Migration behavior of radioactive cesium in forests and mountains

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Japan Atomic Energy Agency

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F-TRACE PROJECT
LONG-TERM ASSESSMENT OF TRANSPORT OF RADIOACTIVE CONTAMINANT IN THE ENVIRONMENT OF FUKUSHIMA
福島長期環境動態研究プロジェクト

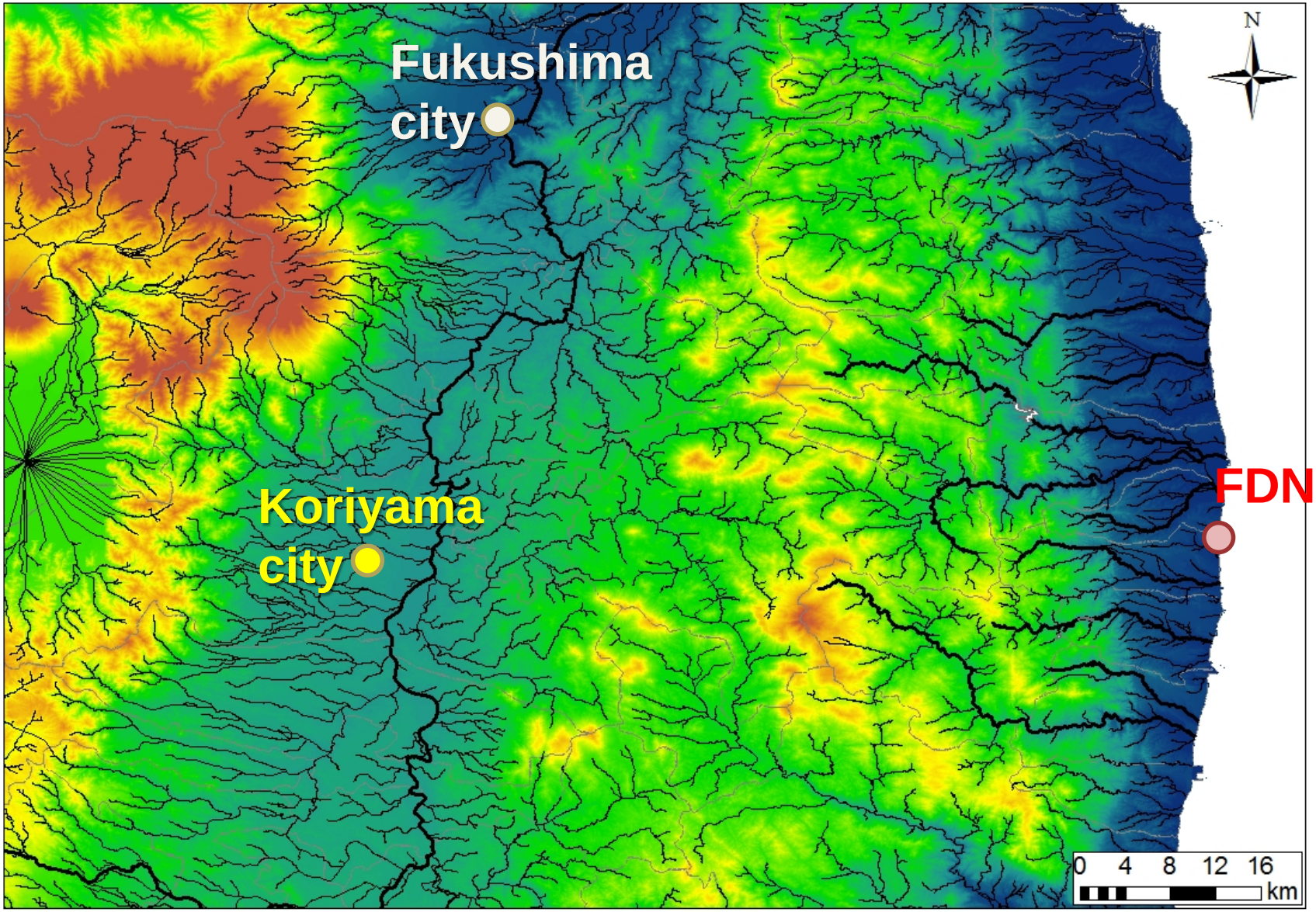
JAEA

2016 SRRCE International Symposium (2016/07/08@Fukushima)

Outline

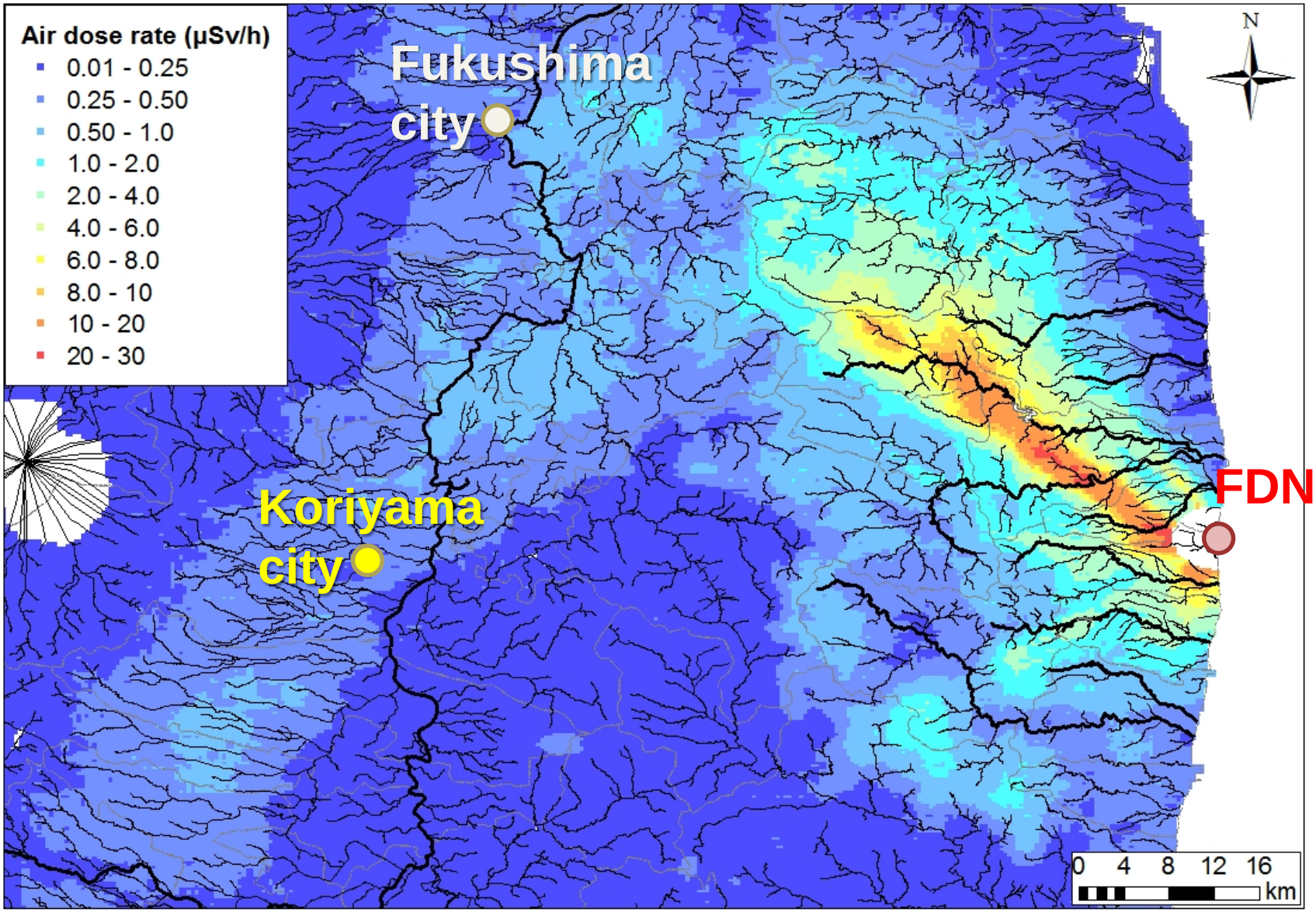
- **Behavior of radioactive Cs in forests**
  - **Characteristics of distribution and transportation of Cs in the environment**
  - **Short-term countermeasures**
  - **Long-term countermeasures**
  - **Issues to be considered**

Topographical characteristics of the Fukushima



Topography of eastern and central part of the Fukushima prefecture.

Contamination by the FDNPS accident

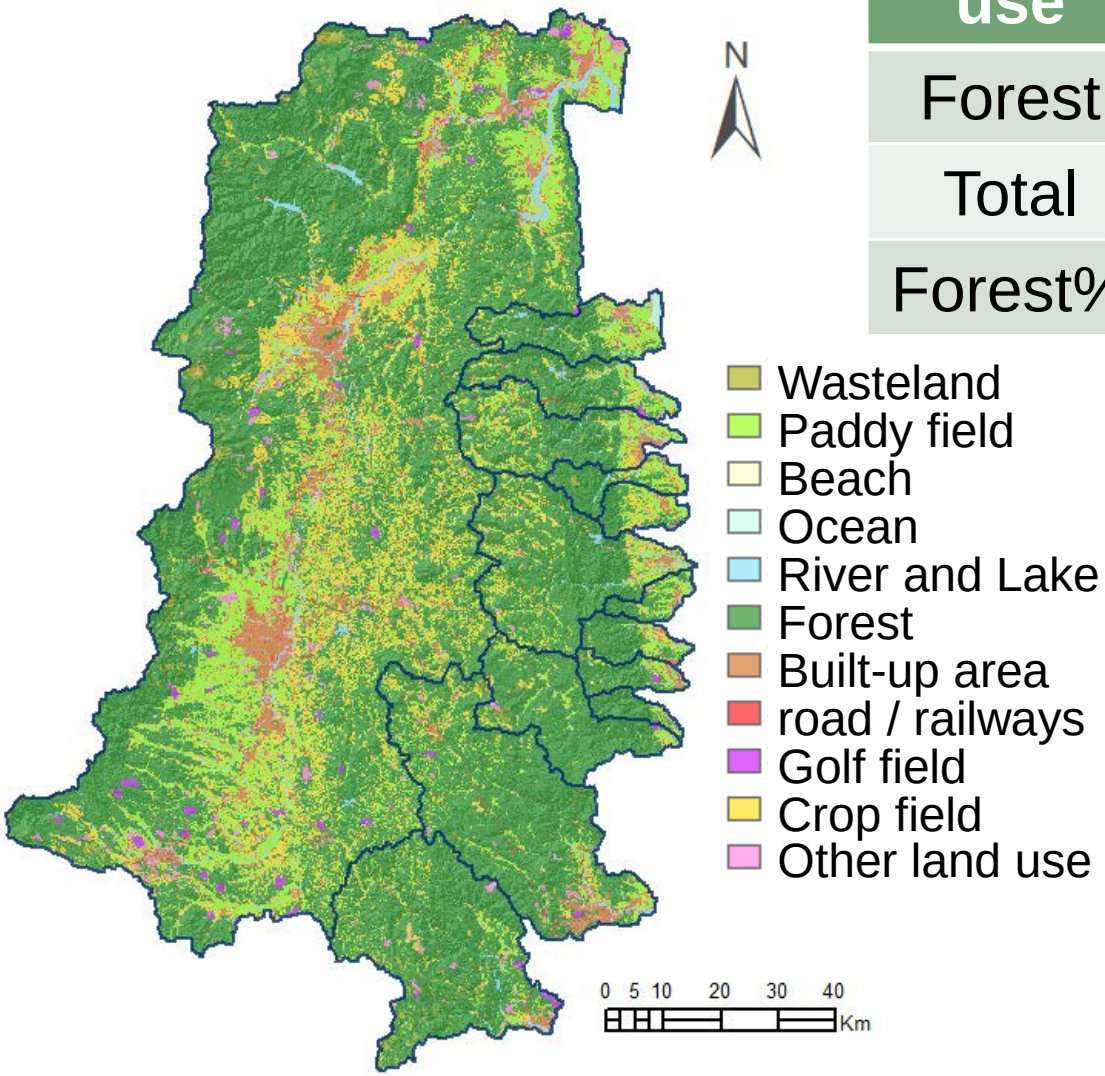


Distribution map of air dose rate in the Fukushima prefecture.

(measured from the 1st Sept. to the 7th Nov. 2014 by NRA and corrected to the 7th Nov. 2014)

Initial Cs distribution: Forests occupied the most

Land use	Area (km^2)	Initial Cs (TBq)
Forest	5,330	920
Total	8,370	1,300
Forest%	64%	**69%**



Land use distribution in eastern Fukushima

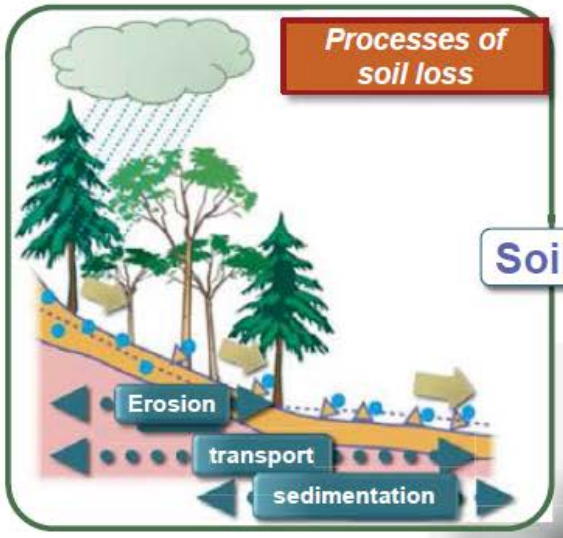
Kitamura et al., *Anthropocene* (2014).

Objective 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

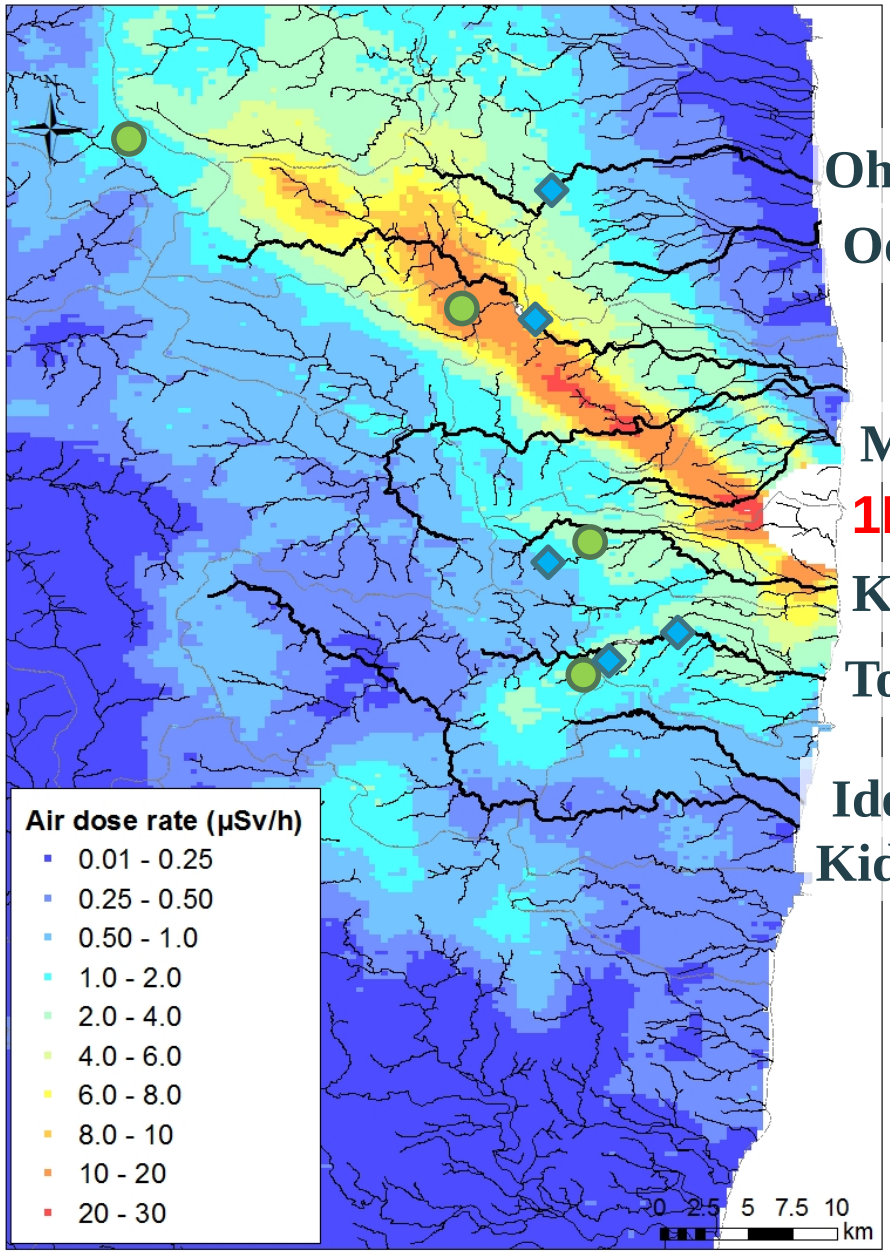


Behavior of each species of radioCs in forests
- → evaluate external irradiation of *forestry workers*
- → apply to evaluate cycle of Cs in *forested ecosystem*

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*

Research area



Ohta

Odaka

Ukedo/Takase

Maeda

1F NPP

Kuma/Ogawara

Tomioka/Oginosawa

Ide

Kido

- **Comparing** behaviors in several river systems with different characteristics is useful to clarify factors dominate transport of RCs.

- **Systematic research** on each river system from forests to estuary makes it possible to evaluate the behavior in whole catchment.

Monitoring of surface runoff and soil loss

Stem flow tank (70 L)

Water Level gauge

Precipitation gauge

Solar battery panel

Surface runoff

Gauge of soil moisture

ca.10 m

ca.6 m

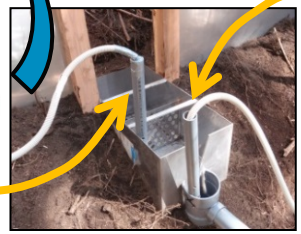
ca. 20 cm height

Water sampler(10 L) (throughfall)

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

Turbidity gauge

Water level gauge



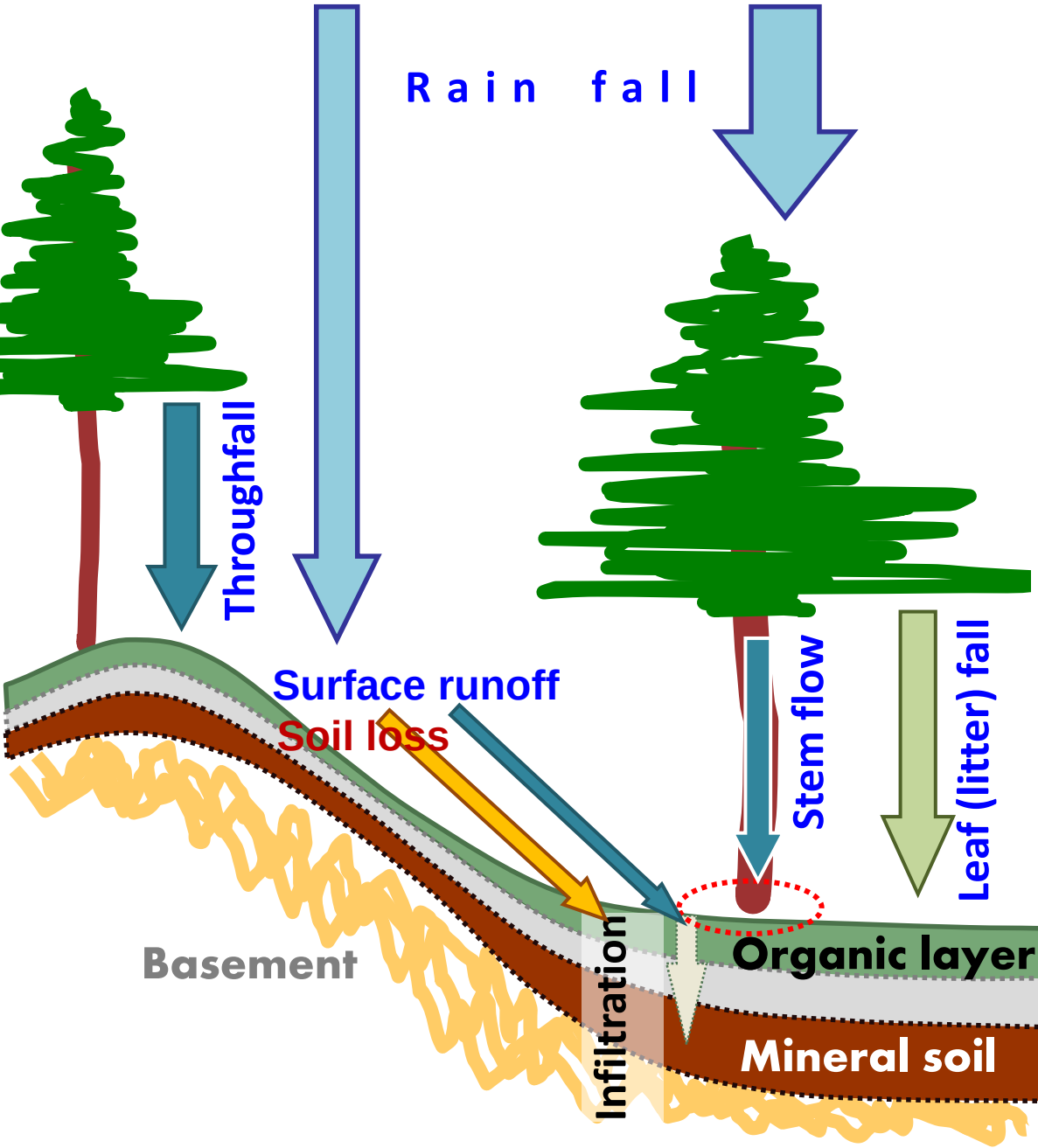
Triangular weir (W 30cm, H 25cm, D 60cm)

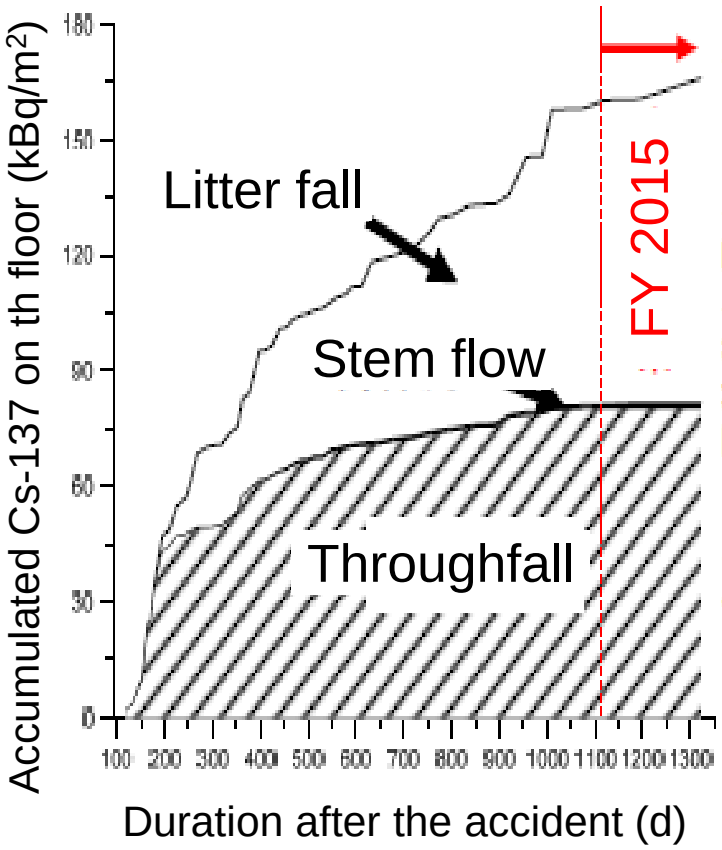
- ***Rainfall*** ***(gross precipitation)***
- ***Throughfall***
- ***Stem flow***
- ***Surface runoff & Soil loss***
- ***Transport of radioactive Cs with Surface runoff & Soil loss on the forest slope***

Flowing into river system

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

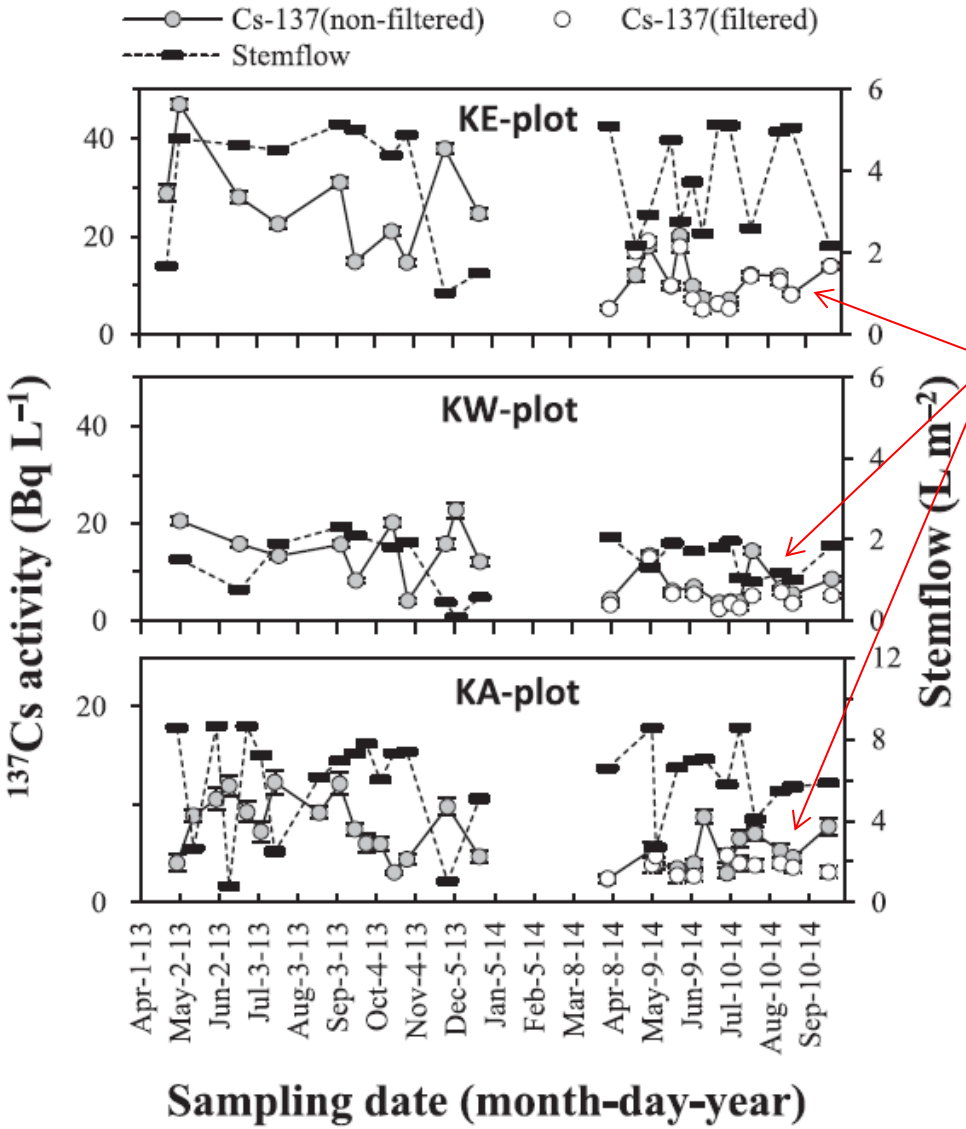
Water, litter and soil movement





Kato et al., *J. Environ. Radioact.* (in press).

Cs in Stemflow



- ✓ Concentration of Cs in non-filtered stemflow sample was similar to that of filtered.
- ➢ Dissolved fraction of Cs was dominant in the stemflow.

Stemflow and its Cs-137 activity. The Cs-137 activity is a volume-weighted average of triplicate at each experimental plot (KE&KW; Kawamata, KA; Kawauchi).

Niizato et al., *J. Environ. Radioact.* (2016).

Cs transported by soil loss

Erosion rate of Cs-137 with soil in observation plots in forests from April to November (8 month).

	2013	2014	2015
Kawauchi Evergreen (Japanese cedar) Steep slope	*0.10%*	*0.06%*	*0.30%**
Kawamata (KE) Deciduous Gentle slope	*0.02%*	*0.10%*	
Kawamata (KW) Deciduous Steep slope	*0.05%*	*0.11%*	*0.23%*

* The outlet to collect eroded soil of this plot was repaired on Nov. 2014.

Based on Niizato et al., *J. Environ. Radioact.* (2016).

Cs adsorbed onto soil

① Original forest soil

- residue
- 3rd 1M HCl
- 2nd 1M HCl
- 1st 1M HCl
- 3rd 1M KCl
- 2nd 1M KCl
- 1st 1M KCl
- 3rd 0.01M NaCl
- 2nd 0.01M NaCl
- 1st 0.01M NaCl

② After H_2O_2 treatment (removal of organics)

✓ Soil samples after sorption experiments were sequentially desorbed by;
- NaCl (simple washing),
- KCl (ionic exchange),
- HCl (inside the solids).

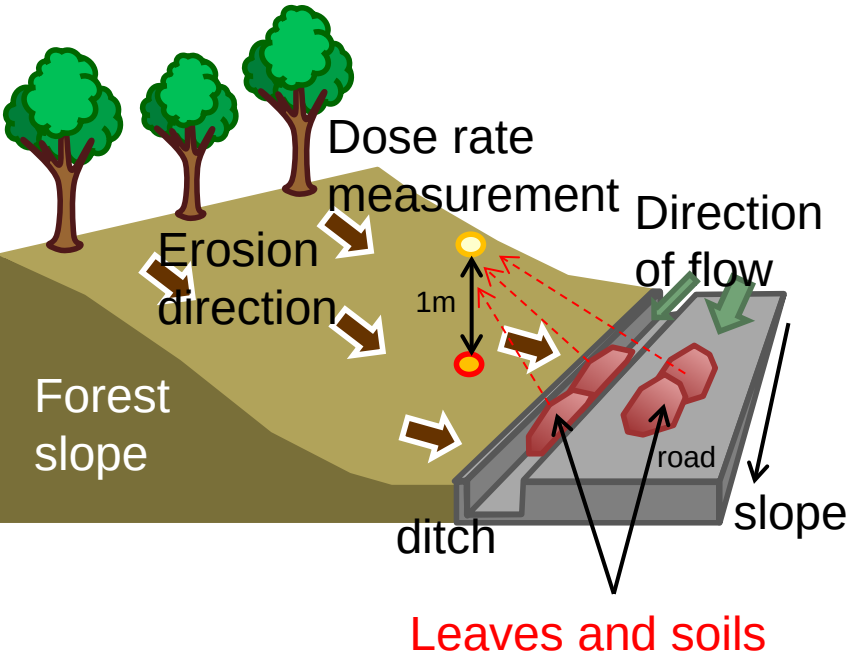
➢ Cs was strongly adsorbed onto soil regardless of organic contents and hardly desorbed.

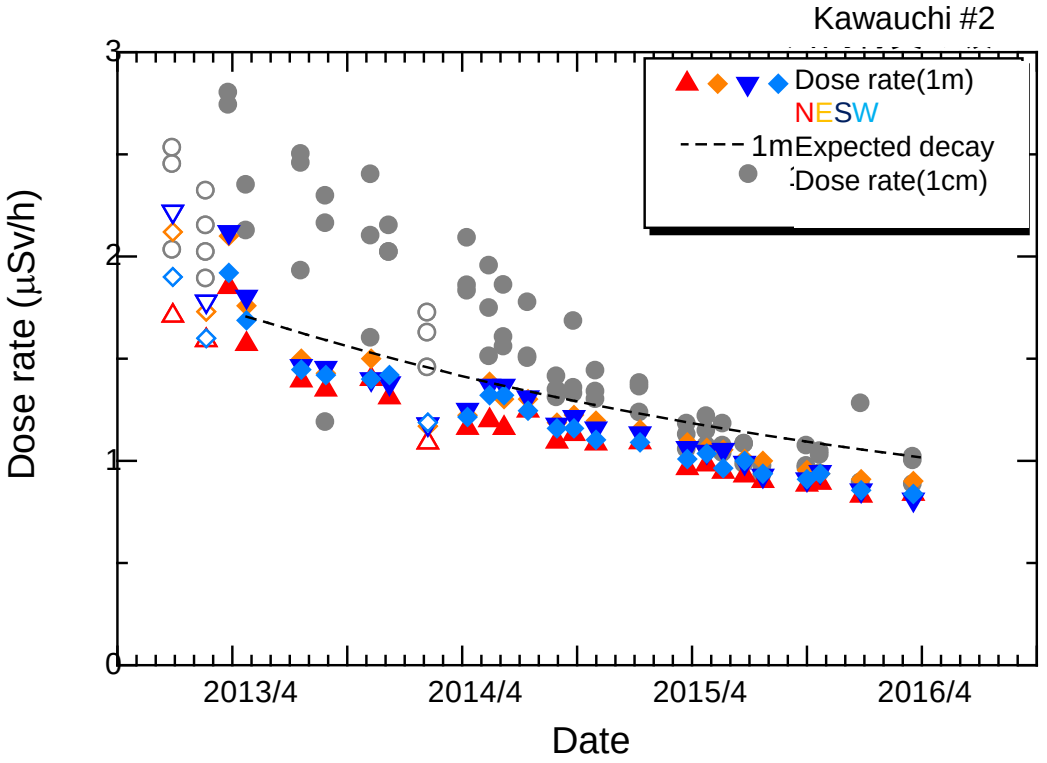
Evolution of dose rate after decontamination

Measurement points for dose rate designated at boundary between decontaminated area (in the Decontamination Pilot Project) and not decontaminated forests in Kawauchi.

Evolution of dose rate after decontamination

Evolution of dose rate after decontamination





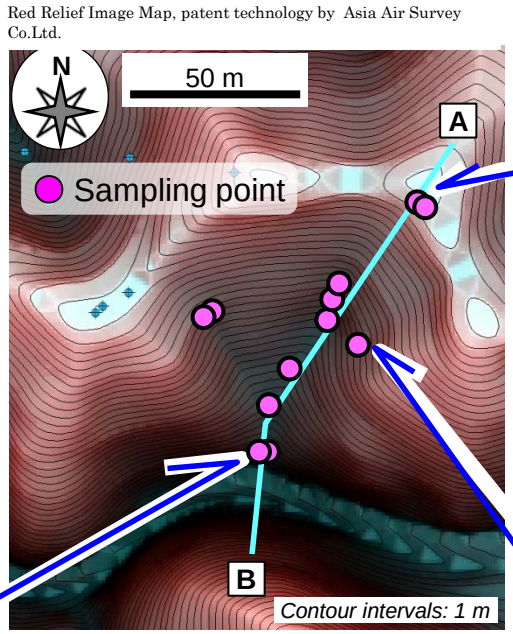
- ✓Dose rates at the surface were scattered (gray circles).
  - ✓Leaves and soils from forests temporally sedimented.
  - ✓However, they were maybe removed by next flowing water.
- ✓Air dose rates showed decrease depending on decay of Cs.

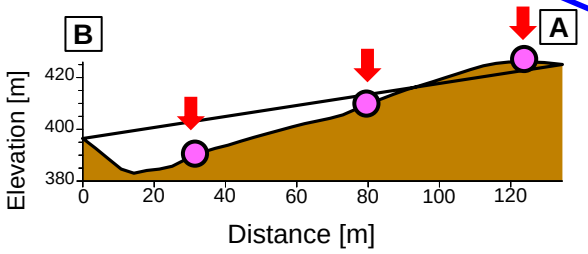
=> Discharge of Cs from forests was quite limited so that increase of air dose rate at forest edge was not significant.

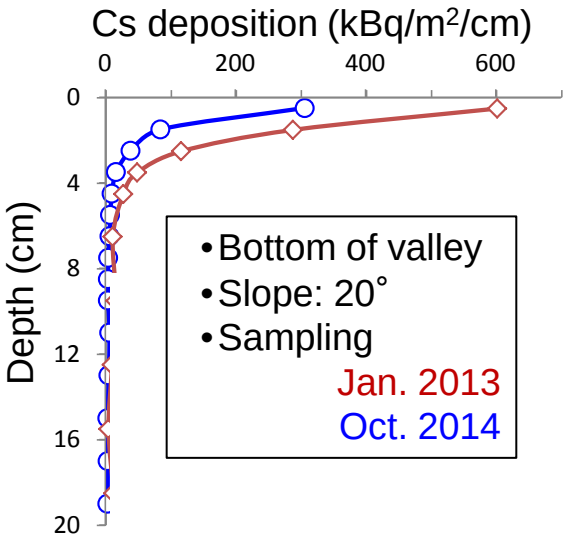
Depth distribution of Cs

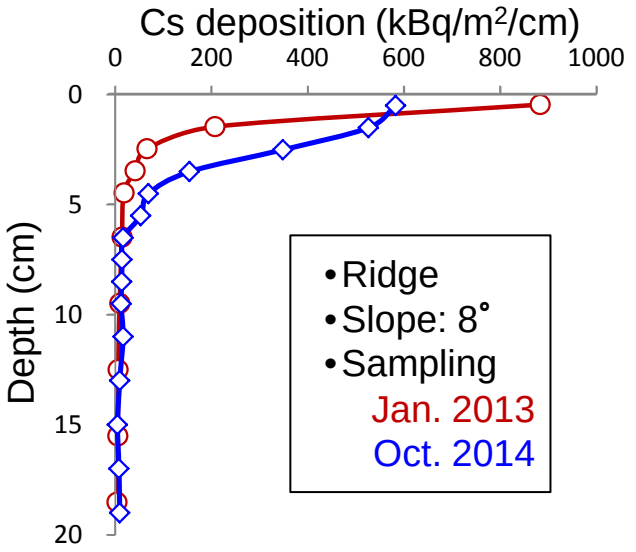
Brown forest soil

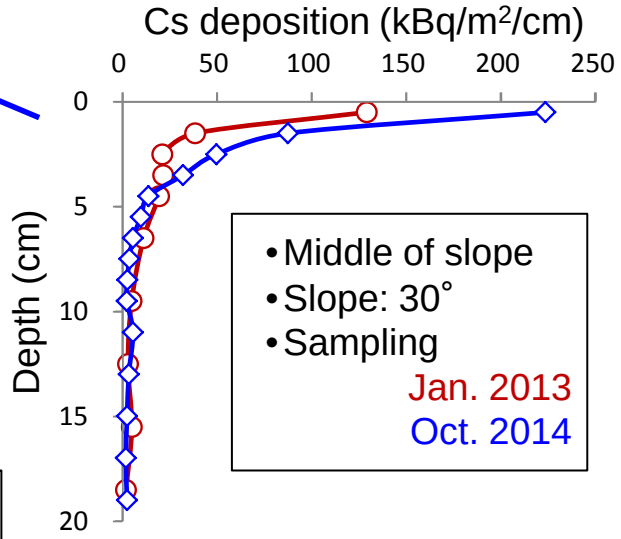
Sample No. : PAK-1, at crest flat





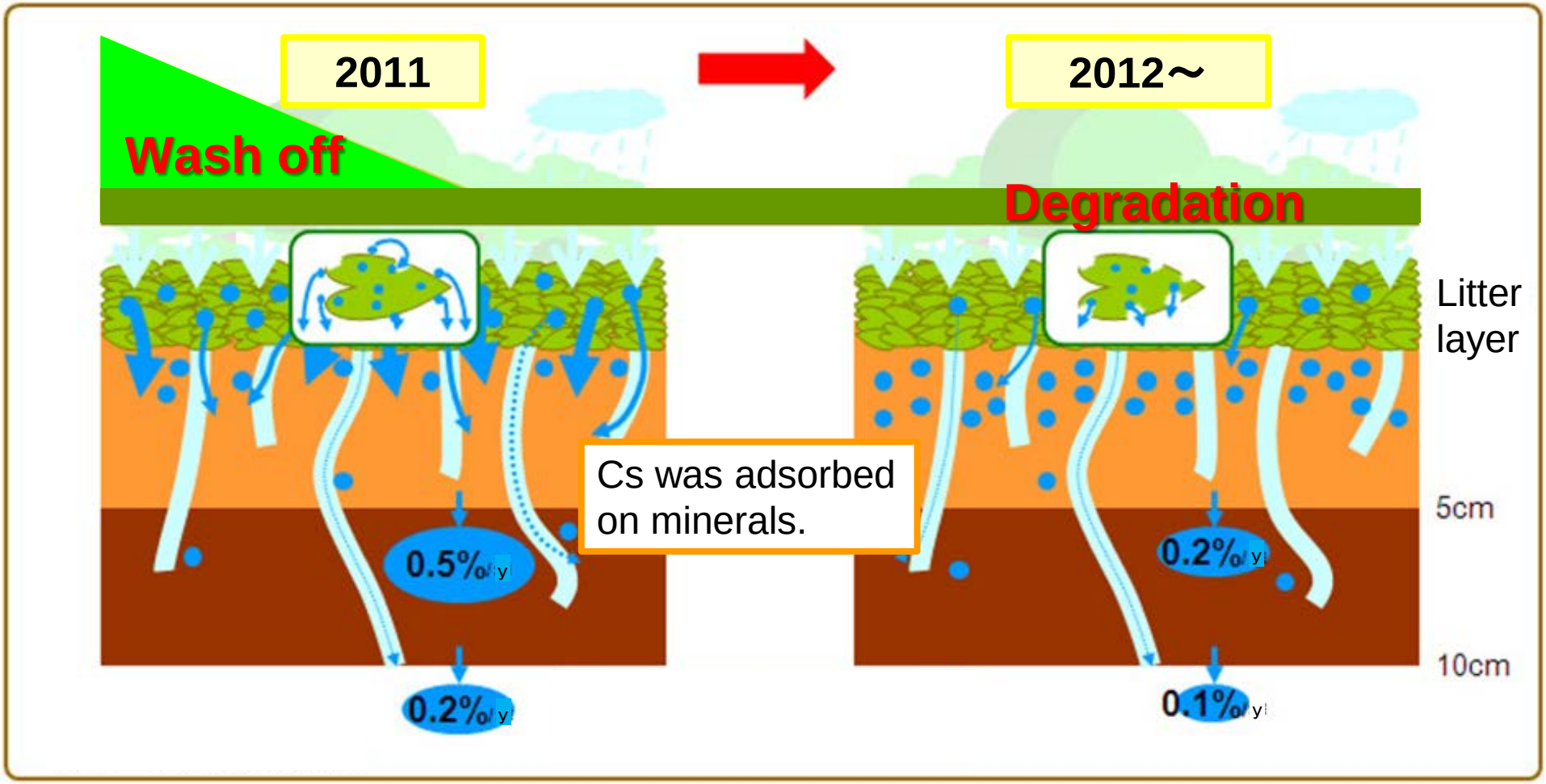






- 84-92% of deposited Cs existed within 5 cm on Oct. 2014.

Migration behavior of Cs

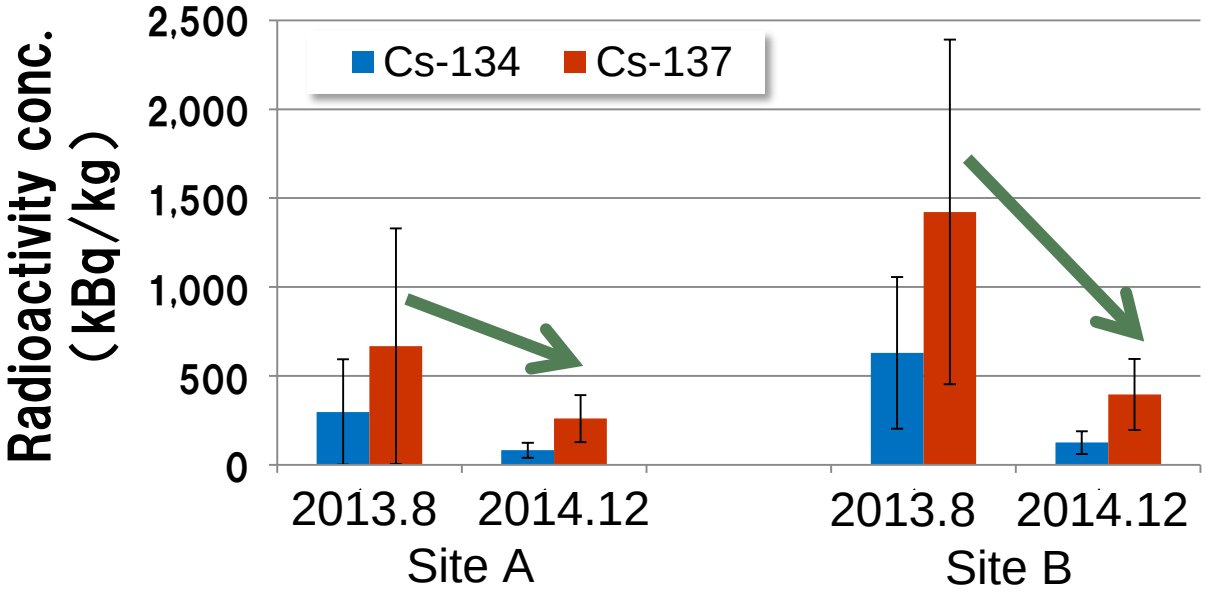


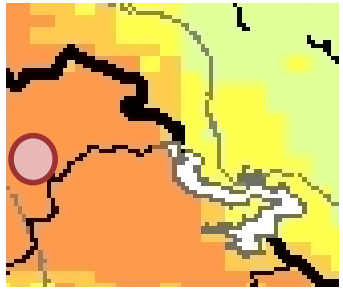
- Process of supply of Cs to the mineral layer has been changed.
- Cs is being accumulated in 0 – 10 cm mineral layer.

http://www.jaea.go.jp/02/press2013/p13102901/index.html

Nakanishi *et al., J. Environ. Radioact*. (2014).

Cs discharged to river system



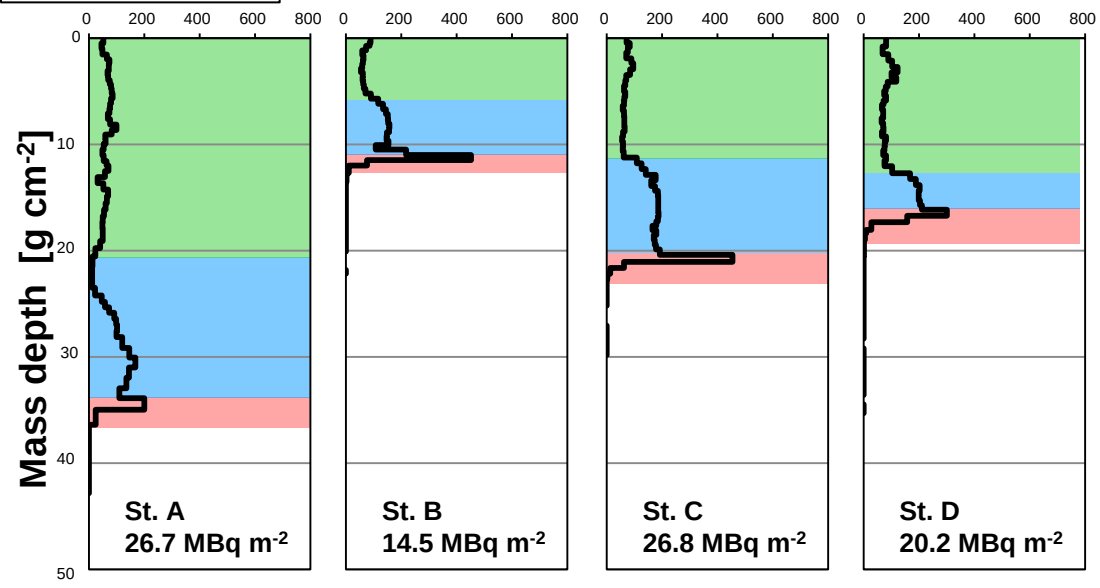


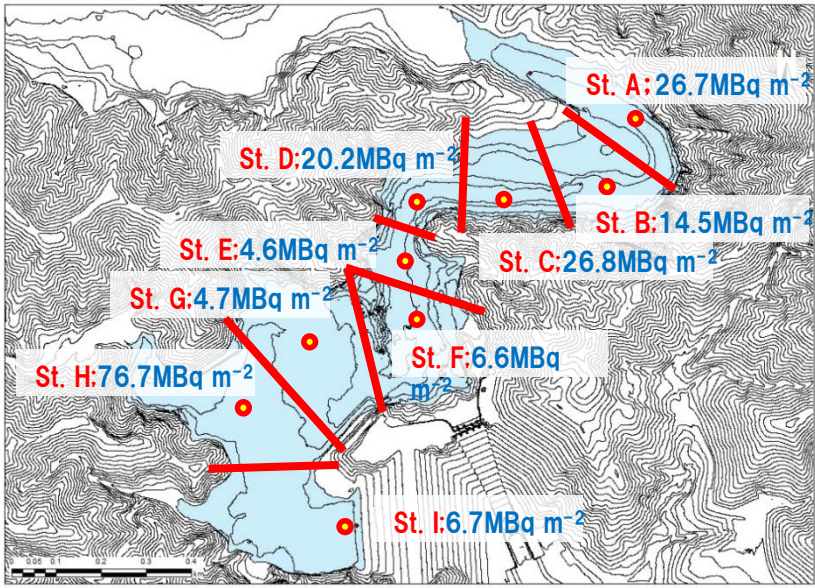
- Surface deposits inside small dams located between moutainside forest and mountain stream were collected.

- Concentration of radioactive Cs in the deposits supplied from forests decreased with the elapse of time.

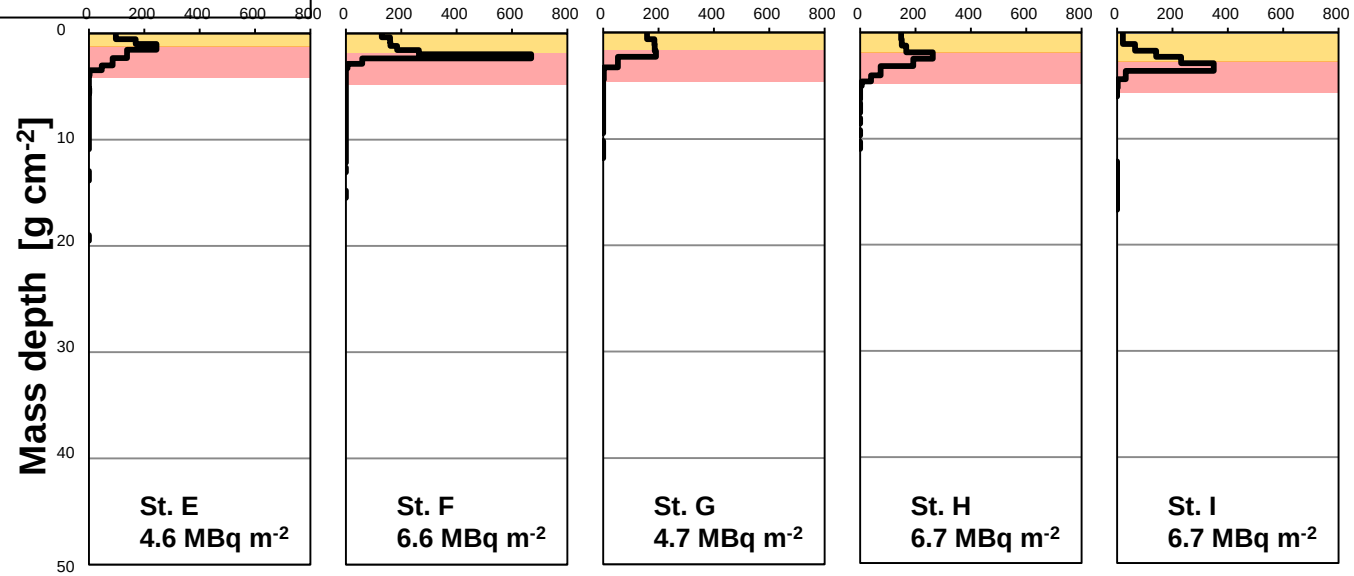
Concentration of Cs in the sediments of the Ogaki dam lake

Upstream





Downstream



- Cs concentration in the bottom sediments of dam lake also decreased with time.

Countermeasures to keep soil in forests

➢ Enough litter layer and vegetation are required.

Wild plants and mushrooms

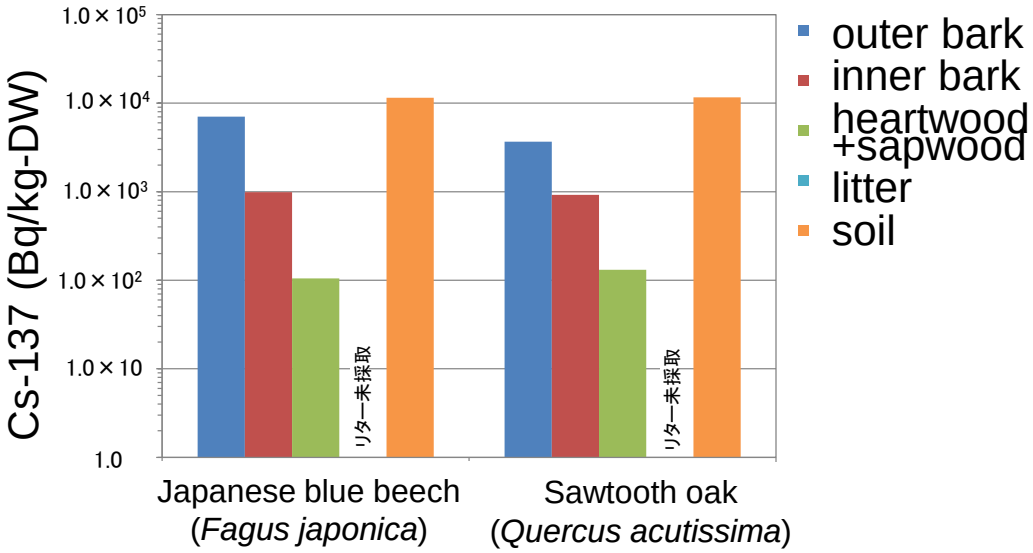
Plants	Sampling	Plant Cs-137 (Bq/kg-DW)	Soil Cs-137 (Bq/kg-DW)	TF
oudo (spikenard)	2015/4	1.5×10^{2}	8.6×10^{3}	1.7×10^{-2}
western bracken fern	2015/4	1.6×10^{3}	1.3×10^{5}	1.2×10^{-2}
bamboo shoot	2015/5	9.2×10^{3}	1.2×10^{4}	7.9×10^{-1}
ostrich fern	2015/5	1.8×10^{2}	1.6×10^{4}	1.1×10^{-2}
giant butterbur	2015/5	2.0×10^{2}	5.8×10^{3}	3.4×10^{-2}
giant butterbur	2015/5	8.8×10^{1}	5.8×10^{3}	1.5×10^{-2}
Eleutherococcus sciadophylloides	2015/5	8.5×10^{3}	1.8×10^{4}	4.8×10^{-1}
Eleutherococcus sciadophylloides	2015/5	1.1×10^{4}	1.5×10^{4}	7.0×10^{-1}
chocolate vine	2015/9	4.0×10^{1}	1.4×10^{4}	2.9×10^{-3}
Vaccinium oldhamii	2015/9	2.0×10^{2}	1.1×10^{4}	1.8×10^{-2}
Vaccinium oldhamii	2015/9	1.0×10^{2}	3.8×10^{3}	2.6×10^{-2}
hana peach	2015/9	3.6×10^{1}	1.6×10^{4}	2.2×10^{-3}
Japanese chestnut	2015/9	1.1×10^{4}	2.1×10^{4}	5.3×10^{-1}
Japanese chestnut	2015/9	1.5×10^{3}	7.2×10^{3}	2.1×10^{-1}
Japanese chestnut	2015/9	1.1×10^{3}	7.0×10^{4}	1.5×10^{-2}
Japanese chestnut	2015/9	4.0×10^{3}	3.6×10^{4}	1.1×10^{-1}

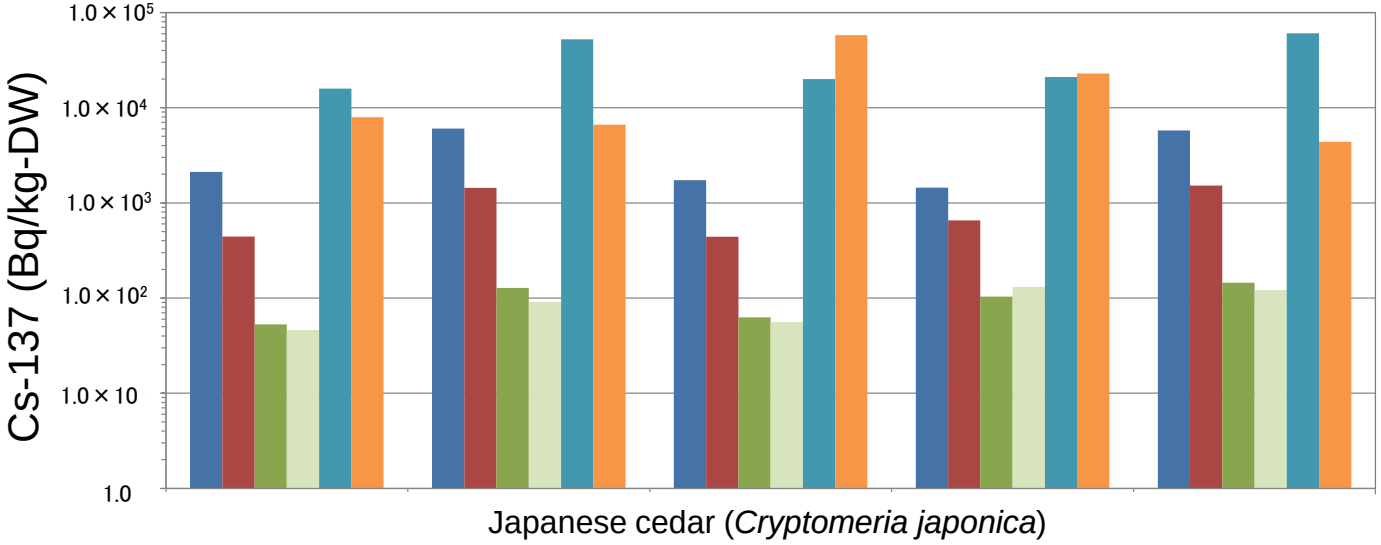
Eleutherococcus sciadophylloides

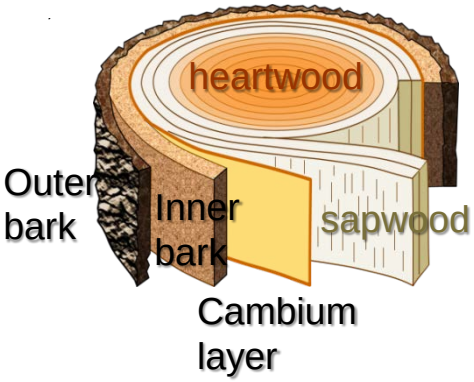
Mushrooms	Sampling	Mushroom Cs-137 (Bq/kg-DW)	Soil Cs-137 (Bq/kg-DW)	TF
Trametes versicolor	2015/4	7.0×10^{3}	1.3×10^{4}	0.56
Hypholoma sublateritium	2015/10	1.2×10^{4}	1.6×10^{4}	0.80
Hypholoma sublateritium	2015/11	1.4×10^{4}	7.1×10^{4}	0.20

Hypholoma sublateritium

Trees



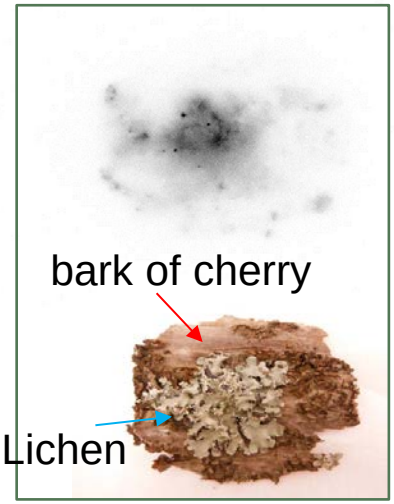




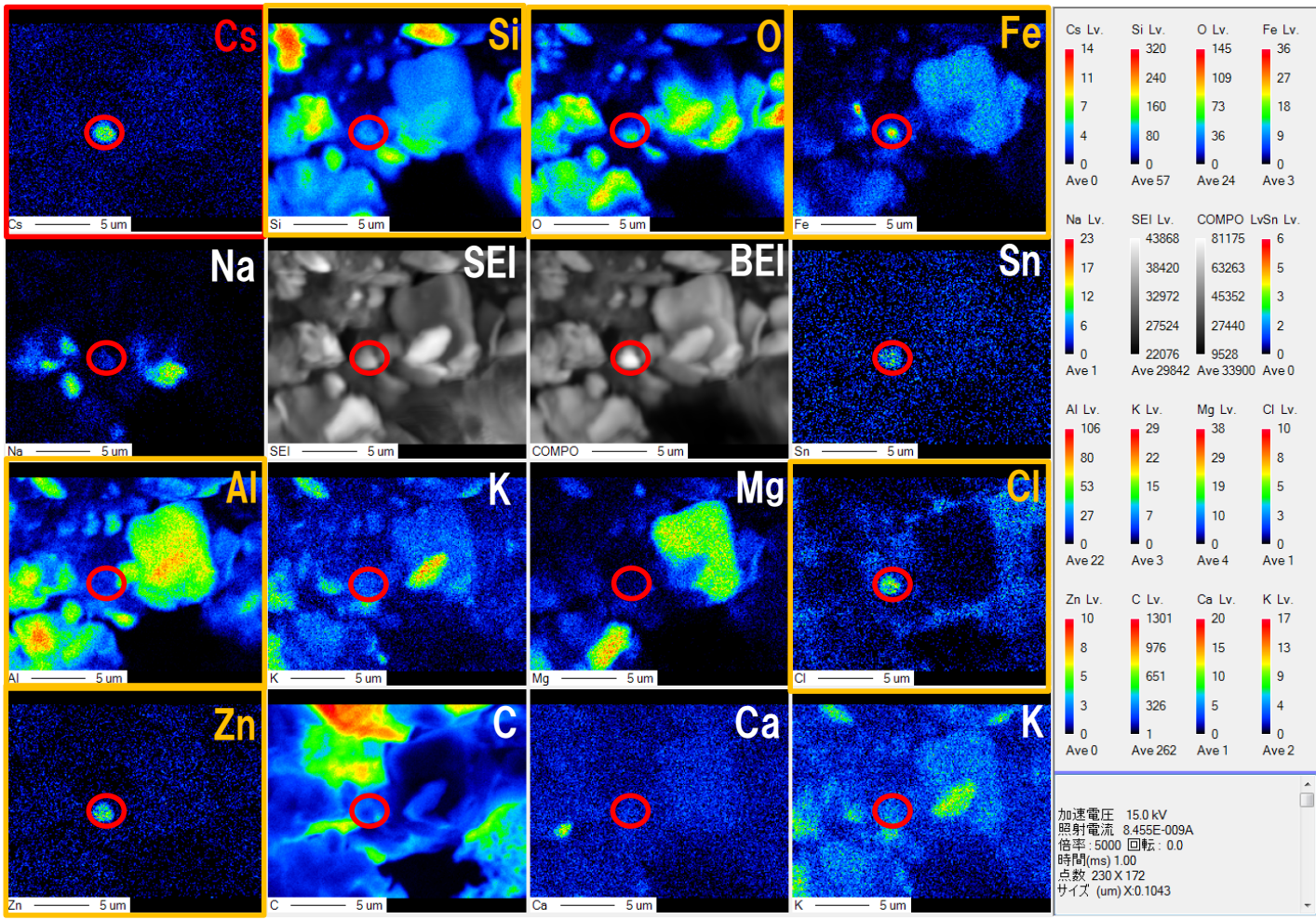
- Concentrations in barks were relatively high.
  => relationship to Cs in stemflow?
- Concentrations in sapwood and heartwood were lower than those of barks.

Particulate Cs on trees and lichens

examples of lichens



examples of lichens

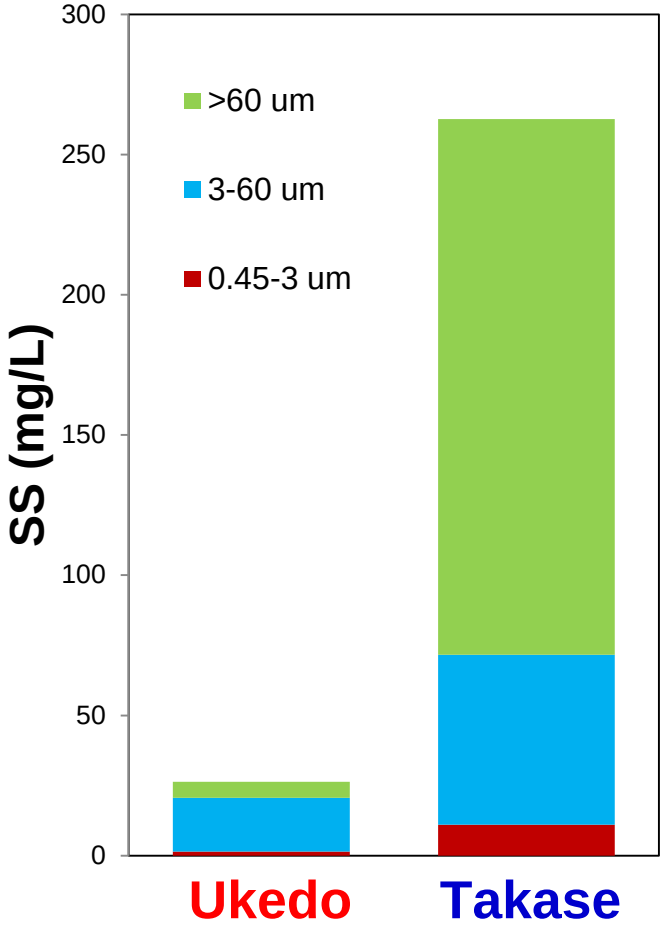


Mapping of elemental distribution around the particle with high concentration of Cs, which could be distinguished by autoradiography.

- Cs Concentrated point was observed on barks by autoradiography.
  => particulate Cs related to dissolved Cs in stemflow?

Dissolved Cs in river water

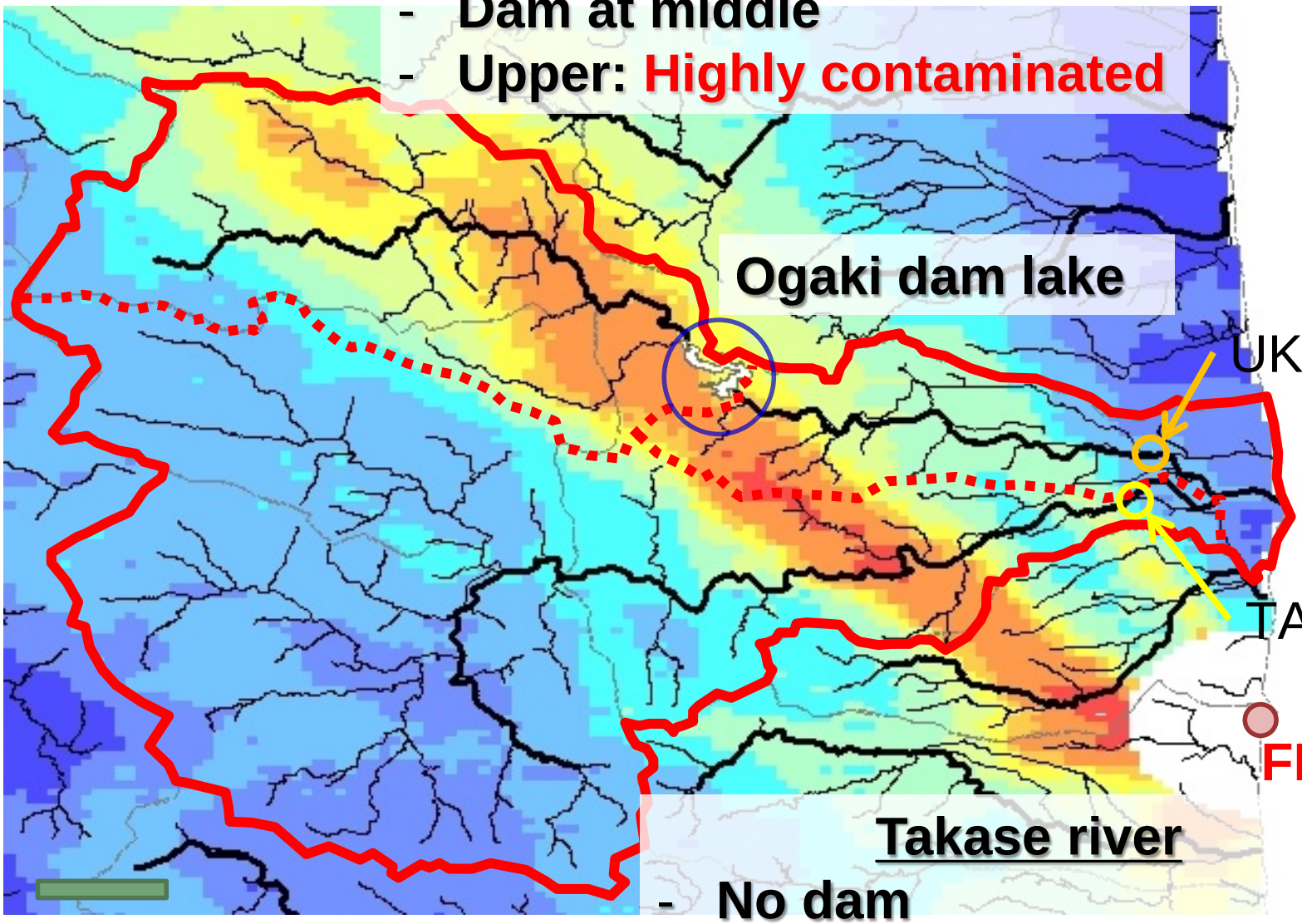
Suspended solids（SS, left）and radiocesium（right）concentration in lower Ukedo and Takase river waters in the tyhpoon in 2013.



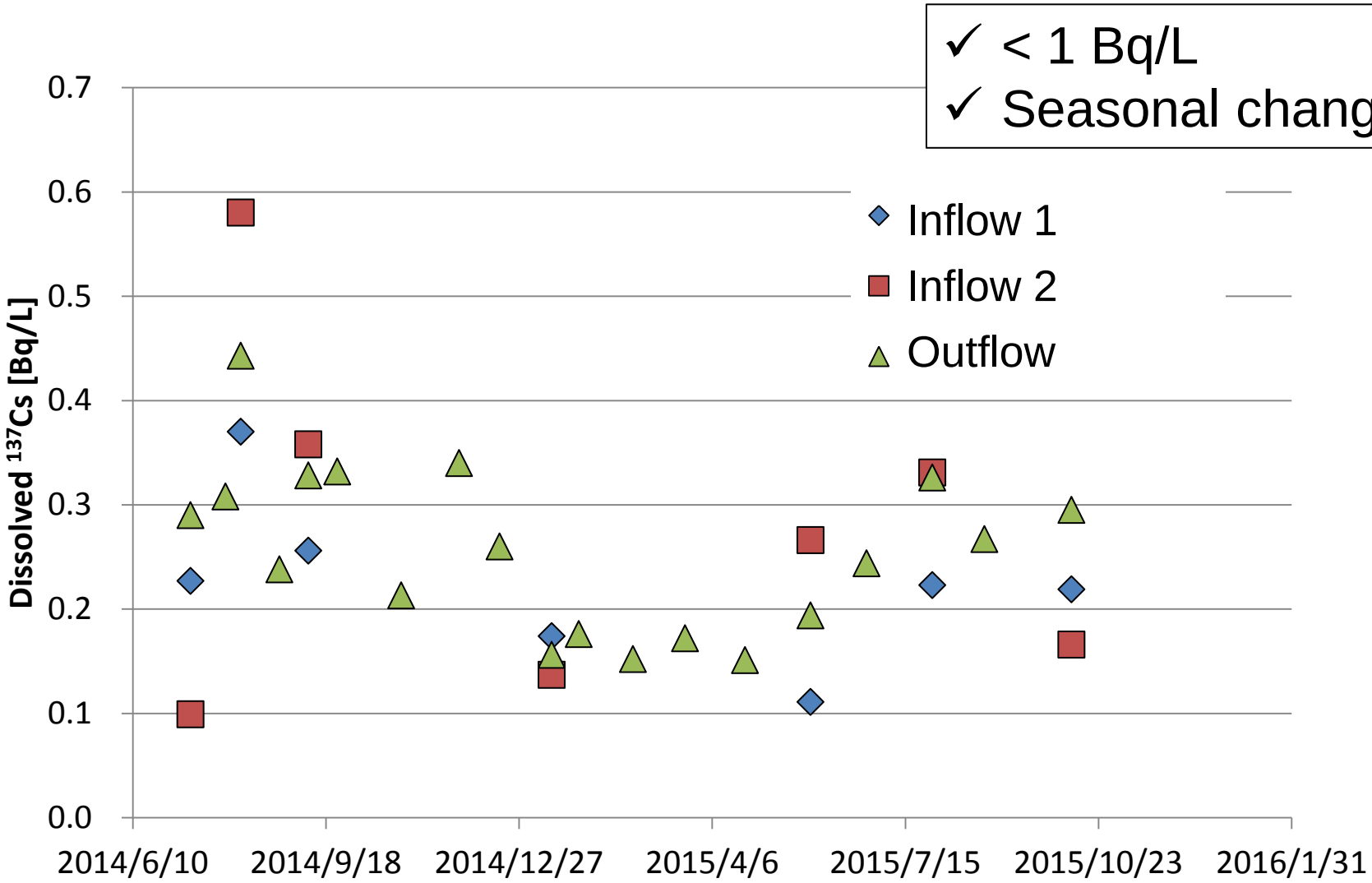
（Bq/L）	Ukedo	Takase
Dissolved ^{137}Cs	**0.31 ±0.03**	**0.05 ±0.02**
SS-bound ^{137}Cs	**2.2 ±0.2**	**2.1 ±0.1**
$^{134+137}$Cs	**3.3**	**2.9**

- ✓ **SS: Ukedo << Takase**
  - ✓ SS supplied upstream did not reach to lower Ukedo river due to the presence of the dam.
- ✓ **Dissolved Cs: Ukedo > Takase**
  - ✓ Higher Cs accumulated along mountain streams might affect.

Comparison of Ukedo and Takase rivers

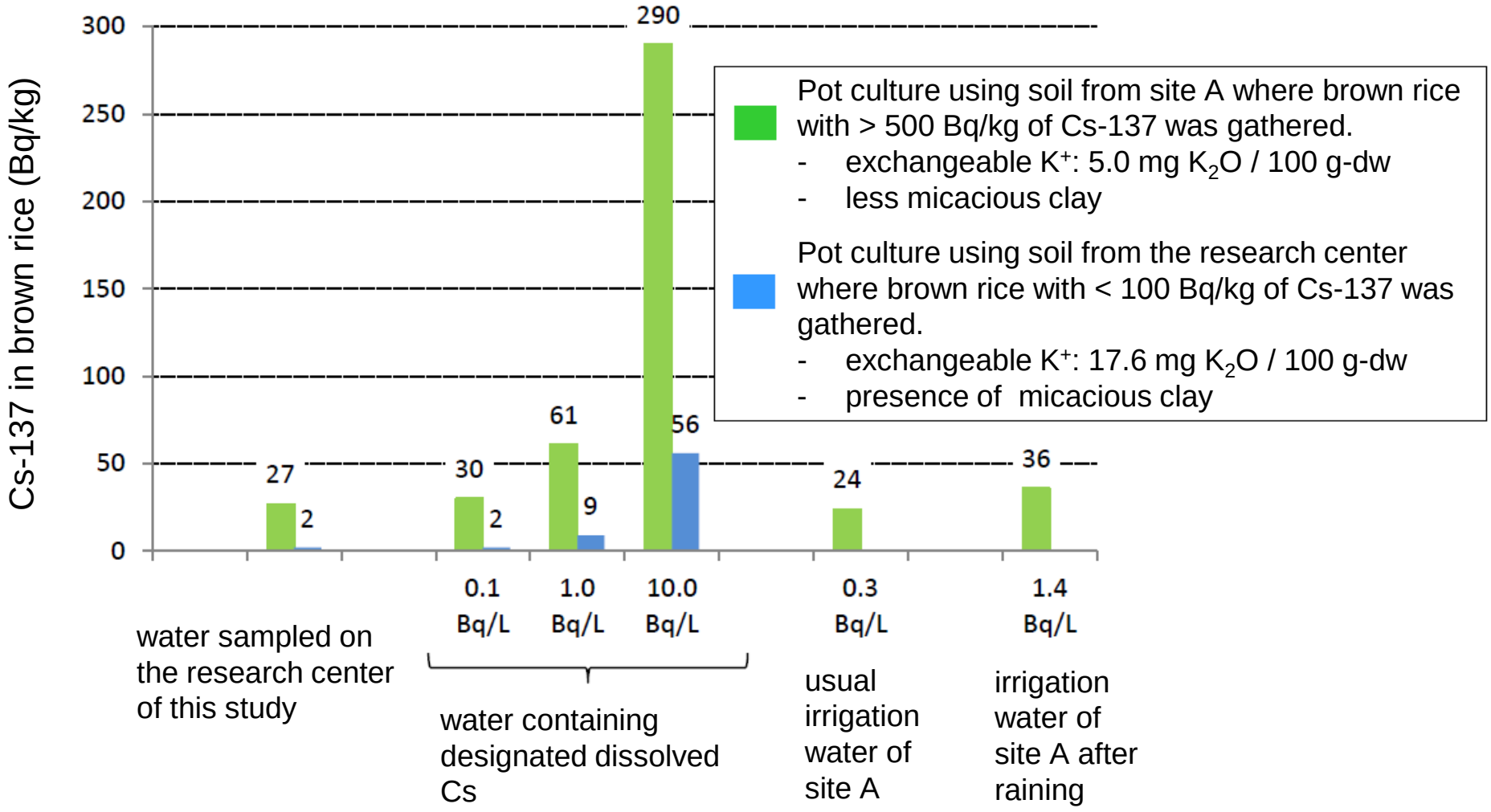


Concentration of Cs in the Ogaki dam lake water



Evolution of concentration of dissolved Cs in inflow and outflow waters of Ogaki dam lake (Ukedo river).

Less effect of dissolved Cs on rice

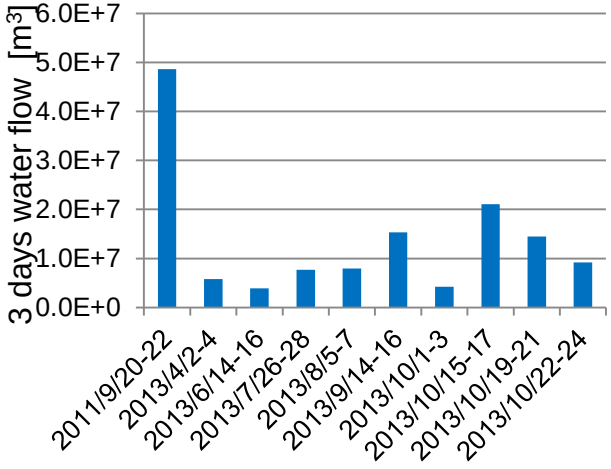


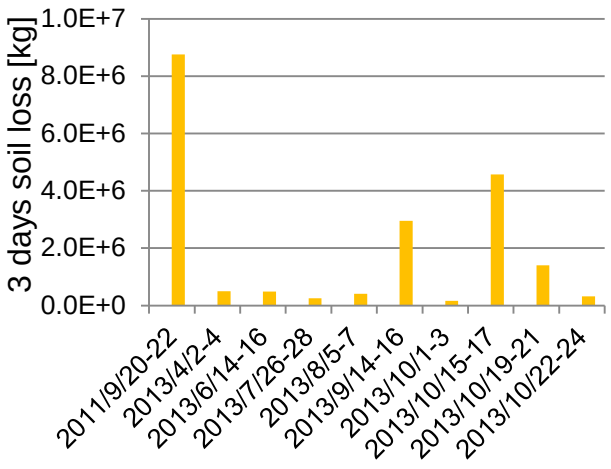
✓ Lower than 1 Bq/L of dissolved Cs in irrigation water could give lower than 100 Bq/kg in rice.

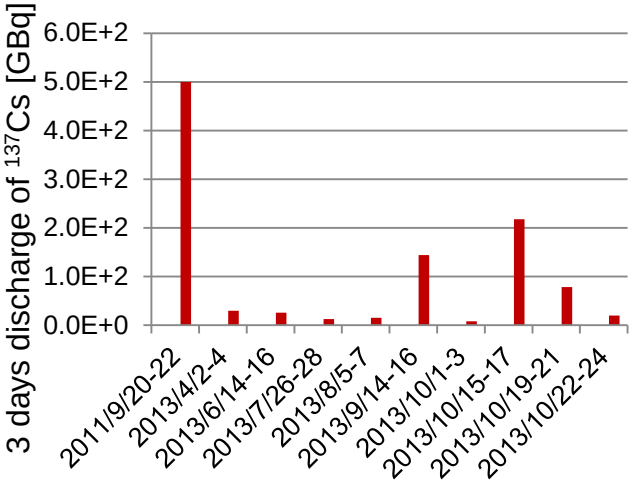
http://www.maff.go.jp/j/kanbo/joho/saigai/pdf/youin_kome2.pdf (in Japanese)

Prediction of Cs discharge from the river

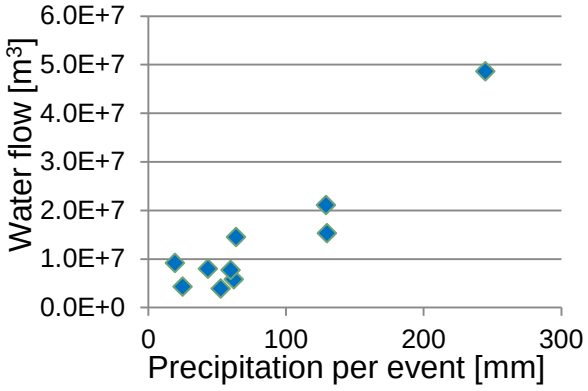
GETFLOWS (physical model for soil loss and water transportation):
Water flow, soil loss and Cs-137 discharge for 3 days during each high water event.

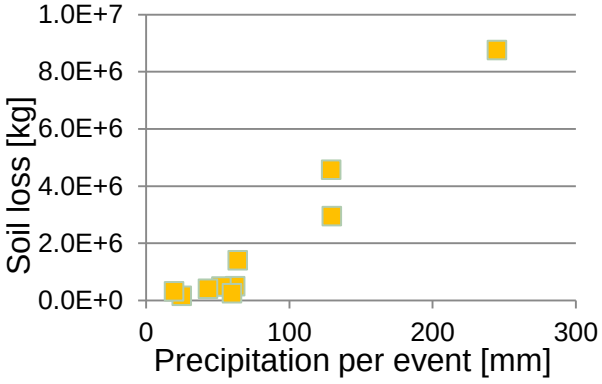


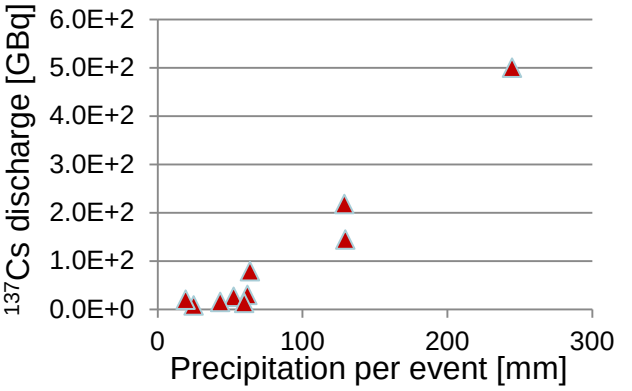




Relationship to precipitation





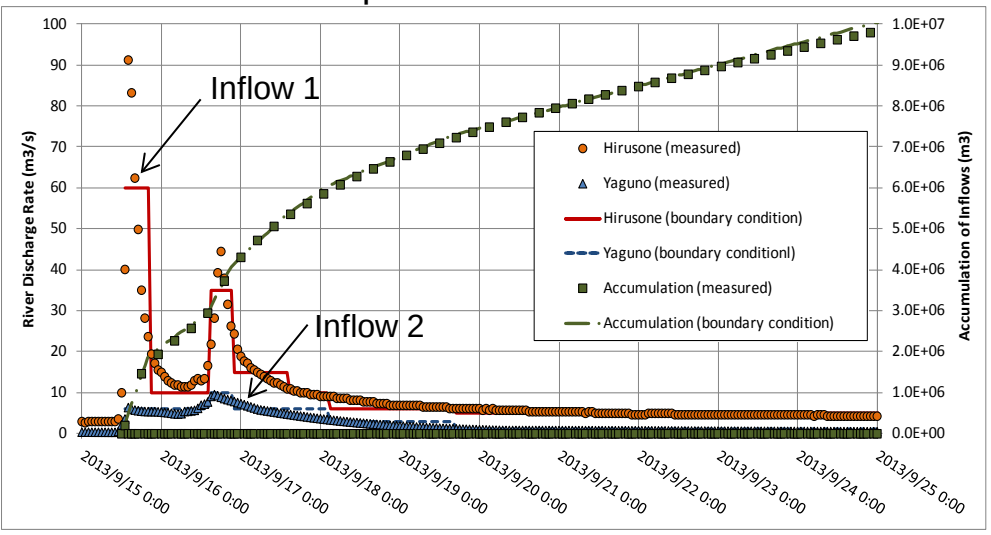


It can be applied to predict the behavior of Cs depending on precipitation.

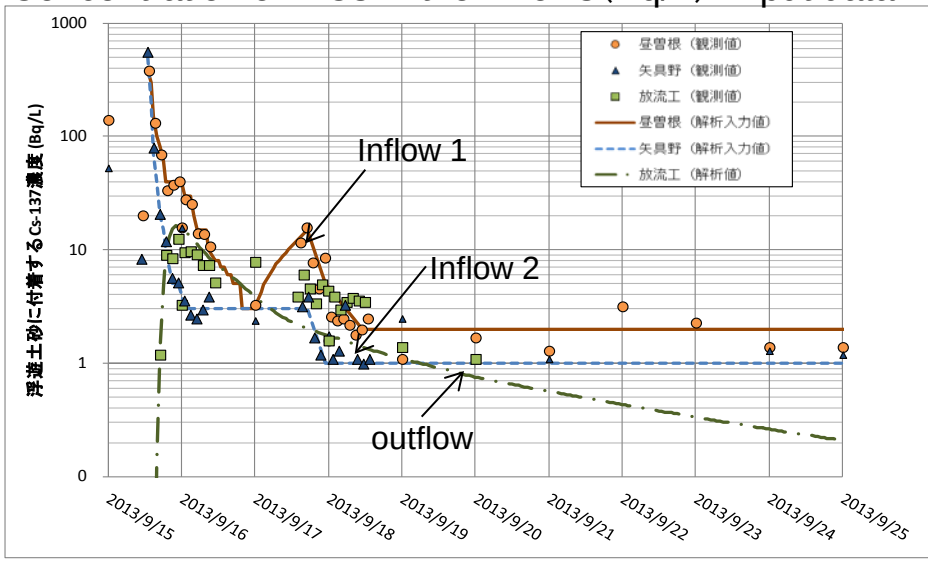
Prediction of Cs sedimentation/discharge in the dam

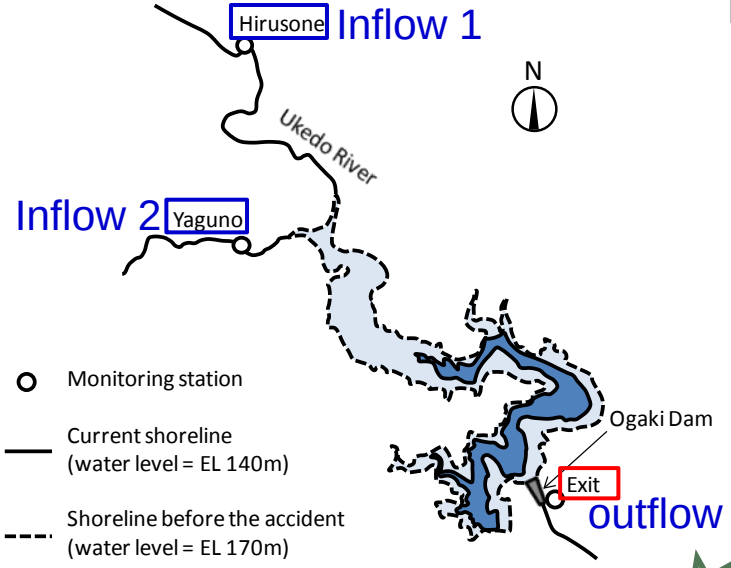
TODAM: 1D transport model for contaminant in rivers

Water flow（m^3/s）: input data

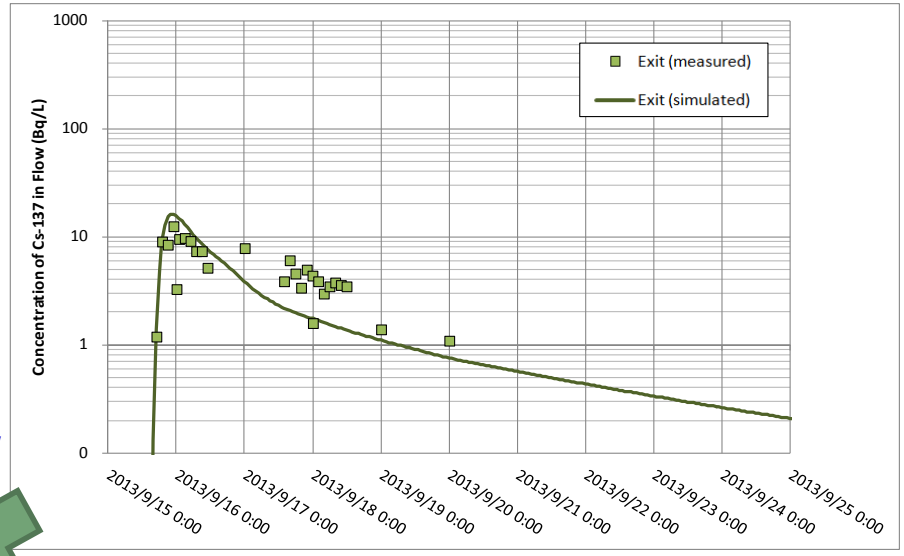


Concentration of ^{137}Cs in the inflows（Bq/L）: input data





Concentration of ^{137}Cs in the outflow（Bq/L）: output



Calculation agreed well to observation.

Kurikami et al., *J. Environ. Radio.*, 137, 10 (2014).

Summary

- **Forests**
  - **Large inventory**: 0-10 cm mineral layer of soil adsorbed Cs, leading to less Cs in river system.
  - **Short-term**: decontaminated near living-sphere, hopefully with something to prevent soil loss.
  - **Long-term**: managed so as to keep enough litter layer and vegetation of forest floor.
  - **To be considered / monitored**:
    - Cs in ecosystem (wild plants, mushrooms, trees) to estimate concentrations in future.
    - Dissolved Cs in water system if it would increase due to any changes of circumstances.

Thank you for you attention !!

http://fukushima.jaea.go.jp/english/decontamination/