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Estimation of sediment yield in an agriculture - forest dominated non-conservative watershed with SWAT model

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Introduction

- **Sediment and sediment-bound pollutants**

  Economic and environmental impacts：

  Declining soil fertility and decreased agricultural yields；

  Reservoir sedimentation；

  Pollution of natural waters.

Introduction

- **Sediment assessment :** ***Challenge?***

Catchment management; Environmental impact assessment

Complexity of the processes involved in the detachment and transport of fluvial sediment.

Different approaches for sediment yield estimation.

①Direct measurement

②Empirical models (rating curve)

③Distributed and process based hydrological models:

EUROSEM (Morgan et al., 1998), WEPP (Nearing et al., 1989); **SWAT** (Neitsch et al., 2002)

Introduction

- **Sedimentyield in non-conservative watersheds :**

SWAT has no mechanism to account for external water (EXT) contributions through subsurface flow from outside the watershed (Chu et al., 2004; Salerno and Tartari, 2009).

SWAT model cannot account effect of EXT on sediment routing.

Shibetsu River Watershed (**SRW**, 672 km^2, Hokkaido, Japan), assuming EXT as constant value (1.38mm/day) and adding it as point-source discharge in the model (Jiang et al., 2011).

<u>**EXT as point-source can't account Spatial Variation!**</u>

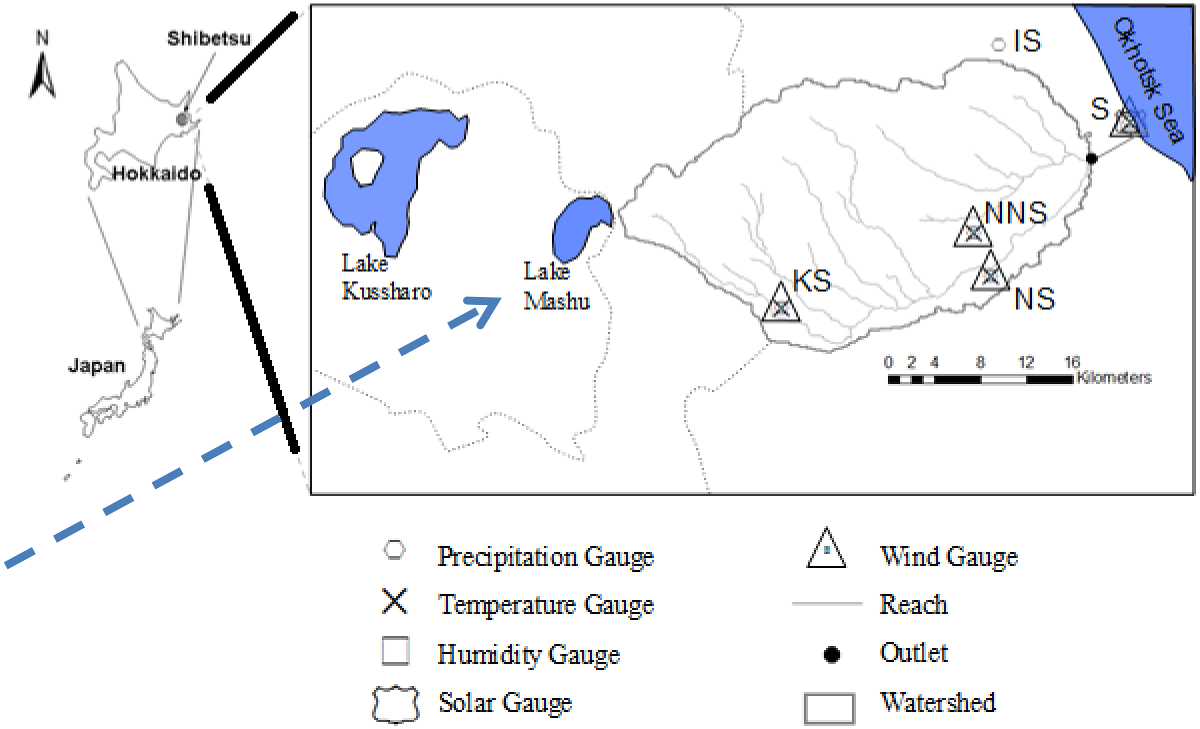
Objectives

(1) Modify SWAT model (SWAT-EXT) to account the spatial variation of EXT contribution to streams and effect of EXT on sediment routing in channels in SRW.

(2) Estimate sediment, particulate organic nitrogen (PON) and particulate organic phosphorous (POP) yield at the main outlet of SRW with SWAT-EXT.

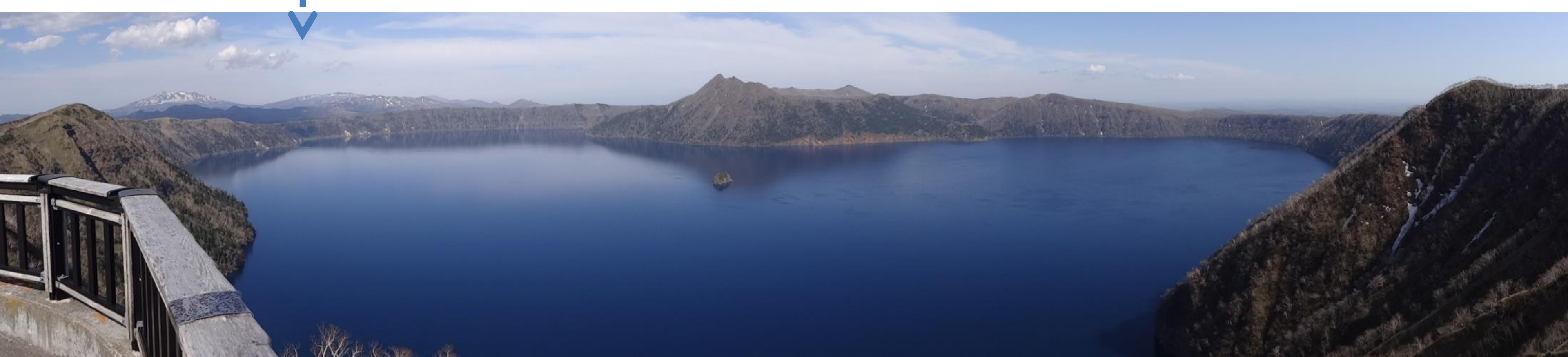
Material and methods

- **Study site**



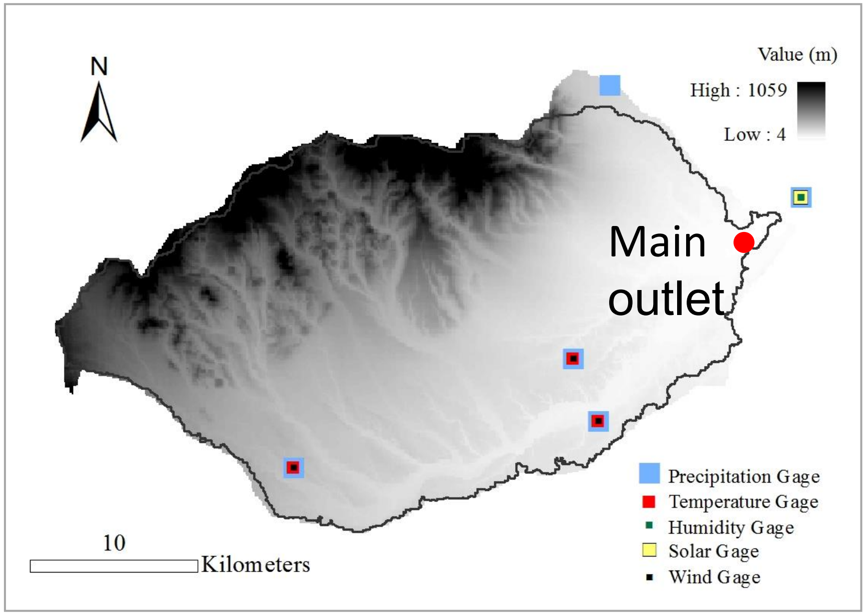
Location of Shibetsu River Watershed (SRW)

Mashu lake

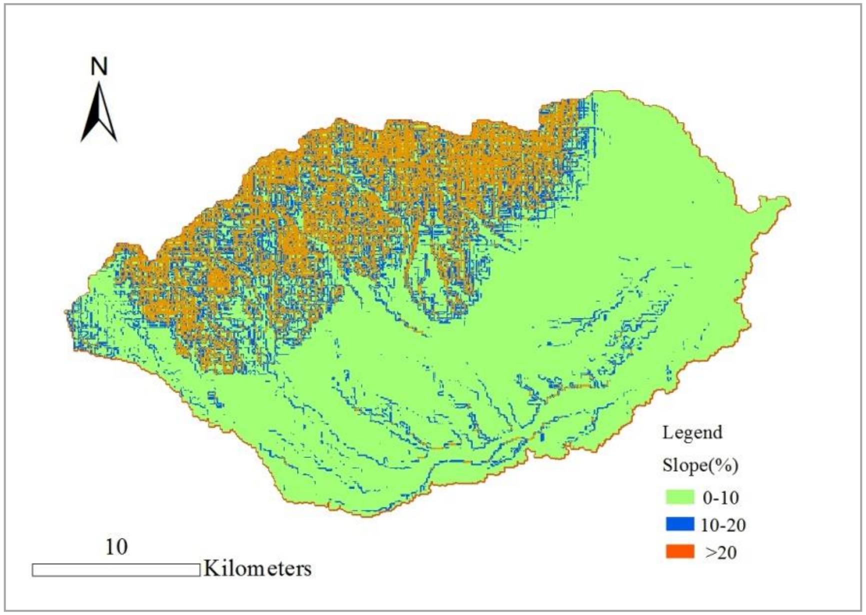


Material and methods

- Study site



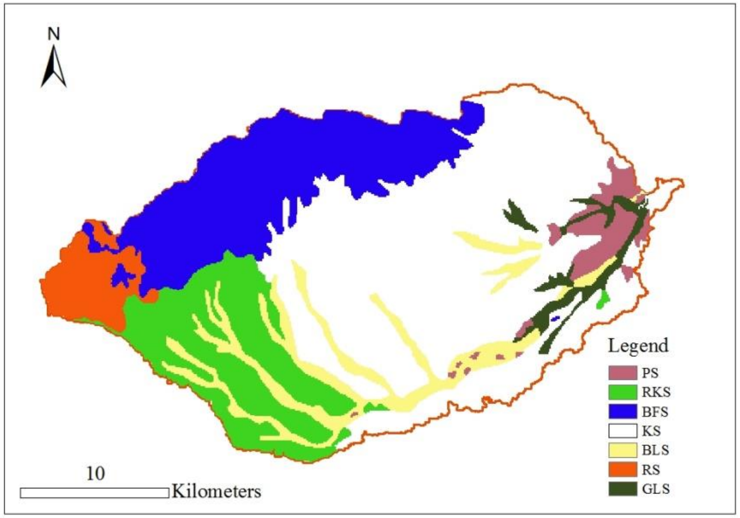
DEM map



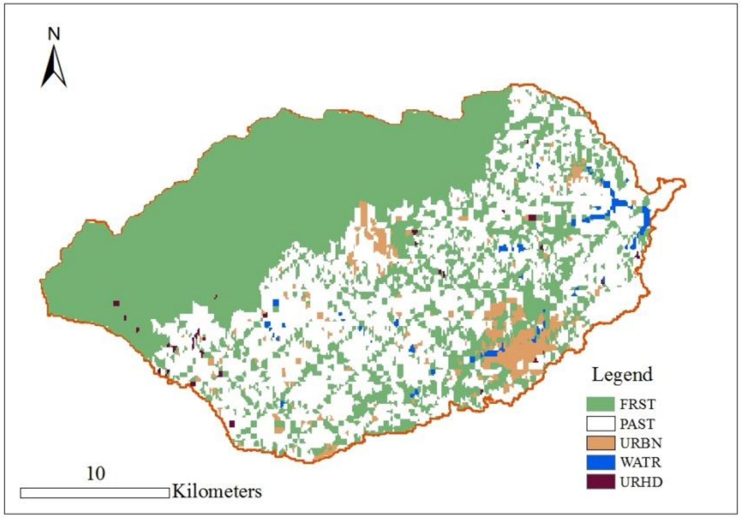
Slope map (%)

Material and methods

- Study site



Soil type map



Land use map

PS: Peat soil

RKS: Regosolic kuroboku soil

BFS: Brown forest soil

BLS: Brown lowland soil

RS: Regosol soil

GL: Gray lowland soil

KS: Kuroboku soil

FRST: Mixed forest

PAST: Pasture

URBN: Urban

URHD: Urban with high density

Material and methods

- Instrumentation and sampling

Daily stream water table (*H*);

Water samples : Automatic sampler;

Concentrations of sediment:

water samples was filtered through 0.7μm membrane filters;

Concentrations of TN, TP, TDN and TDP:

0.2μm membrane filters;

Alkaline persulfate digestion and HCl-acidified UV detection.

Concentrations of PON and POP:

TN-TDN & TP-TDP

Daily stream discharge (*Q*) :

Calibrated *H*-*Q* equations;

Sediment load (Qs) : rating curves

Annual:

$$Qs = 0.0102\ Q^{2.6658}$$

($N=646$, $R^2=0.57$, $P<0.01$)

May:

$$Qs = 0.0545\ Q^{2.038}$$

($N=63$, $R^2=0.36$, $P<0.01$)

TN: total nitrogen
TP: total phosphorous
TDN: total dissolved nitrogen

TDP: total dissolved phosphorous
PON: particulate organic nitrogen
POP: particulate organic phosphorous

Material and methods

- Modified SWAT model (SWAT-EXT)

Conservative environment, <u>total water entering channels per day from a HRU</u>:

$$q=q_{surf}+q_{lat}+q_{gw}$$

For non-conservative environment:

$$q=q_{surf}+q_{lat}+q_{gw} + EXT$$

q: total water entering channels as streamflow (mm);
q_{surf} : urface runoff contribution to streamflow (mm);
q_{lat} : lateral flow contribution to streamflow (mm);
q_{gw} : internal groundwater contribution to streamflow (mm);
EXT: external groundwater contribution (1.38 mm/day),
calculated from annual water balance budget (Jiang et al., 2011).

<u>Overland erosion:</u>

Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975)

<u>Channel erosion and deposition:</u>

Modification of Bagnold's sediment transport equation (Bagnold, 1977)

Material and methods

- Model calibration

Streamflow

Calibration (2003-2005) and validation (2006-2008)

Sediment loads

Calibration SWAT-EXT (2003 and 2004) and validation (2007).

- Model performance evaluation

Coefficient of determination (**R^2**);

Nash and Sutcliffe efficiency coefficient (**E_{NS}**);

Relative error (**Re**).

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n} (X_{oi} - X_{si})^2}{\sum_{i=1}^{n} (X_{oi} - \overline{X_{oi}})^2}$$

$$Re(\%) = \left| \frac{\sum_{i=1}^{n} X_{si} - \sum_{i=1}^{n} X_{oi}}{\sum_{i=1}^{n} X_{oi}} \right| * 100$$

Results and Discussion

No	Parameters		value
1	v__CN2.mgt	Initial SCS runoff curve number for moisture condition	26.53
2	v__ALPHA_BF.gw	Baseflow alpha factor (days)	0.42
3	v__REVAPMN.gw	Threshold depth of water in the shallow aquifer for revap to occur (mm)	210.02
4	v__SOL_AWC.sol	Available water capacity of the soil layer (mm H_2O/mm soil)	0.10
5	v__ESCO.hru	Soil evaporation compensation factor	0.29
6	v__CANMX.hru	Maximum canopy storage (mm H_2O)	98.74
7	v__GW_DELAY.gw	Groundwater delay (days)	79.62
8	v__CH_N2.rte	Surface runoff lag coefficient	0.09
9	v__SFTMP.bsn	Snowfall temperature (°C)	-4.04
10	v__SMTMP.bsn	Snowmelt base temperature (°C)	-0.15
11	v__SMFMX.bsn	Maximum melt rate for snow during years (mm/ °C /day)	3.22
12	v__SMFMN.bsn	Minimum melt rate for snow during years (mm / °C /day)	0.63
13	v__TIMP.bsn	Snowpack temperature lag factor	0.28
14	v__SURLAG.bsn	Manning's “n” value for the tributary channels	0.92

Results and Discussion

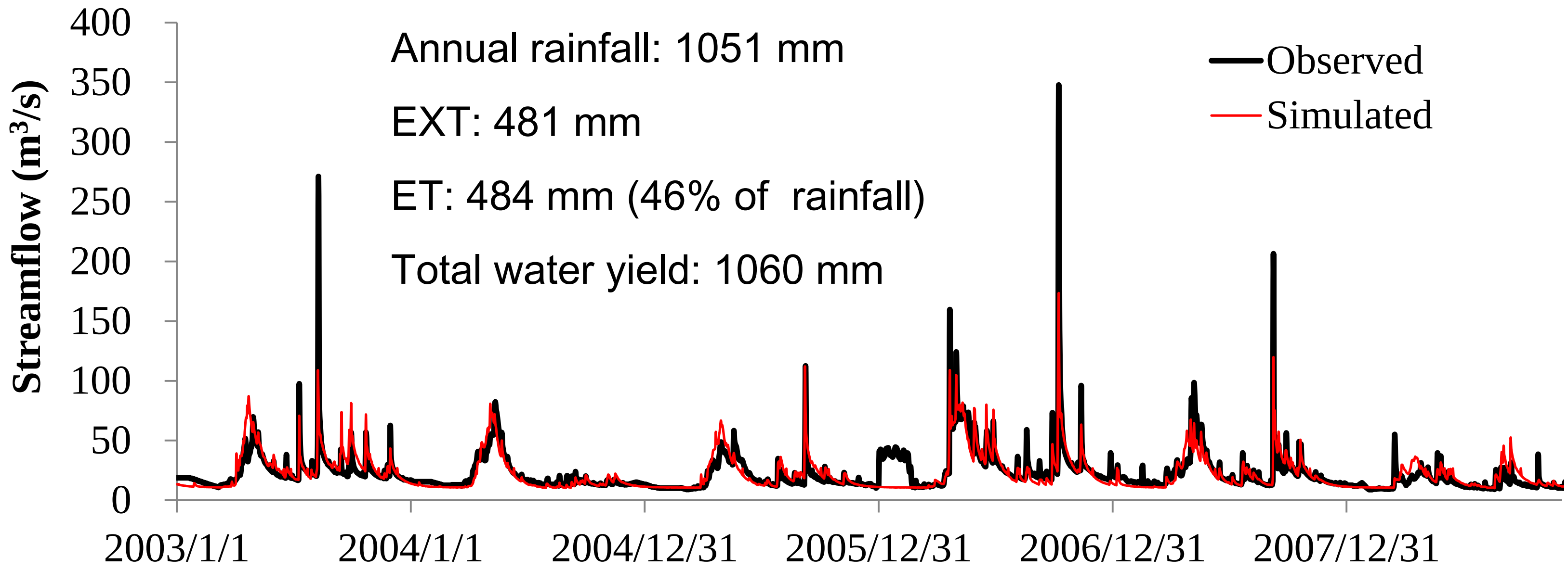
No.	Parameter	Definition of Parameters	Value
1	v__USLE_C(FRST).crop.dat	Minimum value for the cover and management factor for the land cover	0.1
2	v__USLE_C(PAST).crop.dat	Minimum value for the cover and management factor for the land cover	0.25
3	v__USLE_P(FRST).mgt	USLE support practice factor	0.9
4	v__USLE_P(PAST).mgt	USLE support practice factor	0.85
5	v__CH_EROD.rte	Channel erodibility factor	0.5
6	v__CH_COV.rte	Channel cover factor	0.56
7	v__ADJ_PKR.bsn	peak rate adjustment factor in tributary channels	1.8
8	v__PRF.bsn	Peak rate adjustment factor in the main channel	0.2
9	v__SPCON.bsn	Coefficient in sediment transport equation	0.007
10	v__SPEXP.bsn	Exponent in sediment transport equation	1.106

USLE soil erodibility (K_{USLE}) factor: Williams (1995)

USLE topographic factor (LS_{USLE}): automatically, GIS interface in SWAT model.

Results and Discussion

- Hydrology



The statistical performance of SWAT-EXT:

R^2 value of 0.60, E_{NS} value of 0.58 and Re of 2.5%.

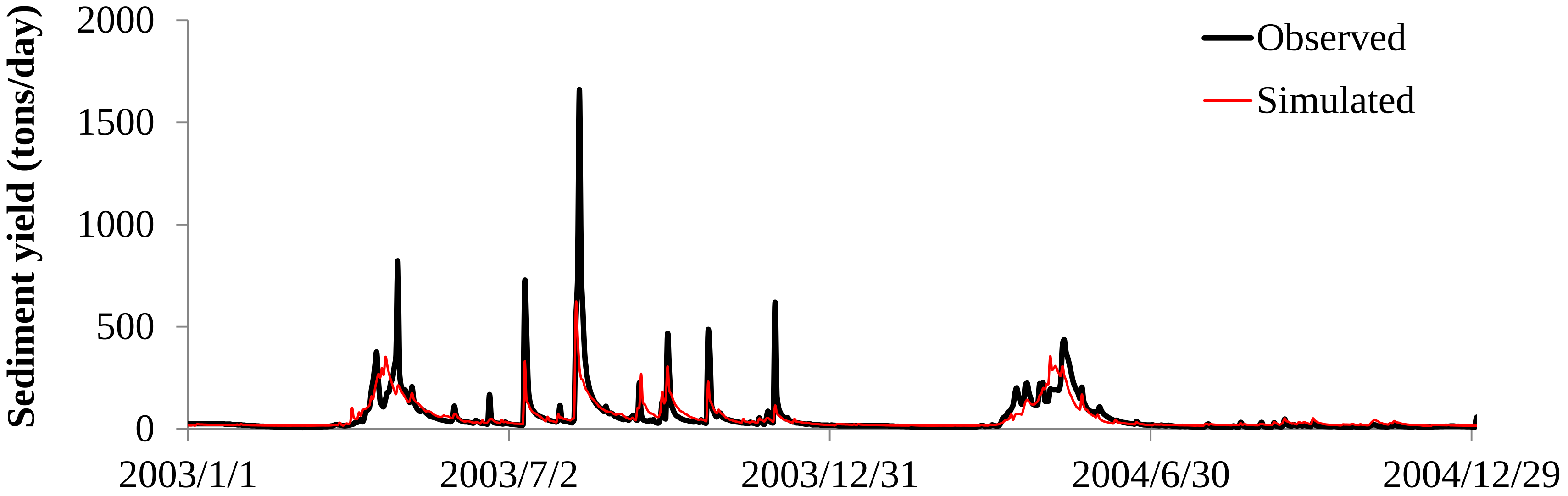
Total water yield of 1060 mm:

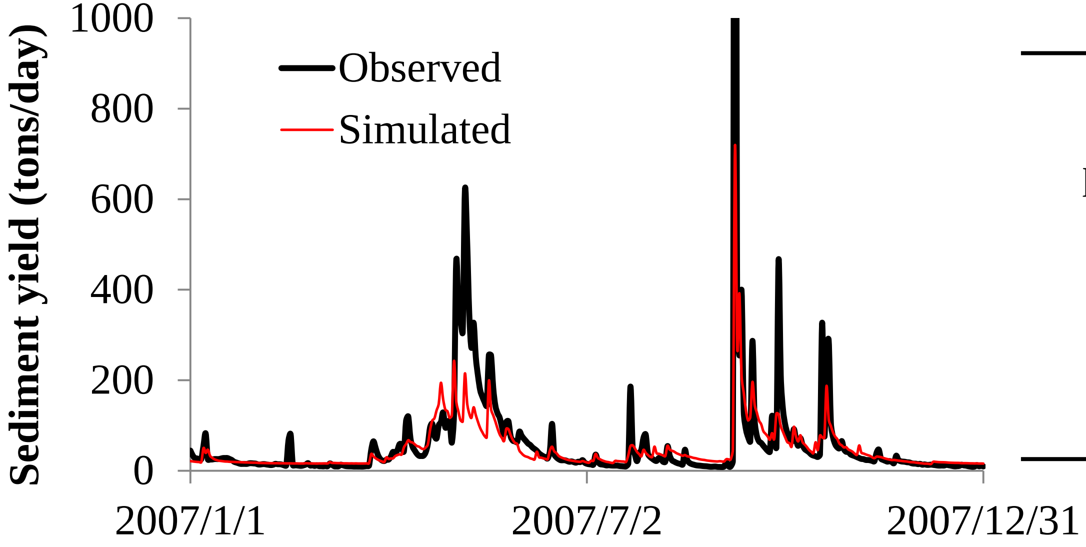
Subsurface water recharge of 1040 mm (including EXT)

Surface runoff of 20 mm

Results and Discussion

- SWAT-EXT for sediment yield estimation

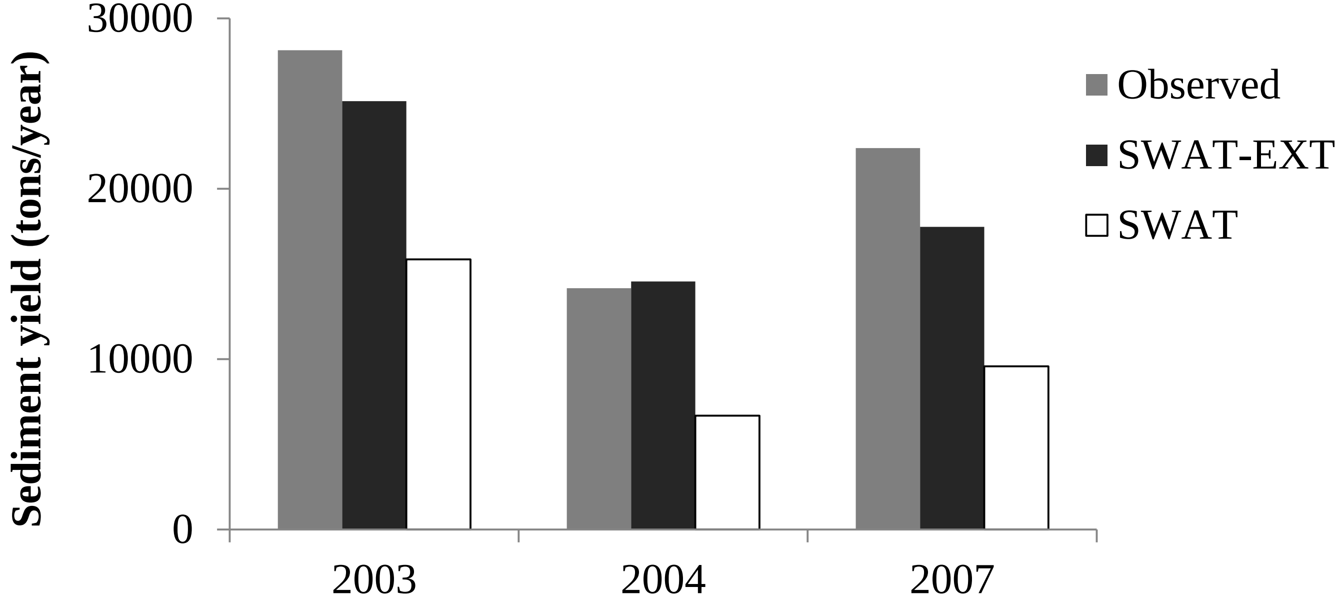




Model performance	SWAT-EXT	
	Calibration	Validation
R^2	0.56	0.70
E_{NS}	0.53	0.49
Re	11%	

Results and Discussion

- External water effects on channel routing of sediment



Mean annual sediment yield

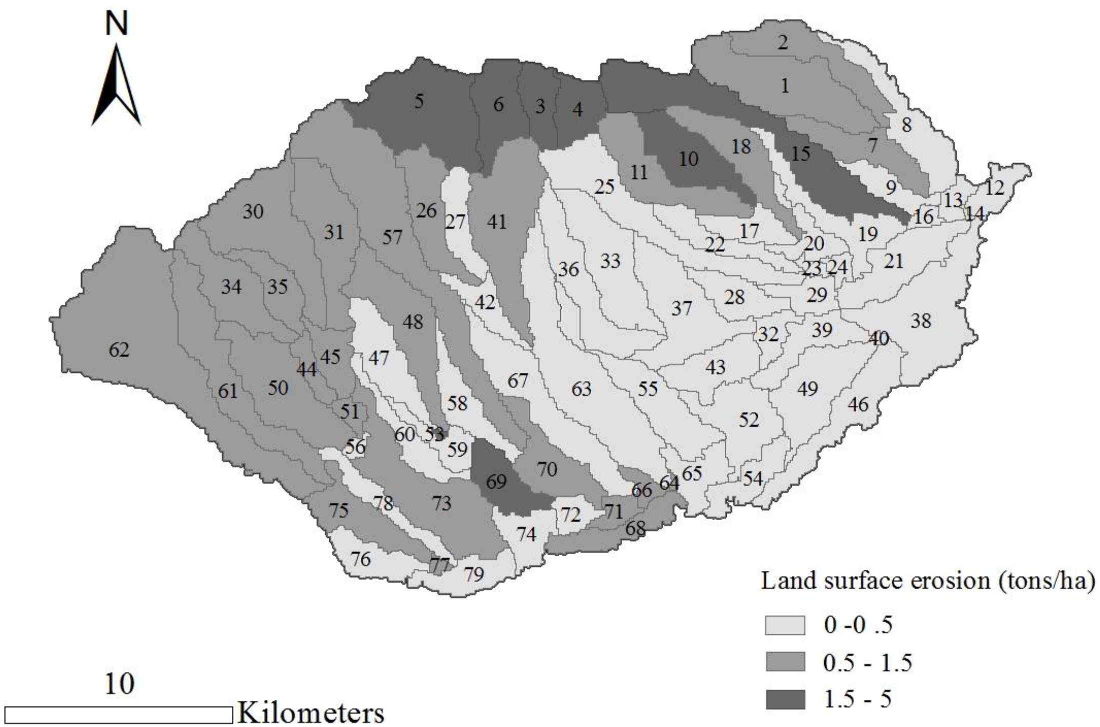
Observed : 21560 tons/year. SWAT-EXT : 19154 tons/year (Re of 11%).

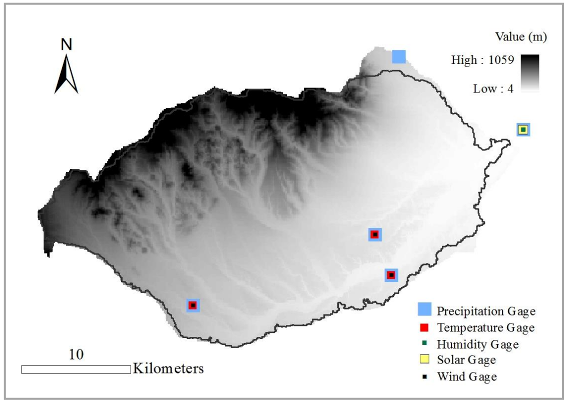
Original SWAT model without EXT: 10707 tons/year (Re of 50 %)

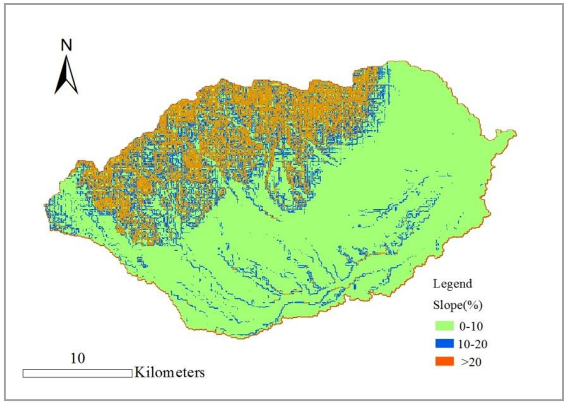
EXT increased sediment export when it entered into channels at SRW

Results and Discussion

- Identify critical source area of land surface erosion







(1) In the forest area:

Sub-basins 3, 4, 5, 6, 10 and 15 had the highest sediment yield.

(2) Under agricultural pasture land:

Sediment yield increased with distance from the watershed outlet

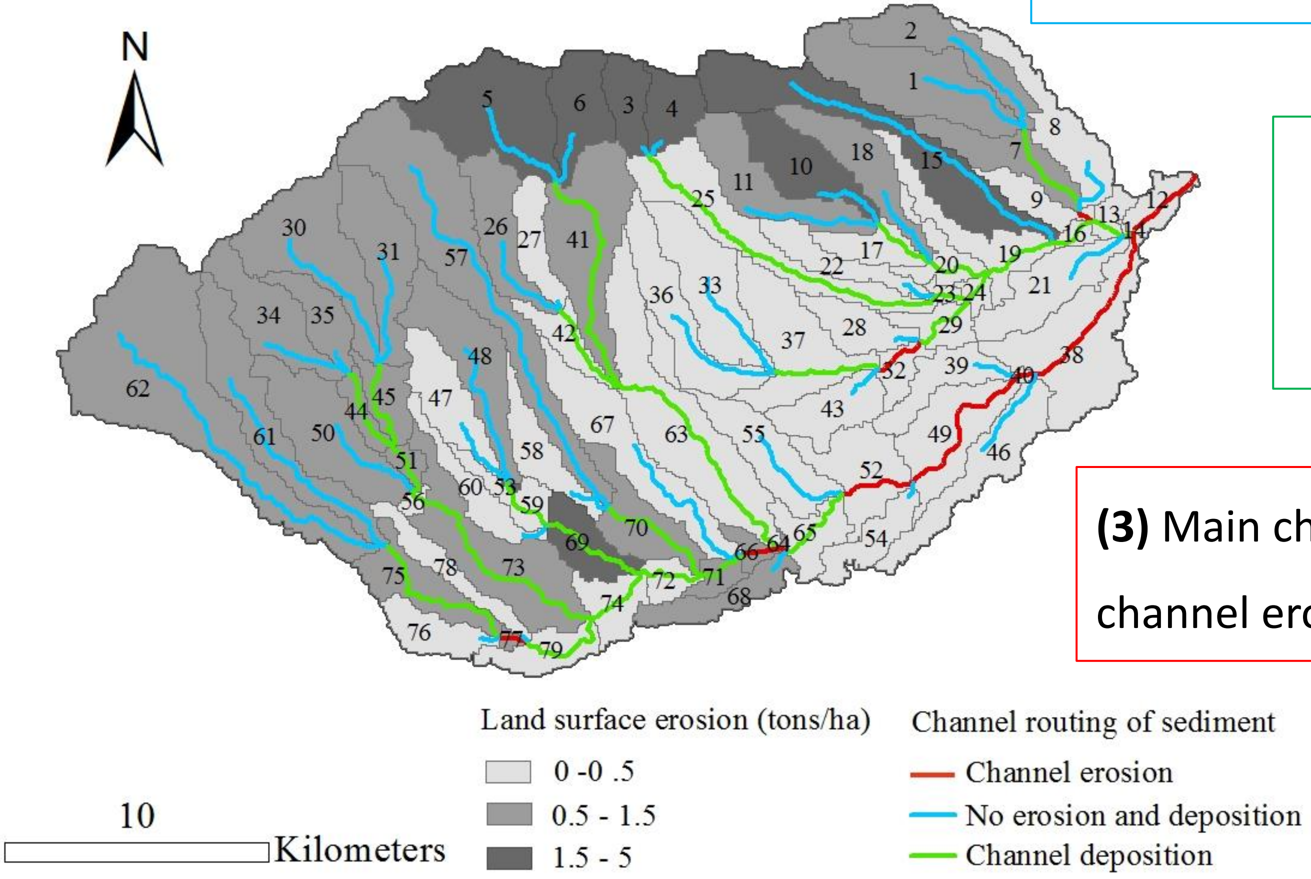
Results and Discussion

- Channel routing of sediment

(1) Channel erosion and deposition were not observed in the first order streams.

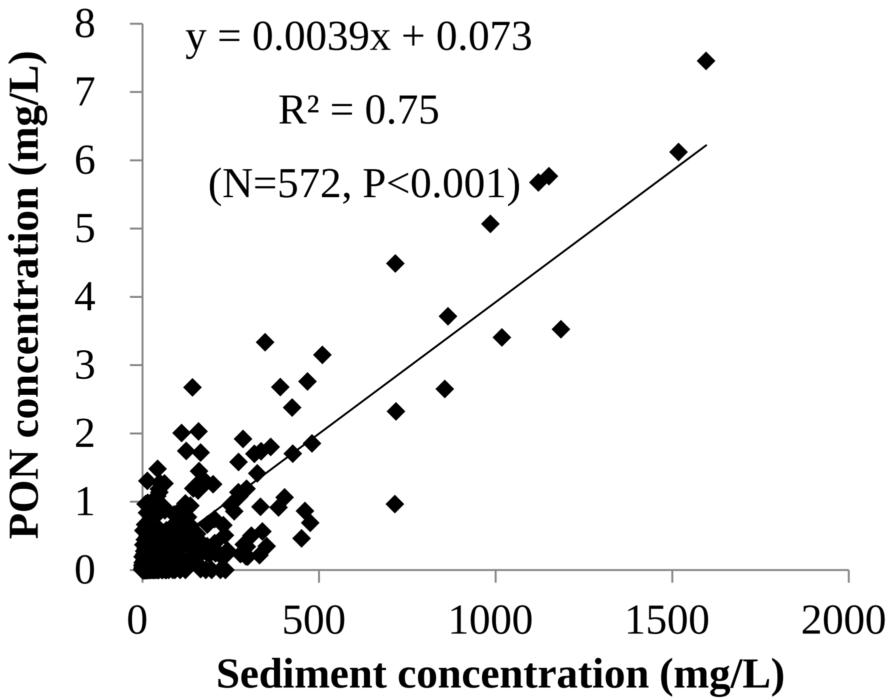
(2) Deposition occurred in second and third order streams.

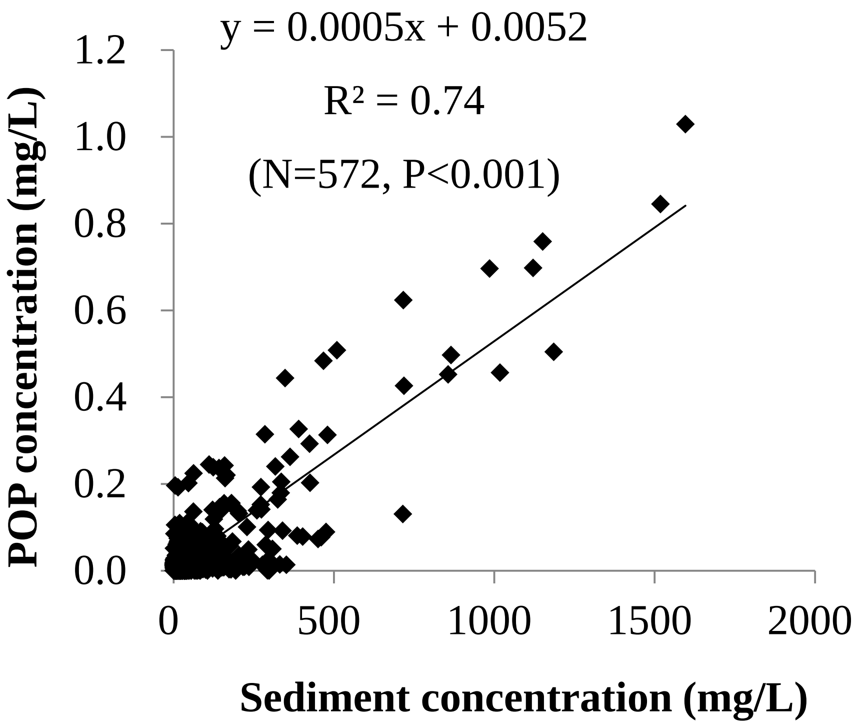
(3) Main channel was identified with channel erosion dominated.



Results and Discussion

- Relationship between sediment, PON and POP concentrations

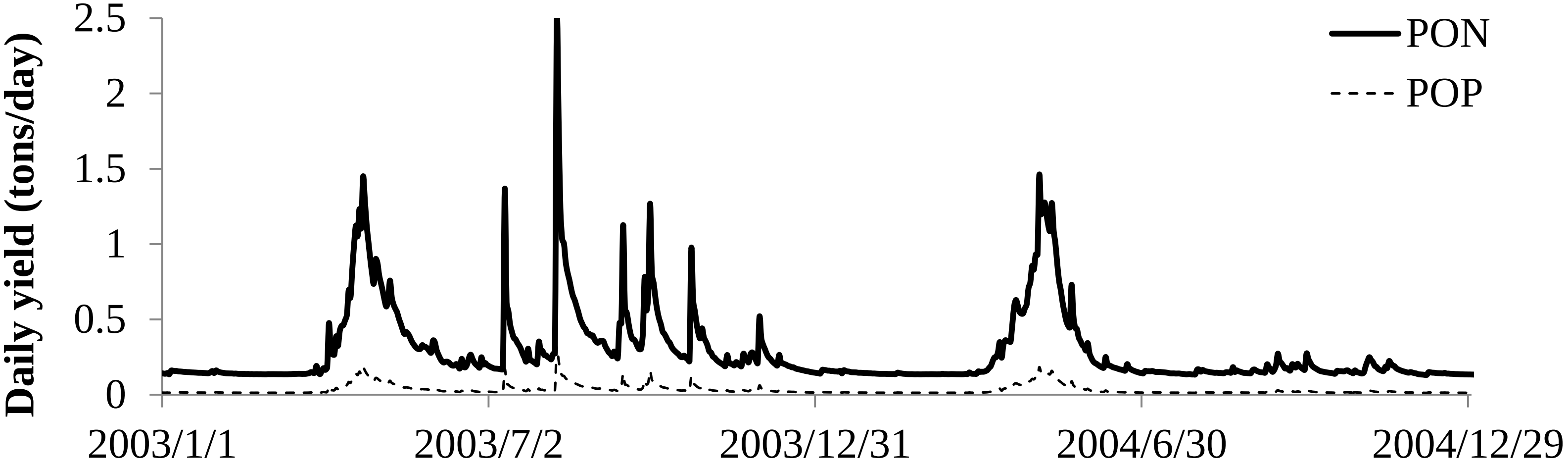


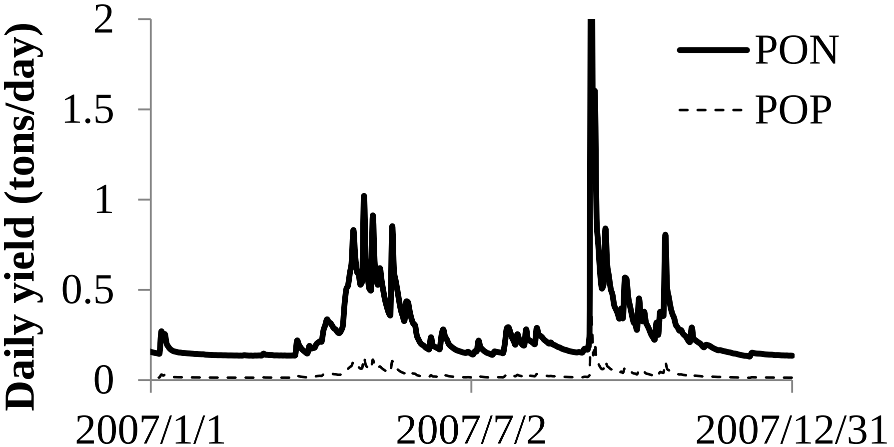


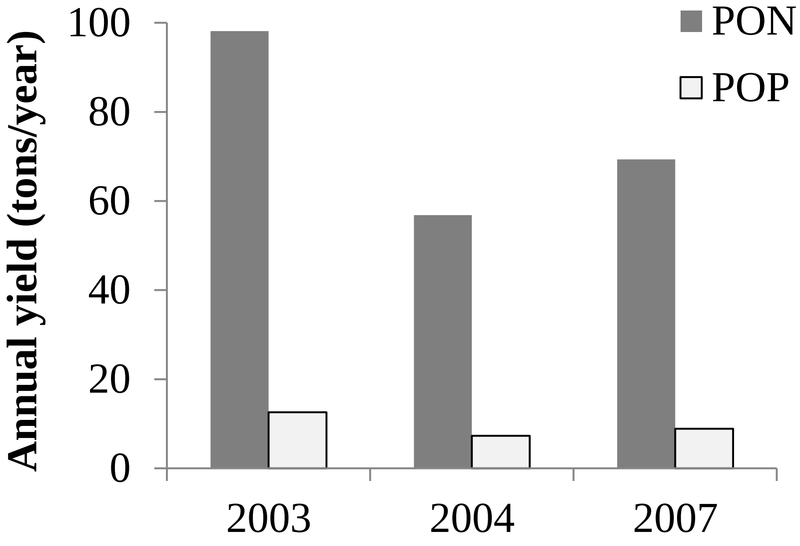
Statistically significant linear relationship between sediment concentration and PON concentration & between sediment concentration and POP concentration

Results and Discussion

- Estimation of PON and POP yield with SWAT-EXT







Conclusion

- SWAT-EXT, which including external water contribution to channel, was proved as an appropriate tool to quantify sediment yield at SRW.
- Sub-basins with steep slope of more than 10 degrees were identified as critical source area of land surface erosion.
- EXT increased channel sediment export but sediment deposition still happened in the second and third order streams.
- Main channel of SRW was identified as channel erosion dominated.
- Linear relationship between sediment, PON and POP concentrations.
- PON and POP yield were estimated based on results of SWAT-EXT.


Thanks for
your attention !