Progress within the F-TRACE Project

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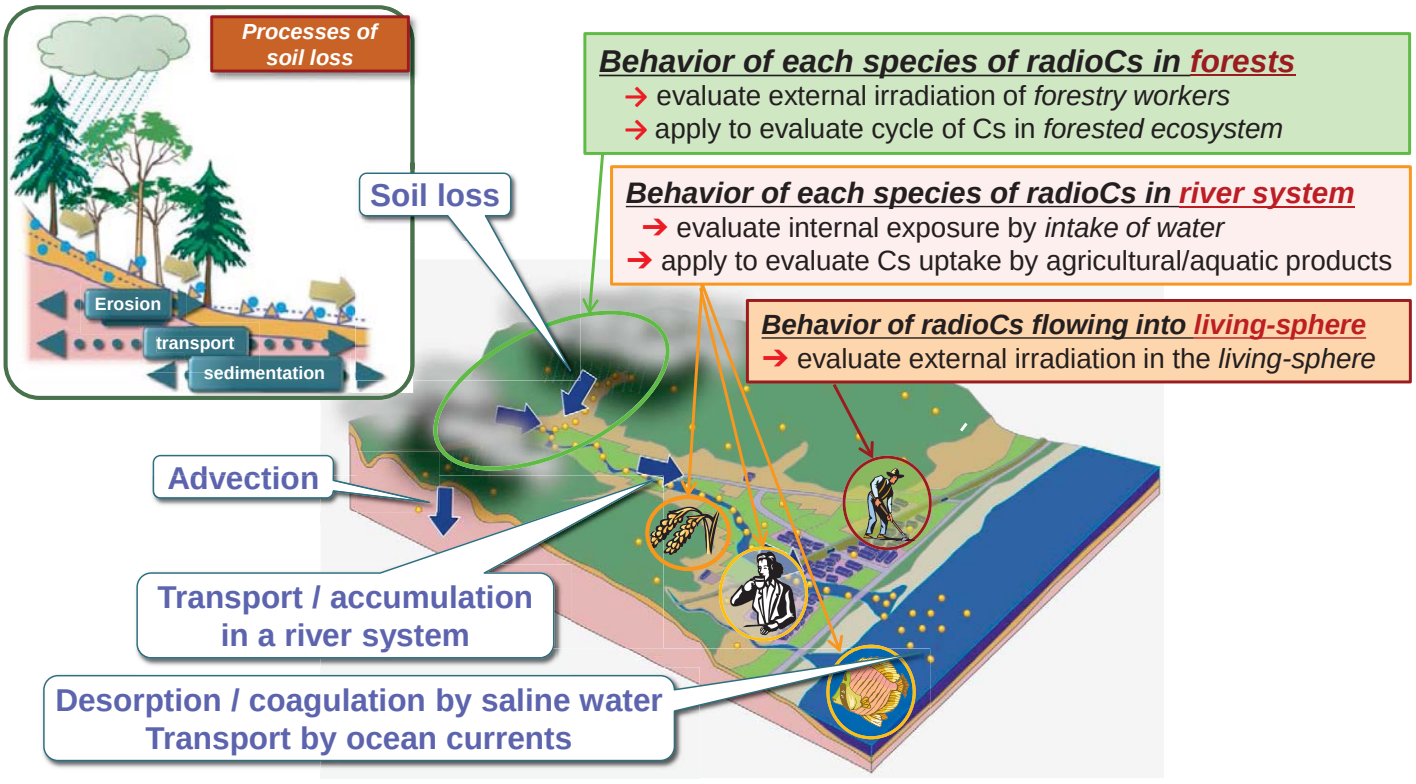
Japan Atomic Energy Agency (JAEA)

Objectives of the F-TRACE project

Develop phenomenological models to describe quantitatively transport of radioisotopes(especially radioactive Cs) along water systems

Transport pathways & processes

Transport behavior of Cs to be modeled

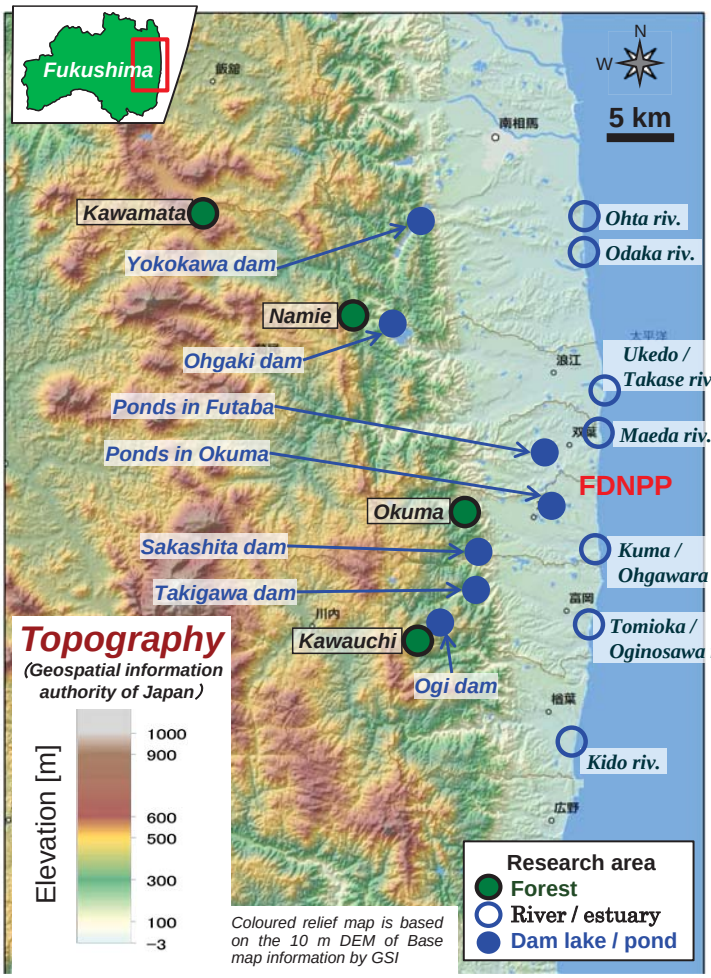


Behavior of each species of radioCs in forests
→ evaluate external irradiation of *forestry workers*
→ apply to evaluate cycle of Cs in *forested ecosystem*

Behavior of each species of radioCs in river system
→ evaluate internal exposure by *intake of water*
→ apply to evaluate Cs uptake by agricultural/aquatic products

Behavior of radioCs flowing into living-sphere
→ evaluate external irradiation in the *living-sphere*

Current research area for river systems



❑ Forest (4 fields)

- ✓ Kawamata (deciduous forest)
- ✓ Namie (evergreen / deciduous forests)
- ✓ Okuma (evergreen forest)
- ✓ Kawauchi (evergreen / deciduous forests)

❑ River and estuary (7 river systems)

- ✓ Ohta (since 2014, high Cs deposition)
- ✓ Odaka (without dam, brakish water)
- ✓ Ukedo (high Cs deposition)
  - Takase (without dam, high Cs deposition)
- ✓ Maeda (without dam, high Cs deposition)
- ✓ Kuma (without dam)
  - Ohgawara
- ✓ Tomioka
  - Oginosawa (through decontaminated area)
- ✓ Kido (through decontaminated area)

❑ Dam lake and pond (5 dam lakes)

- ✓ Yokokawa (since 2014, Ohta river)
- ✓ Ohgaki (Ukedo river)
- ✓ Sakashita (since 2014, Ohgawara river)
- ✓ Takigawa (Tomioka river)
- ✓ Ogi (Oginosawa river)
- ✓ Ponds for irrigation

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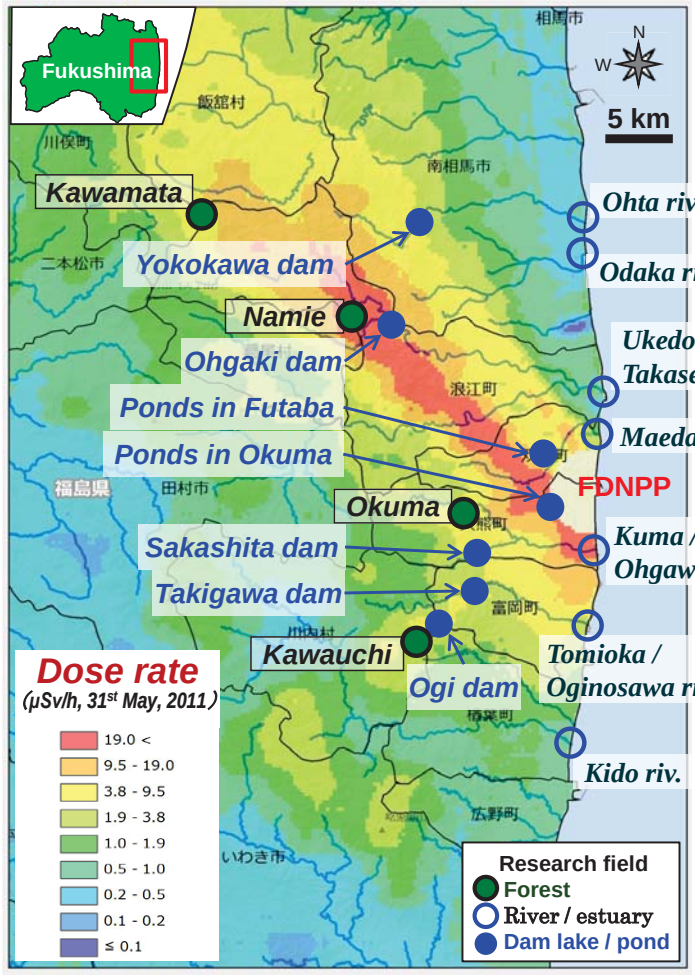

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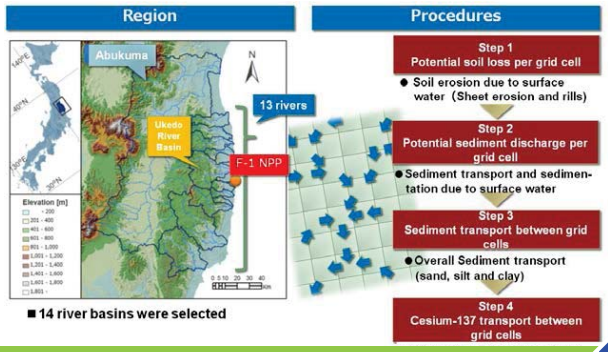
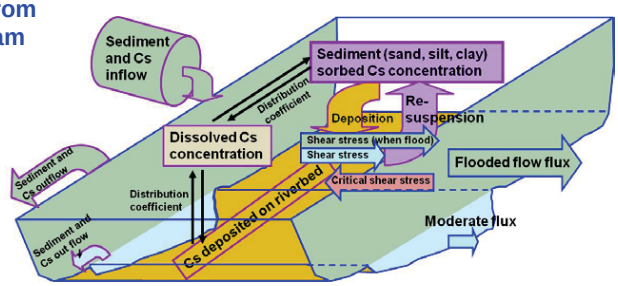
Overview of the numerical models



Amounts from upper stream and sides

Model treats dispersion equations of sediment concentration (sand, silt, clay) and cesium concentration (dissolved, sediment-sorbed)

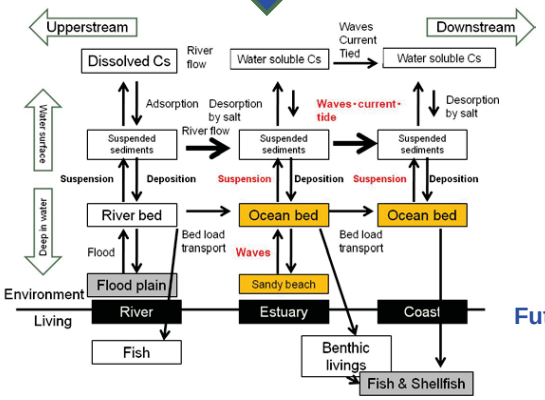


Soil and Cs transport model: SACT

1D/2D river models: TODAM, iRIC

Amounts from *land surface*

Amounts from *rivers*



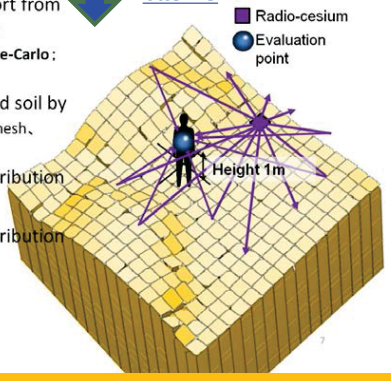
Future radio-cesium *distribution map*

- Calculate radiation transport from radio-cesium on surface to measurement points (**Monte-Carlo**; **250,000 × 50,000**)
- Interaction between air and soil by gamma rays (200m、12.5m mesh、17 × 17)

①Radio-cesium conc. distribution
②Surface topography
③Radio-cesium conc. distribution profile in z-direction

$C = C_0 \cdot \exp(-1.2) \cdot z$

Future radio-cesium distribution on *river basins*



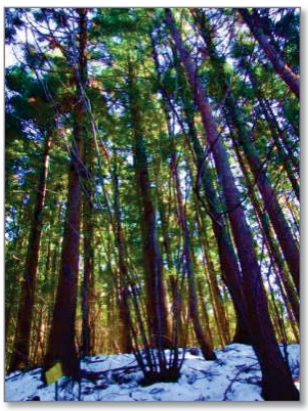
Future radio-cesium distribution on *coastal field*

Air dose evaluation models: PHITS, MCNP

3D reservoir/coastal models: FLESCOT, ROMS

Forest investigation

Ogi, Kawauchi (deciduous broad-leaved forest)

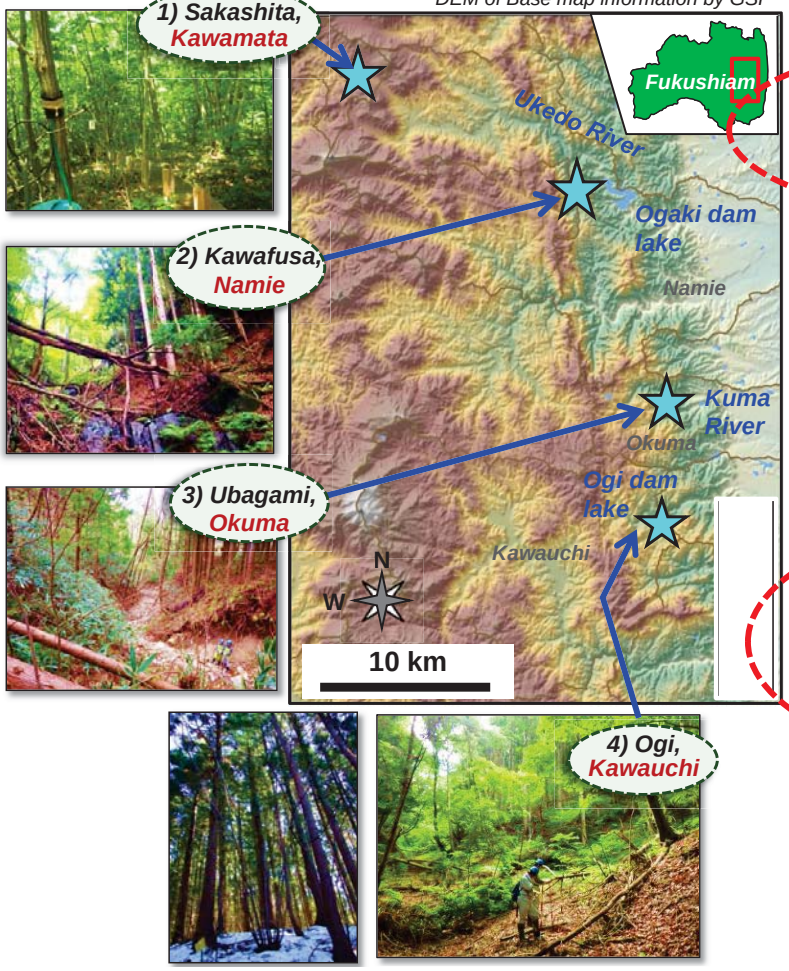


Ogi, Kawauchi (evergreen coniferous forest)

Ubagami, Okuma (evergreen coniferous forest & deciduous broad-leaved forest)

Forest: Investigation area

Coloured relief map is based on the 10 m DEM of Base map information by GSI



Vegetation	Topography	Soil
1) Kawamata Town, Sakashita		
✓ Deciduous broad-leaved forest	✓ South-facing valley ✓ Gentle to steep slope	✓ Brown forest soil
2) Namie Town, Kawafusa (Ukedo River & Ogaki dam lake)		
✓ Evergreen needle-leaved forest (lower stream) ✓ Deciduous broad-leaved forest (upper stream)	✓ East-facing valley, steep slope ✓ Gully erosion	✓ Transported soil
3) Okuma Town, Ubagami (Kuma River)		
✓ Evergreen needle-leaved forest	✓ North-facing, gentle to intermediate slope ✓ Gully erosion	✓ Brown forest soil (thick A horizon)
4) Kawauchi Village, Ogi (Ogi dam lake)		
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< Ogi B > ✓ Evergreen needle-leaved forest	✓ South-facing valley ✓ Steep slope	✓ Brown forest soil
< Ogi C > ✓ Deciduous broad-leaved forest	✓ South-facing slope ✓ Intermediate to steep slope	✓ Brown forest soil (thick organic layer) ✓ Transported soil

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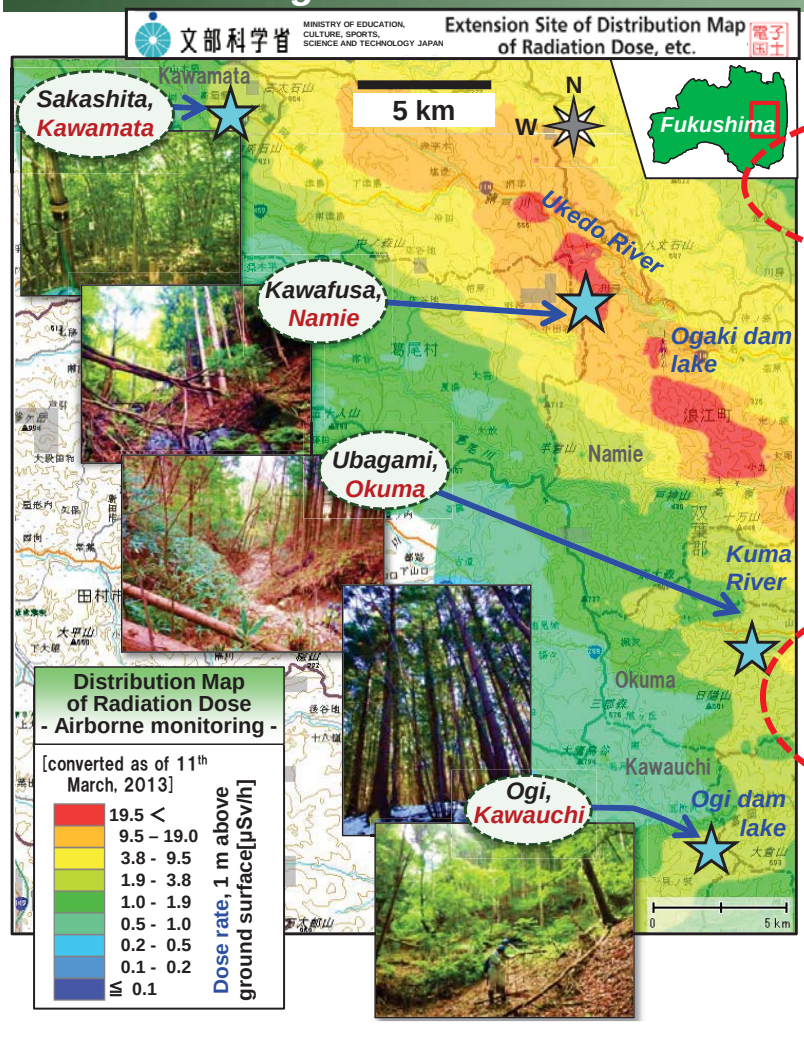

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Forest: Site characteristics and radioCs distribution

❑ Vegetation (field investigation, remote sensing)

- ✓ Tree species, height, tree density, undergrowth
- ✓ Litter fall, liter composition, litter sampling
- ✓ Vegetation and land use mapping

Vegetation map

❑ Topography (field investigation, DEM analysis)

- ✓ Topographic surveying, micro topography & its distribution
- ✓ Slope map, slope orientation map, sedimentation point

❑ Soil (field investigation, lab analysis)

- ✓ **Soil type, distribution, soil horizon sequence, sampling, grain size distribution, mineral composition, radioCs concentration**

Soil sampling by scraper plate (sampling interval: 1 cm)

Soil thickness measurement by penetration test

❑ Transport process

- ✓ **Dose rate**
- ✓ **Forest floor, slope**

Dose rate measurement

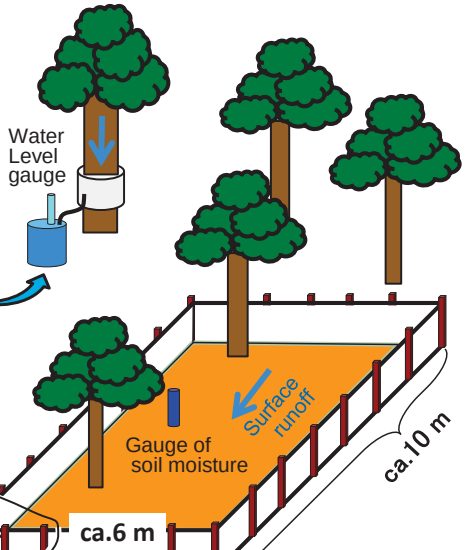
Soil loss on the mountain slope→

➢ ***Relationship* among vegetation-topography-soil characteristics-radioCs concentration & distribution**

➢ **Conceptualisation of *real* transport processes of radioCs**

Forest : Monitoring of surface runoff and soil loss

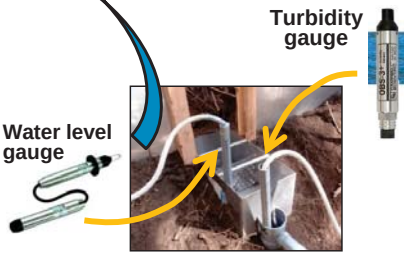
Stem flow tank (70 L)



Precipitation gauge

Water sampler(10 L) (throughfall)

Tanks for soil & water catchment (200 L x 2)



Triangular weir (W 30cm, H 25cm, D 60cm)

❑ ***Rainfall* (gross precipitation)**

❑ ***Throughfall***

❑ ***Stem flow***

❑ ***Surface runoff* & *Soil loss***

❑ ***Transport of radioCs with Surface runoff & Soil loss on the forest slope***

Flowing into river system

➢ ***Assessment of radioCs input and output in the forest floor*** *per unit period and area from forest [ex. Bq/m²/year]*

Forest: Transport and sedimentation processes in the forest floor

Transport & sedimentation processes

❑ by Rainfall
- ✓ Rainfall run-off (overland flow, downslope flow)
- ✓ Raindrop erosion
- ✓ Stem flow
- ✓ Litter flow (run-off over the litter layer, esp. broad-leaved forest)
- ✓ Rainy season（July to October）
- ✓ Whole forested area

❑ by Frost action
- ✓ Freezing and thawing action (frost heave, frost creep)
- ✓ Downslope transport of thawing soil
- ✓ Winter season (December, January to February)
- ✓ South-facing forested area, thin litter layer

❑ by Mass movement
- ✓ Small-scale mudslide
- ✓ Very steep forest slope
- ✓ Mainly, rainy season and snowmelt season (late Feburary to March)
- ✓ Small area in the forest

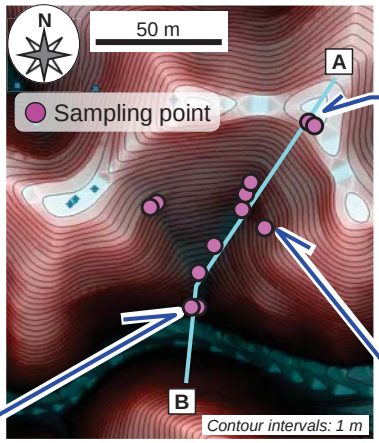
❑ by Snow movement and Snow melting
- ✓ Erosion by melting water
- ✓ Shaving and grooving of top soil
- ✓ Snow season and snow melt season
- ✓ Small area in the forest

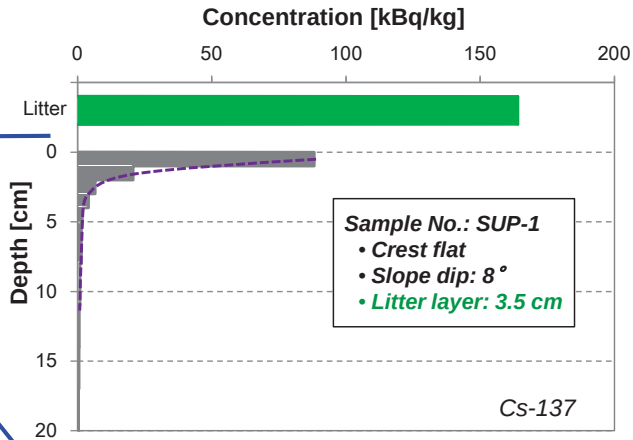
Forest: Depth distribution of radioCs (Evergreen coniferous forest)

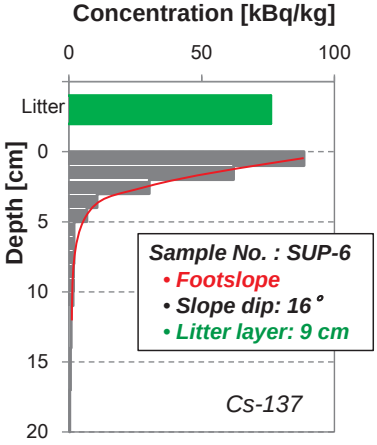
Brown forest soil

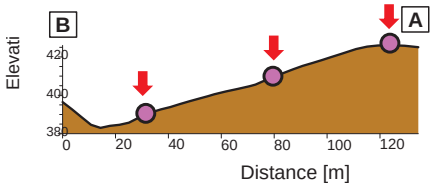
Sample No. : PAK-1, at crest flat

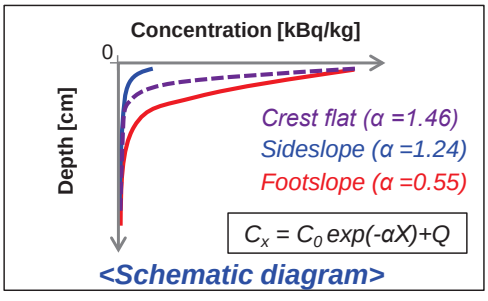
Sampling date: January 2013

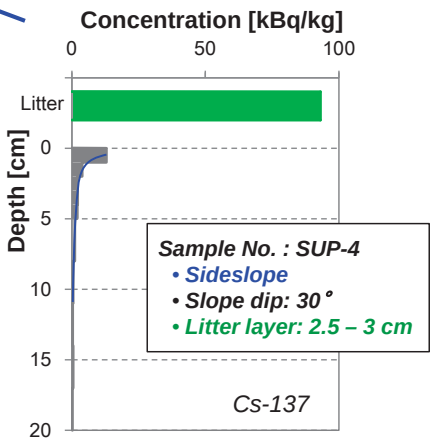






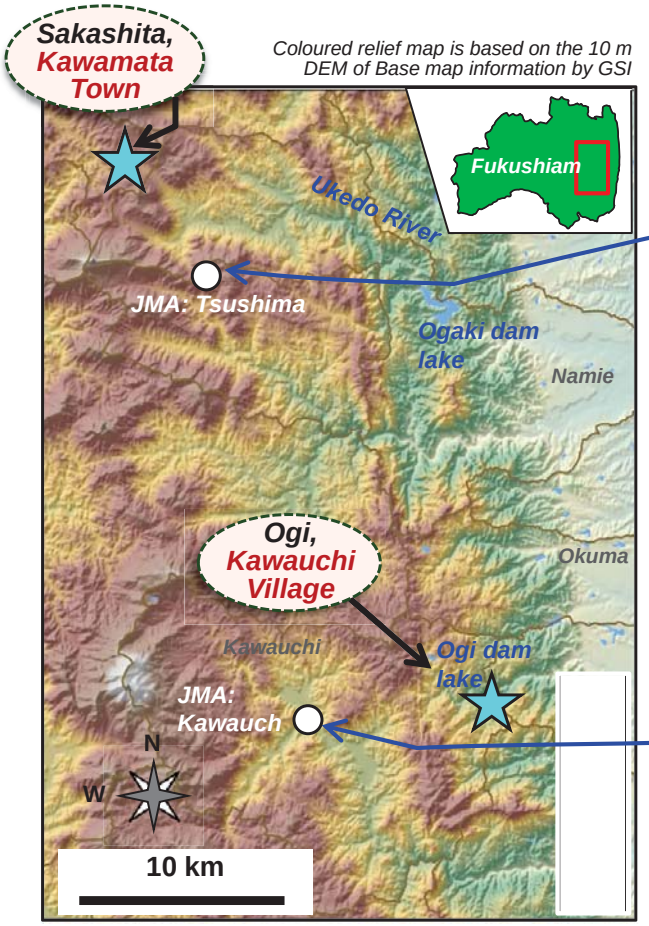


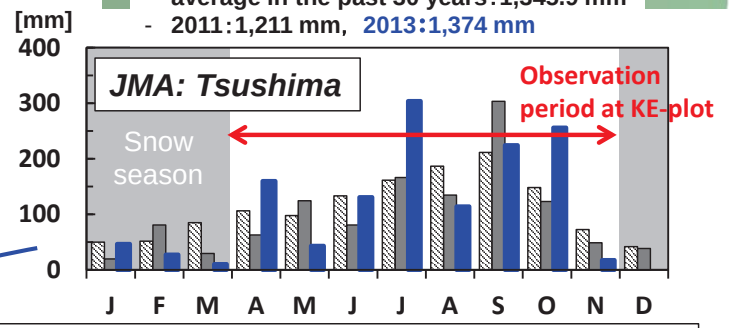




Forest: Precipitation near the observation plot
(AMeDAS, Japan Meteorological Agency)

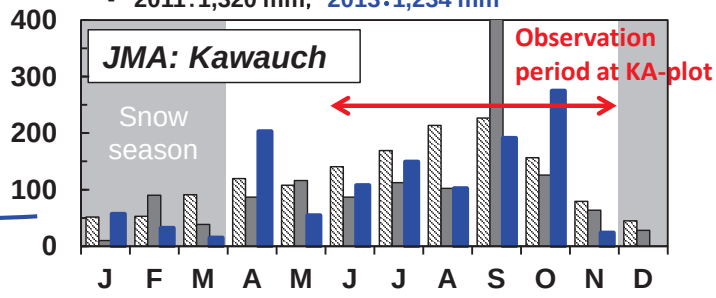
<Annual precipitation>
- average in the past 30 years：1,345.9 mm
- 2011：1,211 mm, 2013：1,374 mm





<Sakashita, Kawamata Town_KE-plot>
- Outflow of radioCs: 470 Bq/m²/year
- Outfow rate of radioCs: 0.1 % per year

<Annual precipitation>
- average in the past 30 years：1,511 mm
- 2011：1,320 mm, 2013：1,234 mm



<Ogi, Kawauchi Village_KA-plot>
- Outflow of radioCs: 1,100 Bq/m²/year
- Outfow rate of radioCs: 0.2 % per year

Forest: Input - output budget of the mountain forest

Forest floor: Input (10^4) > Output (10^1 - 10^2) [Bq/m²·4 weeks]

Input

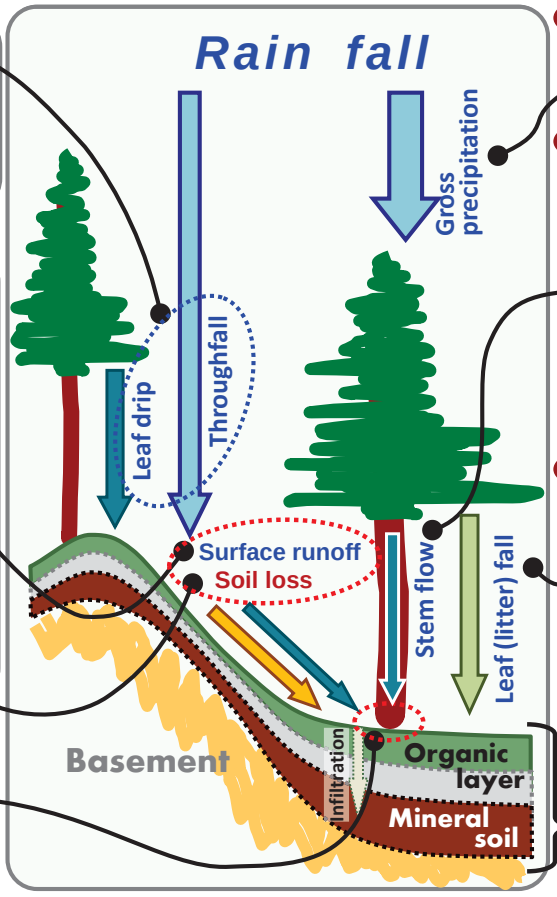
Throughfall
- ✓ 756 mm/yr (Japanese Cedar, Kawauchi)
- ✓ Input to the forest floor → 155 Bq/m²·4 weeks

Output

Surface runoff
- ✓ 1.1 L/m²·4 weeks (Sept.)
- ✓ Output from forest floor → 18 - 28 Bq/m²·4 weeks

Soil loss (rainy season)
- ✓ 1.2 - 4.2 g/m²·4 weeks
- ✓ Output from forest floor → 36 - 84 Bq/m²·4 weeks

✓ Relatively higher pH in forest soil in the vicinity of the stand



Input

Gross precipitation
Not detectable(less than 1.8 Bq/L)

Input

Stem flow; 27-175 L/m²·yr
- ✓ Input to the forest floor
  - → Japanese Cedar forest; 21 – 268 Bq/m²·4 weeks
  - → Deciduous broad-leaved forest; 78 – 310 Bq/m²·4 weeks

Input

Litter fall (pre-existing data in Kawamata)
- ✓ Input to the forest floor
  - → Japanese cedar forest ≒3,125 – 4,250 Bq/m²·4 weeks
  - → Mixed forest ≒1,238 Bq/m²·4 weeks

Depth profiles of radioCs are related to the geomorphology, mainly exist until 5 cm depth

River investigation

Kuma River, Okuma Town (upstream)

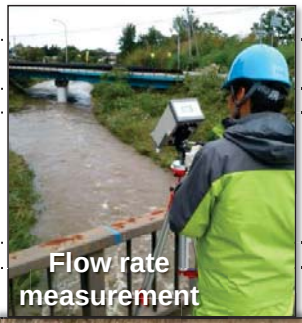
Ukedo River, Namie Town (middle stream)

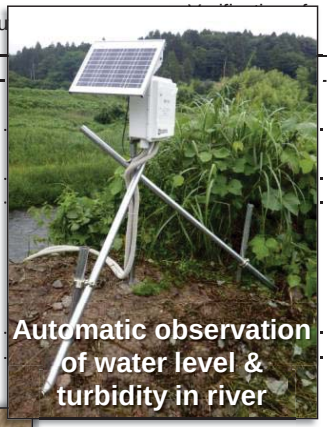
Odaka River, Minami-soma City (downstream & river mouth)

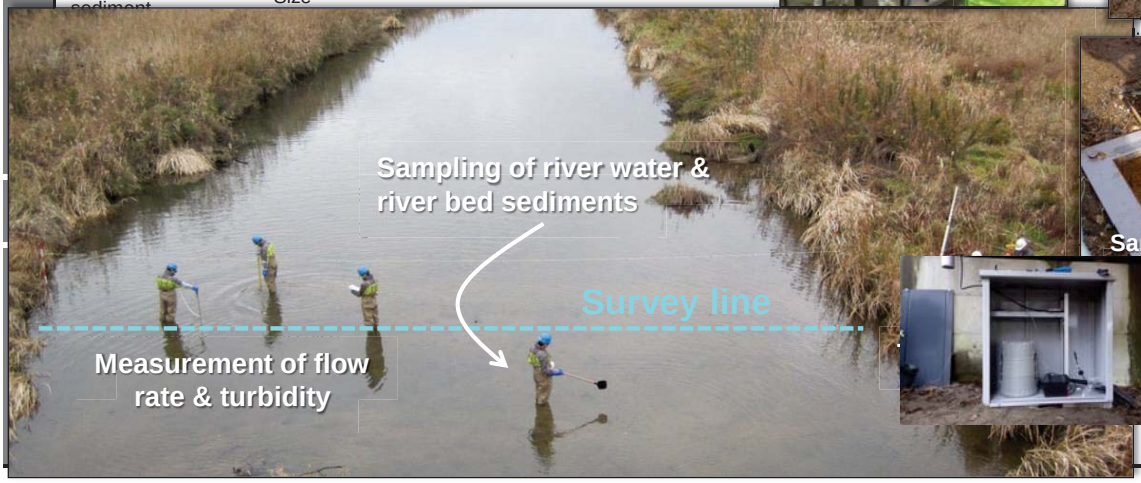
River: Items of observation and how to use data

Investigation	Data set	Parameters after data processing
Periodical: Surveying	Shape	
Dose rate measurement	Dose rate	
River measurements	Flow rate	
	Turbidity	
		Flow velocity
Water sampling	SS conc.	
	Cs conc.	
	SS size	
	SS mineral	
	Other ions	
		Kd of Cs on SS
Sampling flood plain sediment	Cs conc.	
	Size	

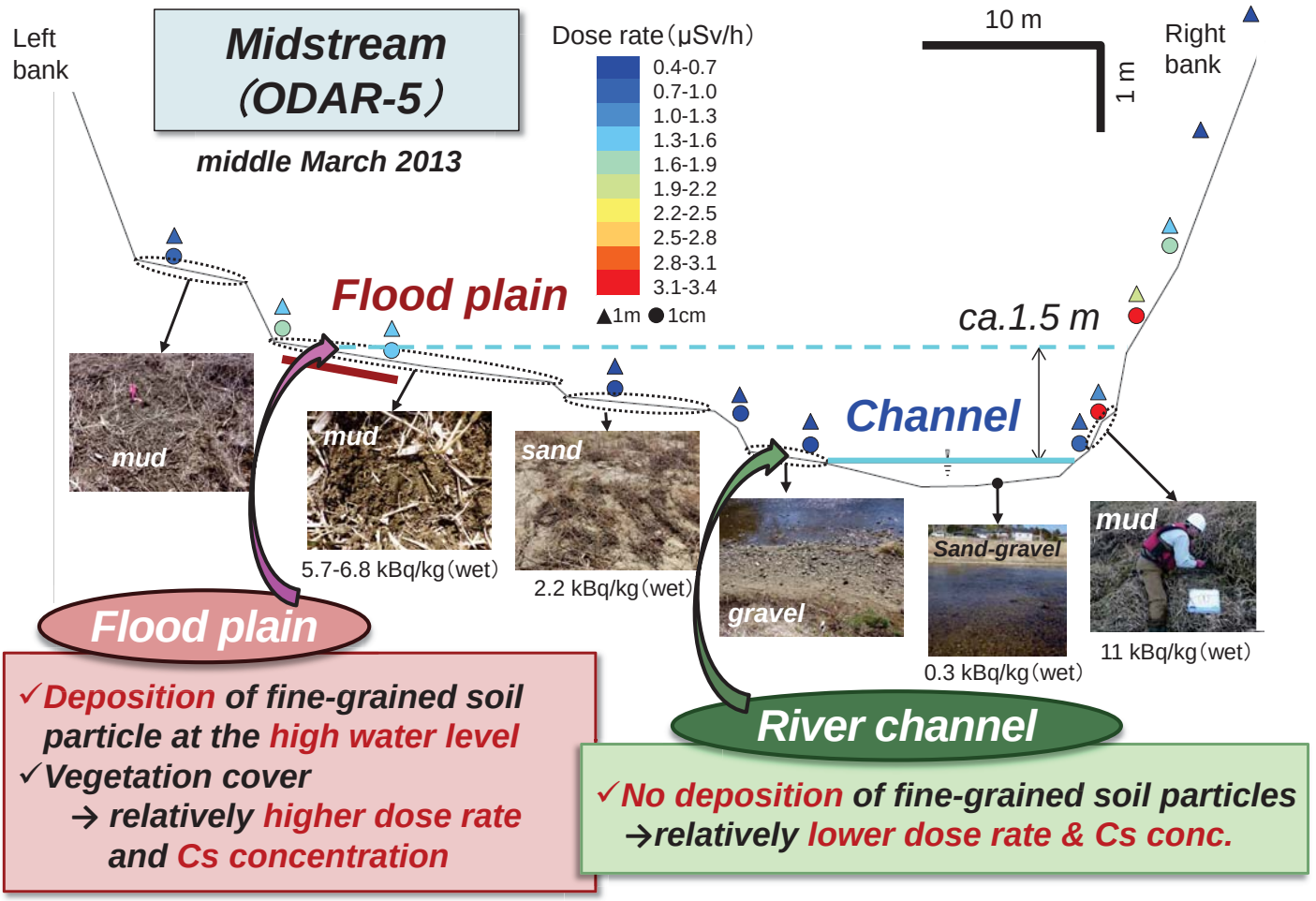
How to use data: Evaluation of mass flow; Understanding mechanism; Inpu…







River: Dose rate distribution in the flood plain, Odaka river



Flood plain

✓ *Deposition of fine-grained soil particle at the high water level*

✓ *Vegetation cover*

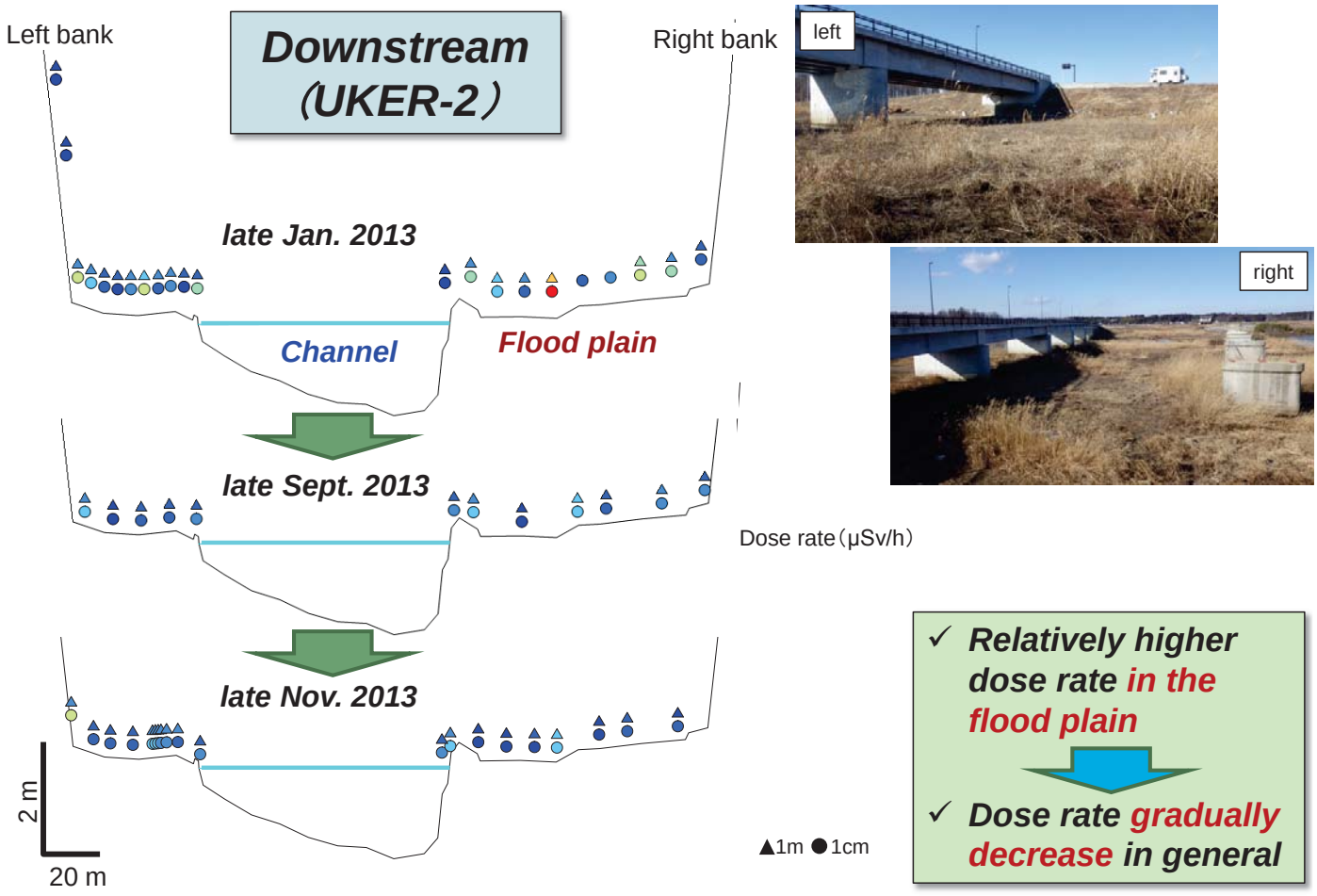
→ *relatively higher dose rate and Cs concentration*

River channel

✓ *No deposition of fine-grained soil particles*

→ *relatively lower dose rate & Cs conc.*

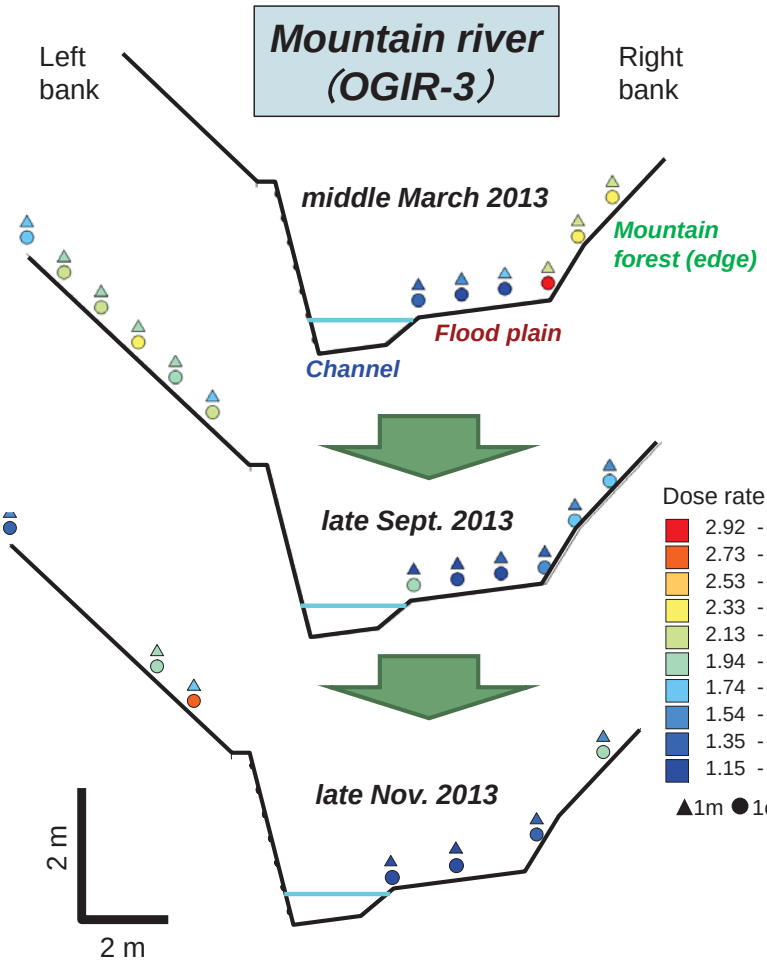
River : Evolution of dose rate distribution in the flood plain, Ukedo



✓ *Relatively higher dose rate in the flood plain*

✓ *Dose rate gradually decrease in general*

River : Evolution of dose rate distribution in the flood plain Ogi



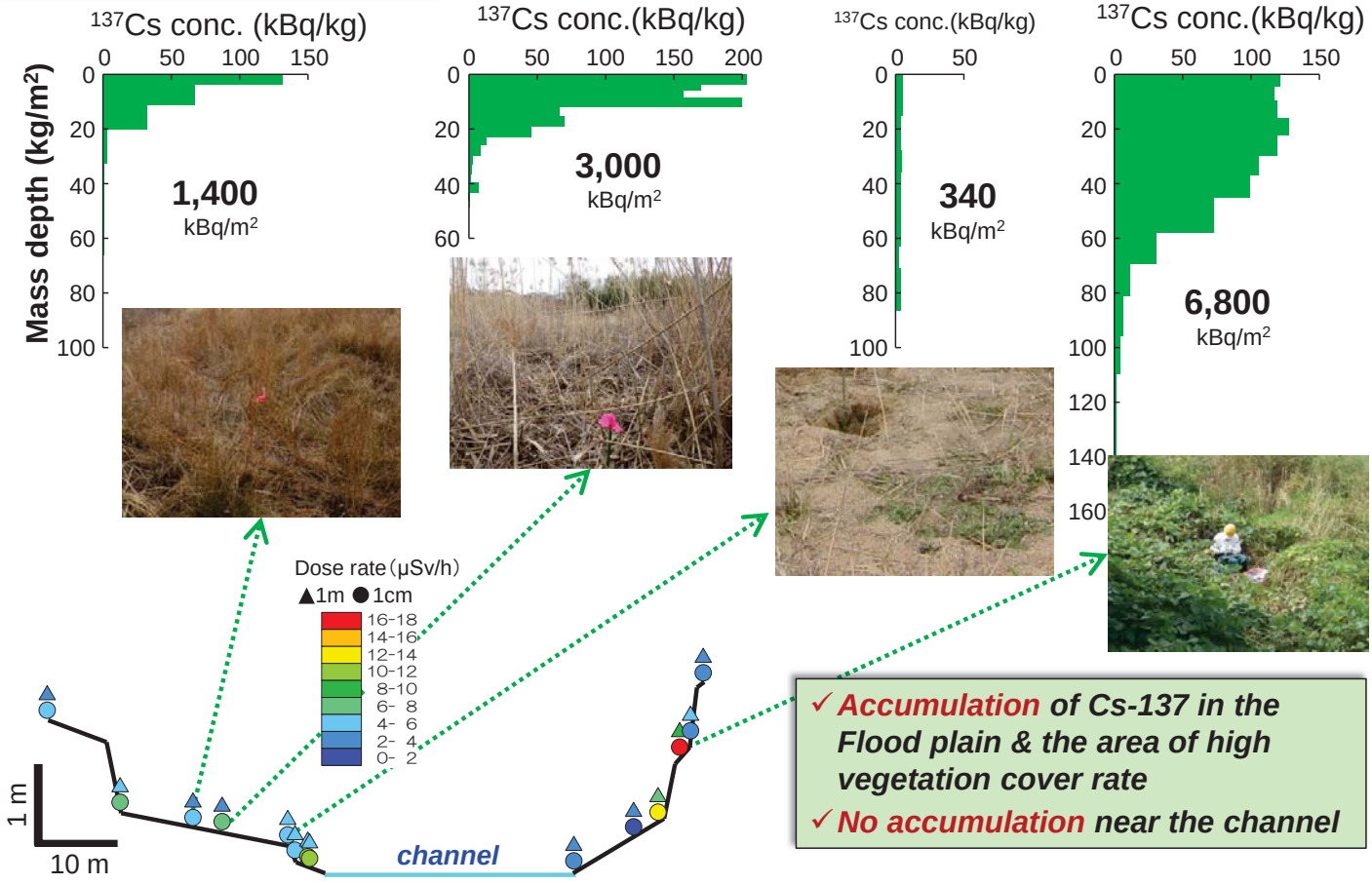
- ✓ Relatively higher dose rate near the bottom of mountain slope & river wall

Decontamination & typhoon event (June to Sept. 2013)

- ✓ No deposition of fine-grained soil particles in the flood plain →relatively low dose rate
- ✓ Relatively higher dose rate in the mountain slope & near the bottom of river wall →Transportation and accumulation of fine-grained soil particles

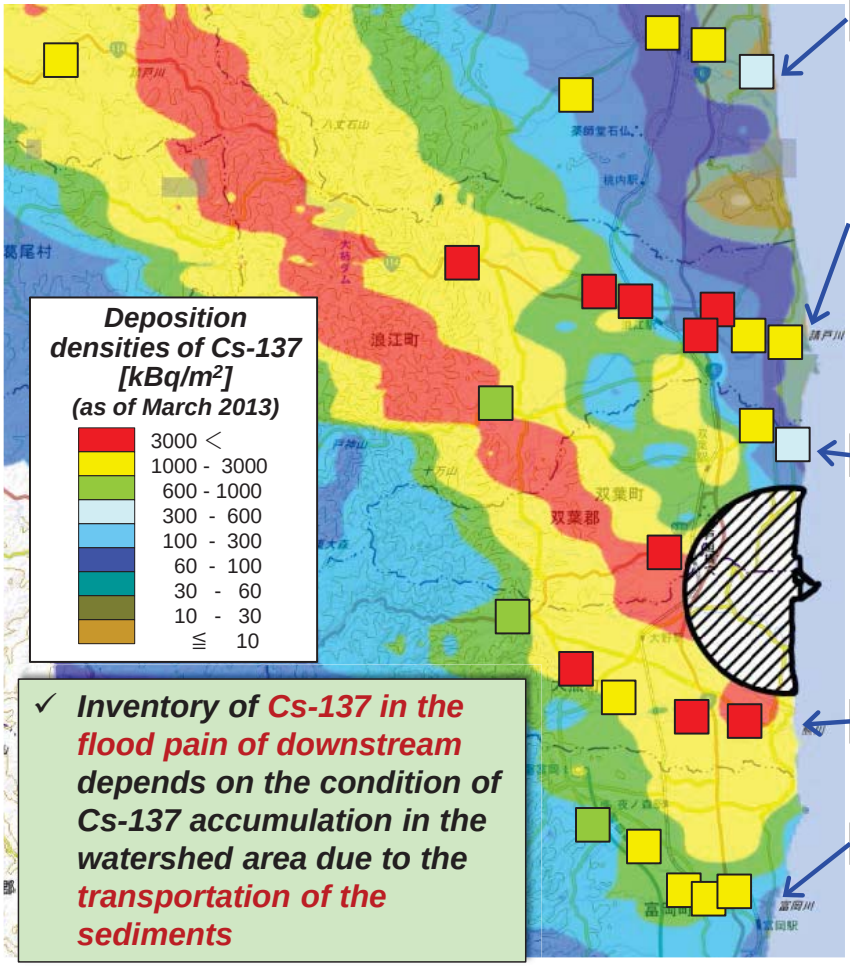
River: Inventory of Cs-137 on the flood plain, Ukedo river

Midstream (UKER-10)



- ✓ Accumulation of Cs-137 in the Flood plain & the area of high vegetation cover rate
- ✓ No accumulation near the channel

River :Inventory of Cs-137 in the flood plain (Sept. to Dec. 2013)



✓ *Inventory of Cs-137 in the flood pain of downstream depends on the condition of Cs-137 accumulation in the watershed area due to the transportation of the sediments*

Odaka riv.

- ✓ *without dam*
- ✓ *Inflow of sea water at the river mouth*

Ukedo riv. & Takase riv.

- ✓ *with dam (Ukedo riv.)*
- ✓ *without dam (Takase riv.)*
- ✓ *relatively higher Cs inventory in the watershed area*

Maeda riv.

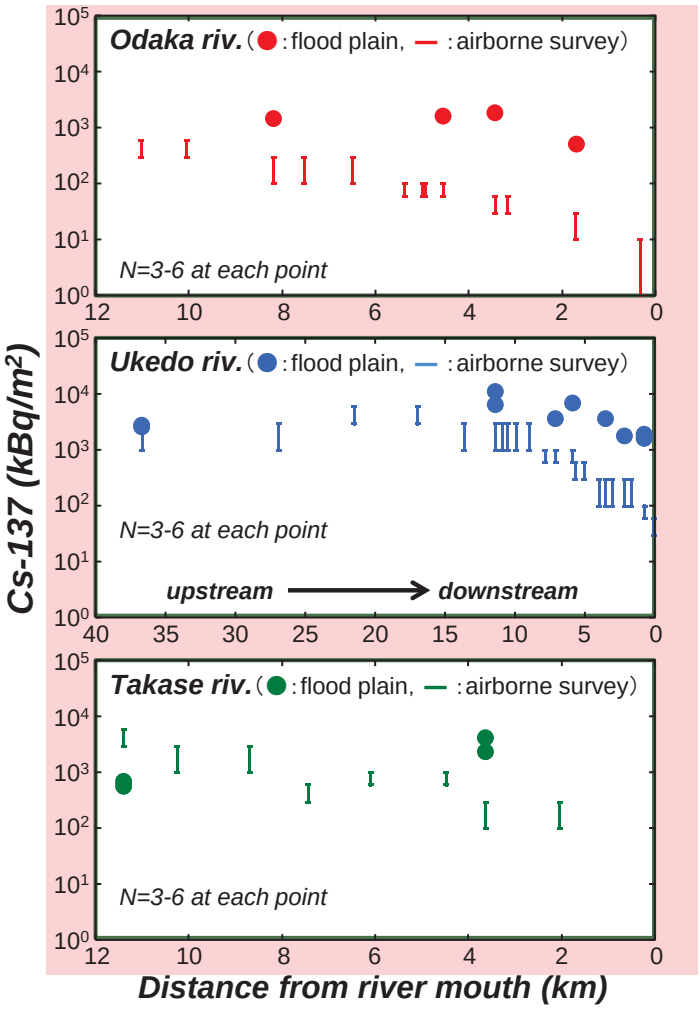
- ✓ *without dam*
- ✓ *relatively higher Cs inventory in the watershed area*
- ✓ *inflow of sea water at the river mouth*

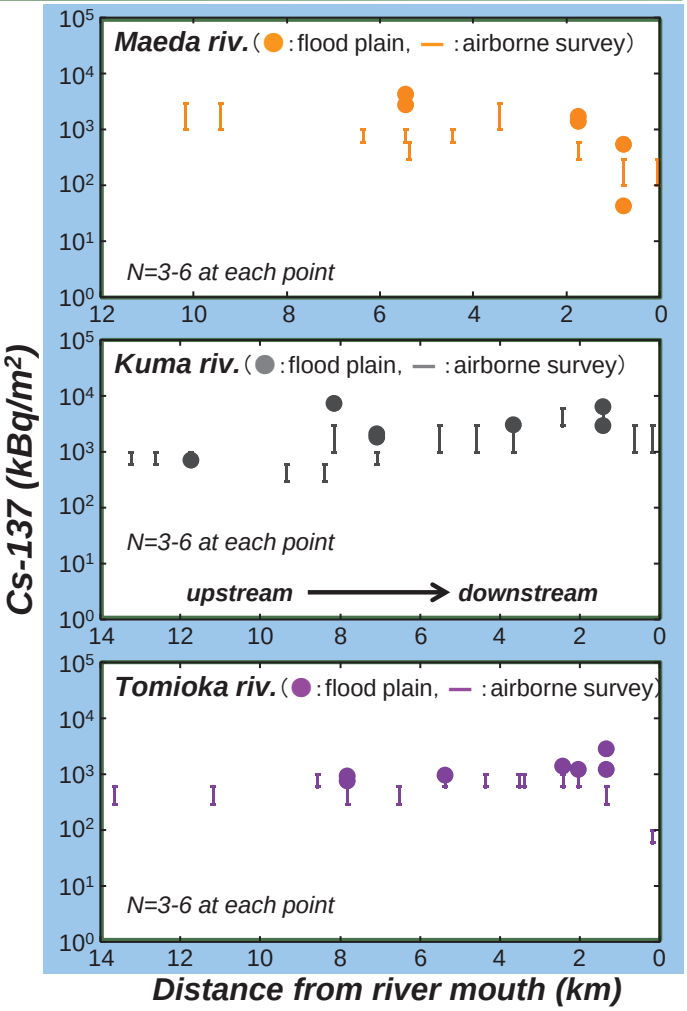
Kuma riv. *without dam*

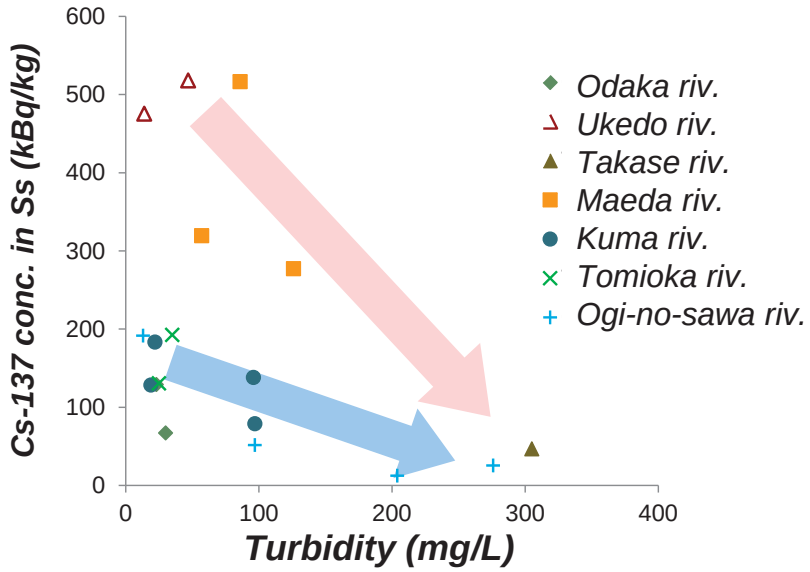
Tomioka riv. & Ogi-no-sawa riv.

- ✓ *Flowing through the decontaminated area*

River :Inventory of Cs-137 in the flood plain (Sept. to Dec. 2013)







❑ ***Concentration of Cs-137 in suspended sediment (Ss) decreased with increase in Ss concentration.***

→*This tendency can be explained by the increase of particle size of Ss accompanied with increase of flow rate.*

Dependency of distribution coefficients on the particle size of Ss can be modeled.

Dam lake investigation

Ogi dam lake, Kawauchi

Takikawa dam lake, Tomioka Town

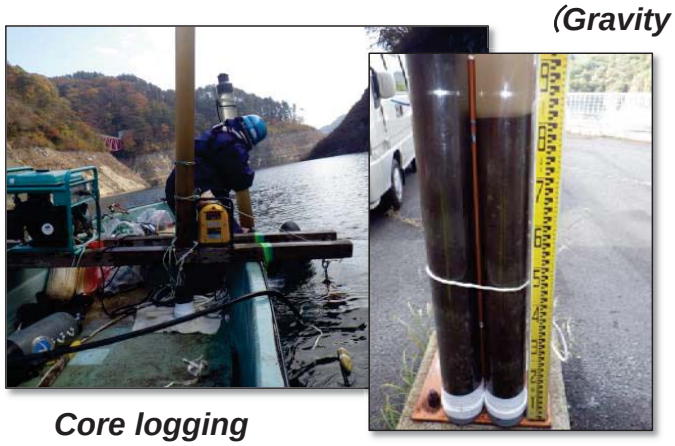
Ogaki dam lake, Namie Town

Dam lake: Sampling of bottom deposits and dam water

Water sampling
(Heyroth sampling bottle)

Core logging
(Gravity core sampler)

Sampling of sinking particles
(sediment trap)



Core logging
(undisturbed sampling)

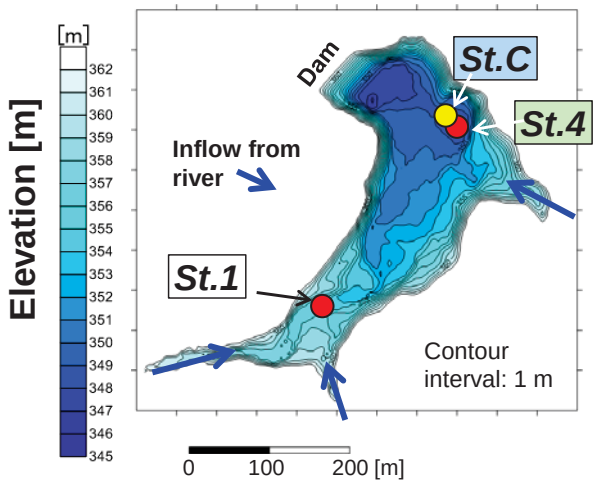
and .....
Measurement of
- ✓ flow direction
- ✓ flow rate

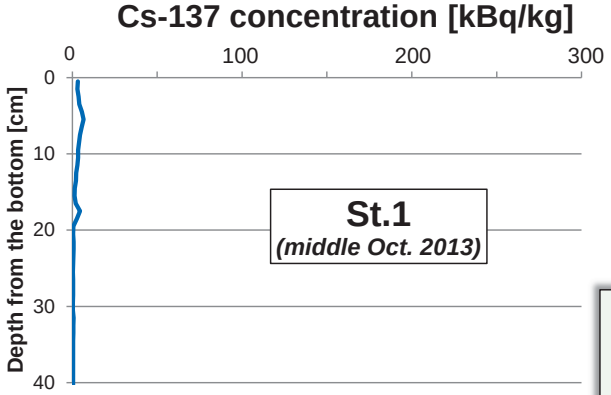
*Installation of ADCP
(Acoustic Doppler Current Profiler)

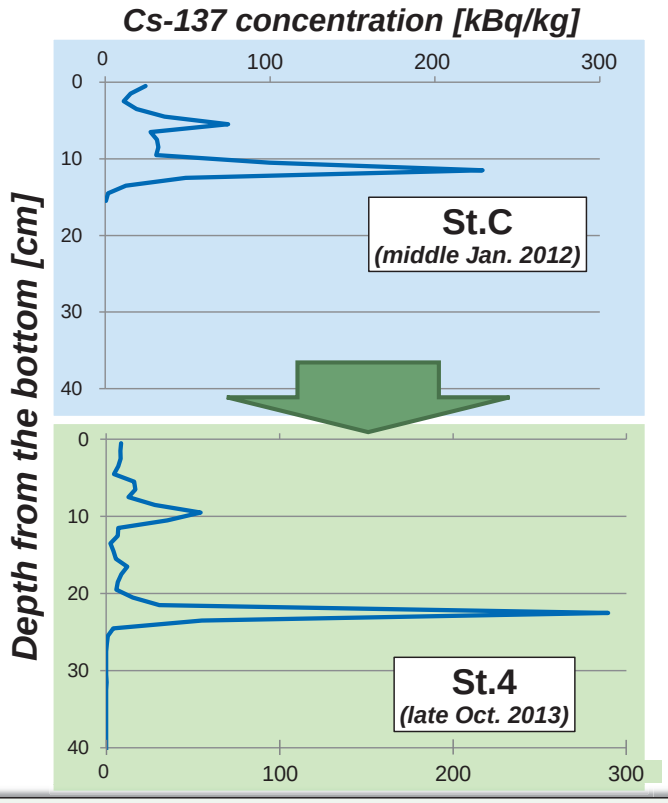
- ✓ turbidity in the dam lake

Input & validation data sets
for the simulation

Dam lake: Cs-137 conc. of the dam lake deposits, Ogi

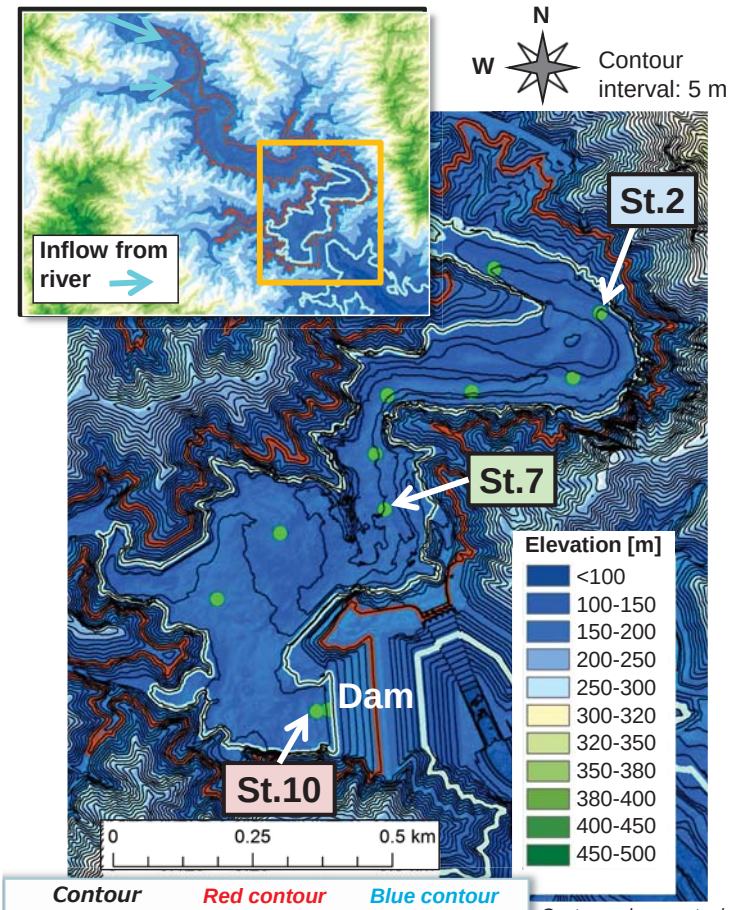






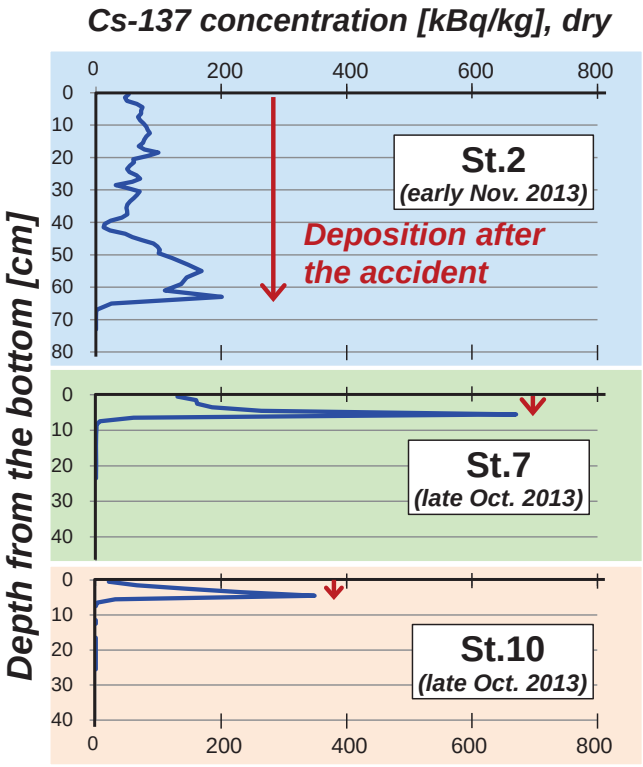
✓ Decrease in Cs-137 concentration of the uppermost part of the lake deposits
→Decrease in Cs-137 concentration of soil flowing from the river to the dam lake

Dam lake: Cs-137 conc. of the dam lake deposits, Ogaki



Contour	Red contour	Blue contour
Status	Filled	Partially filled
Water level (depth)	170 m (33.5 m)	140 m (3.5 m)

Contours above water level is based on the results of the airborne laser scanning survey by GSI



✓ ***Total accumulation of Cs-137 in the lake deposits is relatively higher in the upstream and lower in the downstream***

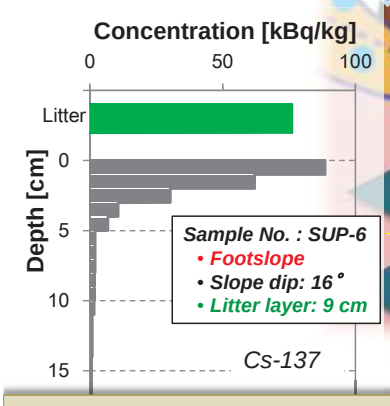
Behavior of radCs in the mountain forest to dam lake

✓ *Overview of observation results in **Ogi region of Kawauchi** village.*
✓ *Cs-137 concentrations were also shown.*

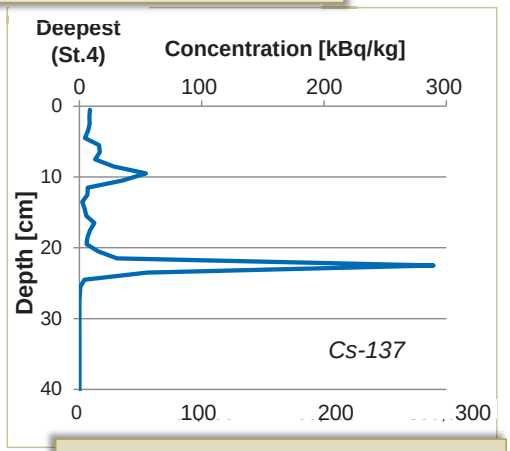
Annual discharge of Cs by surface runoff : approx. 0.2 % of the total amount of Cs in the topsoil

Throughfall : ~2 Bq/L

Stem flow : ~30 Bq/L



Most of Cs existed within 5 cm depth.



Maximum peak at several tens cm depth in the lake deposits

Erosion

Surface of topsoil : ~30 kBq/kg

Soluble Cs in the lake water : < 0.01 Bq/L

Sedimentation

Surface of lake deposits : ~10 kBq/kg

Behavior of radCs in the dam lake, river system and estuary

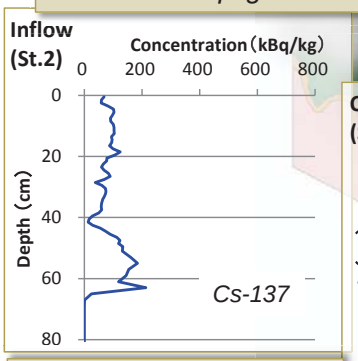
- ✓ *Overview of observation results in **Ukedo river system of Namie** Town.*
- ✓ *Cs-137 concentrations were also shown.*

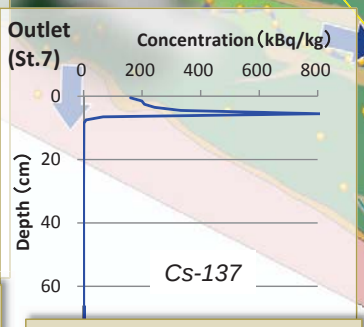
*Soluble Cs in the **lake water**: 0.12 Bq/L*

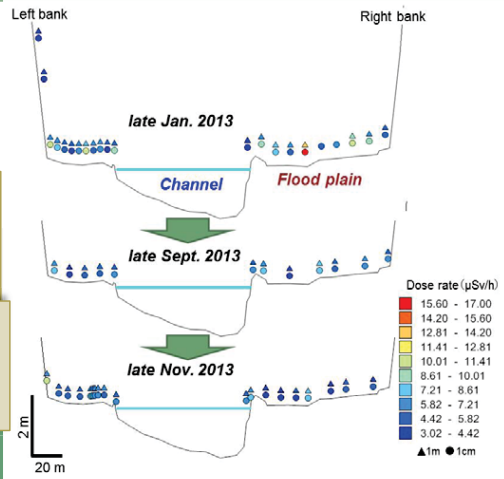
***Flood plain**: ~100 kBq/kg (no ~slightly increase)*

Surface of lake deposits: 100 ~200 kBq/kg

***River bed:** ~10 kBq/kg (decrease)*







Evolution of dose rate distribution in the flood plain

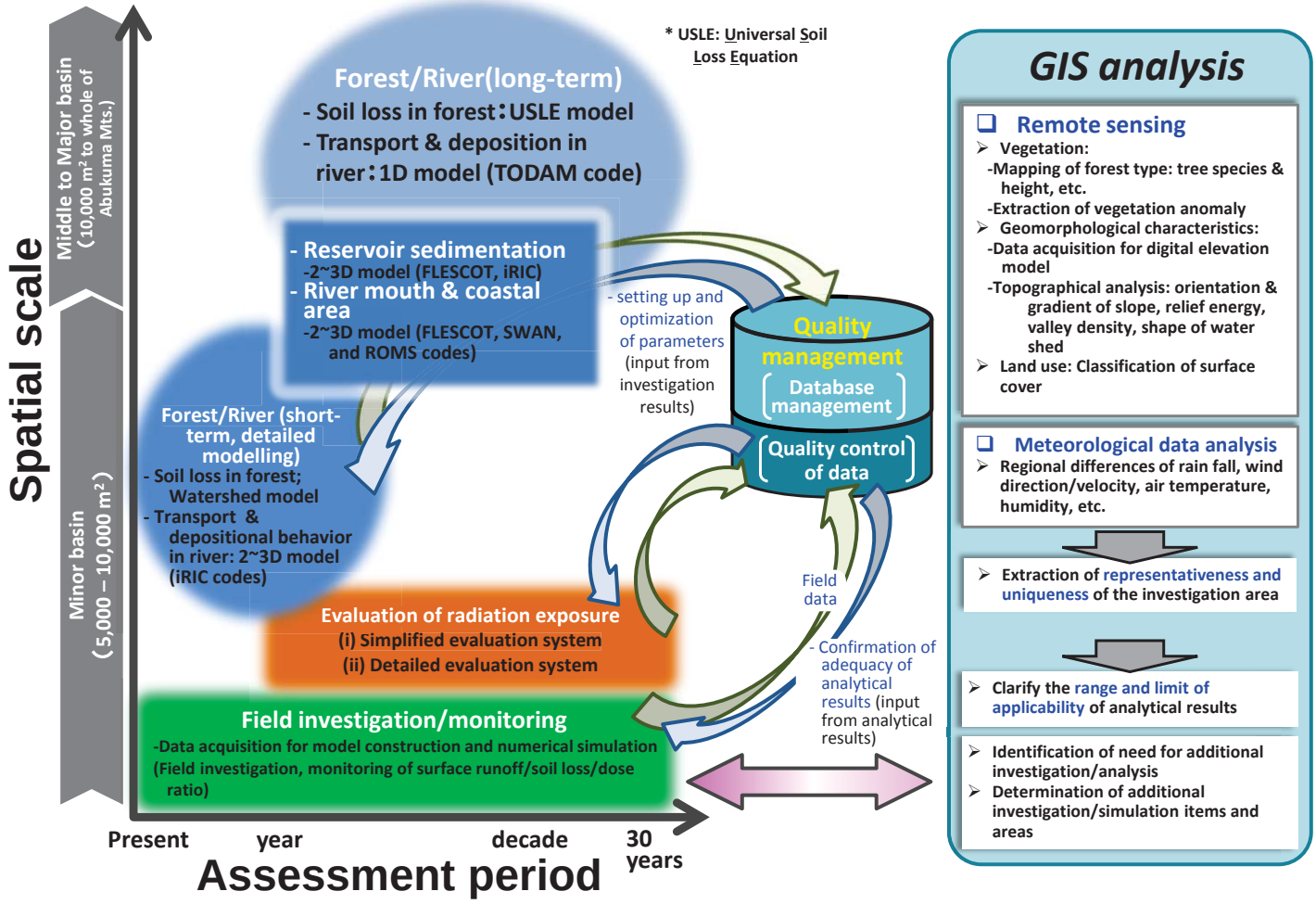
Maximum peak at several tens cm depth in the lake deposits. → large size fraction

Maximum peak at several cm depth in the lake deposits. → small size fraction

***Estuary** sediment (silt): 1 ~5 kBq/kg*

Depth profile of Cs concentration in the bottom sediment of Ogaki dam lake.

Application of analysis method appropriate to the spatial and assessment scales, combination with GIS analysis



Summary

- ***Transport behaviors of radioCs in the forests, river systems, dam lake, ponds and estuary were investigated mainly in Abukuma mountains and the coastal area of Fukushima Prefecture, FY2013***

- ***Consequently,***
  - *Annual discharge of radioCs from the topsoil of the **mountainous forest** by runoff was estimated to be 0.2 % of the total amount of radioactive Cs in the topsoil.*
  - *Accumulating behavior of radioCs in the **river system** was clarified.*
    - ✓ *River: fine sediments with high Cs concentration in the flood plain*
    - ✓ *Dam lake: thick coarse sediments with low Cs concentration near the inflow point*
      thin fine sediments with high Cs concentration near the outlet
  - *Concentration of radioCs in the river bed tended to decrease with the elapse of time.*
  - *Compared to the concentration of radioCs in the **dam lake** sediments, that of lake water was of extremely low.*
    - ✓ *e.g. Ogaki dam lake : lake water 0.12 Bq/L ⇔ bottom sediment surface 200 kBq/kg*
  - *Peak concentration was observed from several to several tens cm depth in the lake deposits.*
  - *Concentration of radioCs in the **estuary** sediment was lower than that of flood plain and river bed sediment.*