Long-term Assessment of Transport of Radioactive Contaminant in the Environment of Fukushima (F-TRACE)

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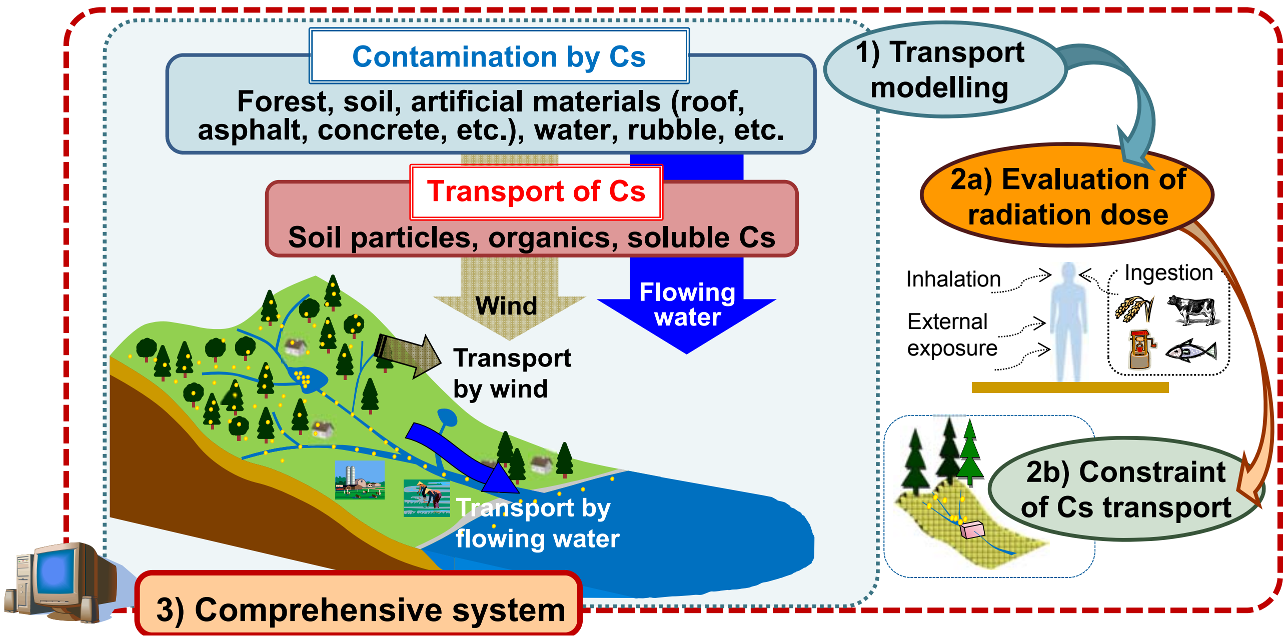
Caesium Worshop (2013/09/30-10/02@CORASSE Fukushima)

Overview of the F-TRACE Project

❑ **Objectives**

1) Elucidate behavior of transport of radioisotopes (Cs at first) from contaminated forest to biosphere and sea.
2) Develop dose evaluation system and methodology to constrain Cs transport, leading to decrease of dose.
3) Construct comprehensive system to predict transport of radioisotopes combining with methods for dose reduction.



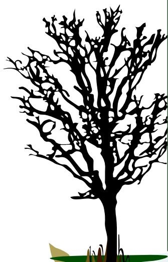
Key phenomena in the Cs transport

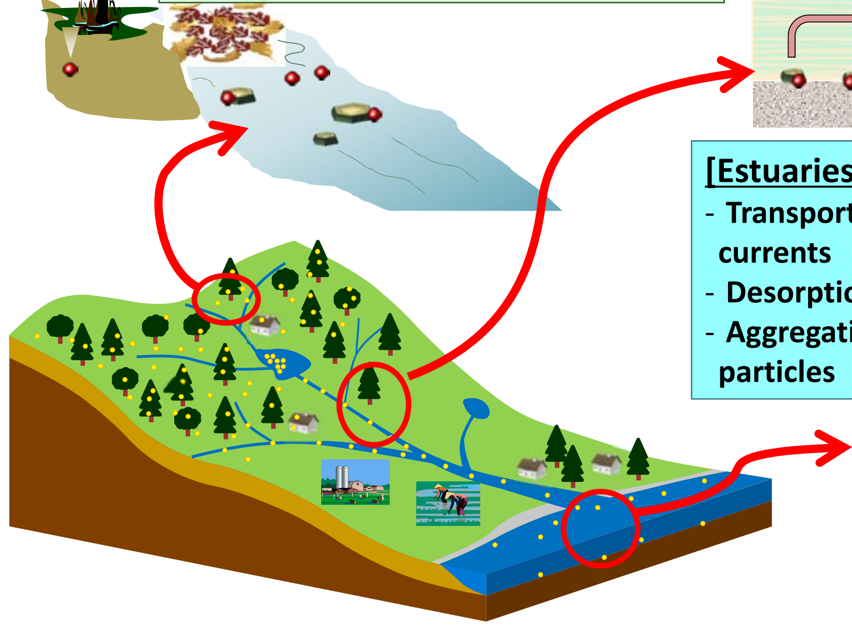
[Mountain forests]

Canopy → Soil surface
- stemflow, litter fall

Soil surface → subsurface
- advection, dispersion

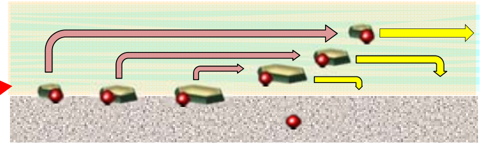
Soil surface → River
- erosion, dissolution, debris flow etc.





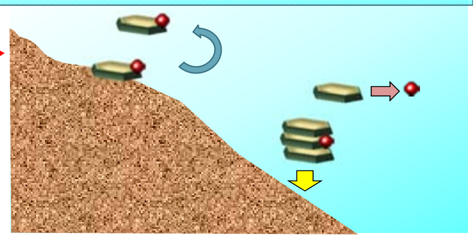
[Rivers & reservoirs]

Transport by flowing water
- with mineral particles
- deposition under the settling velocity
- trapping by plants on the flood channel

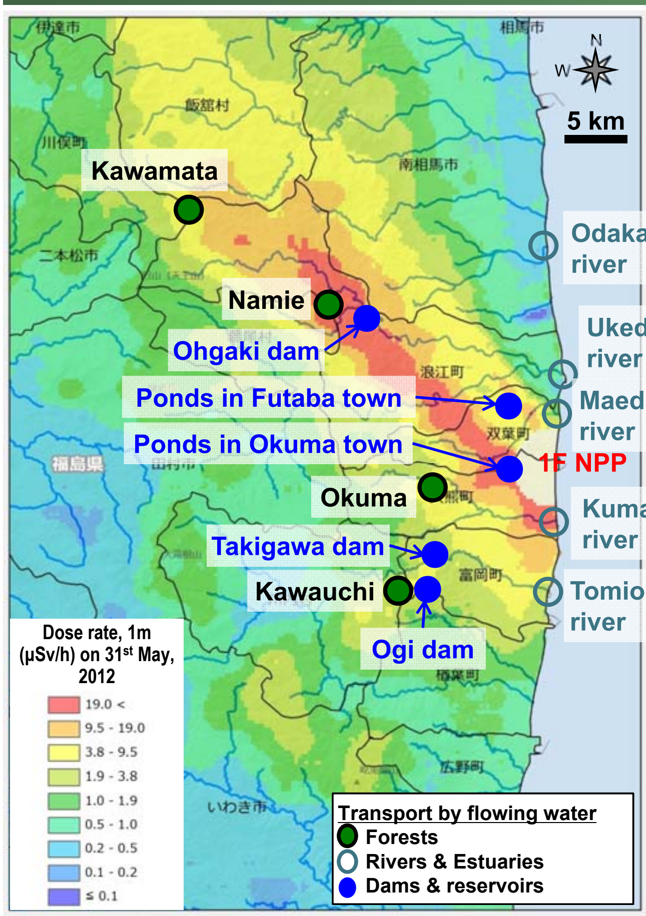


[Estuaries]

- Transport by tides, waves, and coastal currents
- Desorption of Cs from soil particles
- Aggregation and deposition of soil particles



Investigation & Simulation Area



Modelling of transport by flowing water:
5 rivers in Pacific coastal region

❑ **Forests investigation**
- ✓ Kawamata (deciduous forest)
- ✓ Kawauchi (ever-green / deciduous forest)
- ✓ Namie (ever-green / deciduous forest)
- ✓ Okuma (ever-green forest)

❑ **Rivers & Estuaries investigation**
- ✓ Ukedo river (highest Cs inventry)
- ✓ Tomioka & Ogi-no-sawa rivers (flow through decontaminated area)
- ✓ Odaka river (high salinity at estuary)
- ✓ Kuma river (no dam deposit)
- ✓ Maeda rivers (flow through the highest dose rate area)

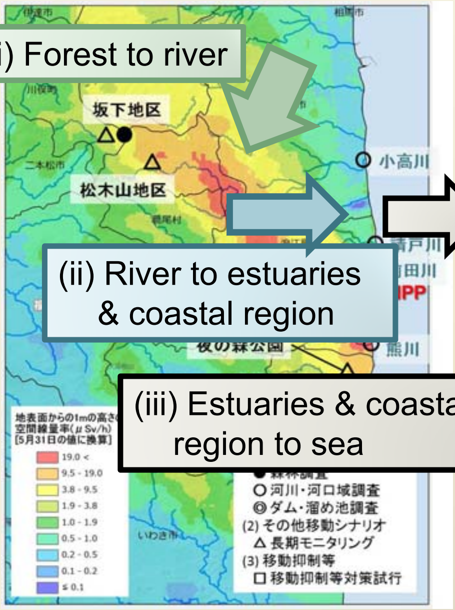
❑ **Dam reservoirs investigation**
- ✓ Ogi dam (Ogi-no-sawa river basin)
- ✓ Ohgaki dam (Ukedo river basin)
- ✓ Takigawa dam (Tomioka river basin)
- ✓ Ponds in Okuma and Futaba town

➢ Flowing from relatively high to low dose rate areas → easy to detect Cs transport

➢ Small scale → less difficulty with the modelling & its validation

From field investigation to the modelling & simulation

Elucidation of transport behavior



(i) Forest to river

(ii) River to estuaries & coastal region

(iii) Estuaries & coastal region to sea

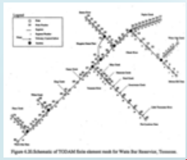
Modelling & Simulation

(i) Contaminated forests to rivers
→Soil loss model
USLE etc.

OUTPUT: Inflow of Cs to the rivers

Results → **Input**

(ii) Rivers to estuaries & coastal region
→1D transport model
TODAM etc.
→2D transport model
iRIC etc.



OUTPUT: Inflow of Cs to the sea

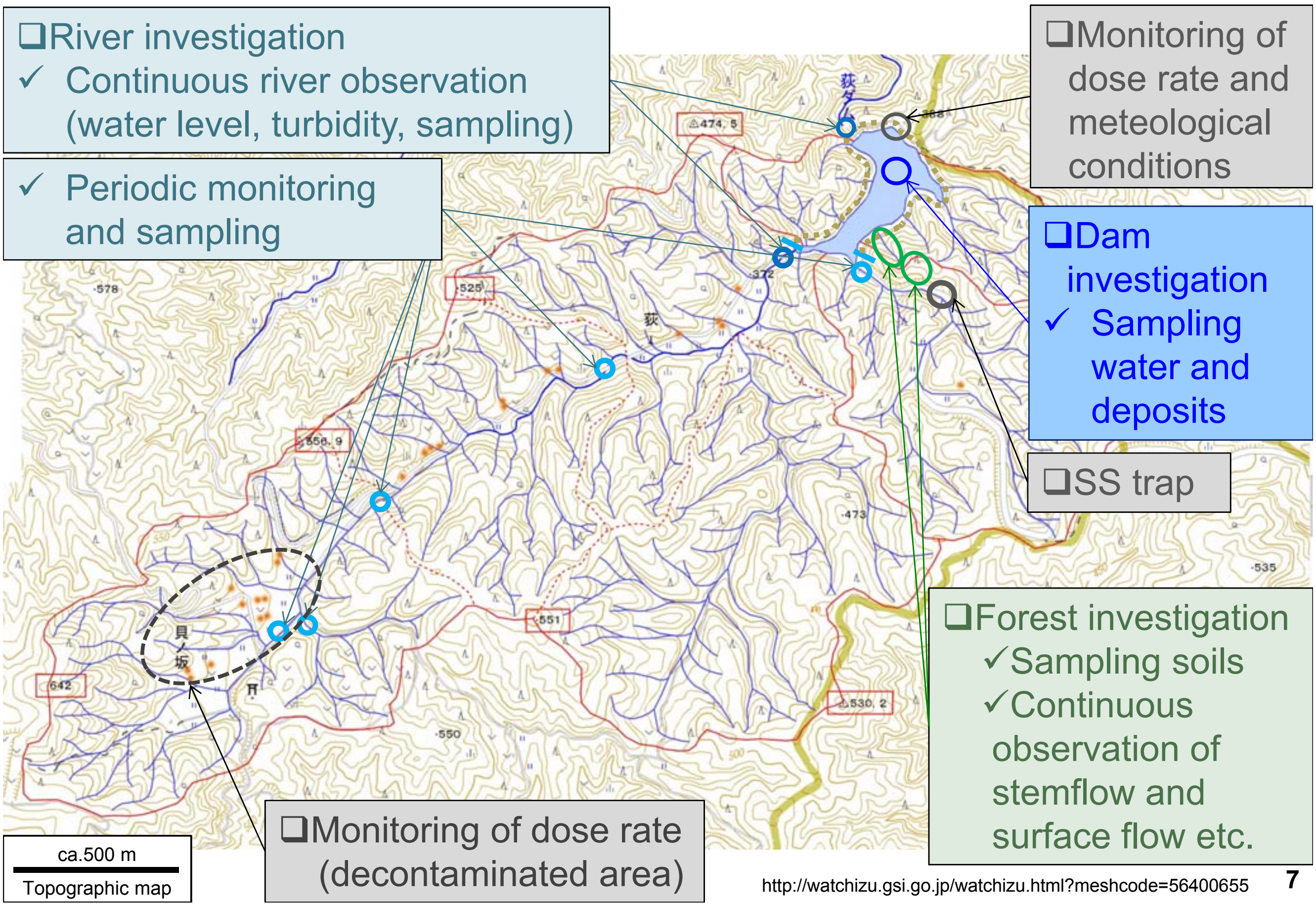
Results → **Input**

(iii) Estuaries to sea
→3D transport & reworking model in estuaries and sea
FLESCOT, ROMS etc.

OUTPUT: Transport and reworking behavior within the coastal region

Field investigation

Example of research area: Ogi-no-sawa basin



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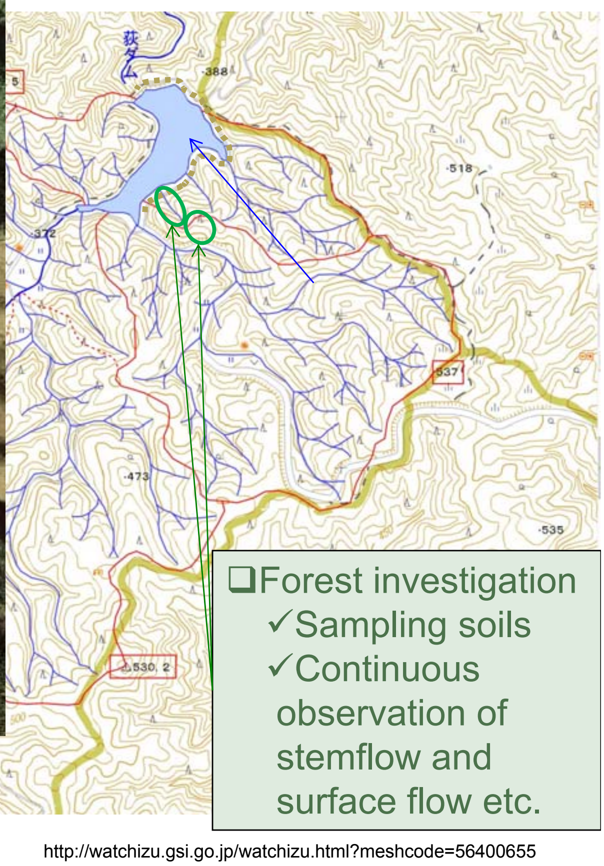
Forest investigation



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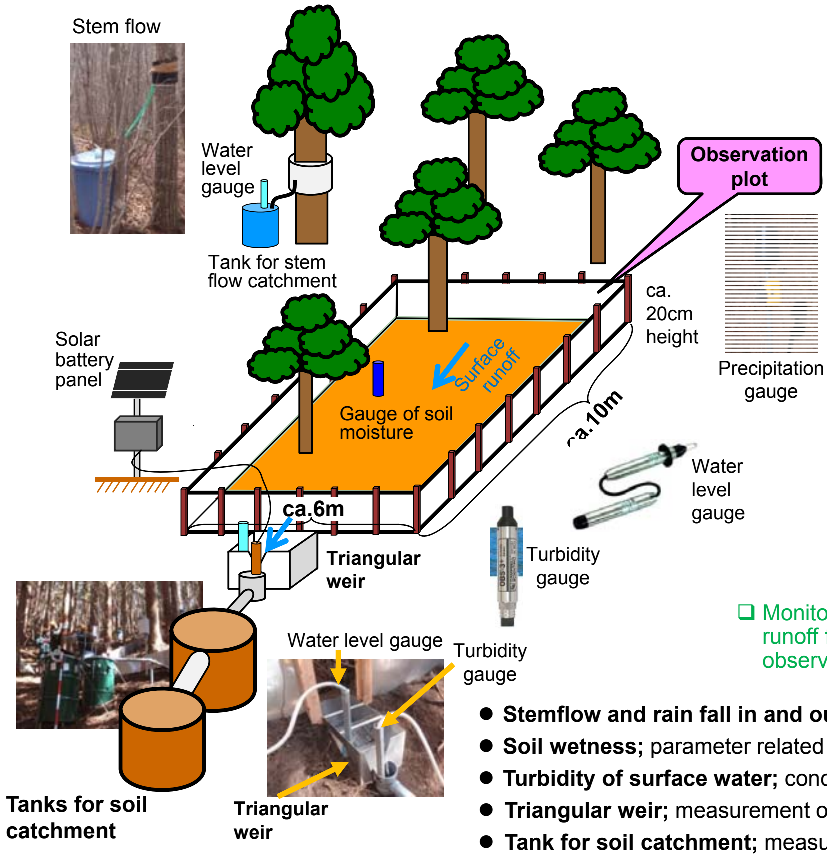
Monitoring of surface runoff and soil loss in the forest

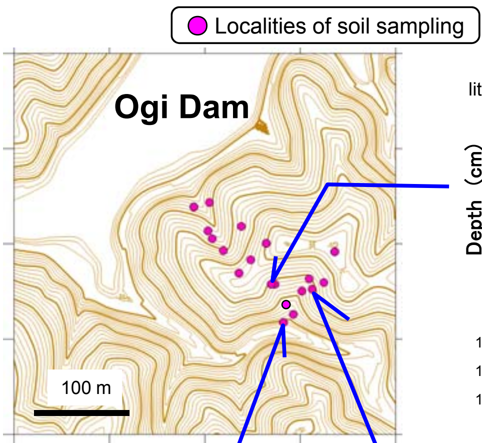


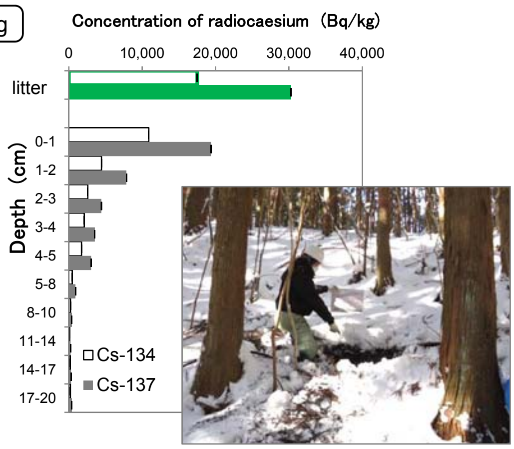
- Monitoring of gross precipitation, throughfall, surface runoff flow and downward movement of soil, etc. in the observation plot at Ogi, Kawauchi Village

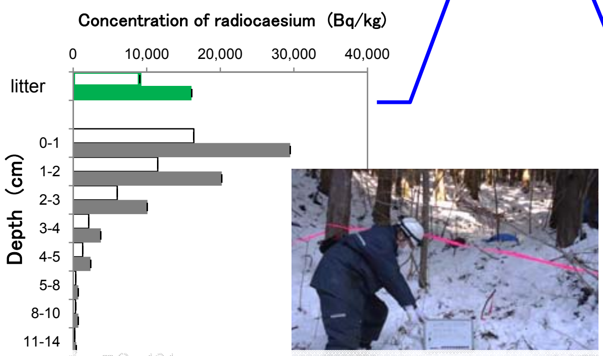
- **Stemflow and rain fall in and out of forest;** source of surface runoff in the forest
- **Soil wetness;** parameter related to an infiltration of surface water into the soil
- **Turbidity of surface water;** concentration of suspended solid in the surface water
- **Triangular weir;** measurement of water level, turbidity, and water sampling
- **Tank for soil catchment;** measurement of soil yield in the observation plot, soil sampling

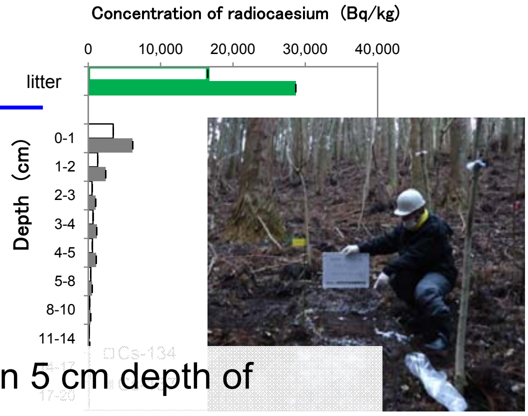
Depth profile of radiocaesium in topsoil of the forest

Soil sampling by scraper plate
- **Until 20 cm depth**
- **1 cm interval until 10 cm depth, and the deeper is 2 cm intervals**



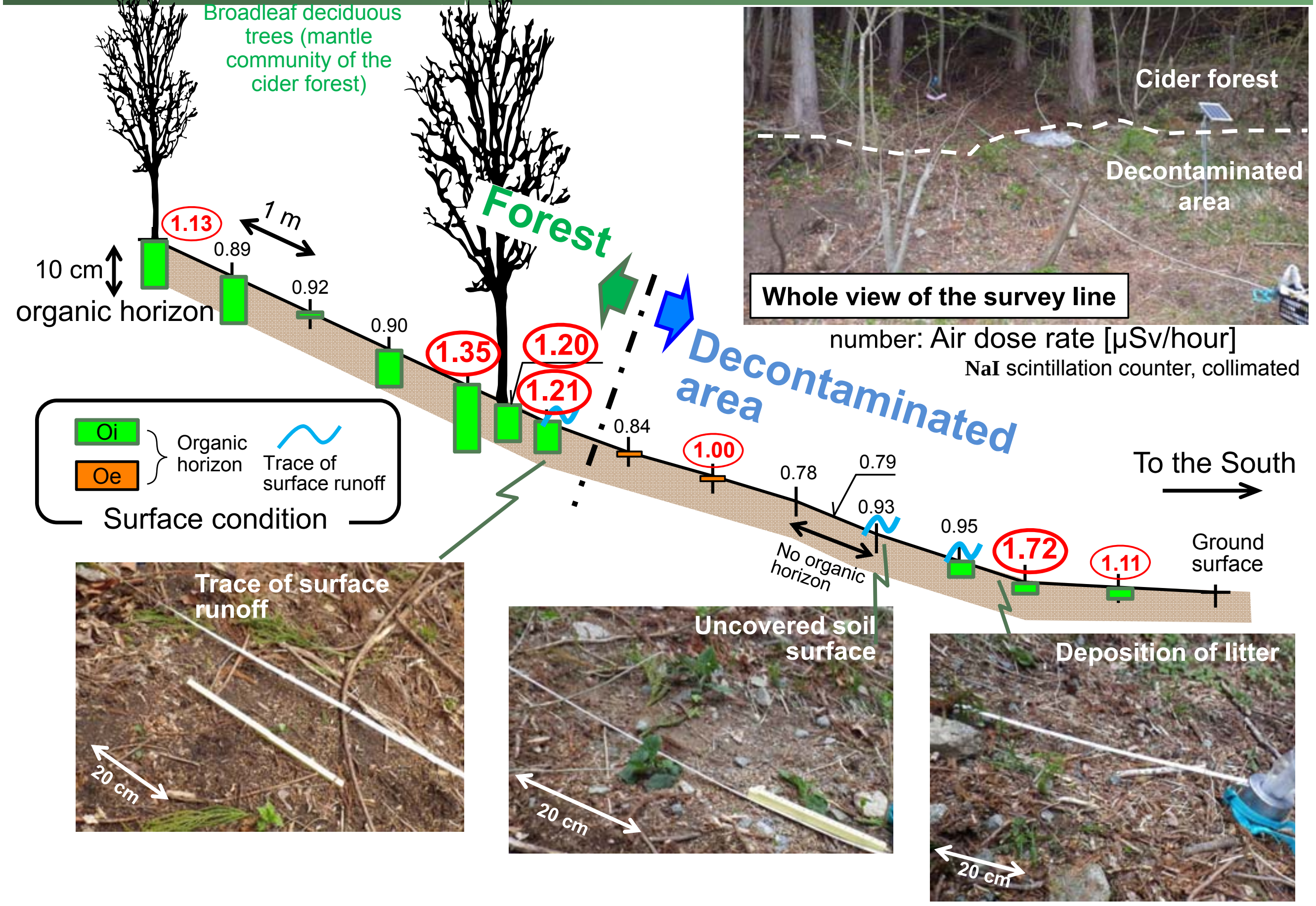






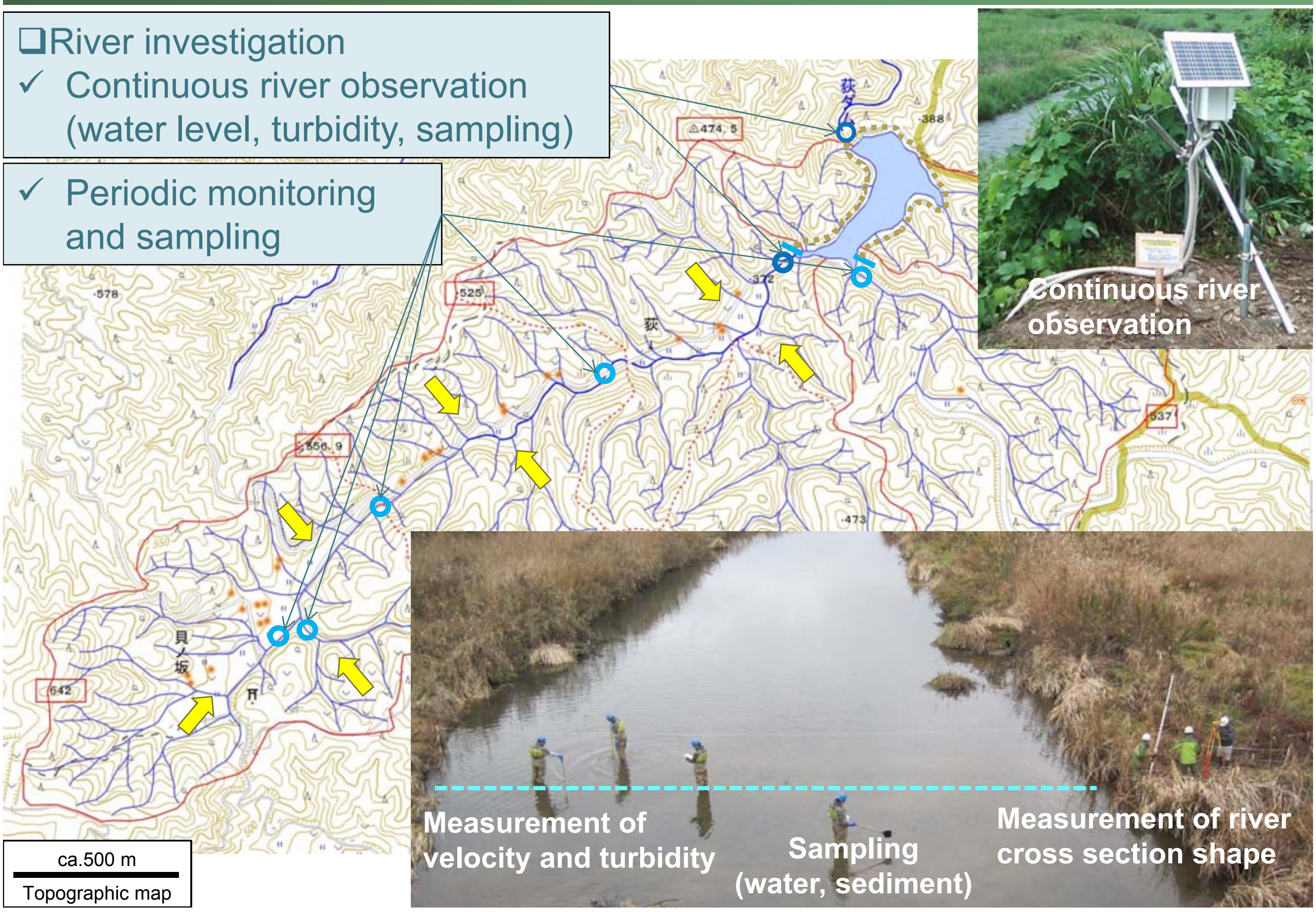
- More than 90% of Cs was still left within 5 cm depth of topsoil (~2 y after the accident).

Dose rate across the edge of the forest

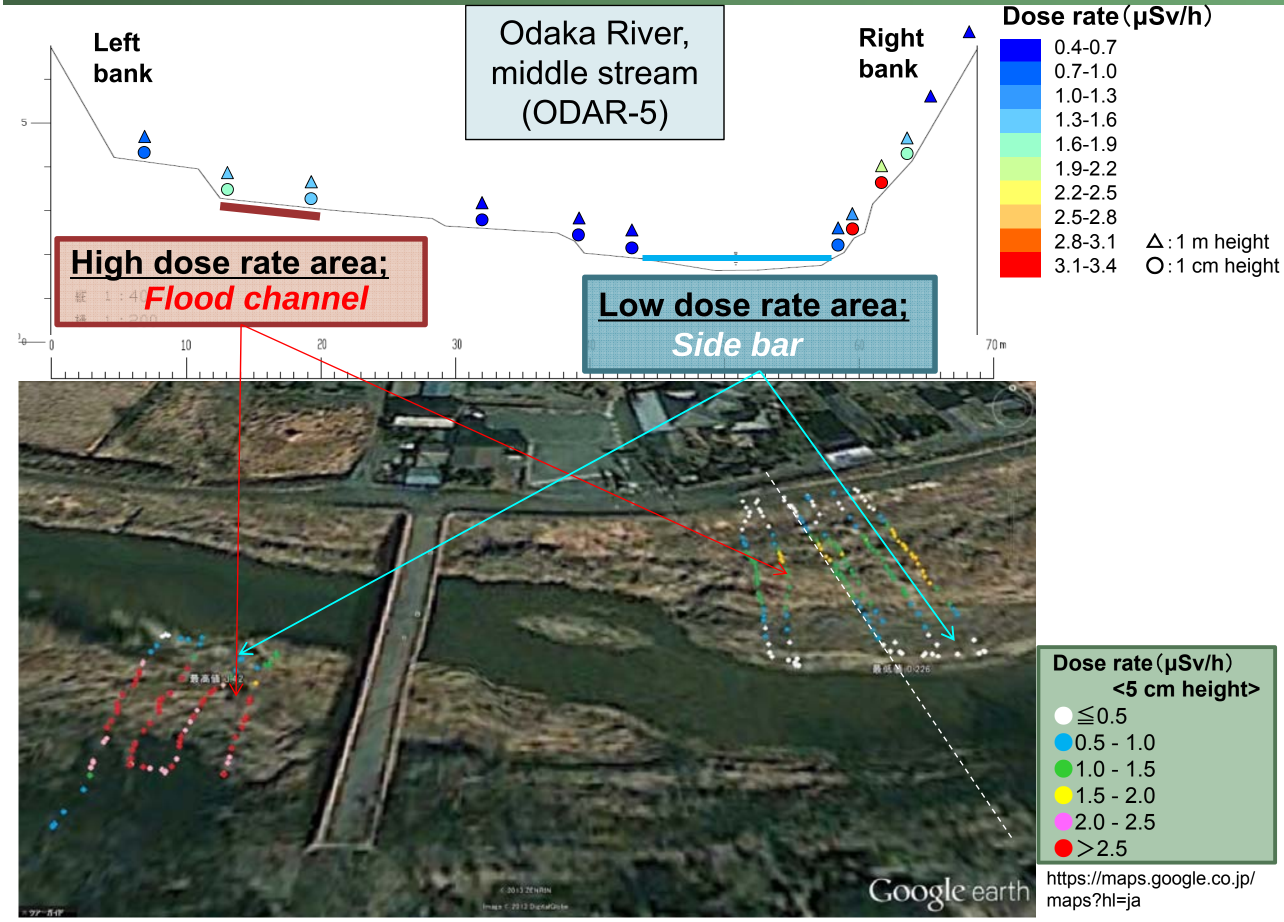


Rivers and estuaries investigation

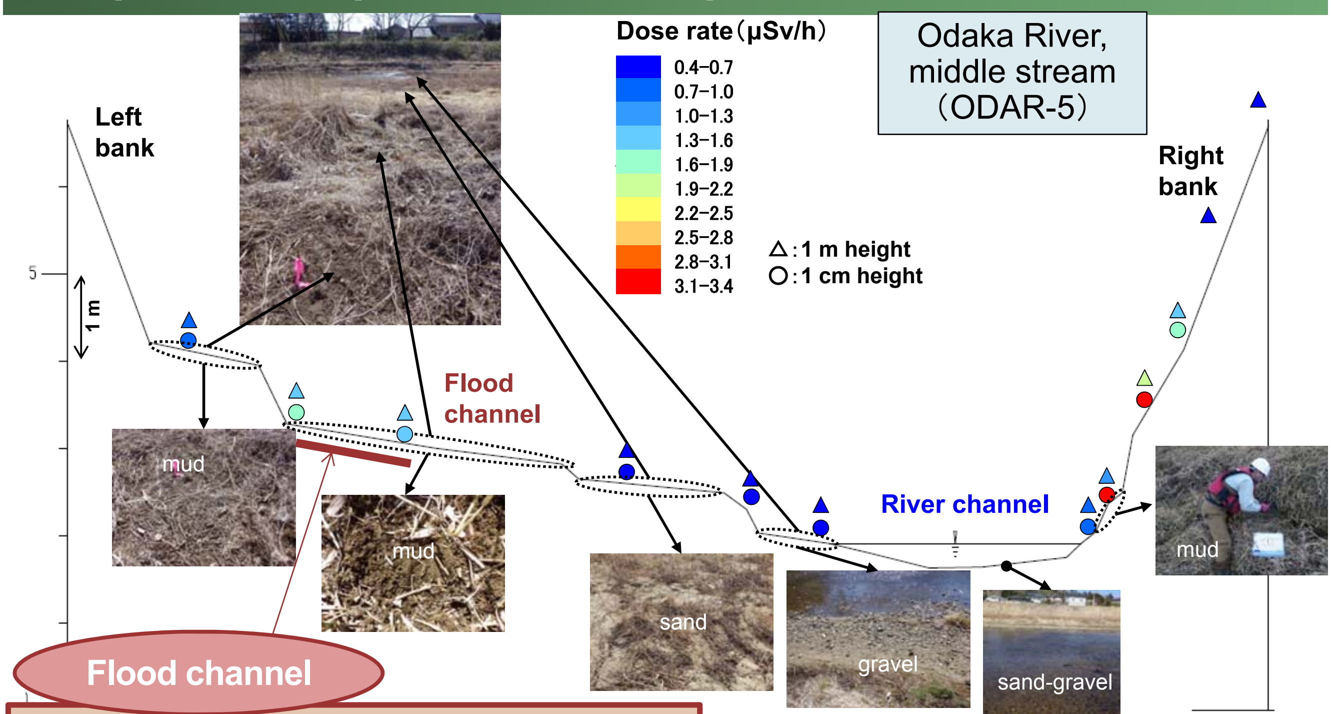
❑River investigation
- ✓ Continuous river observation (water level, turbidity, sampling)
- ✓ Periodic monitoring and sampling



Distribution of dose rate across the river



Depositional process of soil particles in the river



Flood channel

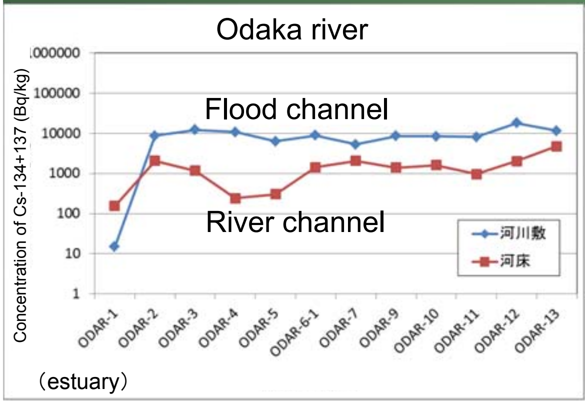
Flowing water only in the high water level
→ Transport of Cs with soil particles

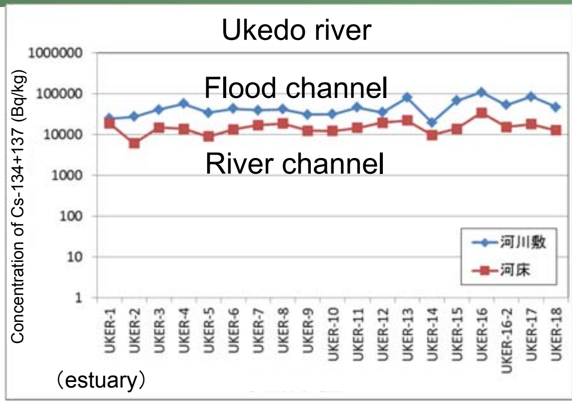
Trapping of fine soil particles by the plants on the flood channel

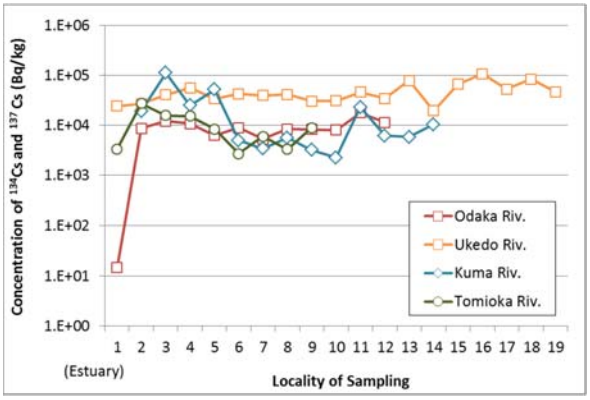
River channel

No deposition of fine soil particles → relatively low dose rate

Cs concentration in the river sediments







Concentration of Cs in flood channel

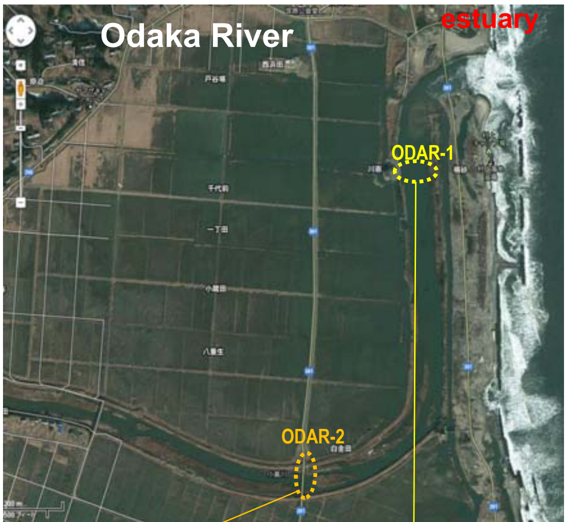
- Cs concentration of sediment in flood channel is higher than that of river channel, but the difference is within one order of magnitude.

⇒Cs is strongly adsorbed onto mineral particles in the sediments.

- Cs concentration drastically decreased at the closest point to estuary in **Odaka River**, where;
  - ✓ no coastal sandbar was formed at estuary,
  - ✓ salinity near estuary was similar to seawater.

⇒Cs was possibly desorbed from soil particles near estuary due to high salinity.

Salinity of river water



ODAR-2

at low tide		unit: %
	left bank	right bank
surface	0.3	0.3
0.5m	2.0	2.1
1m(0.7m)	1.9	1.9
at high tide		**unit: %**
	left bank	right bank
surface	0.1	0.1
0.5m	1.6	1.6
1m	1.7	1.6

ODAR-1

at low tide			unit: %
	left bank	center	right bank
surface	1.2	1.4	1.3
0.5m	1.3	1.7	1.4
1m(0.7m)	1.8	1.7	
at high tide			**unit: %**
	left bank	center	right bank
surface	2.3	2.1	2.0
0.5m	2.4	2.5	2.3
1m	2.3	2.5	

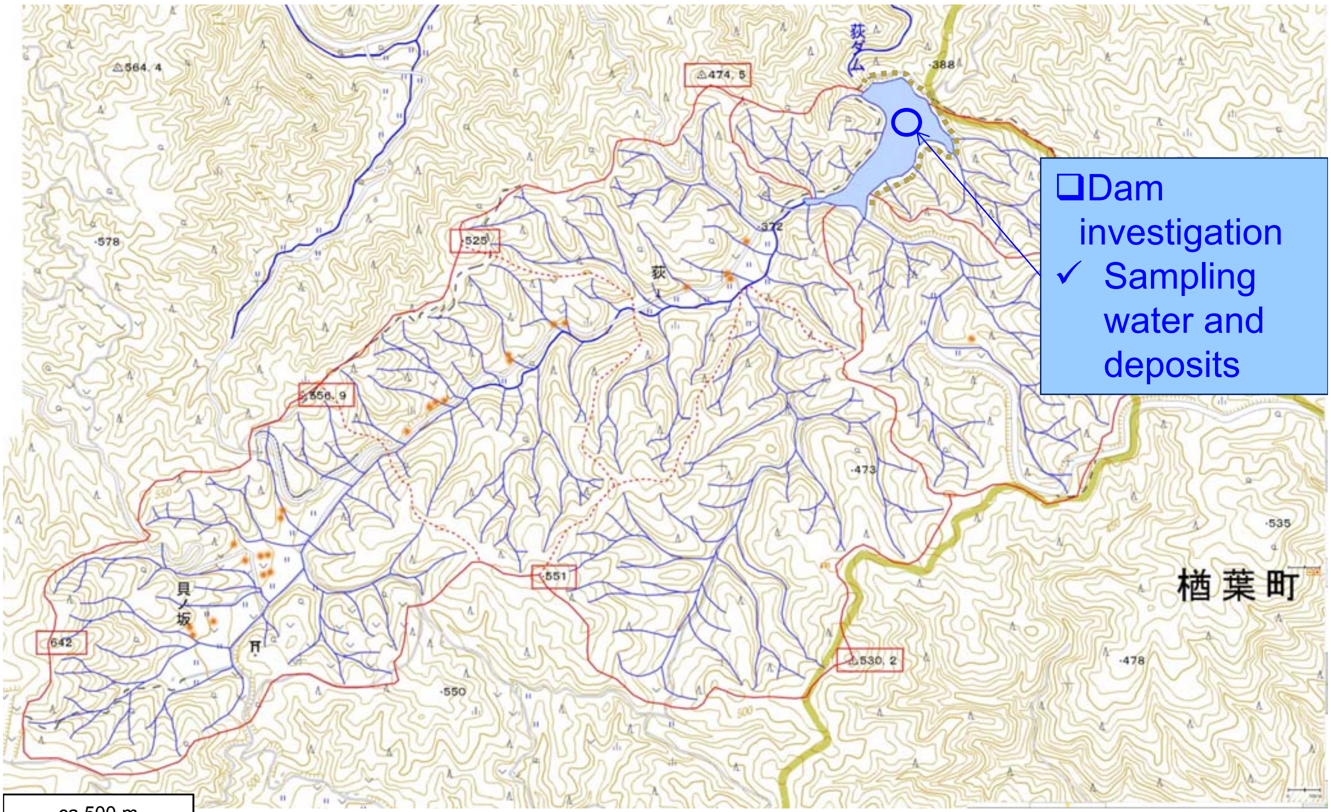
UKER-2

at low tide			unit: %
	left bank	center	right bank
surface	≦0.01	≦0.01	≦0.01
0.5m	≦0.01	≦0.01	≦0.01
1m	≦0.01	≦0.01	≦0.01
at high tide			**unit: %**
	left bank	center	right bank
surface	≦0.01	≦0.01	≦0.01
0.5m	≦0.01	≦0.01	≦0.01
1m	≦0.01	≦0.01	≦0.01

UKER-1

at low tide			unit: %
	left bank	center	right bank
surface	0.01	0.01	0.02
0.5m	0.01	-	0.03
1m	0.01	-	0.24
1.5m	0.01	-	0.35
2m	-	-	0.33
at high tide			**unit: %**
	left bank	center	right bank
surface	0.01	0.01	0.08
0.5m	0.01	-	0.10
1m	0.01	-	0.26
1.5m(1.2m)	0.02	-	0.52
2m	-	-	0.44

Dam reservers investigation



ca.500 m

Topographic map

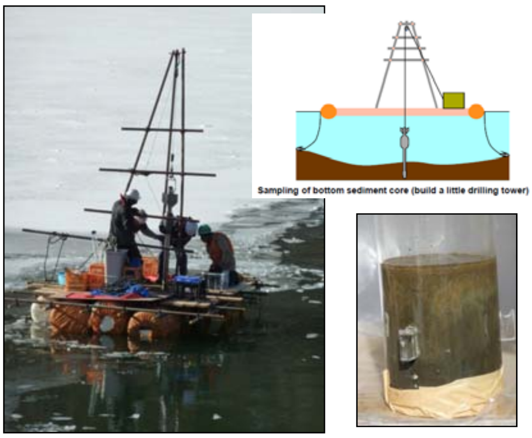
http://watchizu.gsi.go.jp/watchizu.html?meshcode=56400655

Sampling of sediments and water in the reservoir

Water sampling
(Heyroth sampling bottle)

Sampling of bottom sediments
（Smith-Mcintyre Bottom sampler）

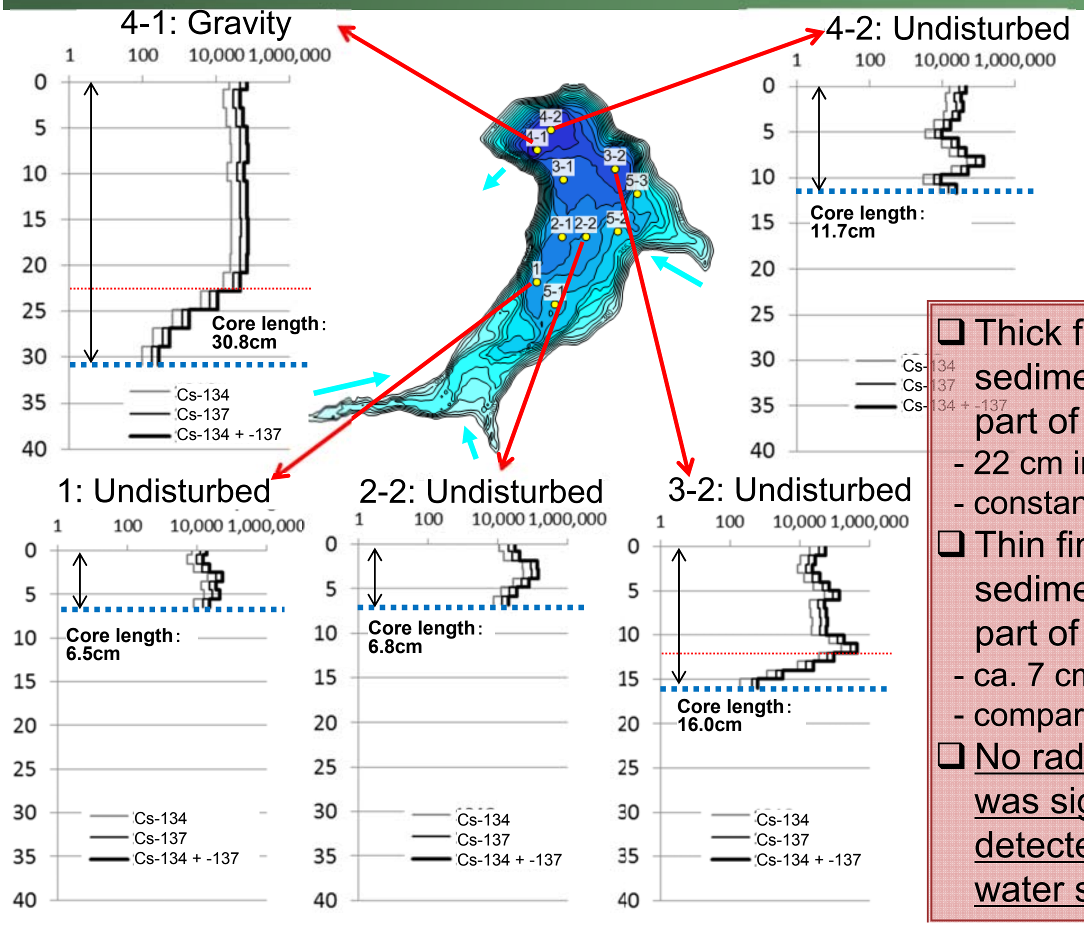
Core logging
（undisturbed sampling）



Core logging
（Gravity core sampler）

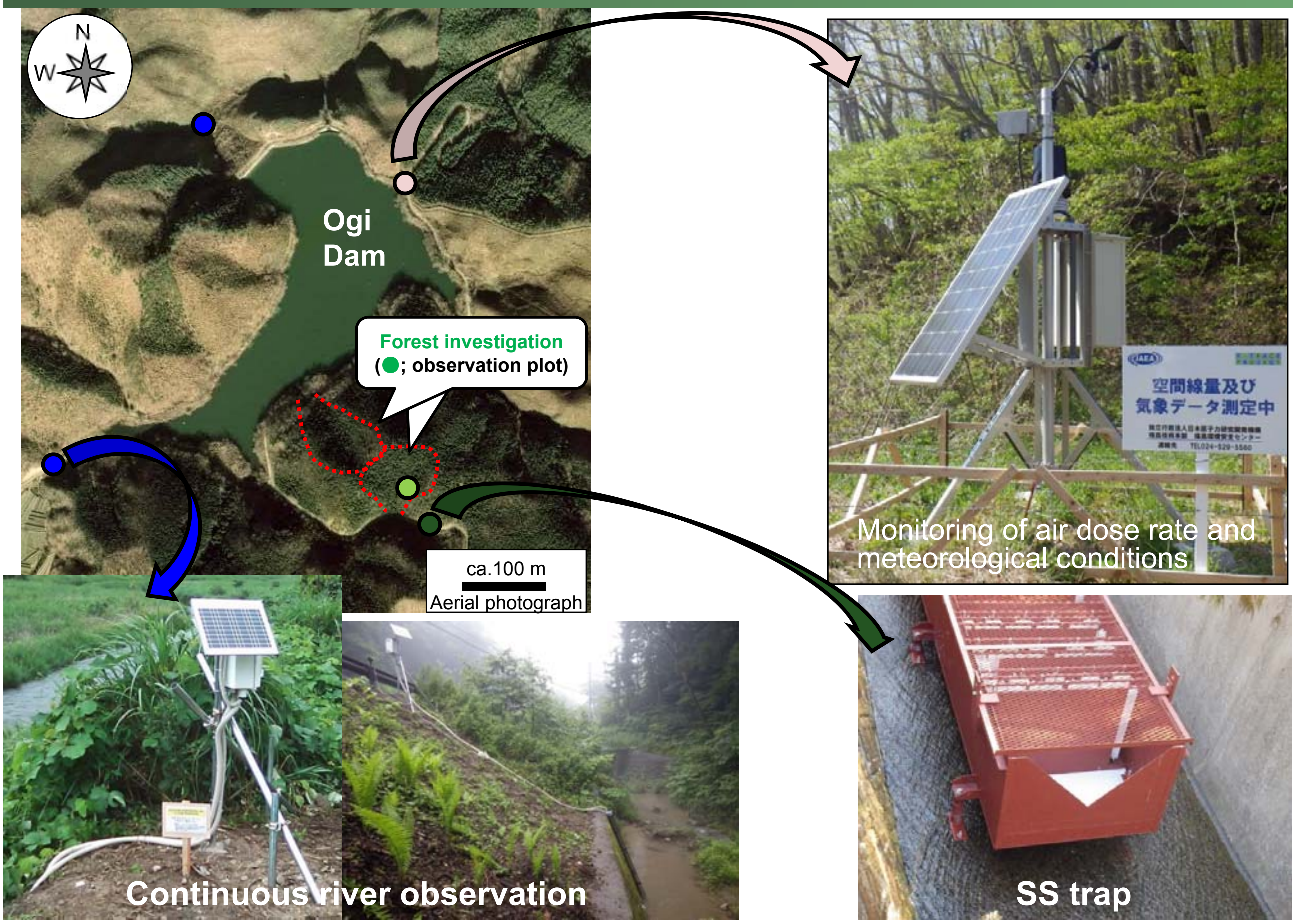
Depth profile of radiocaesium in the bottom sediments

Vertical axis : depth (m)
Horizontal axis : concentration of radiocaesium (Bq/kg)



- ❑ Thick fine-grained sediment at deeper part of the dam
  - 22 cm in thickness,
  - constant Cs conc.
- ❑ Thin fine-grained sediment at shallow part of the dam
  - ca. 7 cm in thickness
  - comparable Cs conc.
- ❑ <u>No radioactive Cs was significantly detected in any lake water samples.</u>

Other investigation and observation around the Ogi dam



Modeling and simulation

Land erosion estimation by USLE

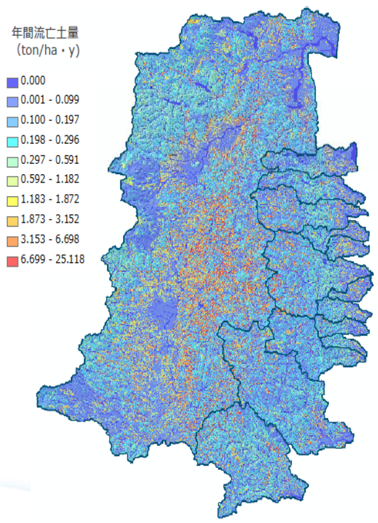
USLE (Universal Soil Loss Equation)

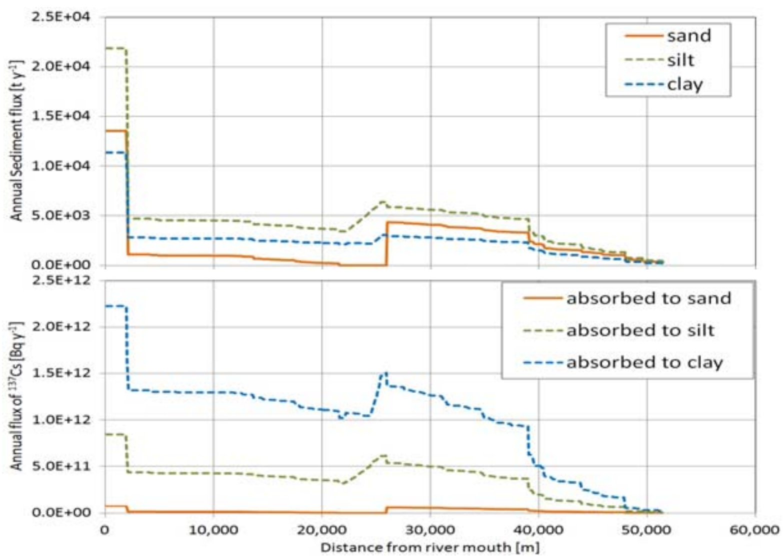
- Developed by the **US Department** of Agriculture
- Applied to many agricultural fields in Japan

A = R × K × LS × C × P

A: the potential annual soil loss (ton/ha/y)
R: the rainfall and runoff factor < precipitation data (from Japan Meteorological Agency)
K: the soil erodibility factor < Soil distribution (from the Cabinet)
LS: the slope length-gradient factor < Geometry (from Ministry of Land, Infrastructure, Transport and Tourism(MLIT))
C: the crop / vegetation and management factor < Land use (from MLIT)
P: the support practice factor < Land use (from MLIT)

Potential annual soil loss





Estimation of annual inflow of soil and Caesium along the Ukedo River by USLE

Cs transport in river networks

TODAM model

- Developed by Pacific Northwest National Laboratory (PNNL)
- Finite element method
- Transport of sediment, dissolved cesium and sediment-sorbed cesium in rivers and estuaries with multiple-channel network (sand, silt and clay are considered)

Main input data

- Geometry of rivers
- River flux
- Physical properties of sediments (e.g. d50, porosity)

in situ

- Adsorption/desorption properties
- Critical share stress
- Dispersion coefficient for suspended sediment and dissolved cesium

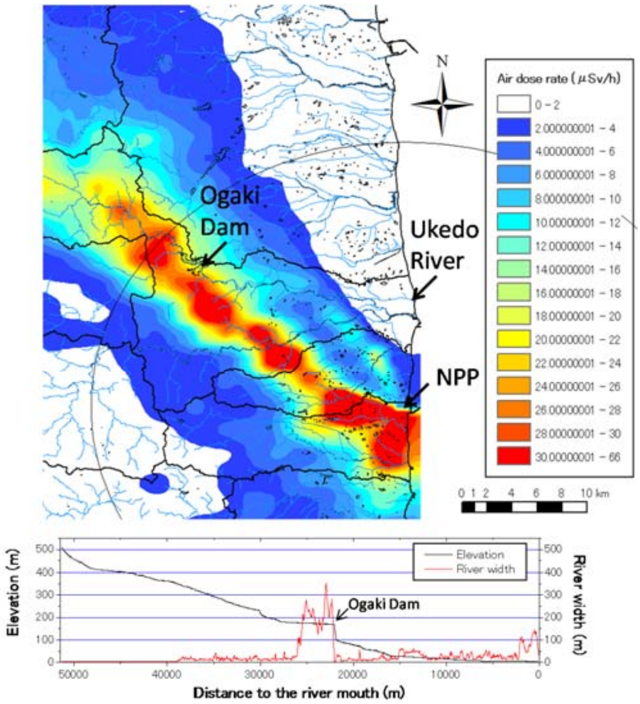
lab.

- Boundary and initial conditions

model data

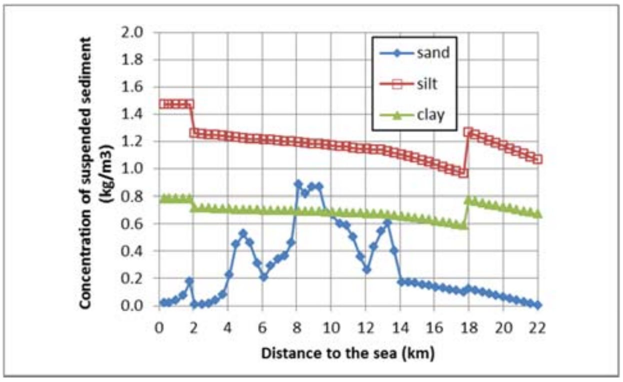
Main output data

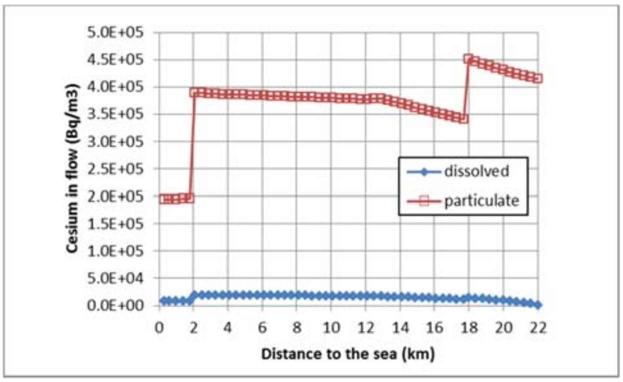
- Spatial distribution and time history of sediment conditions
- Spatial distribution and time history of concentration of dissolved and sediment-sorbed cesium

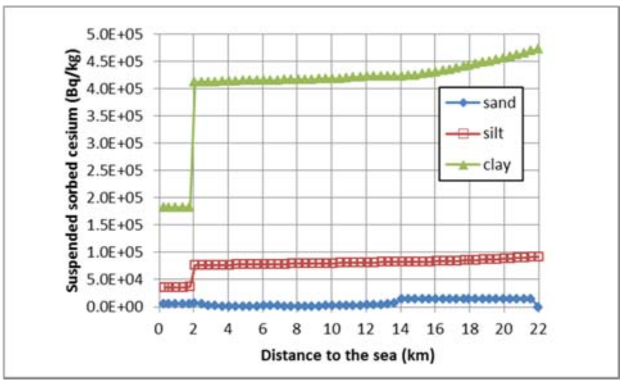


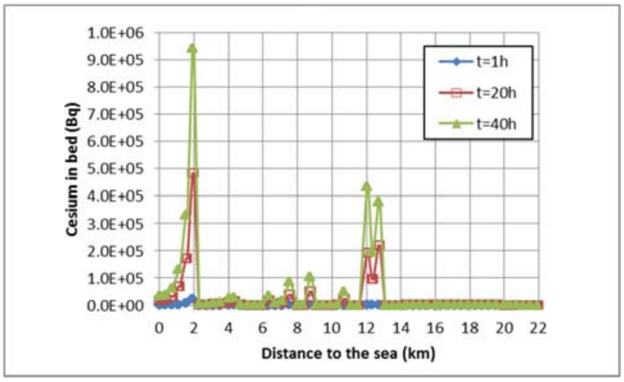
Location of Ukedo river for model calculation by TODAM

Examples of model calculation of river









Cs transport in estuaries

Numerical model (under consideration)

- FLESCOT
- ROMS
- Nays2D

Main input data

- Geometry of rivers and estuaries
- River flux
- Wind velocity and direction
- Temperature
- Velocity and direction of an ocean current
- Wave height and period
- Salinity concentration

in situ

- Physical properties of sediments (e.g. d50, porosity)
- Adsorption/desorption properties
- Critical share stress
- Dispersion coefficient for suspended sediment and dissolved cesium

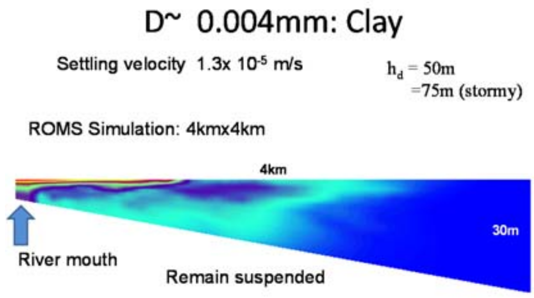
lab.

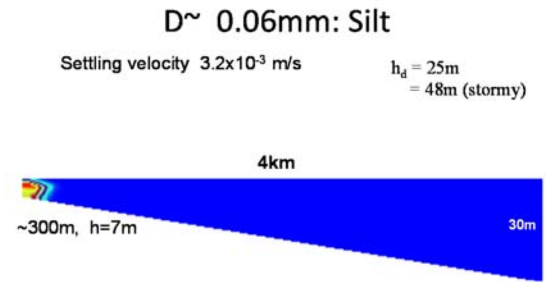
- Boundary and initial conditions

model data

Main output data

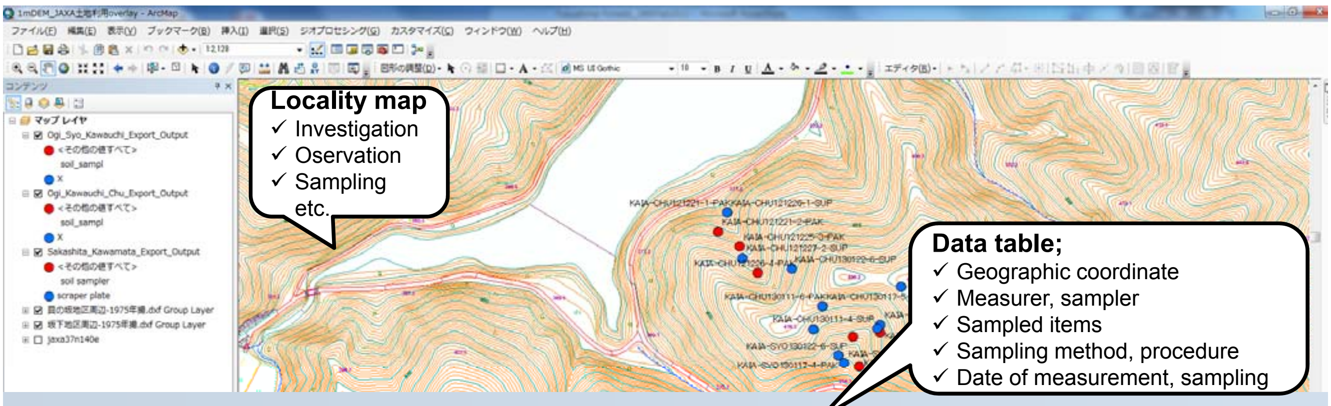
- Spatial distribution and time history of sediment conditions
- Spatial distribution and time history of concentration of dissolved and sediment-sorbed cesium





Example of the simulation of the Ukedo river by ROMS

Data integration into ONE MAP (under construction)



	date_of_measurement	measurer	soil_sampling_50cm_depth	soil_samling_20cm_depth	litter_sampling	soil_inves	
7	11-Dec.-2012	Niizato, JAEA	O (2-Dec-2012) by JAEA	X	X	X	X
7	19-Feb-2013	Niizato, JAEA	O (10-Dec-2012) by MST	X	O		
7	19-Feb-2013	Niizato, JAEA	O (11-Dec-2012) by MST	X	O		
7	19-Feb-2013	Niizato, JAEA	O (13-Dec-2012) by MST	X	O		
6	11-Dec.-2012	Niizato, JAEA	O (13-Dec-2012) by MST	X	O		
6	11-Dec.-2012	Niizato, JAEA	O (14-Dec-2012) by MST	X	O		
4	11-Dec.-2012	Niizato, JAEA	O (17-Dec-2012) by MST	X	O		
6	19-Feb-2013	Niizato, JAEA	O (17-Dec-2012) by MST	X	O		
6	13-Feb.-2013	Niizato, JAEA	O (17-Dec-2012) by MST	X	O		
7	5-Feb.-2013	Niizato, JAEA	X	O (12-Dec-2012) by MST	O		
0	13-Feb.-2013	Niizato, JAEA	X	O (14-Dec-2012) by MST	O		
5	13-Feb.-2013	Niizato, JAEA	X	O (17-Dec-2012) by MST	O		
9	7-Feb.-2013	Dohi, JAEA	X	O (18-Dec-2012) by MST	O		

- ❑ Data with geographic coordinate (topographic survey on the field investigation)
- ❑ Overlying the all of data into **ONE MAP**, then we can analysis the spatial relationship among physical geographic information, radioactivity of soil and surface water, etc.

Summary

- Radioactive Cs is strongly associated with mineral particles.
  - High concentration (10^4 - 10^5 Bq/kg) in river and reservoir sediments,
  - Low concentration (< 2 Bq/L) in river and reservoir water,
  - Indicate large distribution coefficient (> 5x(10^4 - 10^5) L/kg).

- Transport of radioactive Cs is dominated by litter and mineral particles.
  - Erosion, transport and sedimentation.
  - Dam reservoirs may be possibly used as reservoirs of mineral particles-borne radioactive Cs, leading to reduction of dose rate.
  - Velocity of Cs migrating in subsurface is low (>90% Cs in 5 cm depth).

- Modeling tools for Cs transportation is being developed.
  - Soil erosion => Water flow transportation => 3-D estuary flow
  - Data is obtained *in-situ* observation and lab-experiment, under QA.
  - Interaction of Cs to litter and mineral particles should be modeled.

Long-term schedule

Research Programme	FY2012 to 2014	After FY2015
Investigation Area	✓ **Abukuma mountains** ✓ **Fluvial lowland/plain on the Pacific coastal region and along the main rivers** ✓ Hills on the Pacific coastal region ✓ Dams and reservoirs in Abukuma mountatins	✓ **Abukuma mountains** ✓ Fluvial lowland/plain on the Pacific coastal region and along the main rivers ✓ **Abukuma River system** ✓ Hills on the Pacific coastal region ✓ Dams and reservoirs in Abukuma mountatins
❑ **Elucidation of migration behavior of radiocaesium**	✓ **Development** of model and simulation for Cs transport in the Fukushima environment ✓ **Test application** of the transport modelling of radiocaesium	✓ **Monitoring** of natural events and processes in the forests, rivers, dam deposits, estuaries, etc. ✓ **Monitoring** of Cs transport ✓ **Model improvement** and simulation
❑ **Assessment of recontamination of the remediated area**	✓ **Post-remediation surveying** ✓ **Construction of transport scenario**	✓ Model development and simulation of the recontamination, and its application
❑ **Development of techniques for control of radiocaesium migration**	**i) Small-scale**; Analysis of cost-effectiveness based on the practical field test	✓ **Proposal and spreading** of the techniques for the controlling of Cs migration to local governments and local residents
	ii) Large-scale; availability of dams and reservoirs	✓ Proposal to the local and national goverments
❑ **Development of evaluation system for radiation exposure**	i) **Development** of simplified and detailed evaluation system ii) **Test application** of simplified evaluation system	✓ **Improvement** of the evaluation systems ✓ Long-term evaluation of radiation dose and application to the other province


Thank you for your attention !
"Witch"s eye" Goshiki-numa, located at the top of Mt. Azuma.