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Long-term pollution trend and source contributions in anastomosing rivers based on multiple analysis models — case study of Jiaojiang River

基于多种统计分析模型深入了解网状河流的长期污染趋势和污染源贡献——以椒江为例

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XVIII
WORLD WATER CONGRESS
Water for All
Harmony between Humans and Nature
第18届
世界水资源大会
水与万物:
人与自然和谐共生

1. Study area 区域概况
2. Calculating pollutants 核算单元污染物收集量
3. Diffuse/ non-point source pollution 面源污染物产生量
4. Water environmental capacity水环境容量测算
5. Source-tracing of pollutants 污染物溯源
6. Recommended methods 推荐工艺方法
7. Performance prediction 水环境提升及效果预测

1 Study area

Overview of Jiaojiang District 区域简介

椒江区位于浙江省沿海的中部，东濒大海，南邻路桥，西接黄岩，北界临海。椒江区域居温黄平原北部，地貌主要类型为沿海冲积平原，占土地总面积的65%。其余为低山丘陵、滩涂和海岛，属中亚热带季风区，气候受海洋水体调节，较同纬度内陆地区温和湿润，四季分明，雨量充沛，雨热同季，夏鲜酷暑，冬无祁寒。椒江区下辖海门街道、白云街道、葭沚街道、洪家街道、下陈街道、章安街道、前所街道。

- **Location** — central coast area of Zhejiang Province
- **Geomorphology** — 1) 65% coastal alluvial plain 2) low mountains and hills, tidal flats and islands.
- **Climate** — mid-subtropical monsoon, changing with ocean movements; mild and humid; distinct four seasons and abundant rainfall
- **Adm.** — Jiaojiang District has 7 streets or neighborhoods.

1 Study area

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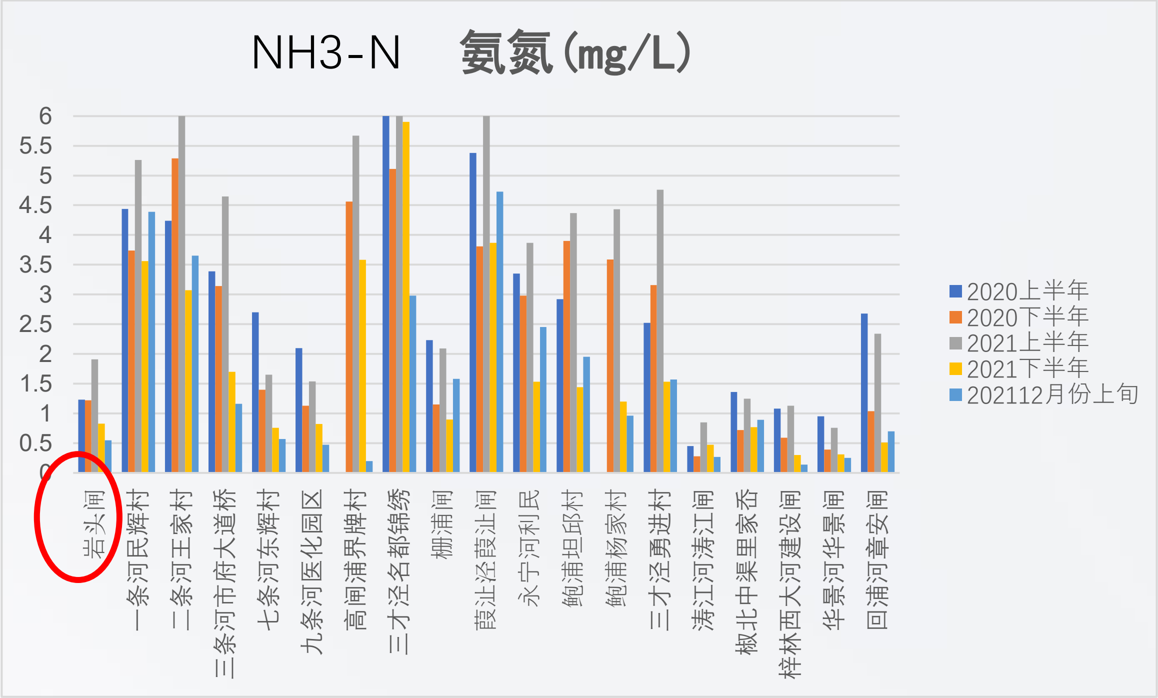
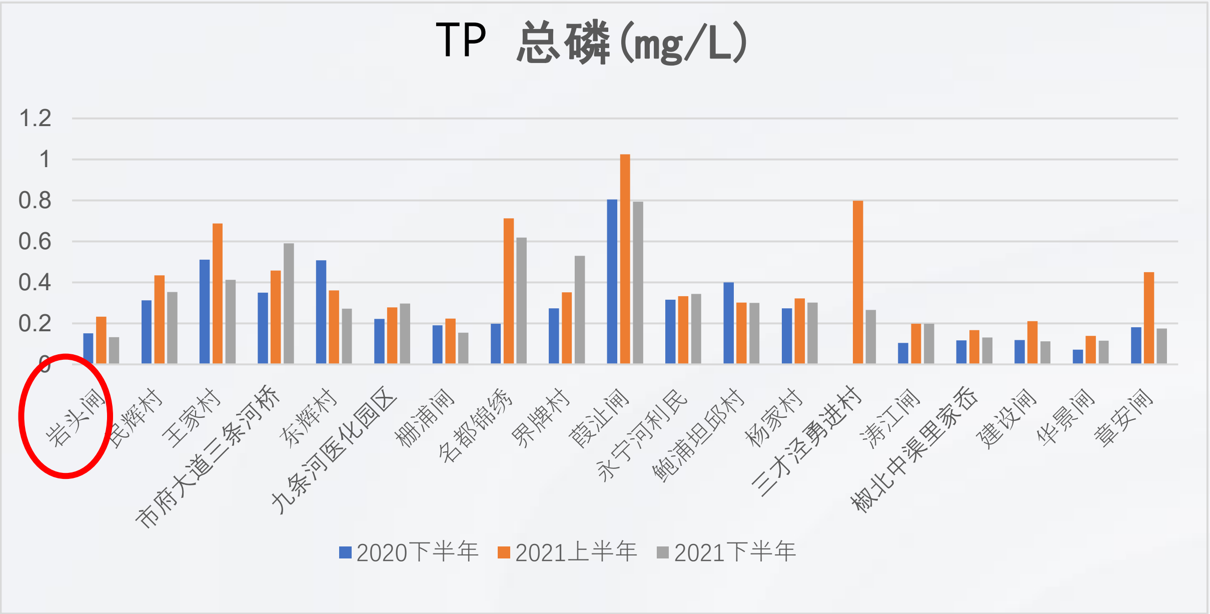
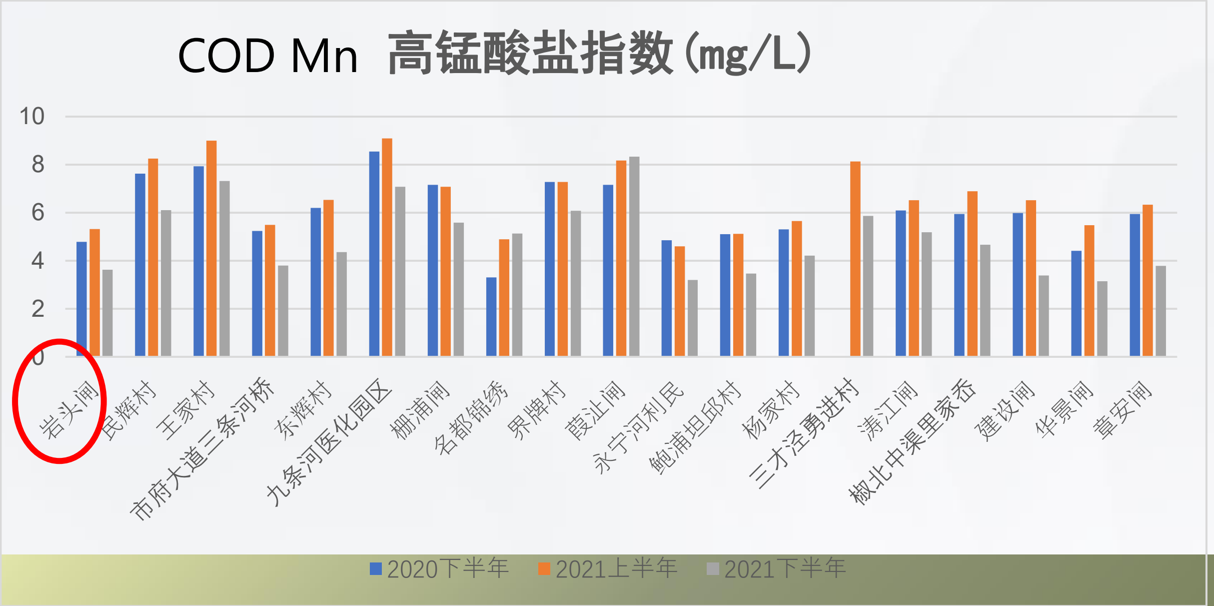
County-level stations 县域交接微型自动站情况



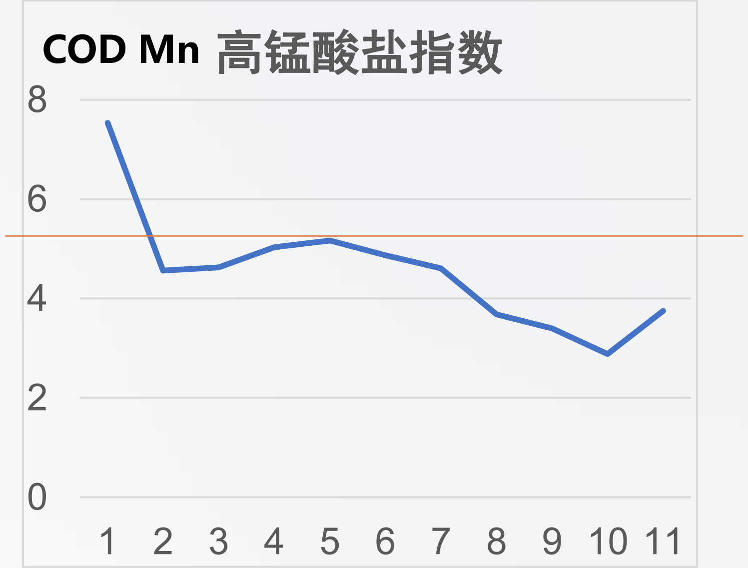


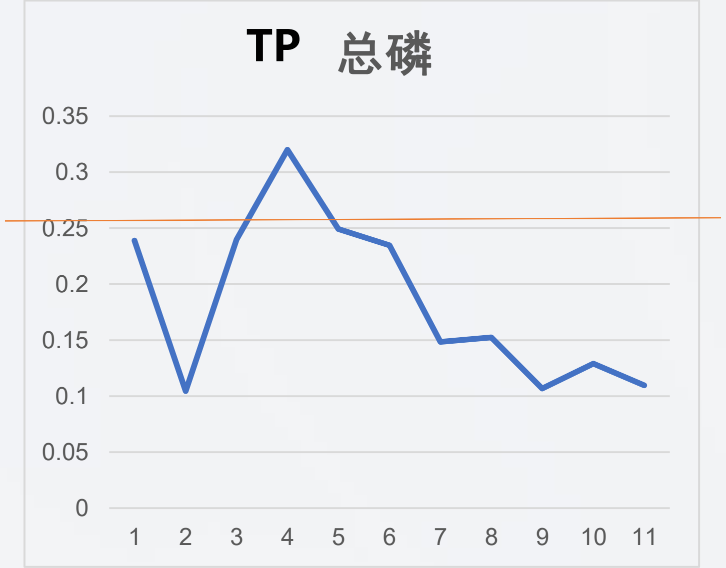


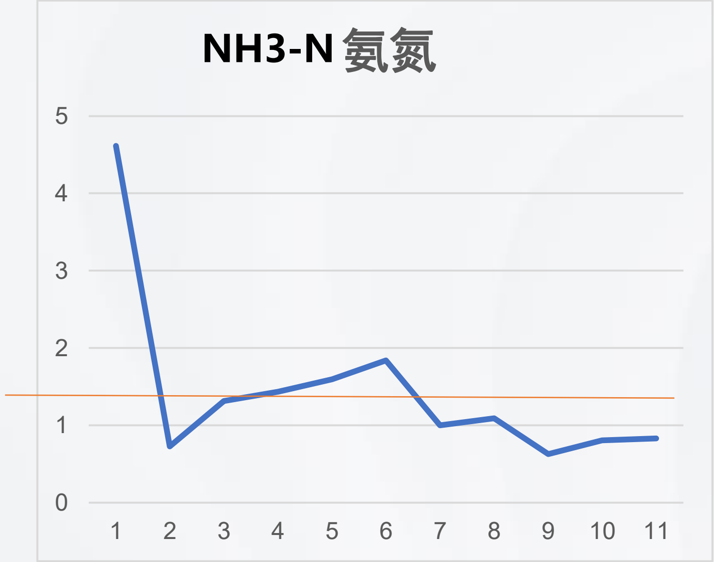
1 Study area

Yantou Gate: COD Mn, TP and NH3-N all exceed standards with max. 1.3, 1.6 and 4.6 times respectively. Exceeding rate: 9%, 45% and 54% respectively.

岩头闸断面：从每月的水质数据来看，高锰酸盐指数、总磷和氨氮均存在超标，最大超标倍数分别为1.3、1.6和4.6倍，对应超标率分别为9%、45%和54%。







2 Calculating pollutants

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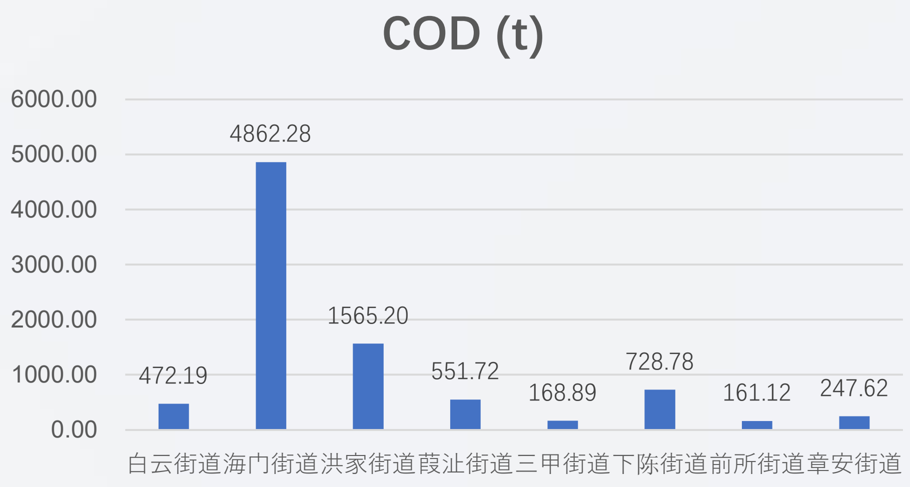
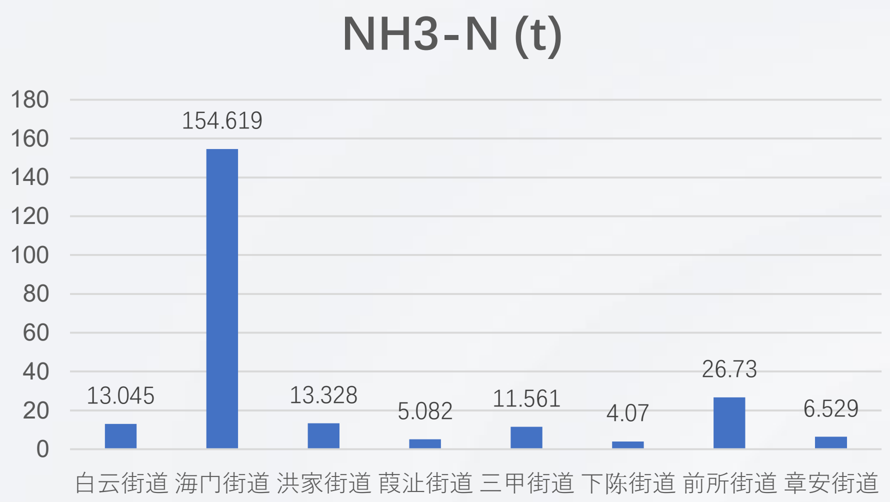
Calculate pollutants from collected by wastwater treatment plants in terms of amount and concentration of inflow. 根据污水处理厂的进水量和进水浓度来计算每年污水处理厂对污染物的收集量。

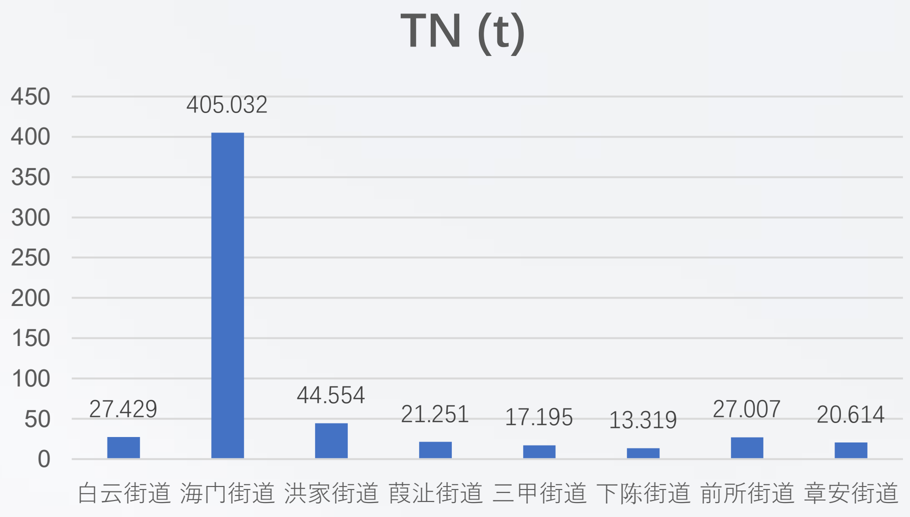
	COD（t)	NH_3-N（t)	TP（t)	TN（t)
Company 1	23894.08	2039.12	223.4	2288.46
Company 2	1097.52	209.17	25.13	219.76
Total	24991.6	2248.29	248.53	2508.22

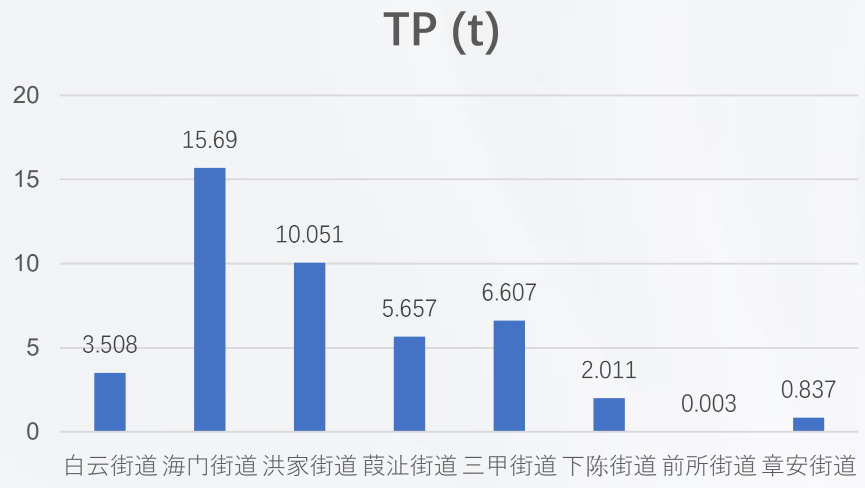
2 calculating pollutants

Industrial wastewater 核算单元工业废水污染物收集量









2 calculating pollutants

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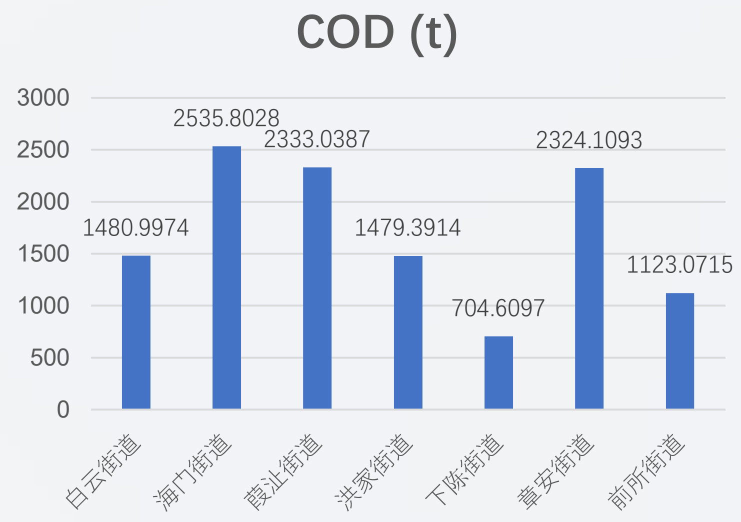
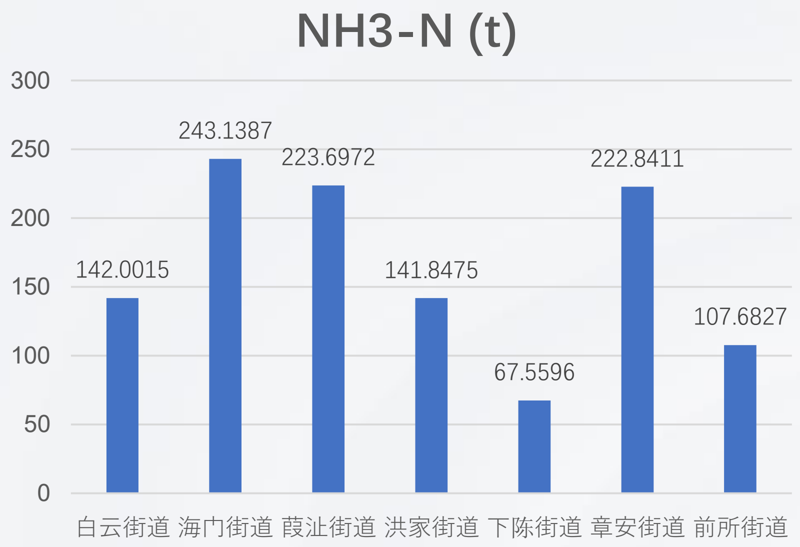
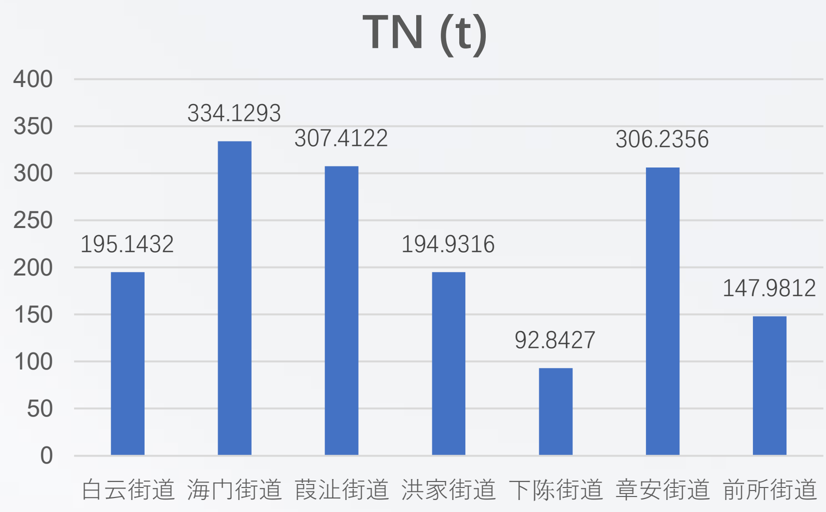
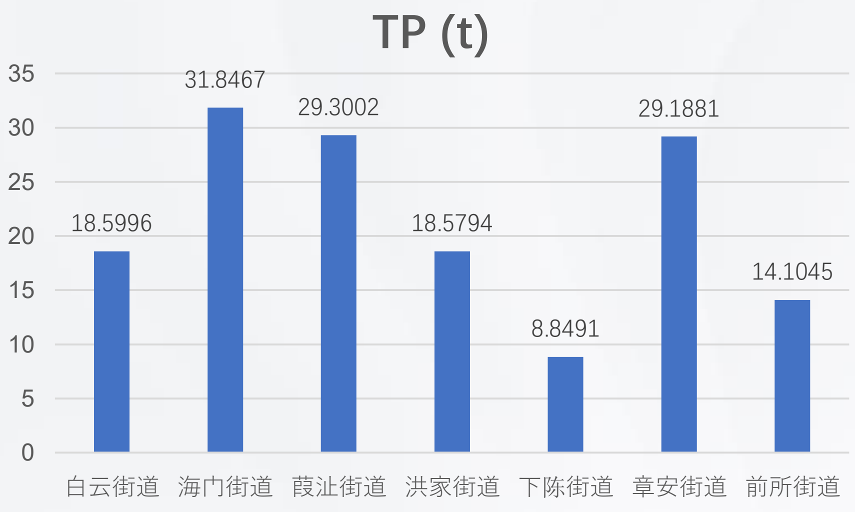
Domestic wastewater 核算单元生活污水污染物收集量









3 diffuse/ non-point source pollution

Land use types

- Hard bottom surfaces (including built-up areas such as residential areas and industrial areas)
- Agricultural land
- Urban parkland

In urban area — pollution carried with surface runoff scouring

In rural area — pollution carried with agricultural tail water and fertilizer residues discharged into the river.

本项目研究范围内土地利用类型多样，主要可划分为**硬质底面**（包括居民生活区域与工业用地等建成区）、**农业用地**、**城市绿地**等。其中城镇硬质底面区域与绿地的污染负荷形式主要表现为**地表径流冲刷**，农业用地的污染负荷形式主要表现为**农业尾水与化肥残余对河道的排放。**

Land type	城市绿地 Urban parkland	硬质底面 Hard-bottom-surfaces	农业用地 Agricultural land
面积（平方千米）Area (km3)	23.235	70.01	117.9926

面源污染计算结果 calculation results	化学需氧量 COD (t)	总氮 TN (t)	总磷 TP (t)	氨氮 NH3-N
城市面源 diffuse source in city (parkland, roofs and roads)	84.3306	3.0416	0.3713	0.6383
农业面源 Agricultural diffuse source	160.4699	32.7359	6.6781	0.2838

4 water environmental capacity

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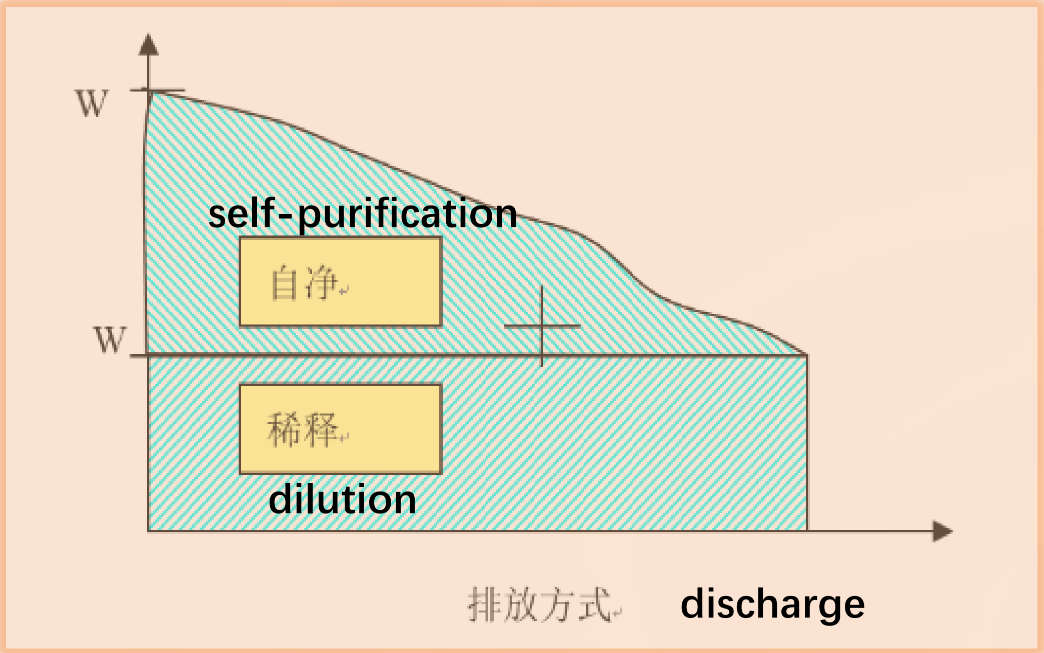
Water environmental capacity — the maximum amount of pollutants that a water body can accommodate under the premise of meeting the water quality standard corresponding to the water environment function.

在给定水域范围和水文条件，规定排污方式和水质目标的前提下，单位时间内该水域最大允许纳污量，称作**水环境容量。**



Water environmental capacity

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PMF model

Receptor oriented models are widely used for **source apportionment** of organic pollutants in environmental media.
Positive matrix factorization (PMF) model is an advanced receptor model, widely recognized and used because of its low dependence on **source spectrum information**.
Calculation process of PMF does not need to put in the pollution fingerprint spectrum,

目前，受体模型广泛地应用于环境介质中有机污染物的来源解析。正定矩阵因子分解法 PMF模型是目前比较先进的受体模型，由于这种受体模型对**源谱信息**的依赖性较低，使得它在国际上得到了认可和广泛应用。PMF的计算过程不需要输入污染指纹图谱.

Basic equation：

$$X_{ij} = \sum_{k=1}^{p} g_{ik} f_{kj} + e_{ij}$$

5 Source-tracing of pollutants

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The PMF model

performs constrained and iterative calculations based on weighted least squares;
obtains optimal result by continuously decomposing the matrix.
Goal is to minimize the objective function Q
PMF模型基于加权最小二乘法进行限定和迭代计算，不断地分解矩阵以得到最优结果，最优化目标是使目标函数Q达到最小化。目标函数Q定义见下式。

Definition of Objective Function Q:

$$Q = \sum_{i=0}^{n} \sum_{j=1}^{m} \left(\frac{e_{ij}}{u_{ij}}\right)^2$$

Calculation of ***uij***

$$u_{ij} = \frac{5}{6} \times MDL \qquad x_{ij} \le MDL$$

$$u_{ij} = \sqrt{(P \times x_{ij})^2 + (MDL)^2} \qquad x_{ij} > MDL$$

5 Source-tracing of pollutants

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PCA-APCS-MLR Model

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Estimates the source contributions of different pollutants or factors in environmental studies. It is based on the principal component analysis (PCA).

主成分分析法(PCA)是进行数据降维的常用多元统计方法，其目的是在大量观测数据中选用有代表性的几个主因子，阐明由大量观测数据提供的主要污染源信息。对PCA分析得到的旋转因子荷载矩阵和特征根计算主因子的特征向量，进一步根据前述特征向量和标准化理化数据得到的绝对主成分得分(APCS)进行多元线性回归(APCS-MLR)，绝对因子得分为自变量，污染物浓度为因变量，可定量表征各个污染源对总体污染的贡献，回归方程的系数可以将APCS分析的因子得分换算为各个污染源的污染物质量贡献浓度。

We compare the analysis results of the two models and find they are generally consistent.

Main pollution sources are **domestic sewage** and **industrial wastewater**, among which domestic sewage accounts for a larger proportion.

通过对两种模型分析结果进行比较，两种方法的分析结果是基本吻合的，主要的污染源是生活污水和工业废水其中生活污水所占比重比较大。

5 Source-tracing of pollutants

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同位素溯源 Isotope tracing

Isotope tracing is to trace the sections with high correlation, such as the sections in the same water system.

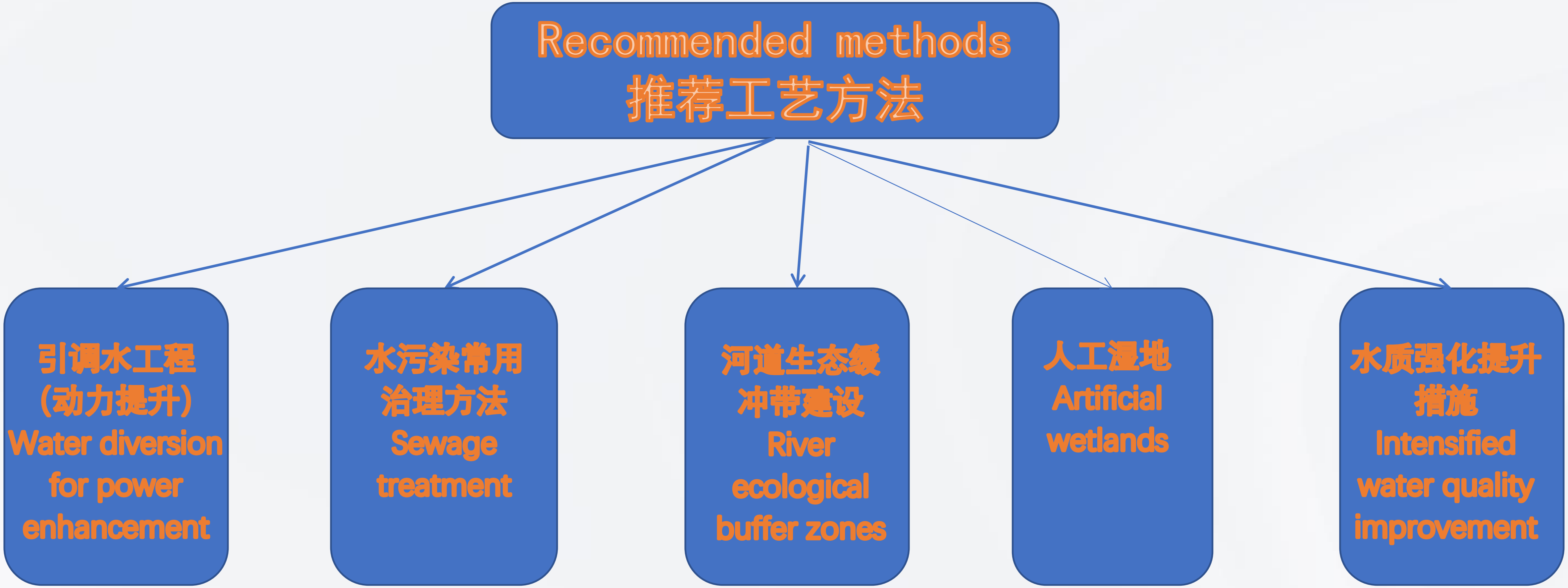
Due to the limitations of this method, it is impossible to directly analyze the industrial wastewater pollution sources.

We compare the tracing results of **domestic sewage**, **agricultural non-point sources** and **rainstorm runoff** with the results of the two models — PMF model and PCA-APCS-MLR Model

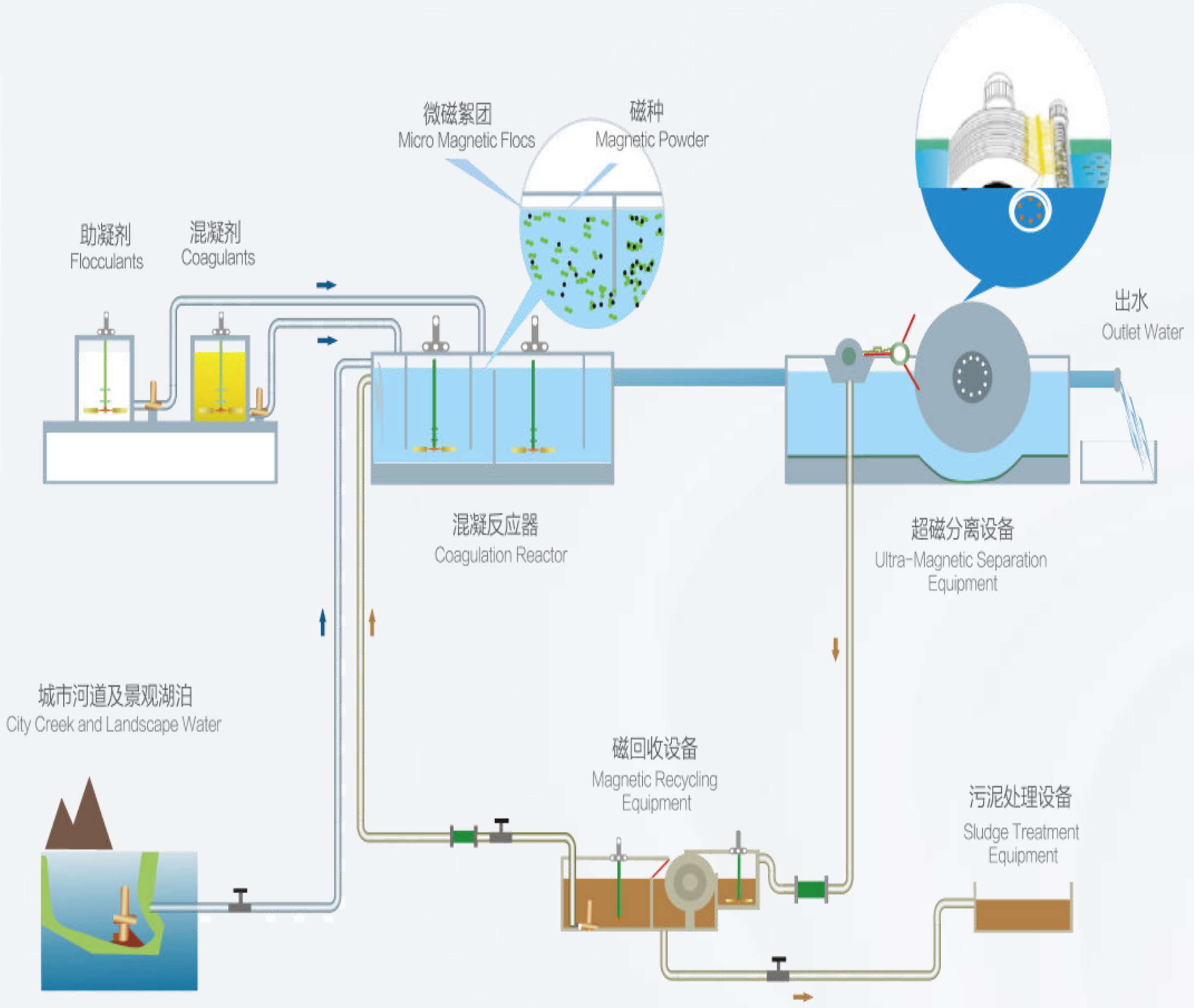
The results show that they are consistent, which can achieve the effect of verifying the tracing results of the above two models.

同位素溯源是将关联性比较大的断面放在一起进行溯源，比如同在一个水系的断面。**由于同位素溯源的局限性，无法直接分析到工业废水污染源**，这里主要将生活污水、农业面源和雨洪径流的溯源结果与上面两种溯源模型的结果进行比对，**比对结果显示比较一致，**可以达到对以上两种模型溯源结果**进行验证的效果。**

6 Recommended methods



6 Recommended methods



超磁分离技术工艺流程图
Super-conducting magnetic separation

6 Recommended methods

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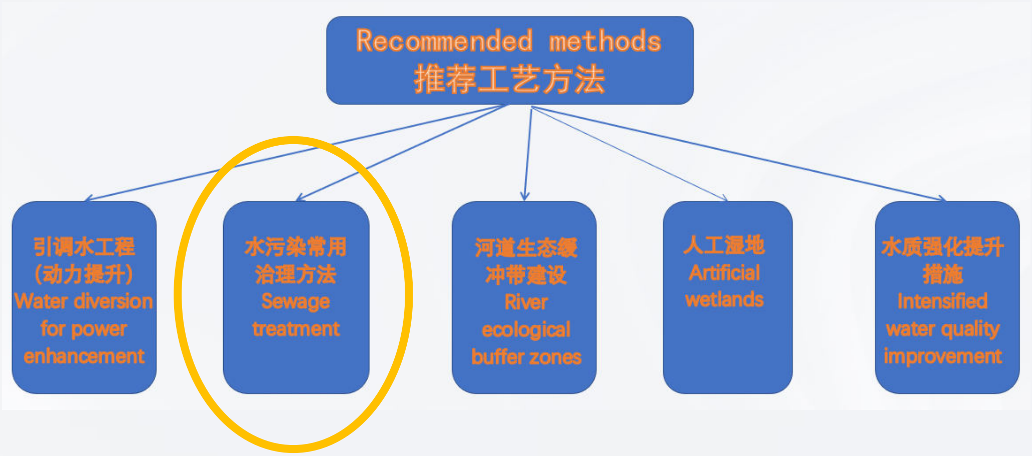


Regular methods:

AO (anaerobic-oxic)

A^2O (**anaerobic-anoxic-oxic**)

BAF (biological aerated filter)

SBR (sequencing batch reactor)

常用水污染治理方法：AO工艺、A^2O工艺、曝气生物滤池（BAF）、SBR工艺

To reduce COD and NH_3-N—

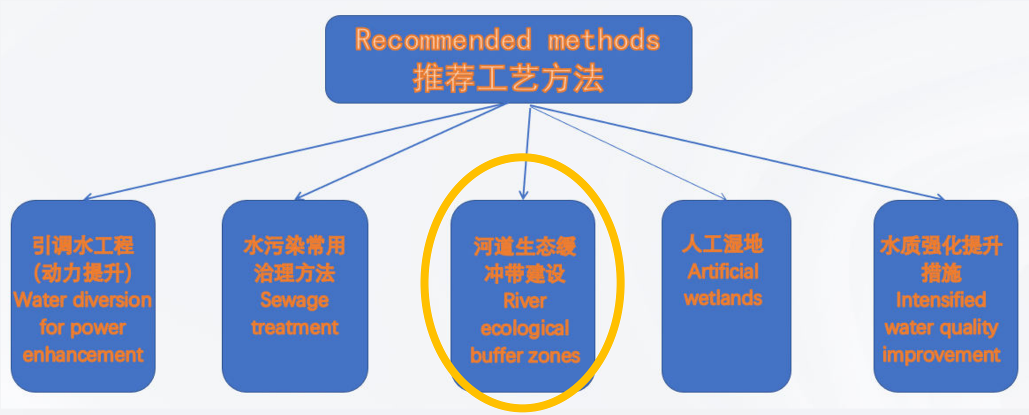
aeration + microorganisms (activated sludge, biofilm)

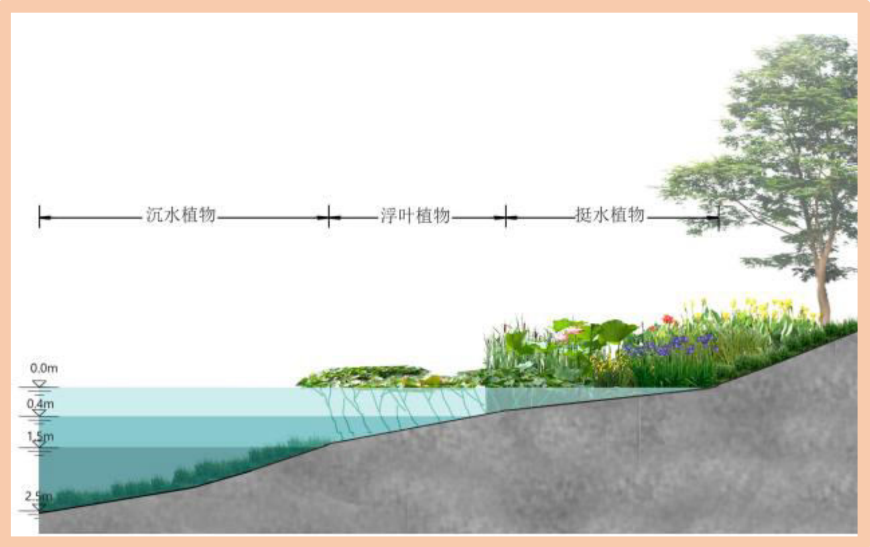
化学需氧量/高锰酸盐指数和氨氮的削减一般会用到的技术为：曝气+微生物（活性污泥、生物膜）技术。

To remove Phosphorus— PAC and PAM

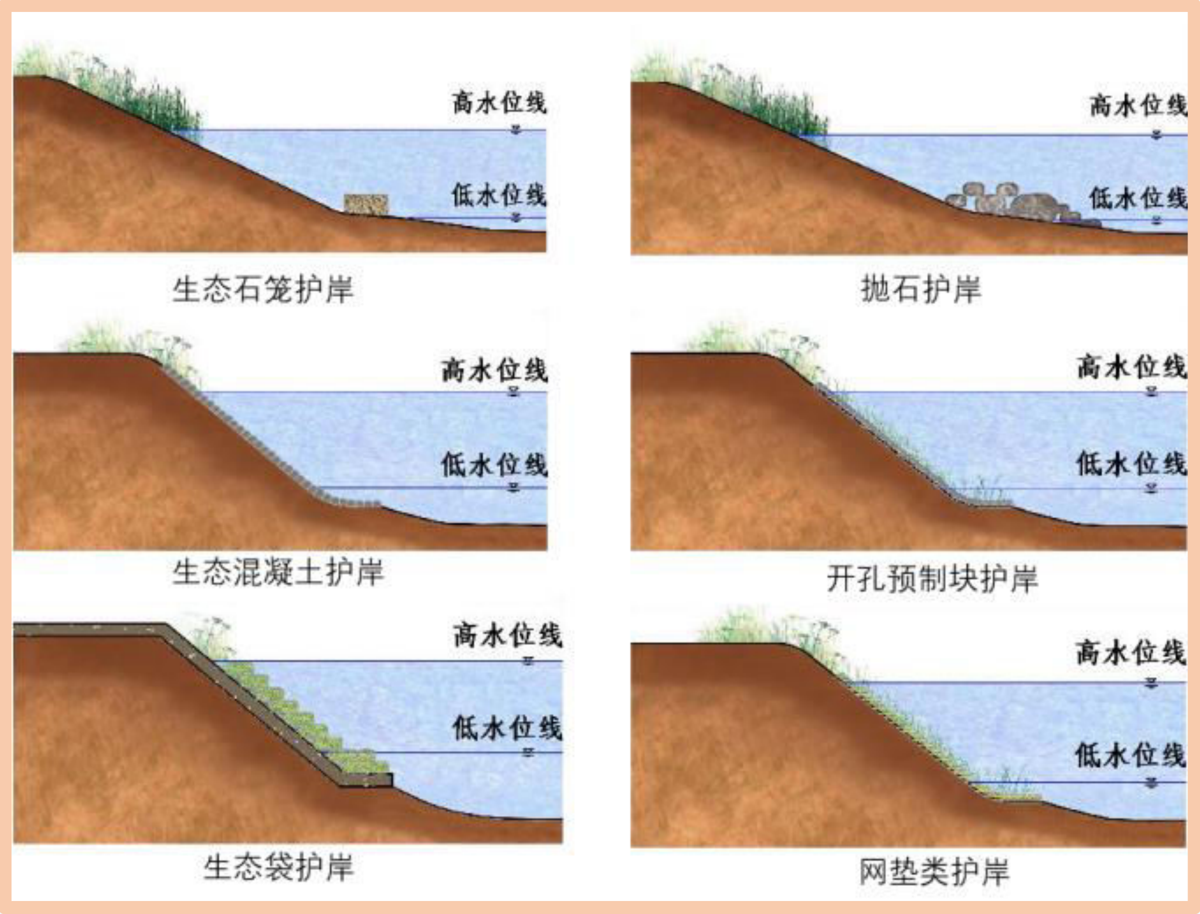
除磷技术工艺流程：污水进入混合反应池，投加PAC、PAM等，充分混合反应，形成包裹磁介质的密实大块絮团，在重力作用下快速沉降至池底污泥区

6 Recommended methods



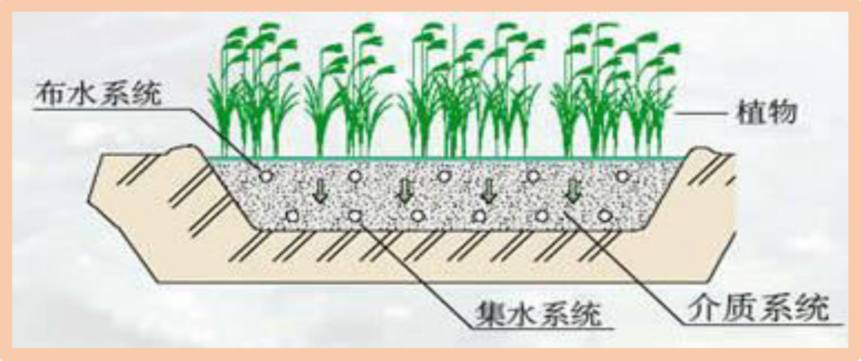


Restoration of aquatic flora in water level fluctuation zone 水位变幅区水生植物群落修复

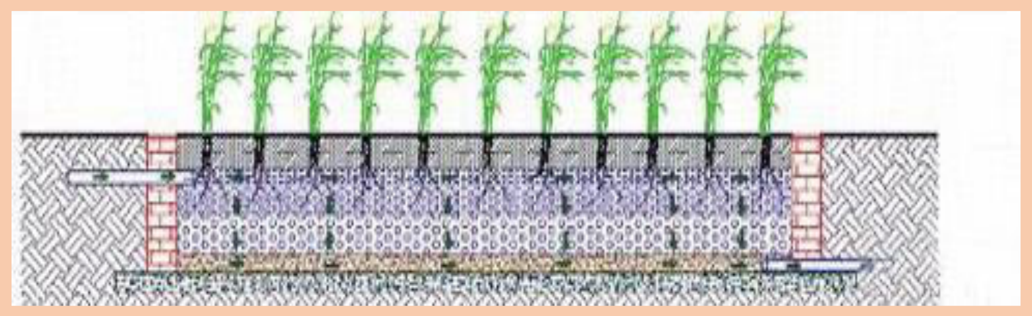


Bank protection部分护岸技术

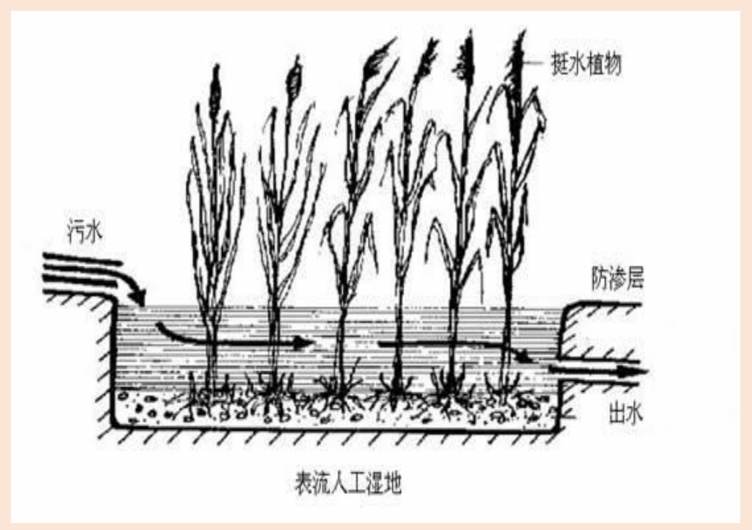
6 Recommended methods



Vertical flow constructed-wetland
垂直流人工湿地



Horizontal subsurface flow constructed-wetland
水平潜流型人工湿地



Surface flow constructed-wetland
表面流人工湿地

Biofilm enhanced treatment
生物膜强化处理系统
+
Water body aeration
水体增氧技术

7 Performance prediction

AHP 层次分析法

Thomas L., Saaty, professor at University of Pittsburgh, operations researcher.

Raised in 1970s

Steps

1
- 建立层次结构模型

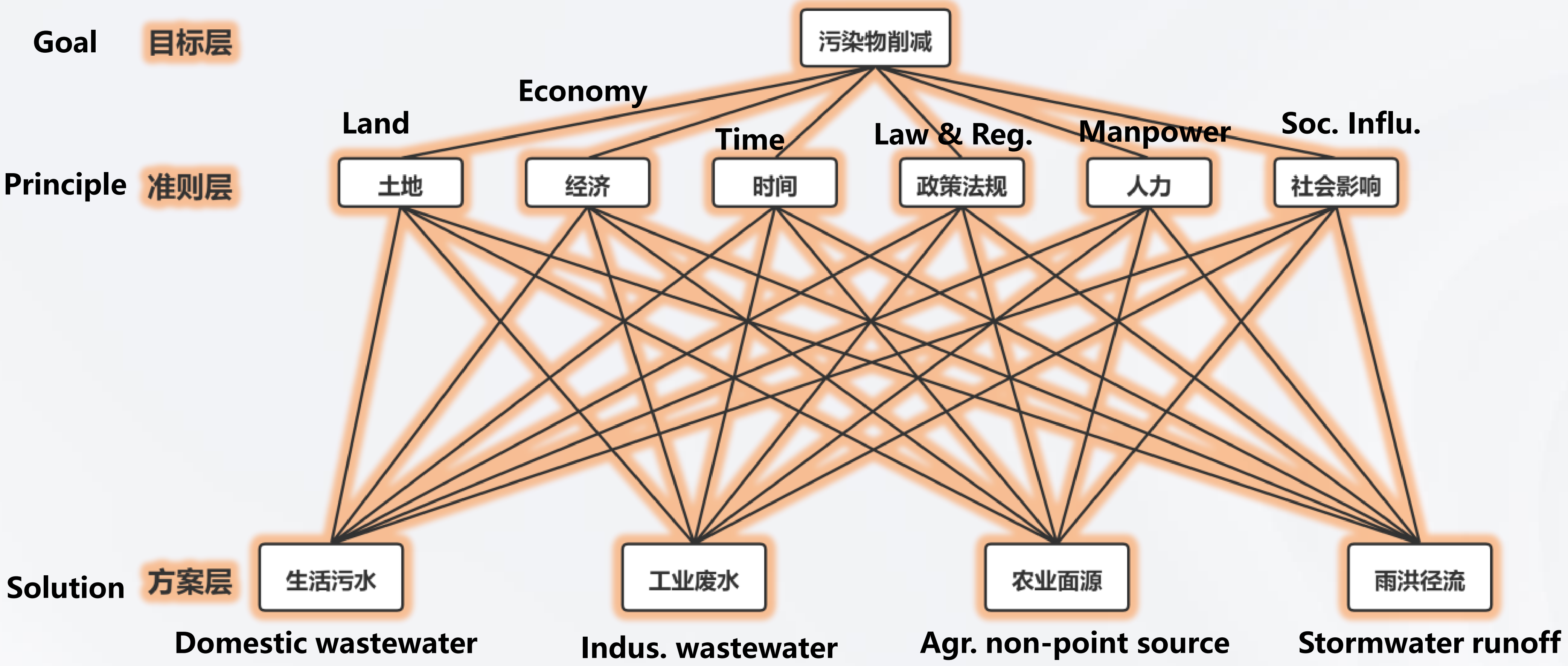
2
- 构造判断（成对比较）矩阵

3
- 层次单排序及其一致性检验

4
- 层次总排序及其一致行检验

7 Performance prediction

Pollution reduction analysis 污染物削减分析



7 Performance prediction

计算结果

各街道污染源治理优先度权重计算

街道	生活污水	雨洪径流	农业面源	工业废水
海门街道	0.3786	0.3311	0.1692	0.1211
葭沚街道	0.3566	0.1537	0.2002	0.2905
白云街道	0.5277	0.2454	0.1245	0.1024
下陈街道	0.4498	0.0859	0.2391	0.2251
洪家街道	0.4251	0.0859	0.2101	0.2789
前所街道	0.3491	0.2563	0.2655	0.1291
章安街道	0.1480	0.2236	0.4160	0.2124

Yellow parts are treatment priorities of each neighborhoods

7 Performance prediction

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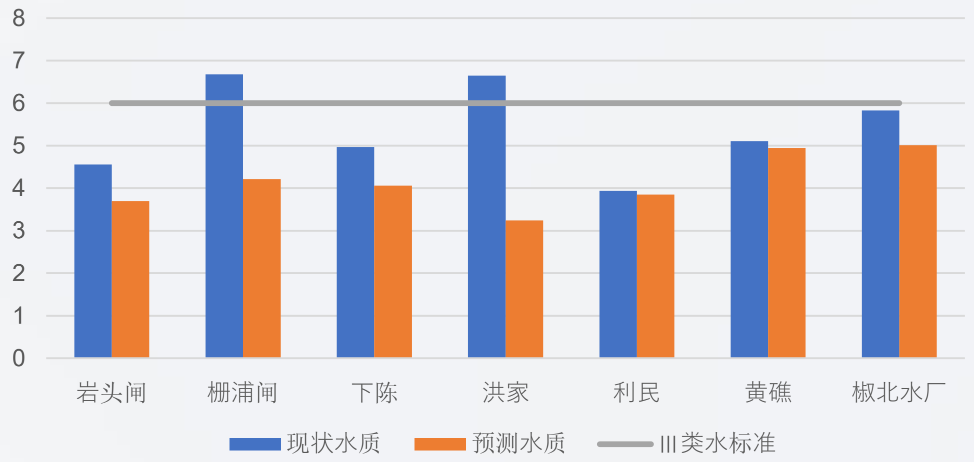
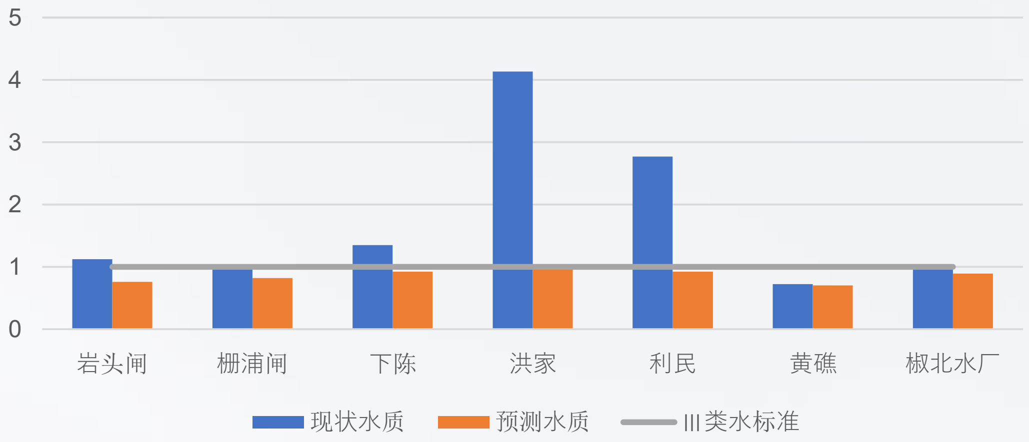
After water diversion engineering measures, estimated water quality:

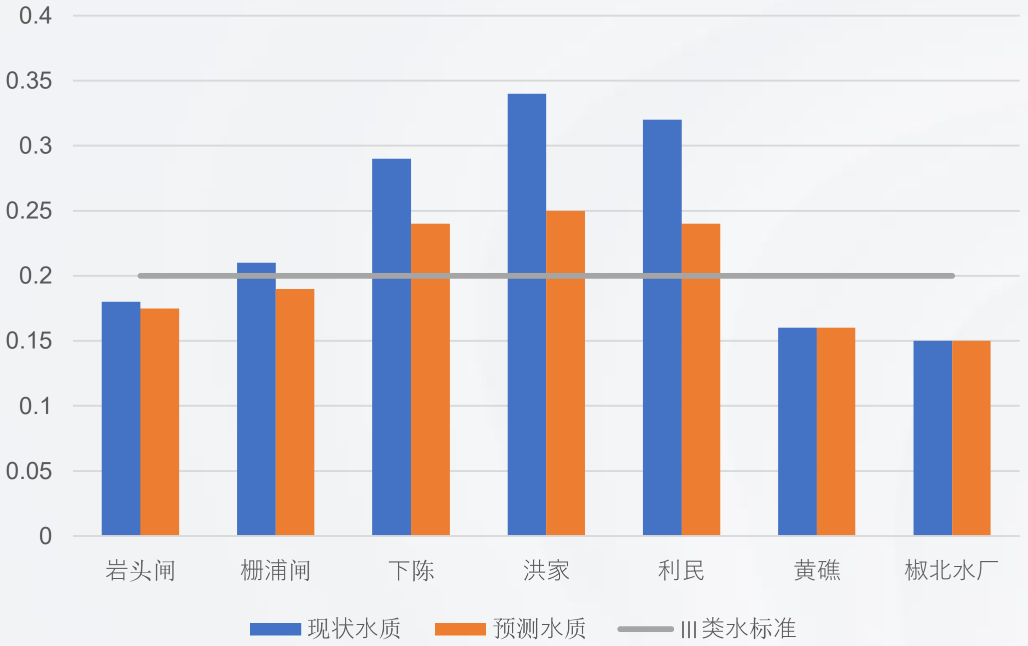
COD Mn 高锰酸盐指数 单位：mg/L



NH3-N 氨氮 单位：mg/L

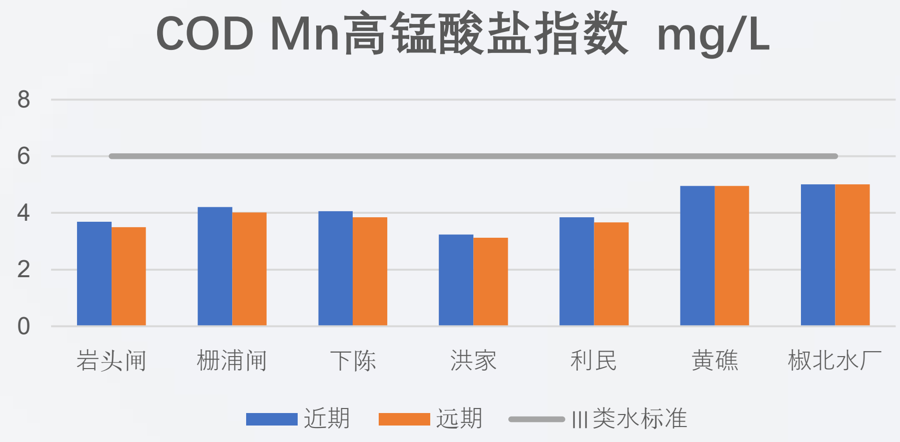


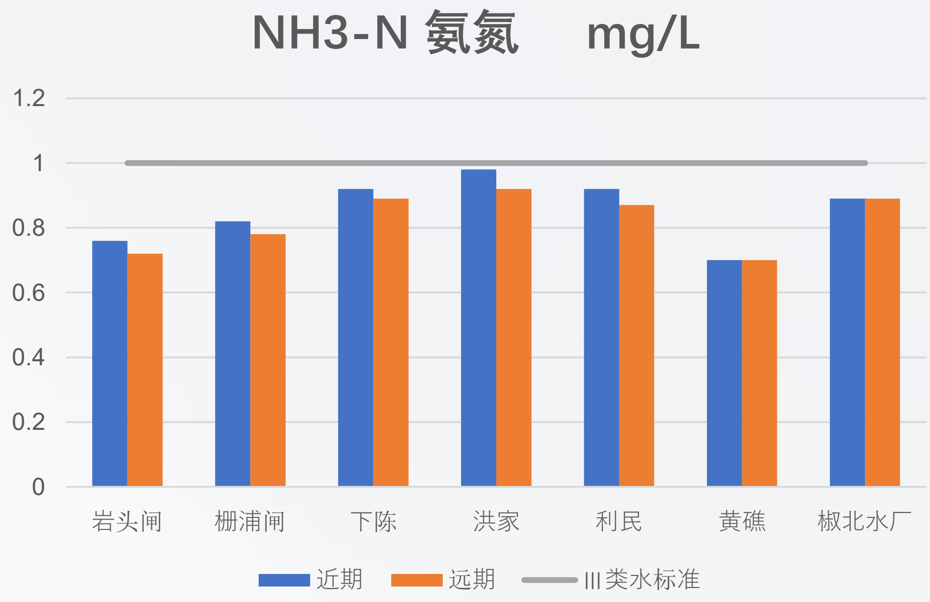
TP 总磷 单位：mg/L

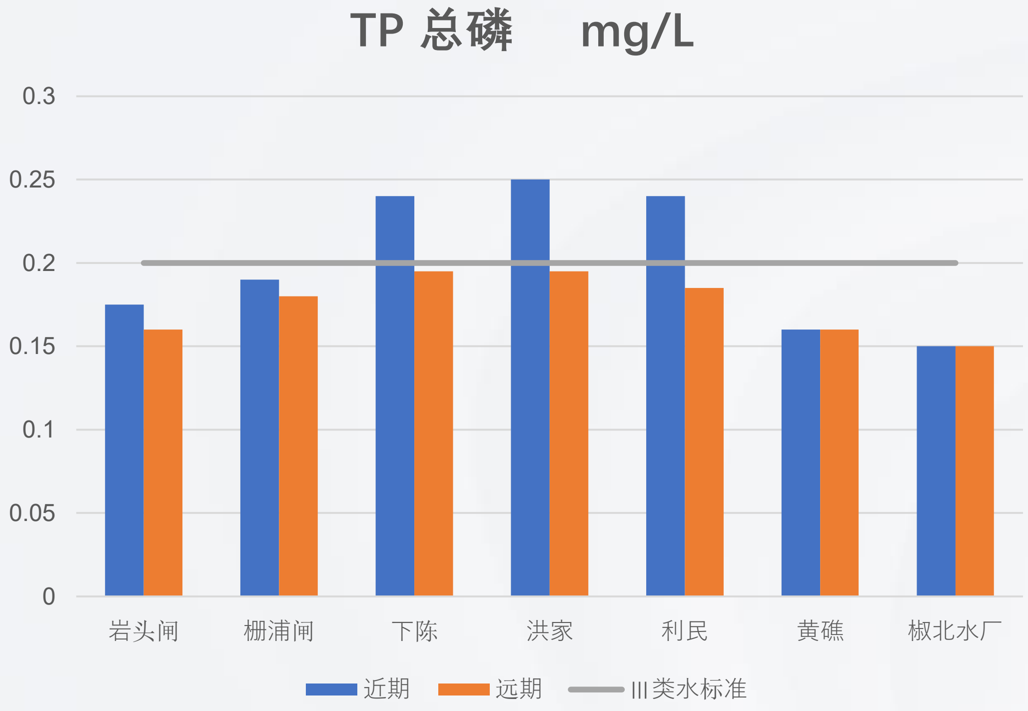


7 Performance prediction

After inflow sewage treatment, engineering measures, estimated water quality:







7 Conclusion

By taking a series of improvement measures, water quality indicators of Jiaojiang District can meet the Category III requirements of the **Surface Water Environmental Quality Standard (GB3838-2002)**. Water environment is being improved steadily and continuously.

在采取引调水、水质提升等一系列水质改善措施后，椒江各主要断面的水质指标可满足《地表水环境质量标准》（GB3838-2002）Ⅲ类限值要求(但少数断面的总磷存在超标风险)，区域的水环境质量会得到较大的改善，可以达到水环境持续改善的目的。

增加入河合流污水治理工程后，预测分析表明，各主要断面的水质指标均可满足《地表水环境质量标准》（GB3838-2002）Ⅲ类限值要求，区域的水环境质量会得到稳定提升，可以达到水环境持续改善的目的。

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基于多种统计分析模型深入了解网状河流的长期污染趋势和污染源贡献——以椒江为例

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