BMP design for a small catchment in Three Gorges Reservoir Area, China

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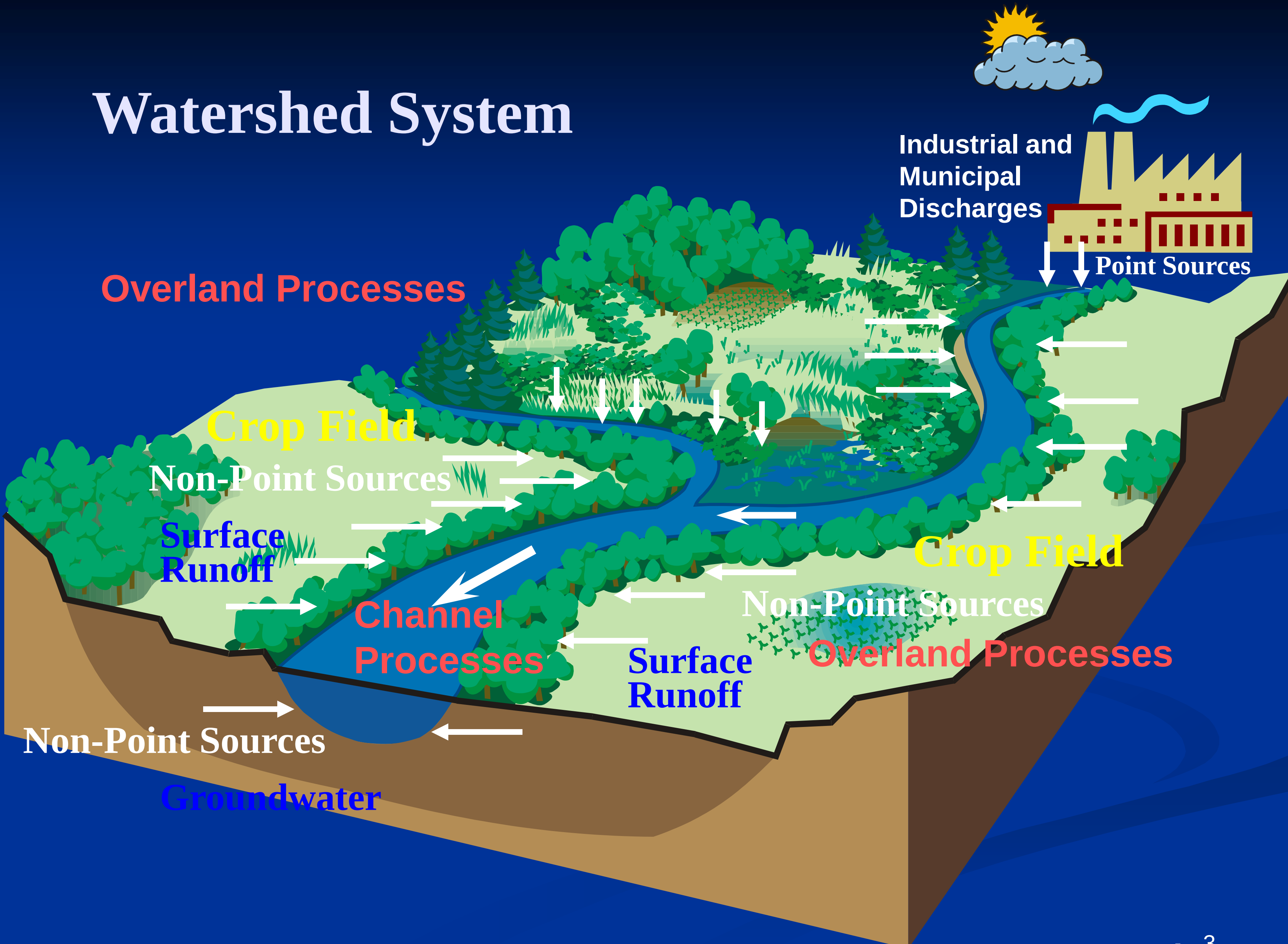
Background

- Non-point sources (NPS) pollution has been an important issue for the aquatic environment and has received increasing attention in recent years.
- Non-point sources (NPS) pollution loading estimate in the large-scale watershed is very difficult in most developing countries because of the data shortage.
- The NPS in Three Gorges Reservoir Area is key to the water quality of Three Gorges Reservoir, but still not very clearly

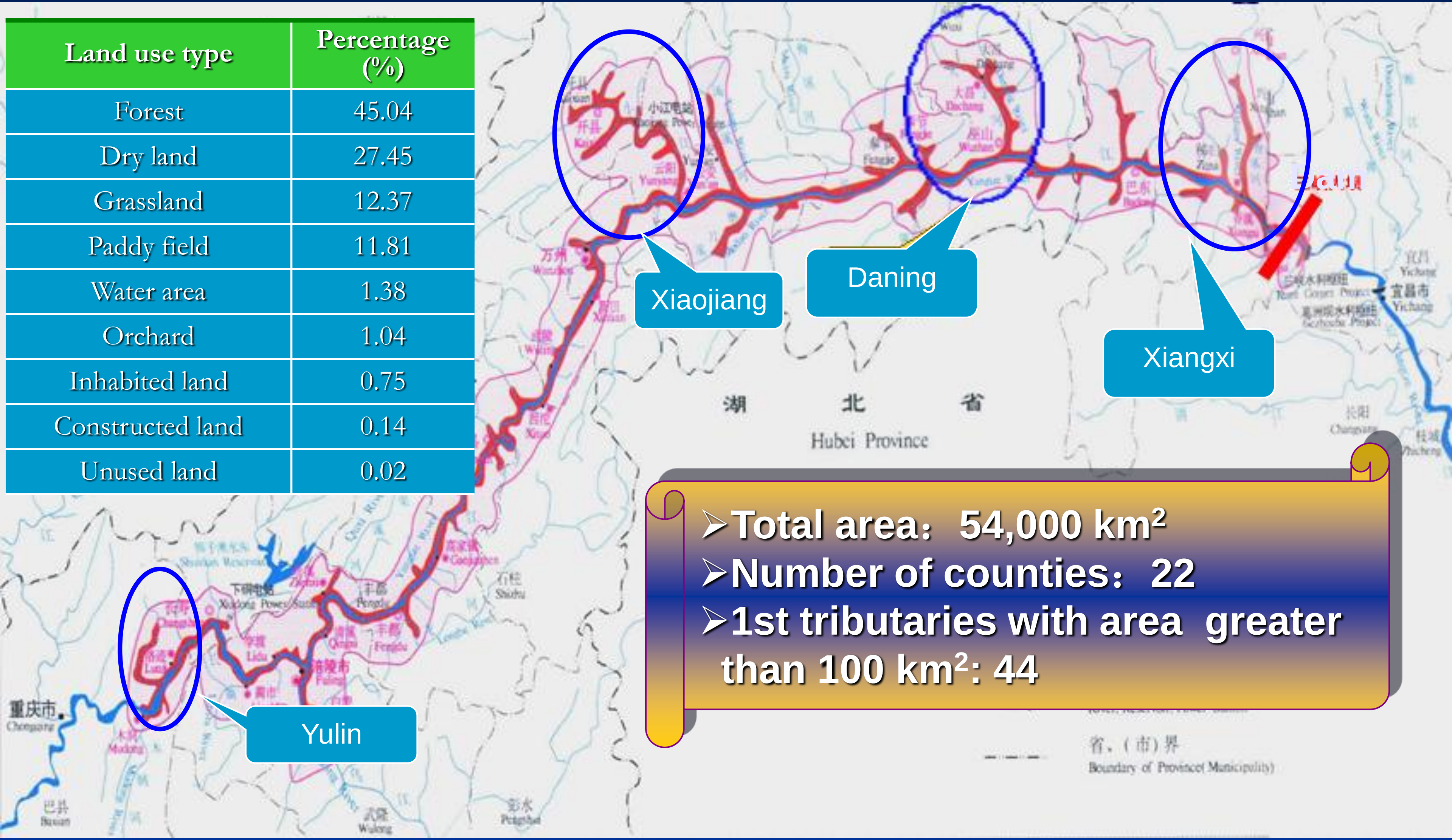
Watershed System



Gu. R. R. ,et al, 2007

Three Gorges Reservoir Area

Land use type	Percentage (%)
Forest	45.04
Dry land	27.45
Grassland	12.37
Paddy field	11.81
Water area	1.38
Orchard	1.04
Inhabited land	0.75
Constructed land	0.14
Unused land	0.02



- Total area： 54,000 km^2
- Number of counties： 22
- 1st tributaries with area greater than 100 km^2: 44

Small-scale Watershed Extended Method (SWEM)

- SWEM is the method which use SWAT or other physical-based models in some small catchments in a large watershed/region.
- Then the results of these small catchments need be extended to the surrounding area until the NPS load in the whole watershed/region can be obtained.
- The selected small catchments should with abound data, so physical-based models can be used.

SWEM application in TGRA

- Regionalization

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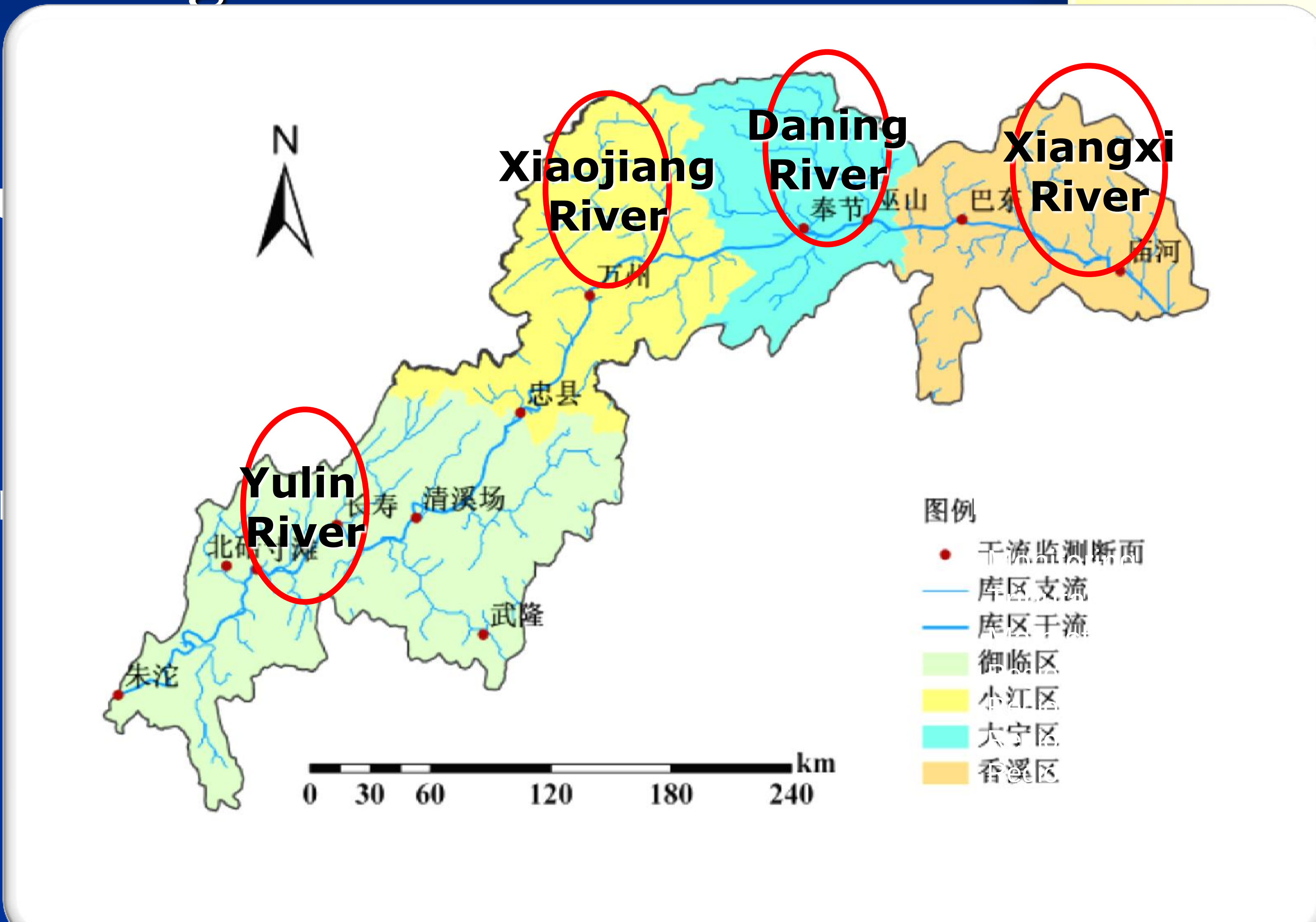


Database establishment

1 Spatial

- DEM,Landform
- Soil, Land use
- Watershed network

2 Attributive

- Land use…
- Soil…
- Physical & chemical..

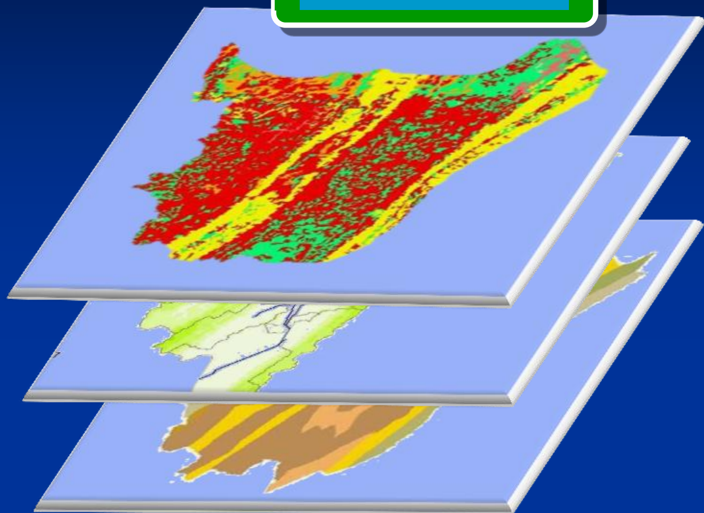
3 Meteorologic

- Precipitation, wind speed
- Temperature, relative humidity
- Solar radiation

4 Hydrological…

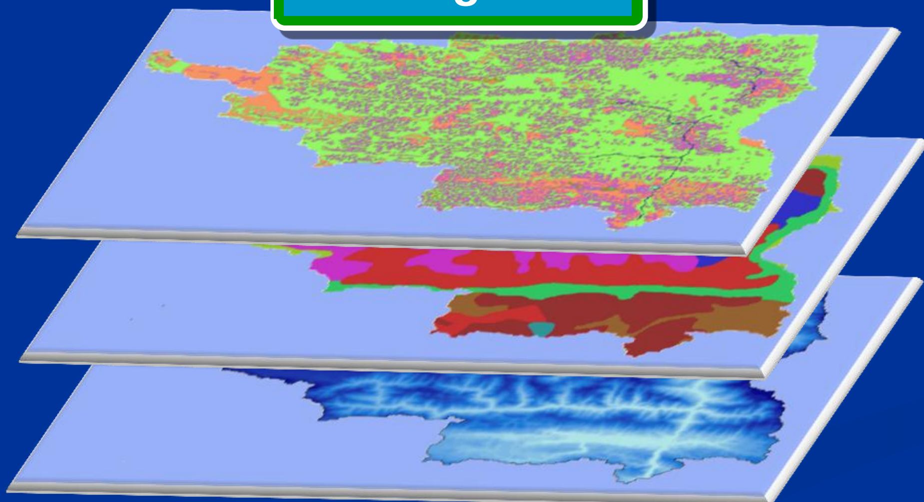
- Stream flow,Sediment
- Water quality
- Crop management practice
- Social and economic data

Yulin river

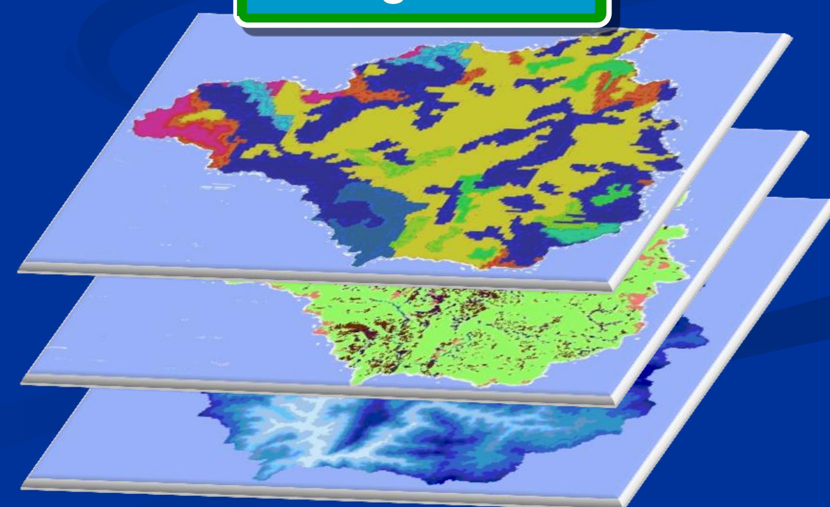


Xiaojiang river

Daning river

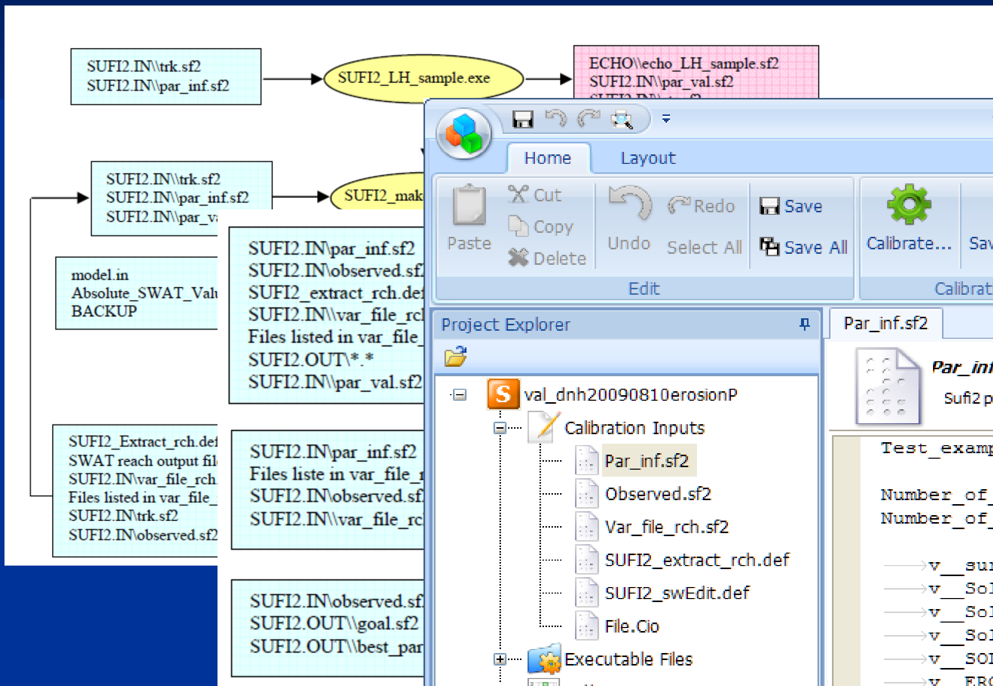


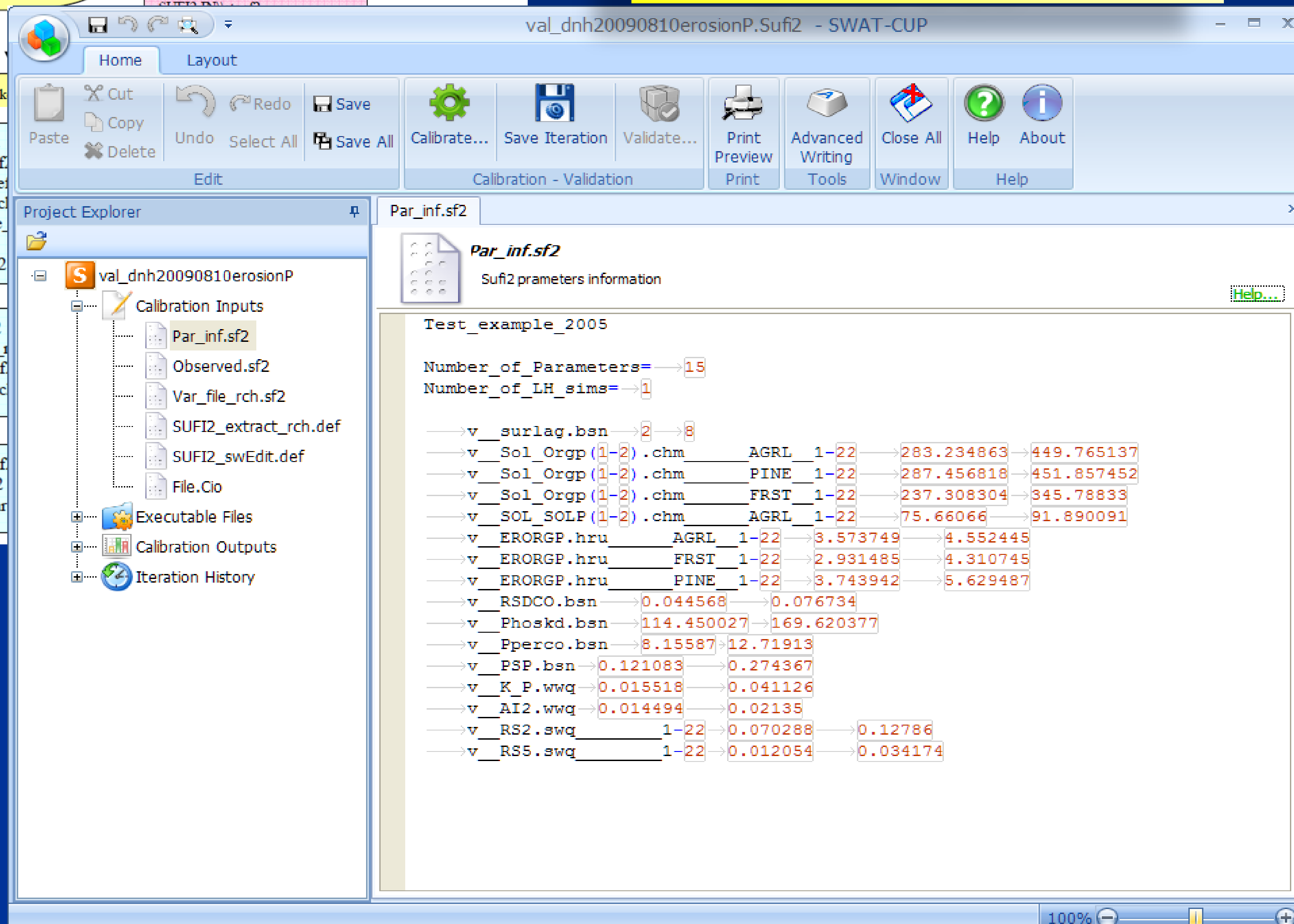
Xiangxi river



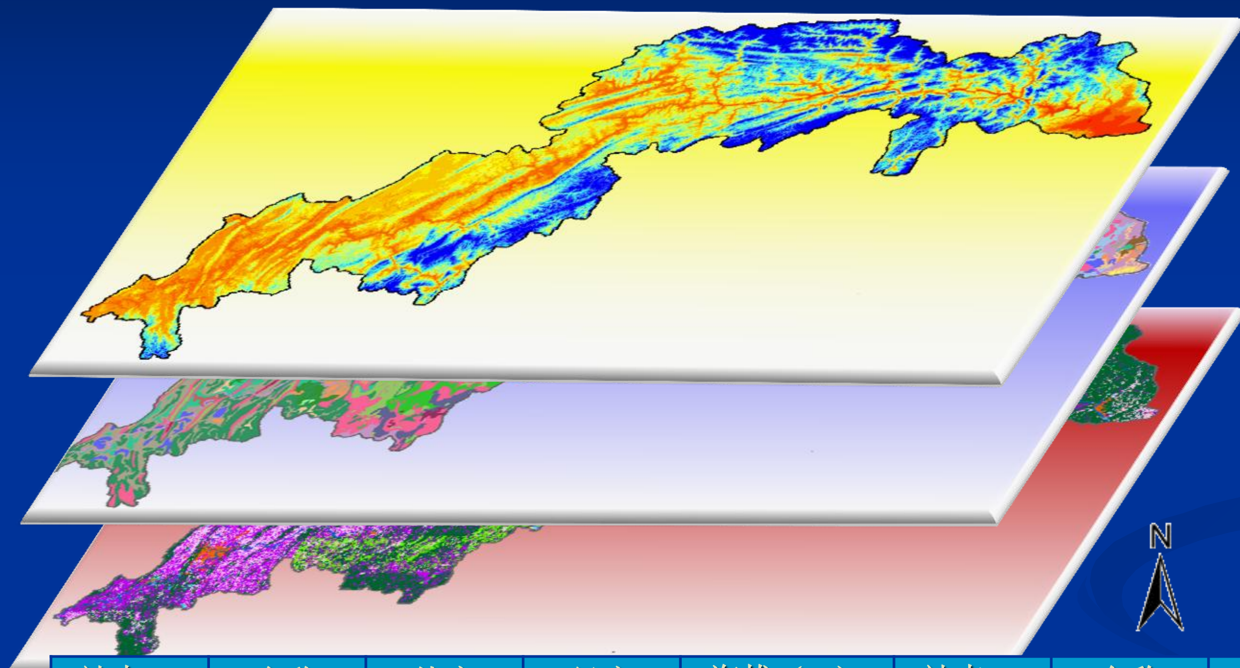
Parameter calibration and validation

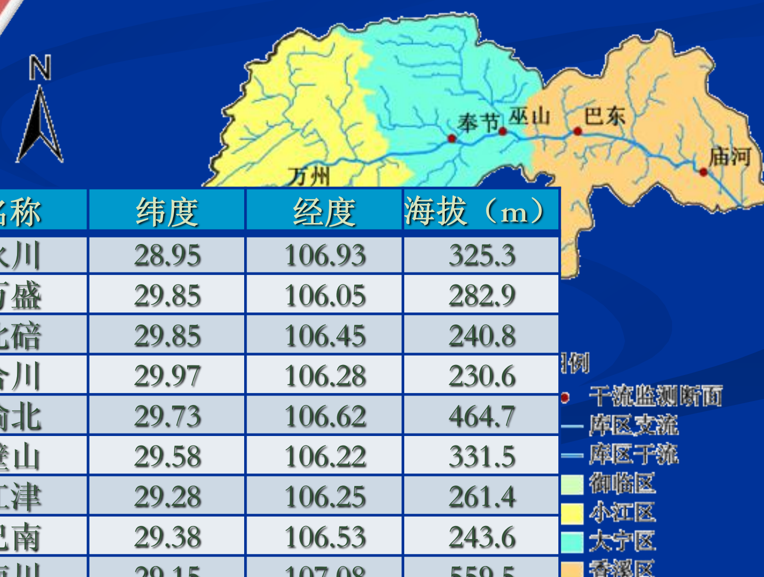
SWAT-CUP





Database of TGRA





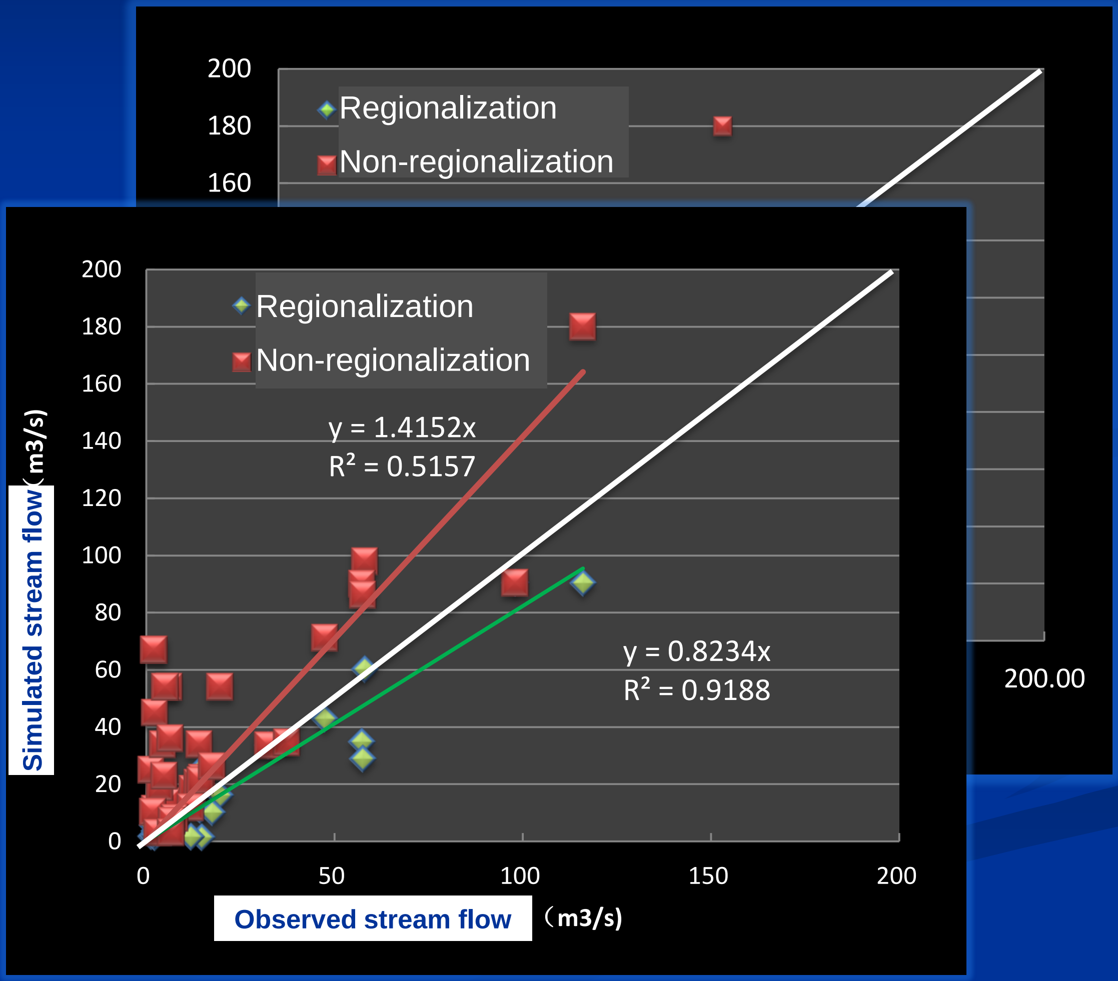
站点ID	名称	纬度	经度	海拔（m）	站点ID	名称	纬度	经度	海拔（m）
57614	习水	28.33	106.22	1180.2	57509	永川	28.95	106.93	325.3
57259	房县	32.03	110.77	426.9	57510	万盛	29.85	106.05	282.9
57355	巴东	31.03	110.37	334	57511	北碚	29.85	106.45	240.8
57378	钟祥	31.17	112.57	65.8	57512	合川	29.97	106.28	230.6
57447	恩施	30.28	109.47	457.1	57513	渝北	29.73	106.62	464.7
57458	五峰	30.20	110.67	619.9	57514	壁山	29.58	106.22	331.5
57461	宜昌	30.70	111.30	133.1	57517	江津	29.28	106.25	261.4
57462	三峡	30.87	111.08	139.9	57518	巴南	29.38	106.53	243.6
57476	荆州	30.35	112.15	32.2	57519	南川	29.15	107.08	559.5
57237	万源	32.07	108.03	674	57520	长寿	29.83	107.07	377.6
57306	阆中	31.58	105.97	382.6	57523	丰都	29.85	107.73	290.5

Simulating evaluation

- Regionalization
  VS
  Non-regionalization

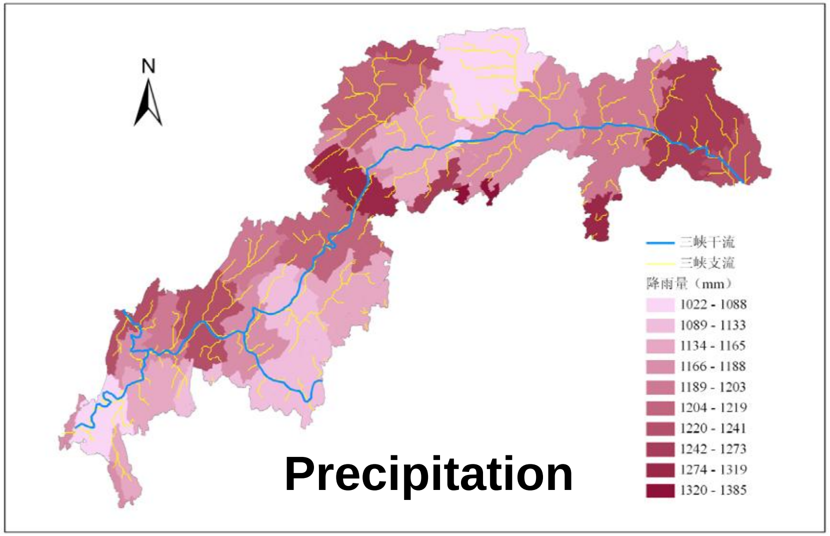
- *R^2*
  0.68 VS 0.92
  K
  1.41 VS 0.82

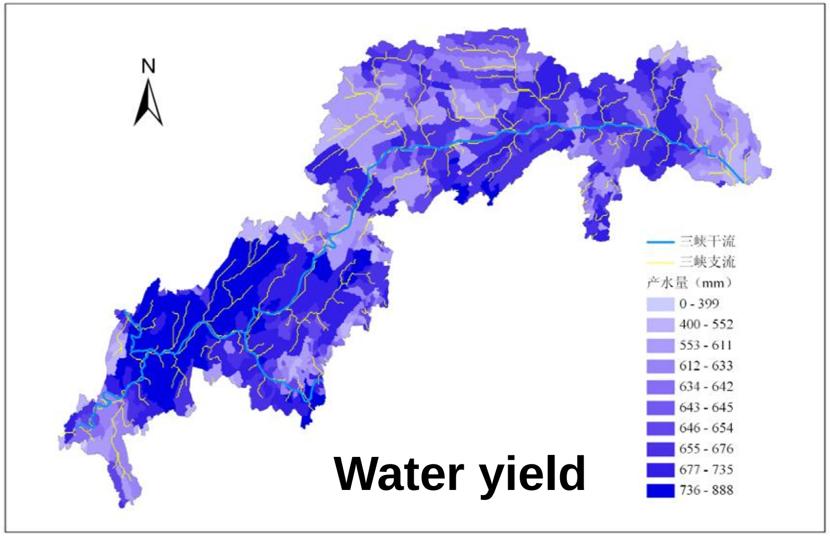
- <u>SWEM showed satisfied applicability in TGRA.</u>



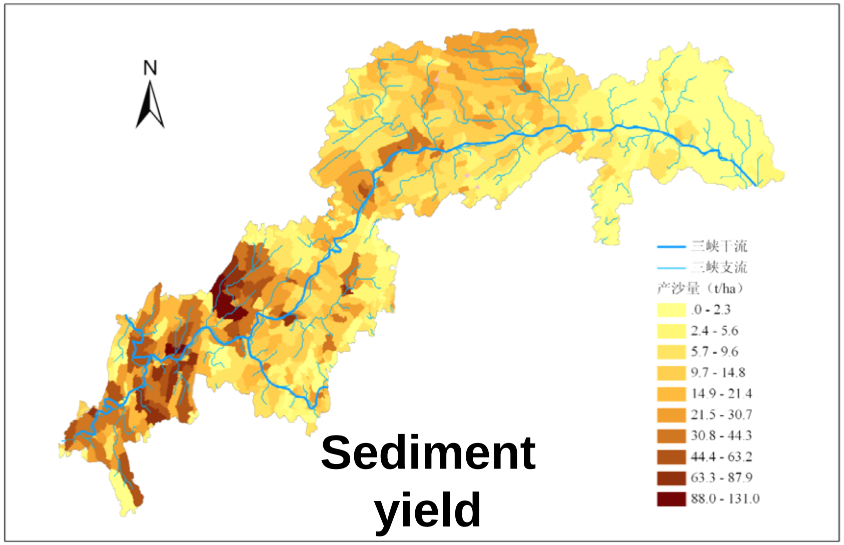
Spatial distribution of NPS pollution in TGRA

❖ **Multi-annual（2001—2009）**

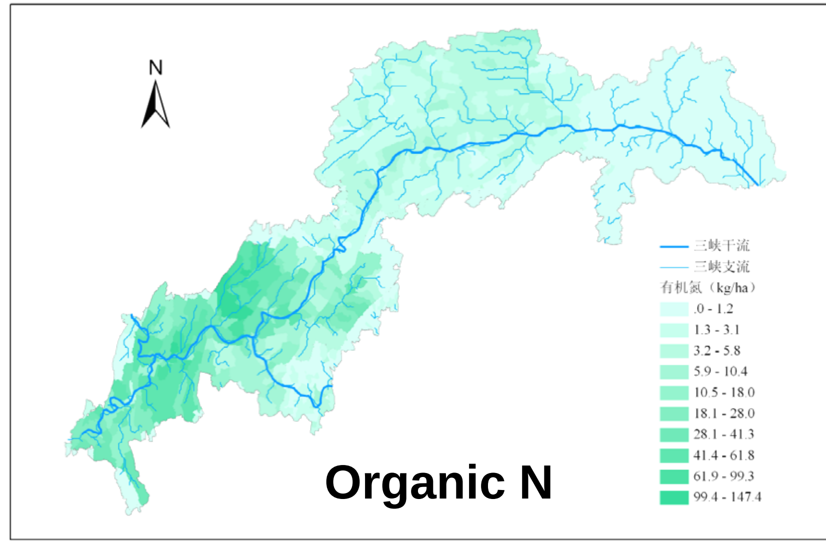




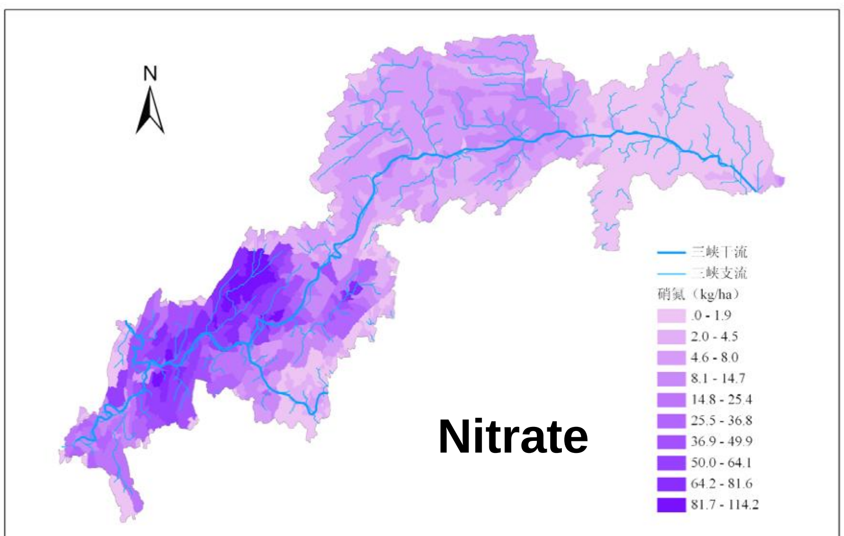
- Varied with the elevation



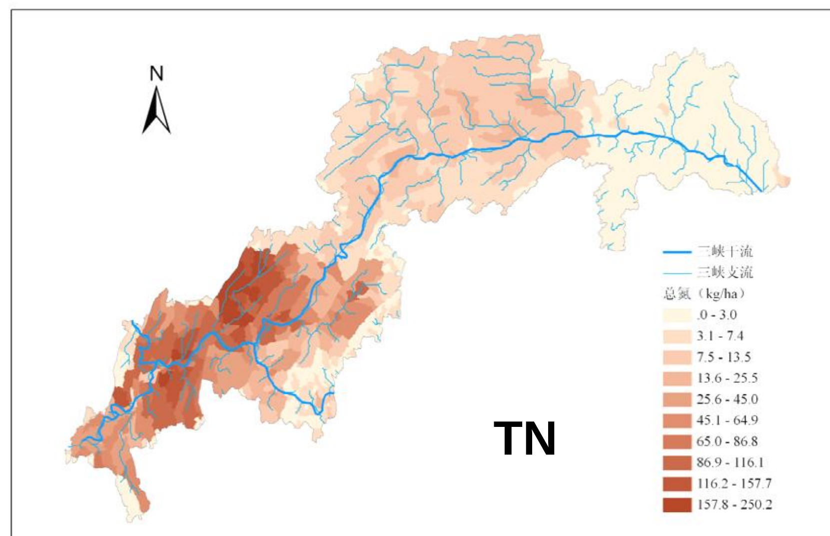
N
三峡干流
三峡支流
产沙量（t/ha）
.0 - 2.3
2.4 - 5.6
5.7 - 9.6
9.7 - 14.8
14.9 - 21.4
21.5 - 30.7
30.8 - 44.3
44.4 - 63.2
63.3 - 87.9
88.0 - 131.0
Sediment yield



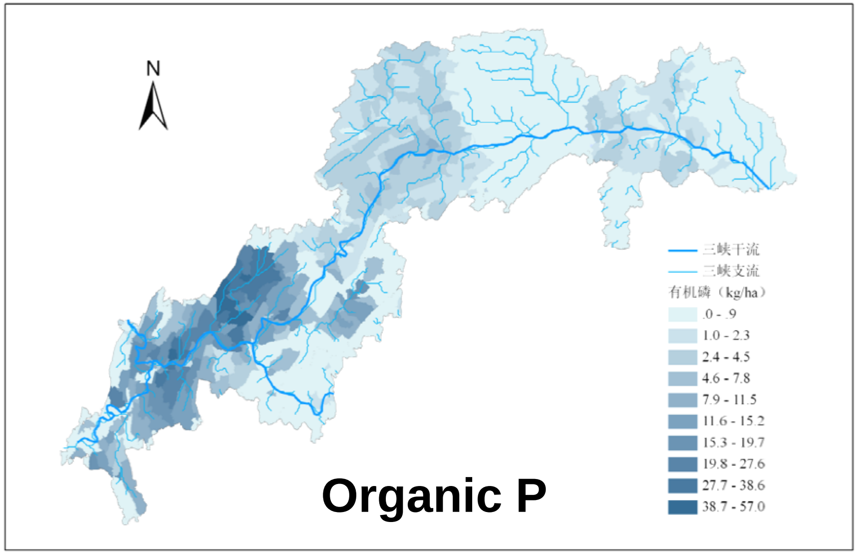
N
三峡干流
三峡支流
有机氮（kg/ha）
.0 - 1.2
1.3 - 3.1
3.2 - 5.8
5.9 - 10.4
10.5 - 18.0
18.1 - 28.0
28.1 - 41.3
41.4 - 61.8
61.9 - 99.3
99.4 - 147.4
Organic N

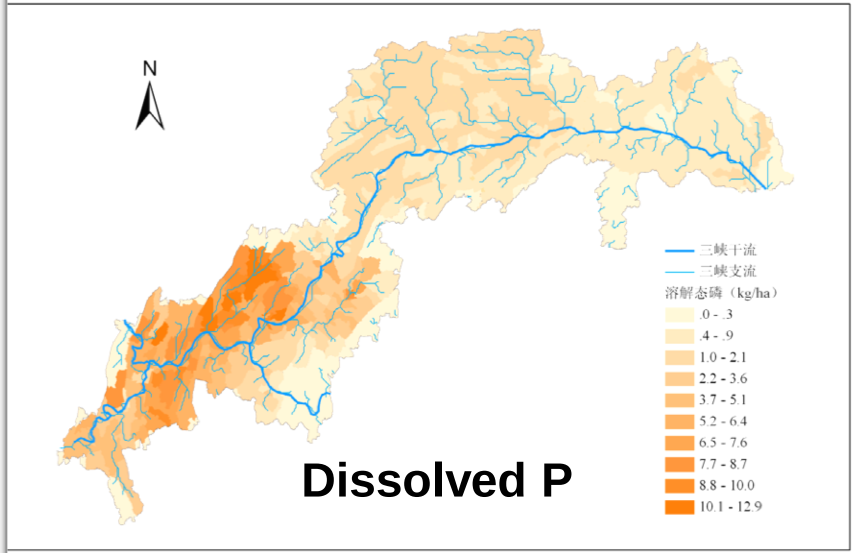


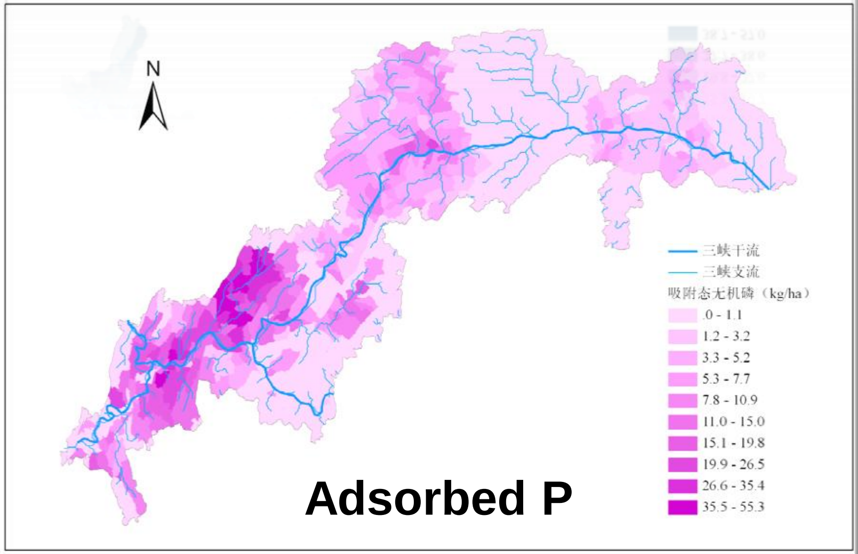
N
三峡干流
三峡支流
硝氮（kg/ha）
.0 - 1.9
2.0 - 4.5
4.6 - 8.0
8.1 - 14.7
14.8 - 25.4
25.5 - 36.8
36.9 - 49.9
50.0 - 64.1
64.2 - 81.6
81.7 - 114.2
Nitrate

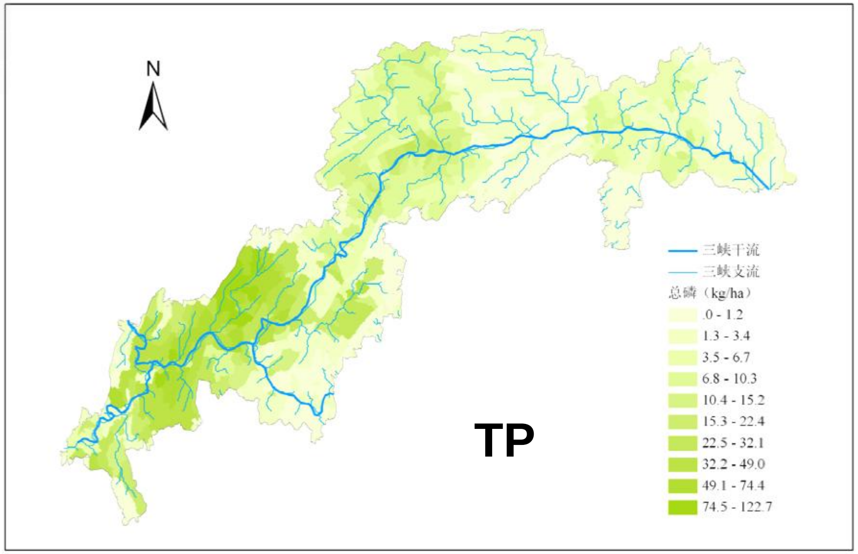


N
三峡干流
三峡支流
总氮（kg/ha）
.0 - 3.0
3.1 - 7.4
7.5 - 13.5
13.6 - 25.5
25.6 - 45.0
45.1 - 64.9
65.0 - 86.8
86.9 - 116.1
116.2 - 157.7
157.8 - 250.2
TN


N
Organic P
三峡干流
三峡支流
有机磷（kg/ha）
.0 - .9
1.0 - 2.3
2.4 - 4.5
4.6 - 7.8
7.9 - 11.5
11.6 - 15.2
15.3 - 19.7
19.8 - 27.6
27.7 - 38.6
38.7 - 57.0


N
Dissolved P
三峡干流
三峡支流
溶解态磷（kg/ha）
.0 - .3
.4 - .9
1.0 - 2.1
2.2 - 3.6
3.7 - 5.1
5.2 - 6.4
6.5 - 7.6
7.7 - 8.7
8.8 - 10.0
10.1 - 12.9

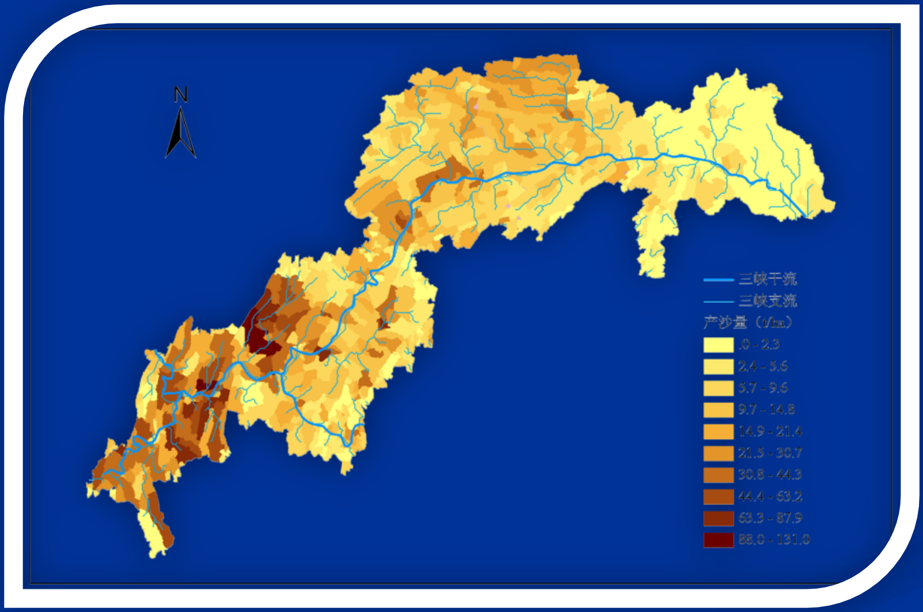

N
Adsorbed P
三峡干流
三峡支流
吸附态无机磷（kg/ha）
.0 - 1.1
1.2 - 3.2
3.3 - 5.2
5.3 - 7.7
7.8 - 10.9
11.0 - 15.0
15.1 - 19.8
19.9 - 26.5
26.6 - 35.4
35.5 - 55.3


N
TP
三峡干流
三峡支流
总磷（kg/ha）
.0 - 1.2
1.3 - 3.4
3.5 - 6.7
6.8 - 10.3
10.4 - 15.2
15.3 - 22.4
22.5 - 32.1
32.2 - 49.0
49.1 - 74.4
74.5 - 122.7

Spatial distribution of NPS pollution in TGRA

■ Sediment

- ❖ Range: 0.1-131.0 t/ha
- ❖ YL（west） > XJ ≈ DN（middle） > XX（east）
- ❖ Main reason: different structure of land use types



- ❖ XX（east）：

  Major land use type: forest;

- ❖ YL（west）：

  Major land use type: farmland;

- ❖ XJ & DN（middle）：

  Even distribution of forest, grassland and farmland

Spatial distribution of NPS pollution in TGRA

❖ Nitrogen

1 Apparent spatial heterogeneity

- ON: 0.1-147.4 kg/ha
- NO_3-N: 0.1-114.2 kg/ha
- TN: 0.1-250 kg/ha

- Variation rate
- ON, TN > NO_3-N

2 Similar pattern with sediment

- Transportation of ON is much associated with sediment.

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- NO_3-N pollution is much associated with the fertilization and exported more in farmland (YL).

Spatial distribution of NPS pollution in TGRA

❖ Phosphorous

1 Apparent spatial heterogeneity

- IP: 0-57.0 kg/ha
- OP: 0-55.3 kg/ha
- TP: 0-122.7 kg/ha

- DP: 0-12.59 kg/ha
- DP is the limiting factor for eutrophicaiton.

2 Distribution pattern

- Similar distribution pattern of OP and TP.
- Different between IP and sediment.

&

- DP showed similar distribution pattern with NO3-N,since the dissolved pollutants have similar transportation process.

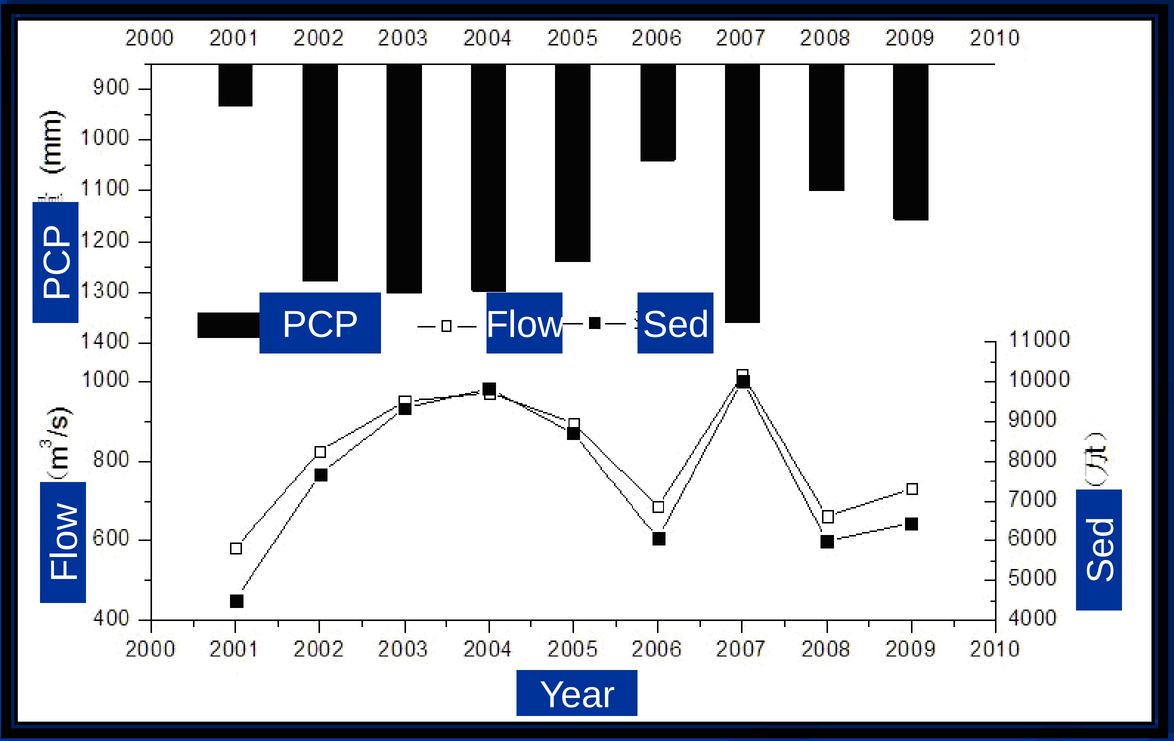
Temporal distribution of NPS pollution in TGRA

- Annual variation

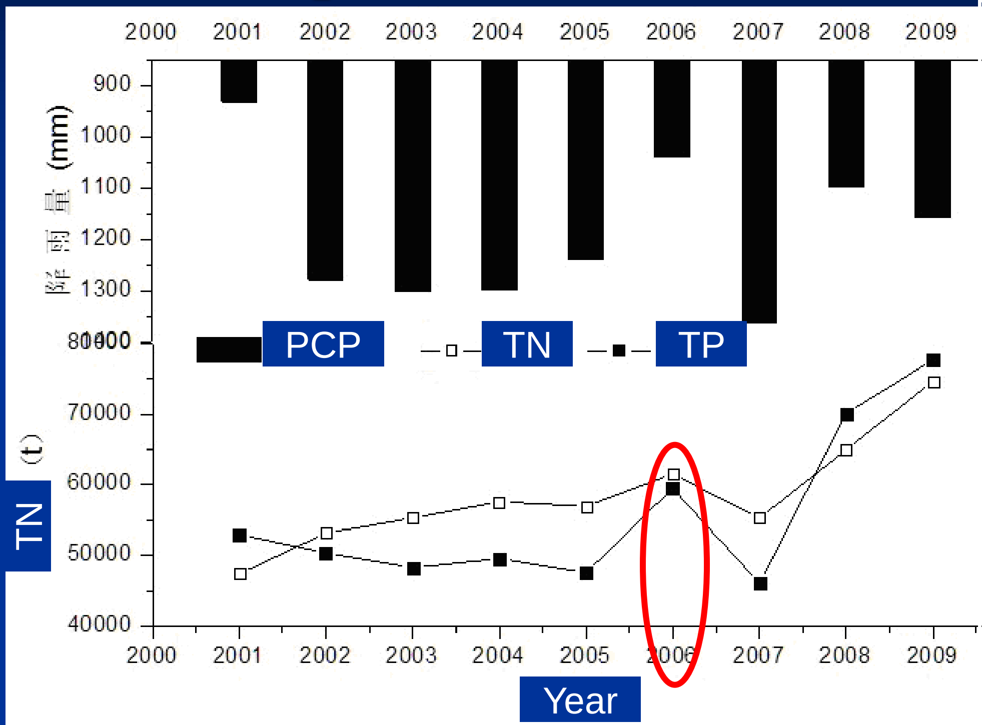
❖ **Stream flow & Sediment**

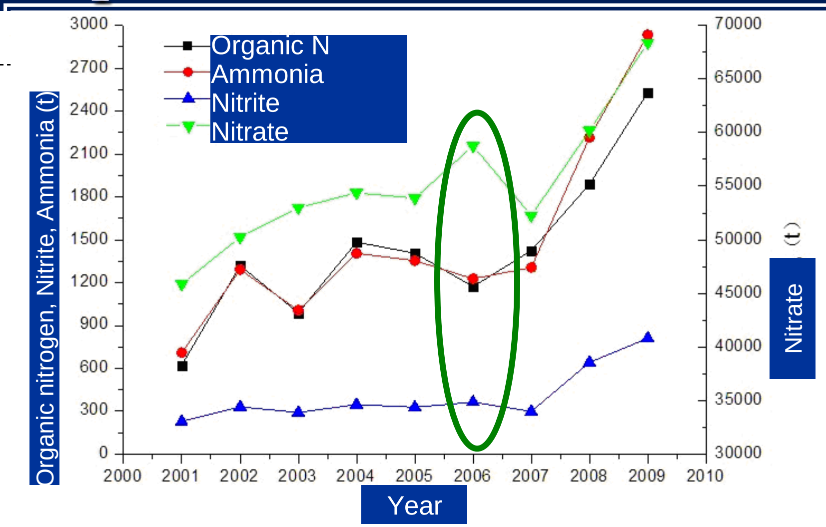
❖ Similar variation trend

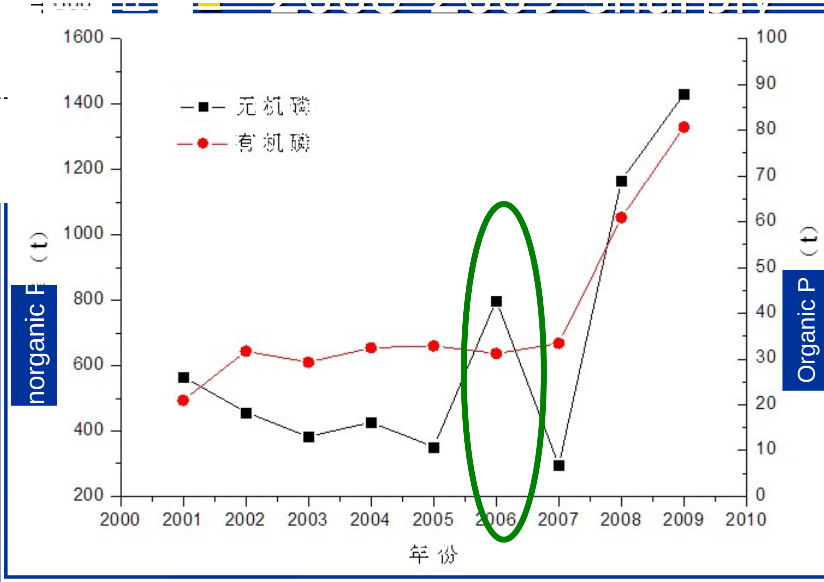
❖ Strong correlation



Temporal distribution of NPS pollution in TGRA



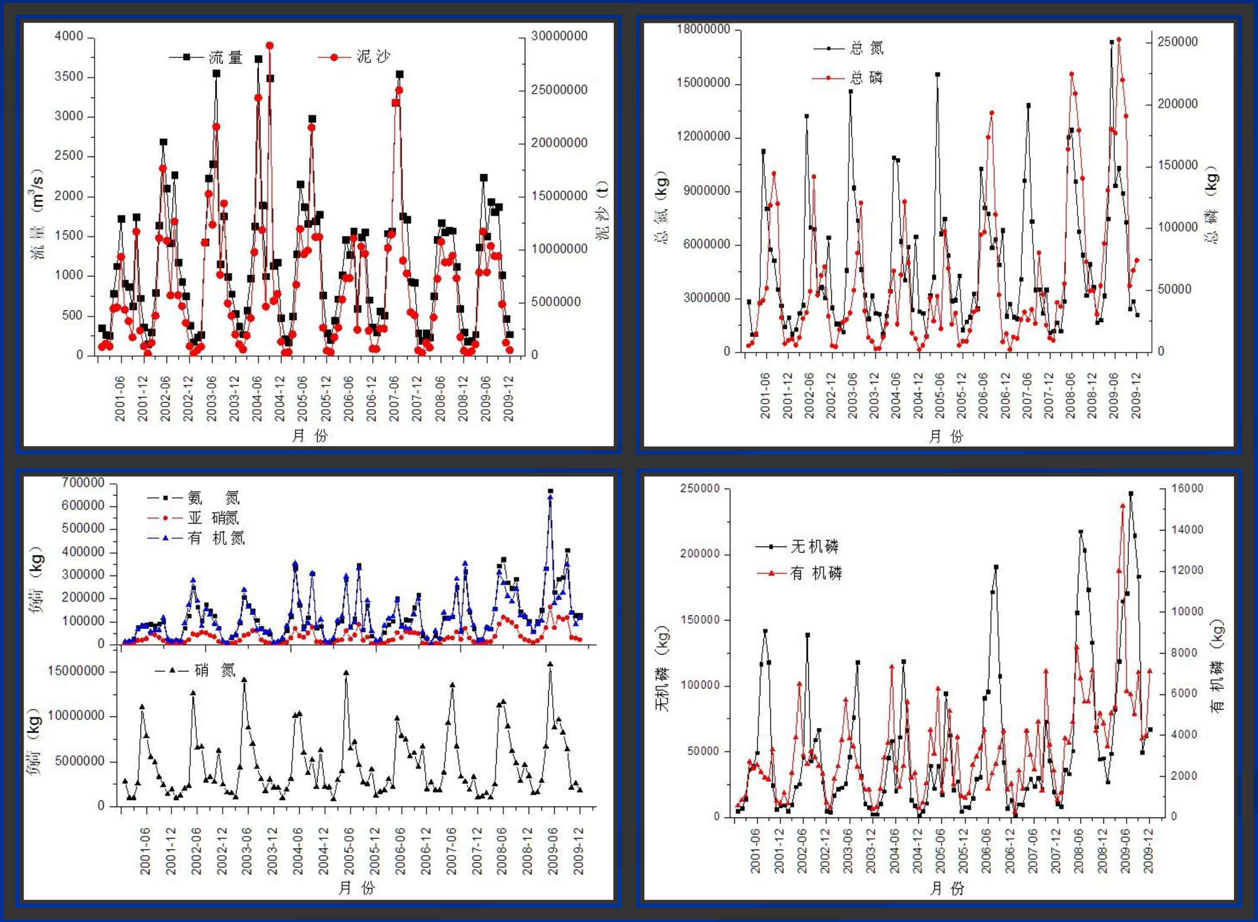




- 2006: NO_3-N ----TN;
  Inorganic P ----TP.
  Dissolved pollutants increased with the water storage by the reservoir.
- NPS pollution loads exhibited an increasing trend.

Temporal distribution of NPS pollution in TGRA

- Monthly variation

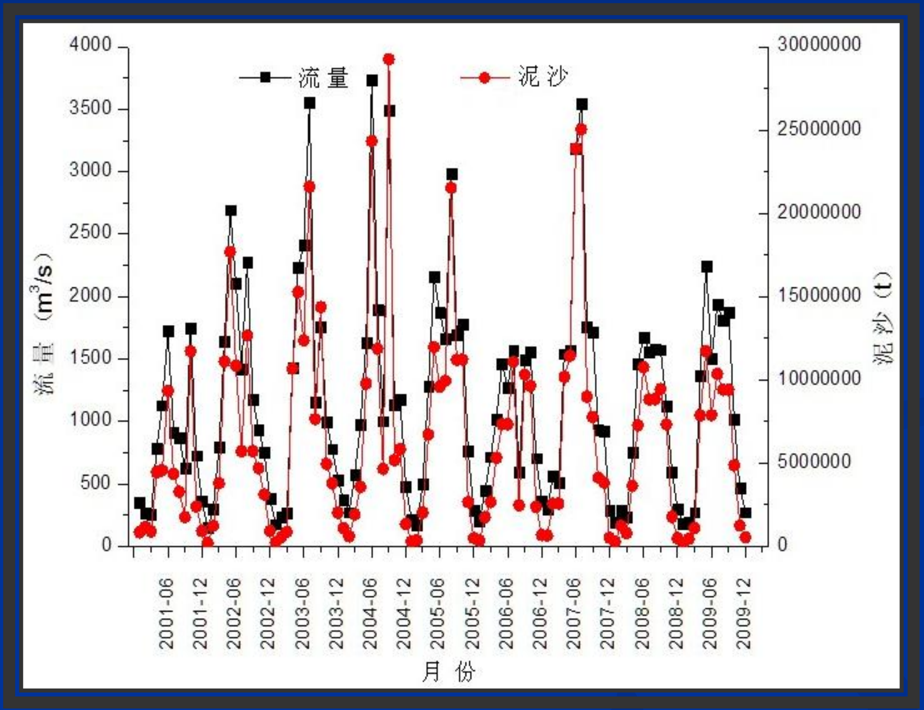


- **Periodicity**
- Lowest in dry season
- Increase in normal season
- Sharply increase in flood season

Temporal distribution of NPS pollution in TGRA

❖ Stream flow — Sediment

$$S = 0.66W - 1146.1$$



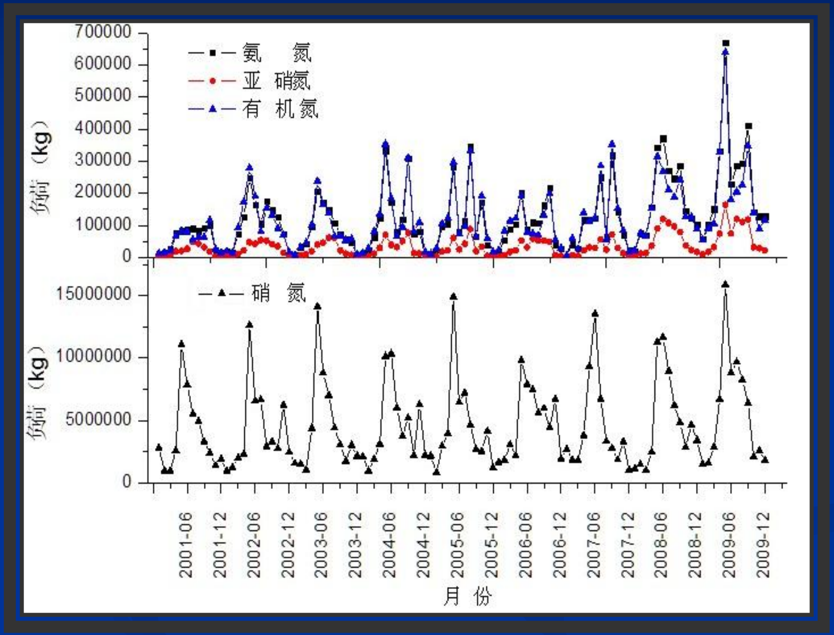
- R^2=0.99
- S—Sediment
- W—Stream flow

- Driving force
- Precipitation－runoff－sediment yield

Temporal distribution of NPS pollution in TGRA

❖ Nitrogen

- Strong positive correlation:
- ORGN－Sediment
- NH_3-N－ Sediment



$$ORGN = 1.29S + 3318$$

❖ $R^2=0.69$

$$NH_3 - N = 1.47S + 2779$$

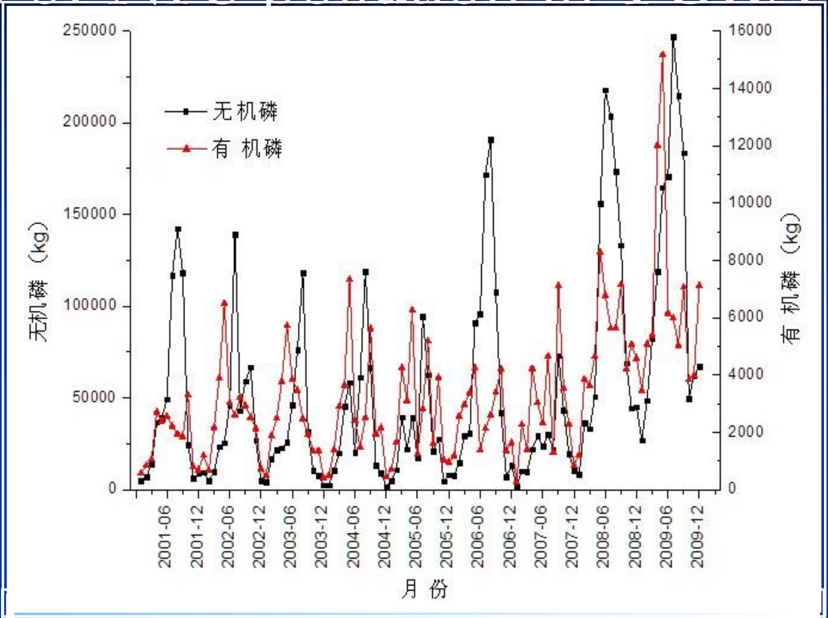
❖ $R^2=0.79$

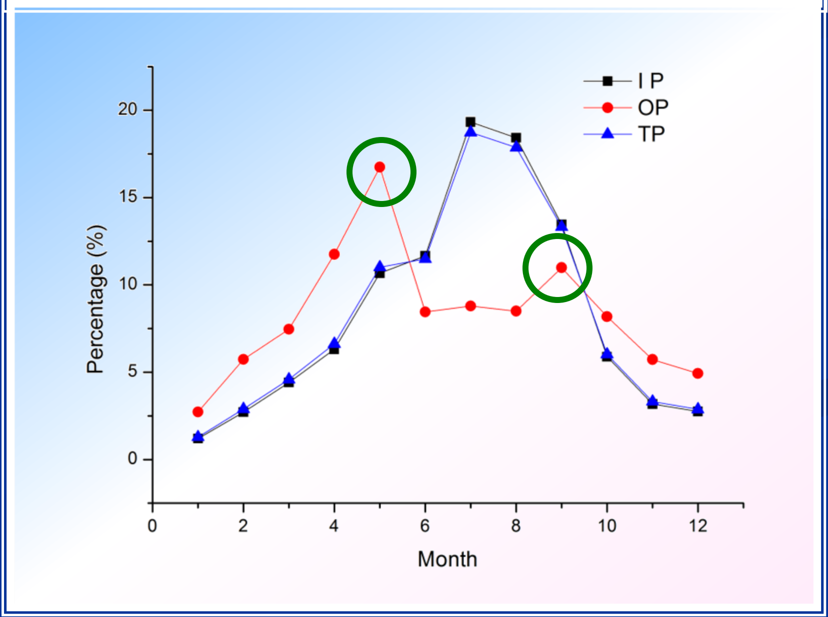
Temporal distribution of NPS pollution in TGRA

❖ **Phosphorous**

- Apr.-Oct.:
  73.4%, 85%

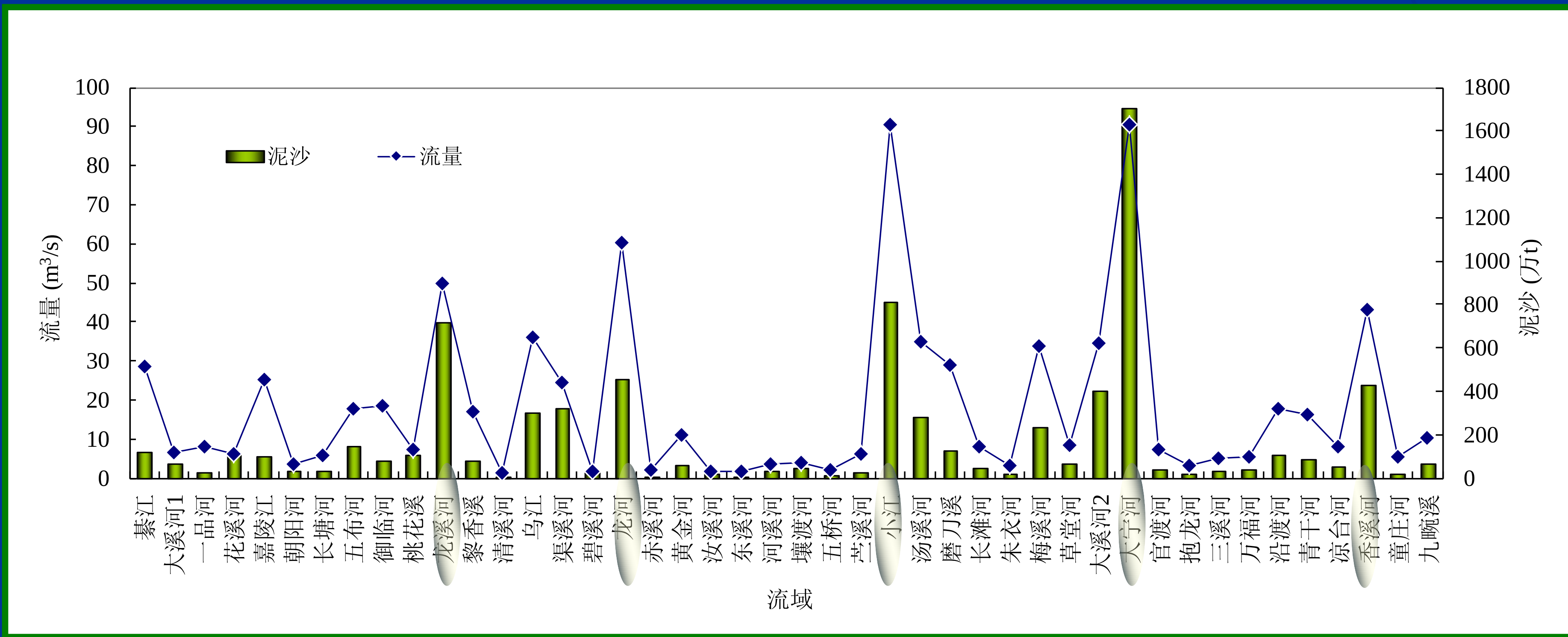
- OP:
- May: 1st peak value
  High precipitation and corresponding eluviation;
- Sep.: 2nd peak value
  Low coverage and degradation from crop residue.





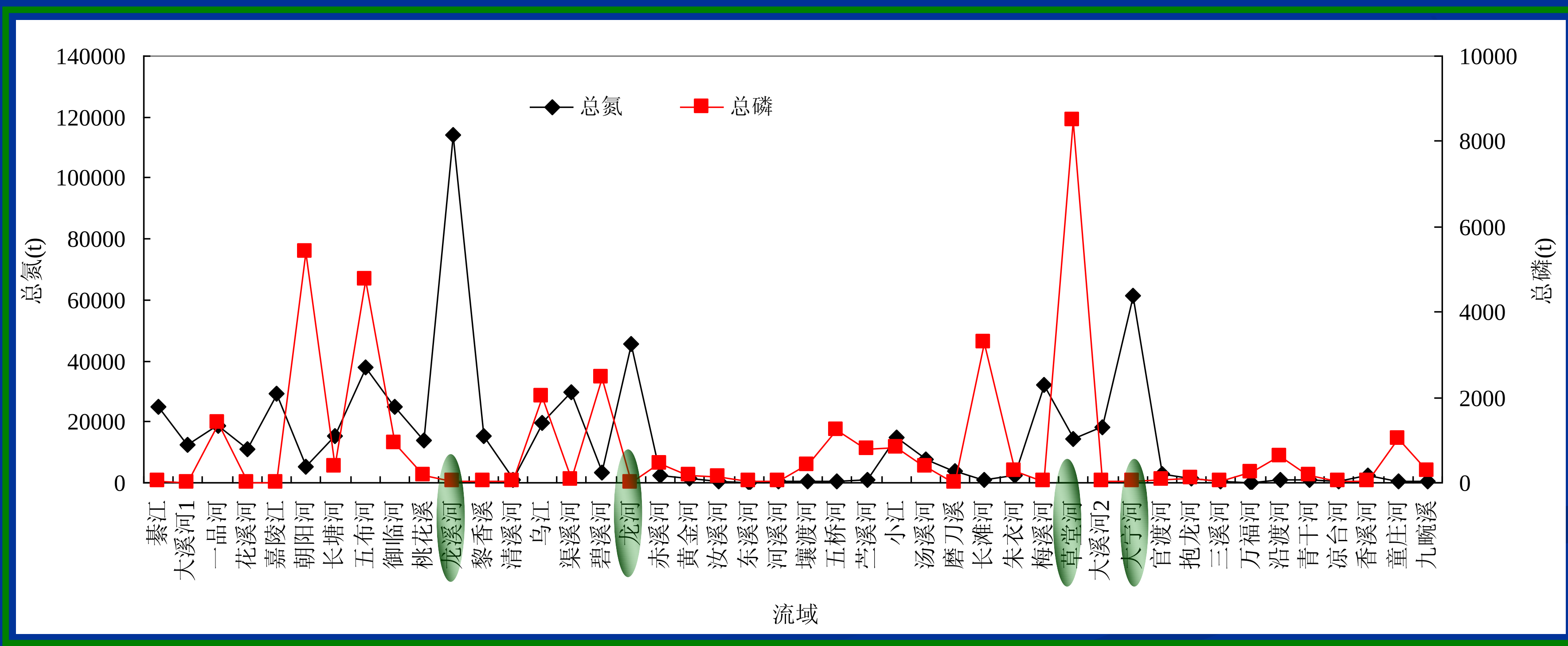
NPS pollution of tributaries in TGRA

- **Sediment**
- Daning, Xiaojiang, Longxi, Longhe, Xiangxi



NPS pollution of tributaries in TGRA

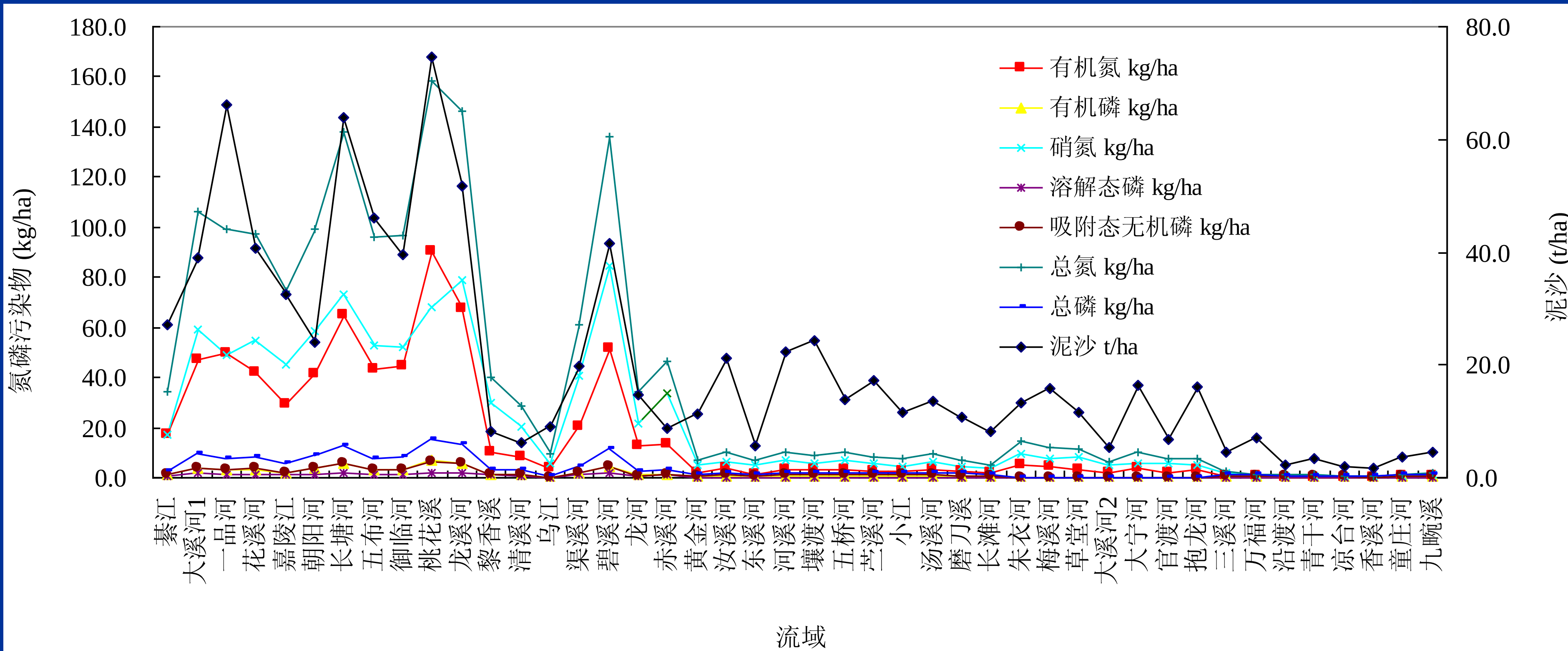
- **Nutrients**
- Daning, Meixi, Caotanghe, Longxihe,



NPS pollution of tributaries in TGRA

❖ Critical polluted watershed (Load intensity)

- ❖ **Sediment:** Taohuaxi, Yipinhe, Changtanhe, Longxihe, Wubuhe
- ❖ **ON:** Longxihe, Changtanghe, Bixihe, Yipinhe
- ❖ **OP:** Taohuaxi, Longxihe, Changtanhe, Bixihe,Chaoyanghe
- ❖ **NO_3-N, IP:** Bixihe, Longxihe, Changtanhe, Changtanhe,Daxihe
- ❖ Common feature: The dominated land use types are dry land and paddy field.



BMP simulation and optimization

❖ Typical watershed -- Daning River Watershed

Land use types

Returning farmland to forest

>15°, >20°, >25°

Tilliage practice

No tillage
Stubble mulch residue
Strip farming
Contour farming
Terrace
Hedgerow

Fertilization management

Reduce the amount of fertilizer

10%,20%,30%

Simulation

Literature review | Parameter modification

CN2、 USLE_P、 USLE_C、 OV_N、 SLSUBBSN、 FILERW

To obtain the removal ratio of these non-structural BMPs.

BMP simulation and optimization

- Land use types change

Scenarios	Removal Of TSS (10^4 t)	Removal rate (%)	Removal Of TN (t)	Removal rate (%)	Removal Of TP (t)	Removal rate (%)
>25°	84.71	21.30	460.92	19.20	64.94	20.60
>20°	106.98	26.90	537.75	22.40	83.54	26.50
>15°	121.29	30.50	640.97	26.70	94.26	29.90

- *CN* value change
- Reduction of fertilization

BMP simulation and optimization

- Tillage practices

Scenarios	Removal Of TSS (10^4 t)	Removal rate (%)	Removal Of TN (t)	Removal rate (%)	Removal Of TP (t)	Removal rate (%)
No tillage	15.11	3.80	100.83	4.20	11.66	3.70
Stubble mulch	72.82	18.31	350.98	14.62	55.29	17.54
Strip farming	45.69	11.49	172.37	7.18	30.70	9.74
Contour farming	36.19	9.10	122.91	5.12	27.61	8.76
Terrace	89.52	22.51	464.77	19.36	66.17	20.99
Hedgerow	54.32	13.66	233.58	9.73	35.34	11.21

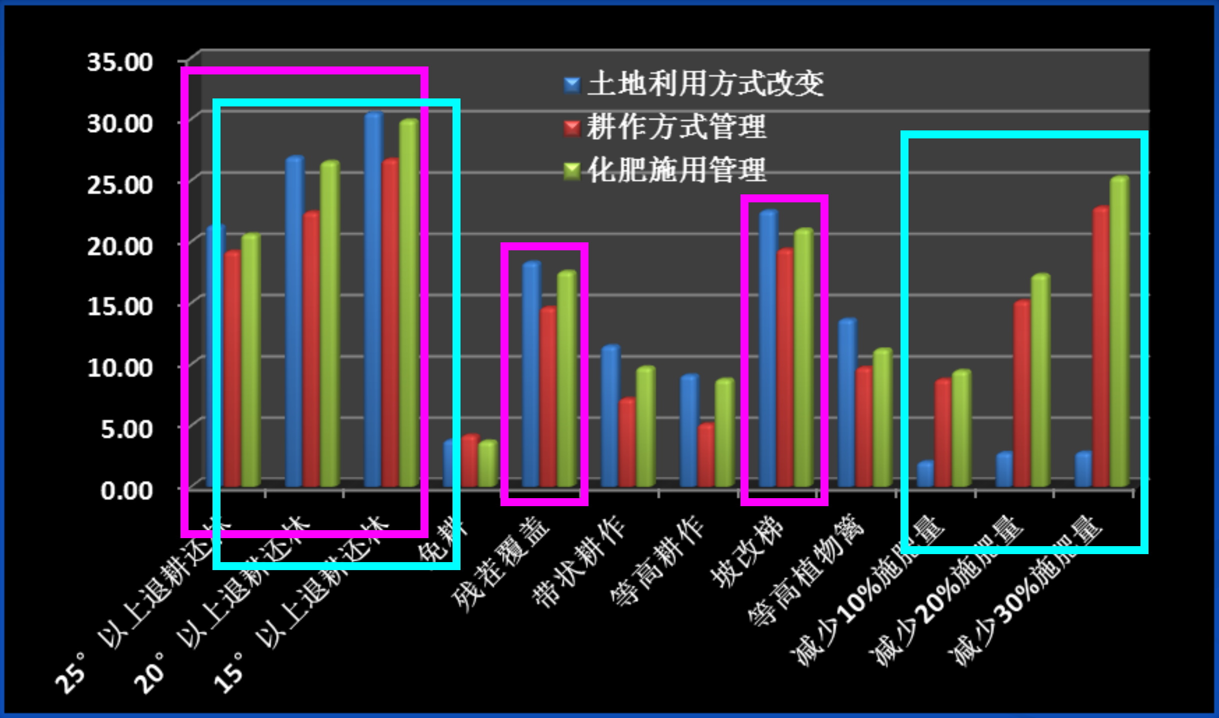
BMP simulation and optimization

- Fertilization management

Scenarios	Removal Of TSS (10^4 t)	Removal rate (%)	Removal Of TN (t)	Removal rate (%)	Removal Of TP (t)	Removal rate (%)
Reduce 10%	8.07	2.03	210.30	8.76	29.79	9.45
Reduce 20%	11.02	2.77	363.70	15.15	54.47	17.28
Reduce 30%	11.17	2.81	547.35	22.80	79.63	25.26

- Enhance the fertilization efficiency
- Develop the formula fertilization by soil testing

BMP simulation and optimization



- **Sediment:** <u>Returning farmland to forest, Stubble mulch, Terrace</u>
- **Nutrients:** <u>Returning farmland to forest, Reduce the fertilization</u>

BMP simulation and optimization

❖ Critical polluted subbasin – Shilonggou (Yulin River)

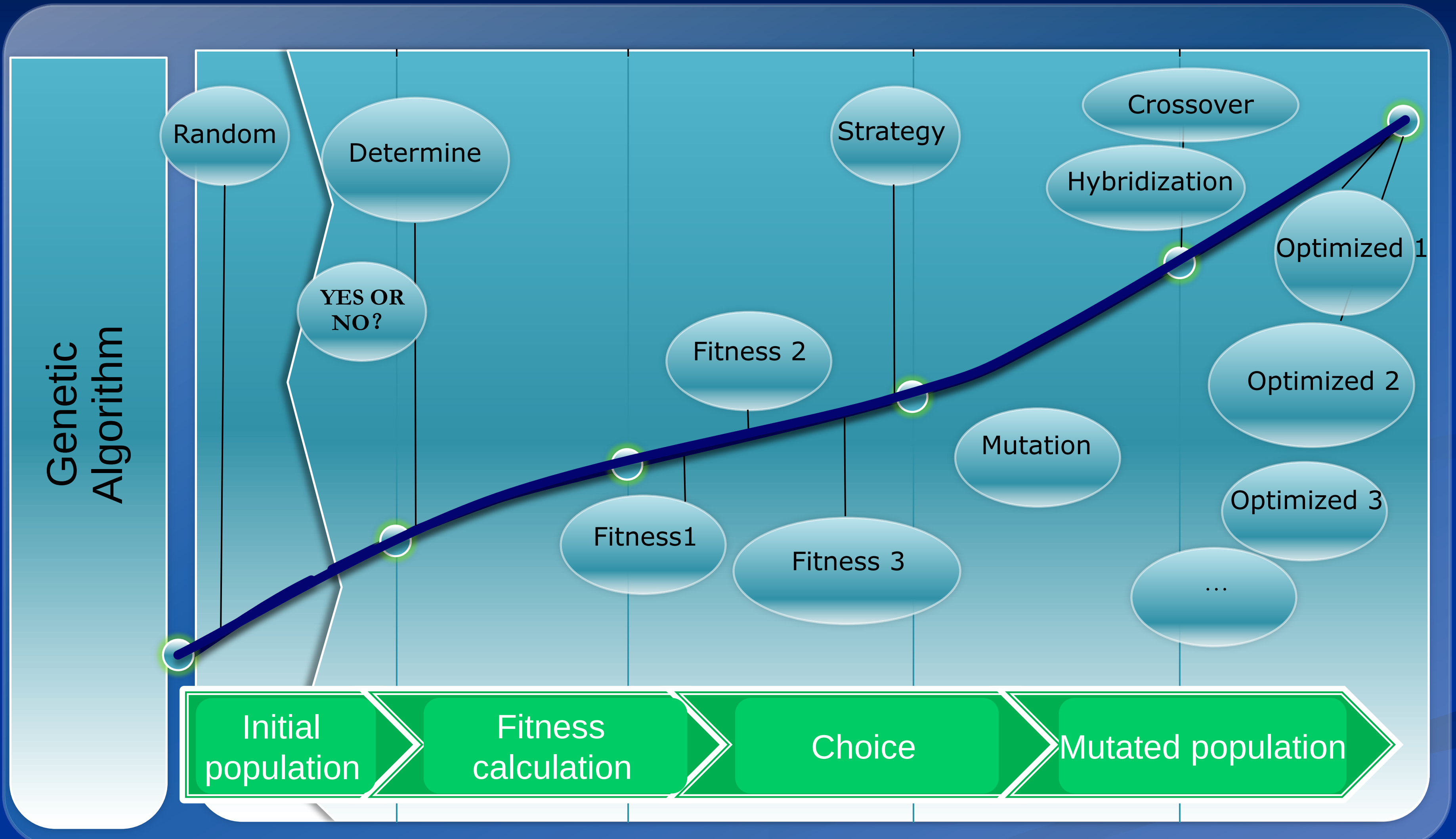
Structural BMPs

- **Constructed wetla**
- **Ecological ditch**
- **Detention Pond**
- **Vegetative filter strips**

Non-structural BMPs

- **Returning farmland to forest**
- **Formula fertilization by soil testing**
- **Conservation tillage**

BMP simulation and optimization



BMP simulation and optimization

Prepare

Database

Modeling

BMPs operability

BMPs efficiency

BMPs cost

Solution

Multi-objective optimization

Literature review

SWAT simulation

Comprehensive index evaluation

Genetic Algorithm

Screening

BMP simulation and optimization

Gene ID	Scenarios	BMPs description
0000	1	No BMPs
0001	2	Constructed wetland (CW)
0010	3	Detention pond (DP)
0011	4	Vegetation filter strip (VFS)
0100	5	Ecological ditch (ED)
0101	6	VFS & CW
0110	7	VFS & DP
0111	8	VFS & ED
1000	9	Returning farmland to forest (RFF)
1001	10	Formula fertilization by soil testing (FFST)
1010	11	FFST & VFS
1011	12	FFST & DP
1100	13	Conservation tillage (CT)
1101	14	CT & VFS
1110	15	CT & DP
1111	16	CT & FFST

BMP simulation and optimization

BMPs	Removal efficiency（%）		
	TSS	TP	TN
Constructed wetland	71±25	56±35	19±29
Detention pond	68±10	55±7	32±11
Ecological ditch	38±31	14±23	14±41
Vegetation filter strip	54~84	-25~40	20
Returning farmland to forest	27	25	24
Formula fertilization by soil testing	0	17	15
Conservation tillage	11	9	8

- **Literature review & SWAT simulation**

BMP simulation and optimization

BMPs	Cost function	Transformed function	Reference
Constructed wetland	$C = 30.6V^{0.71}$	$C = 3176.4V^{0.71}$	Brown et al., 1997
Detention pond	$C = 24.5V^{0.71}$	$C = 2543.2V^{0.71}$	U.S. EPA, 2003
Ecological ditch	\$0.25—\$0.50/ft^2	￥22.2—￥44.5/m^2	WERF, 2003
Vegetation filter strip	\$0.30—\$0.70/ft^2	￥26.7—￥62.2/m^2	WERF, 2003
Returning farmland to forest		￥ 230 /Mu	National standard
Formula fertilization by soil testing		￥ 800 /50Mu	Sampling and testing standard
Conservation tillage		￥ 30 /Mu	National standard

BMP simulation and optimization

Efficiency fitness

$$D_i = \begin{cases} 2 & for \quad D_m \le D_x \\ 2 - \dfrac{D_m - D_x}{D_m - D_s} & for \quad D_s \le D_x \le D_m \\ 1 & for \quad D_x \le D_s \end{cases} \qquad D = \frac{\sum_i \omega_i D_i}{\sum_i \omega_i}$$

Cost fitness

$$C = \begin{cases} 2 & for\ C_m = C_x \\ 1 + \dfrac{C_s - C_x}{C_s - C_m} & for\ C_m \le C_x \le C_s \\ 1 & for\ C_s \le C_x \end{cases} \qquad C_x = \sum_{i=1}^{n} C_{\cos t,x}(b_i)$$

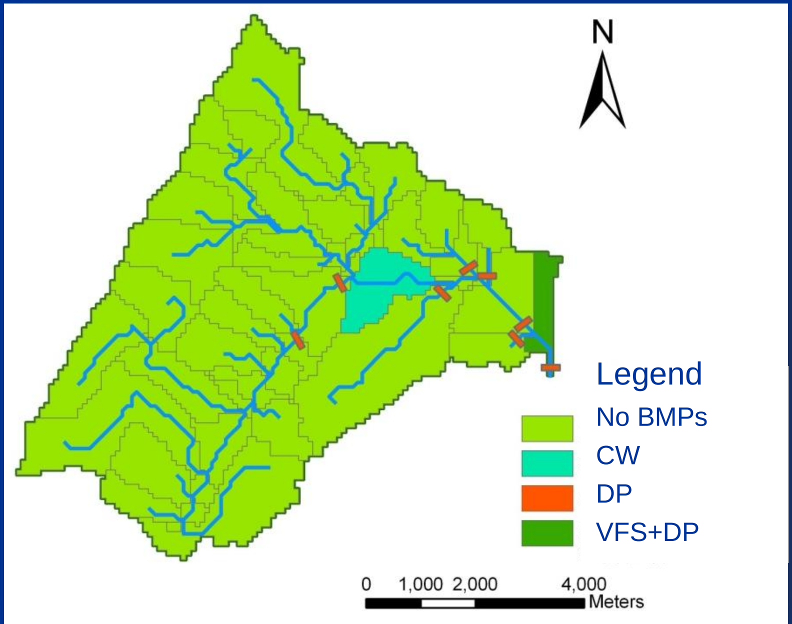
Operability fitness

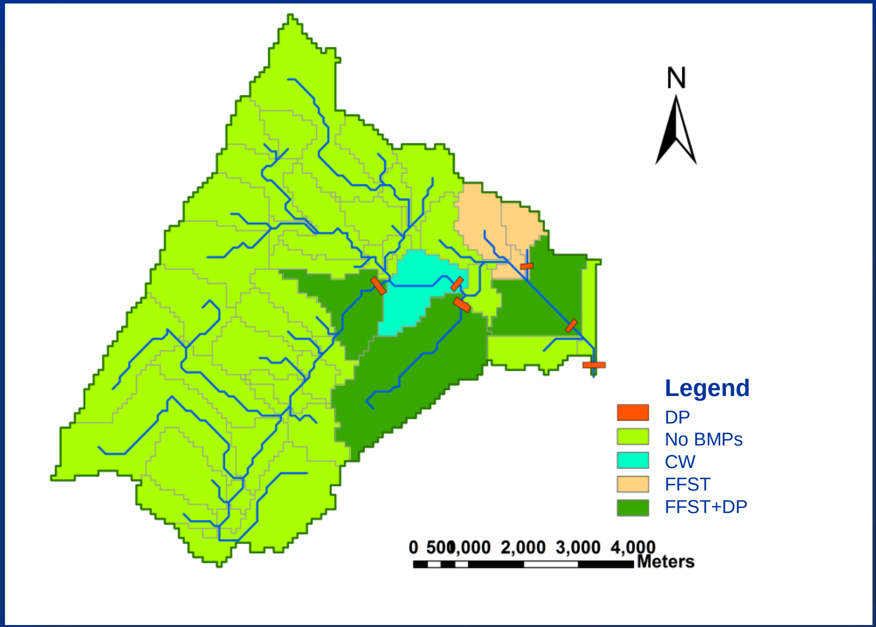
$$G = \begin{cases} 0 & for \quad G_s \le G_x \\ \dfrac{G_m - G_x}{G_m - G_s} & for \quad G_s \le G_x \le G_m \\ 1 & for \quad G_x \le G_m \end{cases} \qquad G_x = \sum_{i=1}^{n} (I_i \cdot W_i)$$

$$F_{D,G} = \begin{cases} D & if\ G = 1 \\ G & if\ G < 1 \end{cases} \qquad F_{G,C} = \begin{cases} C & if\ G = 1 \\ G & if\ G < 1 \end{cases}$$

BMP simulation and optimization

- Structural BMPs VS Structural + Non-structural BMPs
- Scenarios of different removal settings
  - **Remove TSS, TN and TP**

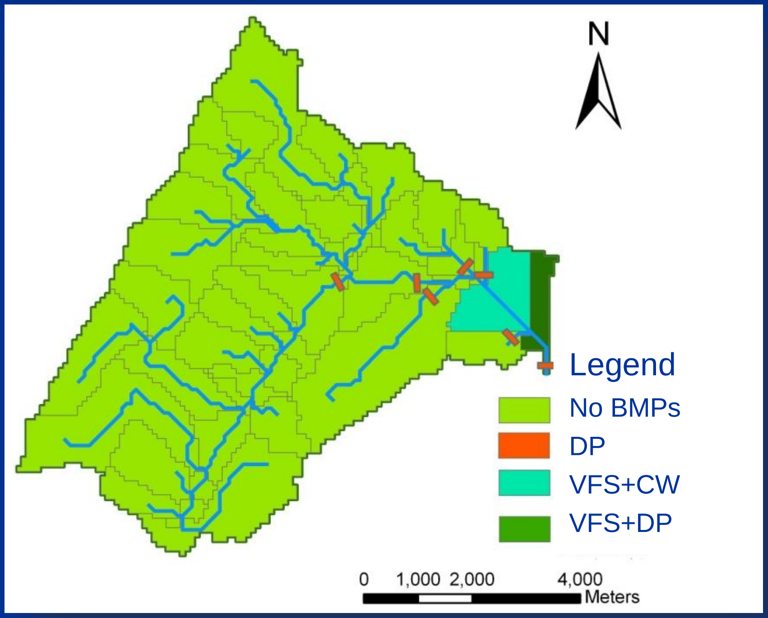


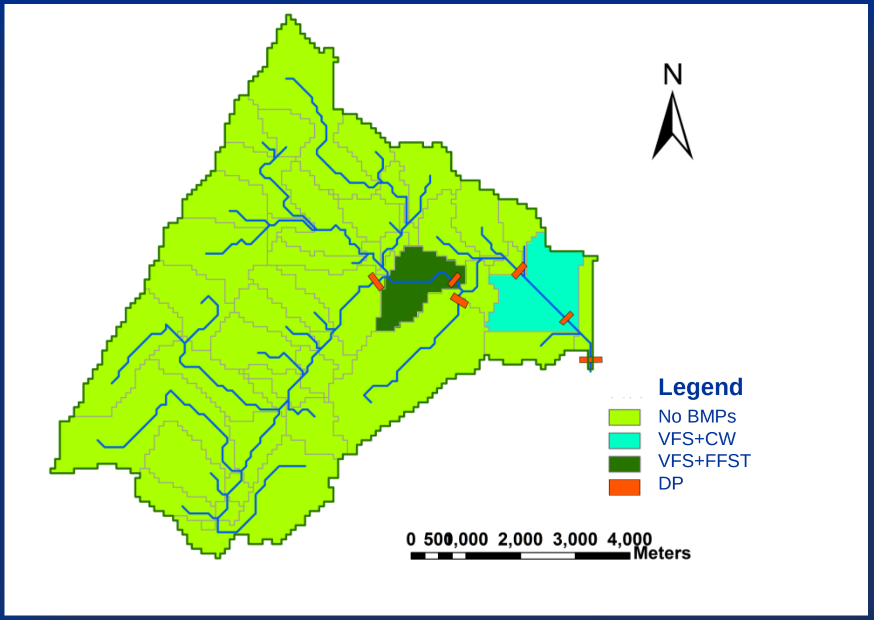


- The number of detention pond decreased and formula fertilization by soil testing was selected.

BMP simulation and optimization

- **Remove TSS first**

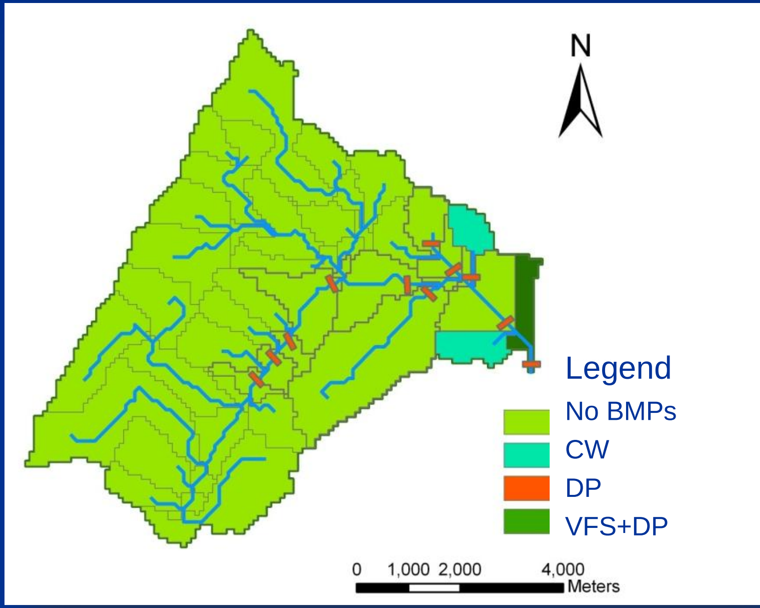


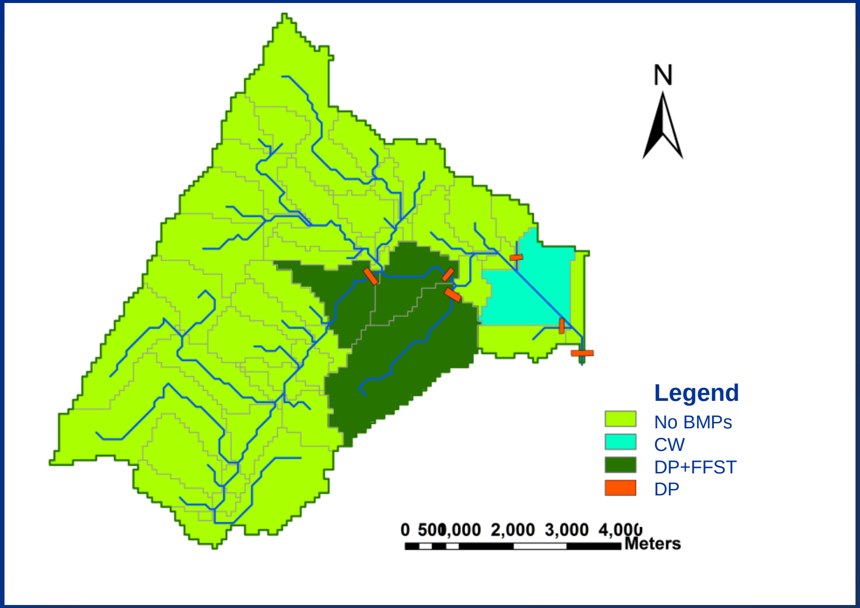


❖ No remarkable difference but formula fertilization by soil testing was selected.

BMP simulation and optimization

- **Remove TN first**

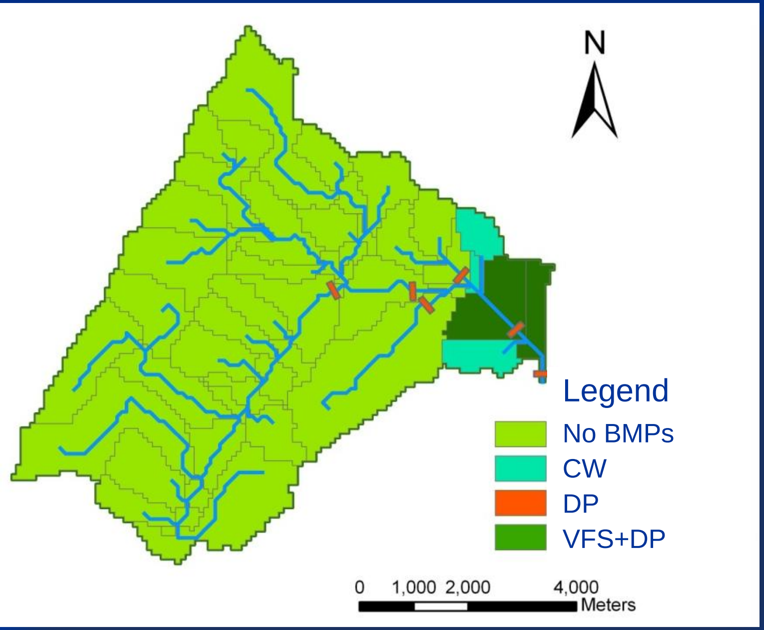


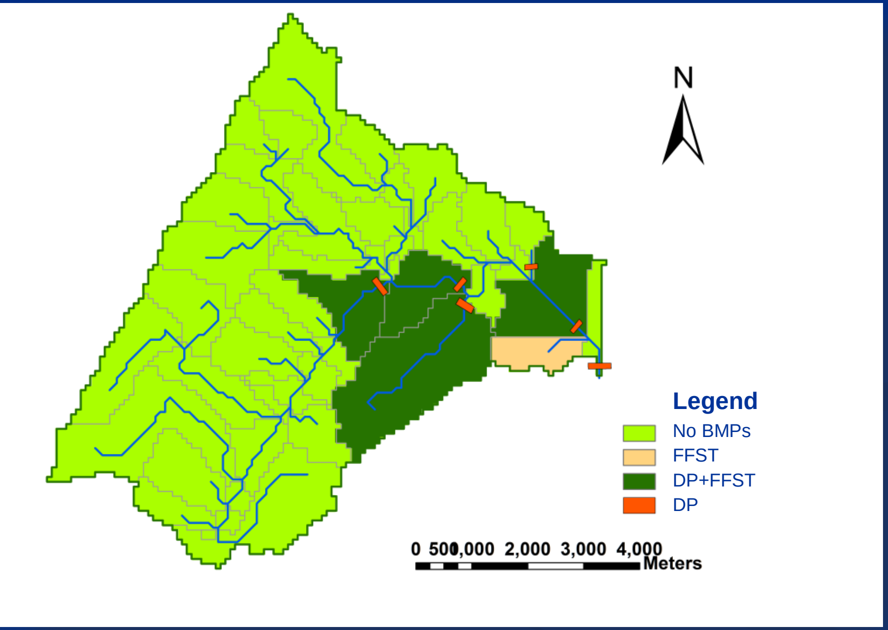


- The number of detention pond decreased and formula fertilization by soil testing was selected.

BMP simulation and optimization

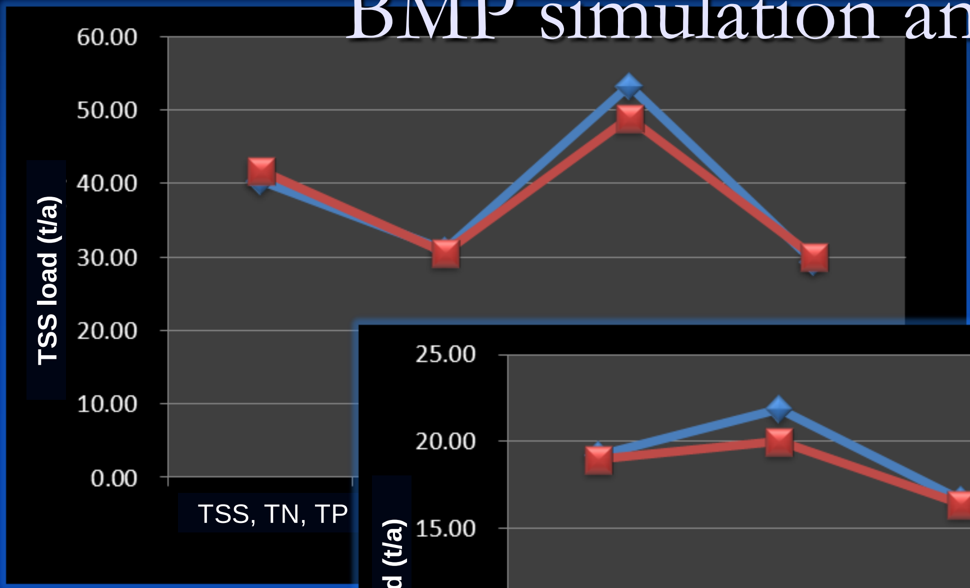
- **Remove TP first**

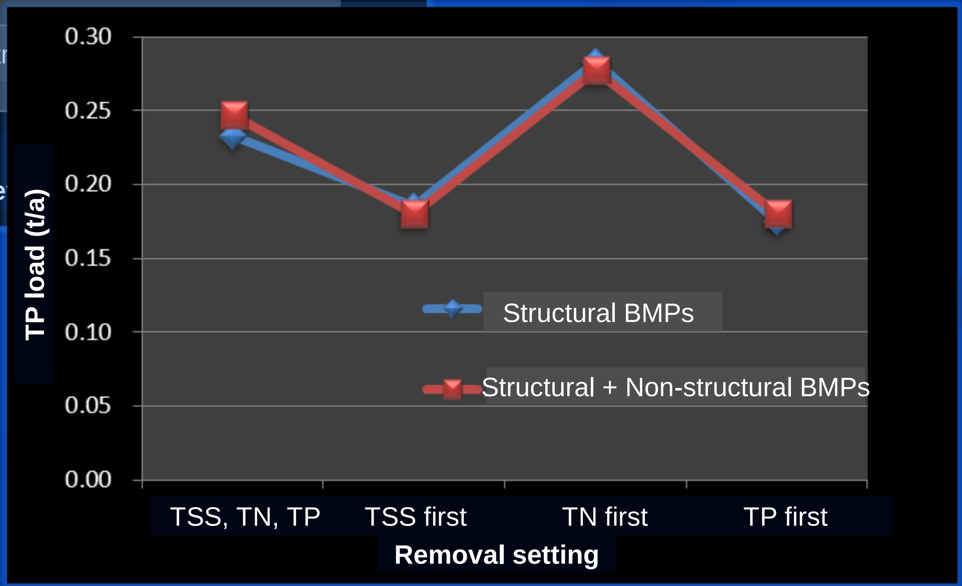




- The number of constructed wetland decreased and formula fertilization by soil testing was selected.

BMP simulation and optimization



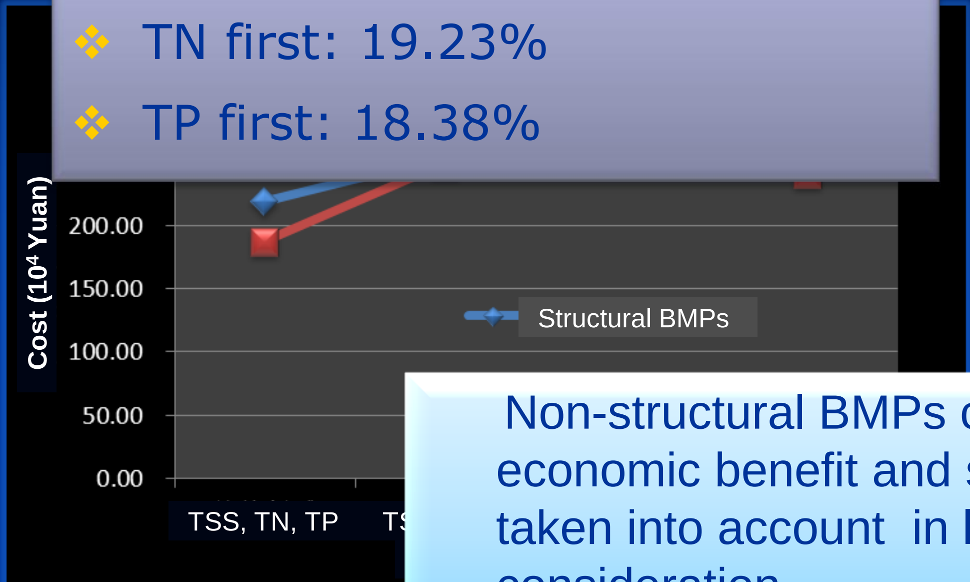


- **Removal efficiency**

- No remarkable difference

BMP simulation and optimization

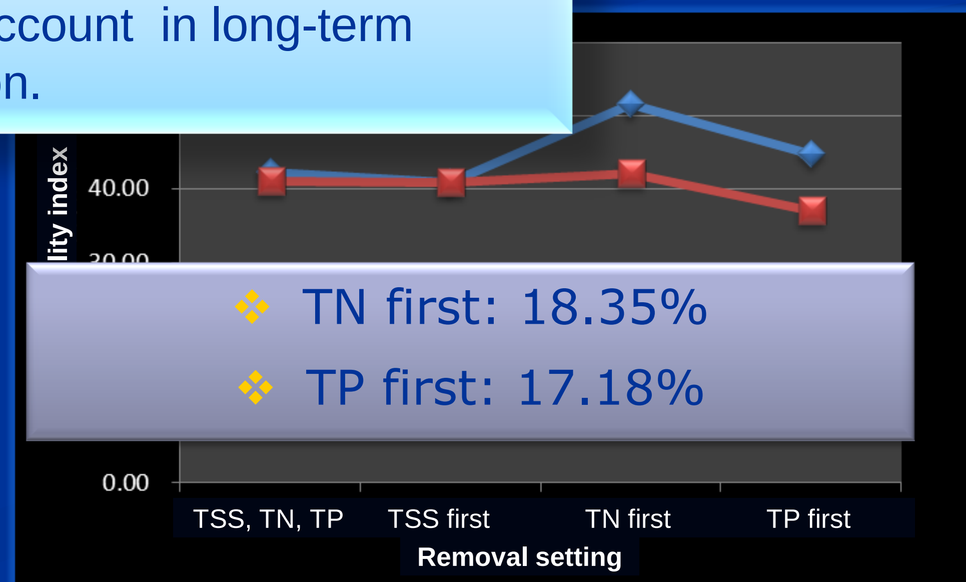
- TSS,TN,TP: 13.67%,
- TN first: 19.23%
- TP first: 18.38%



- **Cost comparison**
- Structural + Non-structural BMPs can save cost to some extent.

Non-structural BMPs can bring more economic benefit and should be taken into account in long-term consideration.

- **Operability comparison**
- Structural + Non-structural BMPs can enhance the total operability to some extent.



- TN first: 18.35%
- TP first: 17.18%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Thank you for your attention!