再生水补给河湖生态修复与风险控制关键技术研究与集成示范

Study and Pilot on Key Technologies of Ecological Restoration and Risk Control of Reclaimed Water Supply in Rivers and Lakes

北京市水科学技术研究院

Beijing Water Science & Technology Institute

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PART ONE

Basic Situation

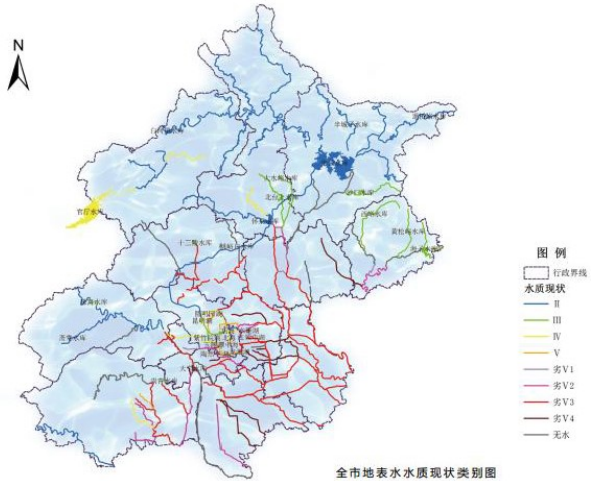
研究背景（Background）

北京市是典型“人多、水少”的资源型缺水城市，水资源仍是制约经济社会可持续发展的主要瓶颈。

Beijing is a typical water-deficient city with “huge population and limited water”, and water resources are still the main bottleneck restricting the sustainable development of economy and society.

- **缺水河流的水生态改善压力大。2014年有水河长占全市监测河段的92%，但其中超过一半的河流水质不达标，41%的劣V类。**
- There is great pressure on the improvement of water ecology in water-deficient rivers. In 2014, the rivers with water accounted for 92% of the monitored river sections in the city, but more than half of the rivers were substandard in water quality and 41% were inferior to Class V.

河段类别	河段（个）	河长（公里）	所占比例（%）
II类	24	959.1	40.8
III类	9	188.2	8.0
IV类	6	97.2	4.1
V类	6	127.7	5.4
劣V类	52	979.0	41.6



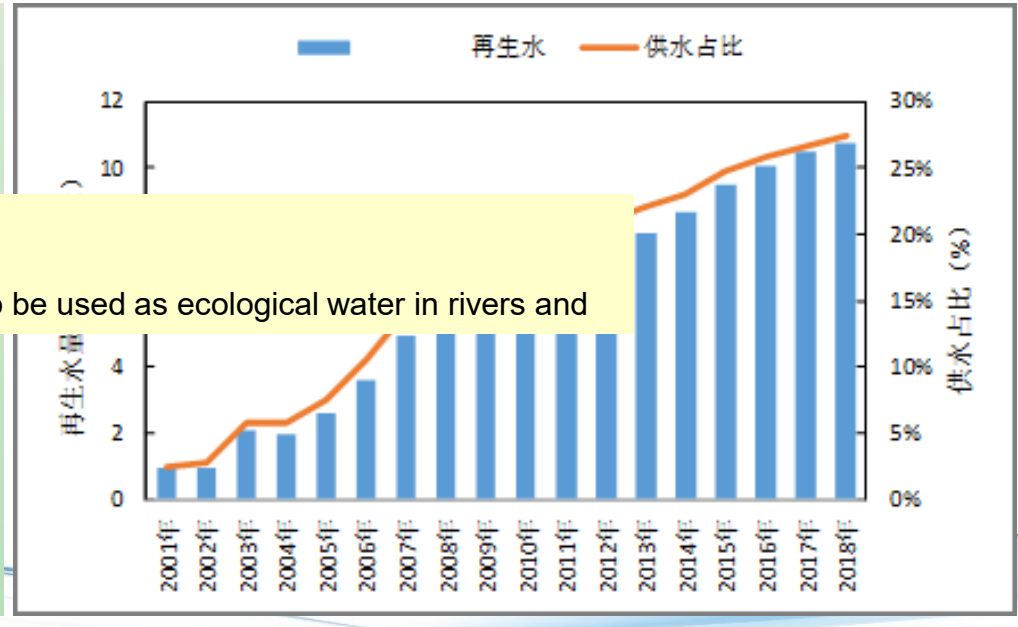
全市地表水水质现状类别图

研究背景（Background）

- **科技促进再生水可利用量增加。2014年全面启动再生水厂建设，再生水生产能力将得到大幅提升，主要出水指标达到地表水IV类。**
- Science and technology promotes the availability of reclaimed water. With the full start of the construction of reclaimed water plants in 2014, the production capacity of reclaimed water will be greatly increased, and the main effluent index will reach Surface Water Class IV.

再生水作为河湖生态用水的利用空间和潜力很大！

There is a huge space and potential for reclaimed water to be used as ecological water in rivers and lakes!



项目总体目标(OBJECT)

面向首都保障水资源可持续利用、改善河湖水环境质量的重大需求

Addressing the great needs of the capital to ensure the sustainable utilization of water resources and improve the environmental quality of rivers and lakes

再生水补给季节性河流的风险识别及源头-过程-末端监测技术方案

Risk identification and source-process-end monitoring technical scheme for reclaimed water recharged seasonal rivers

再生水补给型河道风险控制和水质保障集成技术体系

Integrated technical system of risk control and water quality guarantee for reclaimed water recharged rivers

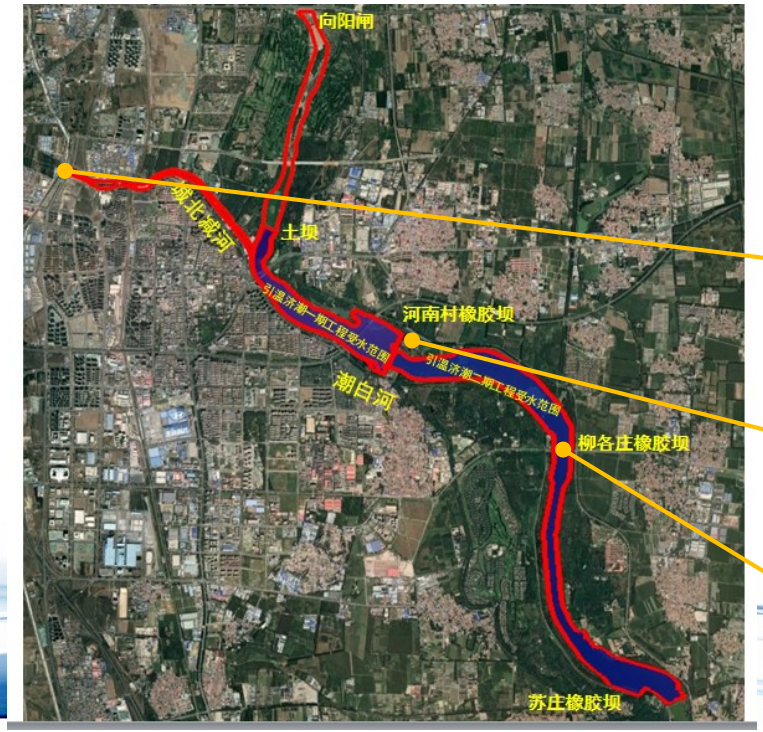
为推动全市再生水可利用量用足、生态功能提升、生态风险最小提供科学依据和决策支撑

Providing scientific basis and decision support for promoting the full use of reclaimed water, the improvement of ecological function and the minimization of ecological risk in the whole city

研究思路(IDEA)

2007年北京探索开展跨流域调水“引温济潮”

In 2007, Beijing explored to carry out inter-basin water transfer by “introducing water from Wenyu River to Chaobai River”

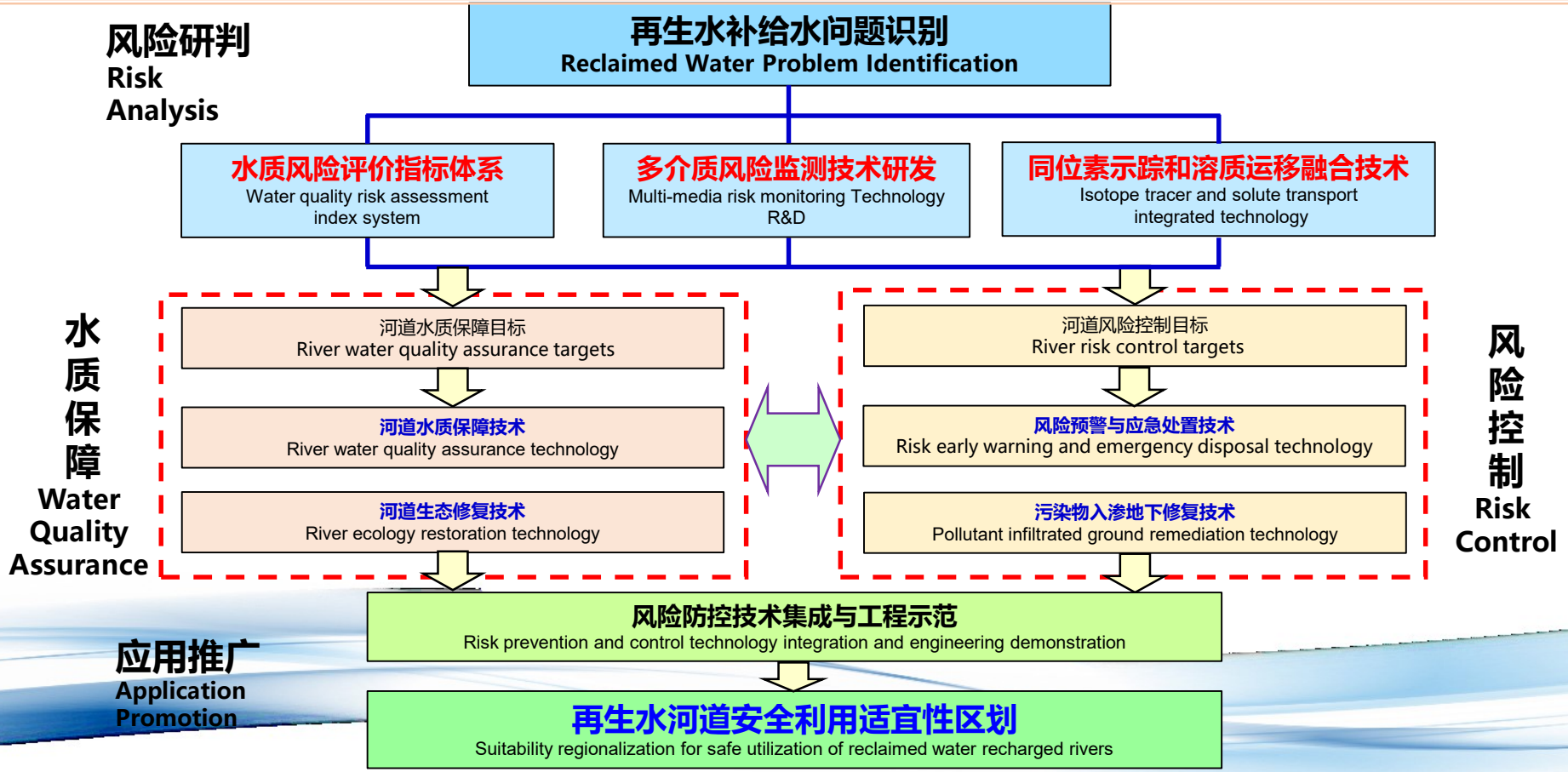


“引温济潮”试验成效还难以满足管理部门的推广需求和市民对再生水的安全质疑

The experimental effect of “introducing water from Wenyu River to Chaobai River” is still difficult to meet the promotional requirements of the authority and the public’s doubts about the safety of reclaimed water.

传统认识 Traditional cognition	主要特点 Main features	核心问题 Core issues
水化学风险 Hydrochemical risks	营养盐、微生物等 Nutrients, microorganisms, etc.	风险因子有待识别 Risk factors need to be identified
威胁地下水 Threatening groundwater	临近水源，渗透性好 Close to water source, good permeability	对地下水影响不明 The influence on groundwater is unknown
河道易水华 Easy occurrence of algal blooms	自净慢，流速低 Slow self-purification and low flow rate	水质保障风险调控 Water quality assurance risk control

研究技术路线（TECHNICAL SCHEME）



主要依托项目（SUPPORTING PROJECTS）

- **本项工作得到了科技部、环保部、市科委、基金委和市水务局等部门的大力支持。**
- This work has been strongly supported by the Ministry of Science and Technology, the Ministry of Environmental Protection, Beijing Municipal Science and Technology Commission, National Natural Science Foundation of China, Beijing Water Authority, etc.

序号 No.	项目名称 Project	服务期 Service period	项目来源 Project source
1	**海河流域水资源调蓄区水质保障及生态修复关键技术研究与示范** Research and demonstration of key technologies of water quality assurance and ecological restoration in water resources regulation and storage area of Haihe River Basin	2014-2018年	国家水专项 National water special project
2	**海河北系（北京段）河流水质改善集成技术与综合示范** Integrated technology and comprehensive demonstration of river water quality improvement in the north system of Haihe River (Beijing section)	2012-2018年	国家水专项 National water special project
3	**灌区土壤环境质量与生态风险评价技术研究** Study on soil environmental quality and ecological risk assessment in irrigation area	2012-2015年	科技部 Ministry of Science and Technology
4	**再生水补水型城市河湖水系生态修复技术集成与示范** Integration and demonstration of ecological restoration technology of urban river and lake water system with reclaimed water supply	2014-2016年	北京市科委 Beijing Municipal Science and Technology Commission
5	**北京城市副中心水环境风险预警与应急处置平台研究** Study on water environment risk early warning and emergency disposal platform of Beijing Sub-Center	2016-2018年	北京市科委 Beijing Municipal Science and Technology Commission
6	**引温济潮工程受水区地表地下水环境监测评价** Monitoring and evaluation of surface water and groundwater environment in water receiving area of the project of “introducing water from Wenyu River to Chaobai River”	2015-2016年	北京市水务局 Beijing Water Authority
7	**再生水灌溉对土壤环境的影响及调控机制研究** Study on the effect of reclaimed water irrigation on soil environment and its regulation mechanism	2014-2018年	国家自然基金委 National Natural Science Foundation of China
8	**炭基催化臭氧氧化纳米纤维分离膜对再生水消毒净化研究** Study on disinfection and purification of reclaimed water by carbon-based catalytic ozonation nanofiber separation membrane	2015-2017年	国家自然基金委National Natural Science Foundation of China
9	**潮白河再生水入渗对地下水环境的影响研究** Study on the influence of reclaimed water infiltration in Chaobai River on groundwater environment	2014-2016年	环保部公益科研 Public welfare scientific research of the Ministry of Environmental Protection
10	**2018年度引温济潮再生水回用潮白河景观对河道及周边地下水环境影响的监测与研究** Monitoring and study on the influence of the use of reclaimed water from the project of “introducing water from Wenyu River to Chaobai River” by Chaobai River landscape on the river and its surrounding groundwater environment in 2018	2018年	北京市水务局 Beijing Water Authority

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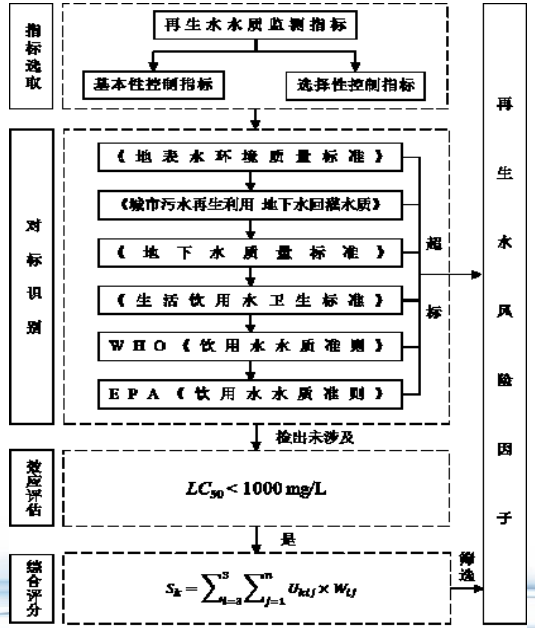
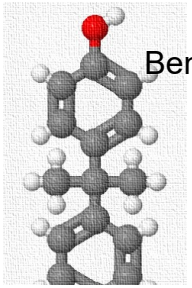
PART TWO

Main Innovation Results

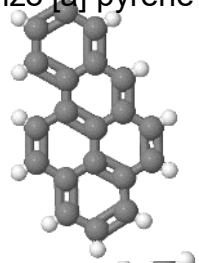
（1）开发了基于SPE（固相萃取）-GC（气相色谱）-MS（质谱）联用的**药品和个人护理用品检测方法**；提出了集成指标选取、对标识别、效应评估和综合评分的**再生水风险因子筛选方法。**

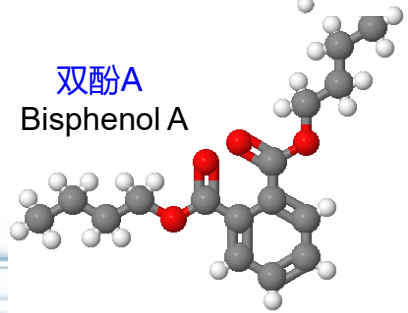
(1) A method for the detection of drugs and personal care products based on SPE (solid phase extraction)-GC (gas chromatography)-MS (mass spectrometry) is developed, and a risk factor screening method for reclaimed water, including integrated index selection, calibration identification, effect evaluation and comprehensive score, is brought forward.





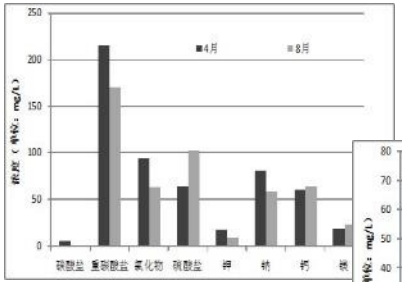
苯并[a]芘
Benzo [a] pyrene

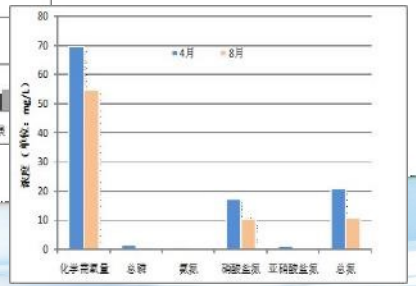




双酚A
Bisphenol A

污染物	再生水	30m地下水	污染物	再生水	30m地下水
氨氮	0.8	0.3	双酚A	1195.0	107.0
萘	856.23	530	苯并(a)芘	14.99	4.11
二氯甲烷	53.16	5.59	邻苯二甲酸二甲酯	141.78	163
芴	70.99	8.98	邻苯二甲酸二乙酯	38.2	30.3
菲	181.56	15.6	邻苯二甲酸二（2-乙基己基）酯	537.95	1870



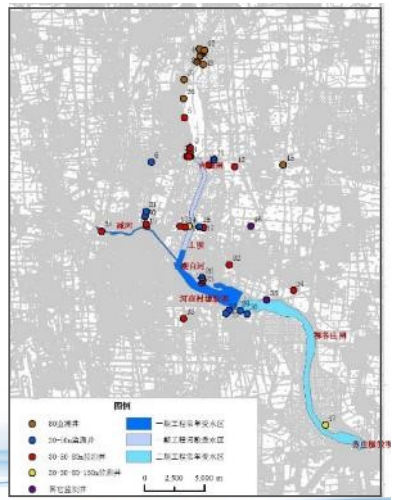


风险因子筛选
Risk factor screening

邻苯二甲酸二（2-乙基己基）酯
Dioctyl phthalate (2-ethylhexyl) phthalate

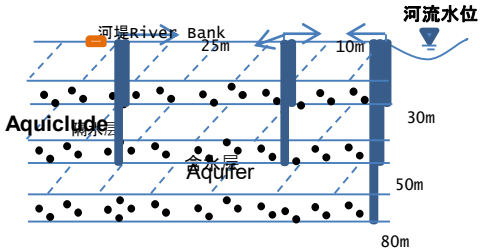
（2）构建了地表水、土壤与地下水环境立体分层监测网络；集成GIS分析技术和大数据挖掘技术，耦合HYDRUS和FEFLOW模型，融合同位素和溶质运移监控技术，界定再生水河湖回用对地下水环境的影响程度和范围。

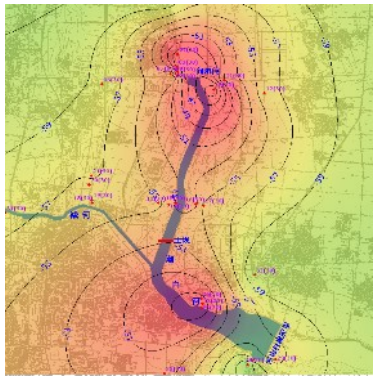
(2) A multi-dimensional stratified monitoring network of surface water, soil and groundwater environment is constructed, the GIS analysis technology and big data mining technology are integrated, the HYDRUS and FEFLOW models are coupled, and the isotope and solute transport monitoring techniques are integrated to define the influence degree and scope of the reuse of reclaimed water in rivers and lakes on groundwater environment.

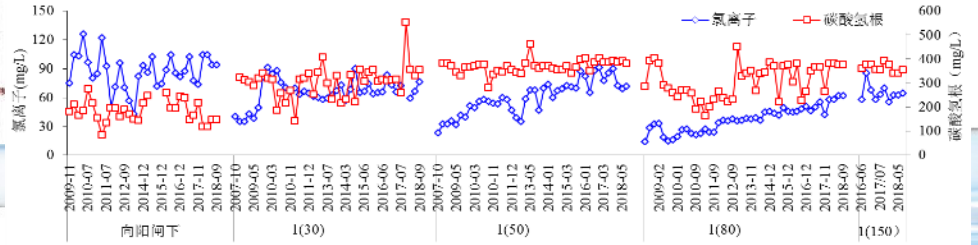


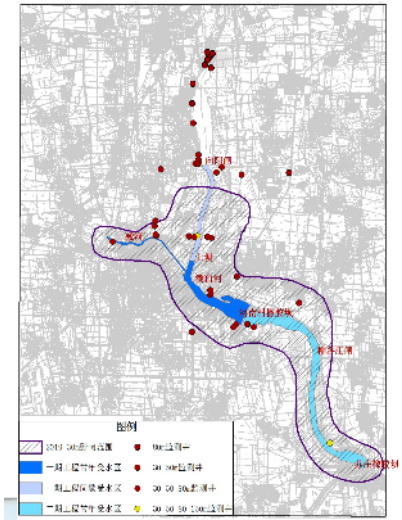
地下水立体分层监测网络

Multi-dimensional stratified groundwater monitoring network







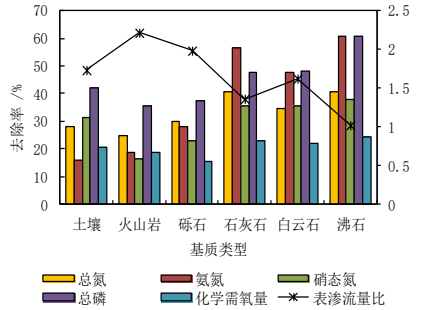


30m含水层水质影响范围

Water quality influence range of 30m aquifer

（3）基于水陆交错带监测和鱼类围网试验研究，提出了岸边带水生植物配置和鱼类种群重建的生境改良方案，重建了结构稳定的新蓄水河段健康水生态系统。

(3) Based on the monitoring of water-land ecotone and the experimental study of fish purse seine, a habitat improvement scheme for the allocation of aquatic plants and the reconstruction of fish population in the riparian zone is put forward, and a healthy aquatic ecosystem of the newly recharged river section with stable structure is reconstructed.

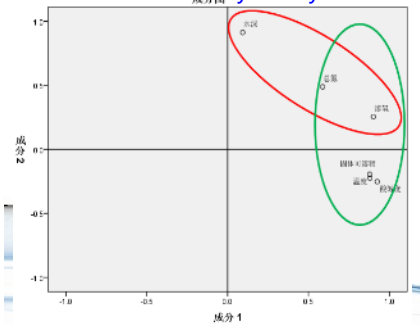


基质对表渗流分配作用

Effect of matrix on the distribution of surface seepage

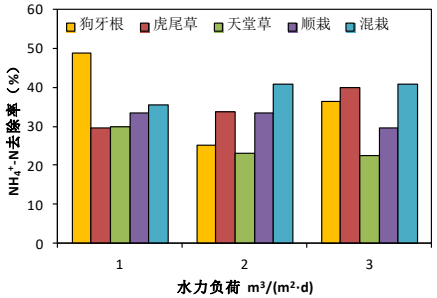
鱼类多样性调查

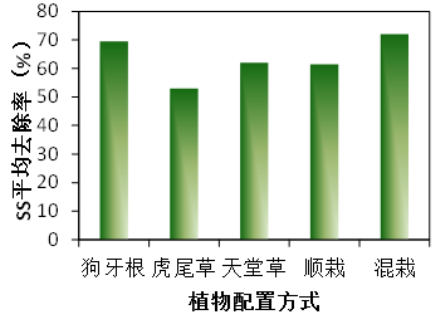
Fish diversity survey

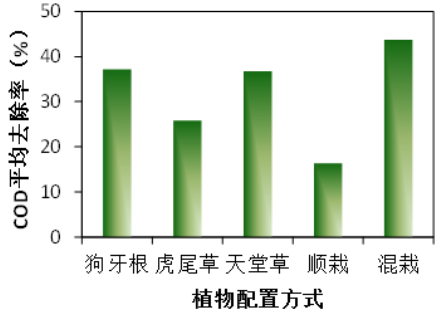


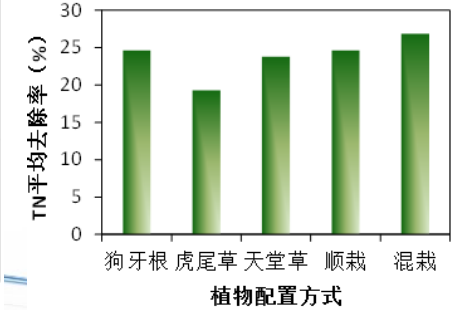
鱼类生长因子识别

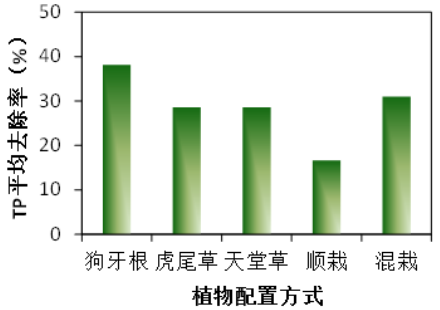
Fish growth factor recognition











岸边带水生植物配置方式优化

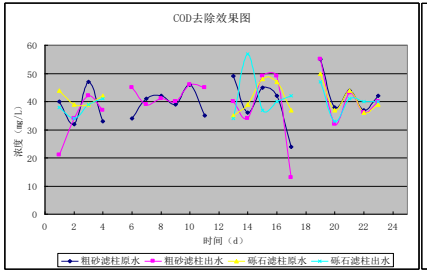
Optimization of allocation mode of aquatic plants in the riparian zone

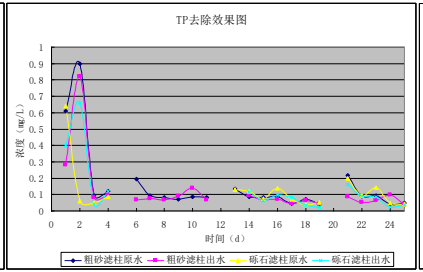
（4）研发了滤井净化技术，构建河道水质立体循环净化系统，对叶绿素a去除率高达90%；基于传统生物浮床原理，研制了悬浮式人工湿地，投资可节省20%，且运行成本低，低碳环境友好。

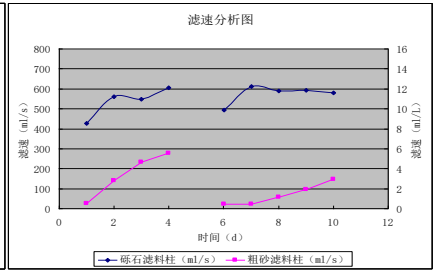
(4) A filter well purification technology is developed, and a multi-dimensional river water quality circulation purification system is constructed, and the removal rate of chlorophyll a is as high as 90%. Based on the traditional biological floating bed principle, a suspended constructed wetland is developed, which can save 20% investment, with low operating cost and friendly low-carbon environment.

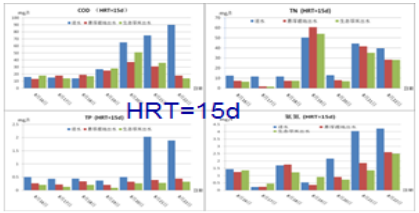
渗滤井循环净化现场试验
Filter well circulation purification field test

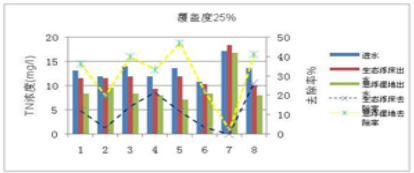
悬浮式人工湿地净化试验
Suspended constructed wetland purification test

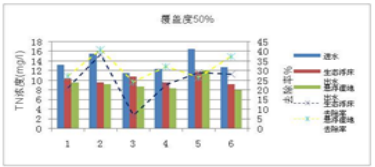


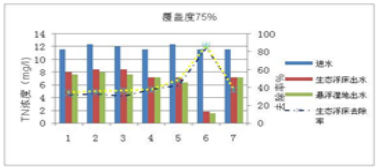






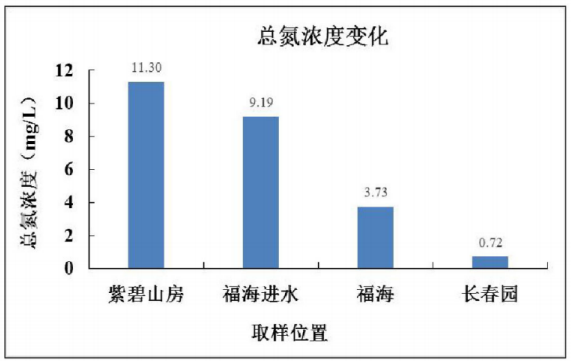


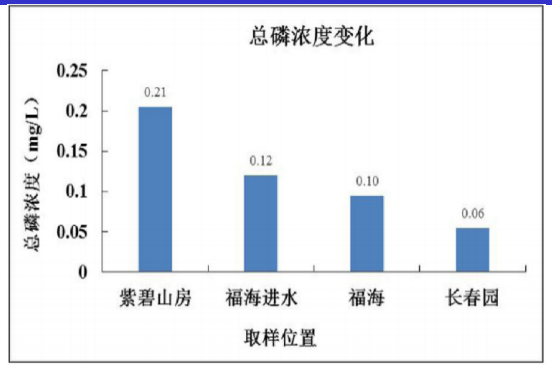




（5）提出了河湖水生态系统构建和管护技术参数，形成了水生态系统优化调控与稳定维持技术，总氮、总磷去除率93.6%、73.1%,修复区水体透明度超过1米，浊度小于3NTU, 呈现水清岸绿、鱼翔浅底的感官效果。

(5) The technical parameters of river and lake water ecosystem construction, management and protection are put forward, and the optimal regulation and stability maintenance technology of water ecosystem is formed. The removal rates of total nitrogen and total phosphorus are 93.6% and 73.1%, the transparency of water in the restoration area is more than 1 meter, and the turbidity is less than 3NTU, delivering the sensory effect of clear water, green banks, and healthy fishes.



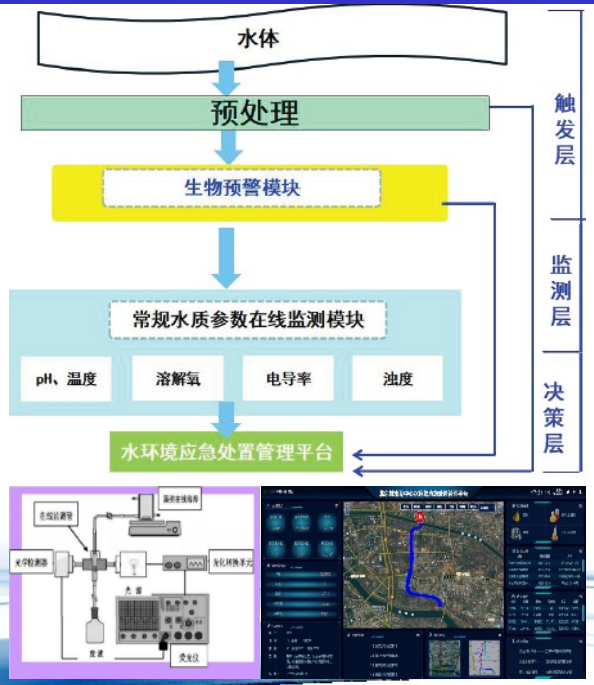


修复治理前

修复治理后

（6）构建了再生水补给型河道“生物+水质“风险预警平台，提出了强化内部水体循环、模块式缓释吸附材料投放等水环境应急修复技术；研发的缓释除磷填料，吸附量是同类产品的2.7-12.6倍，抗板结时间延长90倍。

(6) A "biology + water quality" risk early warning platform for reclaimed water recharged rivers is constructed, and the emergency remediation techniques of water environment such as strengthening internal water circulation and launching modular slow-release adsorption materials are put forward. The adsorption capacity of the slow-release phosphorus removal filler is 2.7-12.6 times that of similar products, and the anti-hardening time is 90 times longer.



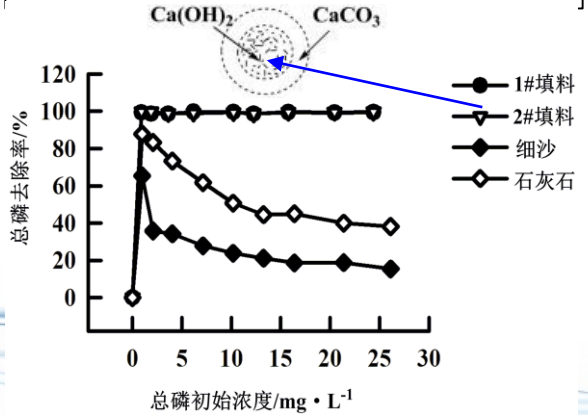
风险预警平台构建

Construction of risk early warning platform

湿地净化-基质改善

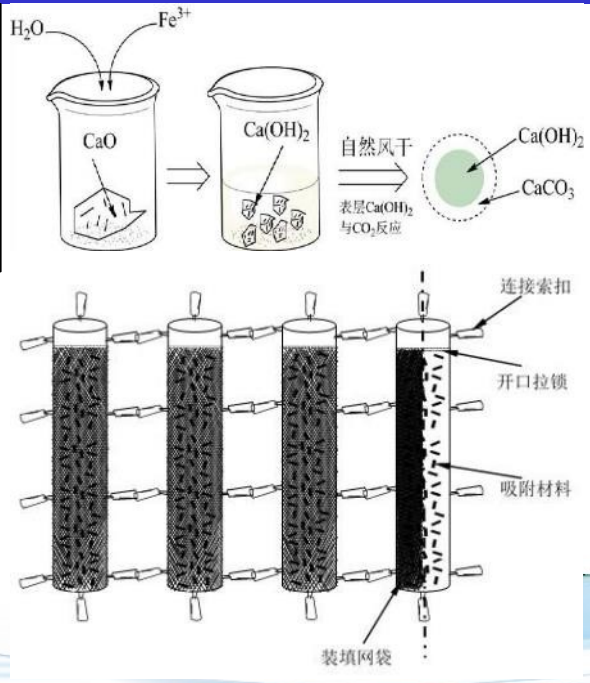
Wetland purification-matrix improvement

- ✓ 成分：$Ca(OH)_2/FeCl_3@CaCO_3$
- ✓ Composition: $Ca(OH)_2/FeCl_3@CaCO_3$
- ✓ 吸附量：2.7-12.6倍（市售）
- ✓ Adsorption capacity: 2.7-12.6 times (on the market)
- ✓ 抗板结时间：90倍（市售）
- ✓ Anti-hardening time: 90 times (on the market)



高性能除磷填料效果

Effect of high-performance phosphorus removal filler

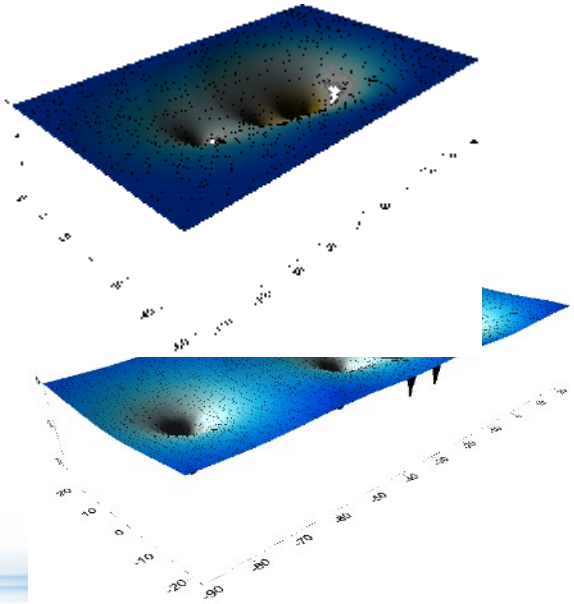


缓释除磷填料应用形式

Application form of slow-release phosphorus removal filler

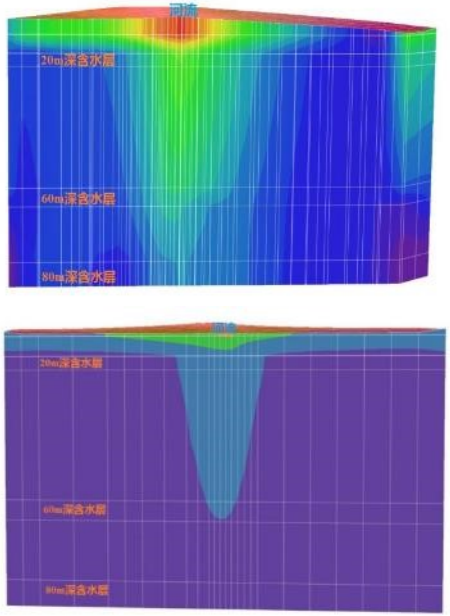
（7）应用野外试验和数值模拟相结合的方法，开展地下水水力调控污染修复关键技术攻关，获取了**水力调控抽水井与监测井**的位置布设、抽水量，以及监测指标和监测频次等**关键参数**。

(7) The key technologies of groundwater hydraulic control pollution remediation are tackled by using the method of field test and numerical simulation, and the location and pumping capacity of hydraulic control pumping wells and monitoring wells as well as monitoring indicators, monitoring frequency and other key parameters are obtained.



不同深度含水层水力调控影响范围

Influence range of hydraulic control of aquifers at different depths



垂向上各含水层氯离子、氨氮浓度影响范围

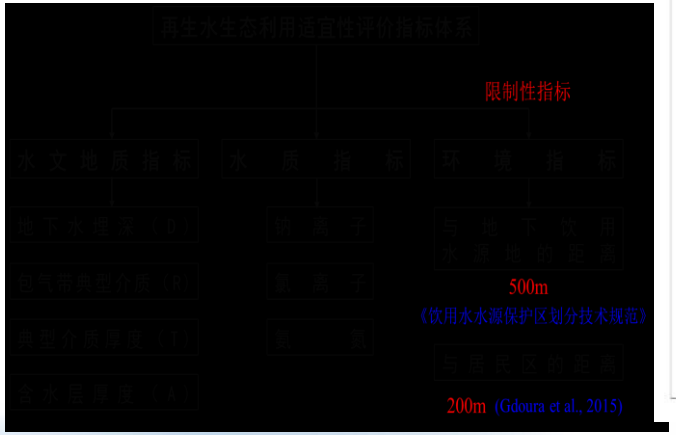
Influence range of chloride ion and ammonia nitrogen concentration in vertical aquifers

现场试验及取样工作照片

Field test and sampling

（8）综合AHP法和专家评分法，提出了再生水河道利用适宜性区划指标体系与评价方法，划定了潮白河流域内超过500平方公里的再生水利用适宜区，支撑了再生水安全利用。

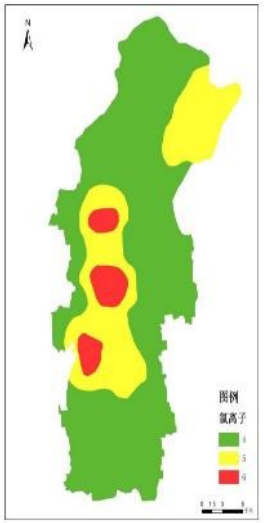
(8) Based on the AHP method and expert scoring method, an index system and evaluation method for the suitability zoning of reclaimed water utilization are put forward, and an area over 500km2 suitable for reclaimed water utilization in Chaobai River basin is delineated, supporting safe utilization of reclaimed water.

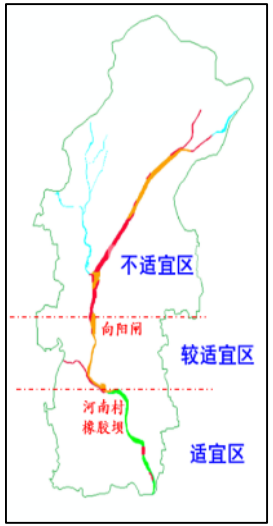


包气带典型介质
Typical medium of vadose zone

地下水埋深
Groundwater depth

氯离子
Chloride ion





适宜性分区图
Suitability zoning map

3

PART THREE

Future Research

A

- **再生水分质利用水质标准和指南**
- Water quality standards and guidelines for the utilization of reclaimed water by quality

B

- **再生水分质利用水质稳定保障技术**
- Water quality stabilization and assurance technology for the utilization of reclaimed water by quality

C

- **再生水园林绿地灌溉利用集成技术**
- Integrated technology of irrigation and utilization of reclaimed water for gardening and landscaping

D

- **再生水生态处理循环利用技术**
- Ecological treatment and recycling technology of reclaimed water

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汇报完毕！
The End

谢 谢！
Thank You!

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