Dynamic behavior of cesium concentration through the river basin

Seiji HAYASHI
Center for Regional Environmental Research
National Institute for Environmental Studies (NIES), Japan

Contents

1． Goals & study area
2． Approach & results from field measurement
3． Modelling & capture of understanding
4． Future perspectives

NIES research project on radioactive substances in multimedia environments

- Understanding of actual conditions on dynamic behavior of radioactive materials
- Prediction of future spatio-temporal distribution
- Prediction of effects by countermeasure options

Field measurements on dynamics with multi time-scale

■Understanding of actual conditions of dynamics (spatial distribution, migration, accumulation, etc.)

Multimedia modeling and long-term simulation

■Target area
Wide area of South-Tohoku/North-Kanto
■Clarification of dynamics/prediction by the combined model of atmospheric, terrestrial, and coastal sea area

Exposure assessment on human health in regional scale (internal/external exposure)

■ Development of analysis methods for short-/long-term exposure
■ Development of exposure (^{131}I) analysis methods (^{129}I)

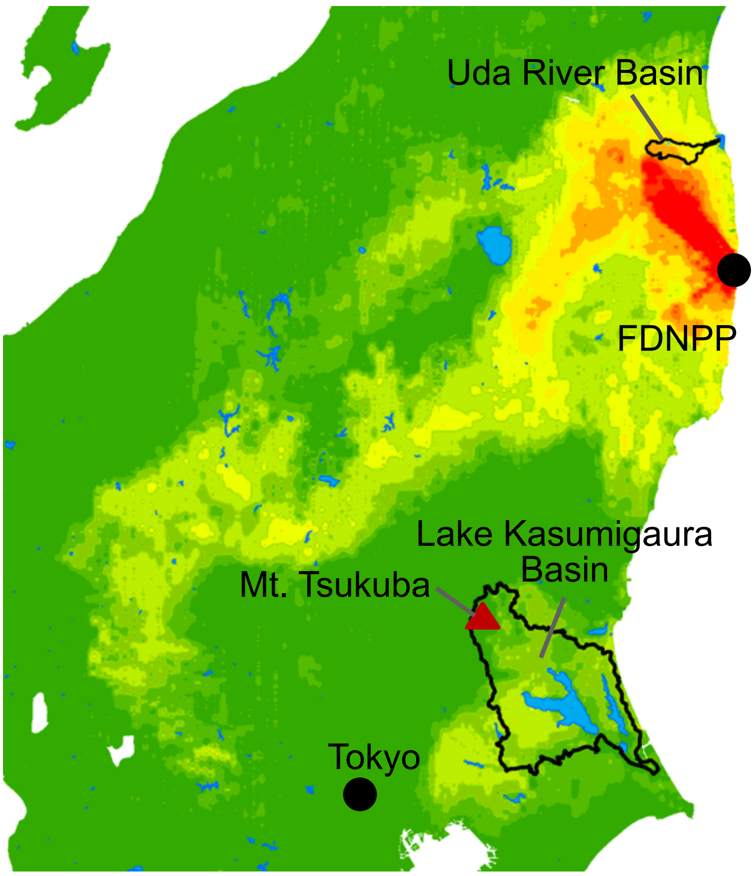
Assessment of biological and ecosystem impacts (small mammals, amphibians, fishes, plants, fungi)

■ Development of impact assessment methods using genetically modified plants and wild fungus
■ Impact survey of rodents

Understanding of influence to human health by radioactive materials

Understanding of impacts to biological/ecosystem by radioactive materials

Study area



Field measurements

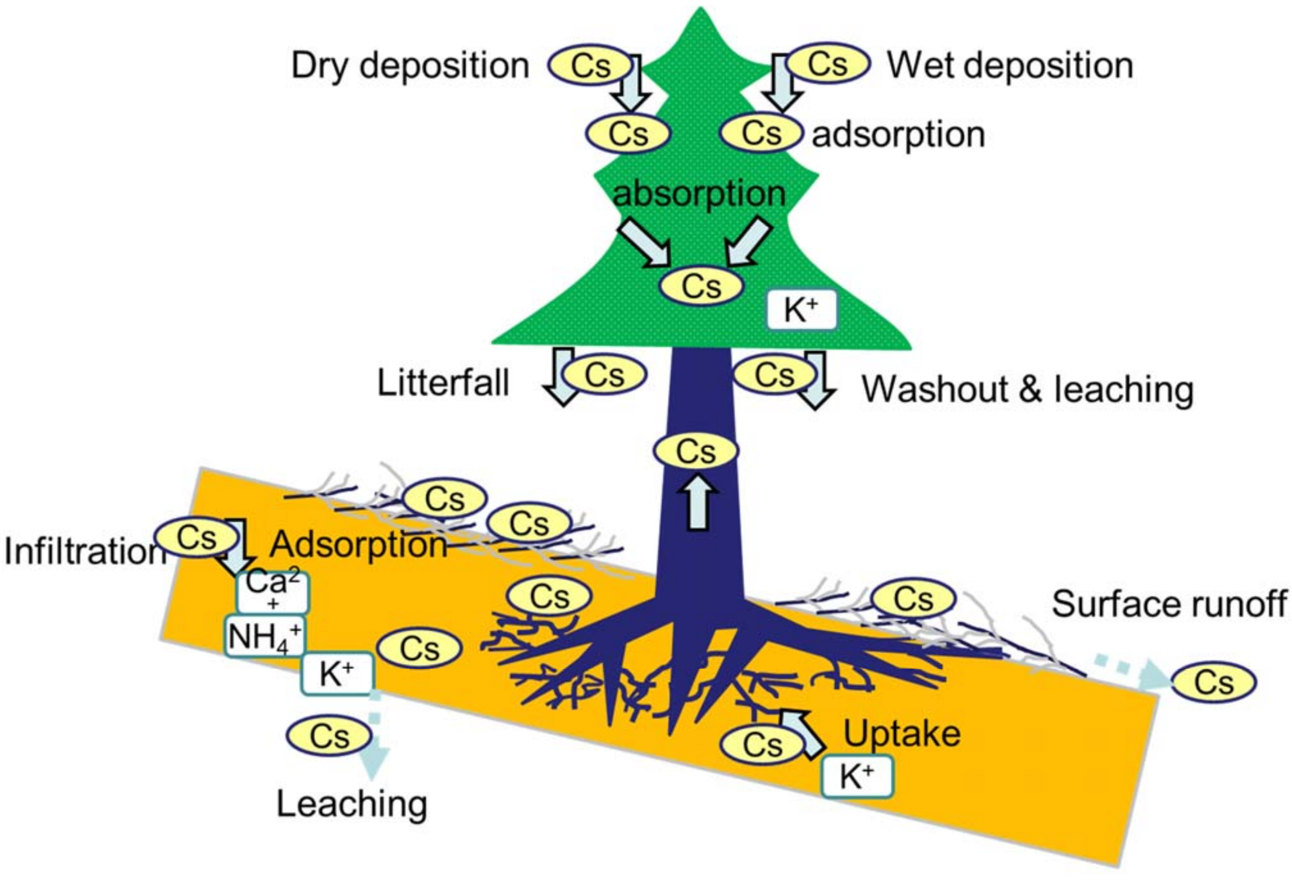
- ✓ Carrying out in the Lake Kasumigaura Basin and the Uda River Basin
- ✓ Starting surveys soon after the accident in the Lake Kasumigaura Basin
- ✓ Transfer of radiocaesium from high to low contaminated area in the Uda River Basin

Multimedia modelling

- ✓ Wide area of South-Tohoku/North-Kanto consisting of 15 river watersheds around Fukushima prefecture
- ✓ Clarification of dynamics/prediction by the combined model of atmospheric, terrestrial, and coastal sea area

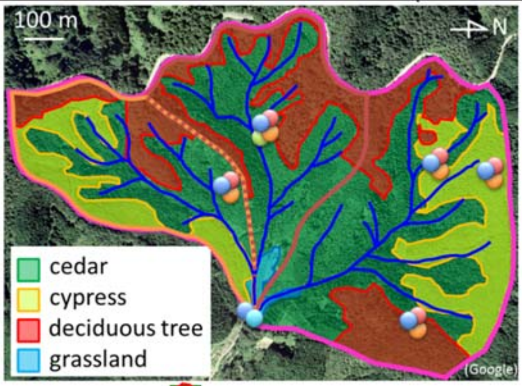
Approach & results from field measurement

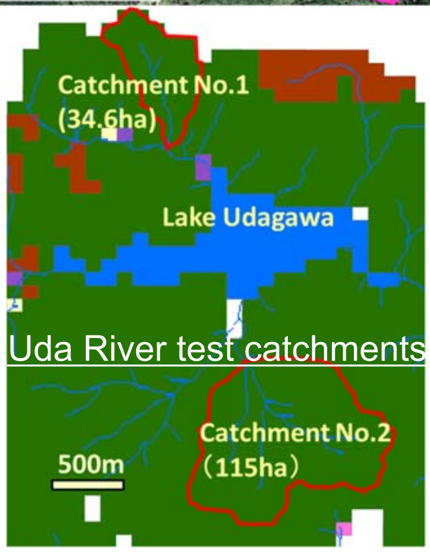
^{137}Cs dynamics in forest area



Study on cycle and runoff of ^{137}Cs in forest area

Mt. Tsukuba test catchment(67.5ha)





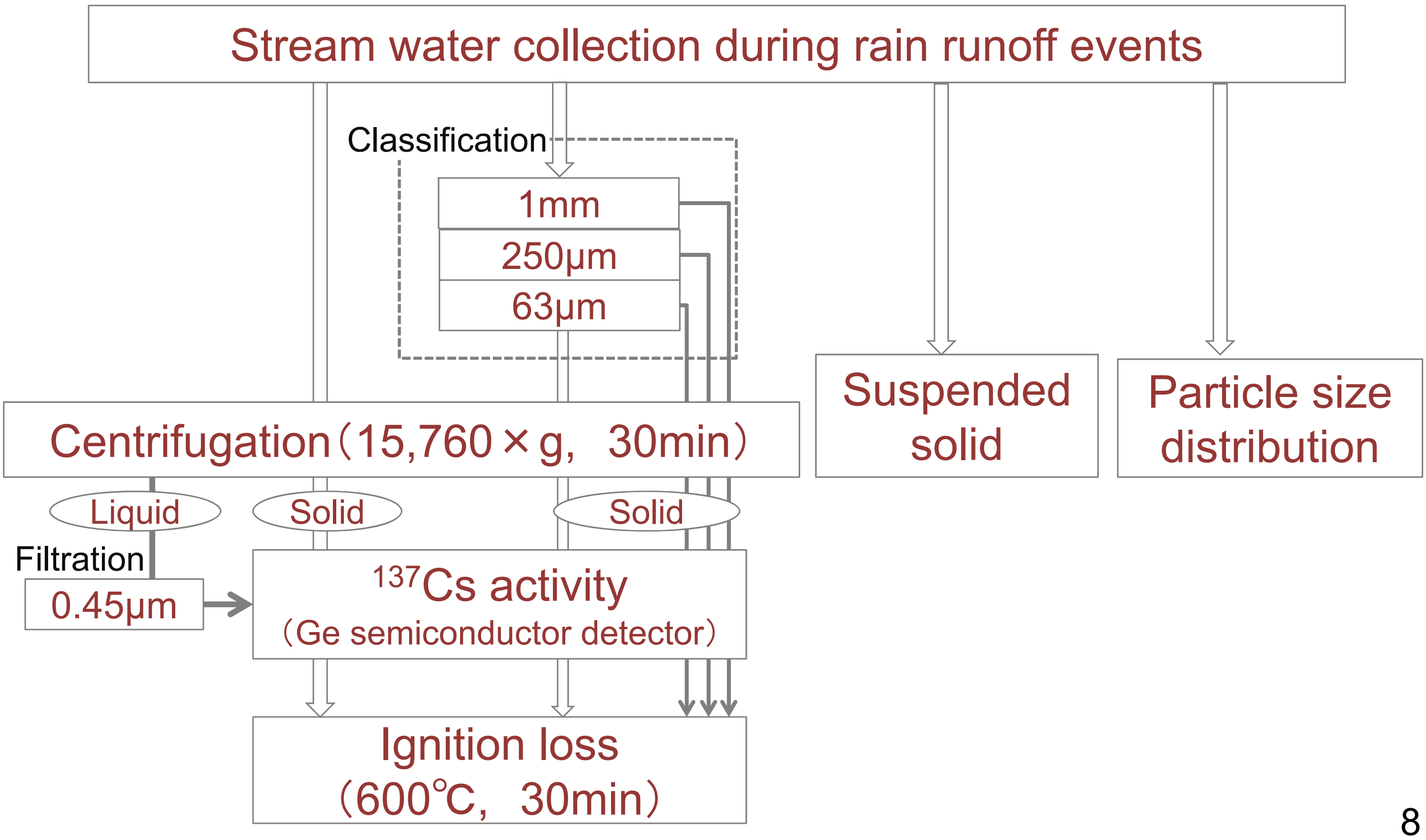
①Survey in Mt. Tsukuba

- Successive survey on throughfall, litterfall, soil, and leaves soon after the accident
  →Understanding of ^{137}Cs cycle characteristics
- Runoff survey
  - ・Classification of suspended solid
  - ・Inspissation of dissolved Cs
  → Understanding of ^{137}Cs runoff characteristics

②Survey in the upper region of Uda River Basin

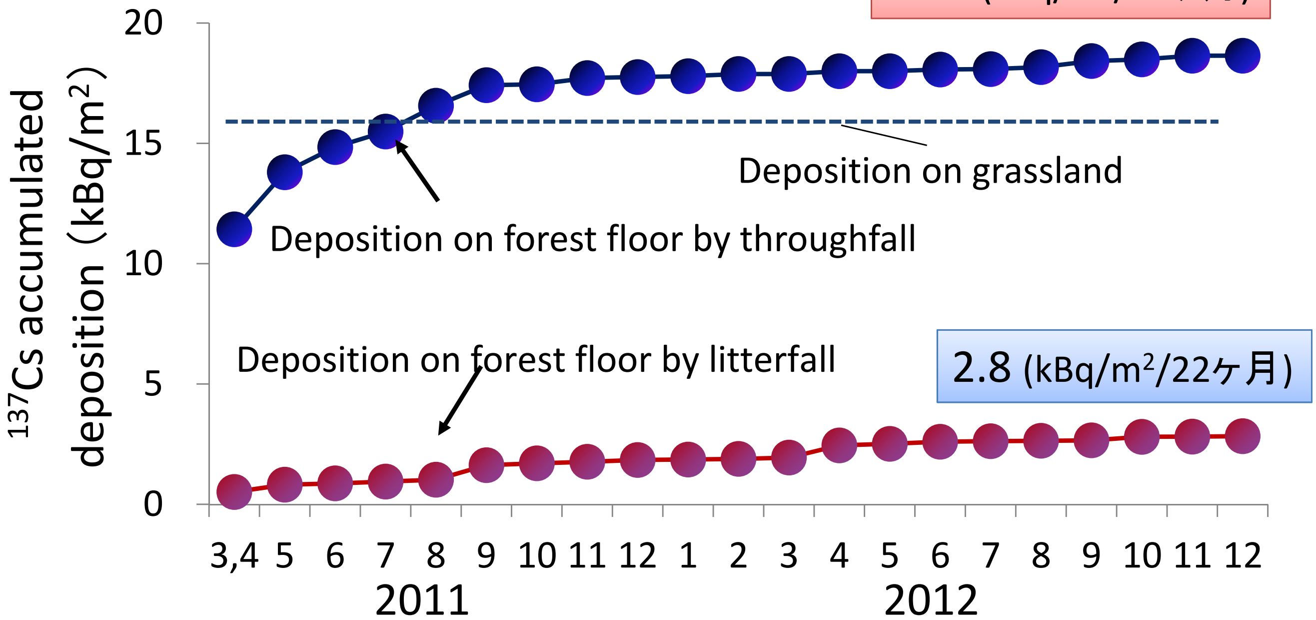
- ^{137}Cs soil profile survey
  → Understanding of ^{137}Cs soil accumulation in different types of trees
- Runoff survey
  → Evaluation of ^{137}Cs runoff volume and ratio

Analysis procedure for ^{137}Cs associated with SS



^{137}Cs deposition on forest floor

Temporal redistribution of ^{137}Cs from the canopy of a cedar forest to the forest floor beneath in Mt. Tsukuba



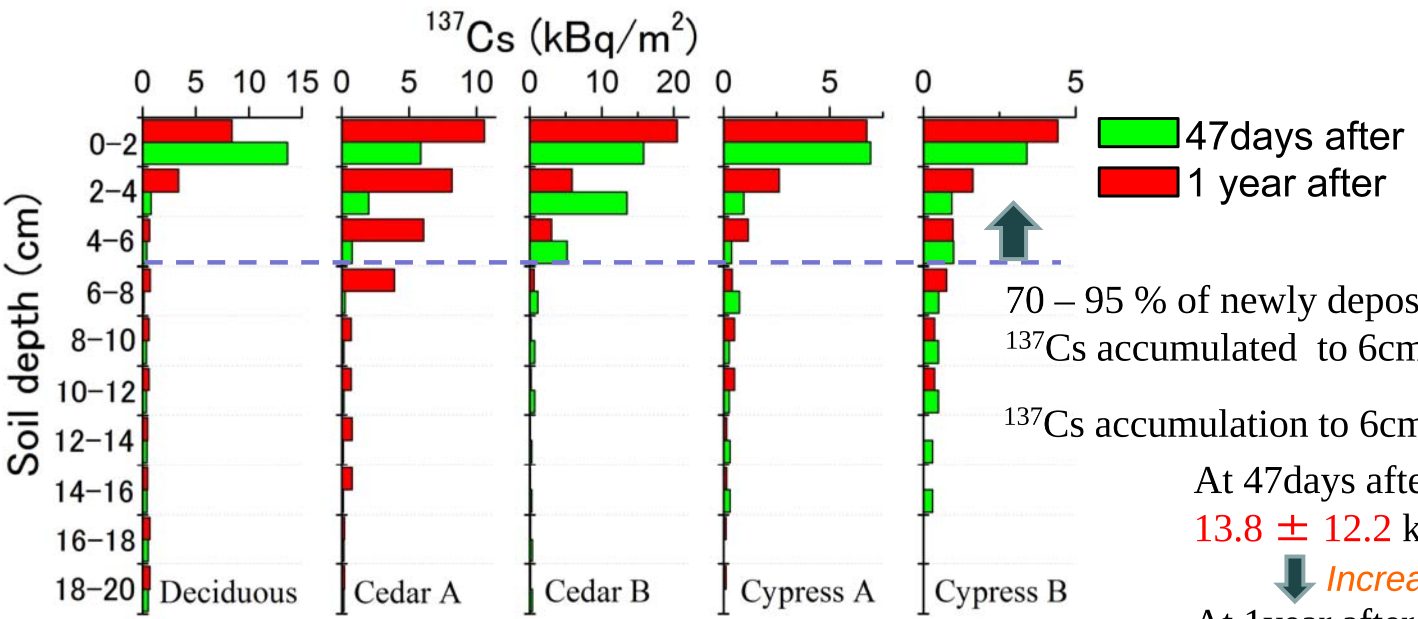
Initial deposition amount on forest canopy

→ Influencing factor on dynamics of radiocaesium in forest for some time after the accident at FDNPP

^{137}Cs accumulation and temporal change in forest soil

- Accumulation into surface soil including litter layer & little downward migration
- Increase of ^{137}Cs accumulation in surface soil from the initial deposition condition by mechanistic decontamination (through fall and litter fall) of contaminated forest canopy

^{137}Cs profiles in forest soils of main tree species in Mt. Tsukuba



70 – 95 % of newly deposited ^{137}Cs accumulated to 6cm depth

^{137}Cs accumulation to 6cm depth

At 47days after,
13.8 ± 12.2 kBq/m^2

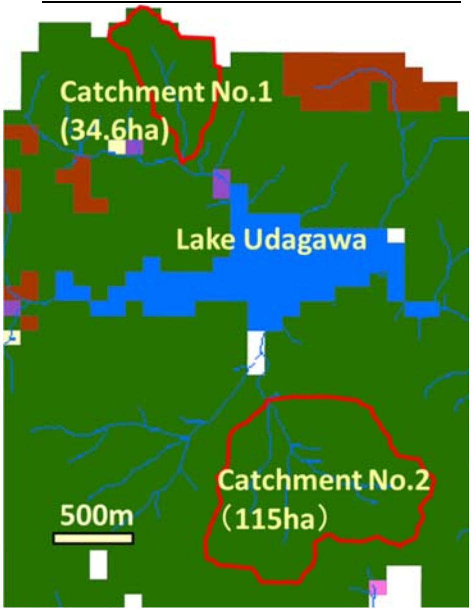
Increasing!

At 1year after,
16.8 ± 9.7 kBq/m^2

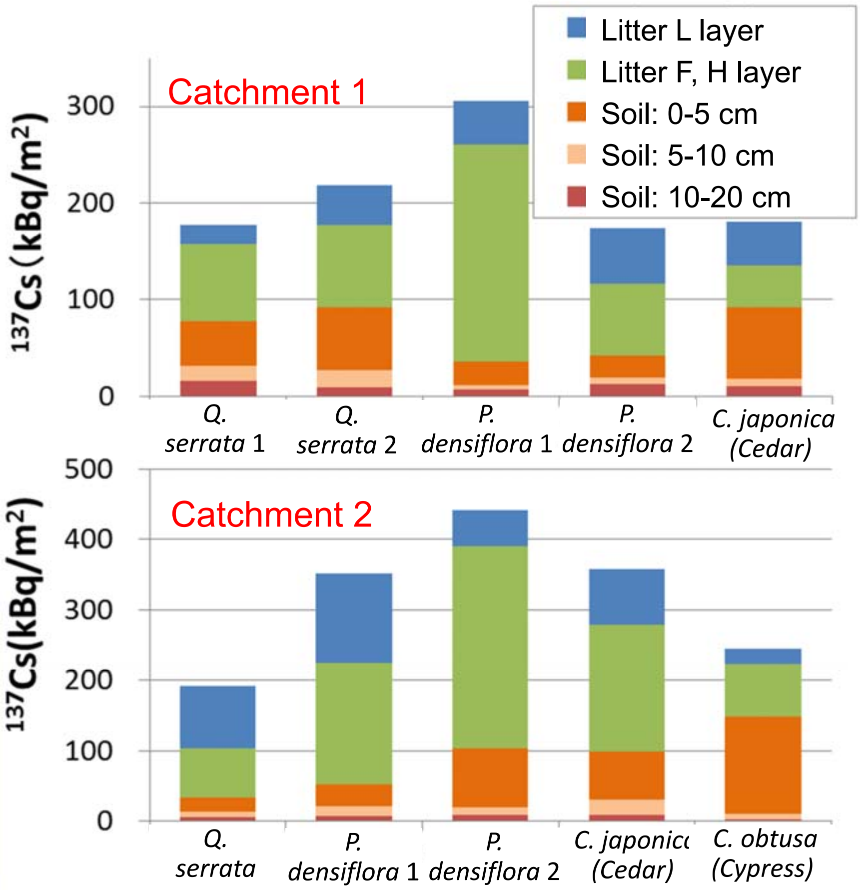
^{137}Cs accumulation in forest soil at the upper Uda River Basin

(Survey date: Sep. 18 to 20, 2012)

Uda River test catchments



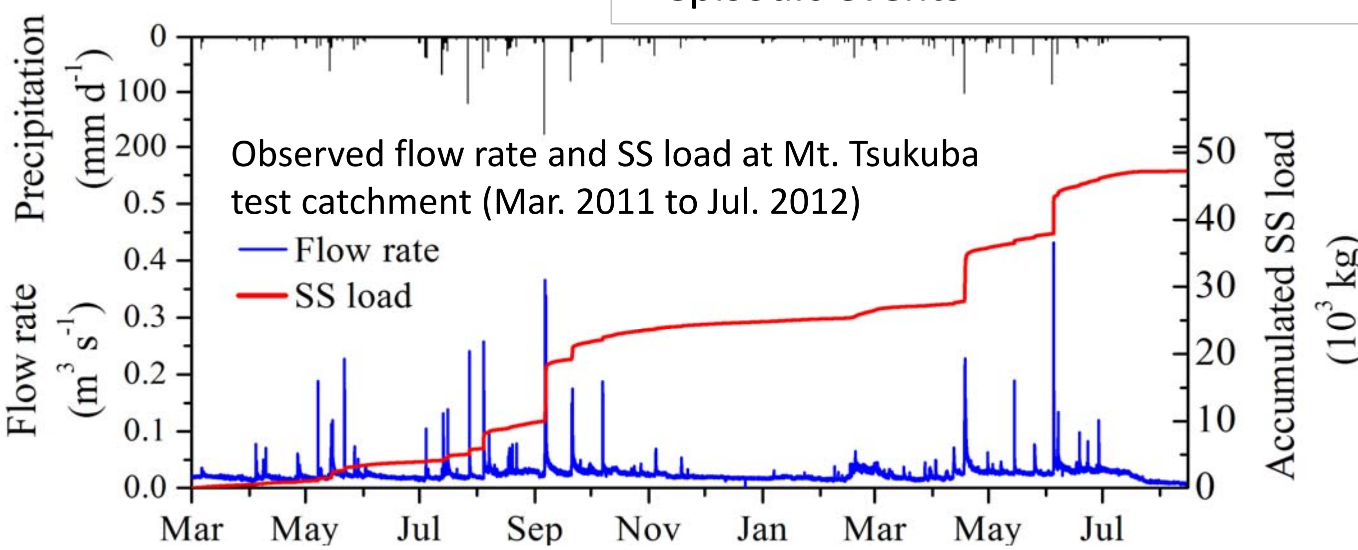
- Over 90 % ^{137}Cs accumulates in the soil up to 5 cm (most in litter layer)
- The highest concentration (6,200Bq/kg dry weight) in surface soil at Japanese cypress



Quantitative runoff characteristics of ^{137}Cs

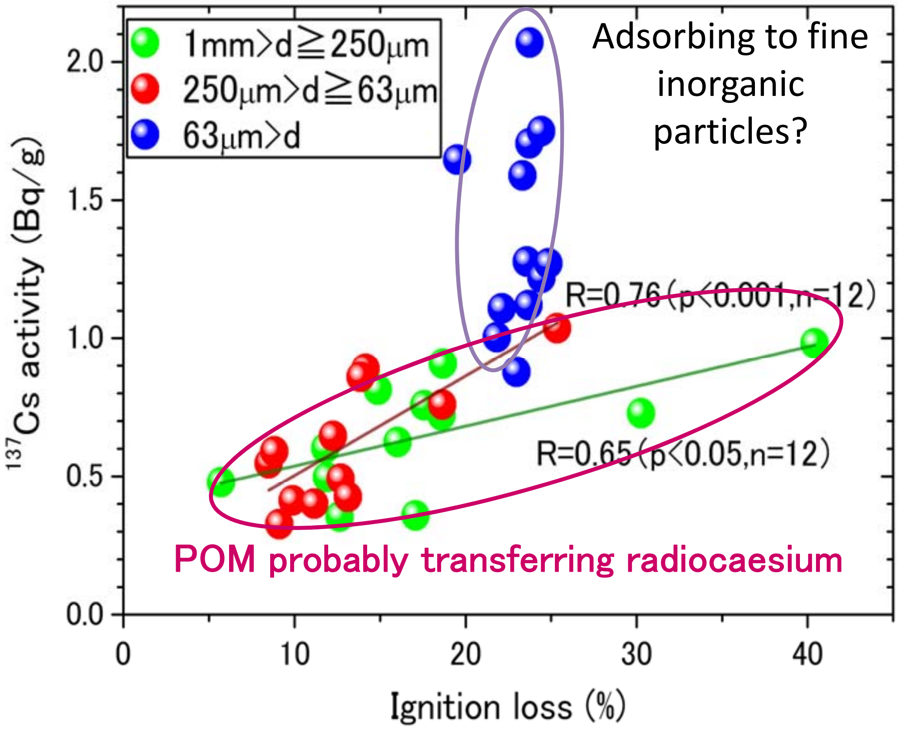
^{137}Cs associated with SS	Mt. Tsukuba (annual)	Upper Uda Riv. (7 months)
Activity (kBq/kg-SS)	0.86	17～22
Runoff load per unit area (kBq/m^2)	0.04	0.41～0.67
Runoff ratio (%)	0.3	0.02～0.03

- ^{137}Cs runoff is mainly associated with suspended solid (SS)
- Runoff ratio is small regardless of contaminated level (<0.3% annually)
- Marked runoff with SS during large episodic events



Qualitative runoff characteristics of ^{137}Cs

<u>Relationship between ^{137}Cs activity and organic matter content of sieve classified suspended solid</u>

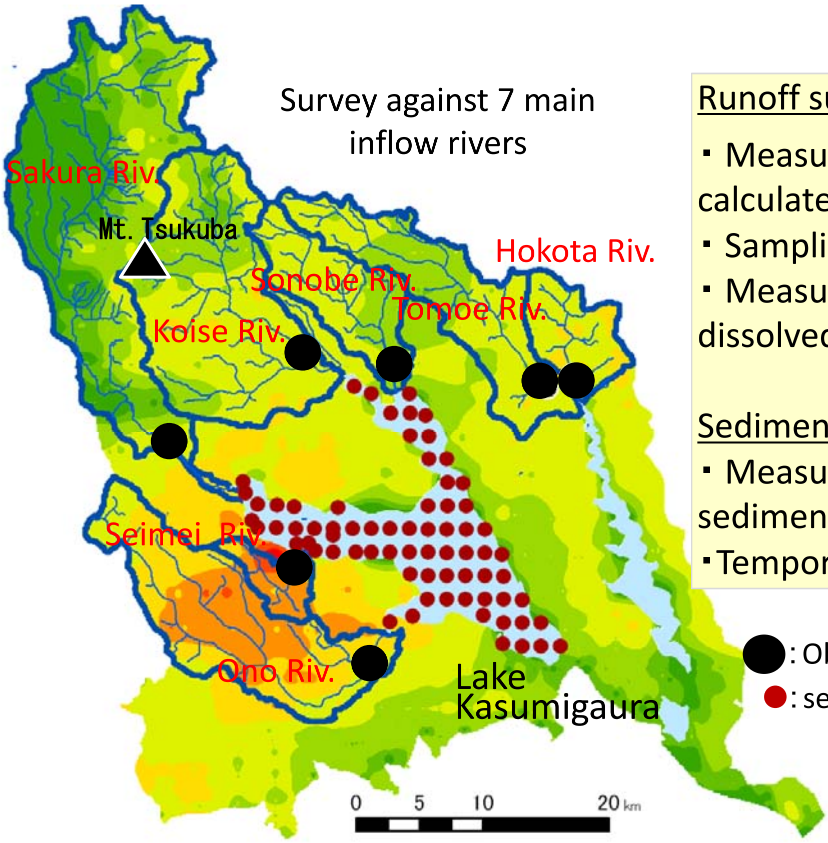


- POM : Particulate organic matter
- A slight amount of fraction over 1mm →below the detection limit of ^{137}Cs
- Fractions over 63μm covering 15～48% of total ^{137}Cs activity

Transfer and the bioconcentration of radiocaesium into aquatic organisms through food web should be concerned

^{137}Cs dynamics in river basin scale

^{137}Cs flow & stock survey in Lake Kasumigaura Basin



^{137}Cs deposition from an airborne monitoring survey on Nov. 11th, 2011

Runoff survey :

・Measuring flow rates, turbidities and SS conc. to calculate SS flux after the accident.

・Sampling river waters during rain runoff events

・Measuring ^{137}Cs activities associated with SS and dissolved

Sediment survey:

・Measuring ^{137}Cs accumulation to 5 - 15cm depth of sediment at 63 points in the lake on Dec., 2012

・Temporal change analysis by stationary sampled core

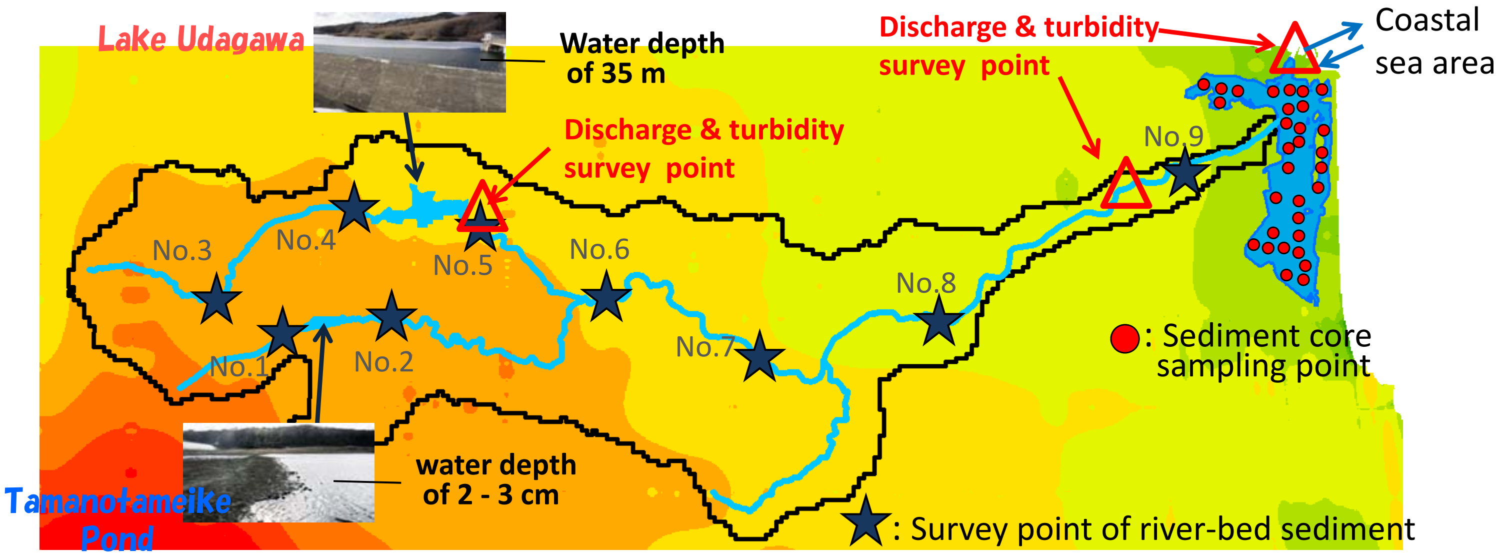
●: Observatory of flow rate and turbidity

●: sediment core sampling point

Cs-137 accumulation in basin (Bq・m-^{2})

<2,500	20,000 – 30,000
2,500 – 5,000	30,000 – 40,000
5,000 - 10,000	40,000 – 50,000
10,000 - 20,000	50,000 <

^{137}Cs flow & stock survey in Uda River Basin



Runoff survey

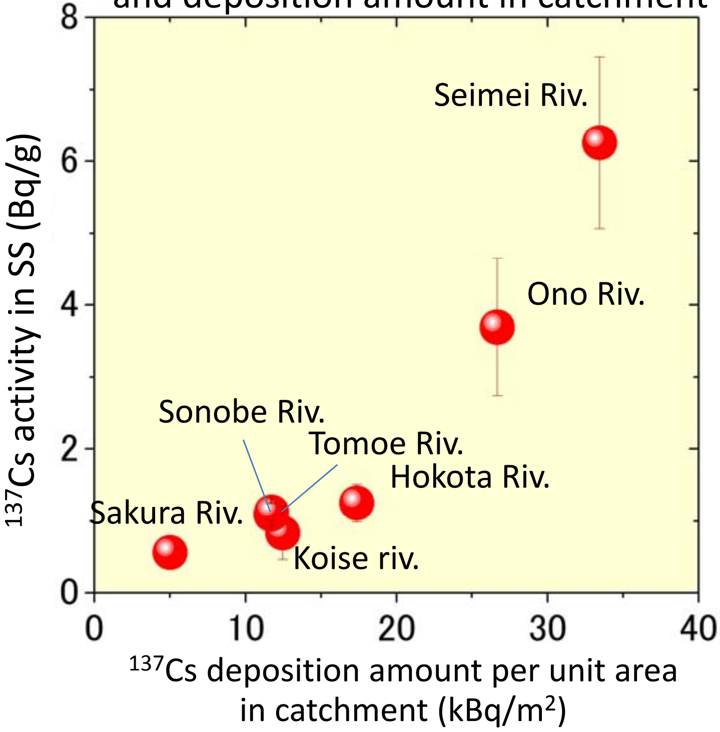
- ^{137}Cs outflow flux from the upstream dam
- ^{137}Cs flux and runoff ratio from the whole basin
- ^{137}Cs inflow and outflow between the lagoon and costal sea

Sediment survey

- ^{137}Cs accumulation amount and profile in the bottoms of upstream dam and pond
- Longitudinal variation of ^{137}Cs activity in the river-bed sediment
- Spatial distribution and total deposition of ^{137}Cs in the lagoon

^{137}Cs runoff from main inflow rivers' catchments of Lake Kasumigaura

Relationship between ^{137}Cs activity in SS and deposition amount in catchment



Estimated runoff volume of ^{137}Cs associated with suspended solid for <u>one year after the FDNPP accident</u>

	Koise	Ono	Seimei	Hokota
SS specific runoff volume (kg/m^2)	0.036	0.016	0.028	0.021
^{137}Cs specific runoff volume (kBq/m^2)	0.030	0.061	0.18	0.026
^{137}Cs runoff ratio (%)	0.24	0.23	0.52	0.15

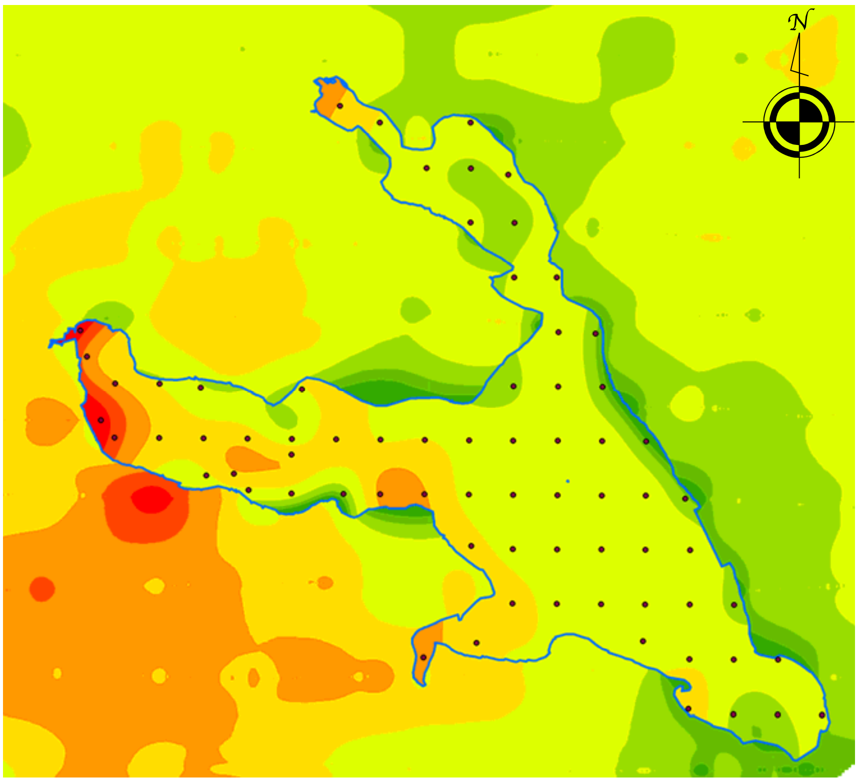
^{137}Cs slightly running off even in catchment scale!

^{137}Cs activity in SS

→ depending on not conc. of SS but initial deposition amount in catchment

Spatial distribution of ^{137}Cs accumulation in sediment of the Lake Kasumigaura

Estimated spatial distributed map of ^{137}Cs accumulation in sediment by spline function using activities of sediment cores

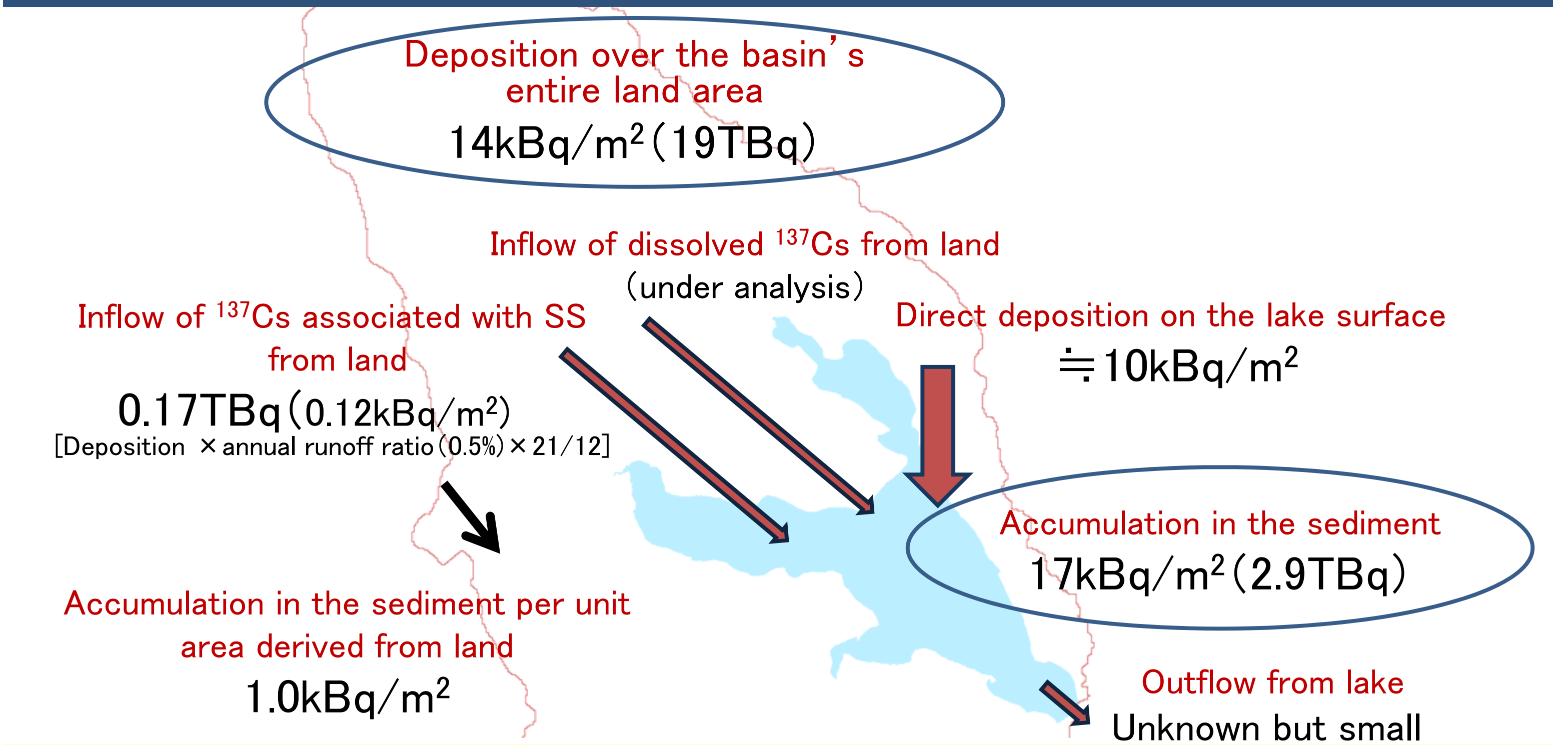


- Higher activities in the western side
  → Effect of initial direct deposition
- Locally high activities at the mouths of some rivers
  → Effect of inflow from the river catchment
- Total accumulation of ^{137}Cs: **2.9TBq (17kBq/m^2)**

Cs-137 accumulation (Bq・m^{-2})

<2,500	20,000 – 30,000
2,500 – 5,000	30,000 – 40,000
5,000 - 10,000	40,000 – 50,000
10,000 - 20,000	50,000 <

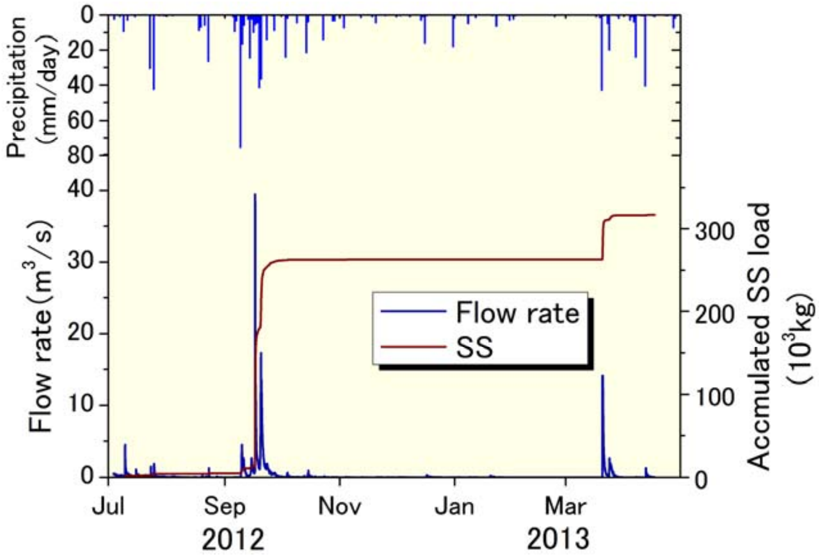
Analysis of stocks and flows of ^{137}Cs in the Kasumigaura Basin in 21 months after the accident



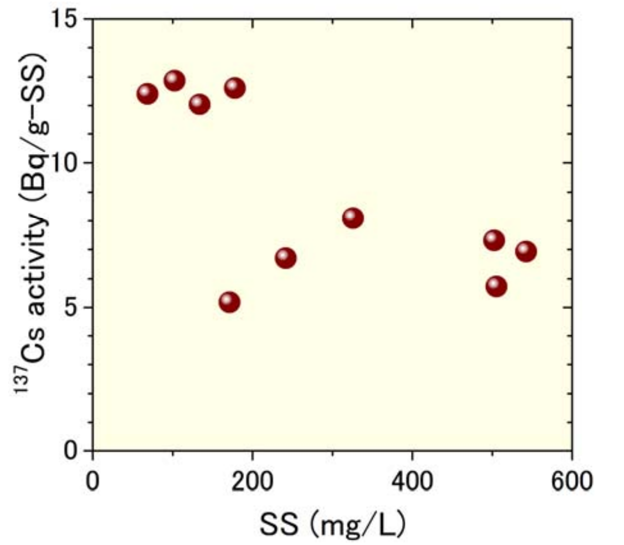
- Small contribution of ^{137}Cs associated with SS both in the past and future？
- Large effect of direct deposition on the lake surface and the runoff of radioactive Cs from impervious soon after deposition on the accumulation in the sediment

^{137}Cs runoff from Uda River Basin

Observed river flow rate and SS load(Jul. 2012 to Apr. 2013)



^{137}Cs associated with suspended soild (SS)



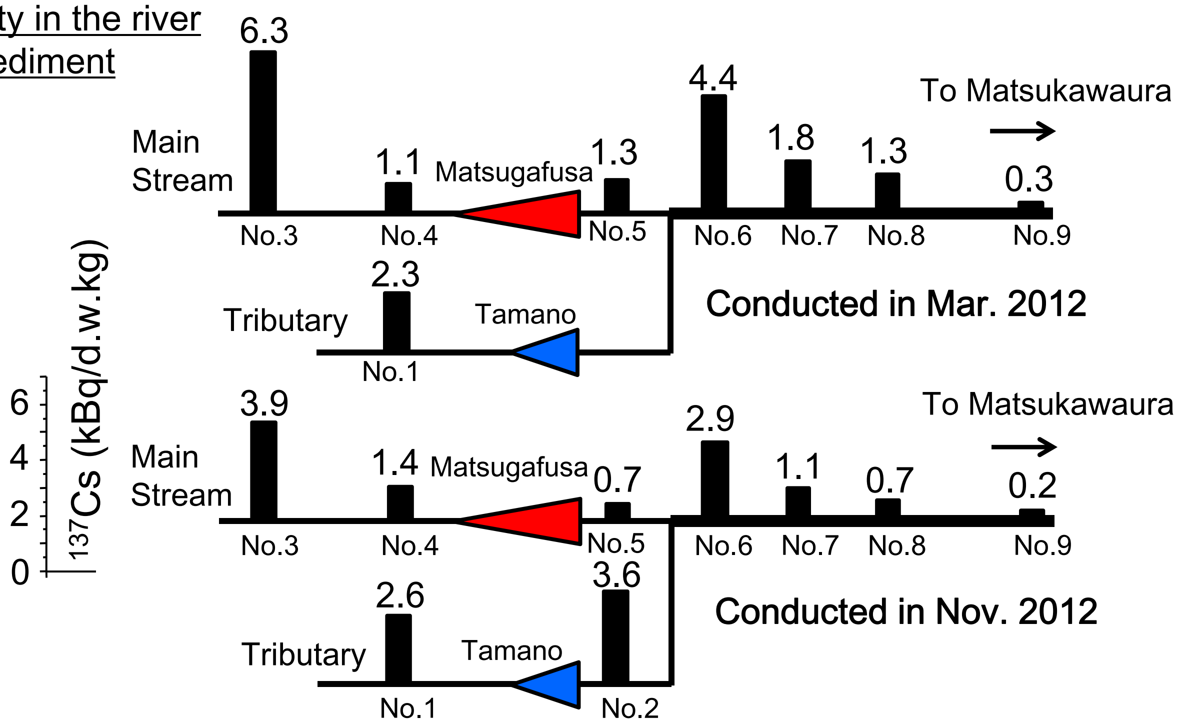
^{137}Cs Runoff condition from whole basin

Total runoff amount associated with SS：0.029kBq/m²(2.8GBq)
^{137}Cs runoff ratio ：0.014%(12年7月~13年4月)

^{137}Cs runoff is currently limited from the whole basin as well as forested area. However, lower rainfall condition than normal should be considered.

Accumulation & migration of ^{137}Cs in the river bed sediment

^{137}Cs activity in the river bed sediment



Change in Activities

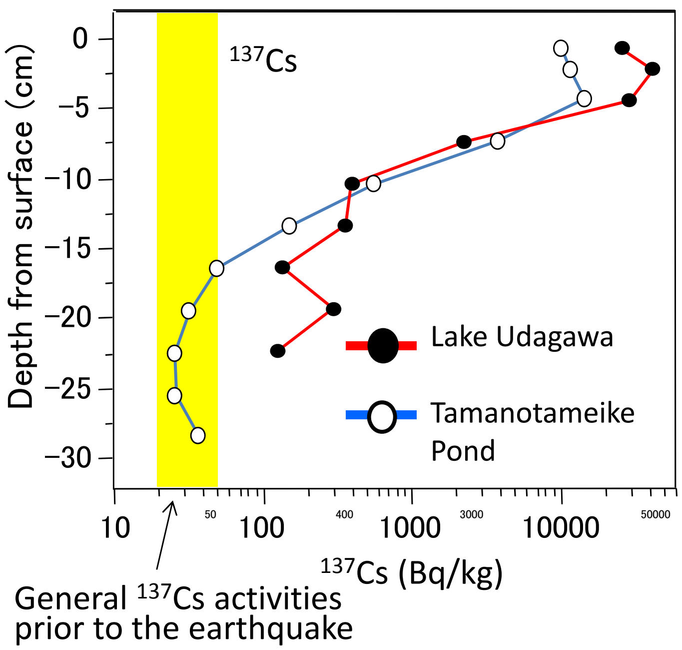
- Upstream > downstream & decreasing to downstream direction
- Small difference between upstream and downstream of dam

→ Highly depending on the contaminated conditions in the vicinity
→ Contaminated deposits in upstream move slowly, most of them have not reached to river mouth

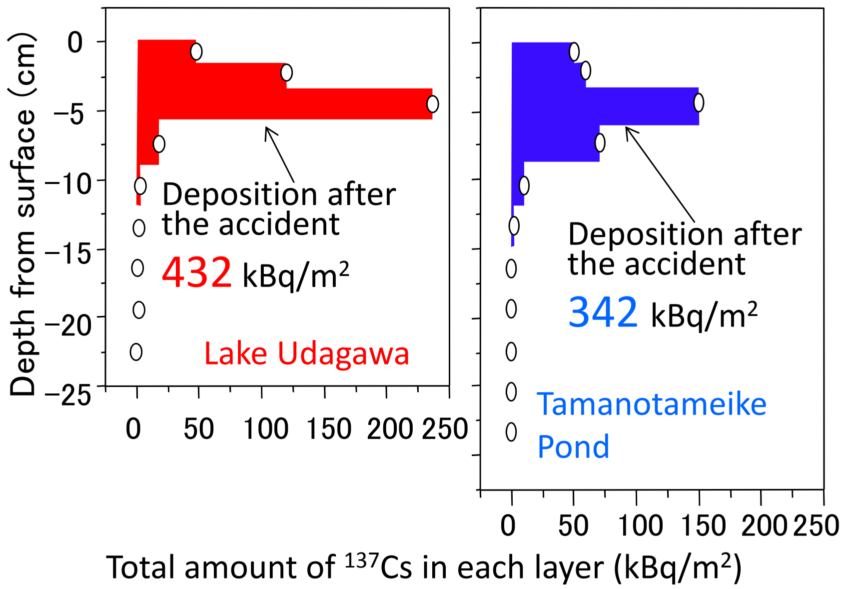
Accumulation of ^{137}Cs in Lake sediment

Carried out on Nov., 2012

Vertical profile of ^{137}Cs activity



Accumulation amount of ^{137}Cs after the accident (kBq/m^2)



^{137}Cs depositions in the lakes are equal or a little grater than deposited amount in their catchment area (300 ±80 kBq/m^2) → Not current inflow but direct deposition and initial inflow probably contribute to the deposition condition in lake sediment

Summary of survey results for ^{137}Cs behavior in river basin

- Mobile ^{137}Cs possibly migrated and accumulated into lake and river beds as sediment immediately after the initial deposition
- Massive migration of ^{137}Cs hardly occurs both now and in the future under normal weather condition
- From macroscopic viewpoint, natural decay rate is lager than those of weathering in upper region and accumulation in lowland area and inflowing water body

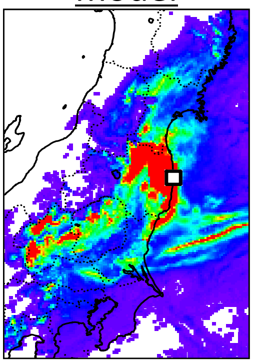
Modelling & capture of understanding

Purpose of this study

- Background
  - It is necessary to know the **long-term fate** of radioactive cesium
  - Understanding and forecasting of fate processes such as **accumulation**, **runoff** and **flow-down** through river system needs to be known, to consider the future actions to the existing terrestrial contamination
- Purpose of the study
  - To establish simulation model for **multimedia fate processes of ^{137}Cs** in Fukushima and surrounding region
  - Simulation will be developed by combining atmospheric transport model (CMAQ) outputs and multimedia fate model G-CIEMS (Grid-Catchment Integrated Modeling System) which has been developed for Japan

Model domain setup

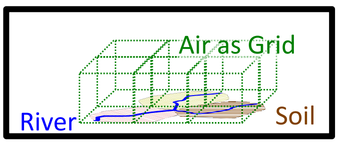
Atmospheric model

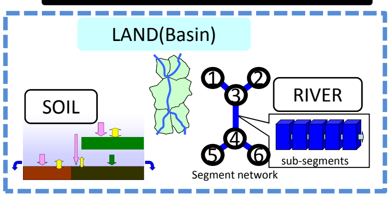


Deposition of ^{137}Cs

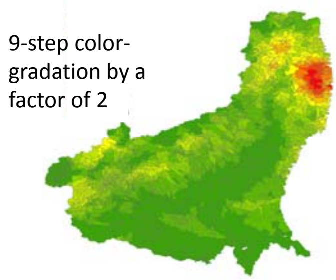
Morino, Y., Ohara, T. and Nishizawa, M.(2011) Geophys. Res. Let., 38, L00G11, and http://www.nies.go.jp/shinsai/index.html

Multimedia G-CIEMS model

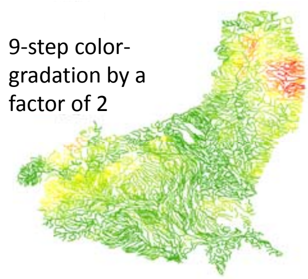




15 river watersheds around Fukushima prefecture



Level of ^{137}Cs in soil at March 23, 2011



Level of ^{137}Cs in river water at March 23, 2011 (Soluble+Particulate, ordinary flow rate)

Parameter setup
- ranges of sensitivity analysis for K_d and runoff rates

Distribution Coefficient (K_d):

- Central value: Geometric mean in IAEA report*
- High-K_d : 5-times higher than the central
- Low-K_d : 5-time lower than the central

Kd (L/kg)	High Kd	Cent Kd	Low Kd
In Soil	6.0×10^3	1.2×10^3	2.4×10^2
In surface water and sediment	1.45×10^5	2.9×10^4	5.8×10^3

Soil Runoff rates

- Forest and Shrub: Based on field observation of ^{137}Cs runnoff in Tsukuba Mt. (0.3%/year)
- Paddy/Farm land: Based on agricultural land guidance (Case1, 3), or 5 times lower than that (Case2, 4)
- Built-up area: Based on airborne monitoring analysis (Case 1, 2), or same as nonvegetated area (Case 3, 4)
- Nonvegetated/Other areas: 20 times lower than the farm land value (Based on plant coefficients in USLE cited in agricultural land guidance

	Soil depth (cm)	Soil runoff rate as bulk (mm/y)			
		Case 1	Case 2	Case 3	Case 4
Forest and shrub	5	0.17	0.17	0.17	0.17
Paddy and other farmland	30	1	0.2	1	0.2
Built-up	3.5	4.6	4.6	0.05	0.05
Nonvegetated and Others	5	0.05	0.01	0.05	0.01

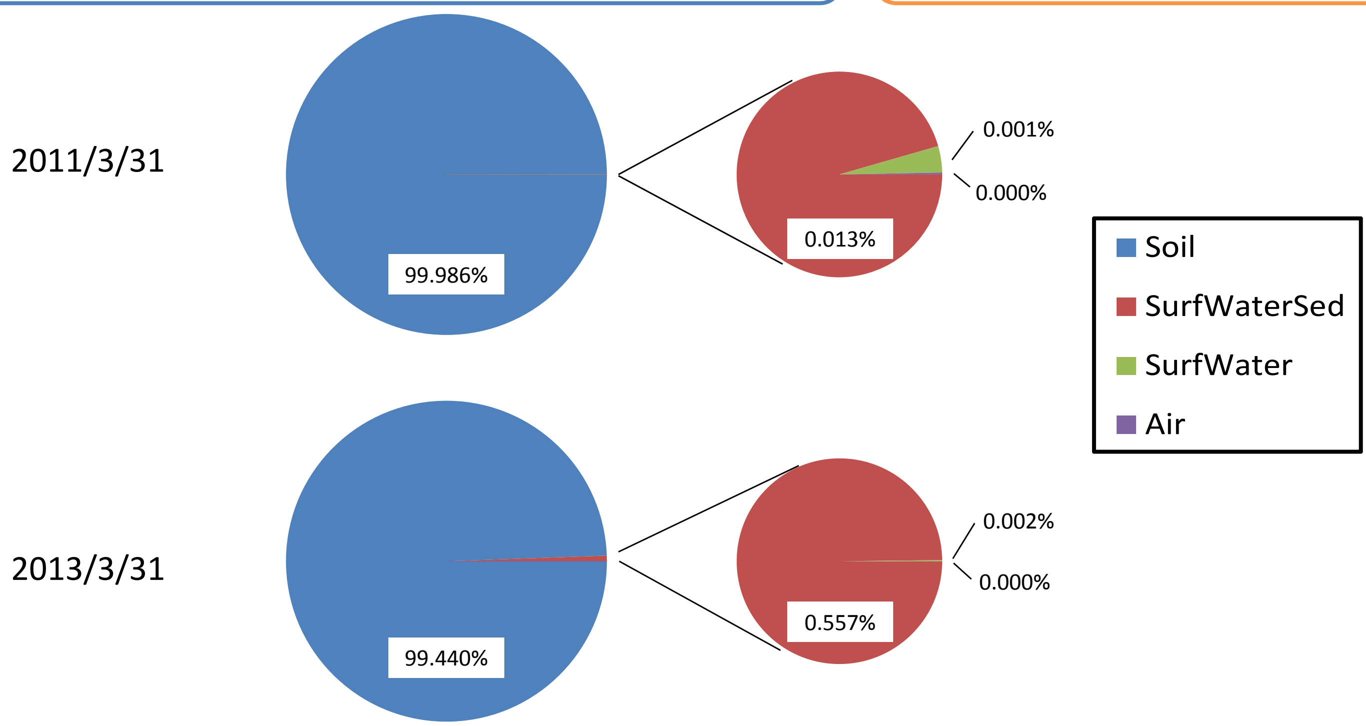
Central condition used in following results.

*IAEA (2010), Technical Reports Series no. 472.

Media distribution of ^{137}Cs in the simulation domain

- Most part of ^{137}Cs exists in soil compartment
  - More than 99% in soil after 2 years

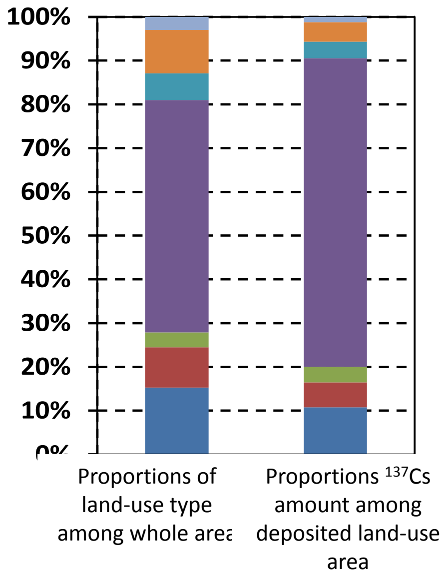
- Second largest part exists in surface water sediment

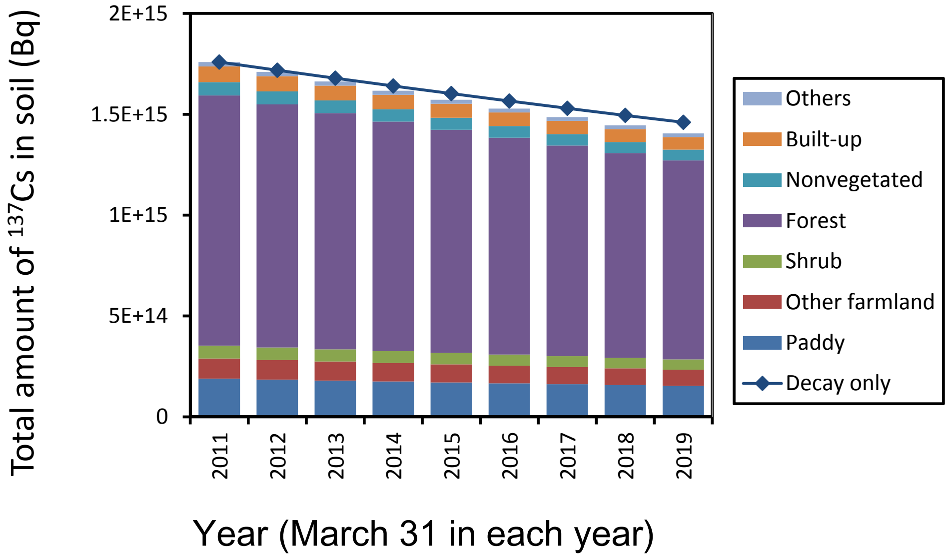


Simulated trend of ^{137}Cs in soil

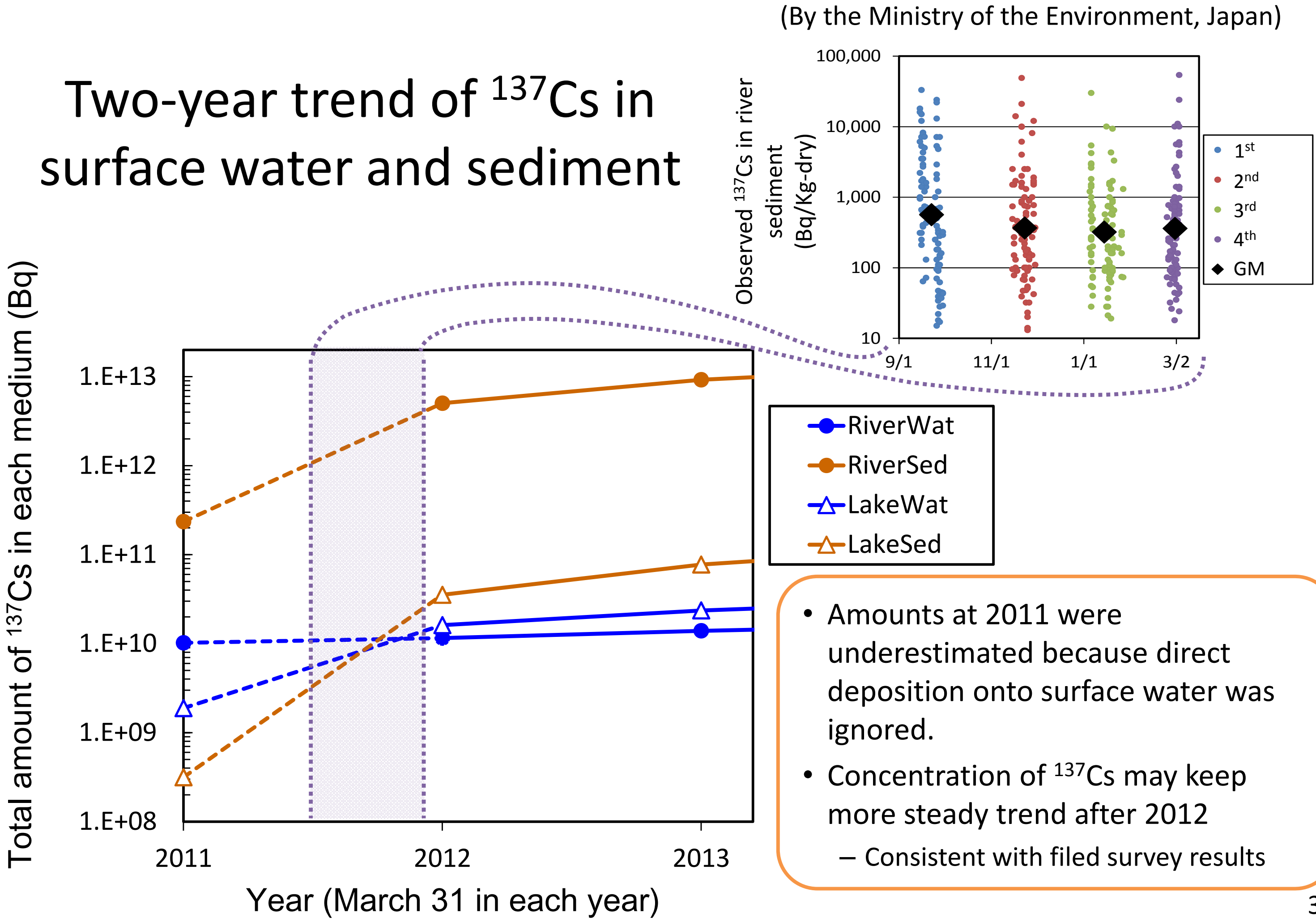
- Most part of ^{137}Cs were mainly deposited to forest area
  - Contaminated plume passed above forest area

- Decreasing trend of ^{137}Cs in soil
  - Simulated to slightly faster than radioactive decay, by runoff processes



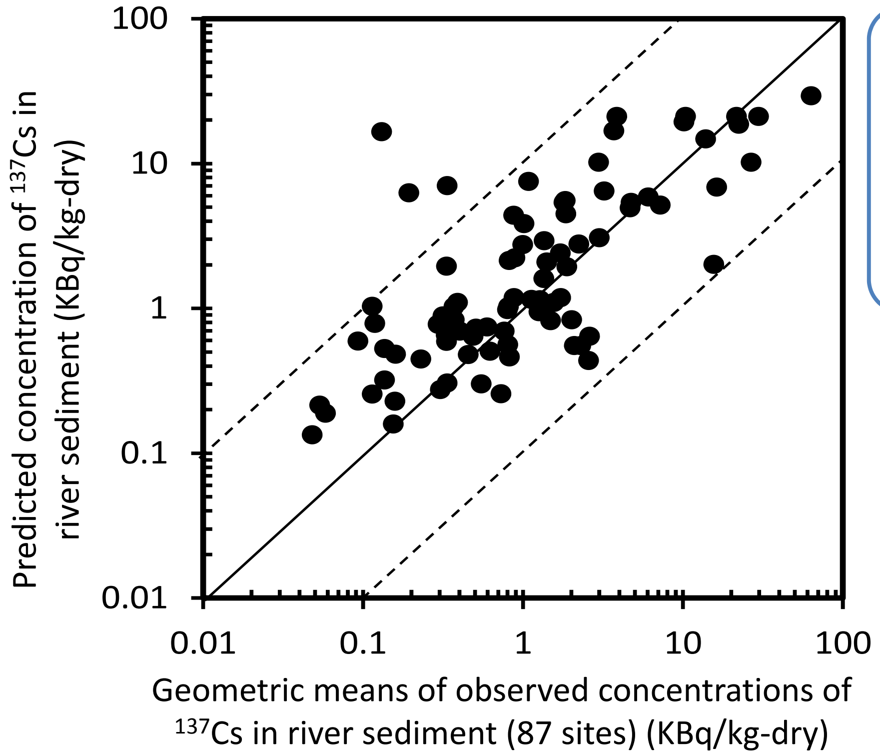


Two-year trend of ^{137}Cs in surface water and sediment



- Amounts at 2011 were underestimated because direct deposition onto surface water was ignored.
- Concentration of ^{137}Cs may keep more steady trend after 2012
  - Consistent with filed survey results

Comparison between observations and predictions of ^{137}Cs concentrations in river sediment

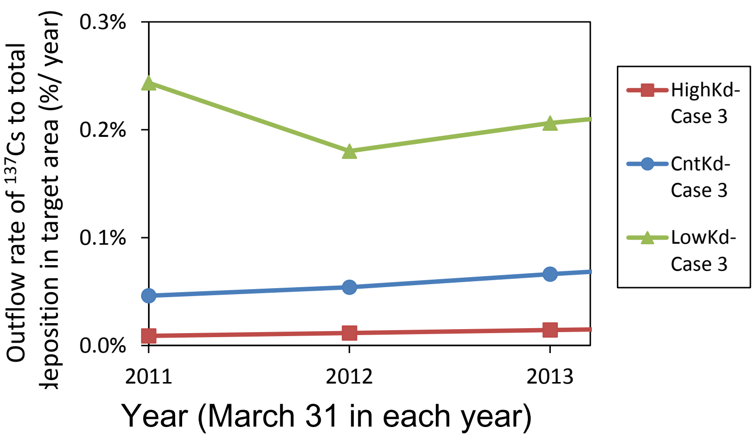


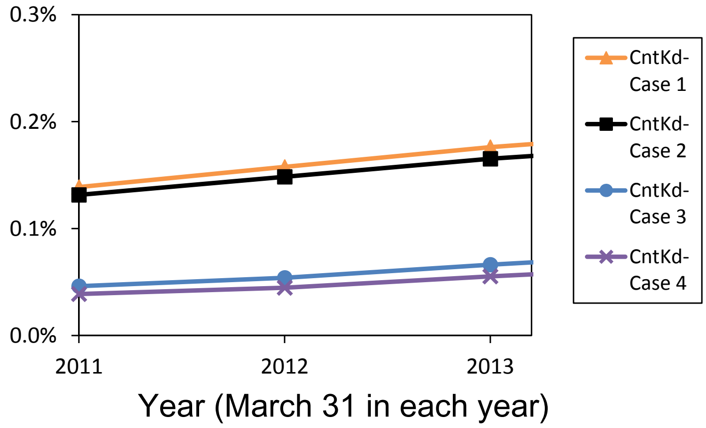
- ➢ Rough consistency between observations and predictions
- ➢ Further study need for more detailed analysis and other compartments

Comparison between geometric means of depth-corrected concentrations of ^{137}Cs in river sediment in Fukushima prf where ^{137}Cs was detected in all four surveys performed in FY 2011, and predicted concentrations in related river sediment at March 31, 2012

Discussion: Sensitivity analysis
- ^{137}Cs Outflow from land of whole model domain to ocean

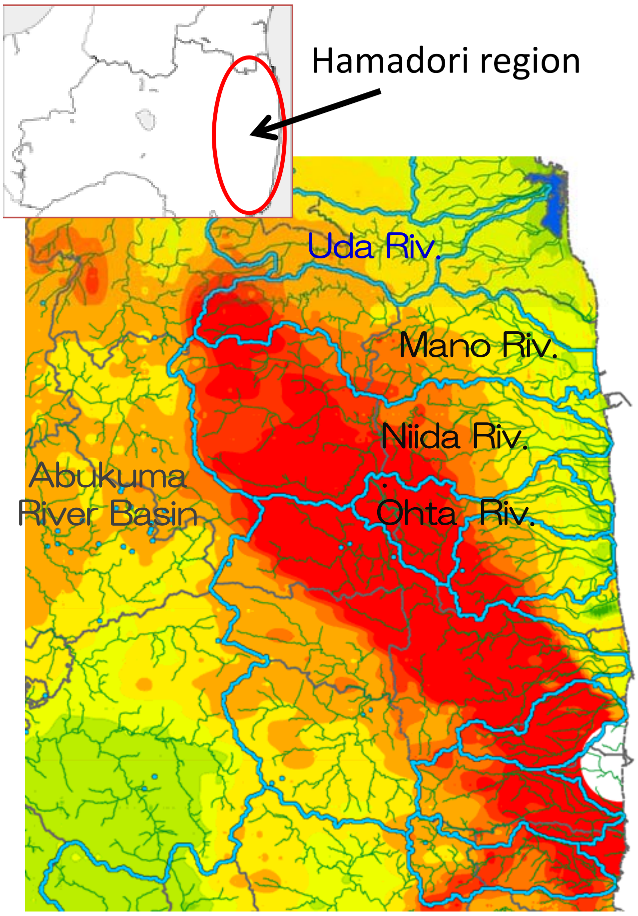
- Outflow flux of ^{137}Cs is simulated to keep steady trend
  - It may be strongly affected by distribution coefficients and soil runoff rates
- Since prediction still contains large uncertainty, model improvement is necessary before the results will be considered confidential





- ✓ Cnt K_d: 1.2 × 10^3 L/kg, High-K_d : Cnt kd x 5, Low-K_d : Cnt Kd / 5
- ✓ Soil Runoff rates (default case is "Case 3")
  - Case 1: High farm land, high built-up, Case 2: Low farm land, low built-up
  - Case 3: High farm land, low built-up, Case 4: Low farm land, low built-up

Future perspectives



- Expand our research target area from the Uda River basin to the main rivers' basins in the north Hamadori region
- Carry out the analysis of the flows and the stocks for Cs not only quantitatively but qualitatively
- Investigate and analyze the transfer characteristics of ^{137}Cs in both terrestrial and aquatic ecosystems
- Develop the detailed simulation model for the target area and validate it using observed data

Thank you for your attention!