Enhanced Constructed Wetland Technologies for Controlling and Remediating Water Eutrophication

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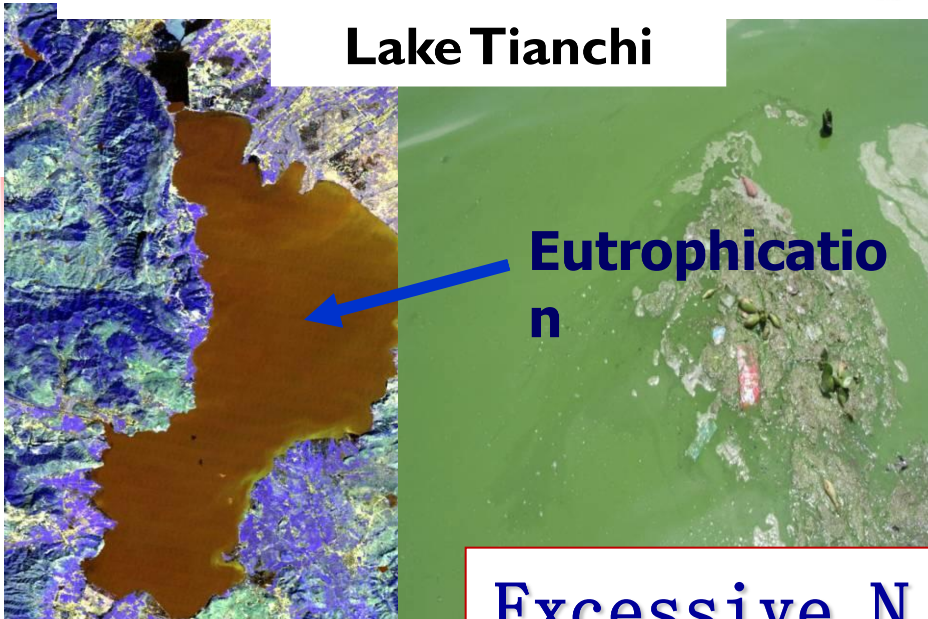
Outline

- Backgrounds
- Approaches of phytoremediation engineering of water eutrophication
- Key issues for phytoremediation engineering of water eutrophication
- Selected examples of practical application
- Conclusions

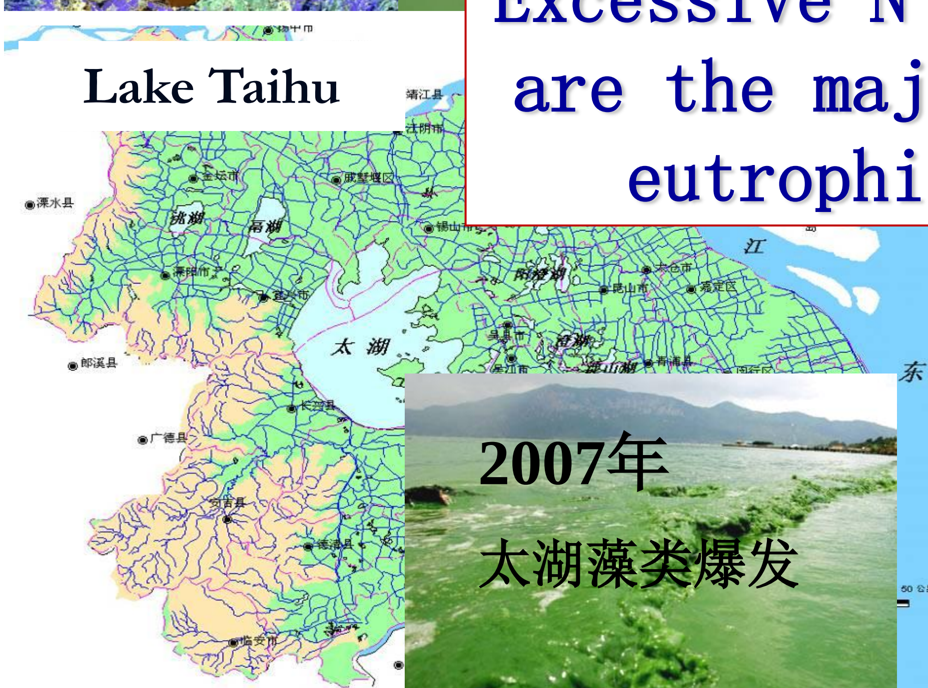
Water Eutrophication

- Eutrophication is a process whereby water bodies, such as lakes/reservoirs, estuaries, or slow-moving streams receive excess **nutrients** that stimulate excessive lower plant growth (algae, periphyton attached algae, and nuisance plants weeds).
- This enhanced plant growth, often called an algal bloom, reduces dissolved oxygen in the water when dead plant material decomposes and can cause other organisms to die.
- Water with a low concentration of dissolved oxygen is called **hypoxic**.

In China water eutrophication is widepread



Excessive N and P loads are the major cause of eutrophication!



Eutrophication of drinking water source reservoirs

Henxi Reservoir

Sunxipu reservoir

Baixi reservoir

Total N $\geq$2.5mg/L、Total P $\geq$ 0.025mg/L

Henxi reservoir

Jiaokou reservoir

Zhoukong reservoir

Eutrophication of city rivers

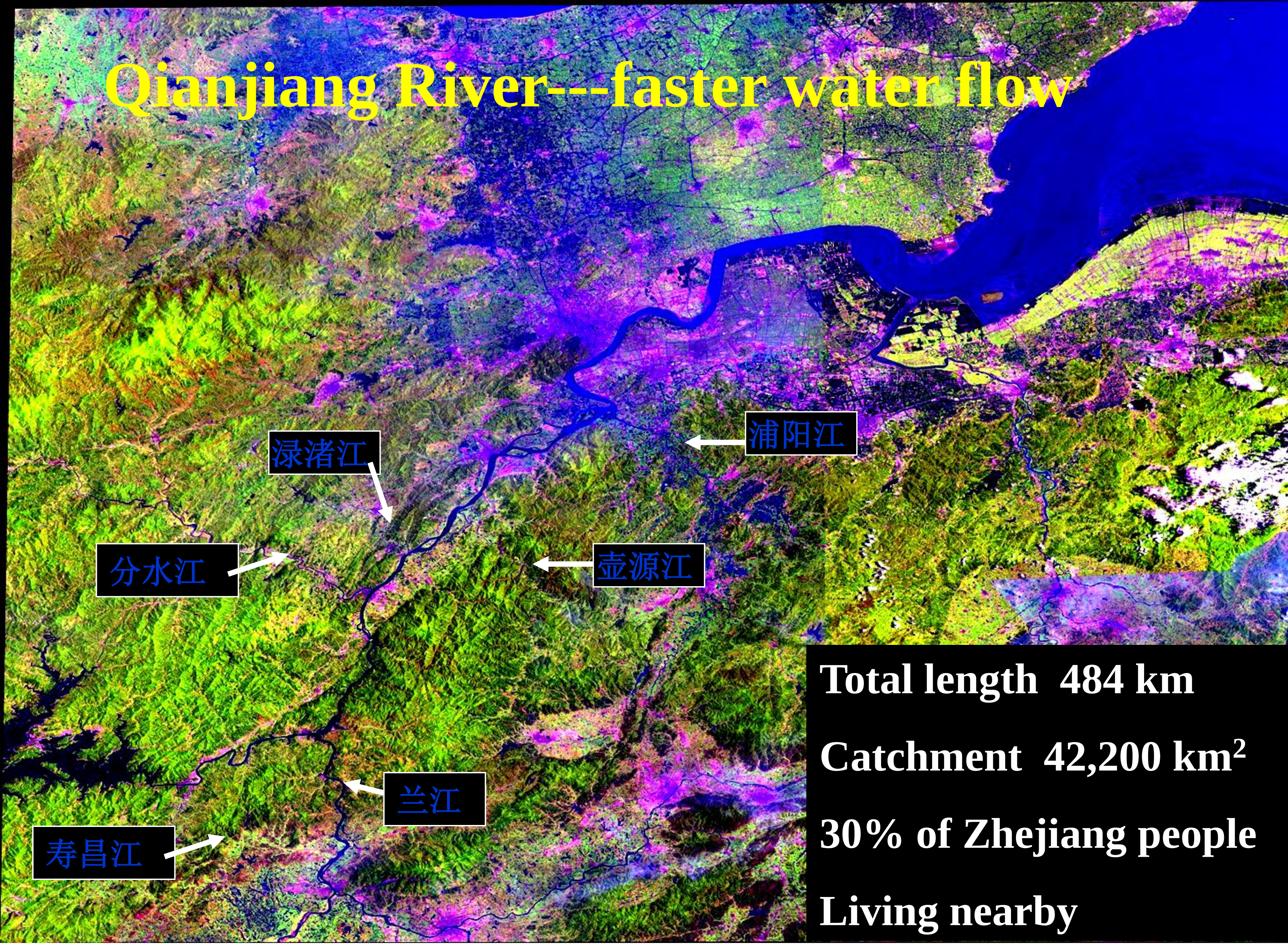
Shaoxing

Jiaxing

Hangzhou

Shanhai

Qianjiang River---faster water flow



Total length 484 km

Catchment 42,200 km^2

30% of Zhejiang people

Living nearby

Algae bloom in Qianjiang River （2004）

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- **Approaches of phytoremediation engineering of water eutrophication**
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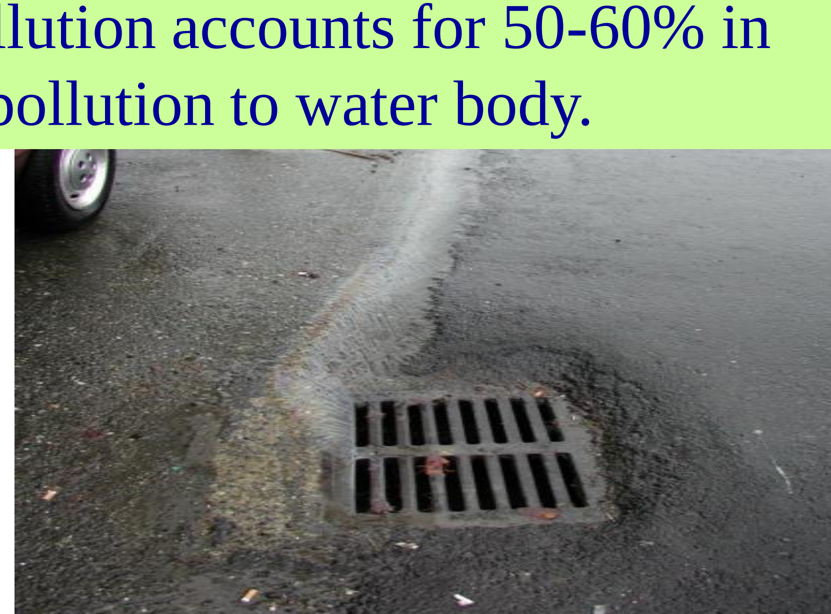
Major sources of nutrients loads

- Sewage water and treatment plant discharges
- Animal wastes discharges
- Fertilizers applied to agricultural fields, man-made forests, vegetable farms , and suburban lawns
- Deposition of nitrogen and phosphorus from the atmosphere
- Erosion of soil containing nutrients

Sources of Water N and P Pollution

In the latest pollution resource survey of whole China, It is reported that agricultural pollution accounts for 50-60% in contributing N and P pollution to water body.



The major technologies used for controlling or remediating water eutrophication

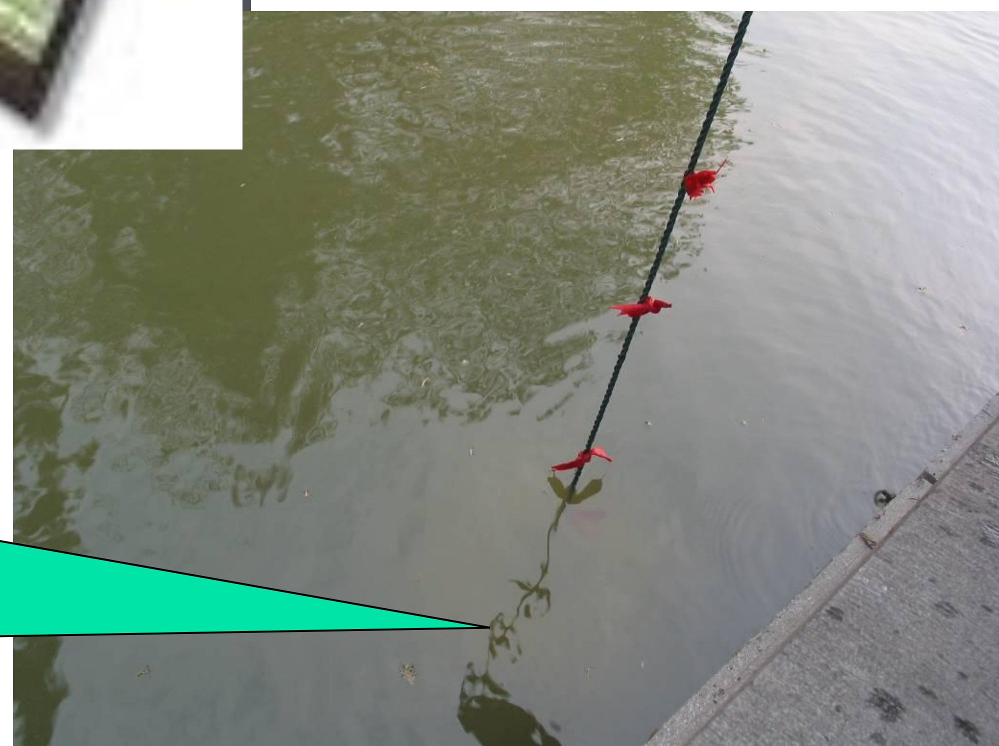
- **Outer-source pollution control: Establishing waste water treatment factories and agricultural non-point pollution reduction.**
- **Inner-source pollution control: Sediment removal, clean water replacement.**
- **Physically and /or chemically algae removal or control.**
- **Phytoremediation engineering: Constructing enhanced plant eco-system to abate nutrient loading into water and remove/recycle nutrients from water body back to terressial ecosystem.**

Comparison of the discharge standard for city wastewater treatment plant (GB18918-2002) with surface water quality standard Grade III(GB3838-2002)

		TN (mg/L)	TP (mg/L)
GB18918-2002	Grade I A	15.0	1.0
	Grade I B	20.0	1.5
GB3838-2002 Grade III		1.0	Rive 0.1 (Lake 0.05)

Difference： 15-20 folds 10-30 folds

Sediment removal and Clean water replacement is a high cost and can't totally control water eutrophication
For example: West Lake , Lake Tianchi



Water transparence : <50 cm

TN: 1.75mg/L

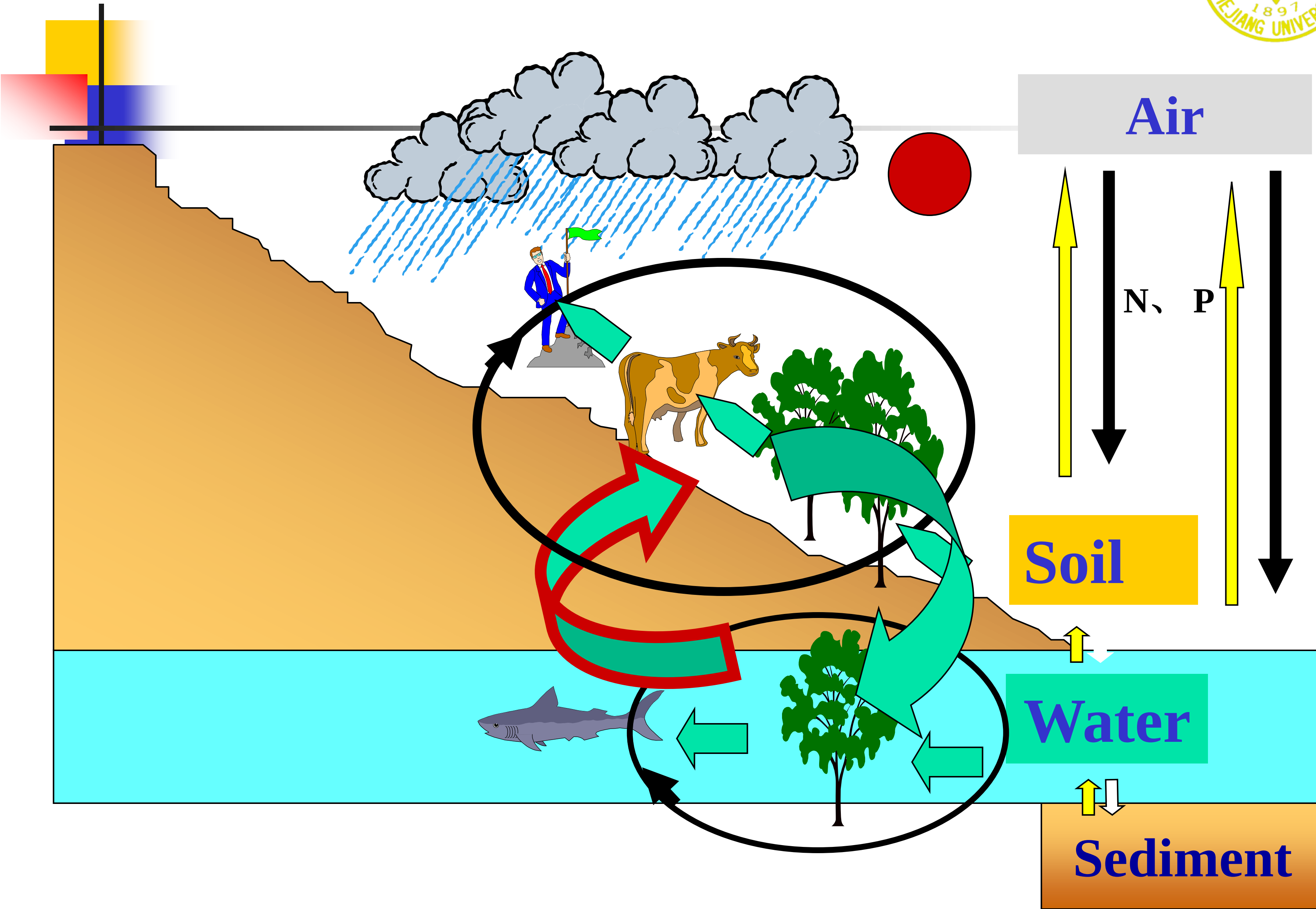
TP: 0.1 mg/L

Nitrate: 0.5 mg/L

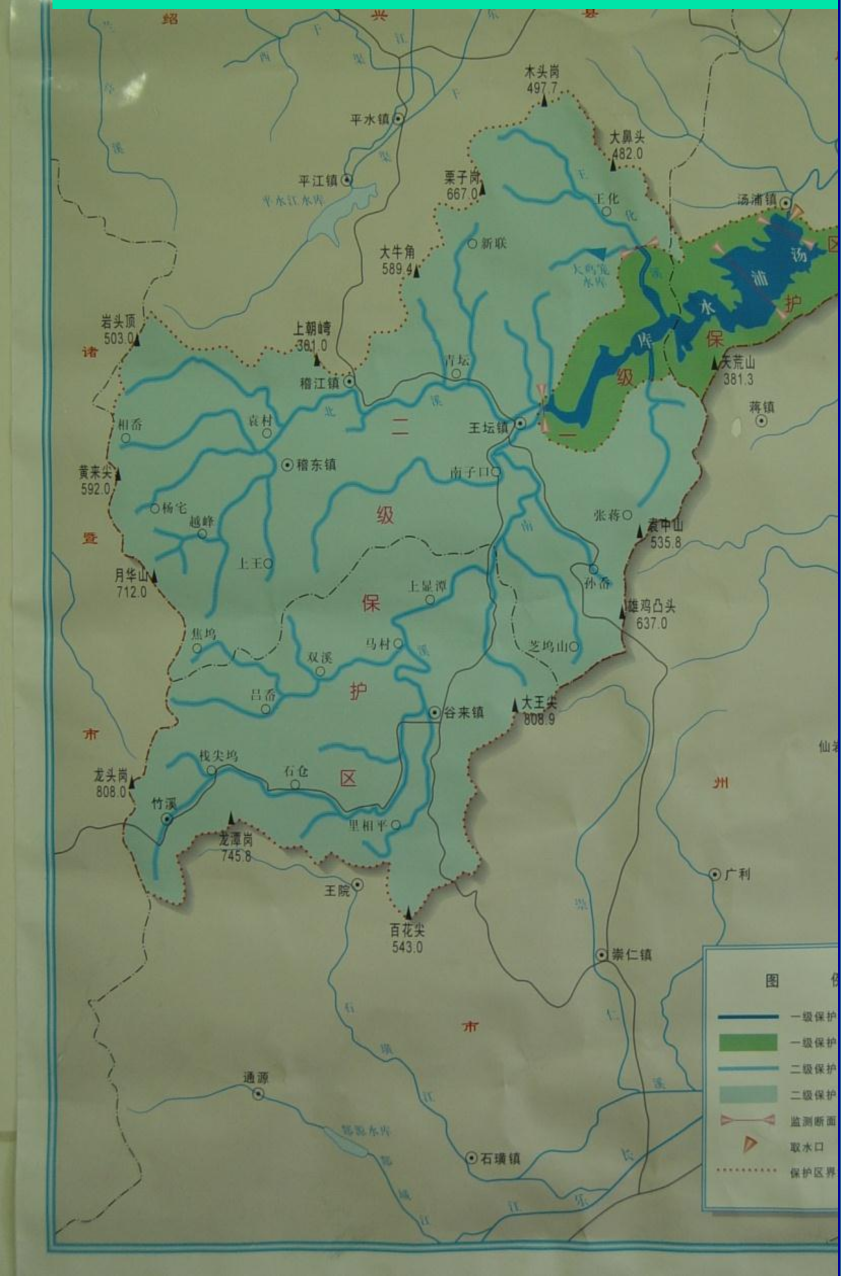
Phytoremediation Engineering

- Is to decontaminate polluted soils or water bodies using sunlight as energy source, special higher plants as the center of decontamination system, and with assistance of physical, chemical, and microbiological measures.
- Constructing and managing high adaptable plant eco-system with great self-purification capacity are the key points of phytoremediation engineering.

Phytoremediation engineering and nutrients/pollutants recycling to enhance soil and aquatic ecosystem health

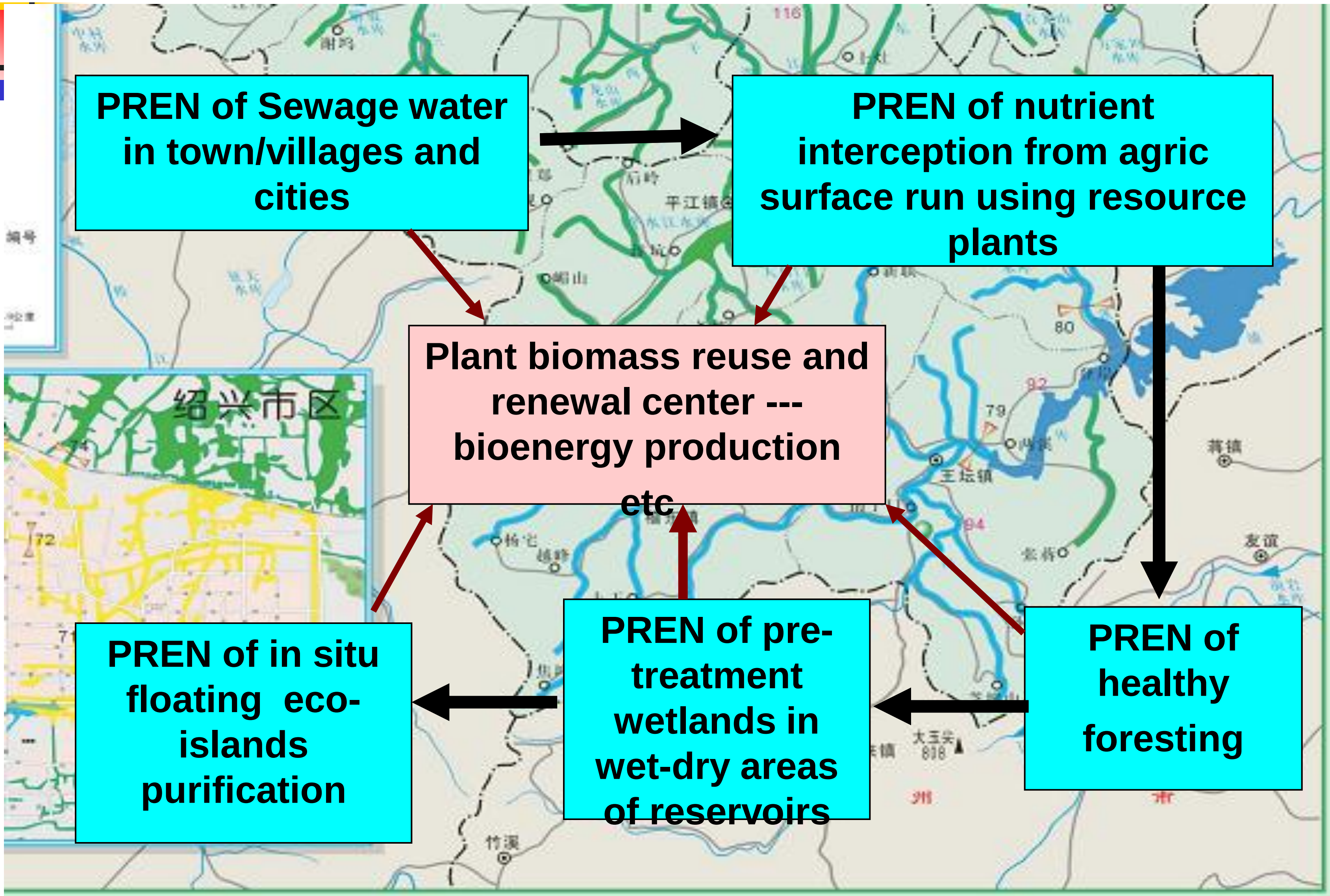


Catchment scale approaches
5+1 Modes?



1. **PREN** of sewage water ecologically treatment in towns/villages and/or secondary discharge of sewage treating plants in cities to reduce nutrients/pollutants discharge
2. **PREN** of non-point polluted nutrients ecologically interception from intensive agricultural systems to abate nutrients surface run loading
3. **PREN** of forest wastes pollution by builting healthy forest ecosystem and management
4. **PREN** of reservoir water ecologically pretreatment by constructing treatment wetlands with efficient purification in wet-dry areas of reservoirs
5. **PREN** of in situ water body ecologically purification by constructing floating eco-islands on water to remove and recycle nutrients/pollutants from

Catchment scale approaches for phytoremediation engineering of water eutrophication



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- Technologies for remediating water eutrophication
- **Key issues for phytoremediation and ecological engineering of eutrophic water**
- Selected examples of practical application

  Conclusions

Key issues for phytoremediation engineering of water eutrophication and resources reuse

- Identification and breeding of special plant species and microbes with highly adaptability and greater nutrient removal efficiency
- Theories and techniques for optimal physical-plant-microbe combinations with efficient purification capacity
- Sustainable management of constructed purification plant-ecosystem and reuse of bio-resources.
- Diagnosis and prediction of watershed ecosystem health and nutrient balance

Screening and identification of efficient plant species

- Submerged plant species
- Floating plant species
- Emergent plant species
- Annual and perennial grasses
- Vegetable plant species
- Energy plant species

Selected efficient plant species

Thalia dealbata）

Rapid accumulation rate of 55g/day for DM， 2.3g/d for N， and 0.2g/d for P

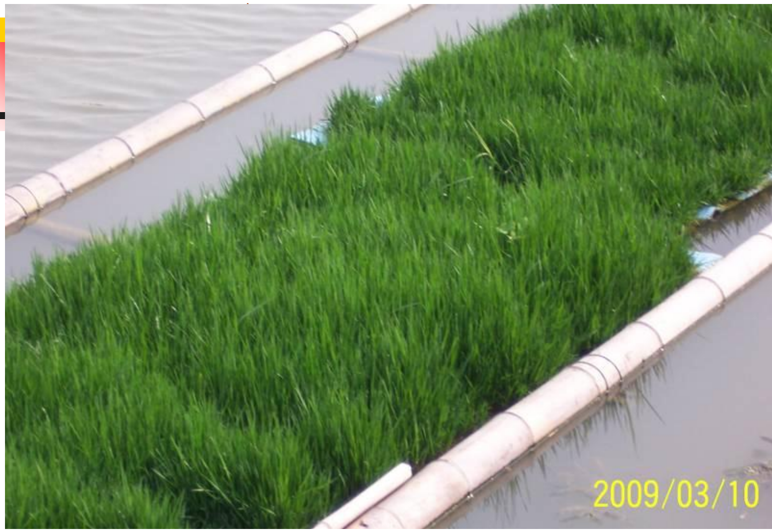
（Pontederia cordata L.）

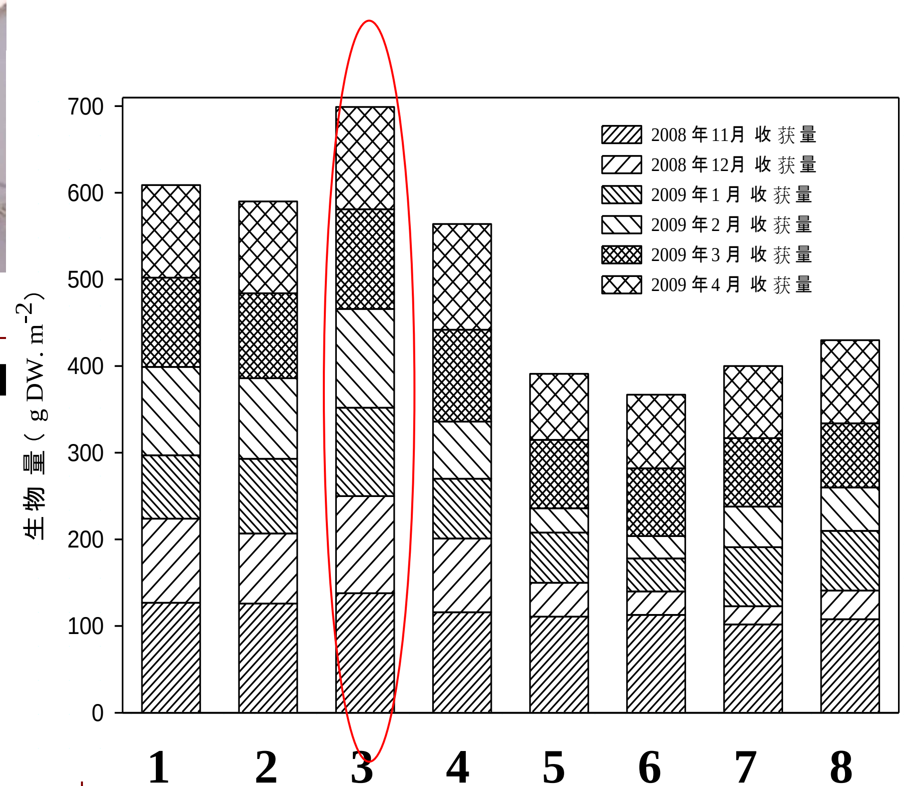
Rapid accumulation rate of 31g/day for DM， 0.8g/d for N， and 0.1g/d for P

Yang et al (2008)

Growth and nutrient removal of different perrennial grasses floating grown on eutrophic water

J Environ Sci & Tech)



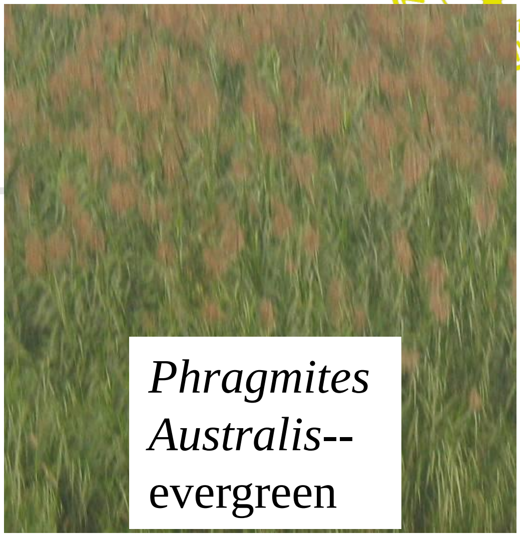


1- ***Geophila herbacea*** **(L) O Kumtze,GH**
2-Lolium perenn **Caddieshack，LCC**
3- ***Lolium perenne*** **Topone，LPT**
4-Lolium perenne **respect，LPR**
5- ***Lolium perenn*** **fairway，LPF**
6- ***Phalaris tuberose*****，PT**
7-Phleum pratense**，PP**
8-Lolium perenne **L，LPL**

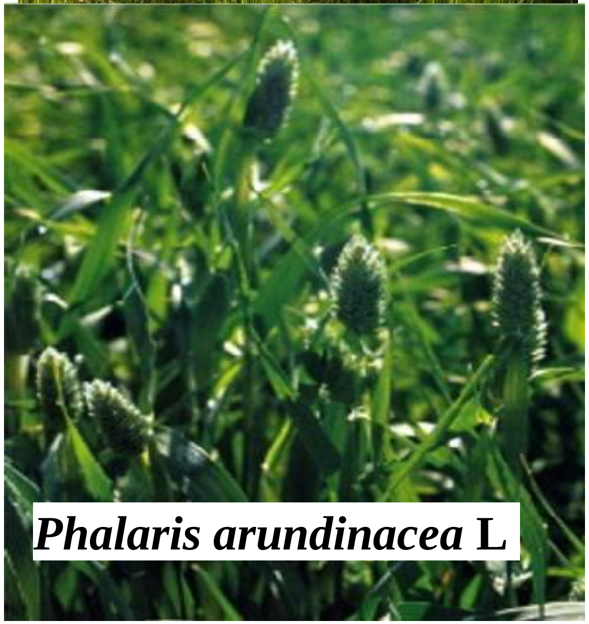
Others special plant genotypes identified

Vetiveria zizanioides

S.sagittifolia Linn



Phragmites Australis--evergreen

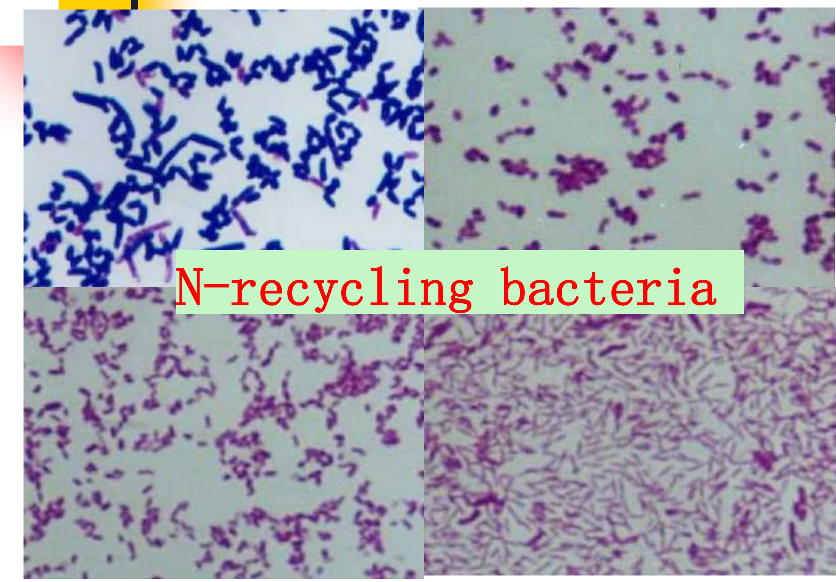


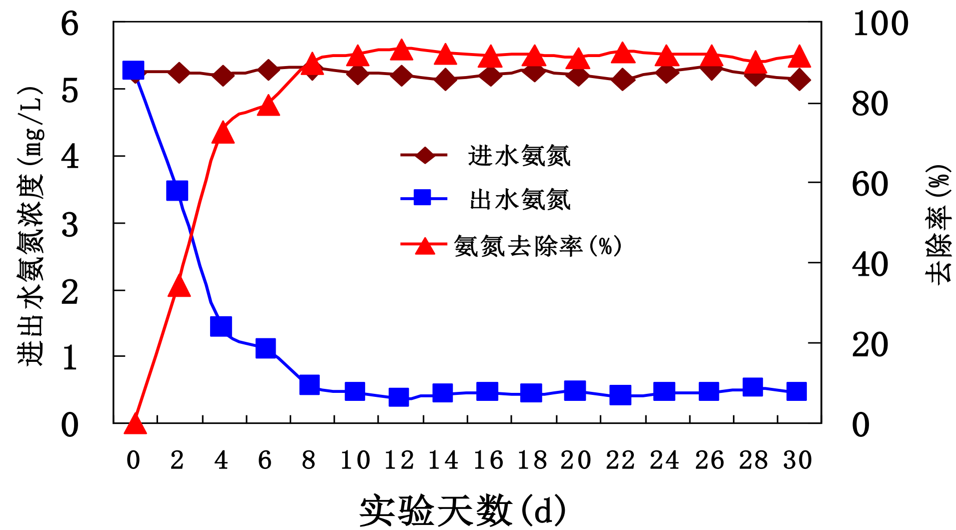
Phalaris arundinacea **L**

Romax

Oenanthe javanica(Bl.)DC

Effcient N recycling microbes isolated from Lake Taihu sediment (Pu et al., 2005)

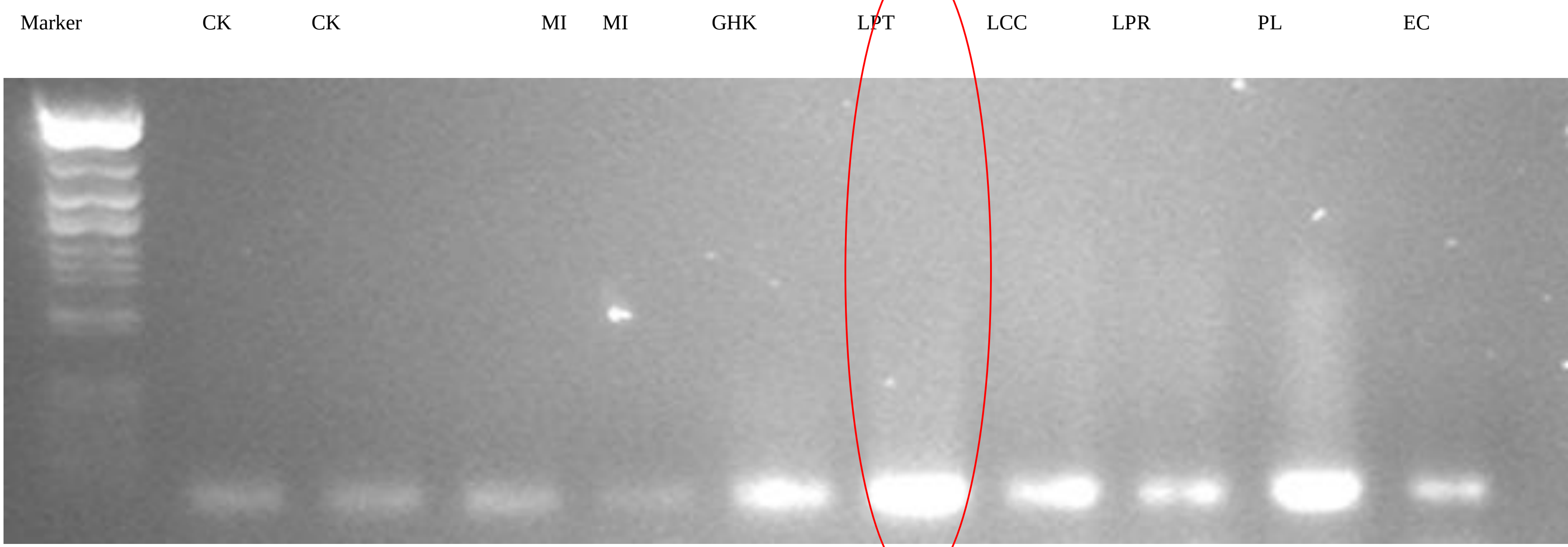




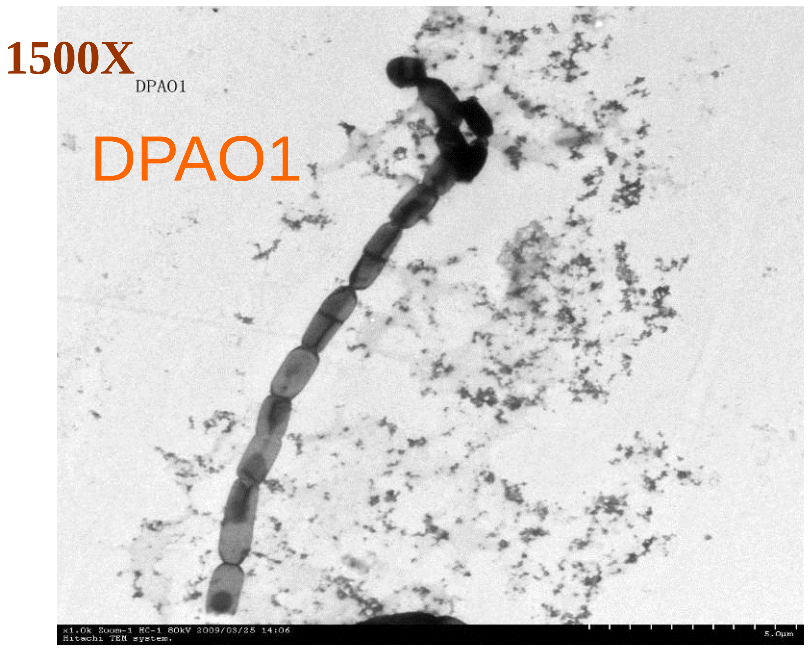
Inoculate microbes enhance N removal

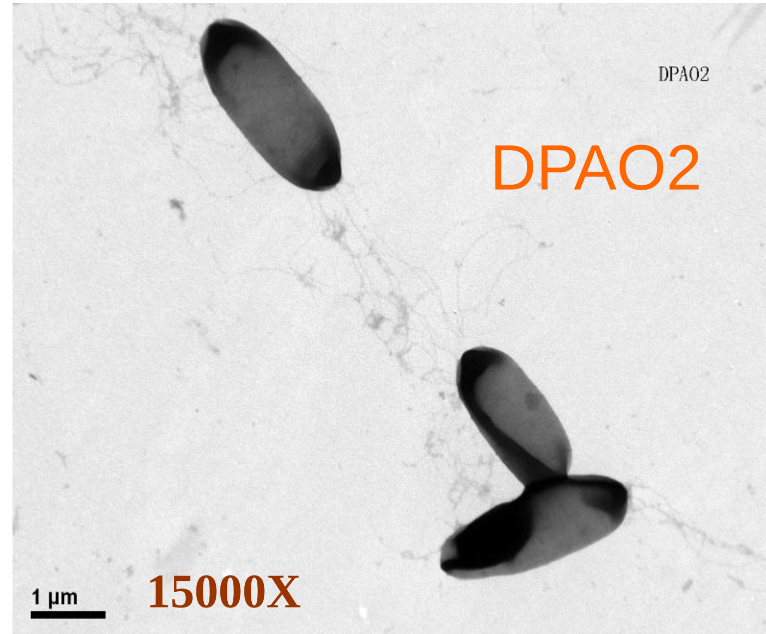
Identification of N-denification and P-accumulating micobes from efficient plant rhizosphere

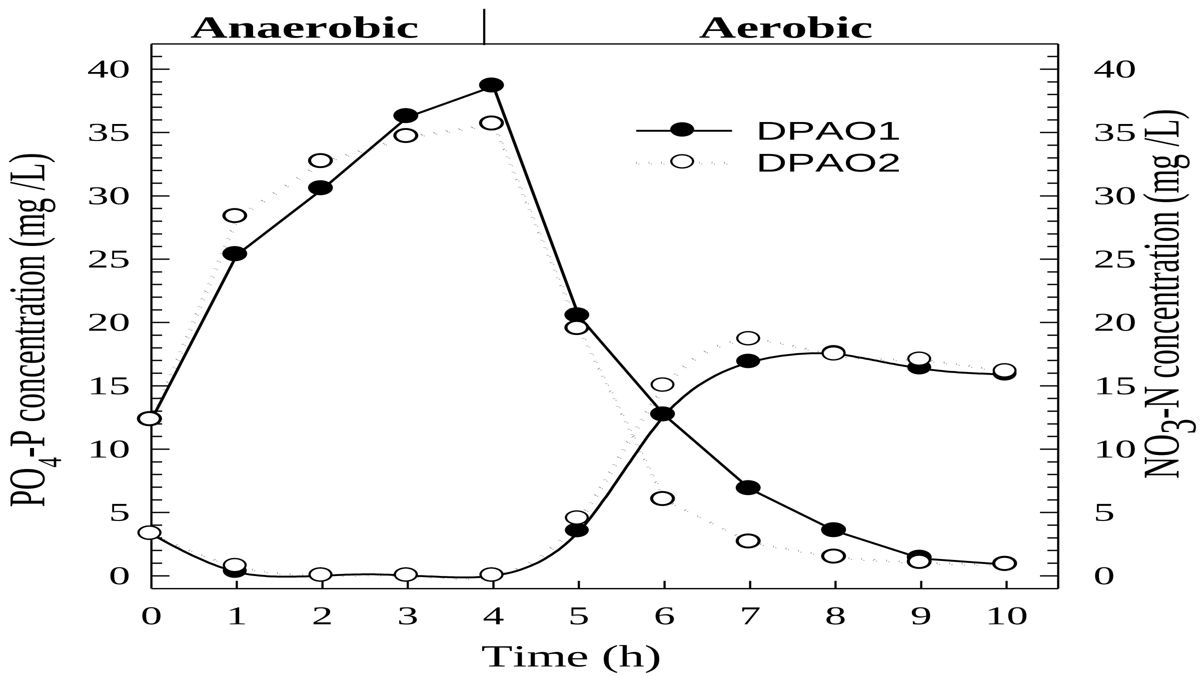
- Selection of special microbes from eutrophic water or efficient plant rhizosphere



Changes of microorganism total DNA with different plant treatment. MI- microbe inhabitor; GHK-*Geophila herbacea (L) O Kumtze*; LPT-*Lolium perenne Topone*: LCC-LPT-*Lolium perenne Caddieshack;* LPR-*Lolium perenne respect*: PL-*Pistia stratiotes L*; EC-*Eichhornia crassipe*


1500X
DPAO1
DPAO1


DPAO2
DPAO2
1 μm
15000X


Anaerobic
Aerobic
DPAO1
DPAO2
PO4-P concentration (mg /L)
NO3-N concentration (mg /L)
Time (h)
0
5
10
15
20
25
30
35
40
0
1
2
3
4
5
6
7
8
9
10

•16S rDNA sequence of DPAO1:1431 bp

TGCAAGTCGAGCGAATGGATTGAGAGCTTGCTCTCAAGAAGTTAGCGGCGGACGGGTGAGTAACACGTGGGTAACCTGCCCATAAGACTGGGAT
AACTCCGGGAAACCGGGGCTAATACCGGATAACATTTTGAACTGCATGGTTCGAAATTGAAAGGCGGCTTCGGCTGTCACTTATGGATGGACCCG
CGTCGCATTAGCTAGTTGGTGAGGTAACGGCTCACCAAGGCAACGATGCGTAGCCGACCTGAGAGGGTGATCGGCCACACTGGGACTGAGACAC
GGCCCAGACTCCTACGGGAGGCAGCAGTAGGGAATCTTCCGCAATGGACGAAAGTCTGACGGAGCAACGCCGCGTGAGTGATGAAGGCTTTCG
GGTCGTAAAACTCTGTTGTTAGGGAAGAACAAGTGCTAGTTGAATAAGCTGGCACCTTGACGGTACCTAACCAGAAAGCCACGGCTAACTACGTG
CCAGCAGCCGCGGTAATACGTAGGTGGCAAGCGTTATCCGGAATTATTGGGCGTAAAGCGCGCGCAGGTGGTTTCTTAAGTCTGATGTGAAAGCC
CACGGCTCAACCGTGGAGGGTCATTGGAAACTGGGAGACTTGAGTGCAGAAGAGGAAAGTGGAATTCCATGTGTAGCGGTGAAATGCGTAGAGA
TATGGAGGAACACCAGTGGCGAAGGCGACTTTCTGGTCTGTAACTGACACTGAGGCGCGAAAGCGTGGGGAGCAAACAGGATTAGATACCCTGG
TAGTCCACGCCGTAAACGATGAGTGCTAAGTGTTAGAGGGTTTCCGCCCTTTAGTGCTGAAGTTAACGCATTAAGCACTCCGCCTGGGGAGTACG
GCCGCAAGGCTGAAACTCAAAGGAATTGACGGGGGCCCGCACAAGCGGTGGAGCATGTGGTTTAATTCGAAGCAACGCGAAGAACCTTACCAGG
TCTTGACATCCTCTGAAAACCCTAGAGATAGGGCTTCTCCTTCGGGAGCAGAGTGACAGGTGGTGCATGGTTGTCGTCAGCTCGTGTCGTGAGAT

Strains	The closest type of colonies from BLAST reports	Similarity(%)
DPAO 1	*Bacillus sp.*	99%
DPAO2	*Microbacterium sp*	99%

TCACCGCAGCGTTGCTGATCTGCGATTACTAGCGACTCCGACTTCATGAGGTCGAGTTGCAGACCTCAATCCGAACTGGGACCGGCTTTTTGGG
ATTCGCTCCACCTCACGGTATTGCAGCCCTTTGTACCGGCCATTGTAGCATGCGTGAAGCCCAAGACATAAGGGGCATGATGATTTGACGTCAT
CCCCACCTTCCTCCGAGTTGACCCCGGCAGTATCCCATGAGTTCCCACCATTACGTGCTGGCAACATAGAACGAGGGTTGCGCTCGTTGCGGG
ACTTAACCCAACATCTCACGACACGAGCTGACGACAACCATGCACCACCTGTTTACGAGTGTCCAAAGAGTTGACCATTTCTGGCCCGTTCTCGT
ATATGTCAAGCCTTGGTAAGGTTCTTCGCGTTGCATCGAATTAATCCGCATGCTCCGCCGCTTGTGCGGGTCCCCGTCAATTCCTTTGAGTTTTA
GCCTTGCGGCCGTACTCCCCAGGCGGGGAACTTAATGCGTTAGCTGCGTCACGGAATCCGTGGAATGGACCCCACAACTAGTTCCCAACGTTT
ACGGGGTGGACTACCAGGGTATCTAAGCCTGTTTGCTCCCCACCCTTTCGCTCCTCAGCGTCAGTTACGGCCCAGAGATCTGCCTTCGCCATC
GGTGTTCCTCCTGATATCTGCGCATTCCACCGCTACACCAGGAATTCCAATCTCCCCTACCGCACTCTAGTCTGCCCGTACCCACTGCAGGCCC
GAGGTTGGGCCTCGGGATTTCACAGCAGACGCGACAAACCGCCTACGAGCTCTTTACGCCCAATAATTCCGGATAACGCTTGCGCCCTACGTAT
TACCGCGGCTGCTGGCACGTAGTTAGCCGGCGCTTTTTCTGCAGGTACCGTCACTCTCGCTTCTTCCCTGCTAAAAGAGGTTTACAACCCGAAG
GCCGTCATCCCTCACGCGGCGTTGCTGCATCAGGCTTCCGCCCATTGTGCAATATTCCCCACTGCTGCCTCCCGTAGGAGTCTGGGCCGTGTC
TCAGTCCCAGTGTGGCCGGTCACCCTCTCAGGCCGGCTACCCGTCGACGCCTTGGTGAGCCATTACCTCACCAACAAGCTGATAGGCCGCGAG
CCCATCCCCAACCGAAAAATCTTTCCAAACGCAGACCATGCGGTCACGTCACATATCCAGTATTAGACGCCGTTTCCAGCGCTTATCCCAGAGTC
AGGGGCAGGTTGCTCACGTGTTACTCACCCGTTCGCCACTGATCCACAAGAGCAAGCTCCTGCTTCACCGTTCGACTTGCATGTGTTAAGCACG
CCGCCAGCGTTCATCCTGAGCCAGGATCAAACTCTAATCACTAGTGAATTCGCGGCCGCCTGCAGGTCGACCATATGGGAGAGCTCCCAACGC
GTGAGCATTTT

Maintaining efficient purification all year round by means of plant rotation and intercropping

- **Oenanthe javanica(Bl.)DC ---Ipomoea aquatica Forsk**
- ***Lolium perenne* ----*Eichhornia crassipe***
- **Beta vulgaris var cicla---- *Pistia stratiotes L.***

Intercropping of different season plants for year round purification

香根草*Vetiveria zizanioides* –黄花水龙**Jussiaea stipulacea Ohwi**

再力花*Thalia dealbata*—聚草*Myriophyllum aquaticum*

美人焦*Canna generalis*—钱币草*Hydrocotyle verticillata*

Principles of combination

- Season compensation
- Space compensation
- Nutrients removal compensation
- Bio control of plant health

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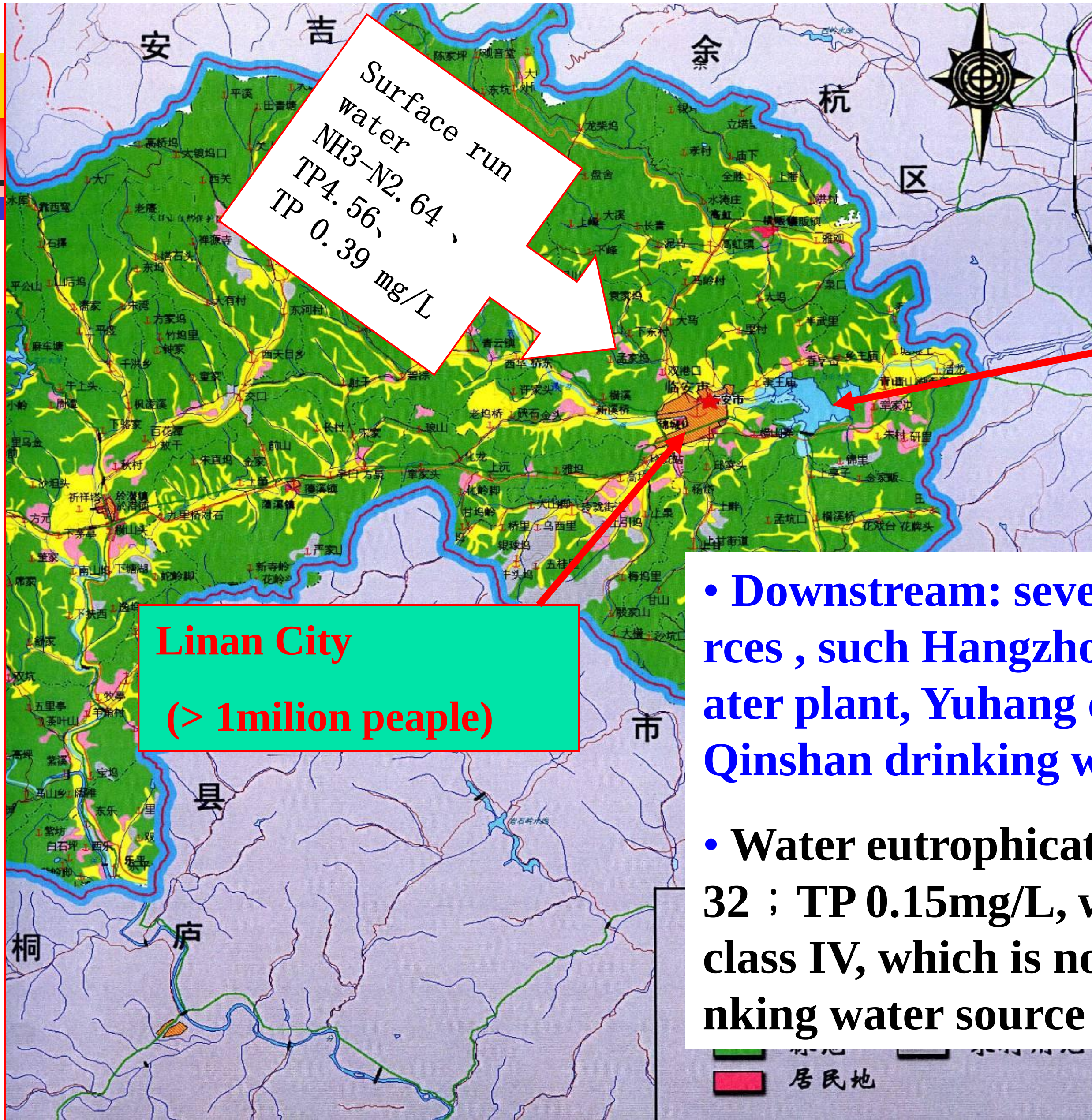
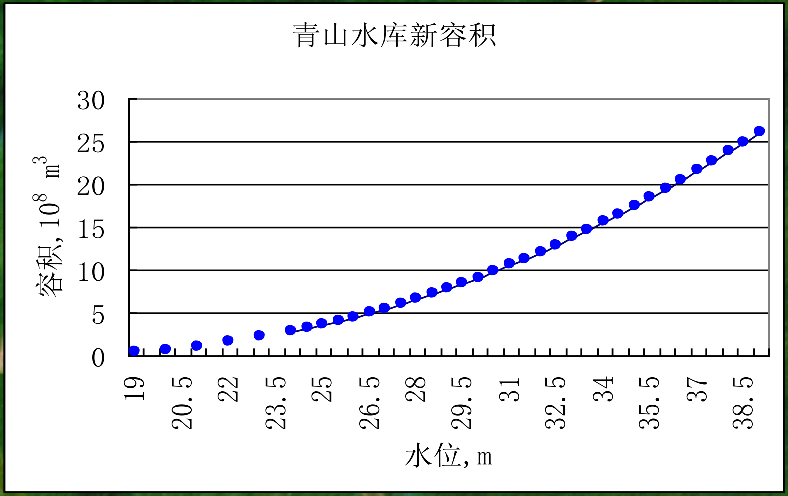
- Backgrounds
- Technologies for remediating water eutrophication
- Key issues for phytoremediation engineering of eutrophic water and resources reuse
- **Some demonstration cases of practical application**
- Conclusion

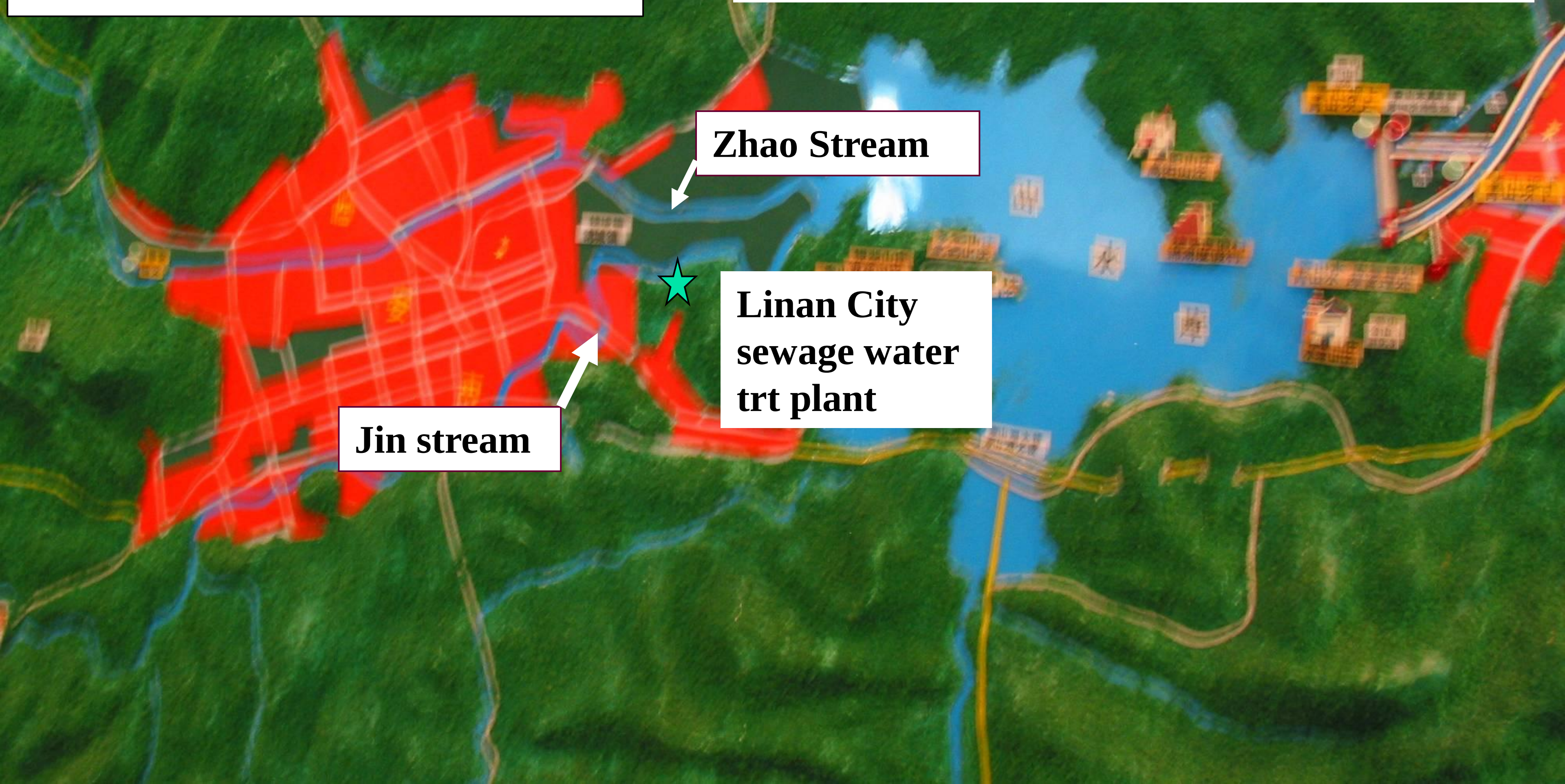
Case 1----Phytoremediation engineering of secondary discharge of sewage water Trt Plant in Linan City



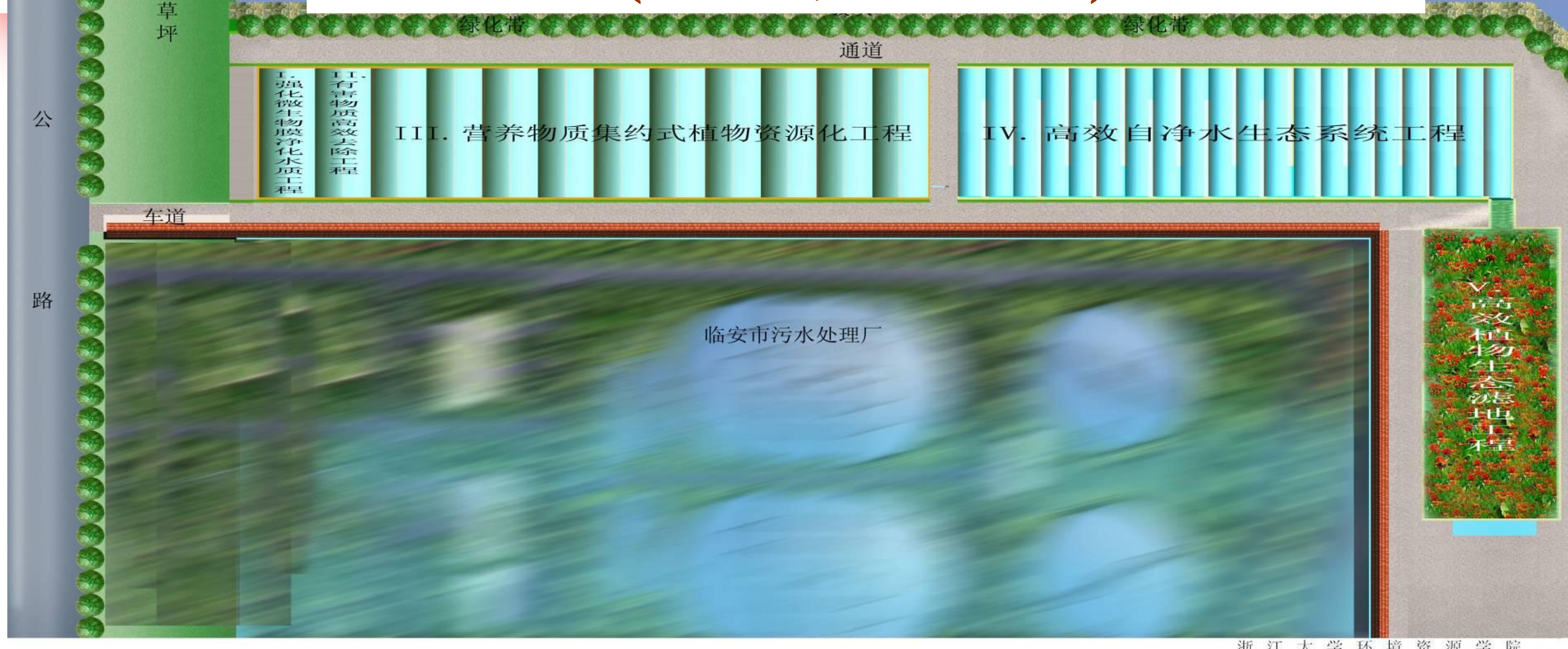
- **Downstream: several drinking water sources , such Hangzhou Xiangfu drinking water plant, Yuhang drinking water plant; Qinshan drinking water plant etc**
- **Water eutrophication: in 2003 NH_3-N 3.32；TP 0.15mg/L, water quality of above class IV, which is not meet the need of drinking water source criteria**



- **Normal water surface area9.5 km^2， wet-dry area11 km^2**
- **Normal water depth 25 m and highest water depth 34 m， with 9 m difference**



Design of phytoremediation engineering for N and P removal of secondary discharge water (Phase I, 3000 ton/d)



The plant-ecosystem was built in August 2006 composed of five subsystems. The total function plot area is 3675m2, water retention time in the system is 1.6 d. Water flow was designed according natural hydraulic power without using electronic energy。

Five subsystems and major functions

I. **Intensified microbial film (IMF)**

degradation, precipitation, and conversion by INCB or microbial film,

II. **Efficient toxicant removal (ETR)**

substrate-plant adsorption, absorption and retention of metals, POPs etc

III. **Collective nutrient phyto-transformation and resue (CNPTR)**

adsorption,absorption,and transformation by plants and rizomicrobes

IV. **Efficient self-purification aquatic ecosystem(ESPAE)**

restoration of natural aquatic eco-system for further decreasing nutrient concnetration

V. **Efficient phy-ecological filter (EPEF)**

Activating sand-plant-microbe interaction to further remove plant residual, COD and others.

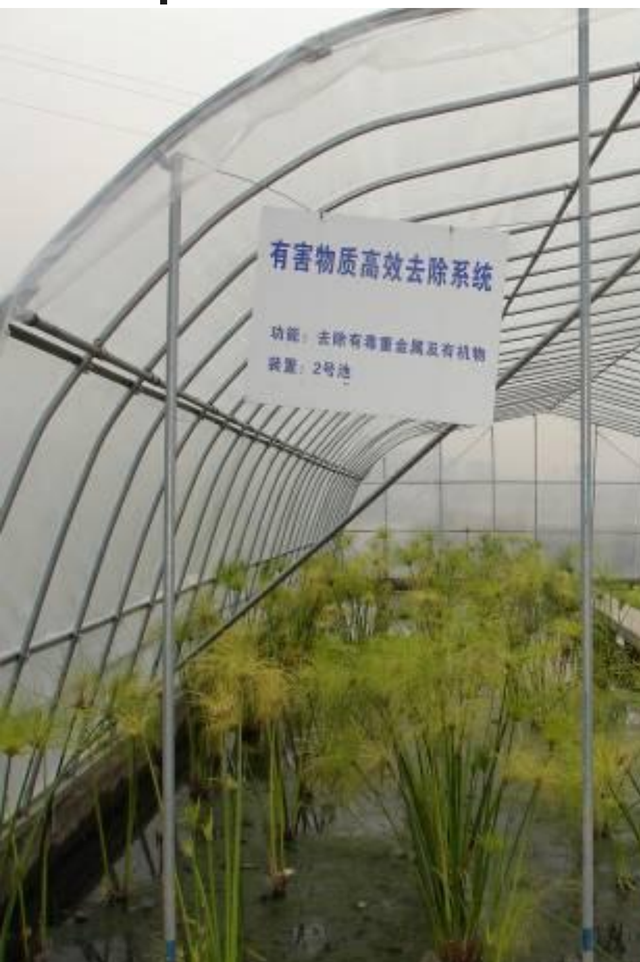
Before PR

Beginning of PREN （2006-05）

After PREN （2007-Present ）

Subsystem I: Intensified microbial film (IMF)（Microbe-substrate－rizo interaction）

Subsystem II **Efficient toxicant removal** (substrate—microbe—plant interaction)



Subsystem III **Collective nutrient phyto-transformation and resue**

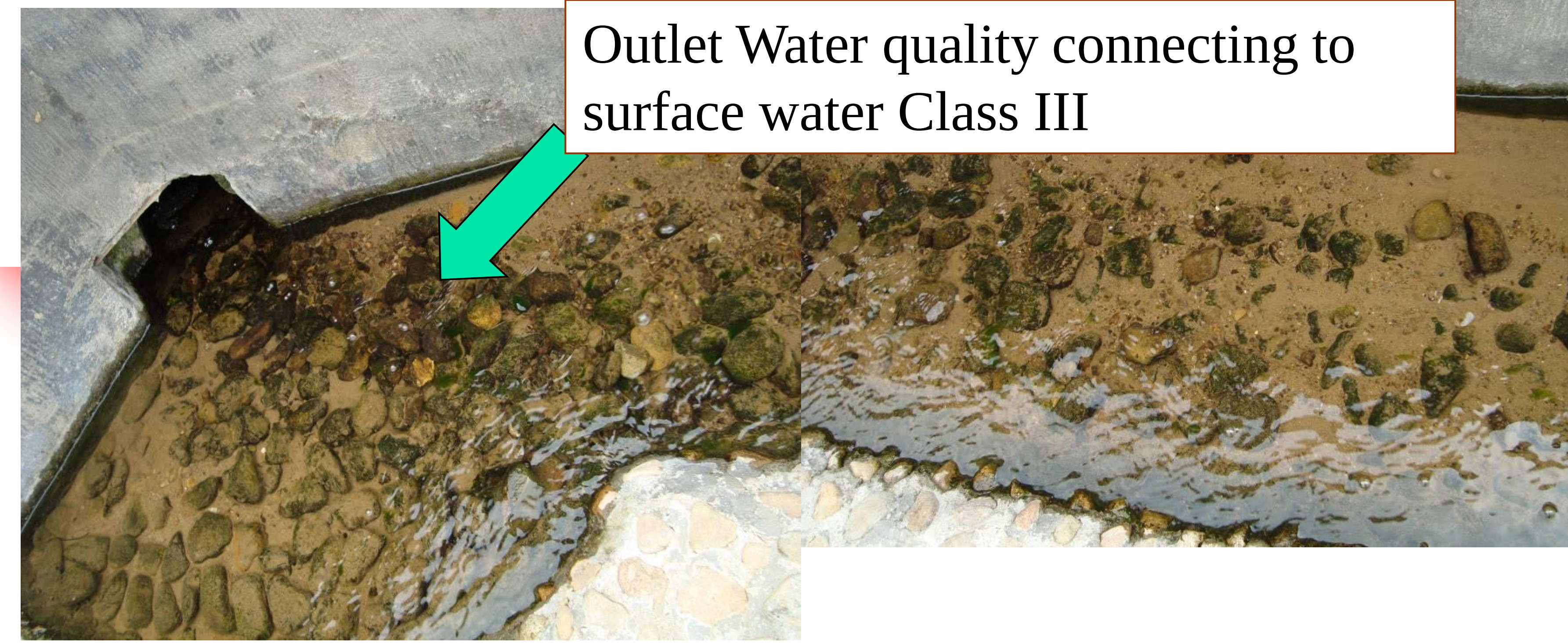
(floating island-plant-substrate-rhizo interaction)

Subsystem IV **Efficient self-purification aquatic ecosystem**

(plant-microbe-animal intercation)

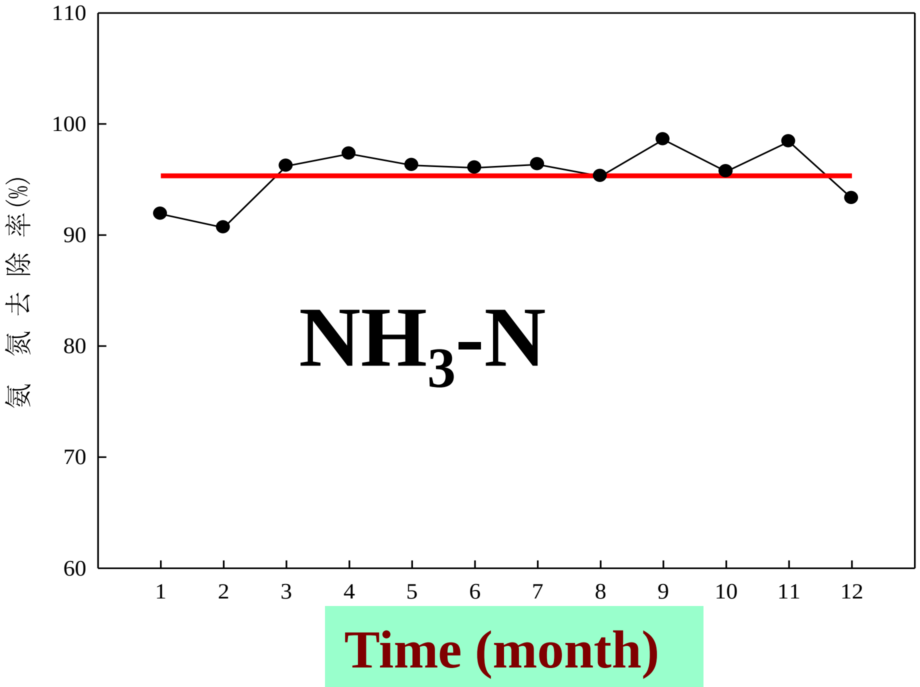
Subsystem V **Efficient physic-ecological filtrate** (physical-microbe-rhizo interaction)

Outlet Water quality connecting to surface water Class III

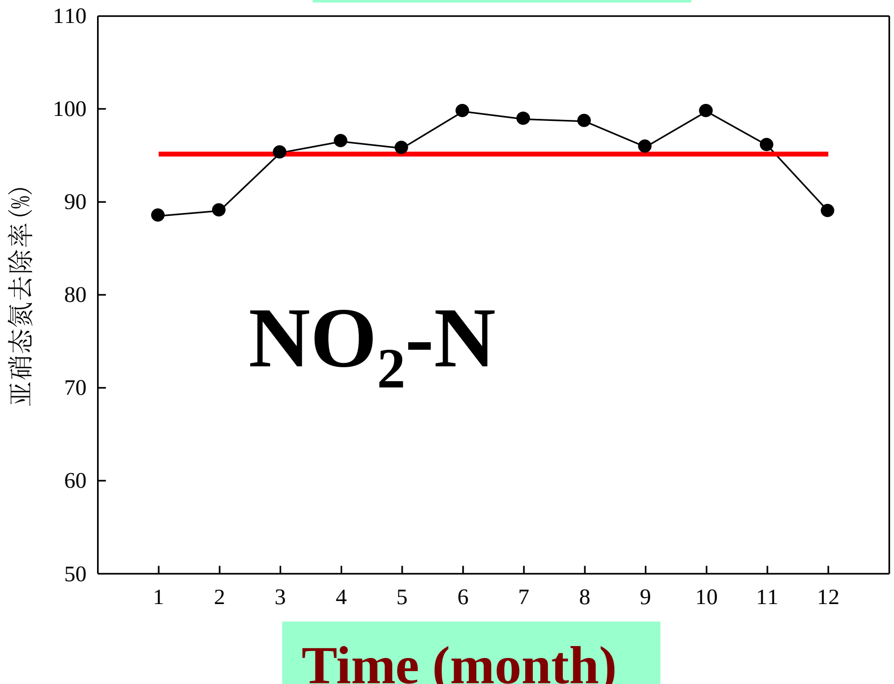


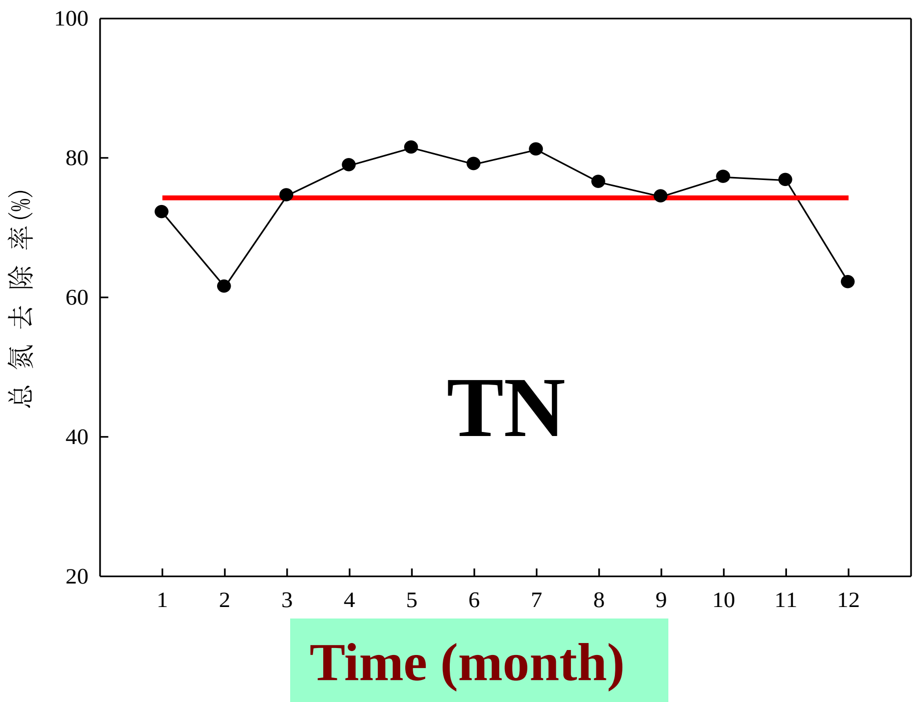
Discharge water quality---TN 12-15, TP 0.5-1.0; COD 80-100 mg/L

Effectiveness of N Removal

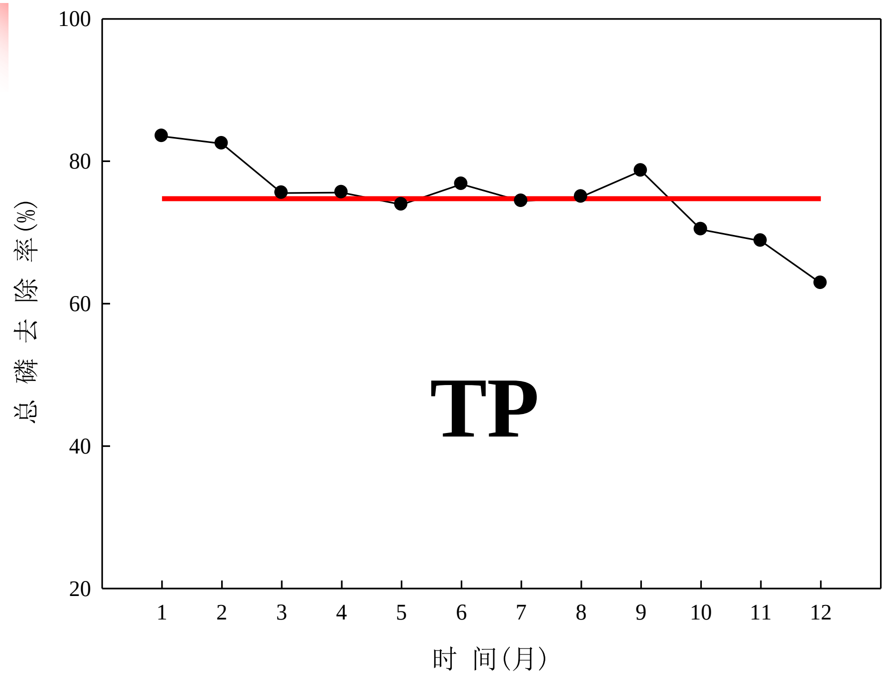


>Highest NO_2-N removal of 99%， with average being 95%
>Highest NH_3-N removal of 98%， with average being 95%；
>Highest TN removal of 81%,average of 75%

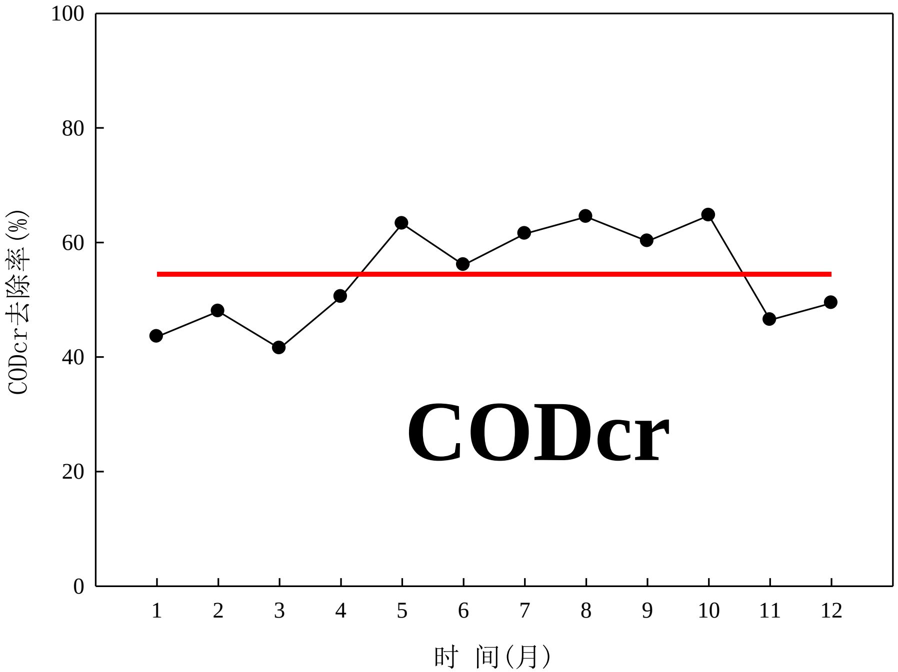




Effectiveness of TP and CODcr Removal



Time (month)



Time (month)

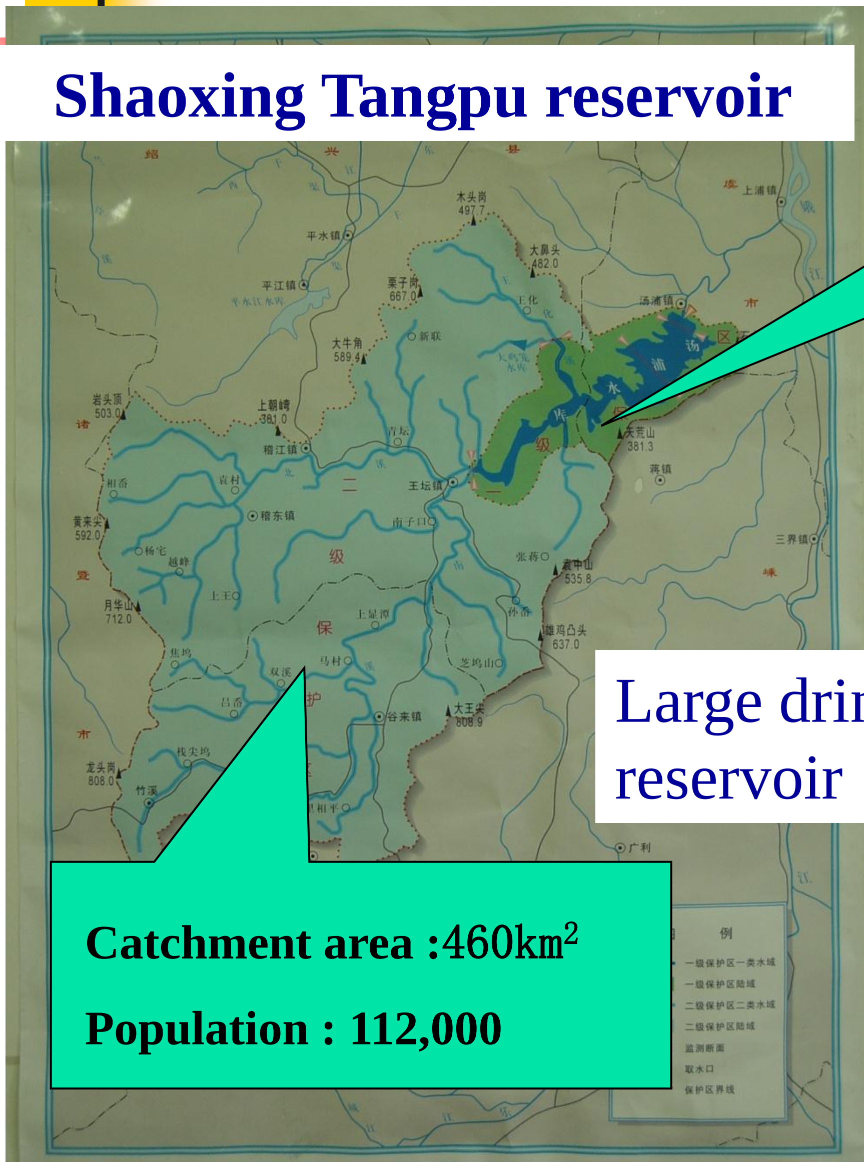
- **Highest P removal of 82.5%，average being 74.6%**
- **Highest CODCr reduction of 64%, average being54%**

Removal of toxic metals from the effluent

Metal	Winter season (μg/L)			Summer season (μg/L)		
	inlet	outlet	Reduced(%)	Inlet	Outlet	Reduced（%）
Hg	2.39	0.98	58.9	3.31	1.09	67.0
Cr	4.62	1.25	72.9	3.75	1.15	69.3
As	3.89	1.45	62.7	3.67	1.36	62.9
Cd	0.10	0.04	60.0	0.25	0.06	76.0
Pb	0.26	0.06	76.9	0.36	0.05	86.1

Phase II: PREN of deep cleaning secondary discharge of Sewage Water Trt Plant of Linan City (60,000 tons/d)

Case 2: Phytoremediation engineering of pre-treatment wetlands in wet-dry areas of reservoir to abate nutrients loading into water body



Shaoxing Tangpu reservoir

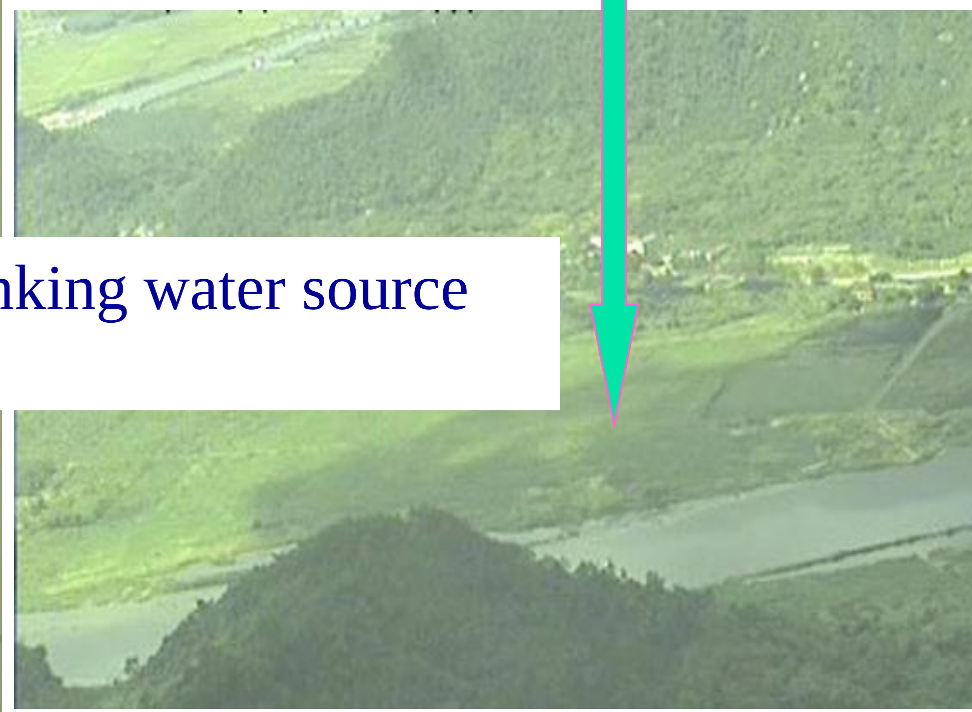
TN >2mg/L

TP:0.03 mg/L

Catchment area :460km^2

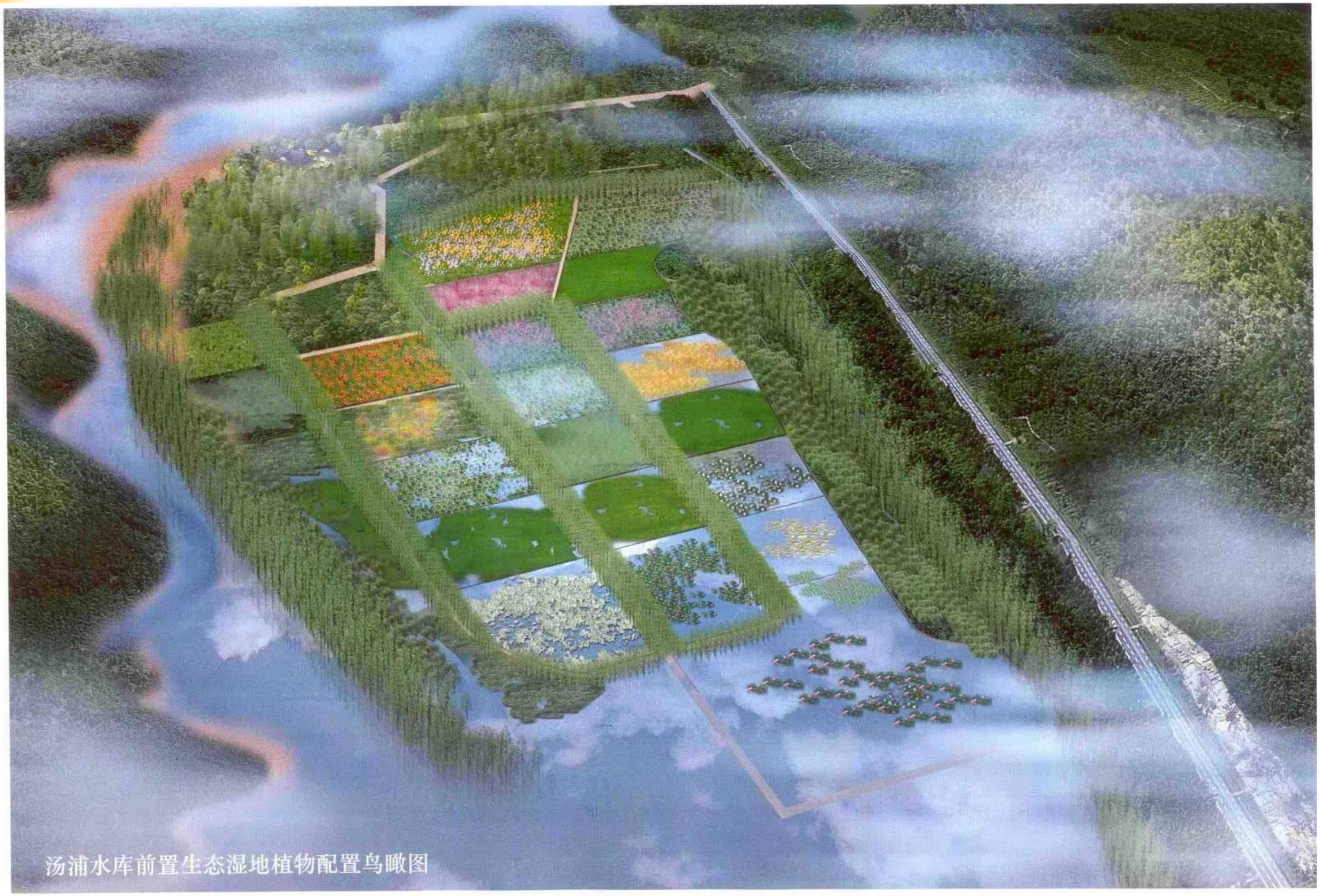
Population : 112,000

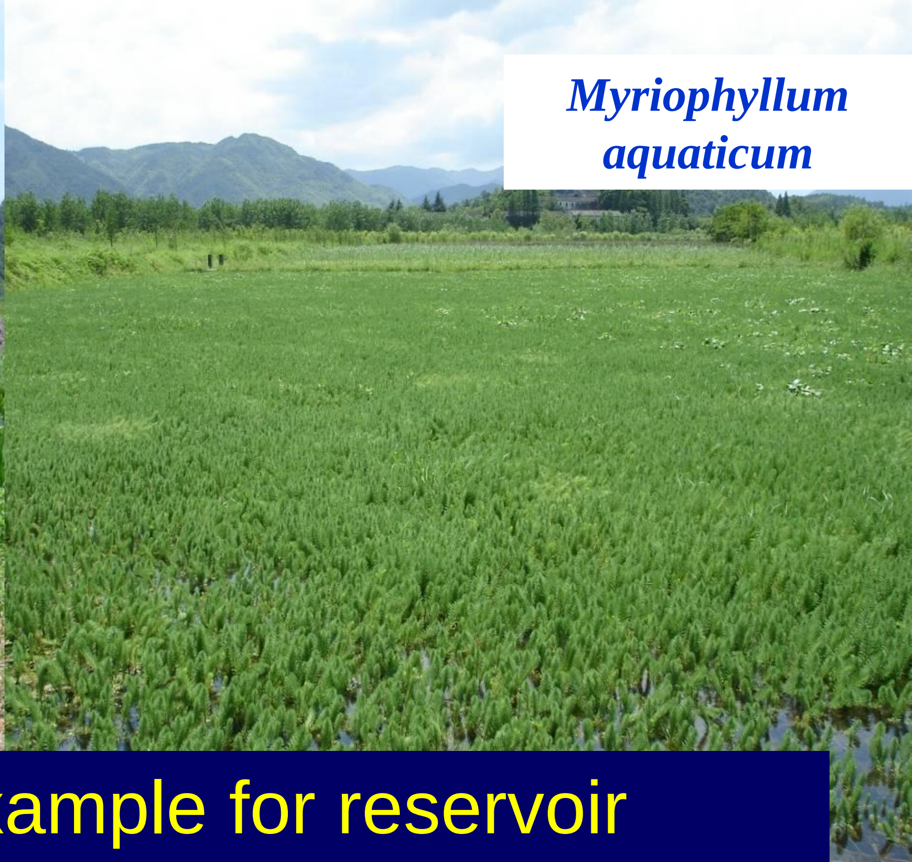
Use wet-dry area s land to construct trt weland with high purification capacity



Large drinking water source reservoir

Design of constructed treatment wetland for removing N and P from non-point pollution





Has become a best example for reservoir eutrophication protection by Ministry of Water Resources of China !

Removal of pollutants by the wetlands

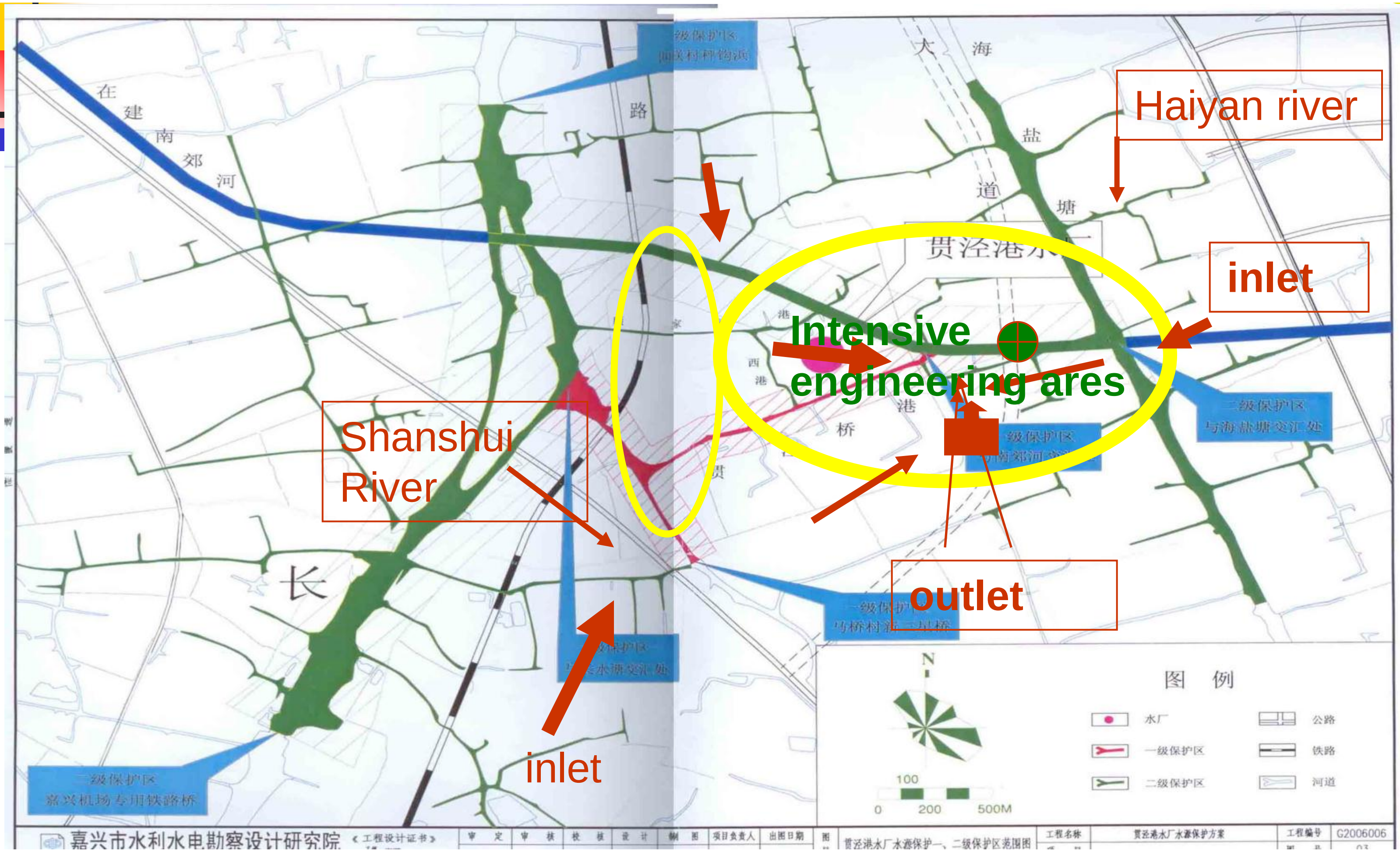
Parameters	2007-7-16			2007-7-31			2007-8-16			2007-8-31		
	Inlet	Outlet	Rem（%）	In	OutT	REM率（%）	In	Out	Rem（%）	In	Out	Rem（%）
NO_3-N (mg/L)	3.271	1.261	61.45	2.446	1.121	54.17	3.066	1.477	51.83	2.878	1.246	56.71
NH_3-N (mg/L)	0.611	0.128	79.05	0.539	0.023	95.73	0.396	0.080	79.72	0.513	0.036	92.98
NO_2-N (mg/L)	0.083	0.018	78.26	0.038	0.008	78.836	0.043	0.002	95.35	0.03	0.006	80.00
TN (mg/L)	4.408	1.487	66.26	3.423	1.242	63.71	3.605	1.112	69.15	4.221	1.348	68.06
TP (mg/L)	0.151	0.0830	45.11	0.1629	0.106	35.18	0.152	0.0945	37.83	0.182	0.123	32.42

PREN in Changtan Reservoir of Tanzhou

PREN in Jiaoku Reservoir of Ningbo

PREN in Yangxi Reservoir of Jinhua

Case III: PREN of cleaning eutrophic water for drinking water source in water-net area
--Jiaxing Guanjinkua drinking water plant



Phase I -100,000 tons/d
Phase II- 600,000 tons/d,


Before PREN
Before PREN
Before PREN
Water quality > Class V

[redacted]

[redacted]

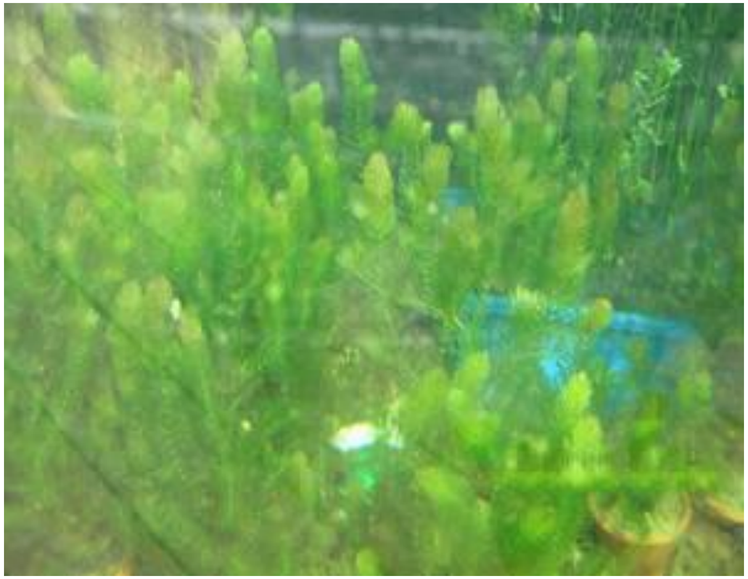
After PREN

III 生物栅净化系统

Subsystem I: Bio-physical sieving

SubsystemII-III: Intensive floating eco-island purification

Sub-system IV; Sunmerged plant dominated efficient aquatic ecosystem purification

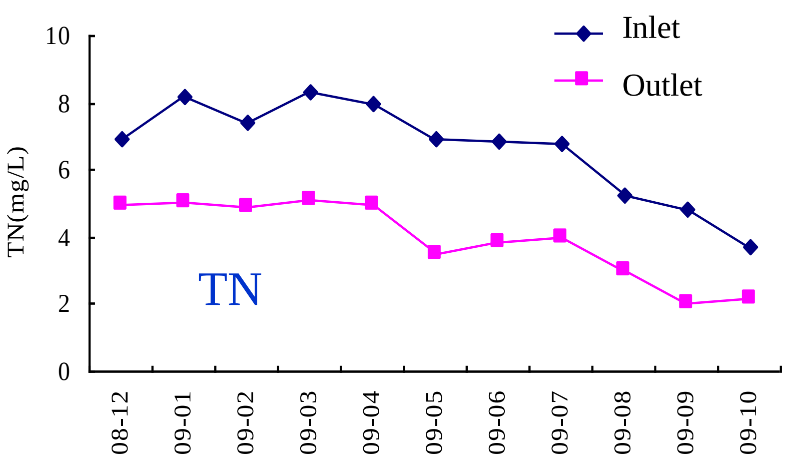


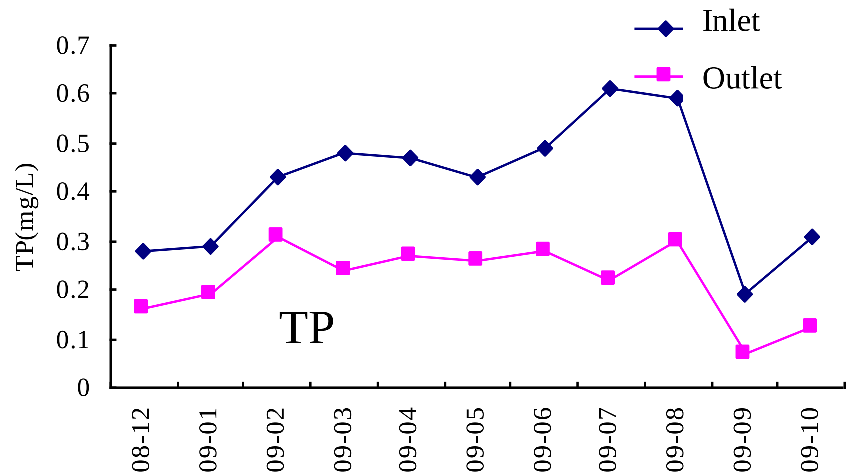
沉水植被实景图

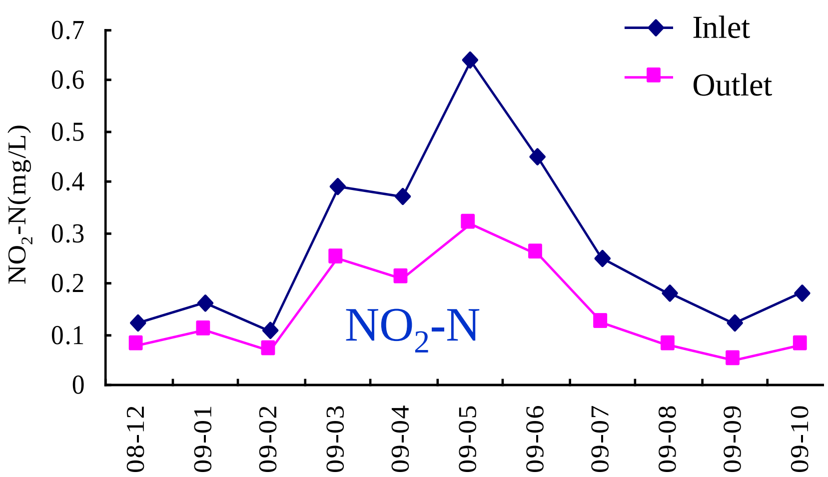
Subsystem V: Bio-physical filter deep purification

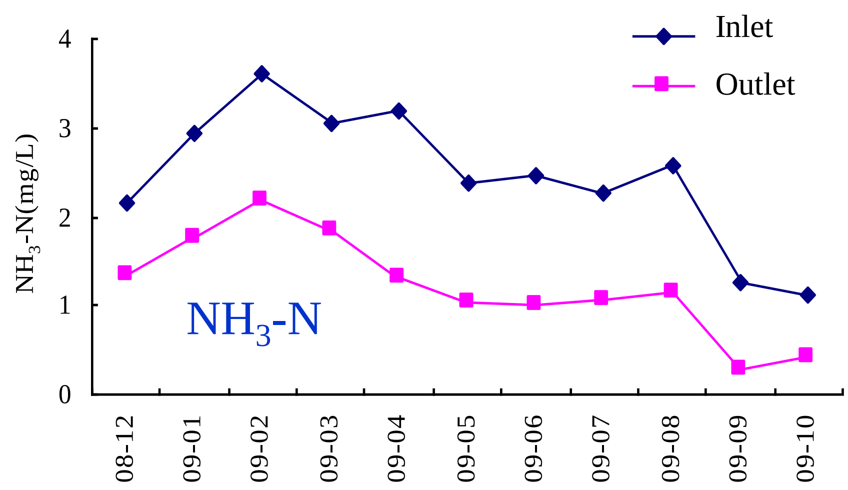
physical substrate-plant–microbe optimal combination

Monitoring of water quality and effectiveness





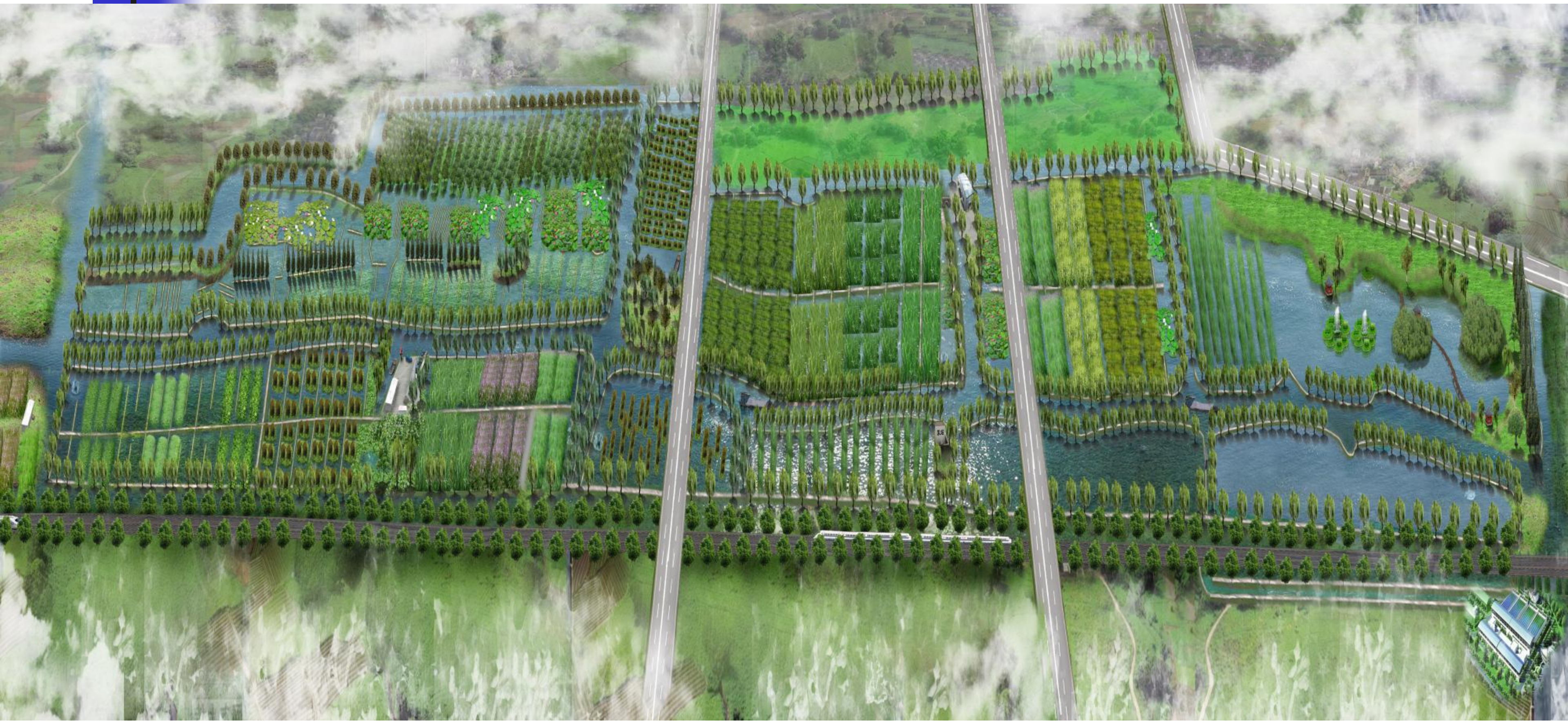




Removal of selected heavy metals, SS, and *E. coli* by constructed floating eco-islands

Item	Cr	Cu	As	Cd	Hg	Pb	SS	*E.coli*
	ng/L	ng/L	ng/L	ng/L	ng/L	ng/L	mg/L	cfu/ml
Inlet	0.38	10.06	2.02	undetected	0.29	0.24	9.70	3500
Outlet	0.05	4.51	1.15	undetected	0.16	0.11	4.50	1000
Removal (%)	86.8	55.1	42.9	-	43.9	54.2	53.6	71.4

PREN of cleaning drinking water source from Changsui river at Jiaxing Haining (300,000ton/d)---Invest 240 mi Yuan



Conclusions and perspectives

- **Phytoremediation engineering of N and P polluted water is an effective strategy for controlling water eutrophication. This technology is based on theories of nutritional ecology and recycling economy, with advantages of being low cost, sustainable, and environmental and ecological sound.**

- **Identification and creation of both physical and biological materials (such as substrate materials, special higher and lower plant genotypes, as well as microbes) with high efficiency of purification and wider adaptation (water logging, cold, heat, nutrient imbalance stress etc) are the among most important issues to be further investigated..**

- **Harvesting and reuse of engineering plants is an important component in efficient and sustainable phytoremediation engineering. More researches and demonstrations are needed to PREN of water eutrophication in combination with bioenergy production on watershed scale.**

Acknowledgements

- **Financial Supports**: Ministry of Sci & Tech of China; Bureax of Sci & Tech of Zhejiang; Ministry of Education of China
- **Cooperators:** Pu Peiming; Wang Guoxiang; Wang Wencheng; Li Jianping; Xiaozhong wang; Zhenli He; P.J. Stoffella; Zed Rengle; etc
- **Students:** Jinbin Xiong; Yunying Fang; Huiqin Chang; Jinbo Cai; Xuefeng Ding; Hong Li; Fengliang Zhao;

Thanks for your attention !