2016 International SWAT Conference

A Heavy Metal Module Coupled in SWAT Model and Its Application

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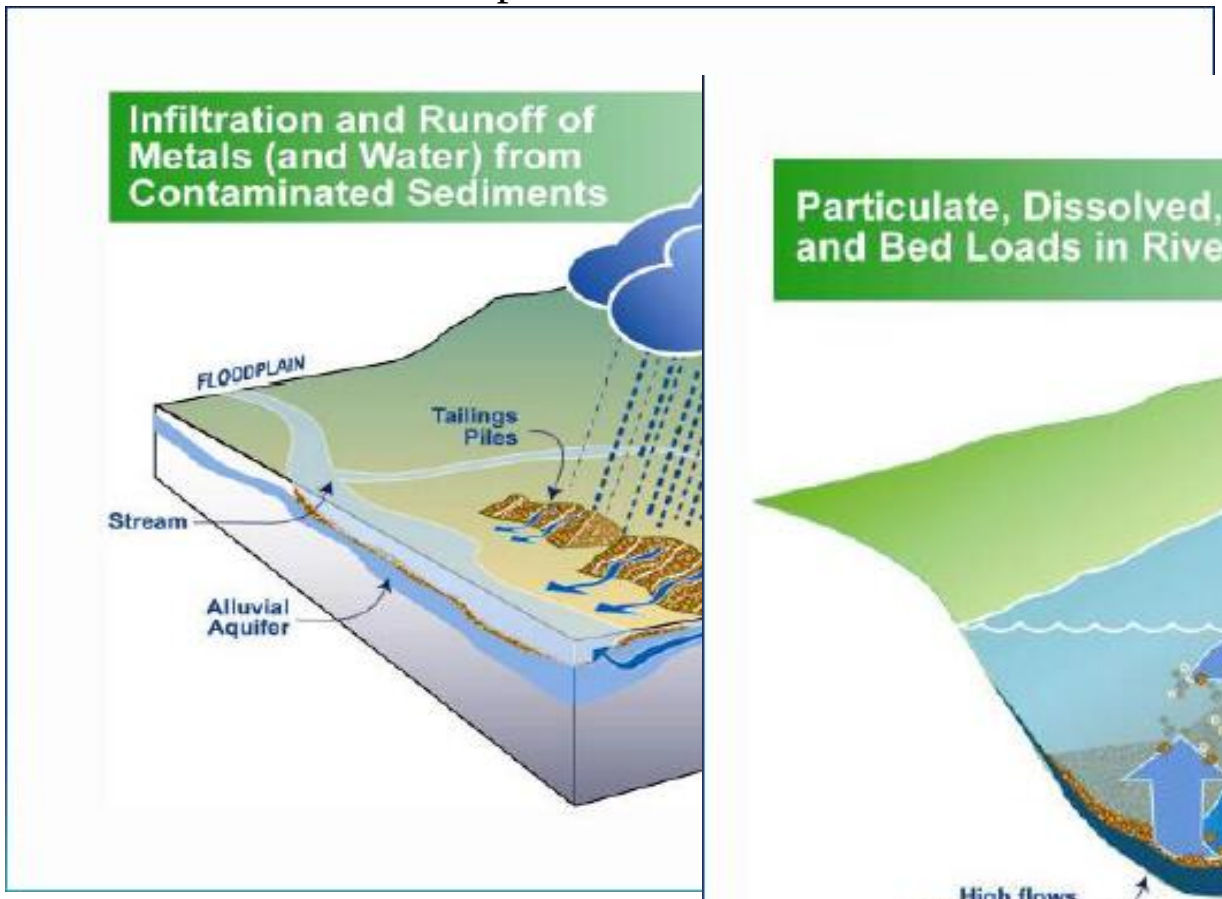
1. Introduction

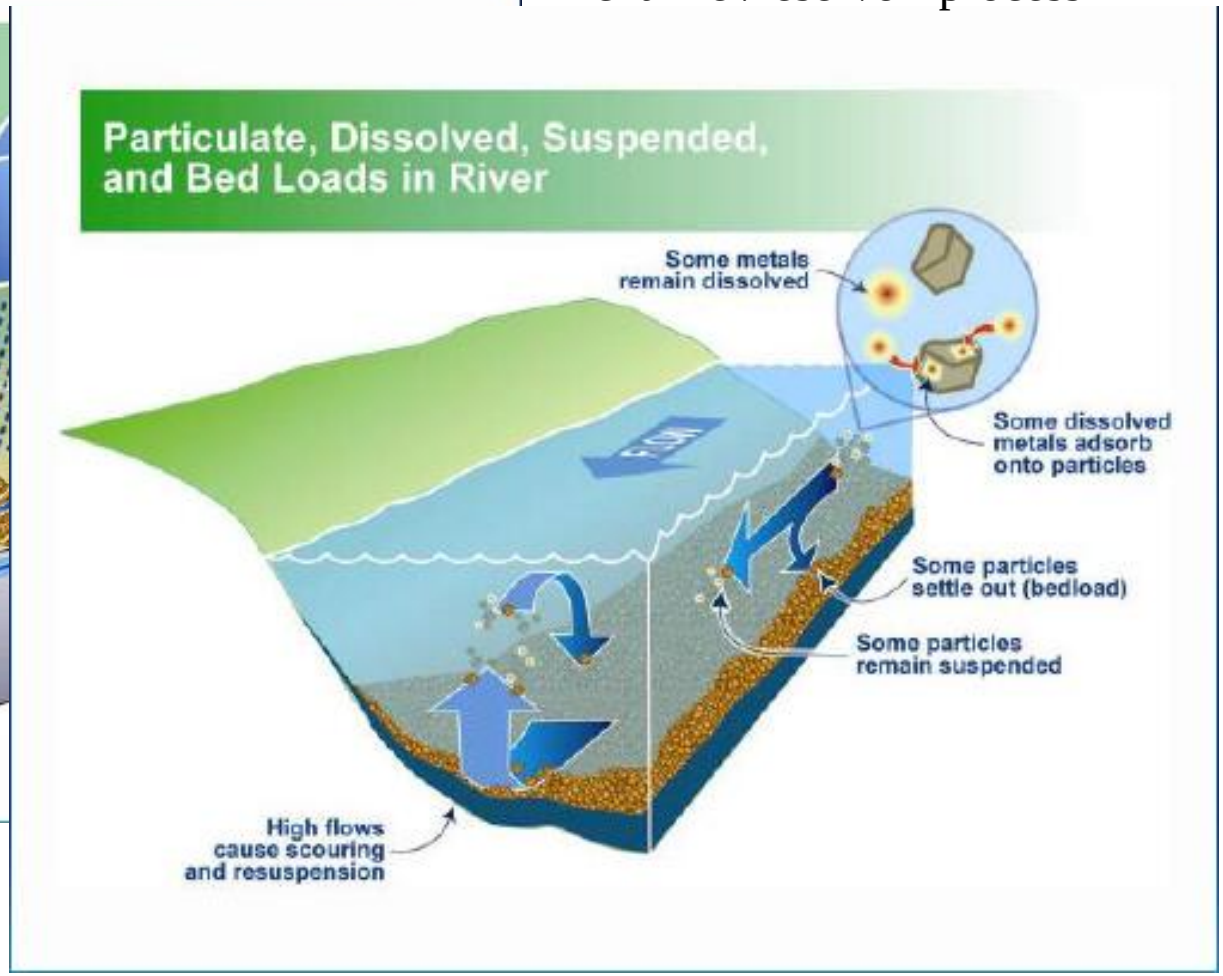
Heavy metal pollution in mining area

1. Introduction

land process [1]



channel/reservoir process [1]

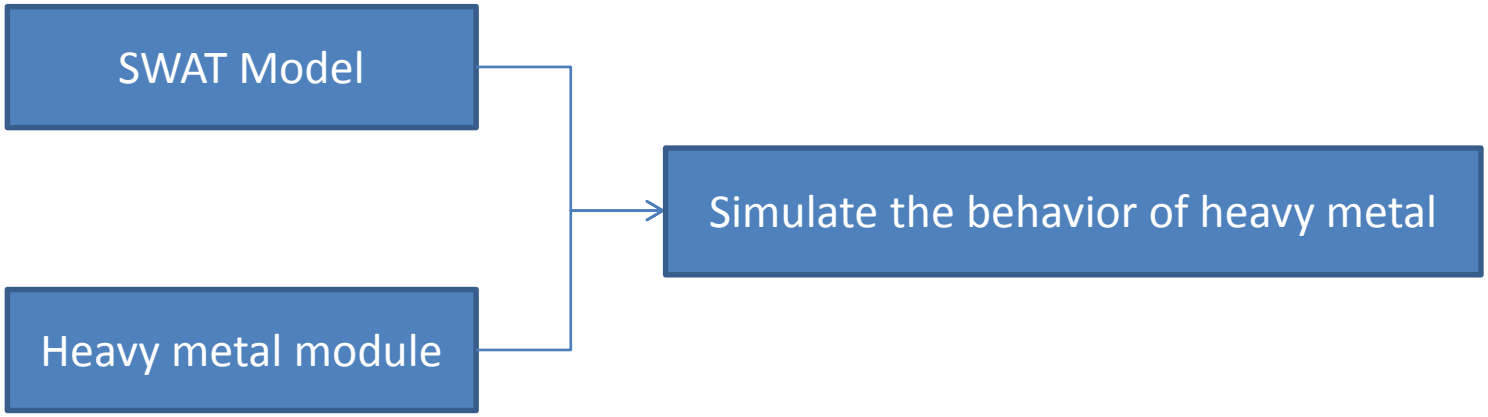


[1]. Statements E I. Comparison of Predicted and Actual Water Quality at Hardrock Mines[J].

1. Introduction

SWAT model

The soil and water Assessment Tool (SWAT) has been proven to be an effective tool for nonpoint-source pollution problem. such as nitrogen and phosphorus and pesticide. However, as far as heavy metals is concerned, the SWAT model, by its own version, only allows point source loading inputs and includes no algorithms to model in-stream processes but simple mass balance equations[2]. which addresses a small part of heavy metal pollution issues.



[2] Neitsch, S.L., Arnold, J.G., Kiniry, J.R. and Williams, J.R., 2011. Soil and water assessment tool theoretical documentation version 2009, Texas Water Resources Institute

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2. Heavy Metal module -- Challenges

- ***Primary Source identification***
  - Drains
  - Waste rocks
  - Tailings
  - Contaminated soil
  - …

- ***Chemical speciation***
  - Solid phase: labile(adsorbed); non-labile(strong bonded, minerals)
  - Aqueous phase: free ions, complexes, colloids

- ***Physical movement***
  - Wind erosion , transport
  - Soil erosion, transport
  - Surface runoff
  - Lateral flow
  - Groundwater flow

2. Heavy Metal module -- Challenges

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2. Heavy Metal module

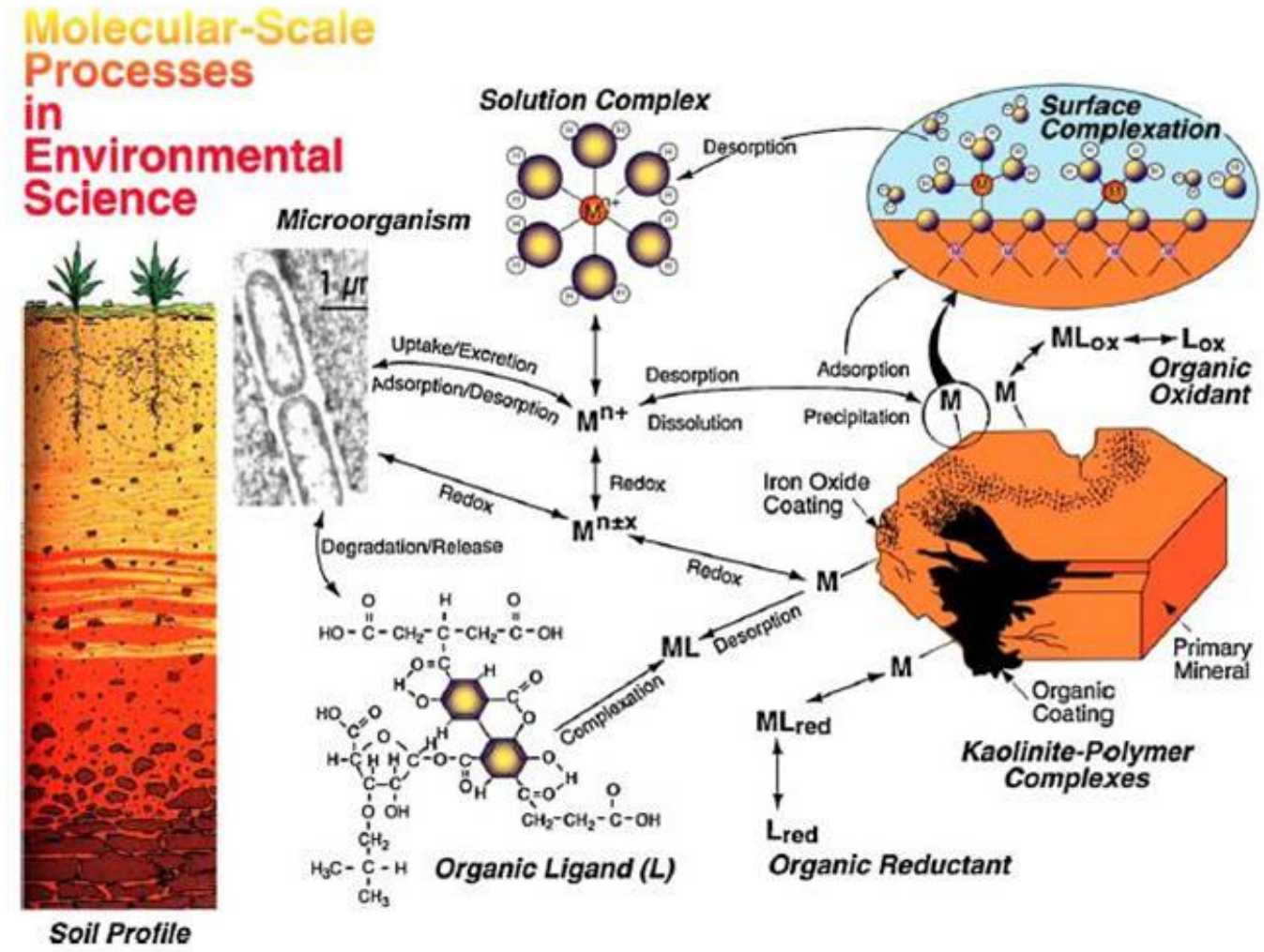


Fig. Molecular-scale environmental processes of metals in soils and aquatic systems[3]

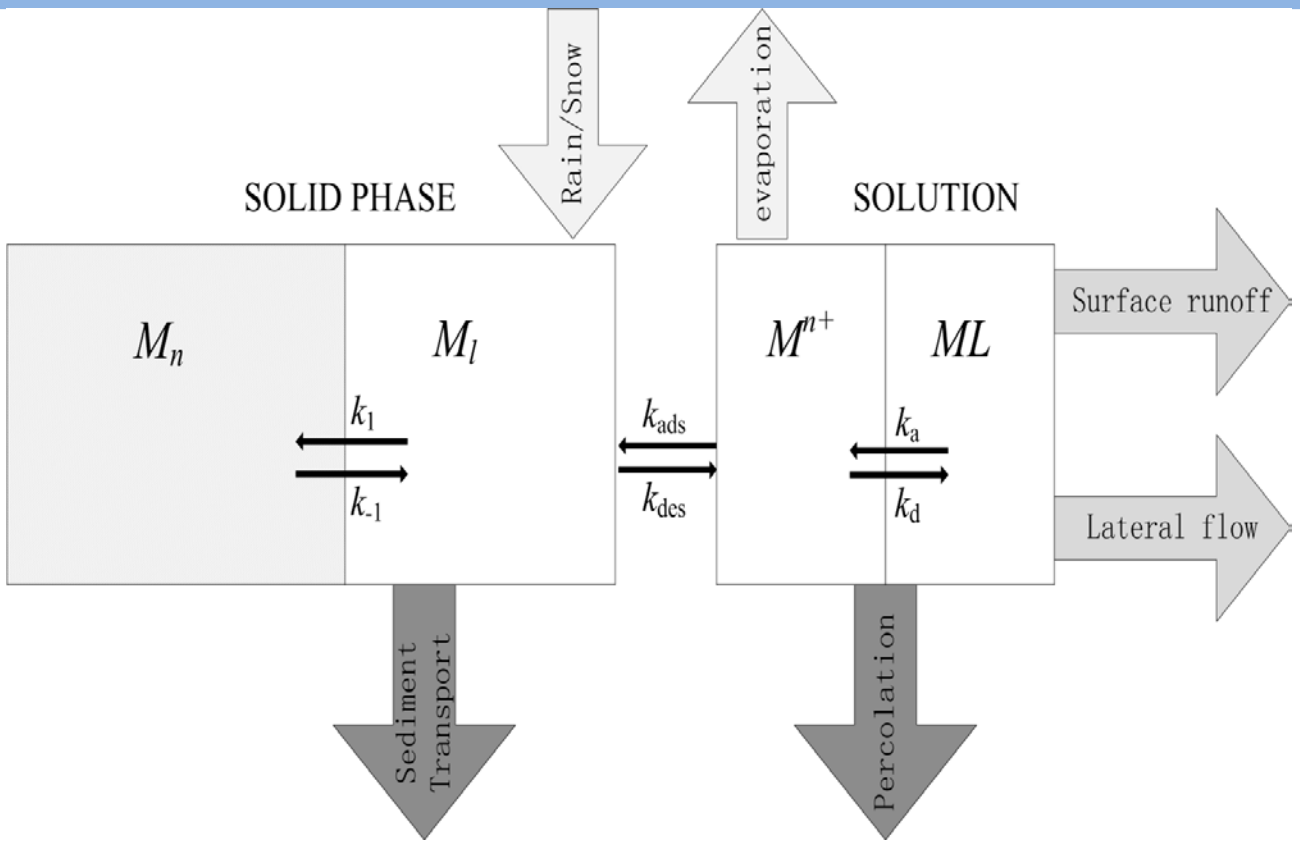
[3]. Brown Jr G E, Chianelli R, Stock L, et al. Molecular environmental science: speciation, reactivity, and mobility of environmental contaminants[C]//Report of the DOE Molecular Environmental Science Workshop. 1995.

2. Heavy Metal module – Transformation model

Tab. Three major reactions in soil-water environment

Reaction	Formulation	Equation
Adsorption & desorption	$M_l \underset{k_{ads}}{\overset{k_{des}}{\rightleftharpoons}} M^{n+}$	$\theta \frac{d\left[M^{n+}\right]}{dt} = -k_{ads}\theta\left[M^{n+}\right] + k_{des}\rho M_l$ $\rho \frac{dM_l}{dt} = k_{ads}\theta\left[M^{n+}\right] - k_{des}\rho M_l$
Complexation	$M^{n+} + L \underset{k_d}{\overset{k_a}{\rightleftharpoons}} ML$	$\frac{d\left[ML\right]}{dt} = k_a\left[M^{n+}\right]\cdot\left[L\right] - k_d\left[ML\right]$ $\frac{d\left[M^{n+}\right]}{dt} = -k_a\left[M^{n+}\right]\cdot\left[L\right] + k_d\left[ML\right]$
Slow reaction	$M_n \underset{k_1}{\overset{k_{-1}}{\rightleftharpoons}} M_l$	$\frac{dM_l}{dt} = -k_1 M_l + k_{-1} M_n$ $\frac{dM_n}{dt} = k_1 M_l - k_{-1} M_n$

2. Heavy Metal module – Land phase process



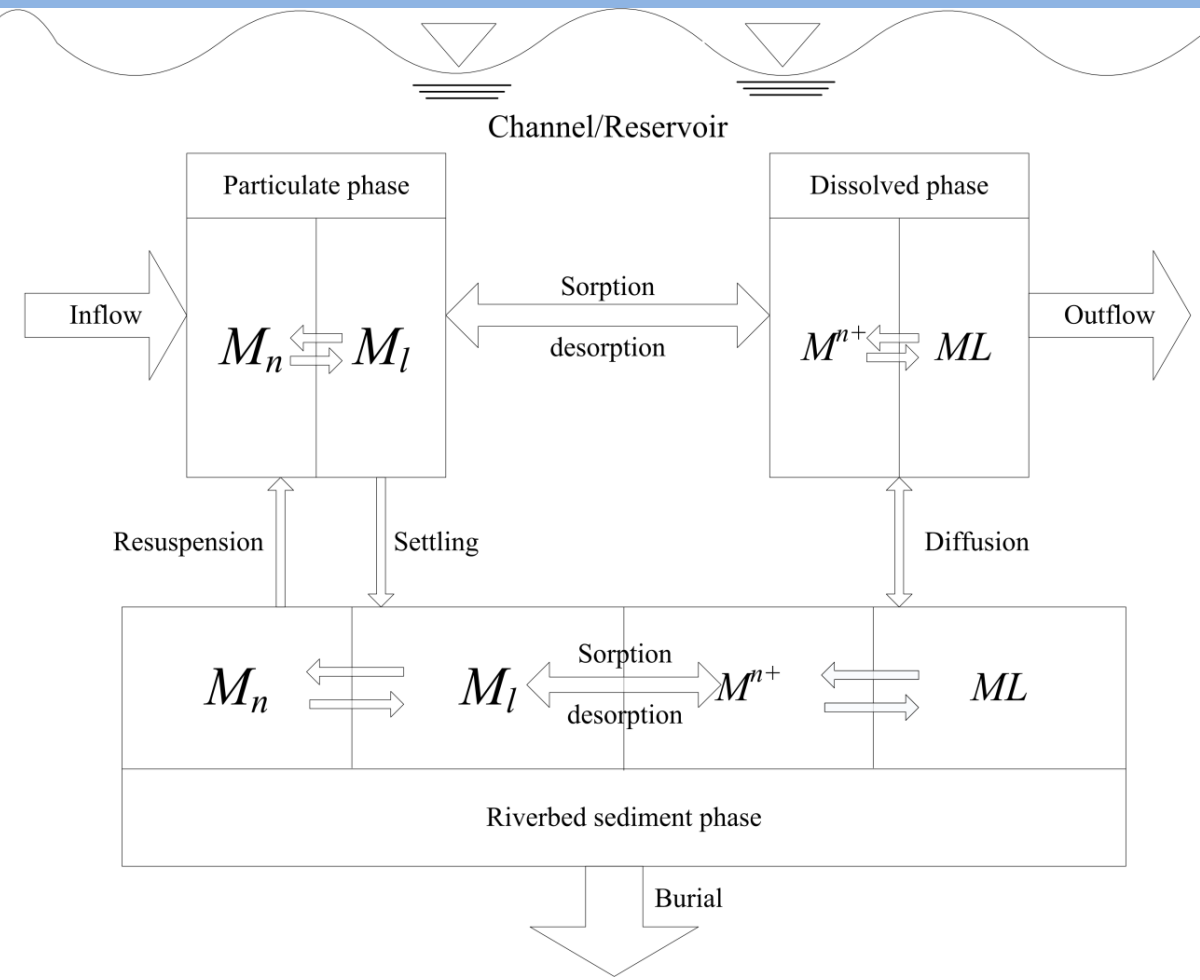
Chemical transformation:

- Sorption
- Complexation
- Slow(aging) reaction

Physical transport:

- Leaching
- Upward migration
- Erosion
- …

2. Heavy Metal module – Channel phase process



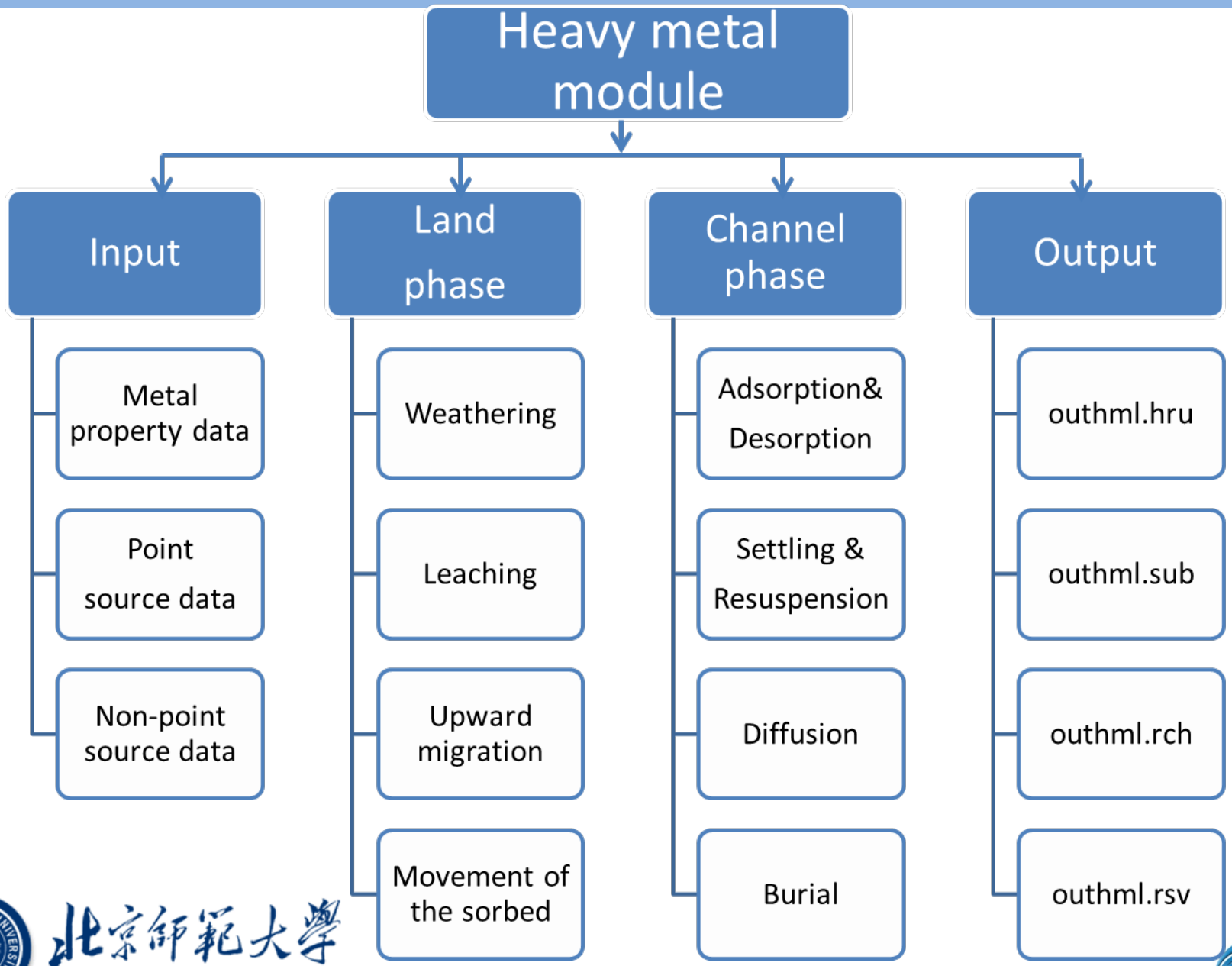
Chemical transformation:

- Sorption
- Complexation
- Slow(aging) reaction

Physical transport:

- Settling
- Resuspension
- Diffusion
- Burial
- …

2. Heavy Metal module -- Module framework



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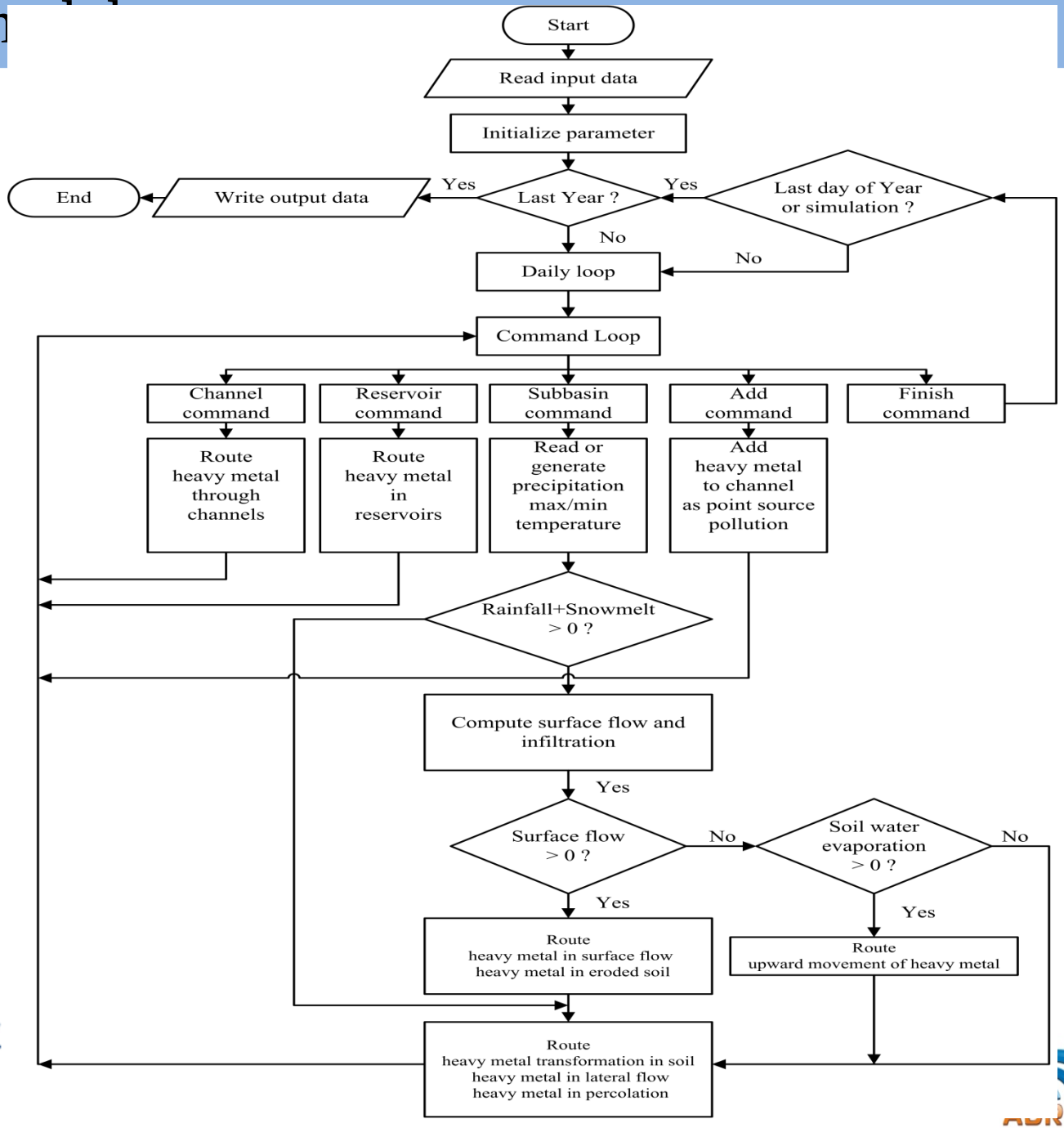
2. Heavy Metal m

Flow chart



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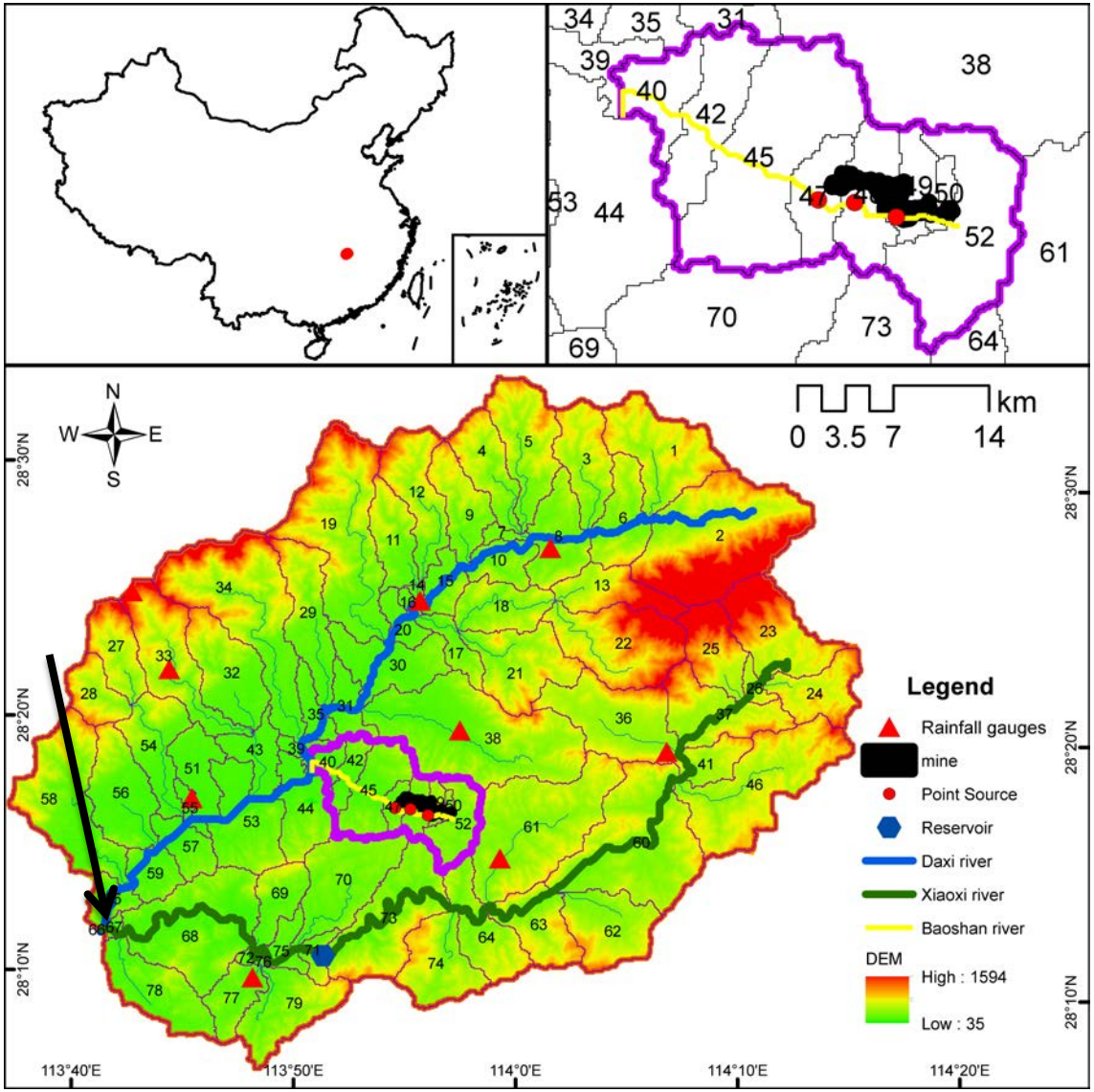
3. Demonstrative Implementation



The upstream Basin of Liuyang River

Location: south-central china

Study area: 1990 km^2

Precipitation: 1290-1840mm(yearly).

Hydrology: Daxi river (blue)

Xiaoxi river (green)

Baoshan steram (yellow)

Mining area: Qibaoshan mine, 6.5km^2

Metal: Zn, Pb, Cu, Cd

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3. Demonstrative Implementation

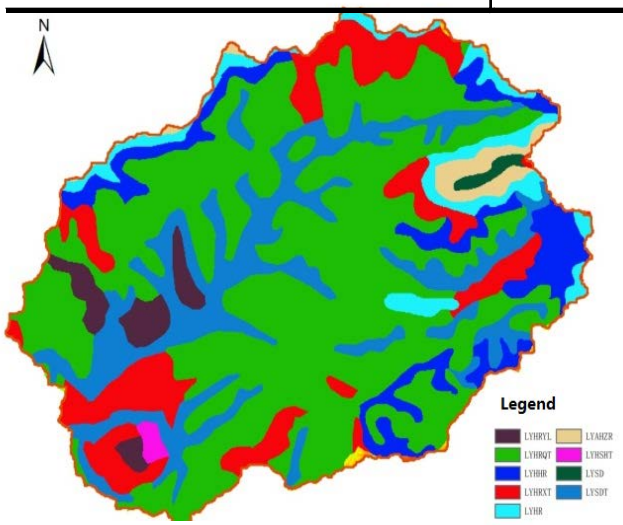
Metal concentration of zinc and cadmium in soil

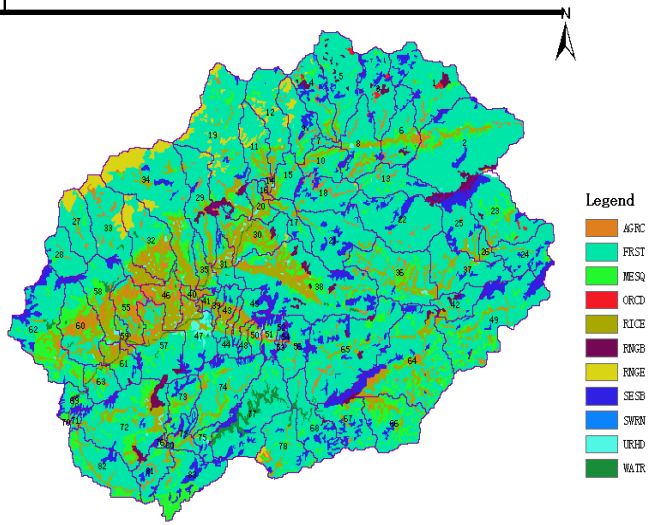
Matrial	pH	OC (%)	Total(ug L^{-1})		Acid-Soluble(ug L^{-1})		Reducible (ug L^{-1})		Oxidizable (ug L^{-1})		Residual (ug L^{-1})	
			Zn	Cd	Zn	Cd	Zn	Cd	Zn	Cd	Zn	Cd
waste rock	—[a)]	1	3110-6175(4797)[b)]	15-250 (97)	1026-3953 (2822)	6.1-204.7 (76.60)	27-219 (105)	0.47-5.14 (1.94)	64-132 (95)	0.26-1.39 (0.80)	1561-1940 (1825)	7.67-35.0 (17.4)
Soils (near the waste rock)	3.0-5.4	2	466-1017 (756)	1.5-4.1 (2.7)	51-80 (69)	0.25-0.65 (0.40)	5-50 (20)	0.06-0.26 (0.13)	32-126 (65)	0.10-0.56 (0.20)	363-856 (637)	0.91-3.33 (1.97)
Soils(near the drain outlet)	3.1-4.9	2	457-688 (538)	0.6-2.2 (1.4)	47-107 (70)	0.02-0.93 (0.35)	5-28 (12)	0.01-0.19 (0.08)	10-45 (33)	0.02-0.19 (0.08)	300-614 (440)	0.52-1.44 (0.92)
undisturbed soils	5.6-6.8	2	118-262 (157)	0.2-0.9 (0.45)	1-15 (9)	0.01-0.41 (0.15)	1-10 (5)	0.01-0.11 (0.07)	2-40 (14)	0.01-0.08 (0.05)	105-237 (137)	0.07-0.29 (0.19)

3. Demonstrative Implementation

Basic data for SWAT model

Type	Description	Data source
Digital elevation model (DEM)	90 m	Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC)
Land use data	90 m	
Soil data	1:1000000	The Institute of Soil Science, Chinese Academy of Sciences
Meteorological data	Daily	Hydrology bureau of hunan province; http://data.cma.cn
Hydrological data	Daily	Hydrology bureau of hunan province





3. Demonstrative Implementation

Additional data of heavy metal module

Parameter	Unit	Metl	typical(initial) value/ fitted value	Source
K_d (in soil)	L kg^{-1}	Zn Cd	1.0-10.0/1.5[a)] 1.0-10.0/3.4	(Sauve et al., 2000; Allison and Allison, 2005)
K_d (in channel)	L kg^{-1}	Zn Cd	1000.0-5000.0/1020.3 500-10000/2153.0	
K_d (in riverbed sediment)	L kg^{-1}	Zn Cd	1.0-50.0/38.0 1.0-80.0/270.7	
k_1	d^{-1}	Zn Cd	$1.3*10^{-3}$ $5.2*10^{-4}$	(Crout et al., 2006; Buekers et al., 2008)
k_{-1}	d^{-1}	Zn Cd	$8.4*10^{-4}$ $7.3*10^{-4}$	

	Parameter	Description	Typical range/Value	Source
Point source[a)]	Flow	Flow of point source for a day(m^3 d^{-1})	9600/9600/2040	Average
	Point-Zn	Point loading of Zn to reach for the day(kg)	6.5/6.5/17.5	Average
	Point-Cd	Point loading of Cd to reach for the day(kg)	0/0/0	Average
Non-point sourcre	M_l	Labile metal concentration in the 1st layer soil(mg kg^{-1})	Zn:300/10/0.5 Cd:15/1/0.2	Average
	M_n	Non-labile metal concentration in the 1st layer soil(mg kg^{-1})	Zn:3000/400/100 Cd:30/3/1	Average
	Hmfr	Fractions of waste dumps and tailings area in HRUs (%)	1.0%-43.6%(10.0%)[c)]	remote sensing
	hmrock	Heavy metal in waste rock (kg ha^{-1})	Zn:1000 Cd:10	Average
	Weathering rate[b)]	Weathering rate of waste rocks and tailings (d^{-1})	10^{-5}-10^{-4}	(Bennett et al., 2000)

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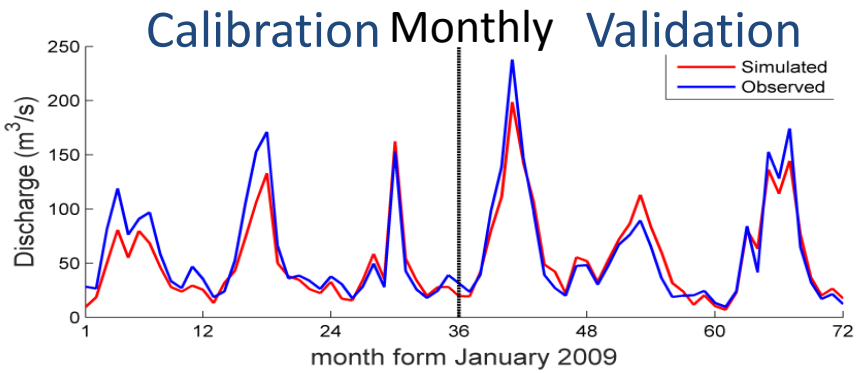
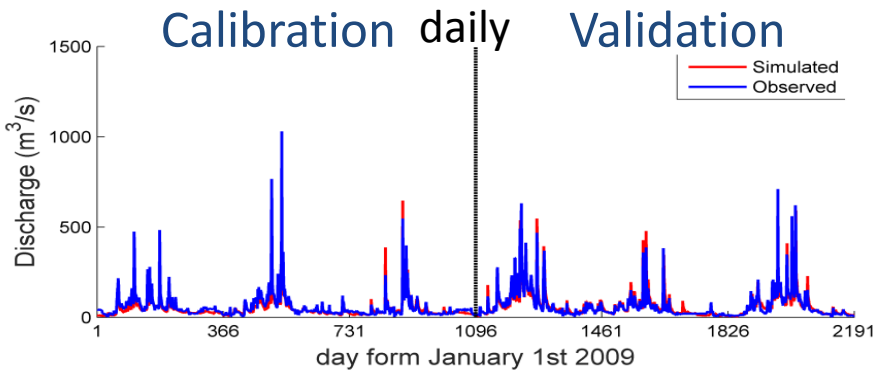
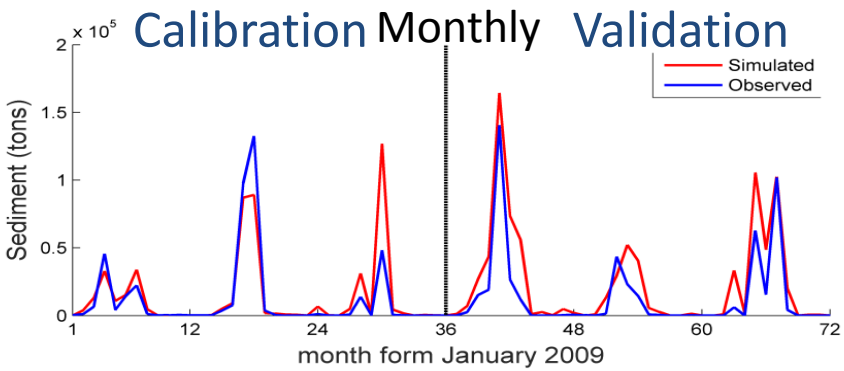
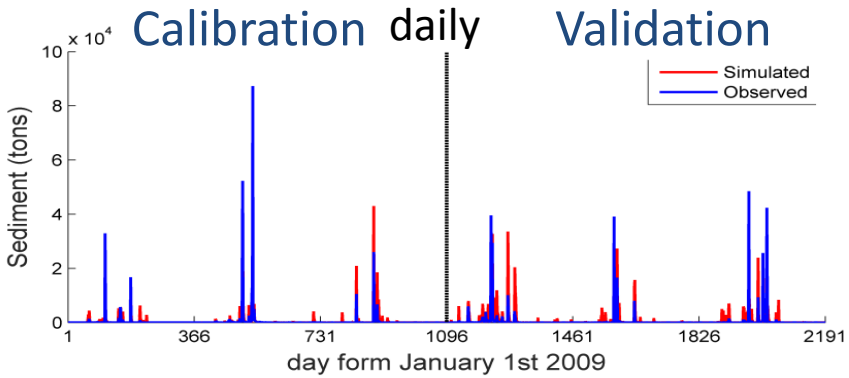
4.Results—Calibration and validation of flow and sediment



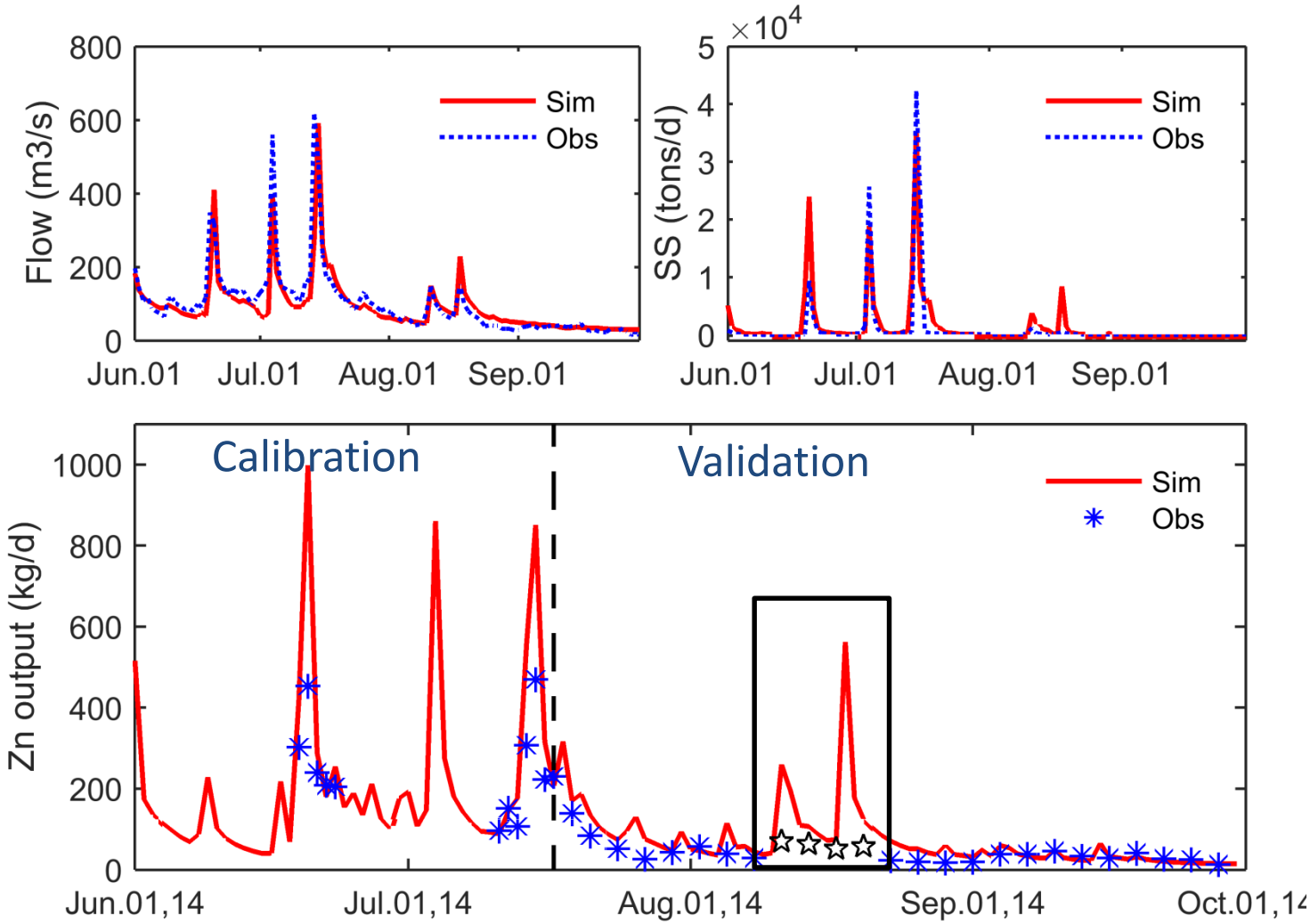






	Period	Time resolution	E_{ns}	r^2
Stream flow	Calibration (2009-2011)	monthly	0.81	0.89
		daily	0.81	0.86
	Validation (2012-2014)	monthly	0.93	0.95
		daily	0.84	0.84
Sediment	Calibration (2009-2011)	monthly	0.70	0.72
		daily	0.73	0.85
	Validation (2012-2014)	monthly	0.64	0.74
		daily	0.50	0.56

4.Results—Calibration and validation of HM module



Dissolved Zn output (watershed outlet)

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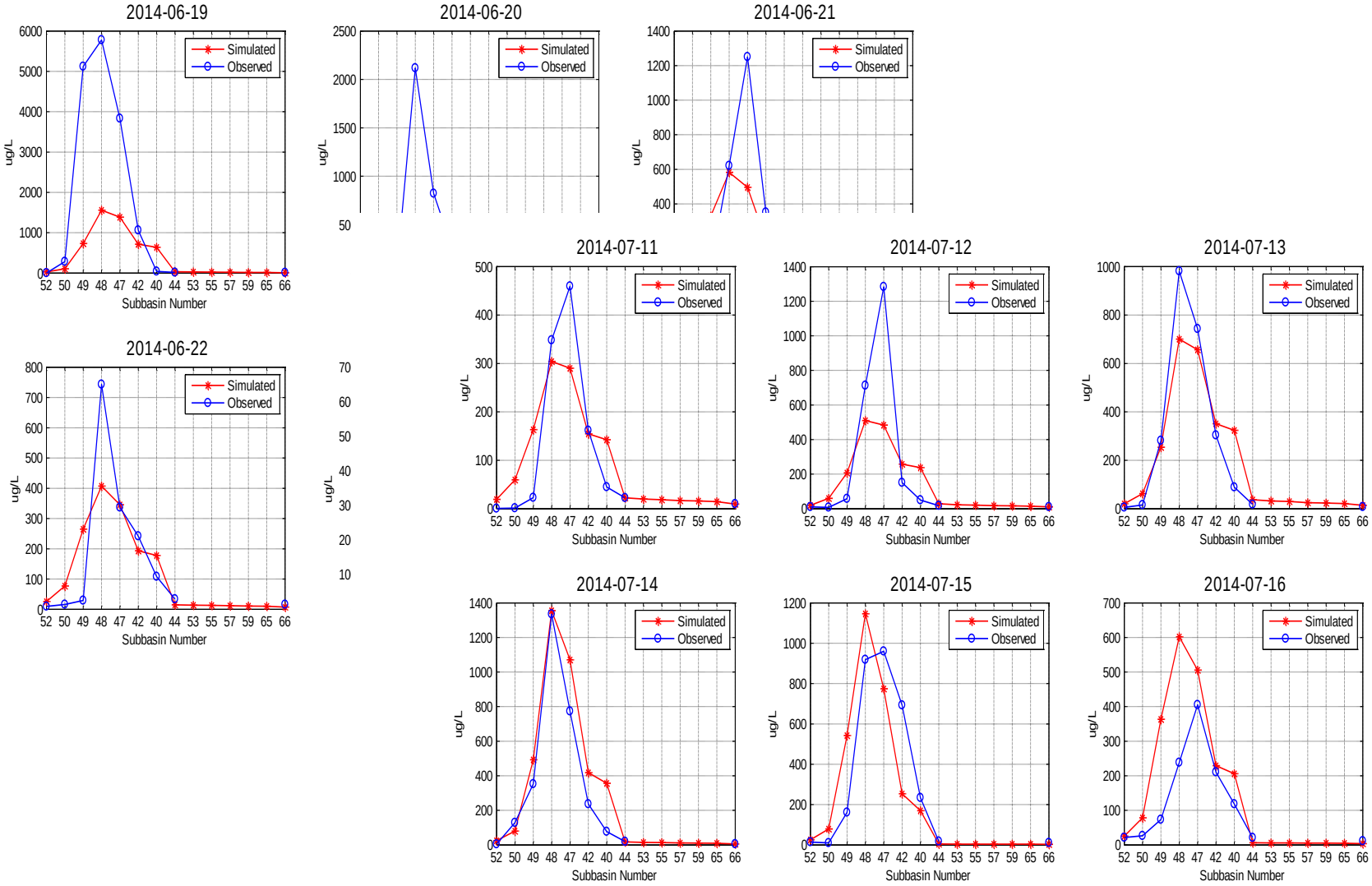
4.Results—Zn (two rainfall events)



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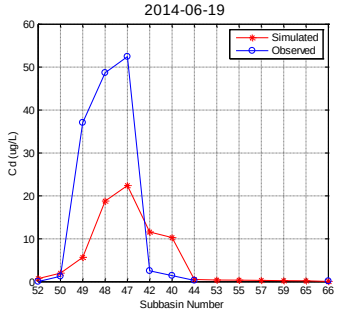
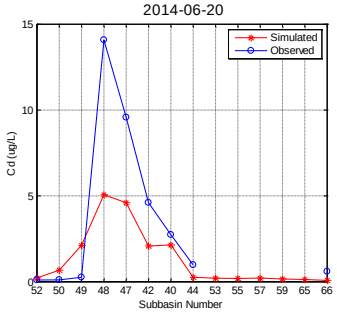
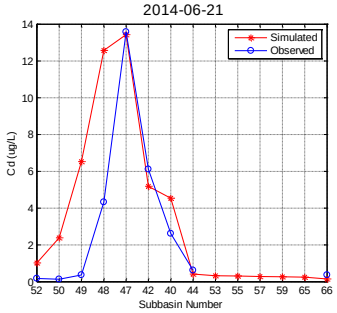
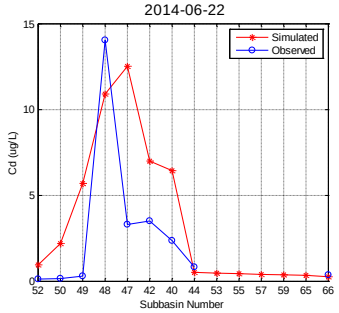
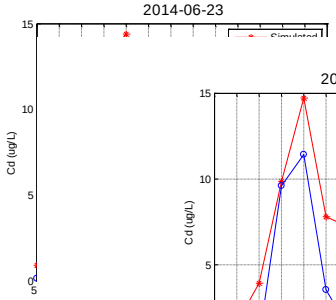
4.Results—Cd (two rainfall events)

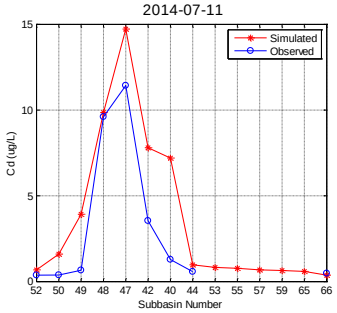


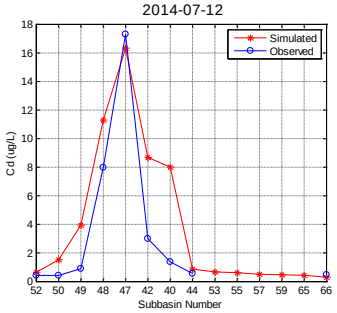


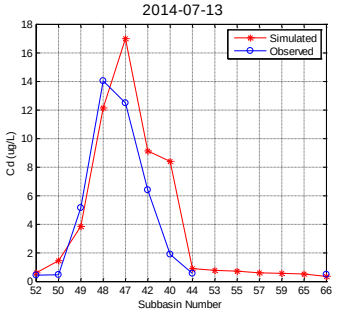


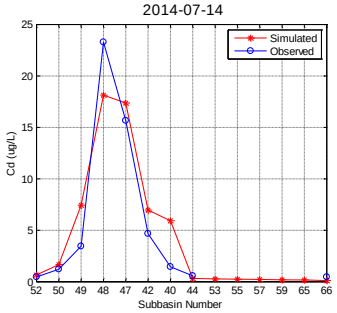


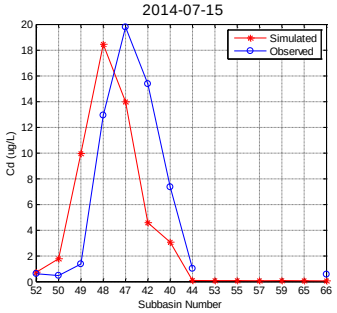


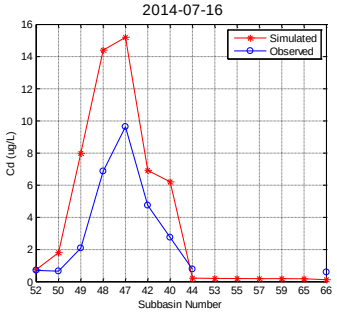












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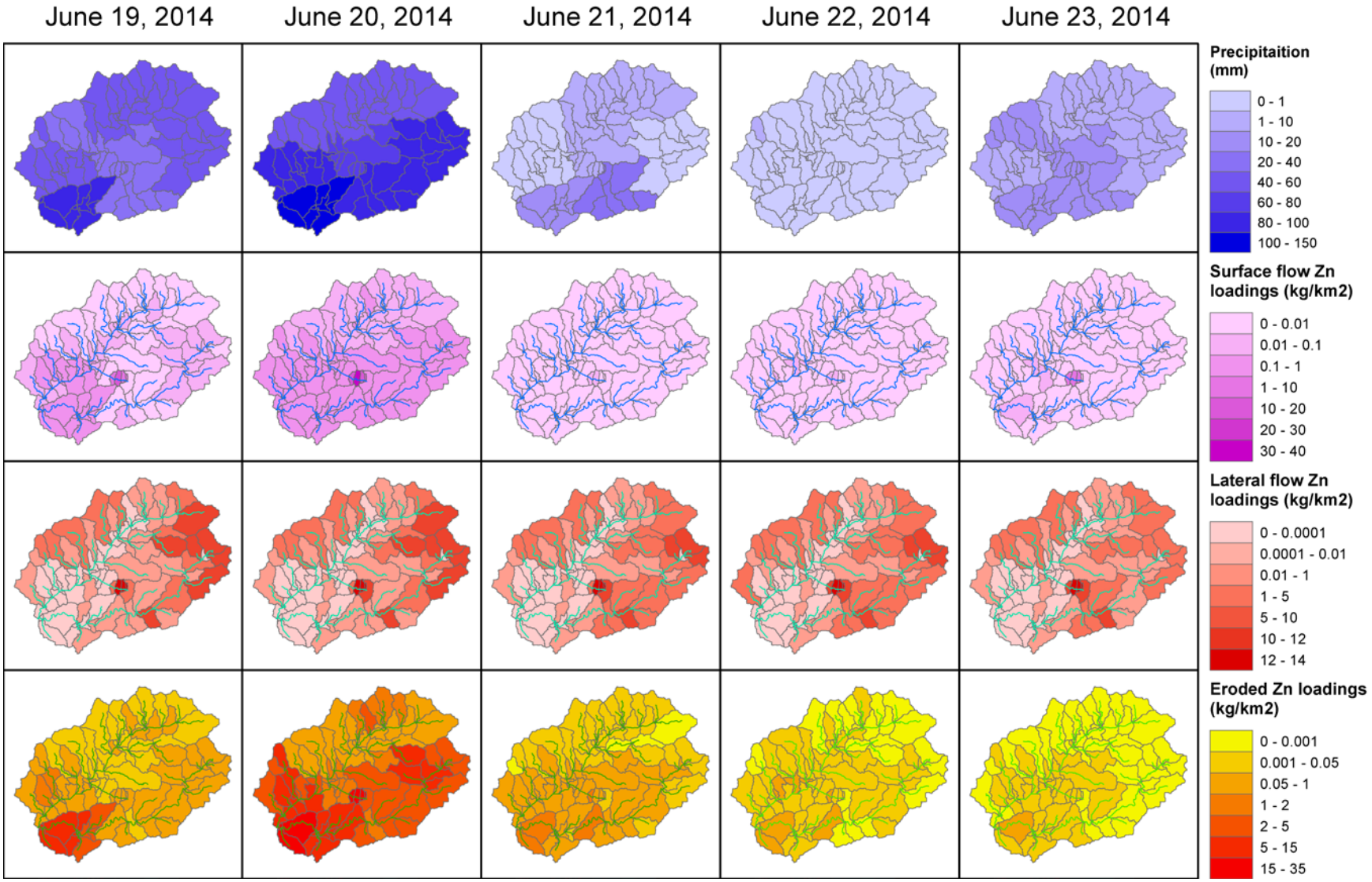
4.Results – Different transport paths



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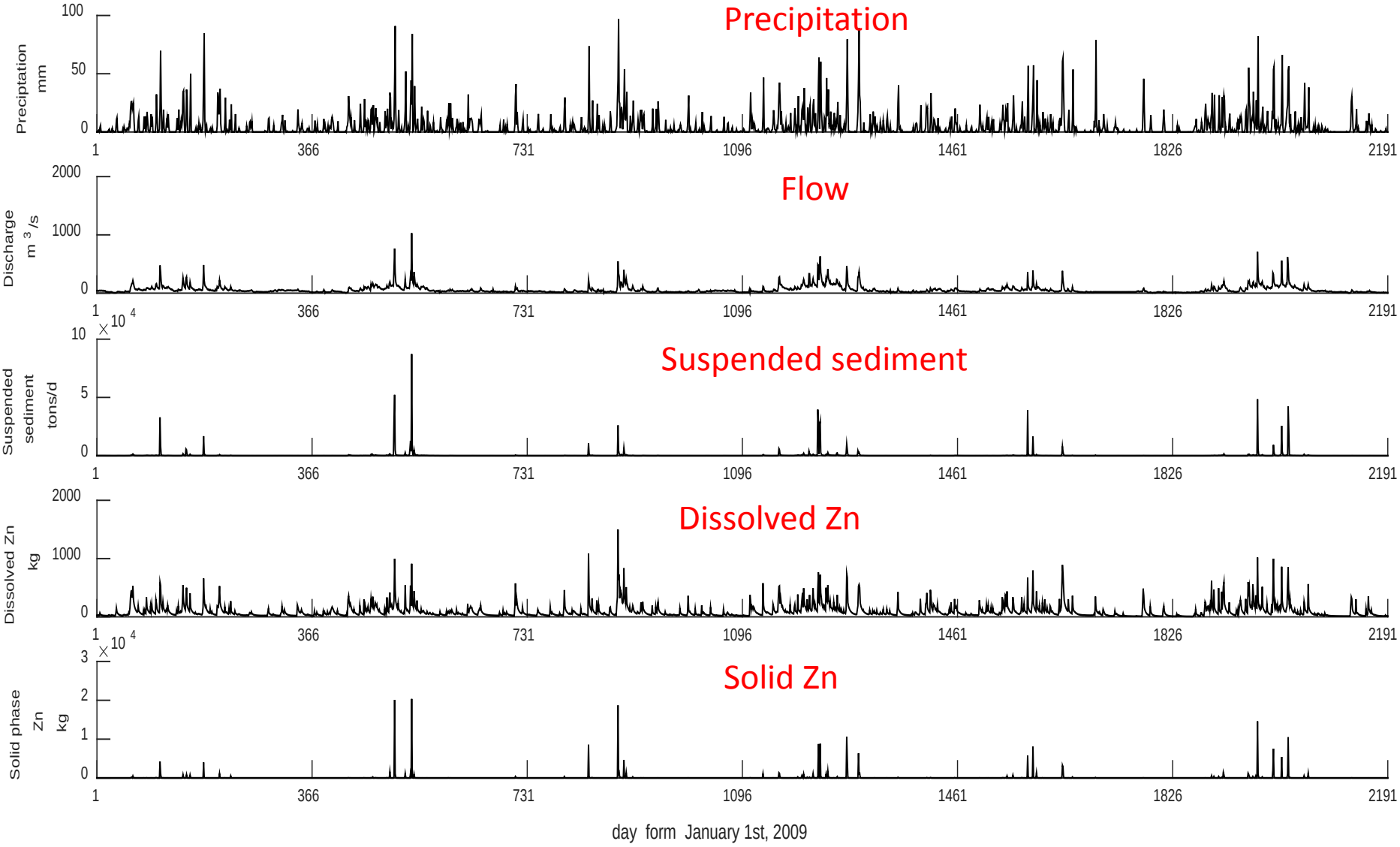
4.Results– Model outputs at watershed outlet



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5. Conclusion and discussion

- The simulation of stream flow and suspended sediment is good both on monthly basis and daily basis.

- A heavy metal module coupled with SWAT model is established to simulate the Zn, Cd dynamics in Liuyang river upstream basin.

- This modified model contains the processes of weathering, leaching, sorption, complexation and so on, which embodies the process of source release, migration and transformation of heavy metal at the watershed scale.

- More measured data are needed to test and improve the heavy metal module.

Thank you very much!

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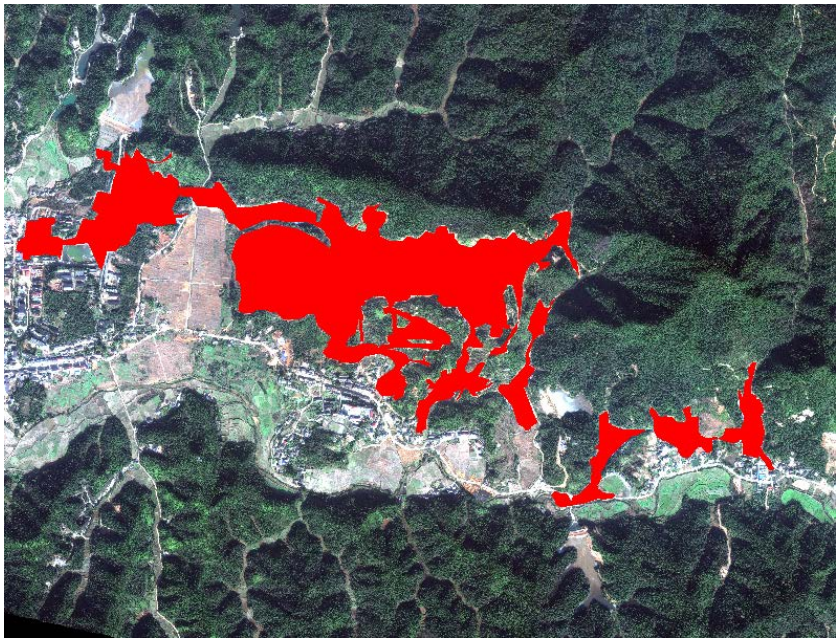
Key parameter: partition coefficient K_d

$$K_d = M_s / [M]$$

Different K_d in different processes

1. Partition between soil and water
2. Partition between suspended sediment and water
3. Partition between bottom sediment and water

Determine the appropriate K_d for various medium



recognize the mine/tailing/piling area in the remote sensing image