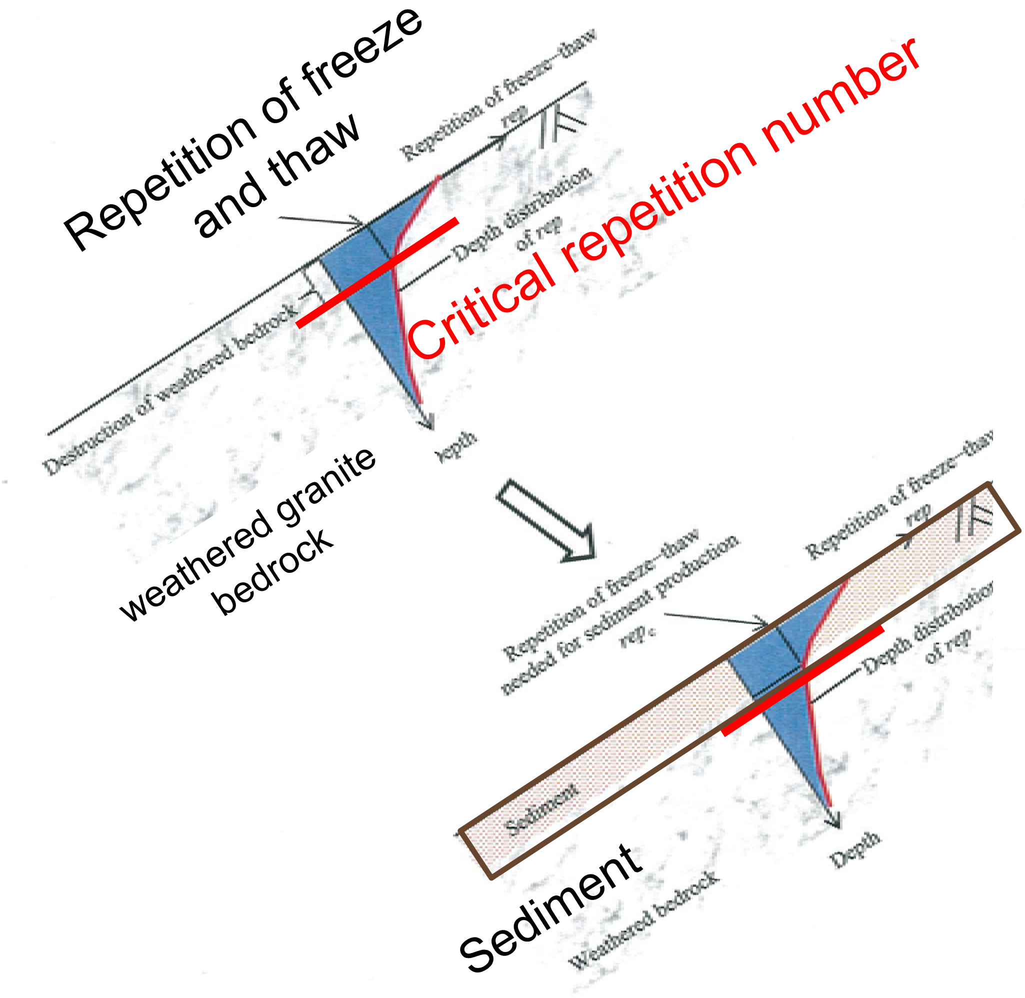
$L\downarrow$= downward longwave radiation (atmospheric radiation)
$L\uparrow$=upward longwave radiation (Earth radiation)
$S\downarrow$=downward short wave emission
$S\uparrow$=upward shortwave radiation
$H$ =latent heat
$lE$ =evaporation latent heat

# Example of calculation



# Sediment production

## Soft rock (Weathered granite)



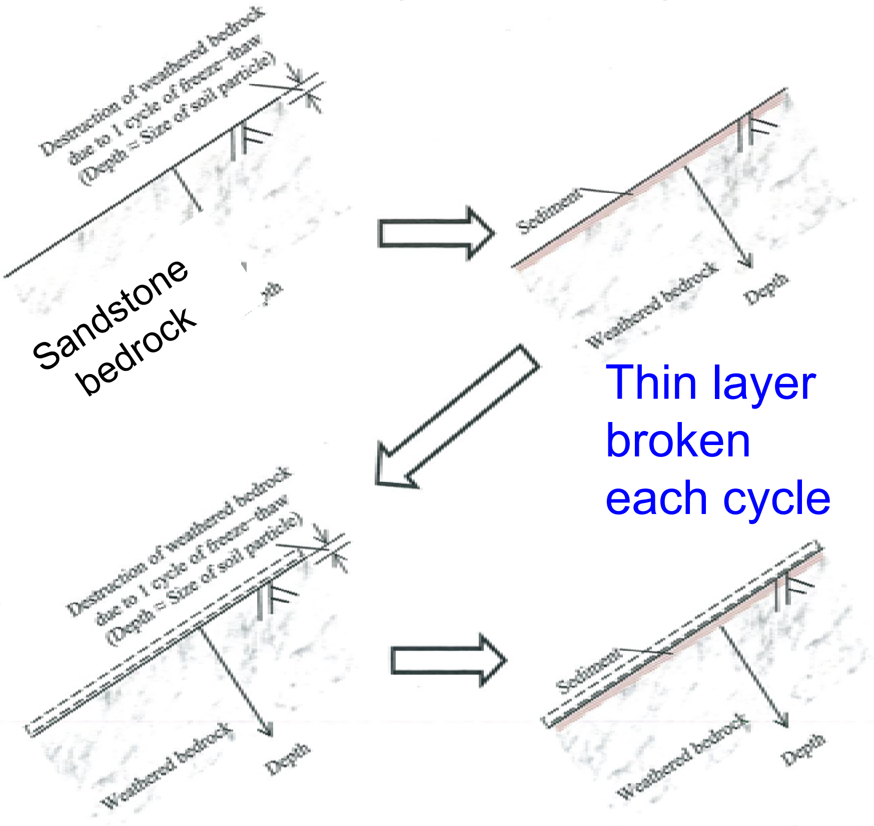
Repetition of freeze and thaw

Critical repetition number

weathered granite bedrock

Sediment

## Hard rock (Sandstone)

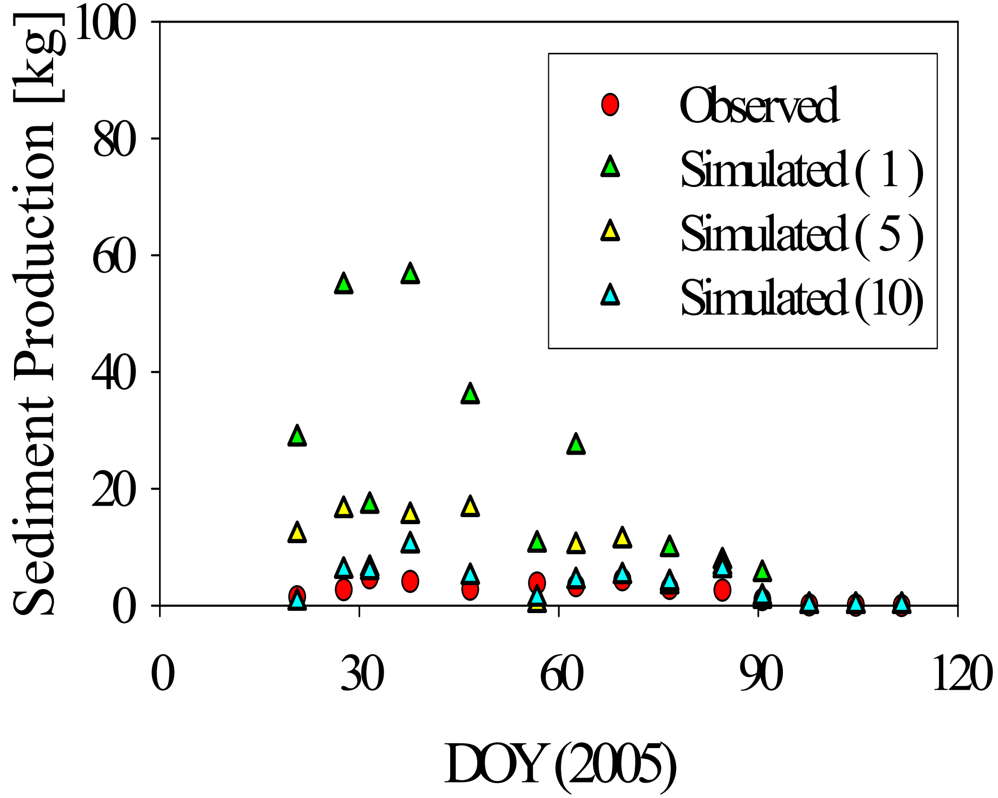


Sandstone bedrock

Thin layer broken each cycle

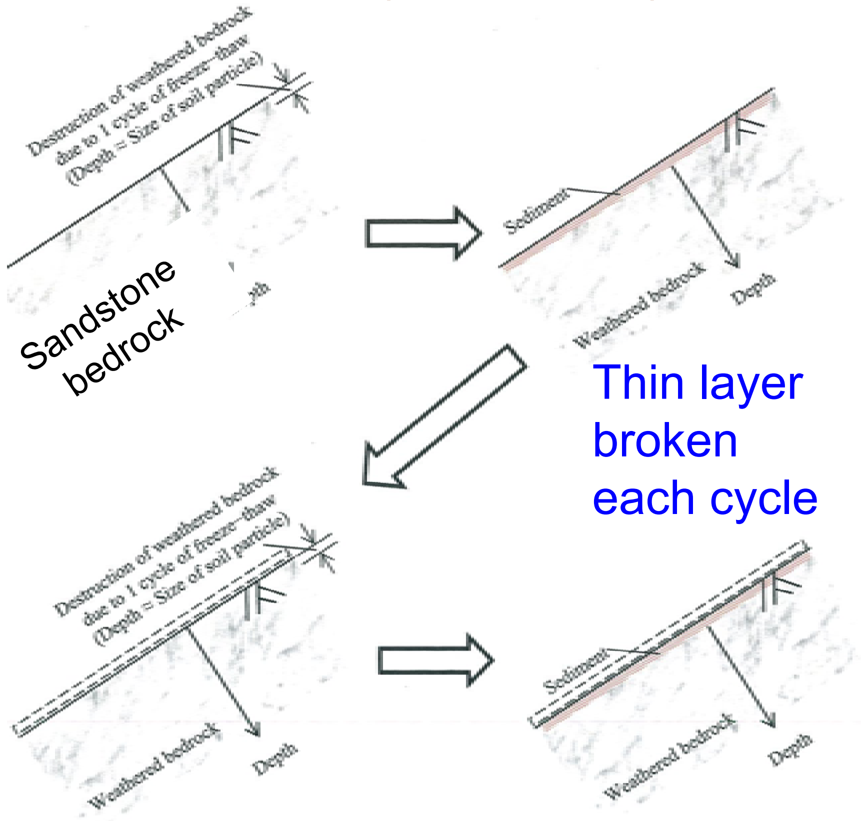
# Sediment production

Soft rock (Weathered granite)



Sediment is produced after 10 cycles.

Hard rock (Sandstone)



Thin layer broken each cycle

# Sediment production

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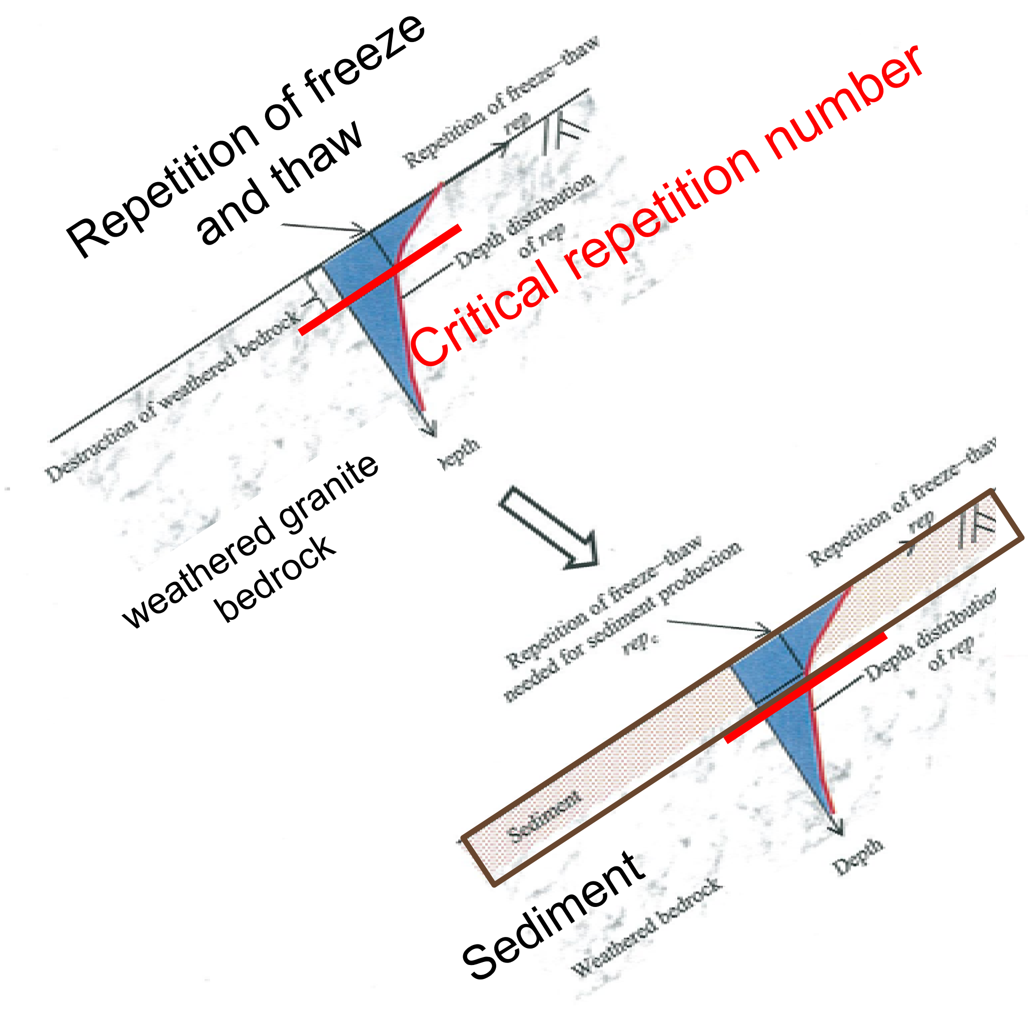


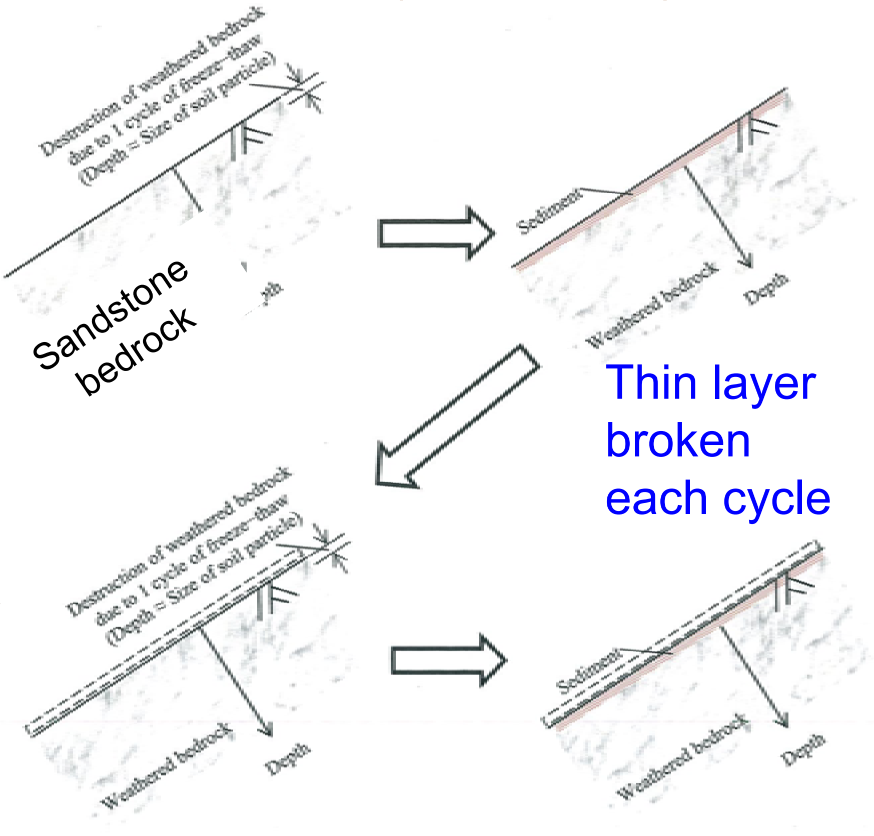
Repetition of freeze and thaw

Critical repetition number

weathered granite bedrock

Sediment

## Hard rock (Sandstone)



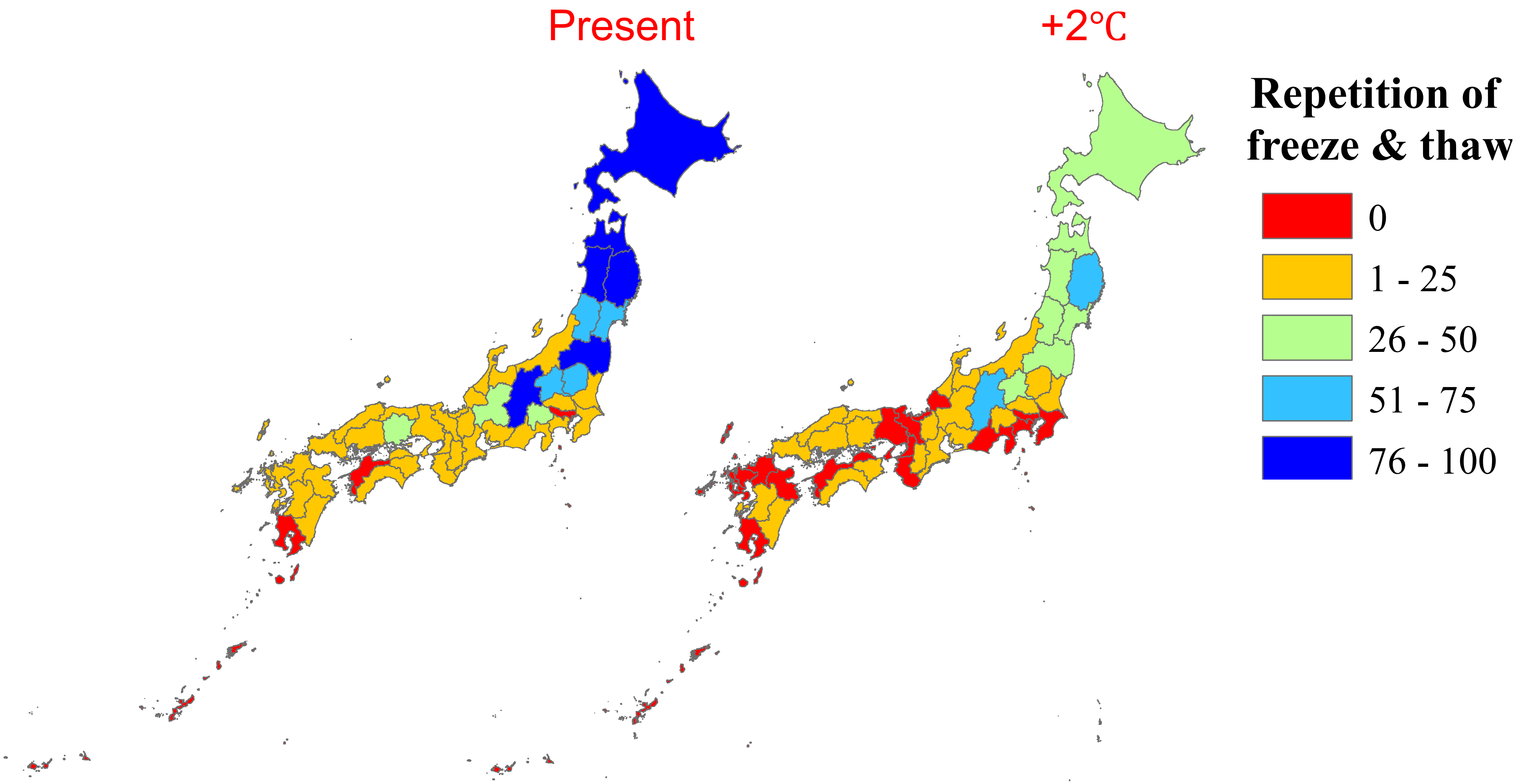
Sandstone bedrock

Thin layer broken each cycle

The surface of bedrock exfoliates in a thin layer (a few millimeters) by each cycle.

# Influence of global warming on repetition number of freeze and thaw

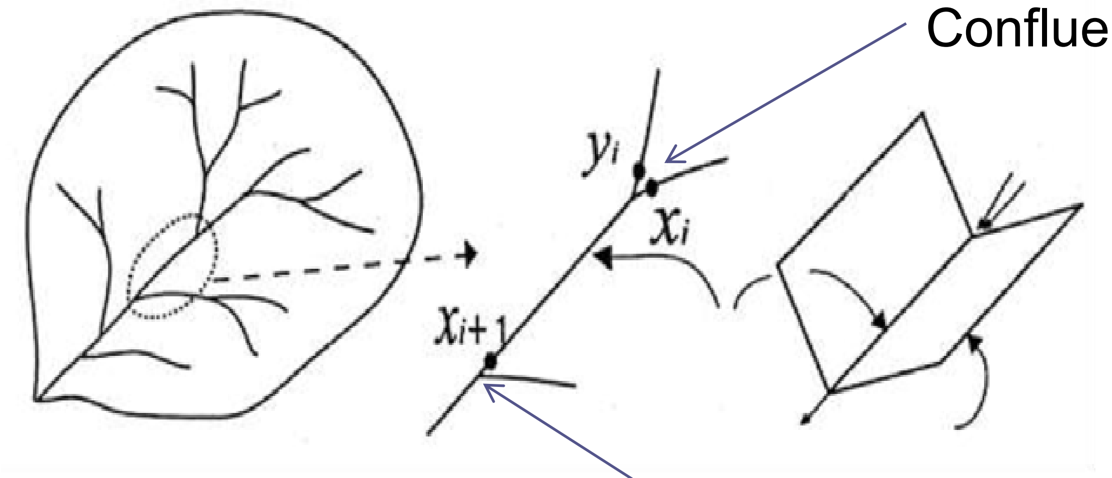
Face to the South Slope angle=45degree



# Sediment Transport Model

by Egashira & Matsuki (2000)

A basin model composed of
unit channels and unit slopes



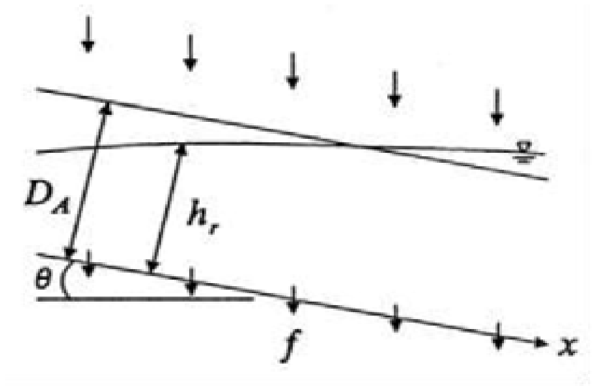
Confluence point

Confluence point

# A Sediment Transport Model

## Seepage flow depth, surface and seepage flow discharges in unit slopes

$$\alpha \frac{\partial h_r}{\partial t} + \frac{\partial q_r}{\partial x} = (r - f)\cos\theta$$



$$\begin{aligned} \alpha &= \lambda_e \;\; (h_r < D_A) \\ &= 1.0 \; (h_r > D_A) \end{aligned}$$

$h_r < D_A$,: $q_r = kh_r \sin\theta$

$h_r \geqq D_A$: $q_r = k_A D_A \sin\theta + \frac{1}{N}\sqrt{\sin\theta}\left(h_r - D_A\right)^{5/3}$

$h_r$ = water depth above bedrock; $q_r$ = water discharge above bedrock; $r$ = rainfall intensity, $f$ = infiltration capacity of soil layer; $\theta$ = gradient of unit slope; $\lambda_e$ = effective porosity of soil layer; $k$ = coefficient of permeability; $N$ = coefficient of equivalent roughness

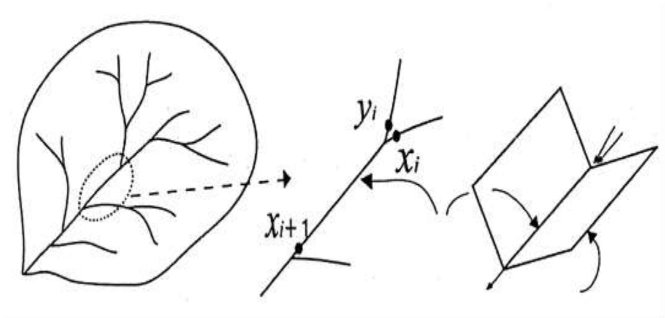
# A Sediment Transport Model

## Flow depth and flow discharge in unit channels

$$\frac{\partial h}{\partial t} = \frac{1}{BL}\{Q(x_i)+Q(y_i)-Q(x_{i+1})\}+\frac{1}{B}q$$

$$Q(x_{i+1}) = \frac{1}{n}BI^{1/2}h^{5/3}$$

$$B=5Q^{0.5}$$



$B$, $h$, $B$, $L$, $I$ and $n$ = water depth, width, length, bed slope and Manning's coefficient of a unit channel; $Q(x_{i+1})$ = the flow discharge in unit channel $i$, $Q(x_i)$ and $Q(y_i)$ = the flow discharge to unit channel $i$, $q$ is the flow discharge per unit length from both unit slopes of unit channel $i$ associated with the rainfall runoff

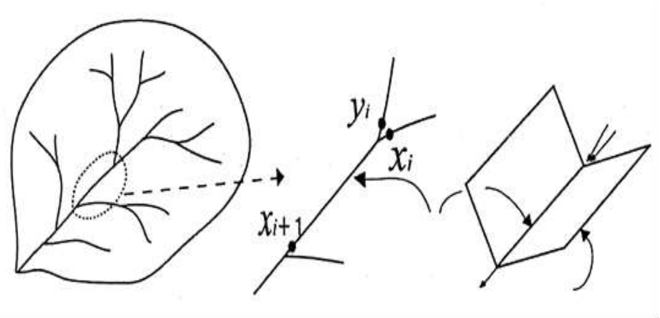
# A Sediment Transport Model

## Bed elevation, grain size distribution of bed material in unit channels

$$\frac{\partial z}{\partial t}=\frac{1}{(1-\lambda)BL}\{Q_s(x_i)+Q_s(y_i)-Q_s(x_{i+1})-Q_{sw}\}$$

$$\frac{\partial P_j}{\partial t}=\frac{1}{\varDelta BL}\{Q_{sj}(x_i)+Q_{sj}(y_i)-Q_{sj}(x_{i+1})\}-\frac{\partial z}{\partial t}\frac{f_j}{\varDelta}$$

$$f_j=p_{j0}\left(\frac{\partial z}{\partial t}\le 0\right), f_j=p_j\left(\frac{\partial z}{\partial t}>0\right)$$



$z$, $\lambda$, $Q_s$, $p_j$, $p_{j0}$, and $\varDelta$ = bed elevation, porosity of deposits, sediment discharge, grain content having the size of $d_i$ in surface layer of riverbed, the grain content in lower layer, and the thickness of the exchange layer; $Q_{sj}$ = the sediment discharge of grain size $d_j$; $Q_{sw}$ = wash load per unit time generated in unit channel $i$..

# Study Field for Application

Watershed concerned

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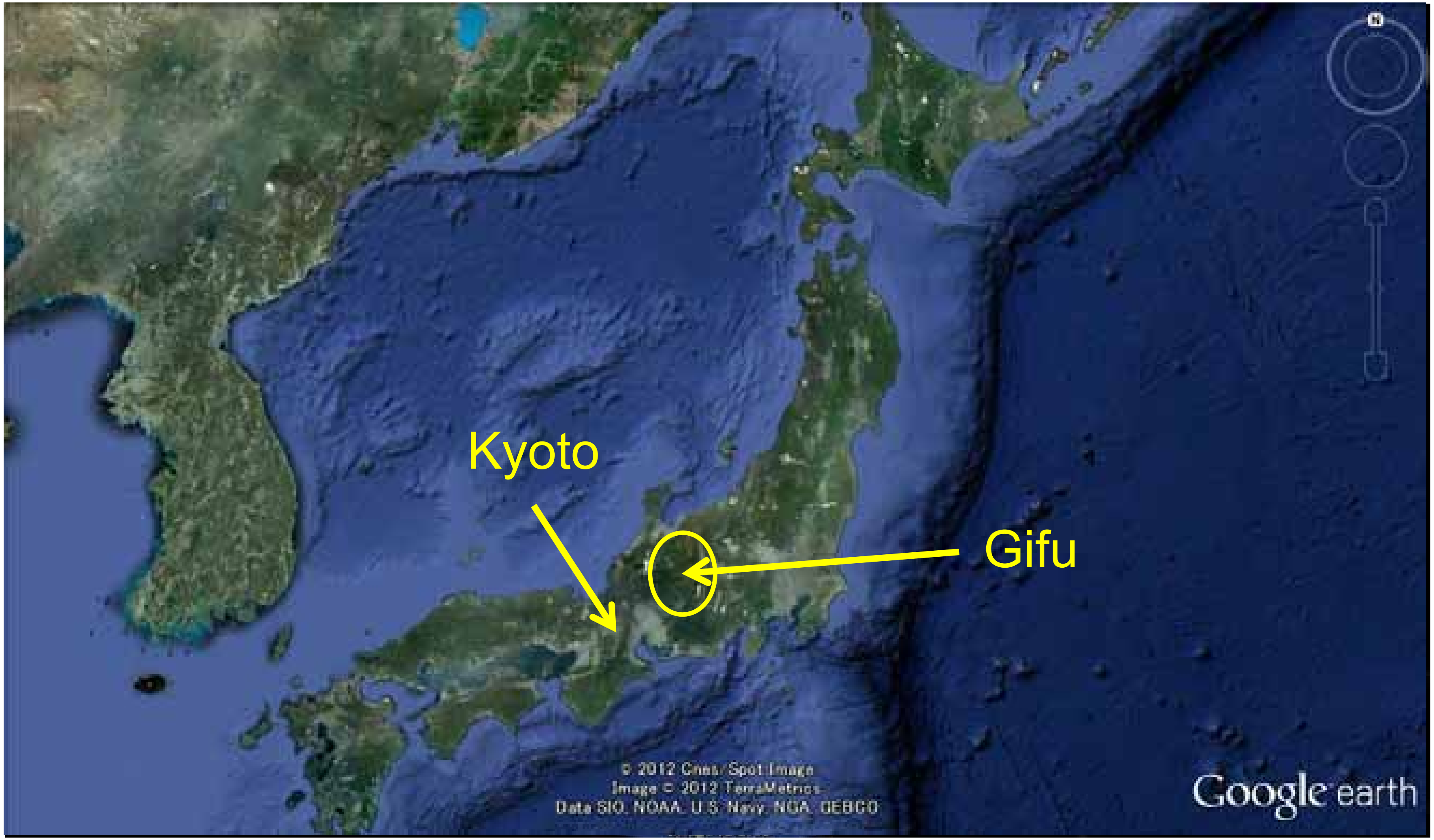

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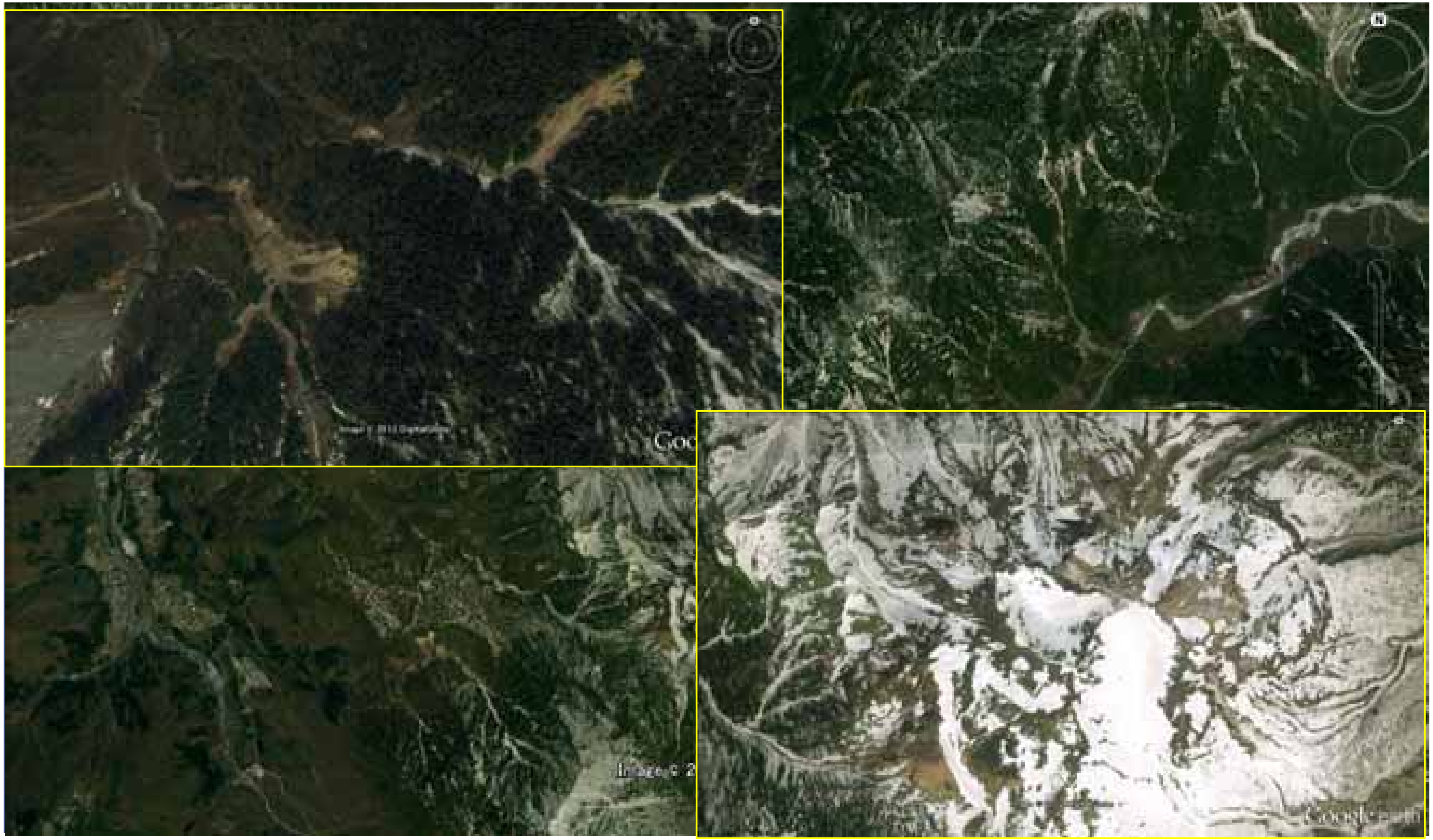
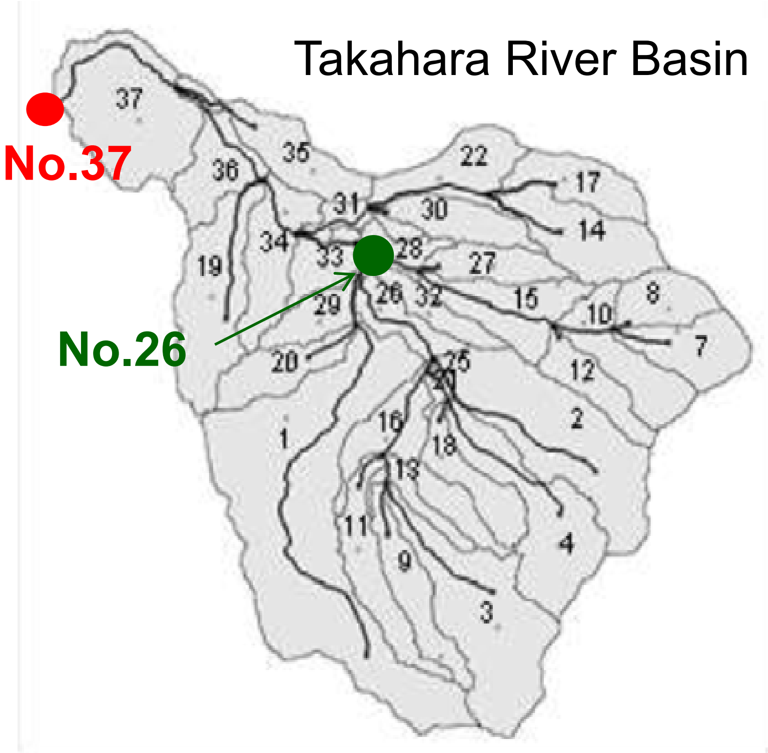
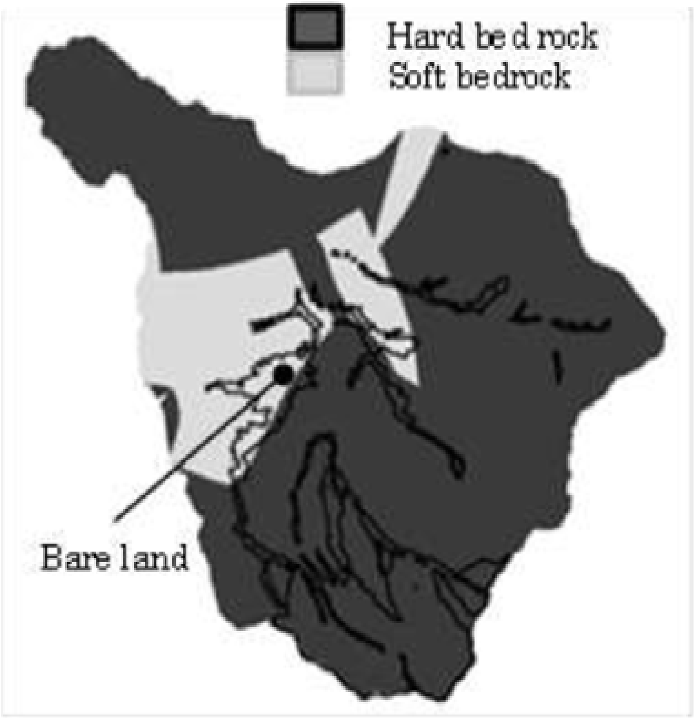


# Study Field for Application

## Watershed concerned



Basin of concerned and the sub- basins



Two types of sediment production and location of bare land

# Properties of sub-basin

## Sediment production in 2009

Considering snow coverage period

### Whole area

Simulation: 2,775$m^3/km^2/year$

Observation:$10^3$ to $10^4$ $m^3/km^2/year$

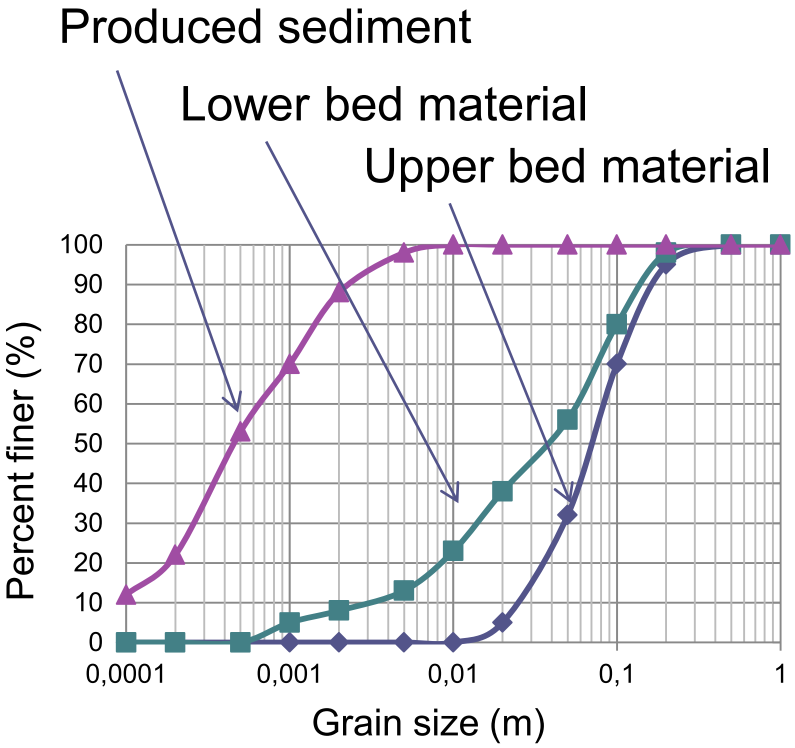
### Hiru-dani watershed

Simulation: 32.3$m^3/year$

Observation: 50.0$m^3/year$

| Sub-basin No. | Unit channel | | | Unit slope | | | | | Specific sediment production |
|---|---|---|---|---|---|---|---|---|---|
| | Elevation1 (m) | Elevation2 (m) | Length (m) | Angle (deg.) | Area ($m^2$) | Width (m) | Length (m) | Ratio of bare land (%) | ($m^3/m^2/year$) |
| 35 | 1134.2 | 1062.9 | 538 | 24.9 | 212711 | 538 | 198 | 0.0 | 0.000000 |
| 19 | 1532.4 | 1125.2 | 940 | 36.6 | 352635 | 940 | 188 | 0.0 | 0.000000 |
| 17 | 1555.3 | 1420.0 | 387 | 38.0 | 165778 | 387 | 214 | 0.0 | 0.000000 |
| 14 | 1601.7 | 1420.0 | 482 | 40.8 | 259848 | 482 | 270 | 0.0 | 0.000000 |
| 22 | 1421.4 | 1265.7 | 696 | 31.2 | 202742 | 696 | 146 | 0.2 | 0.000038 |
| 30 | 1298.3 | 1265.7 | 110 | 25.0 | 150607 | 110 | 687 | 0.0 | 0.000000 |
| 31 | 1267.7 | 1179.1 | 471 | 27.4 | 69255 | 471 | 74 | 0.0 | 0.000000 |
| 27 | 1363.3 | 1331.4 | 115 | 32.5 | 126725 | 115 | 553 | 0.0 | 0.000000 |
| 12 | 1627.8 | 1578.6 | 80 | 41.7 | 131846 | 80 | 822 | 0.0 | 0.000000 |
| 8 | 1764.9 | 1703.6 | 103 | 39.0 | 135409 | 103 | 660 | 0.0 | 0.000000 |
| 7 | 1885.6 | 1703.6 | 325 | 42.1 | 185373 | 325 | 285 | 4.6 | 0.000898 |
| 10 | 1708.7 | 1578.6 | 335 | 41.1 | 216219 | 335 | 323 | 3.5 | 0.000326 |
| 15 | 1581.3 | 1331.4 | 877 | 39.0 | 222799 | 877 | 127 | 15.9 | 0.003544 |
| 28 | 1332.3 | 1220.8 | 439 | 26.6 | 70703 | 439 | 81 | 2.1 | 0.001309 |
| 20 | 1482.8 | 1300.4 | 348 | 36.4 | 157486 | 348 | 226 | 0.4 | 0.000081 |
| 1 | 2049.4 | 1300.4 | 2468 | 33.8 | 1219812 | 2468 | 247 | 34.0 | 0.005381 |
| 29 | 1301.5 | 1239.2 | 314 | 36.4 | 108815 | 314 | 173 | 11.4 | 0.006378 |
| 11 | 1653.6 | 1572.3 | 259 | 30.8 | 198362 | 259 | 382 | 39.6 | 0.003288 |
| 3 | 1973.1 | 1611.1 | 931 | 37.7 | 503233 | 931 | 270 | 62.5 | 0.012216 |
| 9 | 1720.7 | 1611.1 | 329 | 39.4 | 175151 | 329 | 266 | 57.3 | 0.006600 |
| 13 | 1612.4 | 1572.3 | 194 | 29.6 | 70530 | 194 | 182 | 4.3 | 0.000404 |
| 16 | 1575.2 | 1393.1 | 598 | 29.7 | 247696 | 598 | 207 | 2.9 | 0.000379 |
| 18 | 1541.4 | 1466.5 | 147 | 34.7 | 149987 | 147 | 510 | 0.4 | 0.000021 |
| 4 | 1957.8 | 1466.5 | 997 | 30.3 | 367001 | 997 | 184 | 13.0 | 0.001446 |
| 21 | 1469.6 | 1393.1 | 219 | 37.6 | 19855 | 219 | 45 | 31.9 | 0.007191 |
| 23 | 1393.8 | 1367.3 | 83 | 35.0 | 3540 | 83 | 21 | 60.0 | 0.017052 |
| 2 | 1999.7 | 1367.3 | 1188 | 35.2 | 554459 | 1188 | 233 | 2.6 | 0.000187 |
| 26 | 1367.8 | 1239.2 | 751 | 31.6 | 113124 | 751 | 75 | 23.9 | 0.018628 |
| 32 | 1239.9 | 1220.8 | 227 | 25.1 | 110229 | 227 | 242 | 0.0 | 0.000000 |
| 33 | 1221.3 | 1179.1 | 367 | 33.0 | 108134 | 367 | 147 | 0.0 | 0.000000 |
| 34 | 1179.7 | 1125.2 | 421 | 35.3 | 221683 | 421 | 263 | 0.0 | 0.000000 |
| 36 | 1126.4 | 1062.9 | 799 | 29.0 | 176856 | 799 | 111 | 0.0 | 0.000000 |
| 37 | 1063.9 | 978.4 | 1006 | 24.7 | 465668 | 1006 | 231 | 0.0 | 0.000000 |

# Grain Size Distribution



Produced sediment

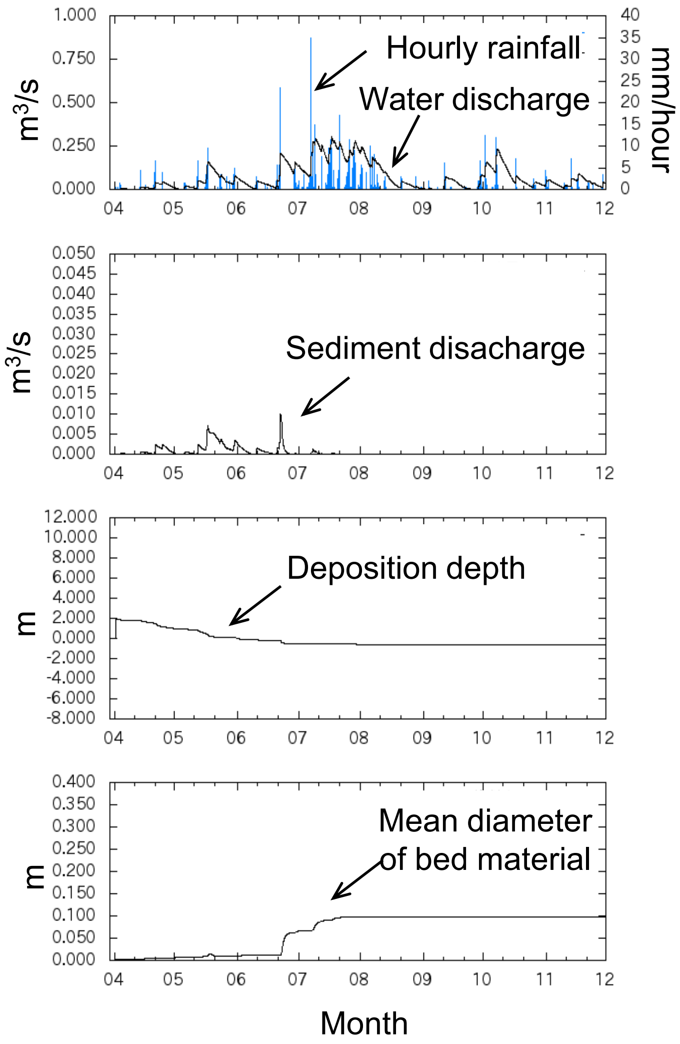
Lower bed material

Upper bed material

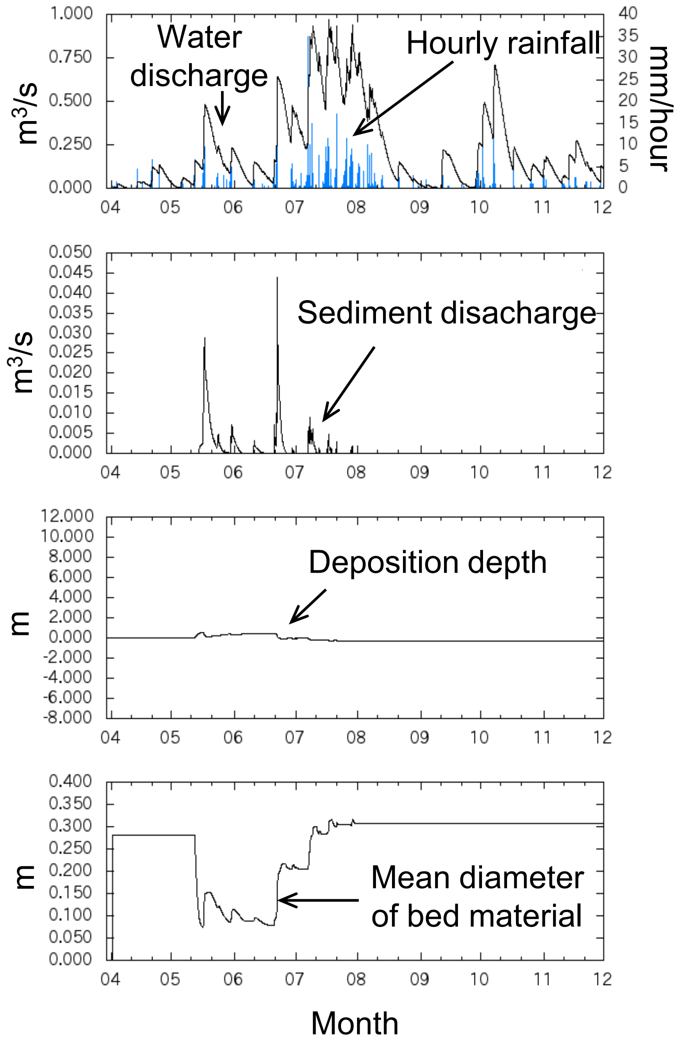
Grain size distribution

# Results for Condition in 2009

## No.26 (Middle reach)

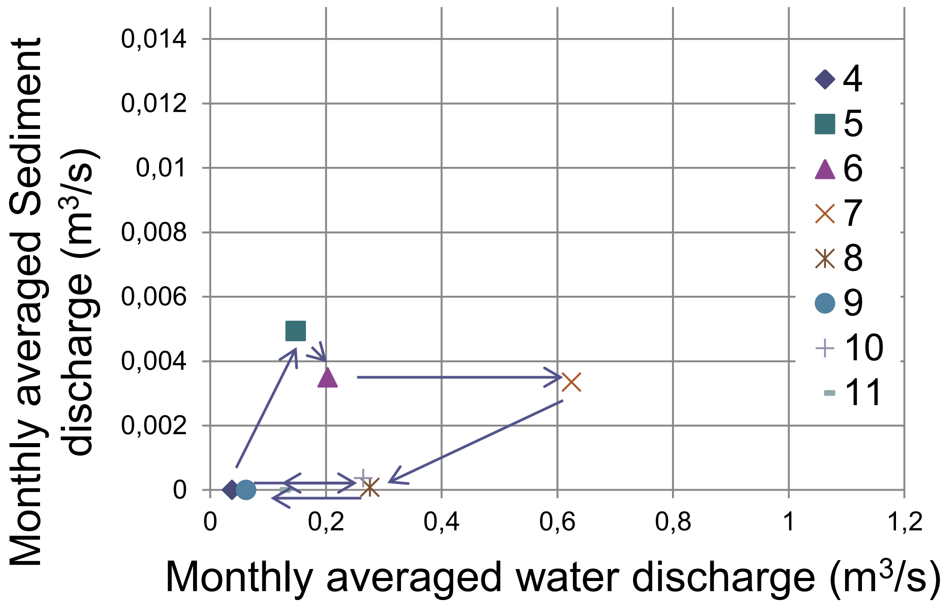


## No.37 (Most downstream)

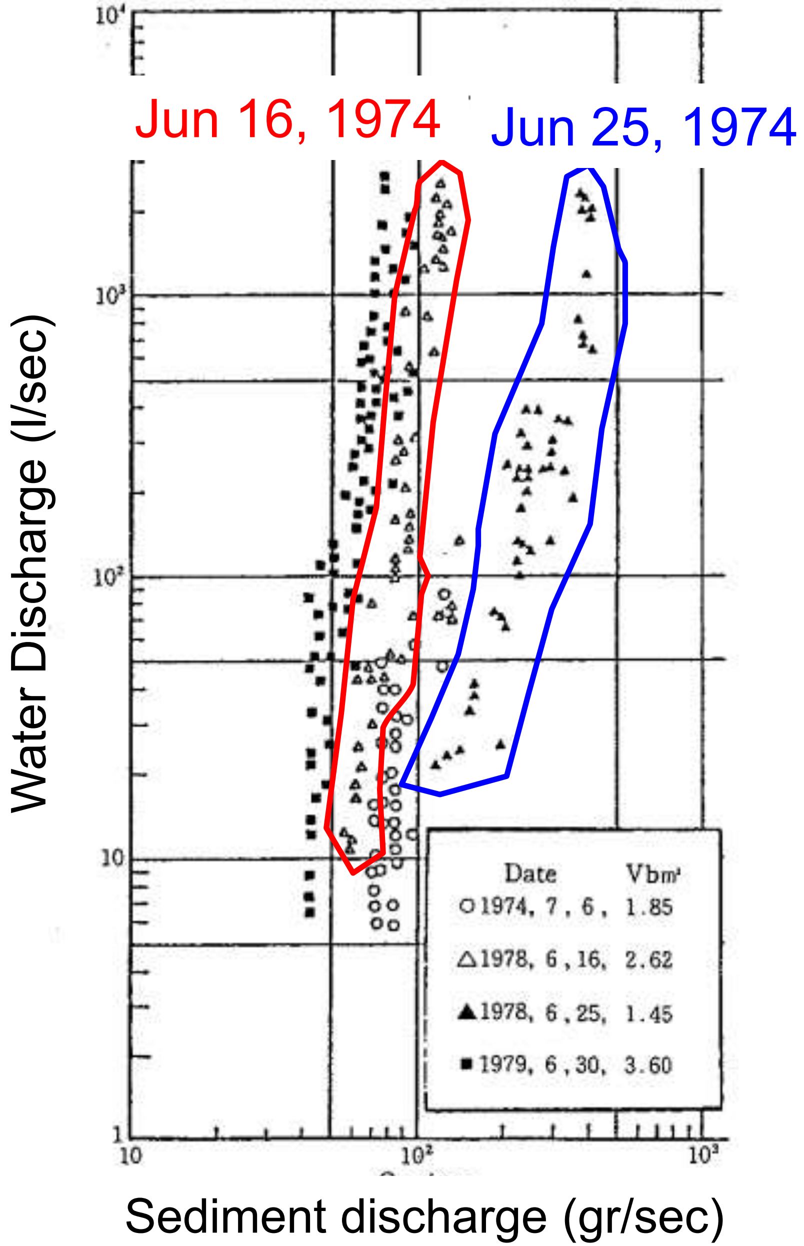


# Relation between Sediment discharge and water Discharge

Simulation



Observation Result



# Conclusions

- A GIS-based model of sediment production and sediment runoff has been proposed. The sediment production model was linked with a sediment runoff model on GRASS GIS.
- Because the sediment production model includes meteorological parameters, it can evaluate the effect of climate changes.
- Simulation of sediment production in the Takahara River Basin has shown the validity of the model by comparing calculated results on sediment production with observation results.
- The combined model could describe the process consisting of sediment production, sediment supply and sediment transport, and also could express ‘sediment supply limit’ condition.
- The validity was not verified quantitatively, but the performance of the proposed model seemed quite reasonable.