Constructed Wetland Study
Of the Proposed GEF Ningbo-Cixi
Wetland Project

South China Institute of Environmental Sciences, SEPA of China
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Chapter One Outline

1.1 Project Name

Constructed Wetland Study of Ningo-Cixi Wetland Project

1.2 Study Object

The project studies the associated constructed wetland system of the two Cixi City’s Wastewater Treatment Plants, and prepares for World Bank and GEF’s approval of the proposed Ningbo-Cixi Wetland Project. The research will reach the extent of Feasibility Study, including demonstration, design and cost estimate of detail wetland schemes.

1.3 Construction Institution

Cixi City Drainage Co., Ltd.

1.4 Construction Site

Cici city, Zhejiang province. The construction site is shown in fig1-1.

1.5 Main Construction and Scale

The associated constructed wetland of Cixi City Wastewater Treatment Engineering will be constructed in two stages: for the North Wastewater Treatment Plant, the scale of year 2010 is 100,000 m$^3$/d, and that of year 2020 is 320,000 m$^3$/d; for the East Wastewater Treatment Plant, the scale of year 2010 is 50,000 m$^3$/d, and that of year 2020 is 100,000 m$^3$/d. Now only consider the scale of year 2010.

(1) North Constructed Wetland: its scale is 100,000 m$^3$/d, which technique is Vegetated Submerged Beds + Free Water System;

(2) East Constructed Wetland: its scale is 50,000 m$^3$/d, which technique is Vegetated Submerged Beds + Free Water System.
1.6 Construction Period

The constructed wetlands will be constructed and used with the secondary wastewater treatment plants synchronously.

1.7 Investment Estimate

Total construction investment of North Constructed Wetland: RMB ¥57,964,500, including:
- Part 1 Engineering Cost: 42,141,800+6,191,300= RMB ¥48,333,100;
- Part 2 Other Cost: 5,970,800+900,400= RMB ¥6,871,200;
- Basic Contingent Cost: 2,405,600+354,600= RMB ¥2,760,200.

Total Construction Investment of East Constructed Wetland: RMB ¥12,776,400, including:
- Part 1 Engineering Cost: RMB ¥10,668,000
- Part 2 Other Cost: RMB ¥1,500,200;
- Basic Contingent Cost: RMB ¥608,400.

1.8 Compilation Base

1.8.1 State Laws and Regulations
1.8.2 Local Regulations and other documents
1.8.3 Standards and Criteria
Chapter Two    Project Background

2.1 General Situation of the Area

Cixi is located on the side of East Sea, 60 km away to the west of Ningbo, 148 km away to the south of Shanghai, 138 km away to the west of Hangzhou. It is the center of the Three Cosmopolitan Golden Economic Triangle – Shanghai, Hangzhou and Ningbo, which is located at Hangzhou Bay Area of the South Loop of Yangtze River Delta Economic Circle. Its regional and transportation advantage is quite significant. Cixi City is in charge of Ningbo City. Its administrative area is 1,154 km$^2$, and its population is 1,015,400.

2.2 Natural Conditions

2.2.1 Topography and Physiognomy

Cixi City is located at the Seashore Plain, north of Ningshao Plain, which position is longitude 121°02'~121°47' east, latitude 30°21'~30°24' north. Its hill area is 166.8 km$^2$, only 16.6 percent of the terrene area. On the north of the hill is the Seashore Plain. The plain’s west is higher than the east, but the north and the south is not the same. In the west part, the plain’s north is higher than its south; and in the middle and the east part, the plain’s north is lower than its south, slightly leaning to the Hangzhou Bay. The ground elevation (Wusong Base Level): that of the west is 4.9 - 6.0m, that of the middle is 4.0 – 5.5m and that of the east is only 3.5 – 4.8m. The coastline is 81.4km long. The resource of tidal marsh is quite rich, and has unique land reserves.

2.2.2 Geology

In geology, Cixi belongs to the south part of the Neocathaysian Second Apophysis and Cretaceous sedimentation basin. It is mainly marine accumulation in plain stratum, and alluviation, lake accumulation and marine accumulation and
transitional strata in piedmont.

2.2.3 Soil

Controlled by geological structure and the physiognomy of the Quaternary Period, the soil forms three zones: it is hill red-yellow soil zone in the south, rice soil zone in valley in front of the hill, Plain Chao soil zone and coastal salty soil zone. The coastal salty soil zone is mainly distributed between the north of Batang River and the seashore and new reclaimed tidal marsh. White salty soil is a little light, moderate, heavy, salty sand soil and light, middle salty clay; the soil in new reclaimed tidal marsh is salty sand and salty clay, which granules is small and homogeneous powder-type clay. Its salty degree is 0.1 to 0.5 percent. Its pH is over 8.0.

2.2.2 Rivers and Hydrology

Cixi belongs to Yaojiang River Watershed, but less than 19 percent of Cixi area drains into Yaojiang River. Main drainage is discharged north into Hangzhou Bay, so it is called North Drainage System. By physiognomy and river distribution the city can be divided into four water systems - Northwest River Section, West River Section, Middle River Section and East River Section. Except that West River Section Water System and the Shiyan Small Water System of Middle River Section are influenced by Yaojiang River, the others all drain into the sea and are used in industry production and agriculture irrigation and landscape. There are tidal marsh reservoirs in Middle River Section and West River Section, which are used for industry and agriculture.

2.2.4 Climate

Cixi is located at the south bound of semitropical zone and belongs to monsoon type climate. The seasonal change is significant. Winter and summer are slightly longer, and spring and autumn are slightly shorter. It is warm and wet. Temperature change is small. Precipitation and sunlight are plentiful. But precipitation distribution is not homogeneous, so it has obvious rainy season and dry season. Sunlight and temperature has changes in region.
Average highest temperature is 28.2°C, average lowest temperature is 15.5°C, and average temperature is 16.0°C. The coldest month in a year is January, which average temperature is 3.8°C. The extreme low temperature is -9.3°C in January 5, 1977.
3.1 Design Object

(1) Polish municipal wastewater, improve the water environment in Cixi city, and reduce the land-source pollutants discharge to the river and/or sea;

(2) Construct a region like a municipal wetland park, let the wetland have a character of nature and garden, restore Hangzhou Bay shore reclamation wetland ecosystem, and prevent the degeneration of the sea ecosystem.

3.2 Project Content

The associated constructed wetland of Cixi City Wastewater Treatment Engineering will be constructed in two stages: for the North Wastewater Treatment Plant, the scale of year 2010 is 100,000 m$^3$/d, and that of year 2020 is 320,000 m$^3$/d; for the East Wastewater Treatment Plant, the scale of year 2010 is 50,000 m$^3$/d, and that of year 2020 is 100,000 m$^3$/d. Now only consider the scale of year 2010. The constructed wetlands will be constructed and used with the secondary wastewater treatment plants synchronously.

North constructed wetland: the total area is 86ha, covering 26ha to the north of Jiutangjiang Wastewater Treatment Plant and 60ha at Bailu Lake. 60ha land at Bailu Lake is used for Stage 1 of North Wastewater Treatment Plant. 26ha land is reserved for wastewater shock load, flood and expansion, and now is designed as free water system given simple utilization. The effluent from North Wastewater Treatment Plant should be elevated by pump station to be sent to 60ha Bailu Lake constructed wetland 1.6km away to the north of the north treatment plant. And 10 percent of wastewater will be sent to the 26ha wetland.

East constructed wetland: The effluent from East Wastewater Treatment Plant should be elevated by pump station to be sent to the 13.4ha constructed wetland, which is located at the cross of Danshuihong River and Shitanghengjiang River.
3.3 Technological Route and Construction Scheme

3.3.1 Technological Route

Figure 3-1 Technological Route Figure of Cixi Constructed Wetland Study
3.3.2 Construction Scheme

North Constructed Wetland
- Pump, Pipeline System
- 42ha FWS (Bailu Lake)
- 16ha VSB
- 26ha FWS (spare)

East Constructed Wetland
- Pump, Pipeline System
- 8.25ha FWS
- 4.24ha VSB

Plant Engineering
Landscape Virescence
Ecological Engineering

Figure 3-2 Construction Scheme of Cixi Constructed Wetland Study

3.4 Design Principle

A. Minimal Impact

Adverse impacts to waters of the Cixi City should be avoided. Potential adverse impacts may include, but are not limited to: disruption of the composition and diversity of plant and animal communities; alteration of the existing hydrological regime of natural wetlands or adjacent surface water bodies; introduction and spread of noxious species; threats to fish and wildlife from toxins and/or pathogens; and degradation of downstream water quality and groundwater sources.

B. Natural Structure

The treatment wetland design should avoid rectangular basins, right structures and straight channels whenever possible. The use of soft structures, diverse and sinuous edges in design configuration, and bio-engineering practices that incorporate the existing natural landscape and native vegetation in the constructed treatment wetland is encouraged. Use landform and gravity to the advantage and design the project for minimal maintenance.
C. Buffer Zones

Design the margins of the constructed treatment wetland system as natural transition zones. Where appropriate, integrated the facility with other natural resource features to provide wildlife corridors and open space.

D. Multi Cells

From a wastewater treatment standpoint, multi cells often provide better treatment in part because “short circuiting ” is minimized. Besides, the use of multi cells may allow for residuals clean-out and repair of flow control structures without disruption of the overall systems operations.

E. Public Acceptance

Consider the constructed treatment wetland project’s effect on neighboring populations and adjacent land uses. Take into account effective actions to prevent potential concerns like drinking water contamination, unpleasant odors, mosquitoes and other safety and health issue. Ensure public support and approval for the safe and beneficial project.

3.5 Design Water Quality

Take constructed wetland as tertiary wastewater treatment technique for the advanced treatment of municipal wastewater. Its purpose is to make the effluent steadily reach the discharge standard, and bring its ecological and landscape value into play.

The effluent from east and north secondary wastewater treatment plants of Cixi City must meet the Class 1A Standard in the National Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant of China (GB18918-2002) according to the objectives of Cixi wastewater treatment.

At the November 2005 World Bank mission meetings it was noted that proposed constructed wetland design would meet most or all of the China Class 1A discharge standard. But the mission indicated that the project should also reflect the GEF needs for reductions in nitrate entering Hangzhou Bay.

Design Institute revised the original constructed wetland treatment system to make the effluent reach 2 mg/L $\text{NH}_3$-$\text{N}$ in open water. Thus it will increase the
ecological benefit of Cixi freshwater rivers and Hangzhou Bay which is the focus of GEF program.

After analysis, the indexes of the effluent and influent in the constructed wetland are shown as Table 2-1.

Table 2-1 Influent and Effluent Parameters of the Wetland Treatment Plant

<table>
<thead>
<tr>
<th>Parameter</th>
<th>COD&lt;sub&gt;c&lt;/sub&gt;r</th>
<th>BOD&lt;sub&gt;5&lt;/sub&gt;</th>
<th>SS</th>
<th>TN</th>
<th>NH&lt;sub&gt;3&lt;/sub&gt;-N</th>
<th>TP</th>
<th>FC (#/L)</th>
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</thead>
<tbody>
<tr>
<td>Influent</td>
<td>60</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>8</td>
<td>1.2</td>
<td>10&lt;sup&gt;8&lt;/sup&gt;-&lt;sup&gt;9&lt;/sup&gt;</td>
</tr>
<tr>
<td>Effluent</td>
<td>50</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>2(5)</td>
<td>0.5</td>
<td>10&lt;sup&gt;3&lt;/sup&gt;*</td>
</tr>
</tbody>
</table>

Note: the number outside the bracket is the controlled index when water temperature is over 12°C, and the one inside the bracket is the controlled index when water temperature is below or equal to 12°C.

* treated by disinfection

3.6 Construction Scale and Scheme Selection

3.6.1 Construction Scale

The associated constructed wetland of Cixi city wastewater treatment engineering will be constructed in two stages: for the North Wastewater Treatment Plant, the scale of year 2010 is 100,000 m³/d, and that of year 2020 is 320,000 m³/d; for the East Wastewater Treatment Plant, the scale of year 2010 is 50,000 m³/d, and that of year 2020 is 100,000 m³/d. Now only consider the scale of year 2010.

The total area of North constructed wetland is 86ha, covering 26ha to the north of Jiutangjiang Wastewater Treatment Plant and 60ha at Bailu Lake. 60ha land at Bailu Lake is used for Stage 1 of North Wastewater Treatment Plant. 26ha land is reserved for wastewater shock load, flood and expansion, and now is designed as free water system given simple utilization.

The area of east constructed wetland is 13.4ha, which is located at the cross of Danshuihong River and Shitanghengjiang River.

3.6.2 Scheme Selection

Compare the following 4 schemes after they satisfy GEF expected effluent
requirement:

(1) Scheme A.

1. Location and area: The constructed wetland is divided into two parts. One is located on the north of the secondary wastewater treating plant, abutting upon the Jiutang River. Its area is 26ha. The technique is Vegetated Submerged Beds + Free Water System + Vegetated Submerged Beds. The other is located in Bailu Lake, which area is 60ha. It uses the free water system technique.

2. Process: The effluent from the secondary enhanced biological treatment process will be sent to the 26ha wetland passing through Jiutangheng River by pipes. The wetland is composed of a composite subsurface wetland, a free water system and a horizontal flow wetland. The effluent from the horizontal flow wetland enters a collection pool, then is elevated by the underwater pump and sent to the 1200-meter-away 60ha Bailu Lake wetland. The influent will be distributed by multi-level distribution wells and then flows into free water system. The final effluent will be discharged into Shitangheng River after disinfected in the disinfection pond. In the flood period the water will go into Hangzhou Bay when the floodgate opens.

3. Problem: the two-level pump elevation increases energy consumption and operation cost, and is difficult for long-term operation and management.

(2) Scheme B.

1. Location and Technique: Exchange the 26ha land in Scheme A to Bailu Lake nearby. The total area is still 86ha and the technique is the same as Scheme A.

2. Problem: Loss of head is still very large and still need two-level pump elevation because a road is between the two parts of wetland. And some part of the wetland should be elevated at the current location for it is 2~3 meter lower than the discharge area. So the construction cost would be increased. At the same time, the land exchange is difficult in time and procedure because the land near Bailu Lake has been used for other purpose.

(3) Scheme C.

1. Location and Technique: the 60ha wetland near Bailu Lake is used for vegetated subsurface beds + free water system + vegetated subsurface beds. The 26ha
wetland on the north of Jiutang River is used as the reserved land for wastewater treating. All construction only needs one elevation. It is reasonable in engineering design, operation and management. This scheme adapts to Cixi City situation. It is predicted that its good removal rate of NH3-N satisfies the water quality requirement of GEF and Hangzhou Bay.

2) Problem: The decease of 26ha land would influence the ecological and landscape effects.

(4) Scheme D

1) Location and Technique: The 26ha wetland on the north of the secondary wastewater treatment plant, abutting upon Jiutang River is used for vegetated subsurface beds + free water system + vegetated subsurface beds. The 60ha wetland at Bailu Lake is used as the reserved land for wastewater treating. It is predicted that its good removal rate of NH3-N satisfies the water quality requirement of GEF and Hangzhou Bay. All construction only needs one elevation, so it is reasonable in engineering design, operation and management.

2) Problem: The decease of 60ha land is difficult to reach Nitrate-N requirement of Hangzhou Bay. And it has a great influence on the ecological and landscape effects.

(5) Scheme E

North constructed wetland will cover 86ha, which is located at 26ha land on the north of Jiutangjiang River secondary wastewater treatment plant and 60ha Bailu Lake. 60ha Bailu Lake land is used for Stage 1 constructed wetland of the north wastewater treatment plant, and 26ha is reserved for expansion. Now only consider simple use of 26ha, such as free water system technique used there. So it can be used not only for Stage 1, but also for future utilization. Only one pump elevation is needed in the whole engineering. It is reasonable in engineering design and operational management.

From above all schemes, Scheme E is recommended. Design Institute did Feasibility Scheme study design
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Scheme A</th>
<th>Scheme B</th>
<th>Scheme C</th>
<th>Scheme D</th>
<th>方案 E</th>
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<tbody>
<tr>
<td>Area</td>
<td>26 ha+60 ha</td>
<td>26 ha+60 ha</td>
<td>60ha</td>
<td>26 ha</td>
<td>26 ha+60 ha</td>
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<tr>
<td>Location</td>
<td>North on the treating plant + Bailu Lake</td>
<td>Bailu Lake and the nearby</td>
<td>Bailu Lake</td>
<td>North on the treating plant</td>
<td>North on the treating plant + Bailu Lake</td>
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<td>Total investment</td>
<td>RMB ¥59,630,000</td>
<td>RMB ¥60,160,000</td>
<td>RMB ¥57,230,200</td>
<td>RMB ¥27,740,000</td>
<td>RMB ¥57,964,500</td>
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<td>Operation cost</td>
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<td>RMB ¥0.135/m³</td>
<td>RMB ¥0.095/m³</td>
<td>RMB ¥0.065/m³</td>
<td>0.105元/m³</td>
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<tr>
<td>Annual operation fee</td>
<td>RMB ¥4,460,000</td>
<td>RMB ¥4,460,000</td>
<td>RMB ¥3,140,000</td>
<td>RMB ¥2,150,000</td>
<td>RMB ¥3,140,000</td>
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<tr>
<td>Total hydraulic loading</td>
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<td>0.14m³/m²·d</td>
<td>0.21m³/m²·d</td>
<td>0.39 m³/m²·d</td>
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<td>Operation form</td>
<td>continuous flow</td>
<td>continuous flow</td>
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<td>continuous flow</td>
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<tr>
<td>Performance</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>TSS</td>
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<tr>
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<td>≤50 mg/L</td>
<td>≤50 mg/L</td>
</tr>
<tr>
<td>BOD</td>
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<td>≤10mg/L</td>
<td>≤10mg/L</td>
<td>≤10mg/L</td>
<td>≤10mg/L</td>
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<tr>
<td>Nitrate-N</td>
<td>3.8-6.3 mg/L</td>
<td>3.8-6.3 mg/L</td>
<td>8.0-10 mg/L</td>
<td>5.2-8.0mg/L</td>
<td>3.8-6.3 mg/L</td>
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<tr>
<td>NH₃-N</td>
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<td>≤1.5mg/L</td>
<td>≤2 mg/L</td>
<td>≤1.5mg/L</td>
<td>≤1.5mg/L</td>
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<tr>
<td>TP</td>
<td>≤0.5mg/L</td>
<td>≤0.5mg/L</td>
<td>≤0.5mg/L</td>
<td>≤0.5mg/L</td>
<td>≤0.5mg/L</td>
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Chapter Three  Project Construction Scheme

<table>
<thead>
<tr>
<th>Operational management</th>
<th>2-level elevation, long-distance water transportation</th>
<th>2-level elevation, long-distance water transportation</th>
<th>1-level elevation, long-distance water transportation</th>
<th>1-level elevation, short-distance water transportation</th>
<th>1-level elevation, short-distance water transportation</th>
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<tr>
<td>Compatibility to the City Development Plan</td>
<td>no reserved land for future wastewater treatment</td>
<td>With the land nearby used, no reserved land for future wastewater treatment</td>
<td>26ha reserved for future wastewater treatment</td>
<td>60ha reserved for future wastewater treatment</td>
<td>26ha reserved for future wastewater treatment</td>
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<tr>
<td>Possibility to be the model of Constructed Wetlands</td>
<td>probable</td>
<td>possible</td>
<td>probable</td>
<td>possible</td>
<td>probable</td>
</tr>
</tbody>
</table>
3.7 North Wetland Design

3.7.1 Technique Design

Its scale is 100,000 t/d, and its area is 86ha. In it, 60ha wetland located at Bailu Lake used combined techniques of composite submerged wetland + free water system. And the other 26ha wetland located to the north of the wastewater treatment plant and abutting upon Jiutanghengjiang River is reserved for future wastewater treatment use to satisfy Cixi Future Discharge Plan. Its design technique is free water system.

Composite submerged wetland: the vertical beds are over the horizontal beds. They are in series and make up of a vertical-horizontal integrated constructed wetland system.

Free water system are composed of fully vegetated zone, open water zone and fully vegetated zone in series.

3.7.1.1 Technique Process

![Diagram of Technique Process]

Figure 3-3 Technique Process Figure

3.7.1.2 Process

The effluent from the secondary enhanced biological treatment, after elevated across Jiuranghengjiang River by crew pumps, will be sent to 60ha Bailu Lake wetland, which is 1.6km to the north of the secondary wastewater treatment plant, and 26ha wetland on the side of Jiutanghengjiang River. Finally the water is discharged into Shitanghengjiang River and Jiutanghangjiang River.
(1) Pump station

The elevation of the effluent from the north secondary wastewater treatment plant is 3.27m, and the elevation of the pipe used to discharge north wetland effluent into Shitanghengjiang River is also 3.27m. So pump station is installed to elevate water to satisfy the operation of the wetland. The pump station will be constructed inside the secondary wastewater treatment plant.

(2) Pipes across the river

The wastewater treatment plant and the target location are at two sides of the river. The pipe has to go across the river. There are some engineering in which wastewater pipes go across rivers in China. Jiutanghengjiang River is 60m wide, about 1.8m deep. The difficulty of construction is moderate.

(3) General drainage channels

Pipes across the river are connected with two general drainage channels. The channels carry wastewater to the 60ha Bailu Lake wetland. Branch pipes will be constructed at 400m away from the pump station. The branch pipes carry 10,000m³/d water to the 26ha free water system abutting Jiuranghengjiang River.

(4) 60ha Bailu Lake wetland

① Water distribution

Water is distributed after it enters 60ha Bailu Lake wetland.

② Composite submerged flow wetland

The composite submerged flow wetland is composed of vertical flow wetland and horizontal flow wetland in series. Perforated pipes are used to provide uniform distribution. When water flows from up to bottom, the effects of stuff absorption, chemical sedimentation, the plant uptake, complexation reaction and microorganisms’ use occur, so the pollutant concentration is decreased. The effluent from vertical flow wetland enters horizontal flow wetland.

③ Free Water System

The free water system is divided into three zones. The first zone is fully vegetated, in which sedimentation and flocculation of the pollutant occur. The second zone is an open water zone with almost no plants except for a few submerged species.
In this zone natural reaeration increases the level of dissolved oxygen, enhancing the nitrification of NH$_4$-N to NO$_3$-N. The third one is also a fully vegetated area similar to the first zone in function, where denitrification of wastewater occurs.

④ Enhanced biological filtration bed

After ecological pond, sewage will finally flow into the enhanced biological filtration bed which is composed of two horizontal flow wetlands in series.

The water flowing through free water system would get some organic carbon sources, and horizontal flow wetland has good anaerobic environment, so denitrification occurs. At the same time, the absorption effect of stuffings can eliminate some P.

⑤ Collection Channel

Collection channels are arranged at the end of horizontal flow wetland.

⑥ disinfection equipment

UV-disinfection is used.

(5) 26ha wetland abutting upon Jiutanghengjiang River

① water distribution

Water distribution is needed after wastewater enters the 26ha wetland. General distribution well and branch distribution wells are installed to distribute water.

② Free Water System

Rough design has done for this plot, and its technique is similar to the free water system of Bailu Lake wetland.

3.7.1.3 Water Balance

Wetland water balance analysis can determine the amount of inflow, outflow, internal increase and decrease.

(1) non rain

The inflow of north wetland is the effluent of the secondary wastewater treatment plant. Its design flow is 100,000m$^3$/d, in which 90,000m$^3$/d enters 60ha Bailu Lake wetland, and the rest 10,000 enters the 26ha wetland. Reduction of water is mainly due to evaporation and seepage. As submerged wetland has anti-seepage design, so only surface evaporation is considered. For free water system, evaporation
and seepage should be considered.

Water balance in free water system can be shown in following equation:
\[
dV_w/dt= Q_o+Q_c+Q_{sm}-Q_b-Q_e+(P+ET+I)A_w
\]
where:
\[
A_w = \text{wetland water surface area (L}^2)\]
\[
I = \text{infiltration to groundwater (L/T)}
\]
\[
Q_b = \text{berm loss rate (L}^3/T)\]
\[
Q_o = \text{wastewater inflow rate (L}^3/T)\]
\[
Q_{sm} = \text{snowmelt rate (L}^3/T)\]
\[
V_w = \text{water volume in wetland (L}^3)\]

Darcy’s Law can be used to describe the infiltration process in soil
\[
Q = K \cdot A \cdot J
\]
where:
\[
Q: \text{ infiltration flow (m}^3/s)\]
\[
K: \text{ infiltration coefficient (m/s), indicates physical attribute of soil}\]
\[
A: \text{ flow section area (m}^2)\]
\[
J: \text{ hydraulic grade}\]

Reference infiltration coefficient of common soils is shown as Table 3-1

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Infiltration Coefficient(k) cm/s</th>
<th>Soil Type</th>
<th>Infiltration Coefficient(k) cm/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>clay</td>
<td>$&lt;10^{-7}$</td>
<td>medium sand</td>
<td>$10^{2}$</td>
</tr>
<tr>
<td>silty clay</td>
<td>$10^{-5} \sim 10^{-6}$</td>
<td>coarse sand</td>
<td>$10^{2}$</td>
</tr>
<tr>
<td>silty soil</td>
<td>$10^{-4} \sim 10^{-5}$</td>
<td>cinnabar</td>
<td>$10^{-1}$</td>
</tr>
<tr>
<td>silt</td>
<td>$10^{3} \sim 10^{4}$</td>
<td>gravel</td>
<td>$&gt;10^{-1}$</td>
</tr>
<tr>
<td>fine sand</td>
<td>$10^{3}$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The soil in new reclaimed mudflats is salty sand and salty clay, which granule is small and homogeneous powder-type clay. Anti-seepage geomembrane is used in submerged wetland substrates. And clay is used as the substrates of free water system and will be tamped, so its infiltration coefficient decreases significantly. Assume its
infiltration coefficient as $10^{-5}$ to $10^{-6}$ cm/s, that is to say $1 \times 10^{-7}$ m/s to $1 \times 10^{-8}$ m/s.

Now for the 26ha free water system, the seepage of Q is $224.6 \sim 2246.4$ m$^3$, the effective volume is $115,200$ m$^3$ (water depth 0.4 ~ 0.8m, average 0.6m), design retention time is 15d, and net water demand is 7680 m$^3$/d. After computed, wastewater supplement volume in a day $Q = 1040$ m$^3 + 2000$ m$^3 + 7680$ m$^3 = 10720$ m$^3$.

For the 42ha free water system of the 60ha wetland, the seepage of Q is $224.6 \sim 2246.4$ m$^3$. The effective volume of the 60ha wetland: is $115,200$ m$^3$ (water depth 0.4 ~ 0.8m, average 0.6m), design retention time is 15d, and net water demand is 7680 m$^3$/d. After computed, wastewater supplement volume in a day $Q = 1040$ m$^3 + 2000$ m$^3 + 7680$ m$^3 = 10720$ m$^3$.

(1) 10ha submerged wetland: $100000 \times 1.0 \times 0.4 = 40000$ m$^3$  (2) 6ha enhanced biological infiltration beds: $60000 \times 0.7 \times 0.3 = 12600$ m$^3$  (3) 42ha free water system: $420000 \times 0.8 \times 0.8 = 268800$ m$^3$ (water depth 0.6 ~ 1.2, average 0.8m). The total effective volume is 321400 m$^3$. The evaporation and seepage volume is: $Q = 2400$ m$^3$ (ET) + $3500$ m$^3$ (I) = 5900 m$^3$. When wastewater supplement volume in a day $Q$ is $90,000$ m$^3$, the actual hydraulic retention time in 60ha wetland is 3.85d.

(2) rainy day

Not only municipal wastewater, but also precipitation enters the wetland. The largest precipitation in Cixi City in last over 20 years is 161.2mm. It occurs on 14:16 of 22 to 18:16 of 23 in September 1981. The corresponding precipitation in a day is 138.2mm. So the increase amount of wetland water due to precipitation is 82,920 m$^3$/d for the 60ha wetland and 35,932 m$^3$/d for the 26ha wetland.

The inflow and outflow control devices of the constructed wetland should be adjusted in large precipitation period, and the 26ha spare wetland can be used as a reservoir. Pumps driven by portable diesel motors can be considered to pump the extra water if in emergency.

3.7.2 Layout

Part 1: 60ha composite wetland located at Bailu Lake(Figure N1);

Four trains of treatment systems. Each train is composed of composite submerged wetland, free water system and horizontal flow wetland in series. The area
of fully vegetated zone, open water zone and wetland islands are respectively 60, 30 and 10 percent of the total area of the free water system.

Part 2: 26ha free water system to the north of Jiutangjiang River Secondary Wastewater Treatment Plant

The plot is reserved for future wastewater treatment. Recently this plot is designed as free water system wetland, and in future it can be constructed to be a wetland which technique is the same as Bailu Lake wetland.

The pump station is constructed in the wastewater treatment plant.

3.7.3 unit design

(1) Pump station

The pump station is semi-underground. It is 3m below the ground. The pump is recommended to use one type and decided based on volume, water quality and lift. Big and small pumps should be matched and only a few types should be used, or a gear-shifted electromotor can be use. A spare pump should be installed. Velocity design is 0.7～1.5m/s for influent pipe and 0.8～2.5m/s for effluent pipe.

(2) General Pipeline

North pipelines uses pressure flow scheme, in which two reinforced concrete pipes are laid in parallel, one for common use, the other for spare use. The backbone pipe begins from the pump station in the secondary wastewater treatment plant to the distribution well in Bailu Lake. The length of the pipe is 2128m, its diameter is DN900～DN1000, and its slope is 0.001. The wastewater flows from south to north along Cisi Road, turns west at Bailu Lake, and finally enters the general distribution well of Bailu Lake wetland. In addition, two branch pipes are installed at the Cisi Road pipeline. They are 570m long, its diameter is DN300, and its slope is 0.001. The wastewater is shunted from Cisi pipeline to the general distribution well of 26ha free water system wetland.

The pipeline is across a watercourse – Jiutanghengjiang River. When the wastewater pipe is below the elevation of riverbed in the watercourse plan and the distance of the top of pipe to the elevation of the riverbed in the watercourse plan satisfies the regulation, the wastewater pipe uses straight types and is constructed by
means of cofferdam or ceiling coil. When the wastewater pipe is over the elevation of the riverbed in the watercourse plan, two 30 degree swerve pipes are used and are constructed by means of cofferdam or ceiling coil. If the riverbed of Jiutanghengjiang is washed out, anti-scouring actions should be considered. Two jointing steel pipes are connected by valves, one for common use, and the other for spare use. When in rush time, two pipes are used in parallel. Once one pipe is in disorder, it can be repair after the influent valve is closed and the emptier valve is opened. And the other pipe can still operate. The pipes is 70m long, its diameter is 0.8m and its design velocity is 2.3m/s.

(3)60ha wetland at Bailu Lake

A. composite submerged wetland

The composite submerged wetland is arranged at the beginning of the whole techniques, and is divided into 4 parallel trains. Each train has two units in series: the first unit is vertical flow wetland and the second horizontal flow wetland.

Total area: \( S = \frac{Q}{q} = 100000 \text{m}^2 \);
Area of single unit of wetland: \( S = 12500 \text{m}^2 \);
Aspect of single unit: \( B \times L = 50 \times 250 \text{m} \);
Diameter of the gravel in the bed: 25～30mm;
Thickness of the gravel: \( h = 1000 \text{mm} \);
Volume of the gravels: \( V = 100000 \text{m}^3 \);
Design slope: 0.3%;
Design water slope: 0.05%～0.1%.

B. Free Water System

Free Water System is designed into two treatment systems. Each is divided into 3 zones: the first and third zones are fully vegetated, and the second one is an open water area. Flow directions are controlled by claybanks and wetland islands. By gravity the wastewater circuitously flows through the wetland: fully vegetated zone – open water zone – fully vegetated zone.

Total area: \( S = \frac{Q}{q} = 400000 \text{m}^2 \);
Chapter Three  Project Construction Scheme

Water depth: $h_1 = h_3 = 600$mm Fully vegetated zones

$h_2 = 1200$mm Open-water zone

Design porosities: 0.65 Fully vegetated zones

1.0 Open-water zones

Vegetation:

Emergent-  reed, bulrush

Submerged-  pondweed

Design bottom slope: 0.3%

Design top slope: 0.05%-0.1%.

C. Horizontal Flow Wetland

The horizontal flow wetland is arranged at the end of the whole technique. It is divided into two parallel trains. Each train has two horizontal flow wetland units in series.

Total area: $S=Q/q=60000$m$^2$;

Area of single unit: $S=7500$m$^2$;

Aspect of single unit: $B \times L = 150 \times 50$m;

Diameter of biological stuffings: 5-15mm;

Thickness of stuffings: $h=700$mm;

Volume of gravels: $V=42000$m$^3$;

Design bottom slope: 0.3%;

Design water slope: 0.05%~0.1%.

D. Collection Channel

The effluent from the wetland enters collection channel. Its parameters are shown in Figure 3-2.

Figure 3-2  Rectangular Section (Non Full Flow) Design Parameters of Collection Channel

<table>
<thead>
<tr>
<th>Far end from the discharge point</th>
<th>Q=Av (m$^3$/s)</th>
<th>0.290</th>
<th>$v=(R^{0.5})/n$</th>
<th>1.044</th>
</tr>
</thead>
<tbody>
<tr>
<td>$v$—velocity (m/s)</td>
<td>$W$—channel width (m)</td>
<td>$H$—water depth (m)</td>
<td>$n$—roughness coefficient</td>
<td>$i$—hydraulic grade</td>
</tr>
</tbody>
</table>
Chapter Three  Project Construction Scheme

<table>
<thead>
<tr>
<th>1.044</th>
<th>1.2</th>
<th>0.232</th>
<th>0.013</th>
<th>0.002</th>
</tr>
</thead>
<tbody>
<tr>
<td>X—wetted perimeter(m)</td>
<td>A—flow section (m²)</td>
<td>R—hydraulic radium (m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.664</td>
<td>0.278</td>
<td>0.167</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Near end from the discharge point</td>
<td>Q=Av (m³/s)</td>
<td>0.580</td>
<td></td>
<td></td>
</tr>
<tr>
<td>v—velocity (m/s)</td>
<td>W—channel width (m)</td>
<td>H—water depth (m)</td>
<td>n—roughness coefficient</td>
<td>i—hydraulic grade</td>
</tr>
<tr>
<td>1.293</td>
<td>1.2</td>
<td>0.374</td>
<td>0.013</td>
<td>0.002</td>
</tr>
<tr>
<td>X—wetted perimeter(m)</td>
<td>A—flow section (m²)</td>
<td>R—hydraulic radium (m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.948</td>
<td>0.449</td>
<td>0.230</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

E. General Drainage Pipe

The general drainage pipe is a concrete pipe, which diameter is 1.5m and slope is 0.001.

(8) Head Loss

The most disadvantaged places of the system are the farthest end to the distribution well, that is to say, the northeast and the northwest of the wetland. The head loss in the most disadvantaged places are is shown in Table 3-3.

<table>
<thead>
<tr>
<th>Equipment/Construction</th>
<th>length/form(m)</th>
<th>Head loss/ hydraulic grade (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>① Distribution system</td>
<td>Porous PVC pipes</td>
<td>0.60</td>
</tr>
<tr>
<td>② composite submerged wetland</td>
<td>240×130×1.0</td>
<td>0.40</td>
</tr>
<tr>
<td>③ free water system</td>
<td>375×240×0.8</td>
<td>0.20</td>
</tr>
<tr>
<td>④ horizontal flow wetland</td>
<td>240×78×0.70</td>
<td>0.30</td>
</tr>
<tr>
<td>⑤ collection channel</td>
<td>225</td>
<td>0.45</td>
</tr>
<tr>
<td>⑥ disinfection area</td>
<td>open ditch</td>
<td>0.50</td>
</tr>
<tr>
<td>⑦ general drainage channel</td>
<td>150</td>
<td>0.15</td>
</tr>
<tr>
<td>total head loss</td>
<td></td>
<td>2.00</td>
</tr>
</tbody>
</table>

F. Disinfection
Chapter Three  Project Construction Scheme

After treated by UV disinfection, the effluent from wetland finally will be discharged into Shitanghengjiang River.

(4) 26ha wetland abutting upon Jiutanghengjiang River

Free water system is divided into two sets of treatment systems. Each set of treatment system has fully vegetated zone, open water zone and fully vegetated zone. Flow directions are controlled by claybanks and wetland islands. By gravity the wastewater circuitously flows through the wetland: fully vegetated zone - open water zone - fully vegetated zone.

Total area: \[ S = \frac{Q}{q} = 240000 \text{m}^2 \]

Water depth: \( h_1 = h_3 = 400 \text{mm} \) Fully vegetated zones
\( h_2 = 800 \text{mm} \) Open-water zone

Design porosities: 0.65 Fully vegetated zones
1.0 Open-water zones

Vegetation:
- Emergent - reed, bulrush
- Submerged - pondweed

Design bottom slope: 0.3%
Design top slope: 0.05%-0.1%

3.8 East Wetland Design

Its scale is 50,000 t/d, and it combines techniques of submerged wetland (including vertical flow and horizontal flow wetland) and free water system (shown in Figure 3-4).

3.8.1 Technique Design

3.8.1.1 Technique Process
3.8.1.2 Process

The effluent from the secondary enhanced biological treatment, after elevated across Jiuranghengjiang River by crew pumps, will be sent to the east constructed wetland. After treated by the wetland, the water finally is discharged into Danshuihong River.

3.8.1.3 Water Balance

1. Evaporation

Annual evaporation in Cixi City is about 1476.9mm, that is to say 4mm/d. So the evaporation of 13.4ha wetland is $536m^3/d$.

2. Infiltration

Assume the infiltration coefficient as $10^{-5} \sim 10^{-6} \text{cm/s}$, that is to say $1 \times 10^{-7} \text{m/s} \sim 1 \times 10^{-8} \text{m/s}$.

For the 8.25ha free water system of the 13.4ha wetland, the seepage of Q is $77.2 \sim 772.2m^3/d$. The effective volume of the east wetland: ①2.52ha submerged wetland: $25200 \times 1.0 \times 0.4 = 10080 \text{ m}^3$ ②1.4ha enhanced biological infiltration beds: $14400 \times 0.7 \times 0.3 = 3024 \text{ m}^3$ ③8.25ha free water system: $82500 \times 0.6 \times 0.8 = 39600 \text{ m}^3$

(water depth $0.4 \sim 0.8$m, average 0.6m)。The total effective volume is $52704 \text{ m}^3$.

The evaporation and seepage volume is: $Q=536 \text{ m}^3 \ (ET)+687.5 \text{ m}^3 \ (1) = 1223.5 \text{ m}^3$. The actual hydraulic retention time in 60ha wetland is 1.08d.

3.8.1.4 Hydraulic Computation

When its hydraulic loading is $0.44m^3/m^2 \cdot d$, the HRT is 1.08d.

3.8.2 Layout

Cixi Authorities determined that the land used for east constructed wetland is about 13.4ha. The general arrangement of wetland is based on the 13.4ha land (shown
in figure E1). It is composed of composite submerged wetland, free water system and horizontal flow wetland in series.

Composite submerged wetland is composed of 3 parallel vertical flow wetland units and 7 horizontal flow wetland units in series. Free water system is composed of 5 units. Every unit has fully vegetated zone, open water zone and fully vegetated zone. Horizontal flow wetland is divided into two levels: 4 units in first-level and 2 units in second-level. The arrangement of wetland islands is the same as that of north wetland. Flow directions are controlled by claybanks and wetland islands. By gravity the wastewater circuitously flows through the wetland: fully vegetated zone – open water zone – fully vegetated zone.

The east pump station is constructed in the east wastewater treatment plant.

3.8.3 unit design

(1) Pump station

The east pump station is constructed in the east wastewater treatment plant. The pump station is semi-underground. It is 3m below the ground. Its type is based on volume, water quality and lift. Big and small pumps should be matched and only a few types should be used, or a gear-shifted electromotor can be use. A spare pump should be installed. Velocity design is 0.7~1.5m/s for influent pipe and 0.8~2.5m/s for effluent pipe.

(2)General Pipeline

Two reinforced concrete pipes are laid in parallel, one for common use, the other for spare use. The pipes begin from the pump station in the secondary wastewater treatment plant to the east distribution wells. The length of the pipe is 60m, its diameter is DN700, and its slope is 0.001.

(2)wetland

A. composite submerged wetland

Total area: \( S = \frac{Q}{q} = 27860 \text{m}^2 \);

vegetated gravel beds are two levels in series. The first level has 3 units, second 6 units. Total is 9 units.

Area of single unit of wetland: \( S = 2800 \text{m}^2 \);
Chapter Three  Project Construction Scheme

Aspect of single unit: BxL=36.0mx78.0m;
Diameter of the gravel in the bed: 25~30mm;
Thickness of the gravel: h=1000mm;
Volume of the gravels: V=27860m³;
Design slope: 0.3%;
Design water slope: 0.05%~0.1%.

B. Free Water System

Free water system is composed of 4 levels in series. The first level has 2 treatment units, and the rest level has 1 unit each. Total is 5 units. The internal design of every unit is similar to that of the north wetland.

Design hydraulic loading: q=0.61m³/m².d;
Total area: S=Q/q=82500m²;
Deep water area: S=17500m²;
Average unit area: S=16500m²;
Water depth: h₁= h₃=600mm Fully vegetated zone and open water zone
h₂=2000mm Deep-water zone
Design porosities: 0.65 Fully vegetated zones

1.0 Open-water zones

Vegetation:
Emergent- reed, bulrush
Submerged- pondweed

HRT: 0.76d;
Design bottom slope: 0.3%
Design top slope: 0.05%~0.1%.

C. Horizontal Flow Wetland

Area: S=Q/q=14500m²
two levels, total 6 units.
Area of single unit: S=2400m²
Aspect of single unit: BxL=35.0mx68.0m
Diameter of biological stuffings: 3-10mm
Chapter Three  Project Construction Scheme

Thickness of stuffings: \( h = 700 \text{mm} \);
Volume of gravels: \( V = 10150 \text{m}^3 \)
Design bottom slope: 0.3%
Design water slope: 0.05%～0.1%.

3.9 Characters of the wetland

Characters of the north and east wetlands are shown in Table 3-4.

<table>
<thead>
<tr>
<th>Table 3-4 Characters of the North and East Wetlands</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Item</strong></td>
</tr>
<tr>
<td>Design Scale</td>
</tr>
<tr>
<td>Area</td>
</tr>
<tr>
<td>Total investment</td>
</tr>
<tr>
<td>Operation cost</td>
</tr>
<tr>
<td>Technique</td>
</tr>
<tr>
<td>Total HRT</td>
</tr>
<tr>
<td>Total hydraulic loadings</td>
</tr>
<tr>
<td>Operation form</td>
</tr>
<tr>
<td>Performance</td>
</tr>
<tr>
<td>Operation and management</td>
</tr>
<tr>
<td>Ecological value</td>
</tr>
<tr>
<td>Aesthetic value</td>
</tr>
<tr>
<td>Compatibility to the City Development Plan</td>
</tr>
<tr>
<td>Possibility to be the model of Constructed Wetlands</td>
</tr>
</tbody>
</table>
Chapter Four  Predict of Constructed wetland treatment effect

The project require that the effluent from east and north secondary wastewater treatment plants of Cixi City must meet the Class 1A Standard in the National Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant of China (GB18918-2002) and the water discharged into the inland freshwater river must meet the requirement of landscape use. At the same time, the World Bank mission noted that the design should not only meet the China Class 1A discharge standard, but also reflect the GEF needs for reduction in nitrate entering Hangzhou Bay. So the Design Institute is expected to make some technical improvements and revise the original constructed wetland treatment system to make the effluent reach 2 mg/L NH$_3$-N in open water. Thus it would increase the ecological benefits to the inland freshwaters of the Cixi City region and Hangzhou Bay which is the focus of GEF program.

Thus, the scheme revises the techniques of the north 26ha wetland and horizontal flow vegetated gravel bed in the east wetland, and uses composite submerged bed to enhance the nitrification-denitrification effect.

4.1 Design Improvement of the Constructed Wetland

4.1.1 Enhancement of the removal rate of N and P

(1) N

The removal rate of N in traditional constructed wetland is only about 20-50 percent, and that in activated sludge process is still lower.

To increase the oxygen supply to constructed wetland and to improve the nitrification effect in order to effectively remove ammonia and nitrogen, is always a highlighted research issue of the technique. As there is good nitrification effect in vertical flow wetland and good denitrification effect in horizontal flow wetland even in very low C/N ratio, the two are combined to enhance the removal of nitrogen in
Chapter Four    Predict of Constructed wetland treatment effect

abroad. The results indicate that the removal rate of N can reach 65 percent when the concentration of NO\textsubscript{3}-N is 1g/m\textsuperscript{2}. In addition, for constructed wetland has good effect to remove organic substances, denitrification process may be lack of carbon sources, so to put organic carbon sources into wastewater can facilitate the removal of nitrogen.

So some experts have some nitrified wastewater go back into sedimentation pond and mix untreated wastewater fully. Denitrification bacteria get carbon sources in sedimentation pond and begin to denitrify. Experiments indicate: the removal rate of N can reach 72 percent. Some put methanol when denitrification, and its removal rate of N can reach 78%.

(2) P

Because the removal of P in constructed wetland is mainly influenced by absorption and sedimentation effects of substrates, proper substrates are critical to the removal of P. Substrates usually used are pumice, sand, LECA, wollastonite, limes and blast furnace slag from industry castoff. Grass carbon, arable layer soil which are rich in organic substances and porous high-carbon coal ash and slag all have potential to absorb P. In gravel-stuffed wetland, phosphate radical ion can react with the calcium in the gravel, generates insolvable calcium phosphate and settles from the water. Therefore, lime is the best stuffing to remove P in chemical reactions. And the ferrated wetland influent helps to the removal of P.

4.1.2 Design Improvement of Constructed Wetland

The nitrogen removal effect of the constructed wetland, esp. the nitrification effect is enhanced. Following revisions are incorporated in the design.

(1) Following improvements are to enhance nitrification effect:

A. The original horizontal flow wetland techniques are revised as composite flow wetland techniques. The downstream subsurface wetland structure forms the aerobic-anaerobic state change inside the substrate beds. It enhances the reaeration of the wetland so that this adjustment facilitates the nitrification. The anaerobic condition in the horizontal flow wetland is better than that of the vertical flow wetland, which promotes the denitrification effect. Thus such techniques have the substantial
potential to remove the nitrogen.

B. Cattails and calamus are planted in the wetland. They all have rhizomes which grow deep into the soil. They can act as the flow channels to enhance the vertical flow and horizontal transfer of the water in the wetland. Their exuberant fibrous root system can dredge the flow and transfer the oxygen, bring plenty of oxygen into the wetland system, increase the energy of microorganisms, and enhance the treatment effect.

Increase the area of emergent vegetation in free water system, decrease the area of open water. This increases the retention time of the wastewater in the wetland and improves the efficiency of the pollutant removal.

(2) Following improvements are to enhance denitrification effect:

A. Cattails and calamus are the major wetland plants. They have a character of large biomass, strong adaptation ability, easy vegetation, and long time to decay. They can provide carbon sources for denitrification.

B. supplement of carbon sources is planned in engineering process design. In vertical flow – free water system – horizontal flow technique, high BOD wastewater from the secondary wastewater treatment plant directly goes into the gravel beds, saving outer supply of carbon sources; in free water system, plants provide carbon sources before wastewater enters horizontal gravel beds. For the horizontal flow wetland is anaerobic, the whole technique forms a good nitrification – denitrification process.

4.2 Performance Prediction of Constructed Wetland

4.2.1 Minimal Requirement of Constructed Wetland Performance

The wetland-associated new Cixi Urban Wastewater Treatment Plants use invert A/A/O technique to remove N and P. The technique enhances the effect to remove P and increase the denitrification speed. Table 4-1 shows the influent indexes of Cixi Urban Wastewater Treatment Plants. Table 4-2 shows the influent and effluent indexes of the constructed wetland, and Table 4-3 shows the minimal treatment requirement of wetland which GEF project expects.
Table 4-1 Influent Indexes of Cixi Urban Wastewater Treatment Plants (unit: mg/L)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>COD&lt;sub&gt;cr&lt;/sub&gt;</th>
<th>BOD&lt;sub&gt;5&lt;/sub&gt;</th>
<th>SS</th>
<th>TN</th>
<th>NH&lt;sub&gt;3&lt;/sub&gt;-N</th>
<th>TP</th>
<th>FC(#/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influent</td>
<td>400</td>
<td>200</td>
<td>300</td>
<td>50</td>
<td>30</td>
<td>5.5</td>
<td>10&lt;sup&gt;8&lt;/sup&gt;-9</td>
</tr>
<tr>
<td>Effluent</td>
<td>60</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>--</td>
<td>1.2</td>
<td>10&lt;sup&gt;9&lt;/sup&gt;-9</td>
</tr>
</tbody>
</table>

Table 4-2 Influent and Effluent indexes of the Constructed Wetland (unit: mg/L)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>COD&lt;sub&gt;cr&lt;/sub&gt;</th>
<th>BOD&lt;sub&gt;5&lt;/sub&gt;</th>
<th>SS</th>
<th>TN</th>
<th>NH&lt;sub&gt;3&lt;/sub&gt;-N</th>
<th>TP</th>
<th>FC(#/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Influent</td>
<td>60</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>8</td>
<td>1.2</td>
<td>10&lt;sup&gt;8&lt;/sup&gt;-9</td>
</tr>
<tr>
<td>Effluent</td>
<td>50</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>2(5)</td>
<td>0.5</td>
<td>10&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

Note: the number outside the bracket is the controlled index when water temperature is over 12°C, and the one inside the bracket is the controlled index when water temperature is over 12°C.

Table 4-3 Minimal Treatment Requirement of Wetland Which GEF Project Expects

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Influent</th>
<th>Effluent</th>
<th>Removal Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD&lt;sub&gt;cr&lt;/sub&gt; (mg/L)</td>
<td>60</td>
<td>50</td>
<td>&gt;16.7</td>
</tr>
<tr>
<td>BOD&lt;sub&gt;5&lt;/sub&gt; (mg/L)</td>
<td>20</td>
<td>10</td>
<td>&gt;50</td>
</tr>
<tr>
<td>SS (mg/L)</td>
<td>20</td>
<td>10</td>
<td>&gt;50</td>
</tr>
<tr>
<td>TN (mg/L)</td>
<td>20</td>
<td>10</td>
<td>&gt;50</td>
</tr>
<tr>
<td>NH&lt;sub&gt;3&lt;/sub&gt;-N (mg/L)</td>
<td>8</td>
<td>2(5)</td>
<td>&gt;75 (37.5)</td>
</tr>
<tr>
<td>TP (mg/L)</td>
<td>1.2</td>
<td>0.5</td>
<td>&gt;58.3</td>
</tr>
<tr>
<td>FC(#/L)</td>
<td>10&lt;sup&gt;8&lt;/sup&gt;-9</td>
<td>10&lt;sup&gt;3&lt;/sup&gt;</td>
<td>≈100</td>
</tr>
</tbody>
</table>

Note: the number outside the bracket is the controlled index when water temperature is over 12°C, and the one inside the bracket is the controlled index when water temperature is over 12°C.

From Table 4-3, the index fores NH<sub>3</sub>-N, TP and FC are very strict, and those of COD, BOD and TSS are not so strict. The treatment of N and P is the focus of tertiary treatment. Land treatment can make full use of physical, chemical and biological treatment. The water quality of wastewater treatment by such technique is better than other wastewater treated by other techniques. 100 percent removal rate of FC is to satisfy the need for landscape and entertainment. 70 – 80 percent FC are removed by constructed wetland, and the rest are removed by disinfection process.

4.2.2 Prediction of Wetland Treatment

The degradation of pollutants for the north wetland mainly occurs in the 26ha
wetland. And the degradation for the east wetland is similar to that for the north wetland. So the prediction of the treatment is detailed in the 26ha wetland of the north wetland.

The major process occurring in the constructed wetland is denitrification effect, because in the most time the constructed wetland, esp. the gravel beds are in the anoxic or anaerobic condition. So the high nitrate/low ammonial effluent from the secondary wastewater treatment plant facilitates the nitrogen polishing effect of the wetland. Feasibility Report on Cixi Urban Wastewater Treatment Plants indicates that in the effluent from current Cixi Wastewater Treatment Plant, the concentration of TN is about 20mg/L, and that of NH₃-N is 2-4mg/L. So most of TN is NO₃⁻. It provide a good condition for denitrification. NH₃-N in the wetland effluent is hoped to be below 2 mg/L which is GEF project expects.

Efficiency of wetland to remove waste is impacted by various environmental factors and many construction and management actions. So based on the seasonal character change of raw water, performance prediction is made in spring, summer, autumn and winter. In every season the effluent quality of the combined techniques - A/A/O technique and constructed wetland – is taken as the limiting indexes to achieve the most potential of the combined technique, so optimal effluent is obtained in every season.

4.2.2.1 Prediction of Wetland Treatment in Spring

In spring the temperature of raw water is 13～25°C. Wetland plants grow slowly and the activity of microorganisms is weak. After May wetland plants grow fast and microorganism system form eventually. Because the optimal temperature for nitrification is 20～30°C, the rate of nitrification declines when temperature is below 15°C. So the major form of N in the effluent from secondary wastewater treatment plants should be nitrate, and the main process in wetland to remove nitrogen is denitrification. At the same time, high COD provides more carbon sources for denitrification in wetland. Thus, secondary wastewater treatment plants should reinforce the operation of nitrification technique to enhance the removal effect of nitrogen in wetland.
Spring is the early stage of plant growth. Plants' root system is not developed, bio-films attached to root system are few, and micro ecological structure of root system is not complete, so denitrification effect of the micro ecological structure of root system to nitrates is very weak. There is many decomposed plants in free water system, and much organic carbon. Conditions for denitrification are satisfied and the efficiency of denitrification effect is high. But decomposed plants release P in spring and free water system remove little P now. However, absorption and uptake effect of the submerged gravel beds is effective to remove P. When two types of wetland are combined in series, free water system can effectively remove nitrogen for denitrification, and provide energy for denitrification in submerged wetland to offset the negative effect of P release.

The effective area of composite submerged wetland is 160000m², and that of free water system is 400000m². From current research and experiences, under the design conditions in spring, removal rate of composite submerged wetland and free water system can reach the indexes shown in Table 4-4. Thus, only when the influent entering the constructed wetland satisfies the indexes in Table 4-4, can the effluent from 60ha wetland reach the target GEF expects.

<table>
<thead>
<tr>
<th>Item</th>
<th>Influent</th>
<th>Pollutant loading g/m²/d</th>
<th>Removed Amount by Composite Submerged Wetland g/m²/d</th>
<th>Removed Amount by Free Water System g/m²/d</th>
<th>Removed Amount by the System g/m²/d</th>
<th>Removal rate(%)</th>
<th>Effluent mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>60</td>
<td>9.01</td>
<td>2.25</td>
<td>1.35</td>
<td>3.60</td>
<td>40</td>
<td>36</td>
</tr>
<tr>
<td>NH₄-N</td>
<td>4.4</td>
<td>0.66</td>
<td>0.20</td>
<td>0.17</td>
<td>0.36</td>
<td>55</td>
<td>2</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>14</td>
<td>2.10</td>
<td>0.63</td>
<td>0.53</td>
<td>1.16</td>
<td>55</td>
<td>6.3</td>
</tr>
<tr>
<td>TN</td>
<td>20</td>
<td>3.00</td>
<td>1.05</td>
<td>0.60</td>
<td>1.65</td>
<td>55</td>
<td>9</td>
</tr>
<tr>
<td>TP</td>
<td>1.1</td>
<td>0.17</td>
<td>0.08</td>
<td>0.01</td>
<td>0.09</td>
<td>55</td>
<td>0.5</td>
</tr>
</tbody>
</table>

4.2.2.2 Prediction of Wetland Treatment in Summer

In summer the temperature of raw water is usually 25～28°C. Wetland plants grow fast and the activity of microorganisms is high. Plants’ root system is not
developed, and micro ecological structure of root system is complete, that is to say, bio-films attached to root system are more than the bio-films in free water system. Therefore the denitrification effect to nitrates of micro ecological structure of root system in submerged wetland is greater than that of the bio-films in free water system. So submerged wetland has better potential to remove nitrogen than free water system in summer.

Plants' fast growth in summer can absorb part of P, but the main removal of P is absorption and sedimentation occurring in stuffing layer and root system layer. Such physical and chemical processes are rarely subject to other factors. So two types of constructed wetland are very good to remove P in summer.

Under the design conditions in summer, removal rate of composite submerged wetland and free water system can reach the indexes shown in Table 4-5. Thus, only when the influent entering the constructed wetland satisfies the indexes in Table 4-5, can the effluent from 60ha wetland reach the target GEF expects.

From the table, it is seen that removal rates of all the pollutants in summer are the highest so that more loading of COD, NO₃-N, TN and TP are allowed to enter the wetland, but the highest loading of NH₄-N should be below 8mg/L to get effluent of 2mg/L NH₄-N.

<table>
<thead>
<tr>
<th>Item</th>
<th>Influent</th>
<th>Pollutant loading g/m²/d</th>
<th>Removed Amount by Composite Submerged Wetland g/m²/d</th>
<th>Removed Amount by Free Water System g/m²/d</th>
<th>Removal rate(%)</th>
<th>Effluent mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>60</td>
<td>9.01</td>
<td>4.51</td>
<td>1.80</td>
<td>6.31</td>
<td>70</td>
</tr>
<tr>
<td>NH₄-N</td>
<td>8</td>
<td>1.20</td>
<td>0.54</td>
<td>0.36</td>
<td>0.90</td>
<td>75</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>11</td>
<td>1.65</td>
<td>0.74</td>
<td>0.50</td>
<td>1.24</td>
<td>75</td>
</tr>
<tr>
<td>TN</td>
<td>20</td>
<td>3.00</td>
<td>1.35</td>
<td>0.90</td>
<td>2.25</td>
<td>75</td>
</tr>
<tr>
<td>TP</td>
<td>1.4</td>
<td>0.21</td>
<td>0.11</td>
<td>0.03</td>
<td>0.14</td>
<td>65</td>
</tr>
</tbody>
</table>

4.2.2.3 Prediction of Wetland Treatment in Autumn

In about 80 percent time of autumn, the temperature of raw water is over 20°C.
Such temperature has little influence on the activity of microorganisms. The plant parts above ground become completely dead after middle November, and the activity of their underground roots and stems turn weak eventually. When water temperature is not below 20°C, the activity of micro ecological structure composed of bio-films attached on root systems is still strong, and physical pickup and absorption and direct denitrification are also effective. So pollutants removal ability of root system is fine when hydraulic loading of the wetland is proper in autumn. Compared with the treatment performance in summer, some pollutant concentrations of free water system in autumn will increase, because some COD, organic N and NH₄-N are released after plants fade, fall into water and decay. Then the cleansing ability of submerged wetland is better than that of free water system.

Under the design conditions in autumn, removal rate of composite submerged wetland and free water system can reach the indexes shown in Table 4-6. Thus, only when the influent entering the constructed wetland satisfies the indexes in Table 4-6, can the effluent from 60ha wetland reach the target GEF expects.

**Table 4-6 Predicted Performance of North Constructed Wetland (60 ha plot) in Autumn**

<table>
<thead>
<tr>
<th>Item</th>
<th>Influent</th>
<th>Pollutant loading g/m²/d</th>
<th>Removed Amount by Composite Submerged Wetland g/m²/d</th>
<th>Removed Amount by Free Water System g/m²/d</th>
<th>Removal rate(%)</th>
<th>Effluent mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>60</td>
<td>9.01</td>
<td>2.70</td>
<td>1.80</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>NH₄-N</td>
<td>8</td>
<td>1.20</td>
<td>0.54</td>
<td>0.36</td>
<td>75</td>
<td>0.2</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>11</td>
<td>1.65</td>
<td>0.74</td>
<td>0.50</td>
<td>75</td>
<td>2.8</td>
</tr>
<tr>
<td>TN</td>
<td>20</td>
<td>3.00</td>
<td>1.35</td>
<td>0.90</td>
<td>75</td>
<td>5</td>
</tr>
<tr>
<td>TP</td>
<td>1.2</td>
<td>0.18</td>
<td>0.09</td>
<td>0.02</td>
<td>60</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**4.2.2.4 Prediction of Wetland Treatment in Winter**

The treatment efficiency of constructed wetland differs because it is a ecological system which energy is from the sun, and the solar radiation differ in a day and a year. The most obvious influence of solar radiation’s cycle to efficiency is that it impacts the temperature of wetland water body and soil. With the change of temperature, the
activity of microorganisms differs, and leads to changed system efficiency. The research of Vyazal shows that temperature change is the most related factor to ammonification. Research indicates that between moderate range of temperature, removal rate of ammonia is relatively steady. Its is typical in North America wetland system that nitrification rate is obviously steady at 10°C; treatment efficiency obviously decreases when the temperature is below 10°C; and it decreases fast below zero when temperature is below 6°C. Denitrification rate is quite low at 5°C.

Raw water temperature in winter is between 8°C-13°C. It has little influence on heterotrophism bacteria’s activity, but can restrain autotrophism bacteria. Because wetland plants fade in winter and underground are dormant, the pollutant cleansing is mainly by physical and chemical reactions of the stuffing layer and the biochemical reaction of the bio-films attached on the root and stuffing layer. The local water volume used in winter is usually 60 percent of that in summer, so low hydraulic loading of constructed wetland helps to get good effluent.

Under the design conditions in autumn, removal rate of composite submerged wetland and free water system can reach the indexes shown in Table 4-7. Thus, only when the influent entering the constructed wetland satisfies the indexes in Table 4-7, can the effluent from 60ha wetland reach the target GEF expects.

<table>
<thead>
<tr>
<th>Item</th>
<th>Influent</th>
<th>Pollutant loading g/m²/d</th>
<th>Removed Amount by Composite Submerged Wetland g/m²/d</th>
<th>Removed Amount by Free Water System g/m²/d</th>
<th>Removal rate(%)</th>
<th>Effluent mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>60</td>
<td>9.01</td>
<td>1.80</td>
<td>2.70</td>
<td>30</td>
<td>42</td>
</tr>
<tr>
<td>NH₄-N</td>
<td>3.1</td>
<td>0.47</td>
<td>0.09</td>
<td>0.16</td>
<td>35</td>
<td>2</td>
</tr>
<tr>
<td>NO₃-N</td>
<td>14.5</td>
<td>2.18</td>
<td>0.54</td>
<td>0.98</td>
<td>45</td>
<td>8</td>
</tr>
<tr>
<td>TN</td>
<td>18.2</td>
<td>2.73</td>
<td>0.68</td>
<td>1.23</td>
<td>45</td>
<td>10</td>
</tr>
<tr>
<td>TP</td>
<td>1.1</td>
<td>0.17</td>
<td>0.08</td>
<td>0.09</td>
<td>55</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Table 4-7 Predicted Performance North Constructed Wetland (60 ha plot) in Winter
4.3 Ammonia (non-ion ammonia) and Involved Public Health

In water the toxicity of ammonia shows in the restraint to growth hydrobiontes. Ammonia is composed of non-ion NH₃ and ionized NH₄⁺ which are in balance. The chemical equation is \( \text{NH}_3 + \text{H}_2\text{O} = \text{NH}_4^+ + \text{OH}^- \). Non-ion NH₃ is much toxic to fish, but NH₄⁺ do no harm to fish, because NH₃ has no electric charge, and is fat soluble. So it is easy to penetrate cytolemma, reduces spawning ability of fish, shrimps and shells, impairs gill tissue and even leads to death.

Colt and Armstrong (1981) reviewed the influences of ammoniate to hydrobionates, and noted that the major effect of non-ion NH₃ is sub-fatal influence, and slow growth is one of most important sub-fatal influences. They said that 0.05-0.2mg/L non-ion NH₃ can make many hydrobionates grow slowly. Robinette (1976) indicated that 0.12mg/L non-ion NH₃ has already influence the growth of Ictalurs Punctatus, so below 0.06mg/L can be regarded as safe concentration. Westers (1981) regarded 0.0125mg/L non-ion NH₃ as the maximum permissible concentration for fish rearing. European Inland Fisheries Advisory Commission advocated in 1970 that the highest limit of non-ion NH₃ for fish to bear in long term is 0.025mg/L. Ma Zhongbin etc. (2004) discovered that safe concentration of non-ion NH₃ for Cyprinnus var. Jian fry is 0.049mg/L. Tang Yehui etc. (2003) speculated that non-ion NH₃ below 0.035mg/L has no obvious effect on growth of young ormer. Pan Xiaoling etc (1998) discovered that that safe concentration of non-ion NH₃ for European eel is 0.219mg/L. Yu Ruilan etc. (1999) discovered that 72h non-ion NH₃ concentration of 0.70mg/L, 96h non-ion NH₃ concentration of 0.56mg/L and 96h non-ion NH₃ concentration of 0.143mg/L are attenuation critical values of respectively crucian carp blood serum AKP, blood serum LSZ and mandarin fish AKP. The safe concentration of non-ion NH₃ for Californian weever is 0.086mg/L, and that of silver carp is 0.156mg/L. Ma Zhongbin etc (2004) noted that at 25°C 24h LC 50 for spotted silver carp and silver carp fries are respectively 0.91mg/L and 0.46mg/L. Zhou Yongxin etc (1986) concluded from experiments that 24h LC 50 concentration of non-ion NH₃ for 1.7cm-long grass carps is 0.469mg/L, that is to say, the safe concentration is
0.047mg/L. Wang Kan (1996) concluded that 24h, 48h and 96 h LC 50 concentration of non-ion NH₃ and safe concentration are respectively 0.92mg/l, 0.49 mg/l, 0.32 mg/l and 0.032 mg/l.

There is some research on total ammonia nitrogen. Ruan Deming etc. obtained through experiments that when the concentration of ammonia nitrogen is over 4mg/L, acute toxicosis occurs in some freshwater fish. Shen Chenggang etc. (1995) discovered that when pH is between 8.0~8.5, the safe concentration of ammonia nitrogen for silver carp is 11~4.1 mg/L. From above, different hydrobiontes have different resistance to ammonia. Accurate ammonia concentration at different pH and temperature to lead to such influences is not available.

When pH, dissolved oxygen, water hardness and temperature are different, the toxicity of total ammonia nitrogen is far different. When pH is below 7, ionized ammonium is the major form of ammonia nitrogen; and when pH is above 11, non-ion NH₃ is the major form. The concentration of NH₄CL in pH 7 water must be ten times of that in pH 8 water to get the same fatal effect. The toxicity of total ammonia nitrogen increases with the increase of pH. Experiments shows that the toxicity of ammonia increases with the decrease of dissolved oxygen. Great changes occur in day and night in summer fine days. With increase of photosynthesis after noon, CO₂ decreases, pH increases, ratio of non-ion NH₃ comes up to the highest value in a day.

The concentration of non-ion NH₃ can be converted from the State Water Quality Standard for Fisheries of China (GB11607-89)(Table 4-7)

Table 4-7 the concentration rate of non-ionized ammonia in the ammonia aqueous solution

<table>
<thead>
<tr>
<th>温度/°C</th>
<th>6.0</th>
<th>6.5</th>
<th>7.0</th>
<th>7.5</th>
<th>8.0</th>
<th>8.5</th>
<th>9.0</th>
<th>9.5</th>
<th>10.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH值</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>6</td>
<td>0.013</td>
<td>0.009</td>
<td>0.012</td>
<td>0.019</td>
<td>0.026</td>
<td>0.039</td>
<td>0.065</td>
<td>0.11</td>
<td>0.16</td>
</tr>
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<td>7</td>
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<td>0.415</td>
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<td>9</td>
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<td>0.141</td>
<td>0.152</td>
<td>0.163</td>
<td>0.174</td>
<td>0.185</td>
<td>0.196</td>
<td>0.207</td>
</tr>
<tr>
<td>10</td>
<td>0.180</td>
<td>0.191</td>
<td>0.202</td>
<td>0.213</td>
<td>0.224</td>
<td>0.235</td>
<td>0.246</td>
<td>0.257</td>
<td>0.268</td>
</tr>
<tr>
<td>11</td>
<td>0.240</td>
<td>0.251</td>
<td>0.262</td>
<td>0.273</td>
<td>0.284</td>
<td>0.295</td>
<td>0.306</td>
<td>0.317</td>
<td>0.328</td>
</tr>
<tr>
<td>12</td>
<td>0.300</td>
<td>0.311</td>
<td>0.322</td>
<td>0.333</td>
<td>0.344</td>
<td>0.355</td>
<td>0.366</td>
<td>0.377</td>
<td>0.388</td>
</tr>
<tr>
<td>13</td>
<td>0.360</td>
<td>0.371</td>
<td>0.382</td>
<td>0.393</td>
<td>0.404</td>
<td>0.415</td>
<td>0.426</td>
<td>0.437</td>
<td>0.448</td>
</tr>
<tr>
<td>14</td>
<td>0.420</td>
<td>0.431</td>
<td>0.442</td>
<td>0.453</td>
<td>0.464</td>
<td>0.475</td>
<td>0.486</td>
<td>0.497</td>
<td>0.508</td>
</tr>
<tr>
<td>15</td>
<td>0.500</td>
<td>0.511</td>
<td>0.522</td>
<td>0.533</td>
<td>0.544</td>
<td>0.555</td>
<td>0.566</td>
<td>0.577</td>
<td>0.588</td>
</tr>
<tr>
<td>16</td>
<td>0.580</td>
<td>0.591</td>
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<td>0.613</td>
<td>0.624</td>
<td>0.635</td>
<td>0.646</td>
<td>0.657</td>
<td>0.668</td>
</tr>
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<td>17</td>
<td>0.660</td>
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<td>0.726</td>
<td>0.737</td>
<td>0.748</td>
</tr>
<tr>
<td>18</td>
<td>0.740</td>
<td>0.751</td>
<td>0.762</td>
<td>0.773</td>
<td>0.784</td>
<td>0.795</td>
<td>0.806</td>
<td>0.817</td>
<td>0.828</td>
</tr>
<tr>
<td>19</td>
<td>0.820</td>
<td>0.831</td>
<td>0.842</td>
<td>0.853</td>
<td>0.864</td>
<td>0.875</td>
<td>0.886</td>
<td>0.897</td>
<td>0.908</td>
</tr>
<tr>
<td>20</td>
<td>0.900</td>
<td>0.911</td>
<td>0.922</td>
<td>0.933</td>
<td>0.944</td>
<td>0.955</td>
<td>0.966</td>
<td>0.977</td>
<td>0.988</td>
</tr>
</tbody>
</table>

39
The controlled index of ammonia for effluent from the constructed wetland is 2mg/L, 5mg/L in winter. The non-ionized ammonia is about 0.02mg/L when pH is 7.5 and the water temperature is 18°C. The State Water Quality Standard for Fisheries of China (GB11607-89) requires that molecule ammonia is \( \leq 0.02 \text{mg/L} \), which would not harm the growth and reproduction of the fishes. And in real environment, when the non-ionized ammonia in the cultivation water is between 0.02-0.2mg/L, it is still safe for the fishes, and doesn’t lead to the fishes’ diseases. Thus mosquitoes and dragonflies would not be so many to lead to public health risk. The ammonia may be higher than 2mg/L in winter because the temperature influences the removal effect, so it may influence some fishes. But the mosquitoes and dragonflies are inactive in low temperature, so they still would not produce public health risk.

4.4 Issue of Nitrates

GEF’s objective is focused on improvement of ‘Broad Ocean’ ecology. However nitrates in Hangzhou Bay is the critical pollutant leading to eutrophication. Nitrates are not limited in the Class 1A standard of China Discharge Standard of Pollutants for Municipal Wastewater Treatment Plant (GB18918-2002). But the water in the constructed wetland is from secondary wastewater treatment technique, in which there is a little organic nitrogen, some ammonia and nitrates, and nitrates is the major. From the predicted treatment performance before, the nitrate concentration of the effluent from 26ha north constructed wetland is controlled at about 8mg/L. After further removal of nitrate in the later 60ha wetland, which treatment potential is estimated at 700mg N m\(^{-2}\) d\(^{-1}\), the nitrate concentration of the effluent can reach about 3.8mg/L. The nitrate concentration of effluent from east wetland can be controlled at about 8mg/L.

Table 4-8 Evaluation Standard of Sea Water Eutrophication
Results from statistical analysis shows: occurrence of red tide increases greatly when solvable nitrogen concentration is over 0.1mg/L and solvable P concentration is over 0.02mg/L. Constructed wetland discharges the effluent in which nitrate concentration is about 3.8mg/L at north wetland or about 8mg/L at east wetland, the nitrate will be diluted to 0.038mg/L or 0.08mg/L in ratio of 100:1 when entering Hangzhou Bay. This concentration makes occurrence of red tide significantly decrease.
Chapter Five Estimated Engineering Investment

North Constructed Wetland Engineering

① 60ha wetland engineering includes: an elevation pump station, drainage steel pipes, a distribution well, general, branch and sub-branch distribution pipes, drainage channels, submerged gravel beds, free water system, roads in the plant (made of gravels), anti-seepage equipment of the wetland, vegetation plantation, metric weirs, virescence sites, earthwork engineering and etc.

② 26ha wetland engineering includes: an elevation pump station, general, branch and sub-branch distribution pipes, drainage channels, free water system, roads in the plant (made of gravels), vegetation plantation, metric weirs, virescence sites, earthwork engineering and etc.

East Constructed Wetland Engineering

Engineering includes: 13.4ha gravel beds combined wetland engineering, inflow concrete pipes, first-level and second-level distribution wells, general, branch and sub-branch distribution pipes, drainage channels, submerged gravel beds, free water system, roads in the plant (made of gravels), anti-seepage equipment of the wetland, vegetation plantation, metric weirs, virescence sites, earthwork engineering and etc.

5.1 Estimated Investment of North Constructed Wetland

Details are shown in Table for Estimated Investment of Cixi Urban Wastewater Treatment Plant North Associated Constructed Wetland Engineering.

Total construction investment: RMB ¥57,964,500
Economics Index: Investment per t water: RMB ¥579.6

Part 1 Engineering Cost: 42,141,800+6,191,300= RMB ¥48,333,100;
Part 2 Other Cost: 5,970,800+900,400= RMB ¥6,871,200;
Basic Contingent Cost: 2,405,600+354,600= RMB ¥2,760,200.
5.2 Estimated Investment of East Constructed Wetland

Details are shown in Table for Estimated Investment of Cixi Urban Wastewater Treatment Plant East Associated Constructed Wetland Engineering.

- **Total Construction Investment**: RMB ¥ 12,776,400
- **Economics Index**: Investment per t water: RMB ¥ 255.53
  - **Part 1 Engineering Cost**: RMB ¥ 10,668,000
  - **Part 2 Other Cost**: RMB ¥ 1,500,200
  - **Basic Contingent Cost**: RMB ¥ 608,400

5.3 Operational Fee

5.3.1 Operational Fee of North Constructed Wetland

Operational fee is RMB ¥ 0.105 per t water

Note: not including fees paid for taking land and power

5.3.2 Operational Fee of East Constructed Wetland

Operational fee is RMB ¥ 0.043 per t water

Note: not including fees paid for taking land and power