Cs Migration Behaviour in the Environment and Its Long-Term Assessment after Decontamination Work in Fukushima

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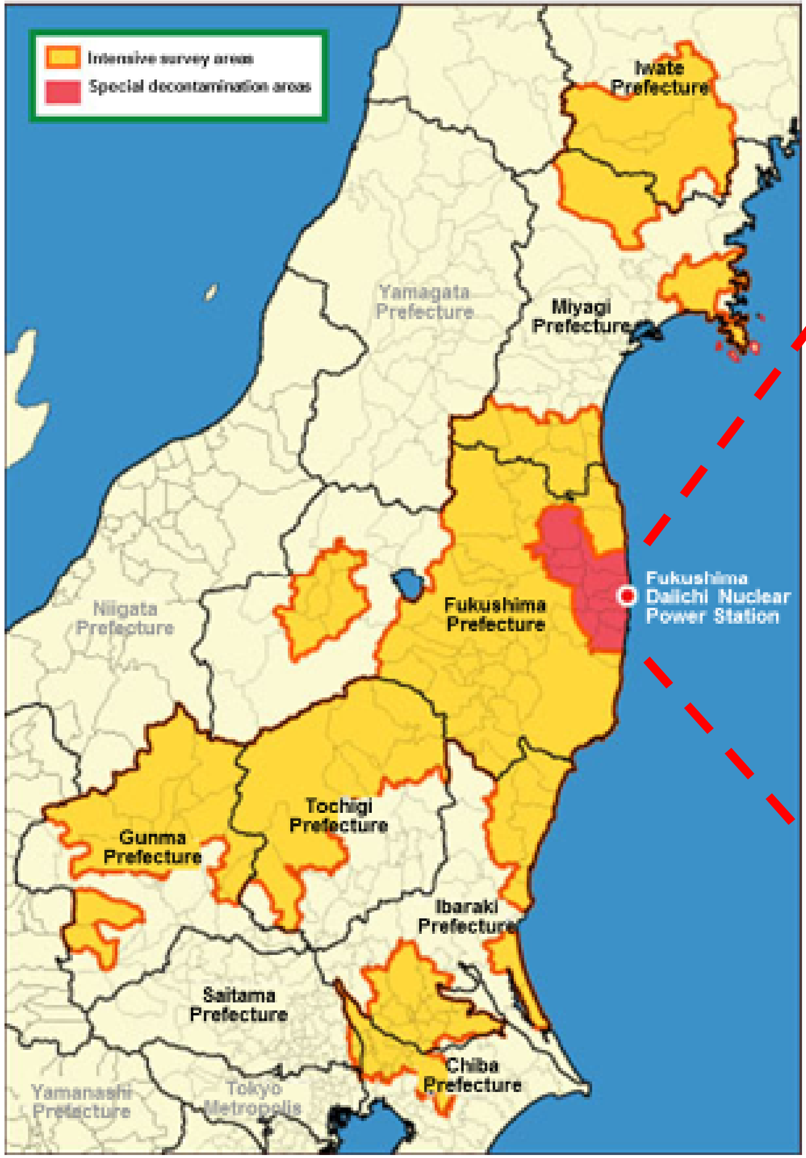
Decontamination Implementation

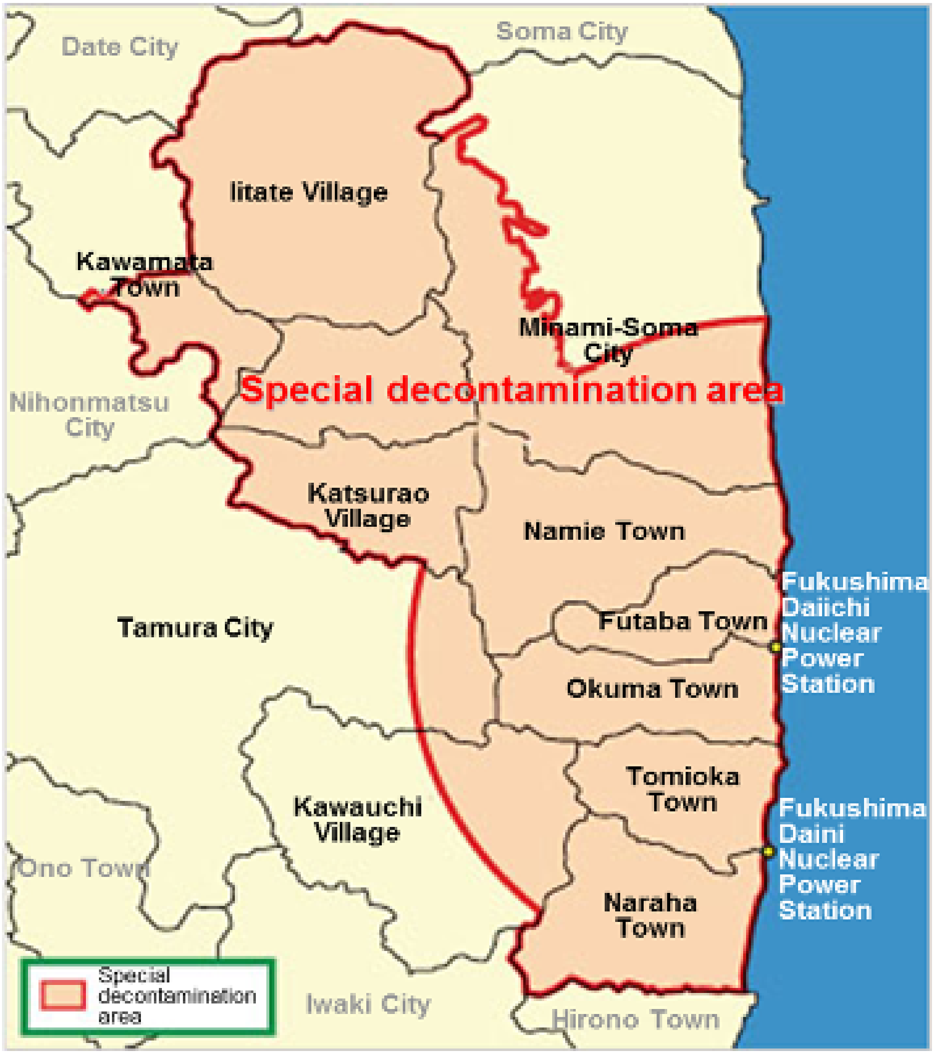
- **Special Decontamination Area(＞20 mSv/y)**
  :11 Municipalities **by National Government**

- **Intensive Contamination Survey Area (1 to 20mSv/y)**
  by Each Municipality Funded by Government
  :104 Municipalities, 8Prefecturs

- **Based on the Guidelines for Decontamination Works**
  Issued by Ministry of the Environment

Special Decontamination Area and Intensive Contamination Survey Area





Reference: Ministry of the Environment Government
Off-site Decontamination Measures
WWW Document,http://josen.env.go.jp/en/documents/pdf/documents_02.pdf

Further Studies Needed for Decontamination works

➢Decontamination for Forest

➢Decrease in Waste Generation

➢Waste Storage and Disposal

➢Possible Recontamination by Weather and Water Flow

Based on Understanding of Cs Behavior in the Environment: Likely Dominated by Sorption Especially on Clay Minerals in the Soil Zone

Cs Transport Behavior

Cs Sorption Significantly Affected by

- Ionic Strength of Aqueous Solutions
- Kinds of Solid phases
- Organic Matter

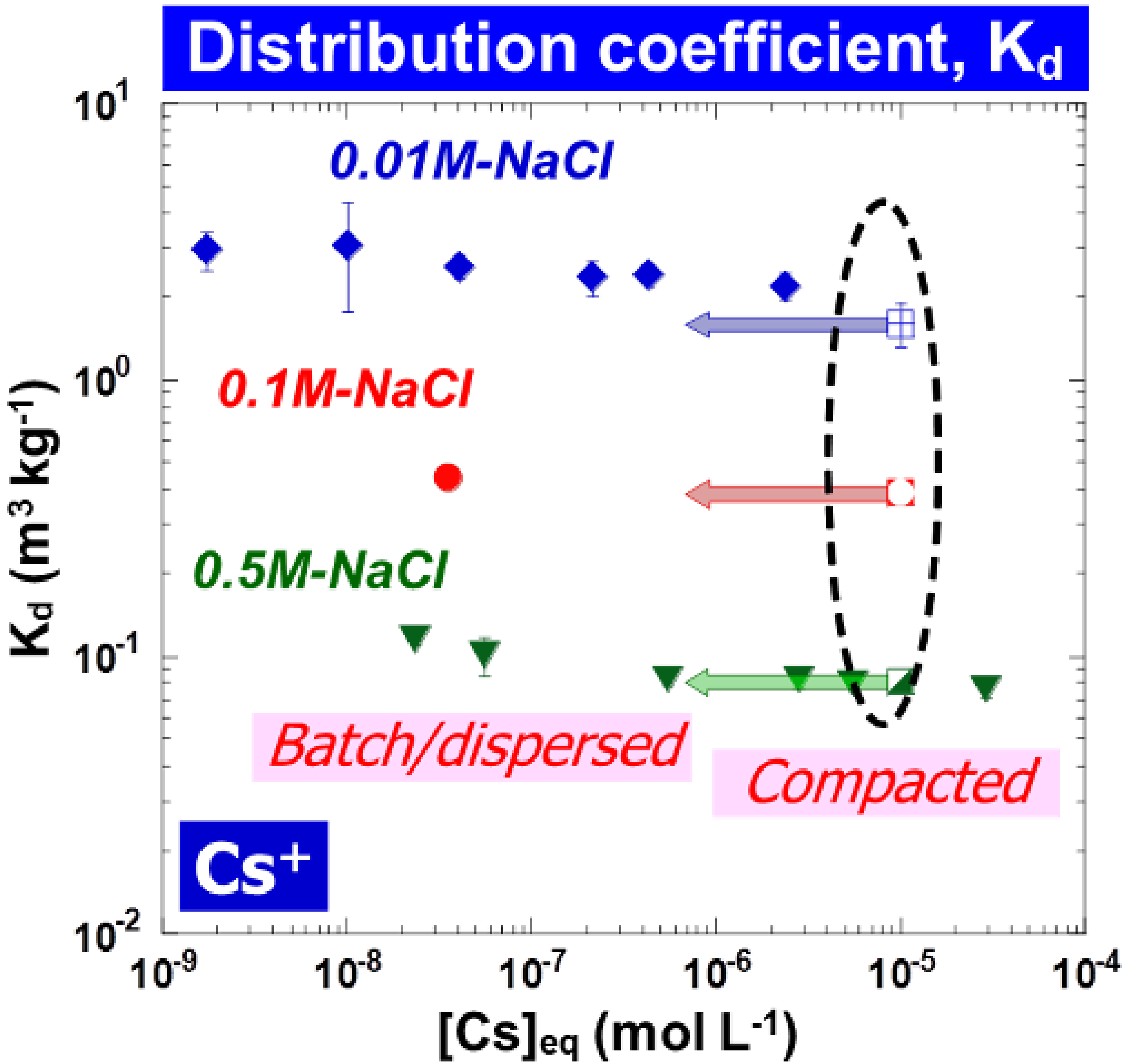
More Important is

- Reversibility of Cs Sorption on Natural Materials

Cs is Rarely Detected from Water, It Means That

- Cs Sorption Likely Irreversible
- Cs Transport Accompanied by Solid Particles, Especially in Fresh Waters

Cs sorption on Montmorillonite



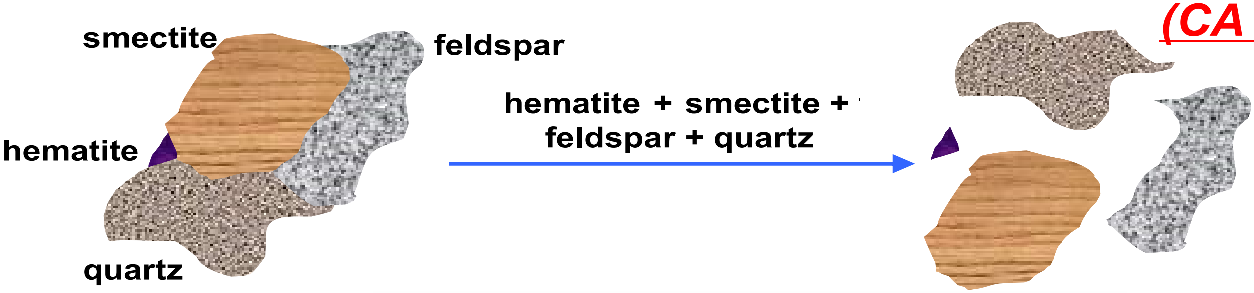
- K_d of Cs is consistent between batch and compacted systems

Clay-based Modeling Approaches

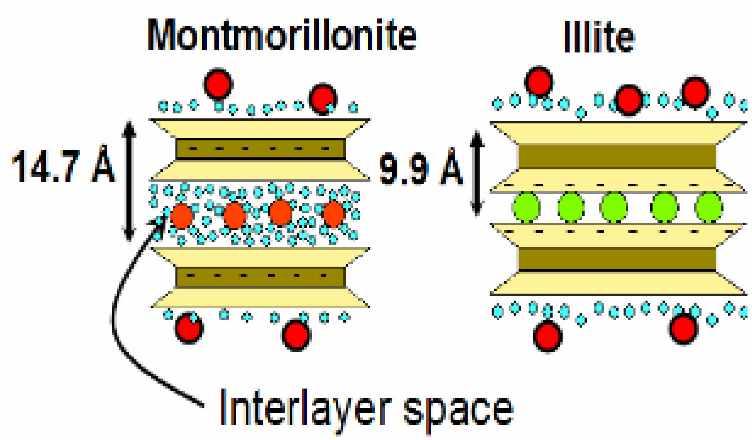
	Sorption model	*Diffusion model*
Bentonite	***Montmorillonite***	***Homogeneous + EDL***
Mudstone / Horonobe	***Smectite + Illite***	***Pore distribution +EDL***
Granite / Grimsel	***Biotite+Chlorite+・・***	***EDL? + Heterogeneous ?***
Soil	***Clay minerals ・・・***	***Unsaturated ? + EDL?***

TSM for complex substrates

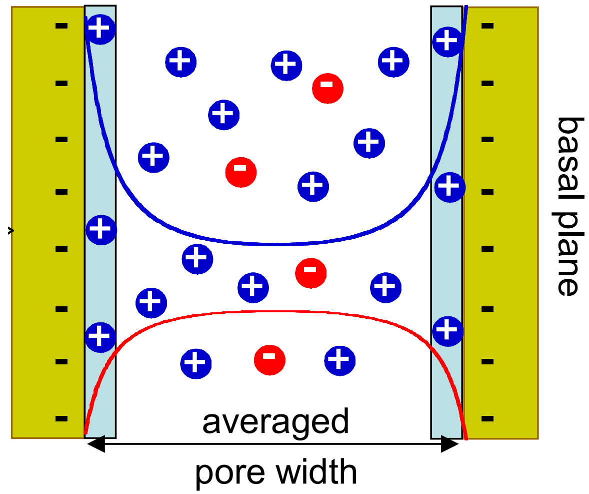
(OECD/NEA, 2005)
Component Additivity
(CA model)



Variation of clay



EDL diffusion model

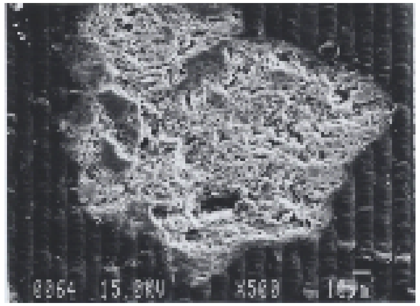


- *homogeneous pore*
- *ionic distribution*
  (cation excess / anion exclusion)
- *viscoelectric effect*

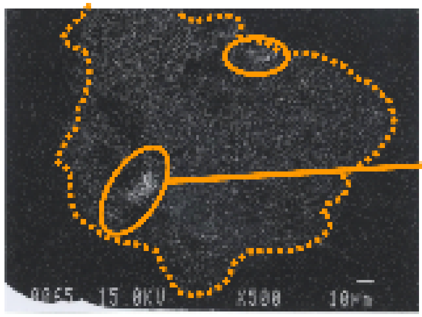
Clay based model approach - Cs/I in Horonobe mudstone -

Sorption and diffusion of Cs/HTO/I as a function of salinity

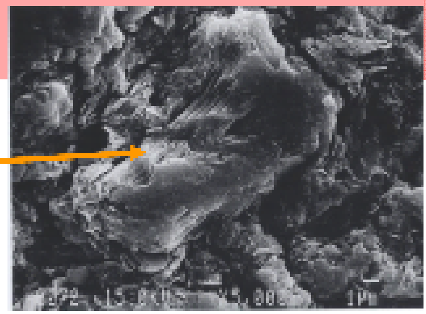
Mapping of sorbed Cs (EPMA)



rock fragment

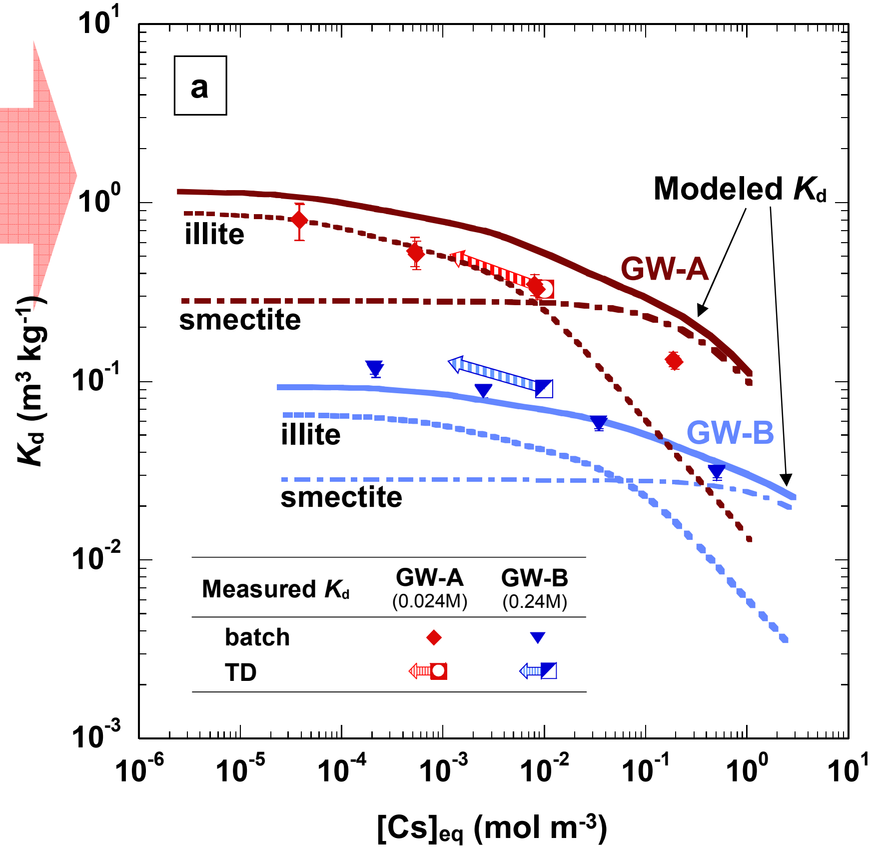


Elemental map for Cs



Illite particle

Clay-based CA sorption model



Experimental and Modeling Approach for Cs Contaminated Soils

Soil Samples

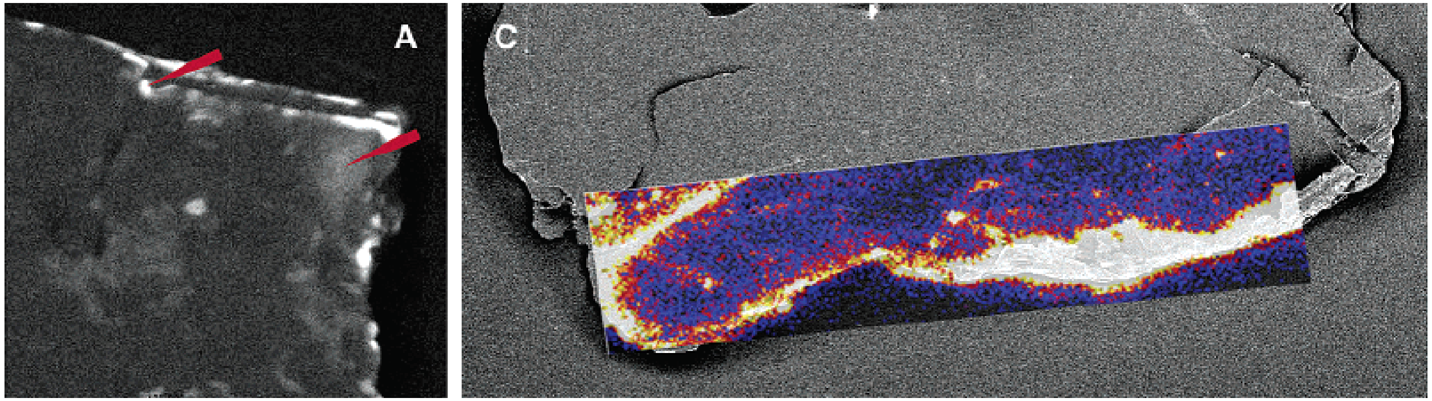
Distribution and Relation between minerals and Cs

Sorption and desorption mechanisms

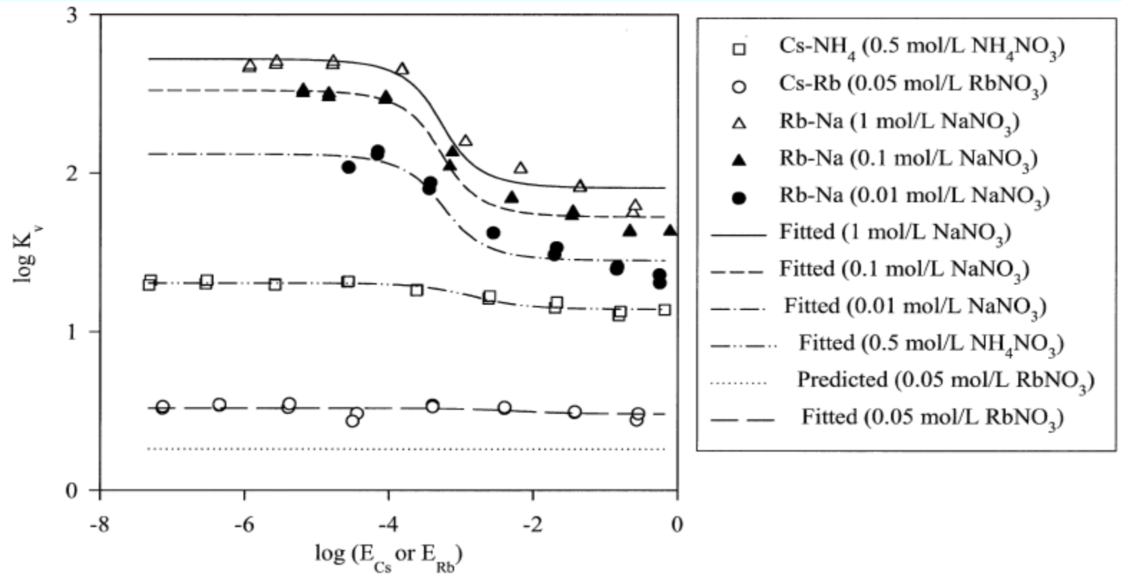
Clay-based model and prediction

- **Mechanistic Understanding**
- **K_d setting / uncertainty**
- **Long-term transport**
- **Decontamination**
- **Safety of storage / disposal**

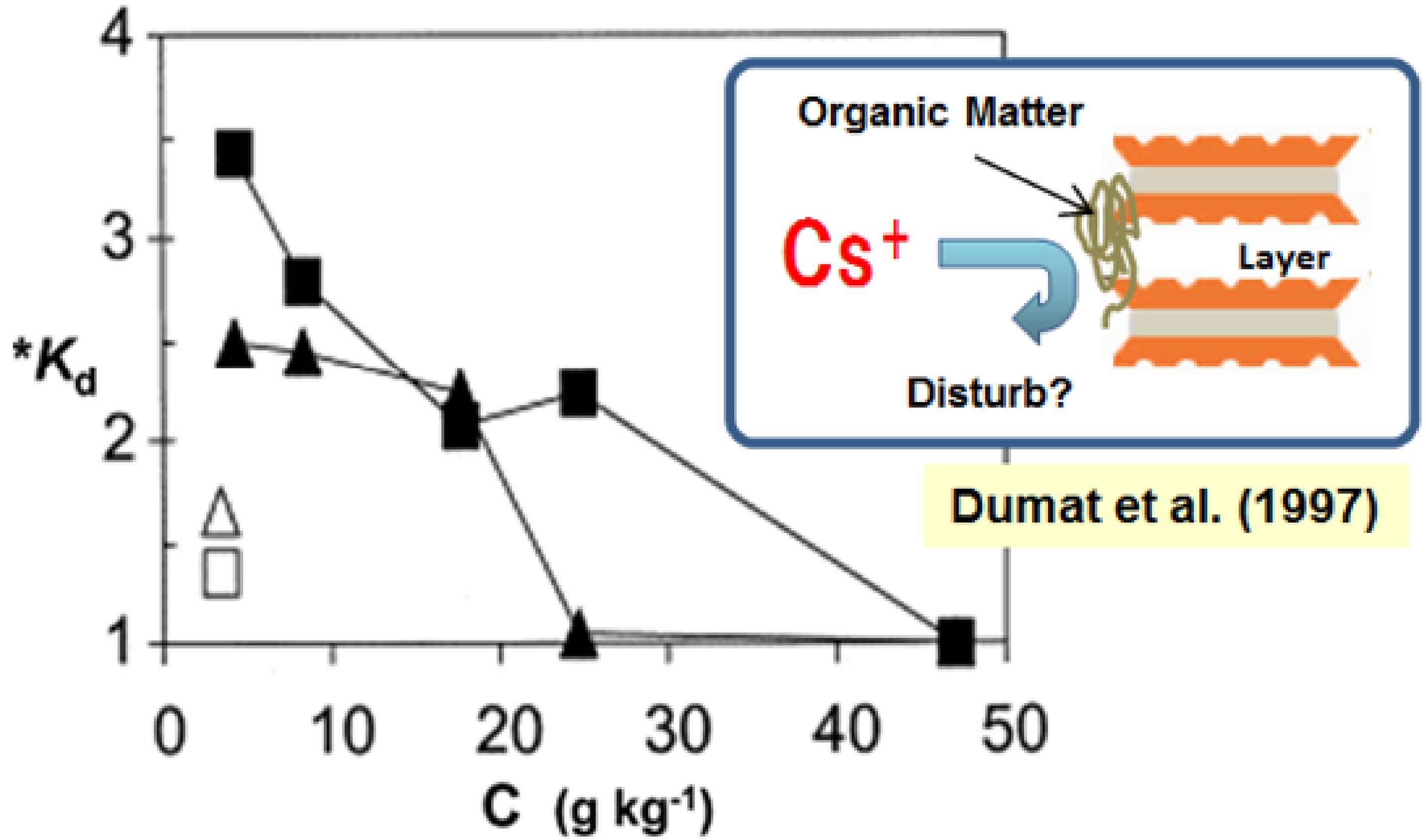
Sorption mechanisms of Cs on Biotite (McKinley et al., 2004)



Cs sorption modeling for Hanford sediments (Liu et al., 2003)



Understanding of Effect of Organic Matter on Cs Sorption



Dumat et al. (1997)

Dependency of Organic Matter on Cs Sorption

Reversibility of Cs Sorption on Natural Materials

Distribution of Cs-137 to different sorption sites in soils
(Tsukada et al., 2009)

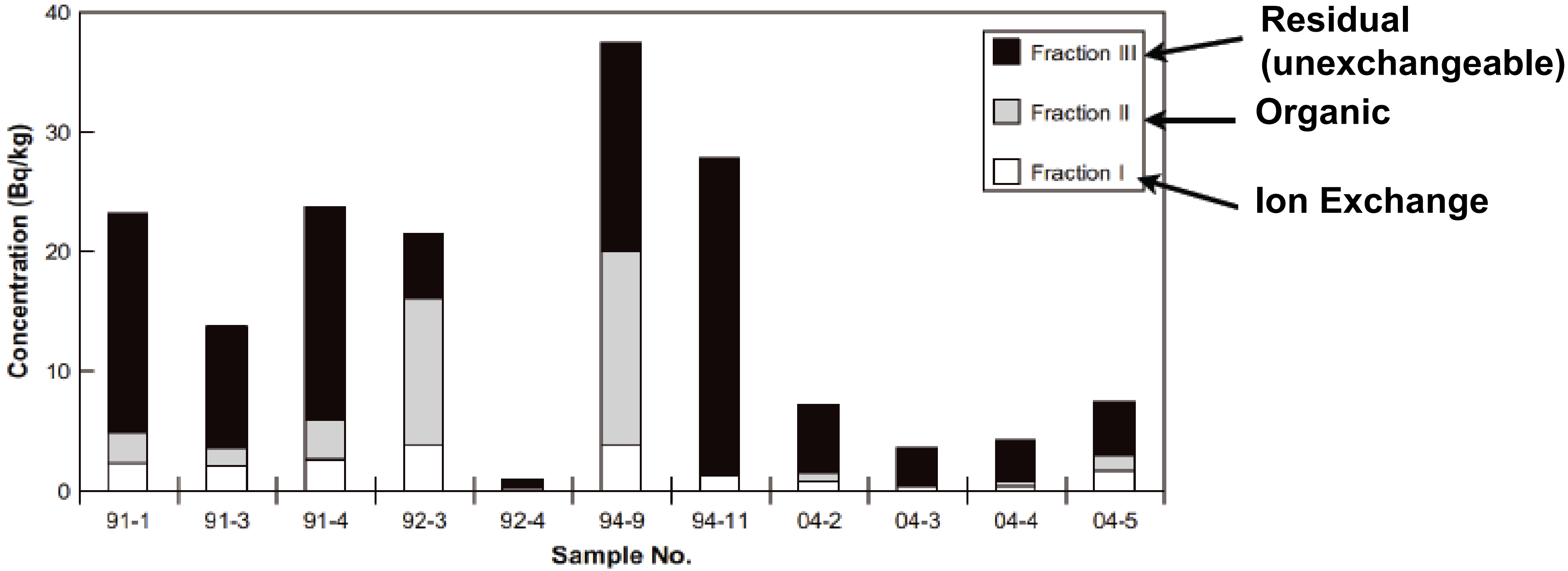


Fig. 2. Concentration of ^{137}Cs in among the fractions in the soil samples.

The Most Difficult Decontamination Work is for Forest

- ➢Forest Covers about 70% of Fukushima Prefecture

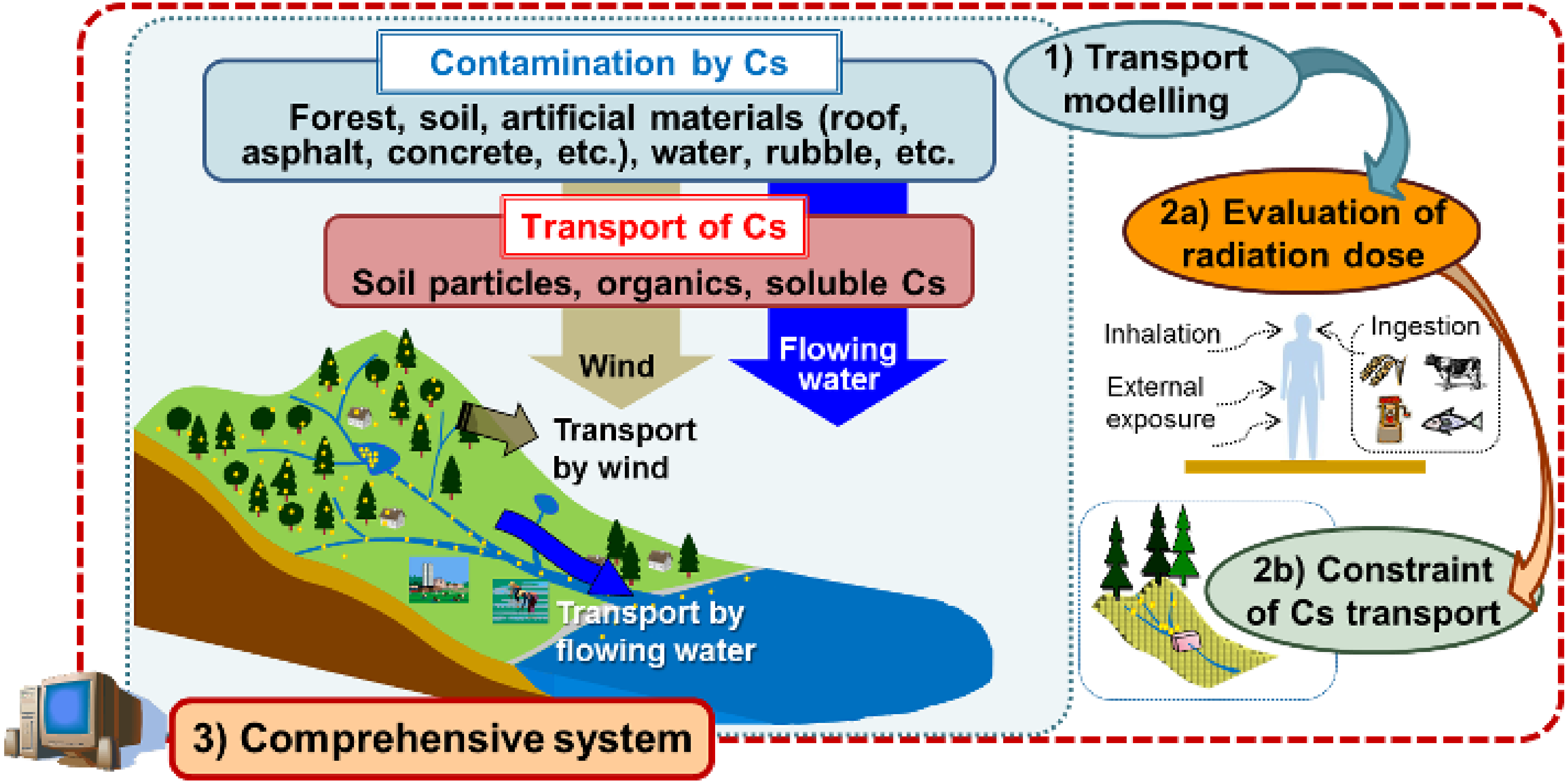
- ➢The Limited Forest Decontamination is Likely Realistic under Consideration of Ecosystem Conservation and Disaster Prevention like Land Slides

- ➢After Decontamination Works,
  Long-term Investigation of Cs Behavior from the Cs Source Term, the Non-decontaminatied Forest :
  River-River Bed ⇨ Dam Reservoir ⇨ Estuary System
  Countermeasures to Prevent Cs Transport can be also Possible.

Overview of the Fukushima-TRACE Project

❑ Objectives

1) Elucidation of transport behavior of radionuclides (esp. radiocaesium; Cs) from contaminated forest to biosphere and sea.
2) Development of dose evaluation system and methodology to constrain Cs transport.
3) Construction comprehensive system for prediction and constraint of radionuclide transport.

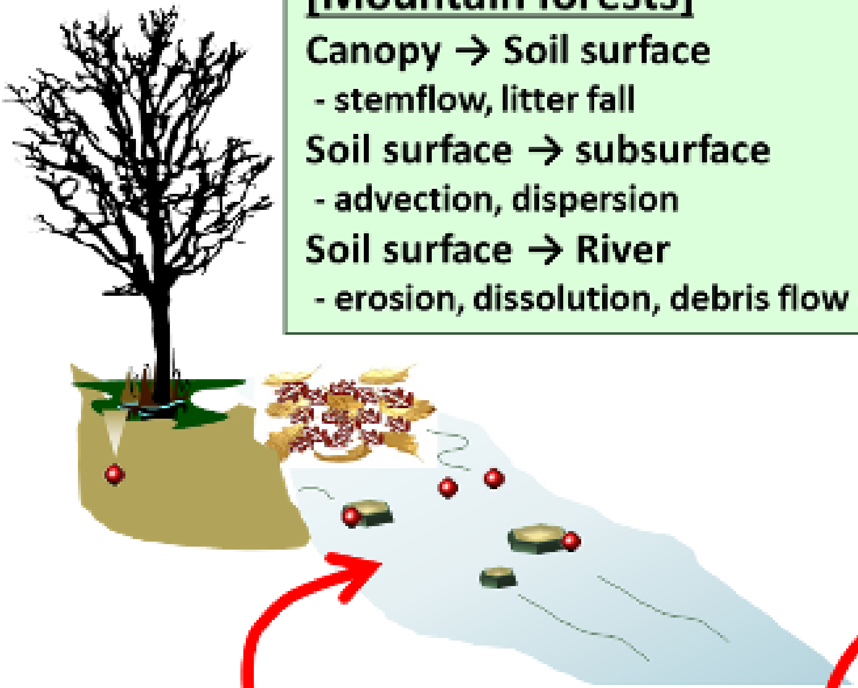


Key phenomena in the Cs transport

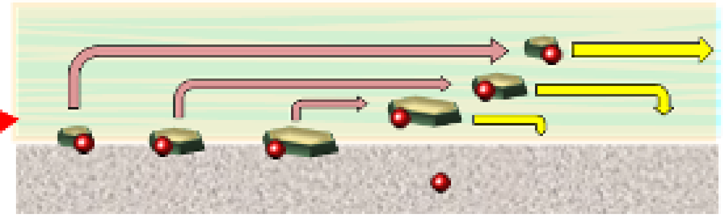
[Mountain forests]
Canopy → Soil surface
- stemflow, litter fall

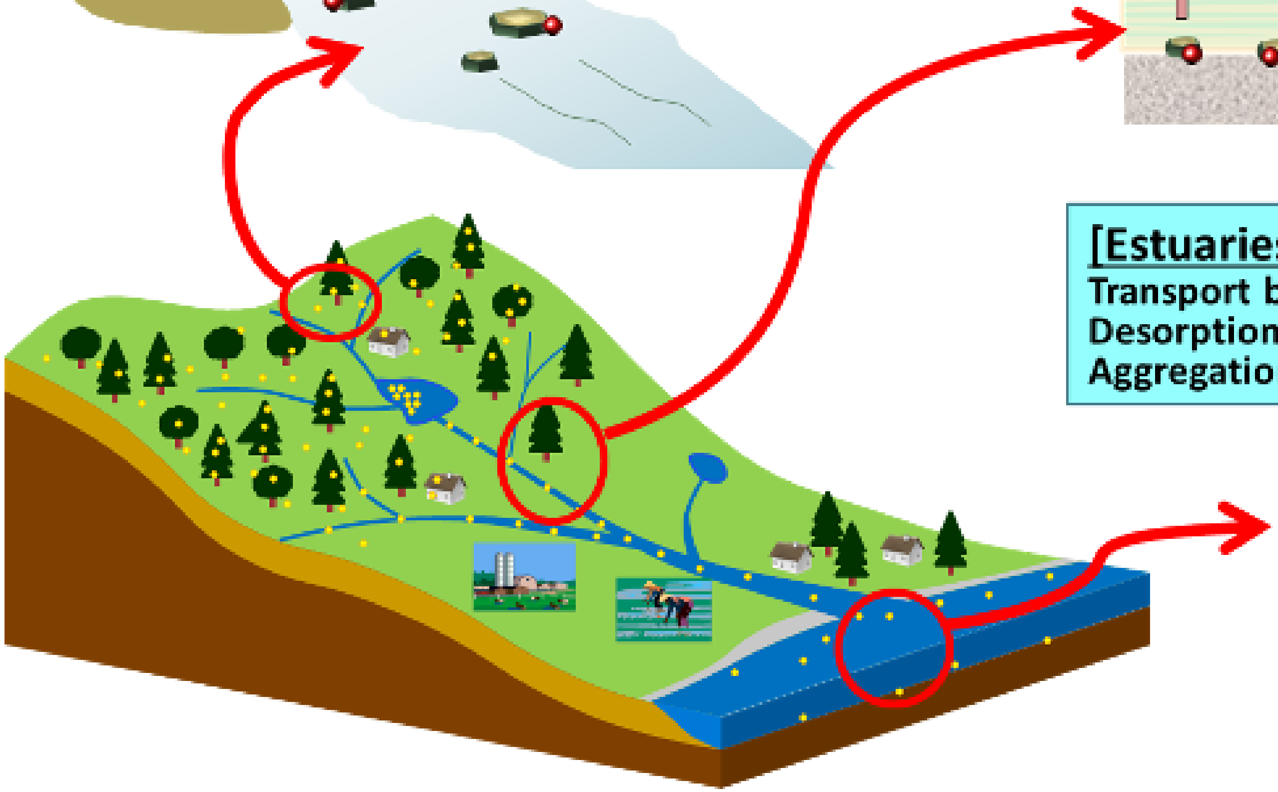
Soil surface → subsurface
- advection, dispersion

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

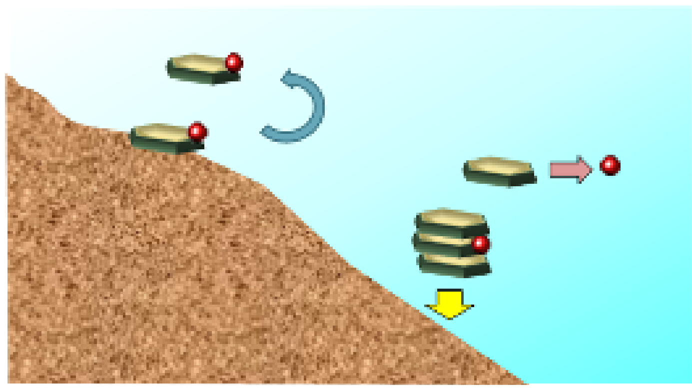


[Rivers & dam deposits]
Transport by flowing water
- with soil particles
- deposition under the settling velocity
- trapping by plants on the flood channel

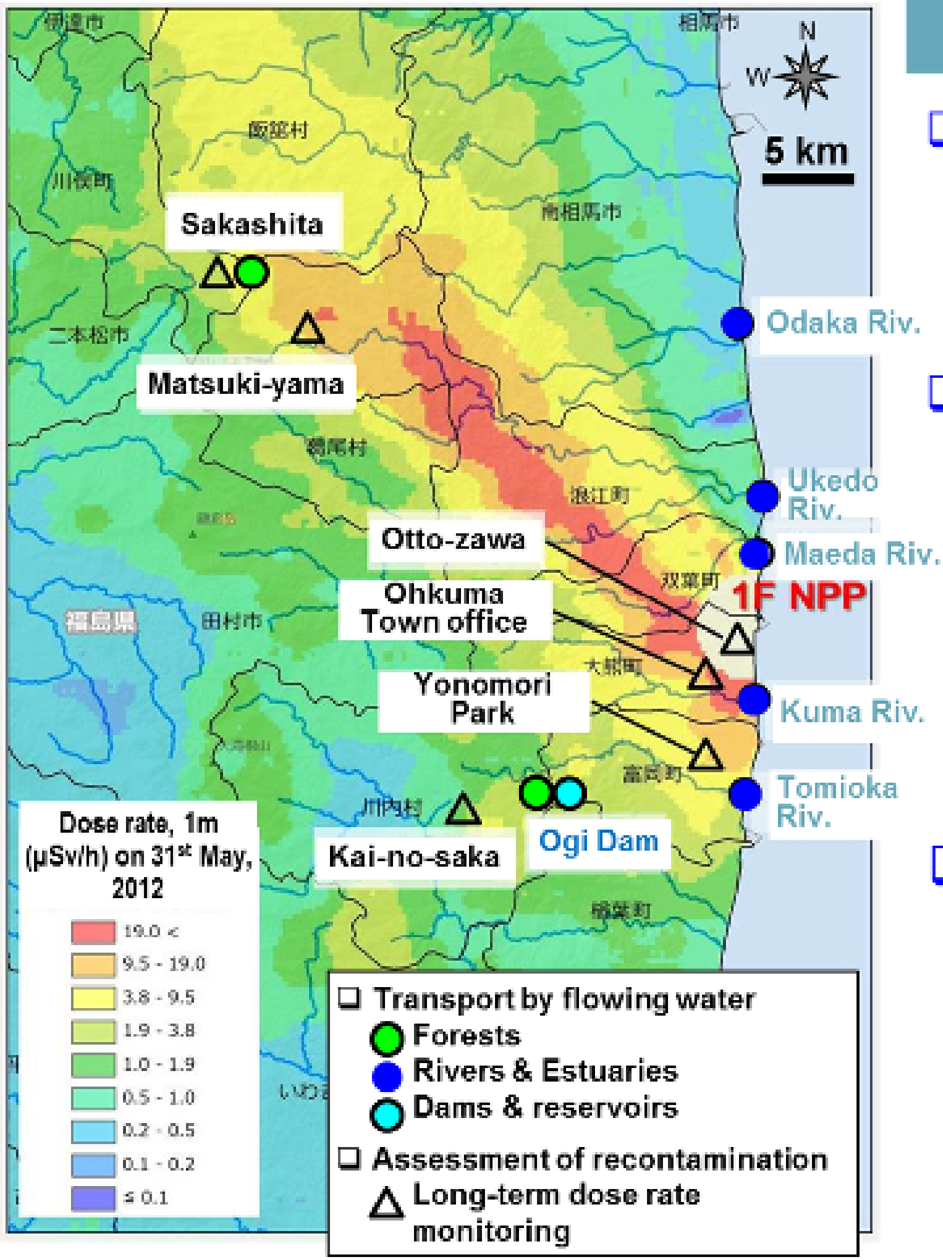




[Estuaries]
Transport by tides, waves, and coastal currents
Desorption of Cs from soil particles
Aggregation and deposition of soil particles



Investigation & Simulation Area



Modelling of Transport by flowing water:
5 rivers in Hama-dori (Pacific coastal region)

- **Forests investigation**
  - ✓Sakashita, Kawamata Town (deciduous broad-leaf forest)
  - ✓Ogi, Kawauchi Village (ever-green needle-leaf forest)
- **Rivers & Estuaries investigation**
  - ✓Ukedo & Takase Rivers (modelling of Cs transport in middle to downstream)
  - ✓Tomioka & Ogi-no-sawa Rivers (integrated modelling from mountain forest to dam)
  - ✓Odaka River (characterisation of soil particles & effects of salinity)
  - ✓Kuma & Maeda Rivers (model confirmation from mountain forest to estuaries)
- **Dam deposits investigation**
  - ✓Ogi Dam (Ogi-no-sawa River basin)

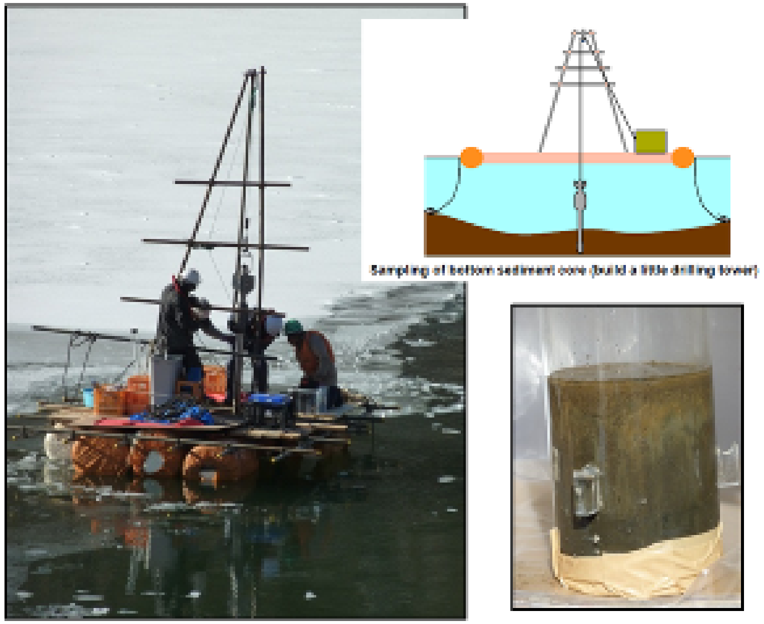
> ➢ Flowing from relatively high to low dose rate areas → easily detectable of Cs transport
> ➢ Small scale → less difficulty with the modelling & its validation

Dam deposits investigation:
Sampling of bottom deposits and dam water

Water sampling
(Heyroth sampling bottle)

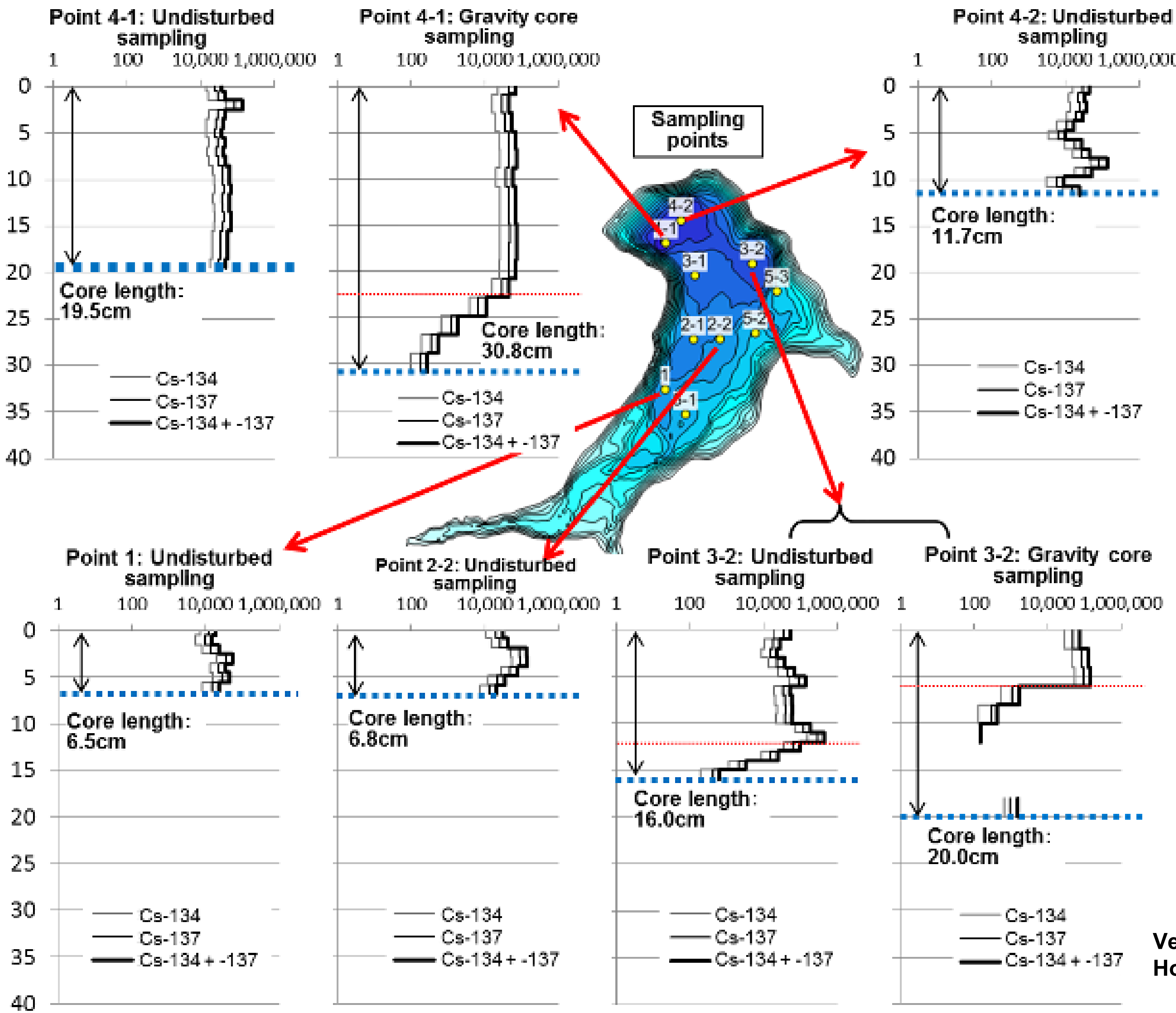
Sampling of bottom deposits
(Smith-Mcintyre Bottom sampler)

Core logging
(undisturbed sampling)



Core logging
(Gravity core sampler)

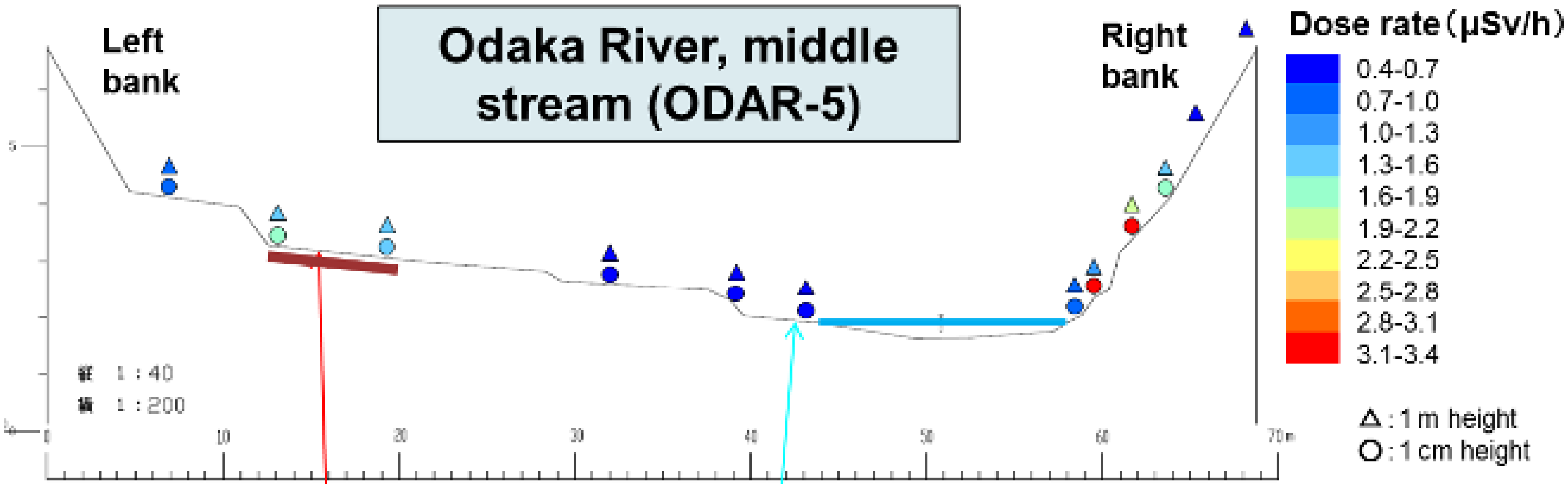
Dam deposits investigation:
Depth distribution of radiocaesium in the bottom deposits

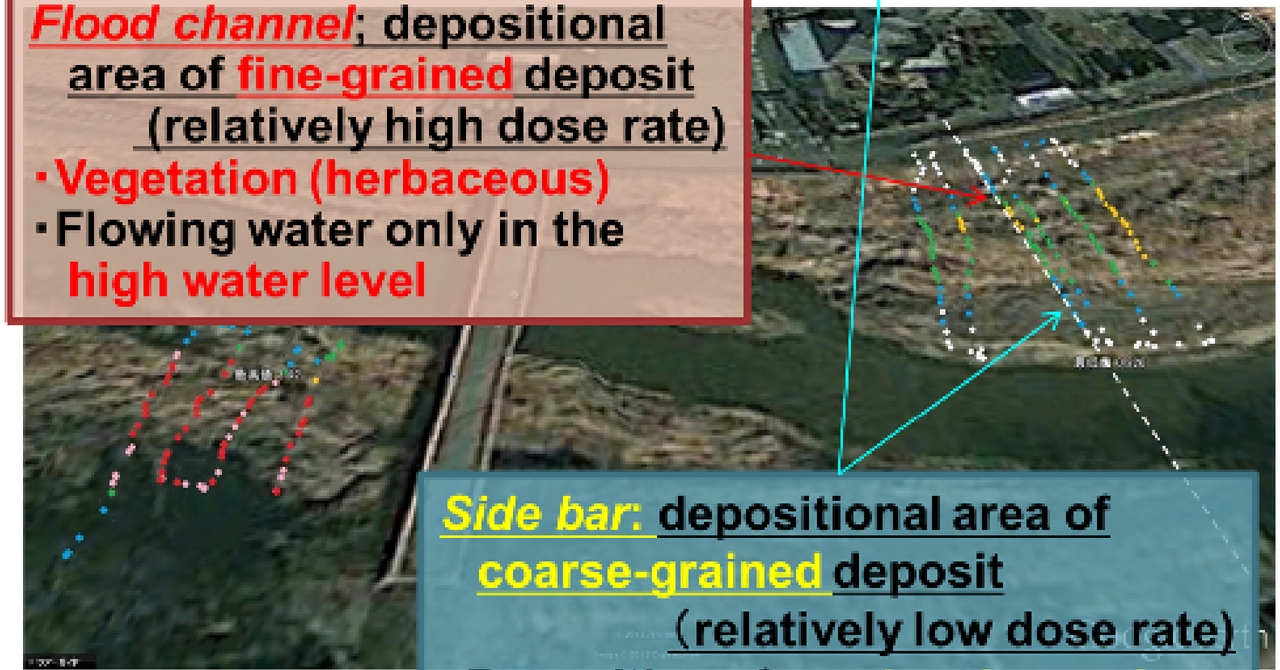


- **Thick fine-grained sediment at deeper part of the dam**
  - 22 cm in thickness,
  - constant Cs conc.
- **Thin fine-grained sediment at shallow part of the dam**
  - ca. 7 cm in thickness
- **Radioactive Cs was NOT significantly detected in any lake water samples.**

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

River investigation: Dose rate across the river





Flood channel; depositional area of **fine-grained** deposit (relatively high dose rate)

- **Vegetation (herbaceous)**
- **Flowing water only in the high water level**

- **Depositional areas of fine soil particles are relatively high dose rate.**
  →Indication of Cs accumulation

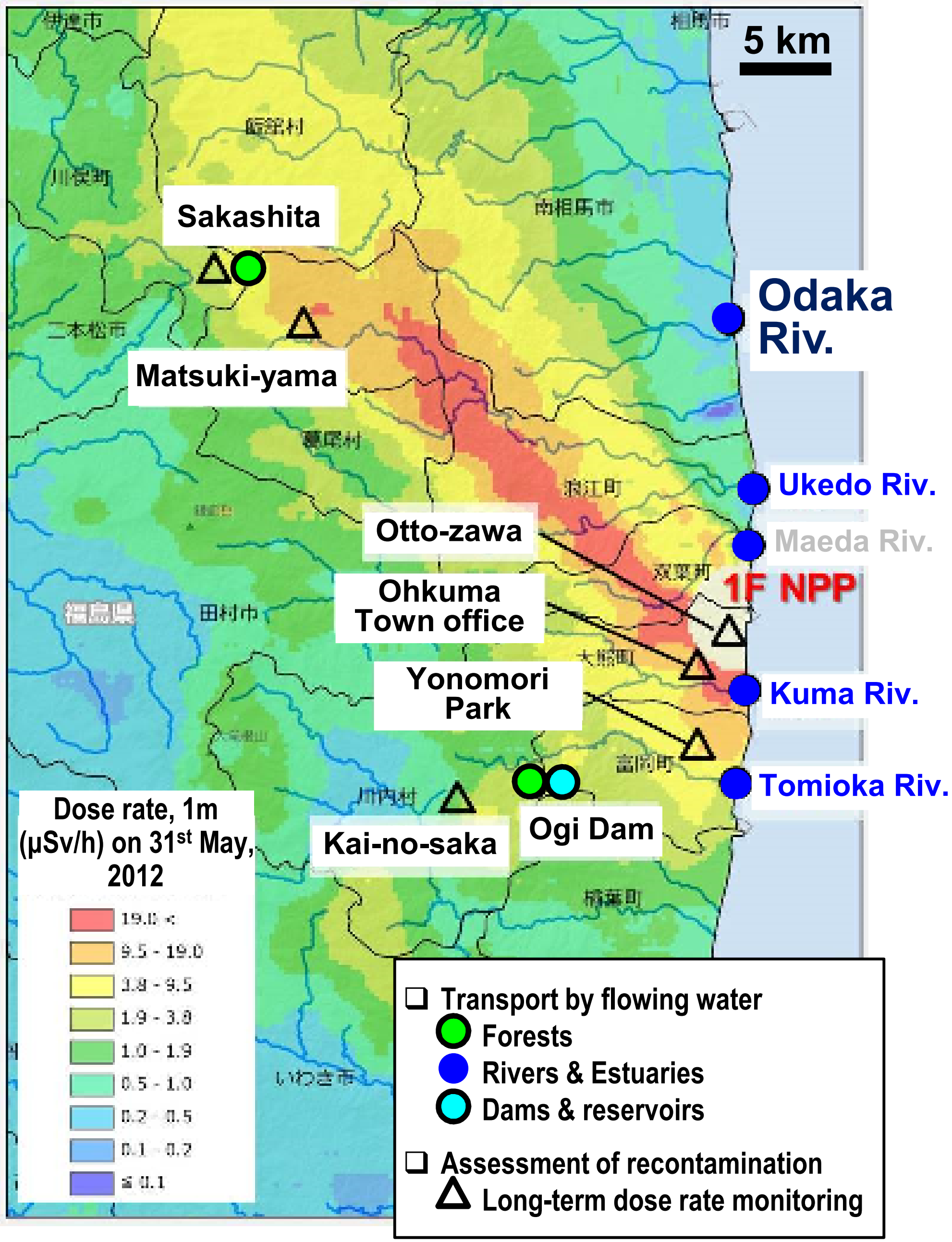
Side bar: depositional area of **coarse-grained** deposit (relatively low dose rate)

- **Deposition of sand and gravel**

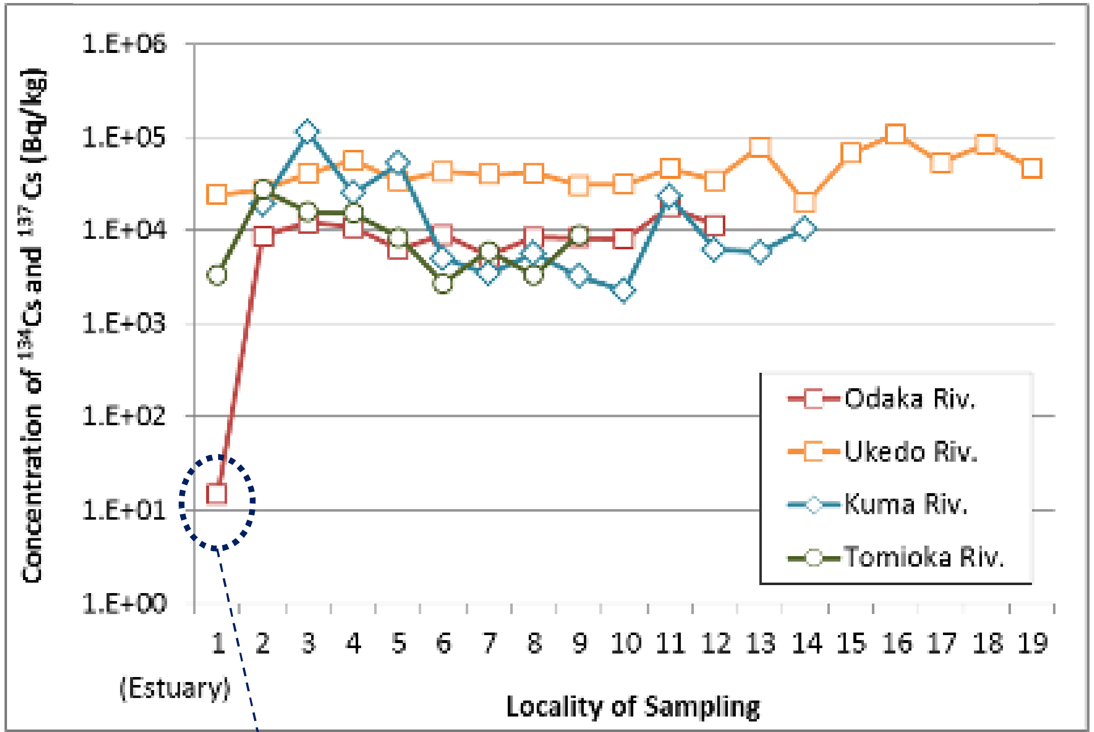
Dose rate（μSv/h）
<5 cm height>

- ≦0.5
- 0.5 - 1.0
- 1.0 - 1.5
- 1.5 - 2.0
- 2.0 - 2.5
- ＞2.5

River investigation: Cs concentration along the river



Concentration of Cs in flood channel

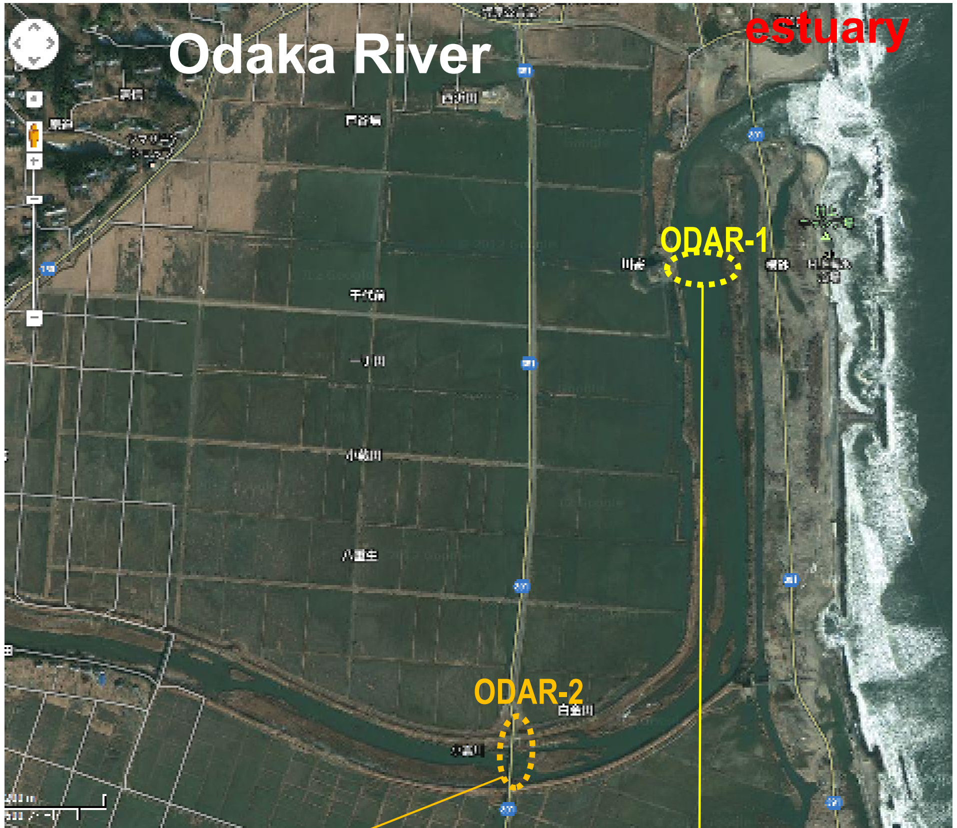


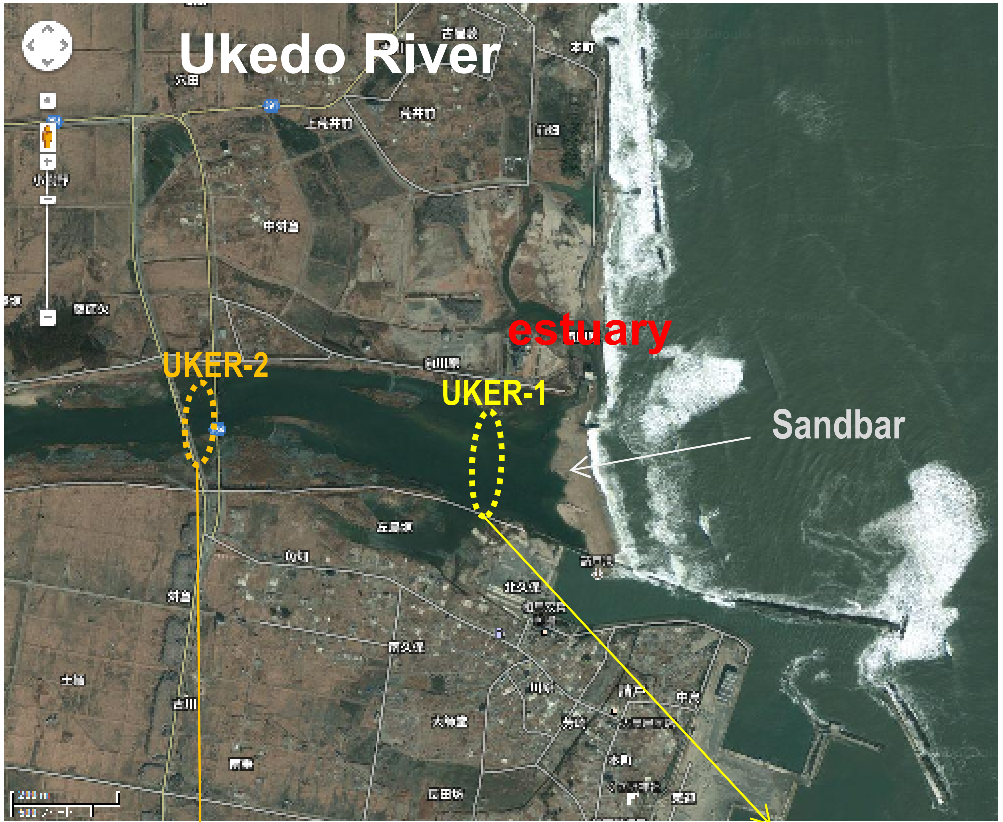
Cs concentration drastically **decreased** at the closest point to **estuary** in **Odaka River**.

- **Coastal sandbar** was **NOT formed** at estuary in **Odaka River**, but formed in other rivers.
- **Salinity** at the closest point to estuary was **similar to seawater** in **Odaka River**, but two orders of magnitude lower in Ukedo River (see next slide).

→ **Cs** was possibly **desorbed** from soil particles **near estuary** in **Odaka River**.

River investigation: 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

Conclusion

➢ Understanding of Cs Behavior and Practical Ways for

- Decrease in Waste Generation
- Long-term Safety Assessment due to Cs Behavior from Un-decontaminated Forest

are Important.

➢ Continuous / Practical R&Ds are Needed to Decrease Uncertainties in Fukushima.