WATER USE CONFLICT BETWEEN WETLAND AND FARMLAND AND ITS MITIGATION STRATEGIES

Case study in typical major grain-producing area (Sanjiang Plain) of Amur River Basin, Northeast China

Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences

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This report on Water use conflict between wetland and farmland and its mitigation strategies in typical major grain-producing area (Sanjiang Plain) of Amur River Basin, Northeast China, was prepared by Dr. Yuanchun Zou and the team from the Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences. The team was entrusted by the Northeast China Office, WWF China. The created intellectual property belongs to both parties.
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Abstract

In recent years, the research on the interaction between wetland and agriculture has become one of the hot issues for scientists, managers and relevant international organizations both at home and abroad. Wetlands, rich in soil and abundant in water, are one of the preferred targets for agricultural development in temperate and tropical regions, easily for those who locate in accessible landform types. The loss of wetlands caused by agricultural development is global and historic phenomenon. In the past, when agricultural science and technology were still underdeveloped, in order to feed the increased population, agriculture developed at the expense of wetland loss. With the socio-economic and scientific and technological development, although the current trend of loss of wetlands caused by agriculture has gradually slowed down, the dependent and competitive roles of wetlands for agriculture in the fields such as land and water resources will become more and more important, due to the further enhancement of the multi-dimensional requirements of food.

This report mainly focuses on the water resources issue of wetland and farmland. Through the field investigation and literature collection, this report is to understand the current situation of contradiction between wetland and agricultural water uses in the main grain-producing areas in Amur River Basin, to analyze the natural and socio-economic driving factors, and to take a typical wetland-agriculture system as a case to assess the water use conflict and put forward pertinent suggestions.

The results showed that Heilongjiang Province, as a major grain-producing province in China, has consumed massive agricultural water resources to maintain the steady grain production in successive years. In recent 20 years, the proportion of agricultural water increased from 72% to 88%, while the proportion of ecological water only hovered around 1% during the same period. Compared with the rest parts of China, the proportion of agricultural water in Heilongjiang is approximate a quarter higher than the national average, while that of ecological water is approximate a half lower than the average. The Sanjiang Plain, the most important grain-producing area in Heilongjiang Province, has unique surface and ground water resources. if there is no long-term unsustainable over-exploitation, it is difficult to cause the conflict of water resources between wetlands and farmlands. The natural resource endowments and the positioning of national policy determined the competitive relationship between wetland and agriculture. Due to the wetland loss and degradation, the total surface water storage in the Sanjiang Plain wetlands has decreased from $144.0 \times 10^8$ t in
the 1980s to $47.0 \times 10^6$ t in 2010, which means that it has lost approximate $2/3$ during the past 30 years. The case study the Qixing River National Nature Reserve (QRNNR) showed that without the rapid development of paddy fields in the surrounding farms, the natural water resource endowment of Qixing River can fully meet the needs of the natural wetland ecosystems. Agricultural development for successive years, especially the dramatically increased requirement for water in paddy fields, intensified the water use conflict between wetlands and farmlands. The main reason for the local continuous decline of groundwater depth was that groundwater extraction was approximate twice as great as the total infiltration recharge from wetlands and farmlands.

The water use conflict between wetlands and farmlands in the Sanjiang Plain does exist, while it is not impossible to be alleviated. From the perspective of seeking for more water sources, groundwater resources in the Sanjiang Plain are currently fully or even over-utilized, while the utilization of surface water resources is relatively low. Therefore, the total water resources management framework should include local area and the upstream area, surface water and groundwater, rainfall and snowfall. The total amount of available water resources in the whole area should be increased through the development of ecological water conservancy projects. From the perspective of water-saving, whether wetlands or farmlands, there is a lot of water-saving potentials. By adopting scientific measures to analyze the water requirements water use timings in wetlands and farmlands, we should scientifically, effectively and reasonably optimize the allocation of water resources and gradually increase the integrated water productivity of the basin and the entire area when combining various measures. Under the premise of an increase in the total amount of available water resources, from the perspective of water equality, we should restrict the overexploitation of agricultural water and improve the right to speak of wetlands. At present, the farmland area in the Sanjiang Plain has become relatively stable. The wetland protection should try its best to maintain the remaining wetland area as the red line, with the simultaneous implementation of various measures to ensure the minimum ecological water consumption of the wetland unconditionally.

Based on above results, this report proposes the management principles such as improving the wetland water resources protection system and integrating wetland protection goals into agricultural policies, adaptive wetland techniques such as stagger water transfer, accurate water recharge, ice and snow melting water resourced, as well as agricultural techniques such as water-saving irrigation, soil water capacity increased, rainfed agriculture,
could mitigate the conflict between wetlands and farmlands. Finally, five key recommendations are put forward as following: to raise the voice of wetland ecological water use and ensure the minimum ecological water requirement of wetlands, to pilot joint management of wetland surface-ground water and wetland-farmland water resources, to encourage and develop agricultural drainage collection-processing-irrigation wetland system (CPI-wetlands), to carry out watershed-scale water productivity assessment and to launch adaptive management addressing climate change.

**Keywords:** Wetland-agriculture interaction, water balance, sustainable development, adaptive management, coordination techniques, Amur River Basin
Chapter I  Background and Significance

1. Introduction

Since the first World Wetlands Day in 1997, water has appeared five times in its theme as a key word: Water for Wetlands, Wetlands for Water (1998), Wetlands: Water, Life, and Culture (2002), No Wetlands - No Water (2003), Forest and water and wetland is closely linked (2011), and Wetland and Water Resource Management (2013). In 2014, Wetlands and Agriculture was used as the direct theme. Thus, these themes showed the importance of studying the conflicts between wetlands and agriculture around water issues.

As far the wetland science itself concerned, hydrology and water resources are the core issues in wetland research. On the one hand, wetland ecosystem plays an irreplaceable important functions in protecting water resources, reduce flooding and maintain regional ecological security; on the other hand, maintaining the natural hydrological regime characteristics and variability of wetland itself, are essential to maintaining the ecological wetlands characteristics, especially for the maintenance of wetland biodiversity. How to maintain the ecological red line of wetland protection, to maintain the stability of the structure and function of the wetland ecosystem and the important ecosystem service capacities, to fully exert the hydrological storage function, and to coordinate the sustainable supply of agricultural water resources, are the urgent major scientific issues should be address under the current situation of human disturbance and climate change.

As far as the national and local strategic needs are concerned, the state and local governments gradually realized the importance of restoration and protection of the palustrine wetlands in the Sanjiang Plain, as the negative effects of wetland reclamation have been increasingly serious. In 2010, the State Council issued the “National Development Priority Zones Planning”, which designated the Sanjiang Plain both as the wetland ecological function area and the rice, soybean and corn positioning industry belt. In addition to the international important wetlands, state-level nature reserves and state-level scenic spots are listed as prohibited development zones, only seven counties (cities) of $4.77 \times 10^6$ ha was listed into the key ecological functional areas with restricted development, and the rest of the Sanjiang Plain is part of the main agricultural producing areas. In this way, existing wetlands may continue to face the threat of agricultural development, both from policy and economy
stresses. With the loss and degradation of wetlands, the sustainable development of agriculture is also facing water crisis. In 2015, Ministry of Agriculture, National Development and Reform Commission and other eight ministries issued the “National Agricultural Sustainable Development Plan (2015-2030)”, which pointed out that the Sanjiang Plain and other major rice producing areas should control the paddy field area and limit groundwater irrigation. The proportion of surface water irrigation should increase to 50% by 2020, and to 100% approximately by 2030. In October 2016, the State Council issued the “National Agricultural Modernization Planning (2016 - 2020)”, which pointed out that the rice cultivation area amount with severe groundwater development and utilization should be controlled to rational level. In December 2016, the State Council issued the “Wetland Protection and Restoration System Program”, which clearly pointed out that the use of water resources should be closely integrated with the protection of wetlands, co-ordinate the coordination of regional or watershed water balance, and meet wetland ecological water requirements. From the perspectives of ecological security and hydrological connection, the comprehensive management methods of river basin are used to establish the wetland ecological water recharge mechanisms. In November 2016, the National Development and Reform Commission issued the “Northeast China Revitalization “Thirteen Five” Plan”, which pointed out to strengthen the key wetland protection in the Sanjiang Plain, Songliao Plain and Songnen Plain and implement wetland ecological recharge projects.

It is the country's major needs to coordinate the water use conflict between agriculture and wetland. Consequently, it is of great importance that how to fully utilize the hydrological regulation function of wetland, to explore the water resources sharing technology between wetland and paddy field without reducing the health of wetlands, and to reduce the utilization of groundwater and improve the utilization efficiency of regional surface water resources.

2. Objectives

This report focused on wetland and farmland water resource issue. According to the United Nations World Water Assessment Programme (WWAP), agricultural water accounts for 70% of the global total consumption, and scientific and rational management of agricultural water resources will make great contribution to global water security (WWAP, 2012). By 2050, global agriculture is to produce 60% more food, and agricultural production in developing countries needs to be doubled to meet population growth. Due to the current unsustainable growth rate of global agricultural water requirement, there is an increasing
need to prompt water use efficiency by reducing agricultural water consumption and increasing crop productivity per unit volume of water consumed (WWAP, 2015). Currently, most irrigated agriculture all over the world is under the circumstance of full-utilizing or overexploiting water resources. Therefore, the ecological characteristics of the hydrologically related wetlands have been affected directly or indirectly, which leads to the degradation of some important ecosystem services that the wetlands have provided or even wetland loss (Junk et al., 2013).

The Sanjiang Plain is the major grain-producing area of Amur River Basin, Northeast China; meanwhile, it is the largest distribution area of freshwater palustrine wetlands in China. Since the 1950s, the area has undergone continuous agricultural reclamation with high intensity. The originally natural wetlands landscape has been completely transformed into China's important commodity grain base, which has made tremendous contribution to improve the national food production and solve people's food and clothing. However, this contribution is at the expense of comprehensive wetland degradation and loss. The driving factors include natural and anthropogenic dimensions. The former is attributed to warming and drying climate change in most part of this area in recent decades. The latter is attributed to agricultural development, which is identified as the main reason for the wetland loss in the Sanjiang Plain (Zou et al., 2018). On the one hand, agricultural reclamation directly causes the reduction of wetland area; on the other hand, agricultural development activities (irrigation and drainage, etc.) have a strong impact on wetland hydrology (e.g. to decrease water level and change flooding cycle), which in turn affects wetland vegetation and results in the succession of plant communities from deep-water marsh vegetation to shallow-water vegetation or seasonal wet meadow. Thus, the change of wetland hydrology is the direct cause of wetland degradation, and the water problem is the most critical issue of wetland management in the Sanjiang Plain.

According to incomplete statistics, by 2016, more than 30 wetland nature reserves have been established in the Sanjiang Plain, of which Honghe, Sanjiang, Lake Xingkai, Qixing River and Zhenbaodao are listed as the Ramsar Sites. The establishment of these nature reserves is of great significance for the protection of the remaining natural palustrine wetland ecosystems in the Sanjiang Plain. Whether to meet the ecological water requirement of these wetlands is crucial to the survival of these wetlands and all those life living in these wetlands.
In this report, we aimed to understand the current situation of the conflict between wetland water use and agricultural water use in the Sanjiang Plain through field investigation and literature collection. In addition, we analyzed the natural and socio-economic factors causing this conflict, and put forward relevant suggestions based on the results.

3. Topics

3.1 Conflict status: to assessment of the typical regional wetland ecological water use, agricultural water use, and to calculate the water gap combined with regional groundwater storage and effective supply, through which to analyze the competition situation between wetland and farmland.

3.3 Driving factors of the conflict analyses: to analysis of the primary cause of the conflict from the perspectives of national macroeconomic policy, agricultural production economic situation, regional climate change and so on.

3.3 Case Study of Typical Wetland: To conduct a case study of typical wetland National Nature Reserve and its surrounding farms in Sanjiang - Songnen Plain.

3.4 This paper puts forward the principles and measures to alleviate the conflict between ecological water use and agricultural water use in the wetland-farmland system, and consider the future precipitation change and water conservancy engineering, the proposed wetland multi-dimensional multi-source water supply and recycling water strategy and technology.
Chapter II  Conflict between wetland and farmland water resources

Water resources provide the fundamental material basis for life and the most crucial support services both for wetlands and farmlands. In the 21st century when the freshwater resources are getting more and more scarce, it is particularly important to coordinate agricultural and ecological water uses. Water safety and water governance due to water scarcity have become the issue of common concern to governments, scholars and the general public, and received more and more attention.

1. Total water resources constraints

The total available water resources are limited globally. Agriculture, the world's largest freshwater consumer and accounting for approximate 85% of global water consumption with most proportion used for irrigation, will continue to increase its demand for water resources. Over the next 50 years, as the population increases, the world needs to raise food production by nearly 50% to maintain the present per capita supply (Jury and Hjir, 2007; Siebert et al., 2010). If the food yield per unit cultivated land area will not be doubled in the near future, given the special weather- dependence of rainfed agriculture, most developing countries can only meet their food needs through expanding irrigated agriculture and rebuilding rainfed agriculture.

China is no exception. Due to the unequally spatio-temporal distribution of water resources, China's agriculture is also facing a shortage of water resources. In the long history of agricultural development, China adjusted the spatial and temporal distribution of water resources through constructing a large number of water conservancy projects to meet the needs of agricultural development (Gao et al., 2014). These water projects are solely or mainly serving agricultural irrigation while lacking consideration of natural ecosystems such as wetlands, which has led to the threats of many wetlands (Junk et al., 2013).

In fact, both the global and local water cycling relies heavily on wetlands. Wetland land cover affects water retention and flows, and thus affects the supply of surface water and groundwater, while transpiration of wetland plants affects rainfall patterns. It can be said that the global and regional water cycles will be significantly altered without wetlands (Russi et al., 2013). To balance the water requirements between wetlands and agriculture needs to
consider the entire water cycling, including blue water (renewable water) and green water (soil water). Water scarcity will become an increasingly important constraint on agricultural development in Asia and Africa and will further aggravate the competition for water resources between wetlands and agriculture (Rijsberman and Silva, 2006). Therefore, more effective measures should be deployed to protect water resources as early as possible to maintain the important ecosystem functions of natural wetlands.

2. Wetland and farmland water requirement assessment framework

No matter wetlands or their surrounding farmland, the water requirement can be divided into five parts: the actual evapotranspiration of vegetation after deducting precipitation, underground water storage changes, surface water storage changes, soil water storage changes and plant water changes. The actual evapotranspiration of vegetation can be measured by direct observation of the evapotranspiration under different regimes of water conditions or indirectly calculated by multiplying the potential evapotranspiration by the canopy cover/crop coefficients, or by multiplying the open water evaporation by LAI-adjusted ratios (Chen and Lu, 1994; Drexler et al., 2004; Sun and Song, 2008; Xu et al., 2011). Among them, most palustrine wetland plants are perennial herbaceous plants that rejuvenate and wither in the same year with the water content of 50%-70% when the aboveground biomass reaches its maximum (Jia and Lu, 2011). Considering the interannual variation and its smaller proportion in the total water storage, plant water storage is generally negligible. For the wetland with large spatio-temporal dynamics, the surface water storage also needs to consider that wetland has different ecological characteristics in abundant, dry and flat water year, and the critical threshold of ecological water requirement of wetland (Yang et al., 2008).

3. Regional water supply and requirement analysis

Taking Heilongjiang Province, where the Sanjiang Plain is located, as an example, the provincial grain production was closely related to the supply of water resources. According to the National Data (2017) from National Bureau of Statistics of China, the proportion of effective irrigation area, rice yield, total grain yield and total sown area of rice in Heilongjiang Province increased linearly from 1996 to 2015 (Table 1), with the annual average yield of rice was $8.75 \times 10^5$ t.
Table 1  Inter-annual variation of rice planting in Heilongjiang Province (Adapted from National Data, 2017)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Linear fitting equation</th>
<th>$R^2$</th>
<th>$P$</th>
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</thead>
<tbody>
<tr>
<td>Effective irrigation area ($A, \times 10^3$ ha)</td>
<td>$A = -433119.71 + 217.49*Year$</td>
<td>0.91</td>
<td>&lt; 0.001</td>
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<td>Rice production ($Y, \times 10^4$ t)</td>
<td>$Y = 174166.04 + 87.54*Year$</td>
<td>0.91</td>
<td>&lt; 0.001</td>
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<tr>
<td>Rice production percentage ($P, %$)</td>
<td>$P = -851.10 + 0.44*Year$</td>
<td>0.27</td>
<td>0.01</td>
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<td>Rice sown area percentage ($S, %$)</td>
<td>$S = -1152.91 + 0.59*Year$</td>
<td>0.77</td>
<td>&lt; 0.001</td>
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</table>

As a major grain-producing province in the country, Heilongjiang Province has consumed massive agricultural water resources to maintain the steady grain production in successive years. Between 2004 and 2015, the proportion of agricultural water increased from 72% to 88%, while the proportion of ecological water only hovered around 1% during the same period (Table 2). Compared with the national average data, the proportion of agricultural water in Heilongjiang was approximate 1/4 higher than the national average, while the proportion of ecological water was approximate 1/2 lower than the average.

The ecological water consumption was less than 2.1% of the agricultural water consumption. When their conflict is expressed as the difference between the two consumptions, the conflict seems intensified year by year, from $185.21 \times 10^8$ m$^3$/a in 2004 to $309.90 \times 10^8$ m$^3$/a in 2015, with an increment by 67.3% in the past 12 years (Table 2).

Table 2  Statistics of water resources utilization in Heilongjiang Province ($\times 10^8$ m$^3$, adapted from National Data, 2017)

<table>
<thead>
<tr>
<th>Year</th>
<th>Total water supply</th>
<th>Surface water supply</th>
<th>Ground water supply</th>
<th>Other water supply</th>
<th>Total water consumption</th>
<th>Total agricultural water consumption</th>
<th>Total industrial water consumption</th>
<th>Total domestic water consumption</th>
<th>Total ecological water consumption</th>
<th>Agricultural water consumption percentage</th>
<th>Ecological water consumption percentage</th>
<th>Difference between agricultural and ecological consumption</th>
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<td>157.7</td>
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On one hand, according to the actual requirement of crop evapotranspiration, the annual water consumption of paddy field was 657.7 mm and that of dryland was 456.3 mm (Wang et al., 2004). According to the average rice planting area ratio of 26.3% in Heilongjiang Province from 2010 to 2015, the average farmland water requirement was 604.7 mm and equivalent to 6047 m$^3$/ha. In the same period, the average grain yield per unit of production was 5020.72 kg/ha, which indicated that 0.8 kg grain could be produced per 1.0 m$^3$ of water consumption. In the same period, paddy yield was 6956.00 kg/ha, which was equivalent to approximate 1.0 kg of rice per 1.0 m$^3$ of water consumption. On the other hand, the water consumed by farmland crops only accounted for a part of agricultural water use, while the other part was consumed by the water from the water sources to the fields. This loss can be characterized by the effective utilization coefficient of irrigation water (i.e., the ratio of net irrigation water used in the field to the gross irrigation water used at the water source).

According to the survey conducted by Si et al. (2017), the total water consumption, actual irrigated area and integrated irrigation quota of Heilongjiang Province in 2016 were $3.06 \times 10^{10}$ m$^3$, $5.05 \times 10^6$ ha and 6058 m$^3$/ha respectively. The average effective utilization
coefficient of irrigation water was only 0.60, which was equivalent to an average water consumption of 606 mm (Table 3) and exceeding the annual average precipitation (Jin et al., 2015). The above calculation also proves once again that the steady consumption of grain in successive years of Heilongjiang province is at the expense of huge water consumption by crops.

Table 3  Statistics of irrigation indicators in Heilongjiang Province in 2016 (Adapted from Si et al., 2017)

<table>
<thead>
<tr>
<th>Irrigation area type</th>
<th>Area ($\times 10^4$ ha)</th>
<th>Water consumption ($\times 10^8$ m$^3$)</th>
<th>Irrigation quota (m$^3$/ha)</th>
<th>Irrigation water effective use coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large (&gt; $2 \times 10^4$ ha)</td>
<td>38.33</td>
<td>49.21</td>
<td>12838.51</td>
<td>0.44</td>
</tr>
<tr>
<td>Medium</td>
<td>64.46</td>
<td>67.20</td>
<td>10425.07</td>
<td>0.48</td>
</tr>
<tr>
<td>Small (&lt;670 ha)</td>
<td>48.78</td>
<td>44.26</td>
<td>9073.39</td>
<td>0.53</td>
</tr>
<tr>
<td>Well irrigation</td>
<td>353.26</td>
<td>145.16</td>
<td>4109.16</td>
<td>0.72</td>
</tr>
<tr>
<td>Total</td>
<td>504.83</td>
<td>305.83</td>
<td>6058.08</td>
<td>0.60</td>
</tr>
</tbody>
</table>

As the largest consumer of agricultural water, once the amount of irrigation water is reduced, the entire amount of agricultural water will be reduced, too. Therefore, it is necessary to intensify the anti-seepage transformation of existing water conservancy facilities, modify a large-scale irrigation district to the collection of small and medium-sized irrigated districts, properly maintain the well-irrigation scale, promote micro-irrigation and sprinkler irrigation in favorable conditions, and control seepage of existing flood irrigation channels. Of course, losses in the water conveyance are not totally meaningless. The evaporation will help to regulate the local microclimate and the infiltration will contribute to recharge of soil and groundwater.
Chapter III  Driving Forces of Conflict

1. Natural factors

1.1 Climatic conditions

The Sanjiang Plain, located in the northeast of China with a total land area of $1.09 \times 10^7$ ha, is an alluvial plain formed by Amur River, Songhua River and Ussuri River. It is bounded on the north by Amur River, on the south by Lake Xingkai, on the east by Ussuri River and on the west by Smaller Hinggan Mountain and Zhangguangcai Mountain. With the temperate monsoon climate, the average annual temperature, frost-free period, sunshine duration, total solar radiation, $\geq 10$ °C accumulated temperature, precipitation and the drying index are 1.6-3.9 °C, 120-150 d, 2400-2700 h, 420.0–501.4 kJ/cm², 2300-2700 °C, 500-600 mm and 1.0, respectively (Yang et al., 2001).

According to the data from the automatic weather station of the Ecological Experimental Station of Mire Wetland in the Sanjiang Plain of the Chinese Academy of Sciences, approximate 85% of the precipitation is rainfall and occurs in May-October; the remaining 15% is snowfall. The amount of snow is usually 40-80 mm, with the maximum snow thickness of approximate 45 cm. When air temperature drops after winter, a large amount of precipitation is frozen on the ground surface and/or in the soil. After thawing in the following spring, the melting ice, snow and new precipitation accumulate together on the soil surface. Due to the blockage of freezing layer, these water usually cannot infiltrate and form spring flood. In the summer, when the new rainfall starts, the ground surface always maintains the flooding or saturation conditions. In most areas of the Sanjiang Plain, the amount of rainfall is greater than the evaporation, which is beneficial to the continuous accumulation of surface water (Yin et al., 2003). In general, the climate resources of the Sanjiang Plain are suitable for the development of wetlands and crop growth.

1.2 Geological and geomorphological conditions

The geological and geomorphological basis is beneficial to the development of wetlands in the Sanjiang Plain. The low plain area accounts for 61.2% of the entire area, where high and low floodplains were $1.60 \times 10^6$ ha and $1.90 \times 10^6$ ha, accounting for 14.7% and 17.7% of the total land area, respectively. Since the early Pleistocene of the Quaternary, the Sanjiang Plain has a geological structure of a depression and is fully subsided. During the late Mid-
Pleistocene, due to the influence of Neotectonic movement, some parts of the plateau and terraces have been lifted up. During this long-term subsidence, the main surface was covered with thick sediments. In most areas, thick clay layers were formed with a thickness of 3-17 m and water seepage coefficient of 0.03-0.95 cm/d. Since the Holocene, the earth crust still dominated by large-scale slow subsidence. Thick Quaternary sediments with different thicknesses deposited at the inner and outer Qixing River and the middle reach of Naoli River. The thickness around the residual hills is less than 50 m, and the other residuals are 100-200 m (Yang et al., 2001; Gu, 2017).

1.3 Hydrological conditions

Palustrine wetlands are widely distributed in the Sanjiang Plain. The gentle terrain slope (1/5000-1/10000) leads to runoff blocked. There are more than 190 rivers with a total catchment area of $9.45 \times 10^6$ ha. The groundwater is under pressure and the pressure head is approximate 4-10 m. The underground aquifer is thick, with some areas over 200 m. The groundwater is covered with thick clay layer of 7-20 m. The abundant groundwater has a stable deep cycle of external supply. The average surface water runoff is $1.16 \times 10^{10}$ m$^3$/a and the groundwater storage is $8.56 \times 10^9$ m$^3$/a. When deducted the repeated calculation of $3.99 \times 10^9$ m$^3$/a, the average water resource in the whole area is $1.62 \times 10^{10}$ m$^3$/a in recent years (Song et al., 2010; Yao, 2013; Zhang et al., 2017).

1.4 Soil conditions

All kinds of wetland soils in the Sanjiang Plain have developed above the clay layer or the parent layer of the sub-clay. The texture is heavy and the drainage condition inside the soil is extremely poor. For the gley peat marsh soil, the profile from top to bottom is the grass roots, humus layer, gley layer and parent material layer. For the peat marsh soil, there are peat layers with different decomposition level below the grass root layer. The grass root layer is composed of the roots of living plants intertwined with the dead but not decomposed plant roots and stems with few mineral particles. The thickness of grass root layer is up to 50-60 cm and the porosity is 72%-93%. With a loose sponge-like structure, the general saturated water content of grass root layer is 830-1030%, the maximum water content is approximate 40%, the water storativity is approximate 0.5, and the water conductivity is 0.008-0.138 cm/s. The grass root layer and peat layer can store water and permeate water, which is the most hydrologically active layer in the marsh soil profiles. For their great capacity of holding water...
and storing water, marsh soils are so called as “soil reservoir” (Chen and Zhang, 1982; Yang et al., 2001; Liu, 2007).

1.5 Vegetation conditions

The dominant wetland plants in the Sanjiang Plain are belong to Cyperaceae and Gramineae. Carex lasiocarpa, C. pseudocuraica, C. appendiculata, C. schmidti, C meyeriana, C. humida, Phragmites australis, Glycera spiculgsa, Typha angustifolia and Equisetum heleochauis etc. are the dominant or constructive species. Reeds are mainly distributed in the middle and lower reaches of Qixing River and Naolihe River and Lake Xiaoxingkai. In addition, Betula fruticasa and Spiraea salicifolis etc. shrub swamps have been extensively reclaimed. Alnus sibiriea only distributes in forest swamps with small area (Liu, 2007). The coverage could be to 90%. Therefore, the plant transpiration plays a decisive role in the total evapotranspiration. According to the field observation, the actual evapotranspiration was greater than that of the open water. The larger the vegetation cover is, there was larger the evapotranspiration. When the vegetation coverage is less than 10%, the evapotranspiration was close to the evaporation of open water, and the difference between them was greater in the sunny days than in cloudy days (Chen and Zhang, 1982; Chen and Lu, 1994).

Thus, the Sanjiang Plain has unique and abundant surface and groundwater resources historically. If there is no long-term unsustainable over-exploitation, it is difficult to cause the conflict between wetlands and farmlands for water resources’ competition.

2. Socio-economic factors

The history and current status of wetland protection and restoration in the Sanjiang Plain, to a certain extent, represent the entire state of China. Driven by the Chinese government's comprehensive development strategy of agricultural modernization, urbanization and new industrialization, wetlands are increasingly threatened by the use of water in the entire basin (Wu et al., 2012).

At the beginning of the founding of New China, the Sanjiang Plain was sparsely populated and was basically untapped. Since the development of the Great North Wilderness by 100,000 officers and soldiers in 1958, China has extensively reclaimed the natural wetlands in the Sanjiang Plain in a planned way. However, due to low mechanization and slow reclamation rate, most of the development areas were island-shaped woodlands and
wetland margins. At this time, the core areas of the Sanjiang Plain, i.e. Naoli River, Belahong River, Nongjiang River and Yalu River still had a large area of wetland landscapes (Yang et al., 2001). Since the late 1970s, the introduction of foreign agricultural machinery has accelerated the reclamation of wetlands. Serious grain underproduction resulting from the flooding hazards in 1973 and 1981 caused the attention of the central government. In 1982, the water protection engineering projects in the Sanjiang Plain were included in the state plan. The Ministry of Water Resources started the project of controlling the floods in the Sanjiang Plain, focusing on flood control and drainage. Since then, flood control projects have been carried out on 10 key rivers. In addition, Tongfu Dike, Taoshan Reservoir, Longtouqiao Reservoir, Balengshan Reservoir and other pivotal water comprehensive utilization projects, have been initially established in the Sanjiang Plain. A large number of construction of flood levees, field drainage and other water conservancy projects have created favorable conditions for the agricultural development. By 2000, the lengths of total dikes and ditches had reached 3120 km 2800 km in the Sanjiang Plain (Wang et al., 2001; Kang et al., 2003).

Since the 1970s, the Sanjiang Plain has begun to grow rice and carried out “treating floods with rice” and achieved remarkable benefits. The planting area of rice in the Sanjiang Plain increased year by year. The paddy fields were only $7.00 \times 10^4$ ha in 1981. Since the rapid development 1990s, 70%–80% of agricultural irrigation water has come from large-scale exploitation of groundwater as the increments of population and agricultural water use. Affected by anthropogenic activities, groundwater circulation conditions in the Sanjiang Plain have become relatively complicated. Precipitation infiltration, lateral flow and irrigation infiltration have occurred in recharged areas. The amount of recharge for irrigation has reached $2.34 \times 10^9$ m$^3$/a, accounting for 37.97% of the total recharge. Meanwhile, the artificial extraction of groundwater was $4.16 \times 10^9$ m$^3$/a, accounting for 64.31% of the total discharge, and artificial extraction had become the main way of groundwater drainage. The increase of the exploitation resulted in the rapid decline of the groundwater depth, which led to the increment of the hydraulic head between the surface water and the groundwater, which in turn changed the exchange between the rivers and the groundwater. The infiltration quantity of precipitation and groundwater evaporation also changed correspondingly. From 1996 to 2000, approximate 97% of the actual irrigated area in the Sanjiang Plain was paddy field and 69% was well-irrigated. Due to the rapid increase of paddy fields, the exploitation of groundwater also increased rapidly. Coupled with the serious human waste and poor management, the groundwater in the Sanjiang Plain generally dropped. The phenomena of
hanging pumps and local over-exploitation had occurred frequently. The balance of groundwater resources in the Sanjiang Plain was subjected to serious damage. Groundwater exploitation in the 1970s, 1980s, 1990s and early 2000s were \(5.67 \times 10^8\) m\(^3\)/a, \(1.18 \times 10^9\) m\(^3\)/a, \(1.24 \times 10^9\) m\(^3\)/a and \(2.14 \times 10^9\) m\(^3\)/a, respectively. In 2000, the development rate of groundwater resources in the Naoli River Basin reached 109.8% and over-exploitation amount was up to \(1.09 \times 10^8\) m\(^3\) (Song et al., 2010; Xu et al., 2012).

At present, as the continuous requirement for groundwater in agricultural irrigation, groundwater exploitation amount is up to \(4.36 \times 10^9\) m\(^3\)/a. Large-scale development of paddy fields for water diversion irrigation has changed the groundwater circulation conditions and the exchange of water. The increment of groundwater recharge due to the use of surface water for irrigation is \(2.04 \times 10^9\) m\(^3\)/a, which will tend to increase with the increment of irrigation area and water consumption in the future. In addition, the use of groundwater for paddy field irrigation increases the circulating water amount of groundwater itself, which is up to \(5.40 \times 10^8\) m\(^3\)/a (Xu et al., 2012).

The impacts of agriculture and water conservancy in the Sanjiang Plain on the wetland have been worsening. According to our survey and calculation, by 2010, 8772 ditches have been completed in the state-owned farms in the Sanjiang Plain with a total length of 28675.4 km and a ditch density of 0.81 km/km\(^2\). Wetland reclamation and ditching not only broke the original landform and land use pattern in the region, but also increased the gradient of regional drainage and hydrology and accelerated the process of surface runoff. As a result, the hydrological regulation function of wetland reduced or even mined. Regression analysis of historical data showed that when ditches increased 1 km, wetlands would lose 0.227 km\(^2\); when cultivated land increased 1 km\(^2\), wetlands would lose 0.557 km\(^2\) (Zou et al., 2018). The total surface water storage in the Sanjiang Plain wetlands decreased from \(5.06 \times 10^9\) t in 1980s to \(9.30 \times 10^8\) t in 2010. The soil water storage capacity decreased from \(9.34 \times 10^9\) t in 1980s to \(3.77 \times 10^9\) t in 2010. As a result, the total wetland water storage amount decreased from \(1.44 \times 10^{10}\) t to \(4.70 \times 10^9\) t, which meant that approximate 2/3 of the water storage has been lost in the past 30 years (Figure 1).
3. Policy-driven changes

3.1 The evolution of national agricultural policies related to wetlands

As an agricultural country, China's cultivate land per capita is far below the global average. China has been and still is struggling to produce enough food to feed its large population. The issue of food security drove the Chinese government to implement a policy of land reclamation. During the past 50 years from 1950 to 2000, the government had led a large-scale reclamation, resulting in the continuous losses of lakes, coastal and palustrine wetlands. As a result of agricultural and industrial water transfers, the freshwater that should have entered wetlands had been dramatically reduced (An et al., 2007).

Since 2004, China has successively implemented a series of financial policies of “Three reliefs & four subsidies”: the reduction and exemption of agricultural taxes, the abolition of special agricultural products taxes other than tobacco leaves, the exemption from animal husbandry tax, the subsidies for crop seeds, the direct subsidies for grain farmers, the comprehensive subsidies for agricultural materials and the subsidies for returning farmland to
forests policy. In order to further mobilize farmers' enthusiasm for grain cultivation and ensure the national food security and farmers' income from grain growing. Since 2004, China has successively implemented the policies of low-purchase-price of grains and temporary-storage of important agricultural products and continuously raised the prices of low-purchase and temporary-storage price. From 2008 to 2014, the low purchase price of rice (initial acquisition and storage price) increased by 74.7%–89.0% (Wei, 2017), which played a very important role in the reclamation of wetlands and the conversion from drylands to paddy fields in Heilongjiang Province. Encouraging rice development policies and both were the stimulating factors for increasing water stress in Sanjiang Plain wetlands. Stimulated by the central government’s rice planting encouraging policies and increased rice price rice prices, the entire the Sanjiang Plain, but the of rice production scale is still expanding despite the water resources problems have been encountered (Wang and Wu, 2011).

On May 20, 2015, the Ministry of Agriculture and other eight ministries and commissions issued the “National Plan for Sustainable Agricultural Development (2015–2030)”, which clearly stated that “in the main rice producing areas such as the Sanjiang Plain, paddy fields should be controlled and the exploitation of groundwater should be limited. Well irrigation should be changed to canal irrigation, and the proportion of canal irrigation should be increased to 50% by 2020 and to approximate 100% by 2030.

In 2017, the No. 1 Document of the CPC Central Commission pointed out that large-scale implementation of agricultural water-saving projects should be implemented. Agricultural water price should be comprehensive reformed. The main responsibility the local governments should be implemented. The establishments of reasonable price formation mechanism and water-saving incentives should be speeded up. Water quota management should be fully implemented, and county-scale water-saving society construction standards and assessment should be carried out. The third national survey of water resources survey and assessment should be implemented. We will step up the construction of Major ecological projects should be emphasized and the construction of river-lake-reservoir connectivity projects should be continued.

3.2 The evolution of national wetland protection policies

Since joining the “Ramsar Convention on Wetlands” in 1992, China has taken a series of measures to protect and restore wetlands. In 2000, seventeen departments under the State Council jointly issued the “Action Plan for Wetland Protection in China”, which clearly
defined the guiding ideology and strategic tasks of wetland protection. In the mid-1990s, a six-year national survey of wetland resources began. In November 2000, China released the “Action Plan for Wetlands Protection in China”. In 2003, the State Council approved “National Wetland Protection Project Planning (2002–2030)”. In February 2004, after approved by the State Council, the State Forestry Administration announced the “National Wetland Protection Project Planning”. In June 2004, the General Office of the State Council issued the “Circular on Strengthening the Management of Wetland Protection” and proposed the rescue and protection of natural wetlands. In 2005, the State Council approved the “Implementation Plan of the National Wetland Protection Project (2005–2010)”, which implemented the rescue the important degraded wetlands with engineering measures. In May 2013, the State Forestry Administration promulgated the “Regulations for Wetland Protection and Management.” In early 2015, the No. 1 Document of the CPC Central Committee pointed out that it is necessary to implement wetland ecological protection and restoration projects, expand wetland areas and enhance wetland functions (Yang et al., 2011; Cui et al., 2017).

Since entering the 13th Five-Year Plan, the protection and restoration of wetlands in China have received unprecedented attention. In March 2016, the “Outline of the 13th Five-Year Plan for National Economic and Social Development of the People's Republic of China” pointed out to guarantee the ecological water levels of important lakes, wetlands and estuaries, to conserve and restore wetlands, rivers and lakes, and to establish a wetland protection system. In April and September, the CPC Central Committee and the State Council successively issued the “Opinions on Accelerating the Building of Ecological Civilization” and the “Overall Plan for the Reform of Ecological Civilization System” both explicitly proposed the establishment of a wetland protection system. All wetlands should be included in the scope of protection and the unauthorized acquisition of occupying key international wetlands, national important wetlands and wetland nature reserves should be prohibited. The function of various types of wetlands should be determined, the protection and utilization behaviours should be regulated, and a wetland ecological restoration mechanism should be established. In December, the General Office of the State Council released the “Wetland Protection and Restoration System Scheme” pointed out that the mechanism of ecological water use, water resources utilization and wetland protection should be closely integrated and coordinated. The water resources in the region or basin should be balanced, and the ecological water requirement of the wetlands should be maintained. From the perspective of
ecological security and hydrology and using the integrated watershed management methods, the wetland ecological recharge mechanism should be established, which should clarify the technical route, capital investment and the responsibilities and obligations of relevant departments. Reservoir water storage and flood discharge should take full account of the needs of relevant wildlife protection. In May 2017, eight ministries and commissions including the State Forestry Administration and the National Development and Reform Commission issued the document calling for the implementation of the “Plan for the Protection and Restoration of Wetlands” and required all localities to promulgate their work plans before the end of this year. In light of local respective actual conditions, efforts should be made to formulate specific systems for wetland protection and restoration. The systems and policies proposed from the “Wetland Protection and Restoration Program” should be developed into local policy measures and institutional measures.

3.3 The evolution and effectiveness of wetland policies in Heilongjiang Province

Heilongjiang, as a major province with rich wetland resource in China, is at the forefront of China's wetland protection and management. According to the Department of Forestry of Heilongjiang Province, the “Decision on Strengthening the Protection of Wetlands” was made in 1998 and the cultivation of wetlands was stopped completely. In 2003, the “Regulations for the Protection of Wetlands in Heilongjiang Province” was promulgated unprecedented in China for the special legislation on wetlands. In 2009, the ecological water recharge mechanism implemented in the Zhalong Ramsar site provided a model for the ecological recharge of wetlands throughout the country. In 2012, a provincial management body, the Heilongjiang Wetland Protection Management Centre, was established. In September 2014, Heilongjiang Province officially started to reformulate, supplement, revise and perfect the content of the former “Regulations for the Protection of Wetlands in Heilongjiang Province”, and the updated regulations came into effect on January 1, 2016. Based on the data from the second survey of wetland resources and combined with the investigation of peat wetland carbon pools in 2015, Heilongjiang Province established a wetland inventory. In December 2016, Heilongjiang Provincial People's Government released the “Inventory of Wetlands in Heilongjiang Province”, which involves 20448 wetland patches with a total area of $5.56 \times 10^6$ ha. By the end of 2016, 138 wetland nature reserves (including 26 state-level and 61 provincial-level wetlands) and 72 wetland parks (including 52 national wetland parks and 20 provincial-level wetlands) have been established in this province. There are 8 Ramsar sites ranking first in the country, including Zhalong, Sanjiang,
Honghe, Xingkaihu, Zhenbaodao, Nanwenghe, Qixing River and Dongfanghong. At present, Heilongjiang Province has established the largest provincial wetland protection network in China.
Chapter IV Case Study

1. Study area

The study area is located in the middle reaches of the Qixing River, including the Qixing River National Nature Reserve and its neighbouring Friendship Farm and 579 farms. It is located in the hinterland of the Sanjiang Plain in the eastern part of Heilongjiang Province (Figure 2). Qixing River National Nature Reserve (QNNR) is located in the Inner Qixing River and belongs to Baoqing County, Heilongjiang Province. It is a Ramsar Site (No. 1977, January 9, 2011) and represents the primitive, typical and complete reed mash landscape. The survived natural wetlands are surrounded by farmland nearby. In recent years, farmlands have been converted from drylands to paddy fields and appeared severe water scarcity (Zhou et al., 2015). The water use conflict between the wetlands and farmlands is becoming serious.

Figure 2  Land use and cover of Qixing River Wetlands and the surrounding farms
Qixing River is a tributary of Naoli River and Naoli River is a tributary of Ussuri River. Qixing River is divided into two parts: the inner Qixing River and the outer Qixing River. The length of the Qixing River is 241 km and the width is 6–30 m with the maximum less than 50 m. The drainage area of Qixing River is $1.08 \times 10^6$ ha and that of the Inner Qixing River is $3.82 \times 10^5$ ha, accounting for 43.4% and 15.3% of the total area of Naoli River Basin (Li et al., 2003). It is originated in Qixinglazi Moutain in Shuangyashan City of Heilongjiang Province, and flows eastward through Sanhuanpao Flood Detention Zone and enters Naoli River. Qixing River is a typical mash river, and set as the boundary between Huachuan County, Shuangyashan City, Baoqing County and Friendship County, but also the agricultural drainage area for the state-owned farms nearby.

QNNR is bounded on the north by the Inner Qixing River with the niobous of State Friendship Farm and Fujin Country, on the southeast by 597 State Farm and on the southwest by Baoqing County. The geographical coordinates are 46°39′45″–46°48′24″ N, 132°00′22″–132°24′46″ E and the average elevation is 80 m. The total area of QNNR is $2.00 \times 10^4$ ha. The temperate humid monsoon climate of QNNR is subjected to annual average temperature of 2.3 °C–3.4 °C and the annual precipitation of 400–600 mm. The rainy season is from May to September, and the monthly average evaporation is 3.84 mm. The main soil types include dark brown soil, albic soil, meadow soil and marsh soil. There are 264 vertebrate animals such as *Grus japonensis*, *Egretta garzetta*, *Capreolus pygargus* and *Mustela sibirica* in the wetlands, as well as 264 higher plants species such *P. australis*, *C. angustifolia*, *Carex lasiocarpa*, *C. meyeriana* and *C. pseudocuraica* (Li et al., 2003; Ramsar Convention on Wetlands, 2014).

2. Agricultural development history

There used to be frequent floods in Qixing River Basin historically, basically a flood every 2–3 years. The surface runoff was difficult of discharge freely after floods, which deteriorated the disasters. According to the statistics of the disaster data since the founding of the People's Republic, the cumulative area of floods and floods reached $1.13 \times 10^6$ ha, accounting for more than 60% of the total area. For example, in 1964, the waterlogging area was $3.80 \times 10^5$ ha accounting for 35% of the total drainage area; the cultivated lands affected by the flood was $2.15 \times 10^5$ ha, accounting for 70% of the sown area of cultivated lands in that year. In 1981, the waterlogging area was $2.60 \times 10^5$ ha accounting for 24% of the total drainage area; the cultivated lands affected by the flood exceeded $4.00 \times 10^4$ ha, accounting
for 88% of the sown area for that year. The grain output reduction exceeded $4.00 \times 10^8$ kg, and the direct economic loss of that year was $4.00 \times 10^8$ Yuan (Wang et al., 1999).

Since the 1980s, the embankment of the Sanhuangpao Flood Detention Zone (SFDZ) has been built on the Inner Qixing River, blocking the overflowing to the Outer Qixing River. The plan in 1974 and the preliminary design in 1978, the main Qixing River, and the stem and branch ditches in farmlands were unified to use the flood control standard of once-in-five-year. In 1978, the “New Design of the Qixing River Remediation Project”, which was compiled by Heilongjiang Provincial Institute of Hydraulic Design and approved by the Ministry of Water Resources, was difficult to be implemented since the project was large and investment was heavy when the national economy was undergoing adjustment phase. In 1981, the “Qixing River Treatment Program” was re-studied when the Sanjiang Plain suffered serious flood disaster, which is the “Recent Design of Qixing River Flood Control and Waterlogging Project”. In 1982, the designers summed up the experience and proceeded from the actual situation seriously to modify the control standards. At that time, wetlands were regarded as wastelands. Nearly $1.33 \times 10^5$ ha of existing cultivated lands in the Qixing River Basin were reclaimed from the low-lying wetlands during the drought of 1974–1980. It is difficult for these newly cultivated lands to achieve the systematic drainage standards in a short term (Wang et al., 1999; Wang et al., 2001).

Through the continuous constructions from 1988 to 1993, the SFDZ had become the controlled flood control project on the Inner Qixing River and the largest flood control area in the Sanjiang Plain. By 2000, the dikes had a total length of 58.5 km, including 19.2 km of main dikes along the Qixing River and the rest dikes of 39.3 km. The spillway was approximate 10 km with a bottom width of 40 m. There was no gate to control the water level in the spillway inlet. The effluent from the spillway entered the Sanhuangpao National Nature Reserve downstream and finally flowed into the Naoli River. The drainage was also one of the most important water sources for the wetlands of Naoli River National Nature Reserve and Dajia River Provincial Nature Reserve downstream. A total of $1.46 \times 10^6$ m$^3$ earthwork was completed. According to the 75% irrigation guarantee rate, the SFDZ can provide irrigation water for $1.61 \times 10^6$ ha of paddy fields under the condition without raising the existing dams. After two decade years of operation, the SFDZ has withstood many flood tests and indeed played a key role in regional flood control (Wang et al., 2001; Liu et al., 2008).
The seasonal variation of groundwater levels in QNNR and surrounding farmlands were closely related to precipitation and irrigation abstraction. When the precipitation was large or the amount of extraction was small, the groundwater level rose significantly; when the precipitation was smaller or the extraction amount was larger, the groundwater level rose less. Wetlands and surrounding paddy fields supply groundwater together to form a vertical water circulation pattern.

In recent years, due to the rapid growth of paddy fields, available water resources for agriculture are only from the groundwater except the incoming water of Qixing River upstream. As a result, exploitation of groundwater by surrounding farms has led to a continuous decline in groundwater depth (Zhong et al., 2010; Liu, 2014). According to statistics, the area planted to rice in Friendship Farm increased 56 times from 377 ha in 1984 to 21347 ha in 2007; the area of paddy fields in 579 Farm increased 123 times from 130 ha in 1985 to 16000 ha in 2009 (Pan et al., 2015). If this phenomenon continues further, it will certainly have an adverse impact on the water resource environment in Qixing River and the entire Sanjiang Plain.

3. Current Status of water resources constraints

3.1 Surface water resources

Qixing River is a typical marsh river in the Sanjiang Plain, with the curved watercourse, very slow gradient, overgrown weeds, contiguous pools, poor water flow, large roughness, and small river network density. Due to the small discharge capacity of the watercourse, when the flow from the upstream mountain is relatively large, it is easy to form a large-scale flooding area over a long period of time. When faced with rainy or farmland concentrated drainage season, the discharge is blocked by the high water level of Naoli River downstream, and the overflow makes most of the floodplain be permanent flooding with the general depth of 0.5–1.0 m. As a northern river, Qixing River is frozen from mid-November to early March every year, with one flood occurring in the middle and late April caused by ice/snow melting and another in late July and middle September by rainfall. The flow is usually discontinued from January to March. The interannual change was significant, with the average annual flow, the maximum and the minimum flow were 6.77 m³/s, 170 m³/s and 0.019 m³/s, respectively. The annual erosion modulus and the average annual maximum sediment concentration are 21.6 t and 4.7 kg/m³ respectively, according to Baoan Hydrological Station located in the upper reach of Qixing River (Li et al., 2003; Gu, 2017).
Qixing River has a length of 56 km in QNNR and the main water of QNNR is recharged by upstream runoff and the atmospheric precipitation. The water quality of surface freshwater is Class II and the pH is approximate 7.0. The underground sand and gravel aquifer is widely distributed in QNNR with good recharging conditions, sufficient supply sources and strong water-rich characteristics. The groundwater belongs to calcium bicarbonate-freshwater freshwater, with the quality of Class I, the salinity generally less than 0.5g/L, pH of approximate 7.0 and depth of 3–10 m. The main recharge of groundwater is atmospheric precipitation, and the main discharges are artificially extraction, which has been widely exploited and utilized (Ramsar Convention on Wetlands, 2014; Gu, 2017).

3.2 Groundwater resources

The groundwater recharges in QNNR and the surrounding Friendship and 579 Farms are precipitation infiltration, river recharge and irrigation infiltration. The main discharges are artificial exploitation. In the history of the region, the depth of groundwater is relatively shallow, which can supply river water year after year. Since 1990, the groundwater depth has gradually increased due to the increasing scale and intensity of groundwater exploitation, resulting in annual recharge from surface water to groundwater (Gu, 2017). The groundwater resource in the entire Naoli River Basin where Qixing River located is $14.13 \times 10^8$ m$^3$/a and the rechargeable amount is $10.77 \times 10^8$ m$^3$/a. In 2000, the over-exploitation percentage of Naoli River Basin reached 109.8% and the over-extraction amount was $1.09 \times 10^8$ m$^3$ (Song et al., 2010).

4. Wetland ecological water requirement

The wetland ecological water requirement can be divided into five parts: the actual evapotranspiration of vegetation after deducting precipitation, surface water storage changes, groundwater storage changes, soil water storage changes and plant water changes. It is equivalent to wetland ecological water consumption and can be expressed as Eq. (1). Due to the variations of surface water level, area and meteorological conditions, the actual wetland ecological water requirement changed interannually. Generally, it can be calculated according to the multi-year average of ecological water consumption (i.e., the water requirement under multi-year average water storage) (Li et al., 2006).

$$W = E - P + \Delta R + \Delta G + \Delta S + \Delta B \quad (1)$$

Where,
Among them, $P$ can be calculated using local average annual precipitation; $ΔR$ is the difference between upstream inflow and surrounding farmland drainage and downstream outflow, which is related to the protection or restoration wetland area and the suitable surface water depth; $ΔB$ is related to vegetation productivity and type; $ΔS$ is related to surface flooding; $ΔW$ is related to groundwater depth and dynamics; $E$ is related to land cover types.

As far as QNNR is concerned, a large number of excavated ditches in wetlands have been blocked and smoothed due to the water conservancy construction in SFDZ and the restoration and protection in QNNR. In particular, through heightening and blocking the cofferdam and embankment around the wetlands, a fully enclosed water resources management has been achieved within QNNR (Cui et al., 2012). Controlled by the above engineering measures, although the surface water level in the reserve still has seasonal changes, the annual variation is limited (unless it encounters extreme drought and flood events). However, there are no monitoring data of inflow and outflow and $ΔR$ can only be assumed as zero to keep the relative stable surface water level of SFDZ. Considering the interannual changes of $ΔS$ and $ΔB$ relative to $E$, $P$ and $G$ are smaller, they generally can be ignored in the calculation. Therefore, the ecological water requirement of QNNR can be simplified as Eq. (2):

$$W = E - P + G$$

Of course, if drought and flood events occur in the year before the calculation, the additional water consumption that is compensated to restore the average flooding area and surface water depth, should be taken into account to calculate the ecological water requirement for the current year.
The precipitation amount of QNNR is calculated as Eq. (3):

\[ P = 10^3 \times A \times p \]  

(3)

Where, \( A \) is wetland area (km\(^2\)); \( p \) is average annual precipitation (518 mm).

At present, the land covers of QNNR include open water as well as different types of wetland vegetation. In addition, there are also building land, cultivated land (mainly dryland) and woodland in the reserve. Considering that the building land does not occupy the ecological water requirement, and the forest land is generally recharged by precipitation only. Although both the two lands produce some runoff, it can be offset by the difference between precipitation and evapotranspiration. Therefore, \( E \) (m\(^3\)/a) was calculated as the sum of wetland and dryland in Eq. (4):

\[ E = 10^3 \times \sum A_i \times E_i \]  

(4)

Where, \( A_i \) is the area of the wetland or dryland (km\(^2\)); \( E_i \) is the evapotranspiration of the wetland or dryland (mm).

As the groundwater level QNNR has been fluctuating downward in recent years, the average depth of groundwater is 4–5 m. The former positive recharging from groundwater to wetlands has been transformed into wetland surface water recharging for groundwater. \( G \) is equivalent to the wetland infiltration as Eq. (5):

\[ Q_{wl} = 10^6 \times \sum (1 + H/Zr) \times k \times A \times T \]  

(5)

Where, \( Q_{wl} \) is wetland infiltration (m\(^3\)/a); \( H \) is the average open water depth (m); \( A \) is the area (km\(^2\)); \( k \) is the saturated soil hydraulic conductivity (m/d); \( Zr \) is buried depth (m); \( T \) is the calculation period (d).

According to the classification statistics of various types of vegetation in QNNR of 2010 (Figure 3) and the related parameters given in the literature (Wang and Yang 2001; Li et al., 2006; Xia et al., 2007; Liu et al., 2008; Zhou et al., 2015; Pan et al., 2015; Gu et al., 2017), the calculated results of Eq. (2)–(5) were as following:

\[ P = 1.04 \times 10^8 \text{ m}^3/\text{a}, E = 1.54 \times 10^8 \text{ m}^3/\text{a}, G = 0.15 \times 10^8 \text{ m}^3/\text{a}, W = 0.65 \times 10^8 \text{ m}^3/\text{a} \]
The above results indicate that unless experiencing extreme precipitation events, existing wetlands of Qixing River cannot achieve rainfed and do not have the ability to supply water to the surrounding farmlands without dike and cofferdam, and the recharge to groundwater cannot offset for the extraction by well irrigation, which means if the over-extraction of groundwater from surrounding farms cannot be prevented and the groundwater depth continue to decline, the ecological water requirement of QNNR will further increase in the future.

5. Surrounding farmland water requirement

The farmland water requirement can be calculated according to the actual water consumption of different farmland types. For example, the actual water consumption of paddy field and dryland in Heilongjiang Province are 561 mm and 424.8 mm respectively (Xia et al., 2007). The average water consumption of paddy field and dryland in the Sanjiang Plain are 652 mm and 388 mm respectively (Wang et al., 2004). Zhou et al. (2015) calculated the annual water consumptions of Naoli River Basin, when both the crop growth and leisure
period and the field water consumption were taken into account. The annual water
c consumptions are 657.7 mm for paddy field and 456.3 mm for dryland, which were used in
this report. According to the summed areas of paddy fields and drylands in Friendship Farm
and 597 Farm of 2010 (Figure 2), the farmland water requirement around QNNR is $12.83 \times
10^8$ m$^3$/a. This value does not take into account the compensation of precipitation and can be
used as the upper limit of farmland water requirement. Assuming that the precipitation in
paddy fields are completely effective, and drylands are rainfed, the farmland water
requirement will be reduced to $1.34 \times 10^8$ m$^3$/a, which can be used as the lower limit.

Another approach of calculating farmland water requirement is to use the irrigation
water quota set by Heilongjiang Province multiplied by the different farmland area.
According to “Heilongjiang Water Quota Standard (DB23/T 727-2016)”, the quota of
soybean surface irrigation in the Sanjiang Plain is generally 936–1404 m$^3$/ha, and 1404–1828
m$^3$/ha in the dry year and 450 m$^3$/ha in wet year; the quota of well and canal irrigation paddy
field are 4500–5250 m$^3$/ha and 5250–6000 m$^3$/ha respectively. In this report, the median
values of 1404 m$^3$/ha, 4875 m$^3$/ha and 5625 m$^3$/ha were used for dryland, well irrigation and
canal irrigation paddy fields, respectively. The well irrigation covers 90% of total paddy
fields (Zhong et al., 2010), and then the average quota for paddy field is 4950 m$^3$/ha.
According to the classification statistics of drylands and paddy fields at Friendship Farm and
579 Farms in 2010 (Figure 6), the farmland water requirement around QNNR is $6.66 \times 10^8$
m$^3$/a, which can be used as the median of farmland water requirement.

Compared with the ecological water requirement of QNNR, the surrounding farmland
water requirement is approximate 10 times of the former.

6. Water cycling in wetland-farmland system

Due to the long-term agricultural development, the wetlands widely distributed in
Qixing River Basin 60 years ago, has now become a patch embedded in agricultural
landscapes (Figure 3). Affected by the hydraulic connection between surface and
groundwater, the wetland ecological water and surrounding farmland water consumptions are
involved in a whole wetland-farmland system. The water cycle of the system shows that this
is a four-dimensional processes including spatial three-dimensional plus time (Figure 4).
According to the land covers of QNNR and the surrounding Farms in 2010 (Figure 3) and the related meteorological and hydrogeological parameters given in the literatures (Guo et al., 2008; Zhong et al., 2010; Deng et al., 2012; Pan et al., 2015; Zhou et al., 2015; Gu, 2017), the total precipitation, evapotranspiration and precipitation recharging groundwater of this system were calculated as following methods.

Due to the relative closure of the Naoli River Basin and the lack of groundwater hydraulic gradient data in the study area, the infiltration recharge of groundwater in this report did not consider the groundwater lateral inflow recharge and outflow discharge (Gu, 2017). Since the groundwater evaporation consumption decreases with the increase of groundwater depth, groundwater no longer evaporates when the local groundwater depth is more than 3–5 m (Yan et al., 2010; Gu, 2017); therefore, this report assumed that groundwater evaporation was zero. Precipitation and irrigation infiltrations were calculated as Eq. (6) and (7):

$$Q_{Pr} = 10^3 \times \alpha \times P \times A$$  \hspace{1cm} (6)
Where, $Q_{Pr}$ is the precipitation infiltration (m$^3$/a), $\alpha$ is the recharge coefficient of precipitation infiltration (dimensionless) and $A$ is the total area of precipitation area (km$^2$).

$$Q_{Pr} = \alpha \times A$$

Where, $Q_{Ir}$ is the irrigation infiltration (m$^3$/a); $\beta_i$ is the infiltration recharge coefficient of different irrigation types (dimensionless); $q_i$ is the irrigation quota (m$^3$/ha) of different irrigation types; $A_i$ is irrigated area of different irrigation types (ha).

Because the infiltration coefficient of canal and well irrigations are similar, this report combined them into $Q_{Ir}$.

Groundwater extraction by well irrigation was calculated as Eq. (8):

$$R_{Gw} = \gamma \times q_{ Pf } \times A_{ Pf }$$

Where, $R_{Gw}$ is the groundwater extraction (m$^3$/a); $\gamma$ is the ratio of well irrigation (dimensionless, 90%); $q_{ Pf }$ is the well irrigation water quota of paddy fields (m$^3$/ha); $A_{ Pf }$ is well irrigation area of paddy fields (ha).

Farmland drainage including paddy field drainage and dryland saturated runoff, which was calculated as Eq. (9):

$$D_{Fl} = a \times q_{ Pf } \times A_{ Pf } + b \times q_{ Di } \times A_{ Di }$$

Where, $D_{Fl}$ is the farmland drainages (m$^3$/a); $a$ is the drainage coefficient (dimensionless); $q_{ Pf }$ is the well irrigation water quota of paddy field (m$^3$/ha); $A_{ Pf }$ is the paddy field irrigation area; $b$ is dryland runoff production coefficient (dimensionless); $q_{ Di }$ is dryland water quota (m$^3$/ha); $A_{ Di }$ is dryland area (ha).

According to Eq. (2)–(9), the calculated index of the wetland-farmland system were as following:

$$P_{Total} = 12.50 \times 10^8 \text{ m}^3/\text{a}, E_{Total} = 14.77 \times 10^8 \text{ m}^3/\text{a}, Q_{Pr} = 1.25 \times 10^8 \text{ m}^3/\text{a},$$

$$Q_{Ir} = 0.90 \times 10^8 \text{ m}^3/\text{a}, R_{Gw} = 4.27 \times 10^8 \text{ m}^3/\text{a}, D_{Fl} = 0.85 \times 10^8 \text{ m}^3/\text{a}.$$
been intensified between wetlands and farmlands. The amount of groundwater extracted by
the wetland-farmland system (4.27 × 10^8 m^3/a) is approximate 2.0 times as many as the sum
of precipitation, wetland and irrigation infiltrations (2.30 × 10^8 m^3/a). This imbalance
between groundwater recharge and discharge is the main reason for the decrease of
groundwater depth. Therefore, how to limit the exploitation of groundwater while rationally
allocate and regulate surface water, to support agricultural development and ensure the
wetland ecological water requirement, has become a key issue for sustainable development in
the region.
Chapter V  Management principles and technical measures

1. Management principles

Due to the regional differences in global climate, agricultural development level, traditions and existing policies, there is little global solutions of harmonizing wetland and farmland water use. However, many experiences and cases of wetland management also show that it is indeed possible to find ways or modes of mutual benefit between wetland and agriculture, especially when local solutions are implemented using local knowledge in larger integrated planning efforts. These principles include to carry out agricultural practices that help to reduce the negative impact on wetlands, to develop multi-functional agro-wetland ecosystems that provide the widest possible range of wetland ecosystem services, and to restore wetlands in agricultural landscapes to enhance regional ecosystem functions and services (Ramsar Convention on Wetlands et al., 2014).

For the major grain producing areas in Amur River Basin located in Northeastern China, the water scarcity is not the lack of total amount of water resources, but the mismatch of seasonal water distribution of surface/groundwater and plant growth/grain production cycle. In addition, projected increased extreme precipitation/drought events also urgently require the exertion of hydrological regulation functions of wetland and farmland surface, soil and groundwater. Therefore, decision-makers and managers should find a breakthrough in the water use time and space to mitigate the conflict between wetlands and farmlands, not only considering the joint regulation of surface and groundwater within the wetland-farmland system, but also considering the impact of future climate changes and water conservancy projects.

Without an unprecedented and coordinated planning, the region will be plagued with more and more water-related issues that threaten the health of wetlands, farmlands and human beings themselves (Jury and Hjir, 2007; Siebert et al., 2010). Only by establishing an effective dialogue between environment and agricultural managers can a win-win and regional sustainable development of food production and wetland protection be achieved (Rijsberman and Silva, 2006).

1.1 Improvement of the wetland water resources protection system
In the wetland protection system, the public participation, science and technology, effective government governance and the rules and policies play as the source, the premise, and the key respectively. With the progress of society, public requirements for wetland benefits have shifted from purely utilitarian requirements to protective claims (the transitional pattern of “non-protection-non-compensation” and “protection-compensation”). There is an example of Bamboo Node Model of the US wetland protection policy, i.e., the evolution of the wetland protection system is like the growth of bamboo. The public, science, government and law at different historical stages influence and restrict each other to jointly overcome the emerging challenges and introduce new laws to form social rules (Chen et al., 2016).

At a time when the conflict between the wetlands and agriculture have become increasingly prominent, the laws and regulations on wetlands water resources management related to agriculture should also enter a new and more rigorous stage. Therefore, Heilongjiang local government should, in accordance with the “Comprehensive Water Resources Planning of China” and other relevant laws and regulations, centralize the wetland water resources clauses that are currently scattered in laws and regulations on water resource management and wetland protection, or make them more operational and sustainable. What is worth to be sure is that Article 32 of the revised “Regulations for the Protection of Wetlands in Heilongjiang Province” issued in 2015 explicitly requires the establishment of a wetland ecological recharge mechanism. These administrative provisions still need to be further perfected.

1.2 Inclusion of wetlands protection objectives in agricultural policies

A precedent case of using wetlands for agricultural economic policies has been proven to be successful. Swampbuster, an article of the “Food Security Act” of 1985 in the United States, which provided that there would be no financial subsidies for the farmland reclaimed from wetlands, and thereby slowed the process of wetland farming. This article, as amended by the “Food, Agriculture, Protection and Trade Act” of 1990, introduced the “Wetland Reserve Program” that was supported by both USDA and the Congress in funding and techniques and provided farmers with the financial stimulus to protect and restore wetlands, through which the trend of wetland conversing to farmland was prevented. The project was effective due to the private ownership of 74% of the wetlands in the United States (Chen et al., 2016).
The goal of wetland protection should be included in the agricultural policies of the province, county (city) and farm scales in the Sanjiang Plain. For example, in the areas where there is a conflict between agriculture development and wetland protection, the preferential subsidies and conditions for agricultural production should be abolished, and the agricultural water price should be reformed. Due to the sharp increment in agricultural water cost and the corresponding decrement of marginal benefits, the enthusiasm of wetland reclamation would be frustrated and oversized grain production would be constrained. Meanwhile, increased agricultural water price would encourage farmers to take water protection measures to save water. In addition, the special budget for wetland ecological water resources should be set to improve the competitiveness of wetlands and make the wetlands a competitive water user. The water use conflict between wetlands and agriculture would be mitigated through economic means such as transfer payment (Wang and Wu, 2011).

2. Wetland technical measures

2.1 Water transfer technology at stagger time

According to the irrigation season of paddy fields, the natural wetlands (e.g. C. lasiocarpa) in agricultural landscape was used to transfer the water at stagger time. Plant biomass and photosynthetic characteristics were observed and measured to study the impact of different water supply strategies on wetland dominant plant (Figure 7).

The methods include the following steps: 1) to keep the wetland surface water level at 0–1 cm, and transfer the excess wetland water resources for farmland irrigation during the germination period; 2) to supply wetlands at the surface water level of 8–12 cm during the vigorous growth period; 3) to periodically supply wetland at the surface water level of 0–1 cm according to the non-irrigation and drainage timings, with the surplus water in the irrigation area and pretreated drainage to recharge wetlands. The result suggested that water transfer at stagger time can form a compensational water supply mechanism, through which the water use conflict between wetland ecological water requirement and farmland water requirement will be mitigated locally, and a new idea is provided for wetland protection and water-saving irrigation of paddy fields in the Sanjiang Plain. (Kang, et al., 2003; Song et al., 2017).
Figure 5 Responses of *C. lasiocarpa* biomass to different water supply strategies (adapted from Song et al., 2017)

2.2 Precise water recharge technology

Precise water recharge technology includes how to determine the recharge timing and what is the minimum water should be recharged. It is generally believed that at the beginning of the growing season when the air gradually warms up while the soil is still frozen, the melt ice/snow water enter into the topsoil. In summer, as the air temperature continues to rise, the wetland evapotranspiration becomes strong and the soil water is consumed significantly. At this time, rainfall becomes the main water source for the wetlands without surface/ground water recharge. However, the rainfall at this time usually cannot meet the demand of all wetland vegetation’s transpiration and the wetland soil water begin to decrease rapidly. Therefore, this is an important time node of ecological water recharge to maintain wetland ecological water requirement. For the Honghe Nature Reserve, the best recharge time is from the end of July to the beginning of August (Li, 2012).

For the wetlands without long-term continuous monitoring data, trigonometric function models and $^{18}$O stable isotope ratio parameters can be used to estimate the soil water retention time at different depths to provide reference for wetland ecological water recharge. The determination of soil retention time is determined by Eqs. (10) and (11):

$$\tau = c^{-1} \sqrt{f^{-2} - 1}$$  \hspace{1cm} (10)

$$\delta = \beta_0 + A[\cos ct - \varphi]$$  \hspace{1cm} (11)

Where, $\tau$ is the average residence time; $c$ is the angular frequency; $f$ is the damping coefficient; $\delta$ is the isotope output value; $\beta_0$ is the average of the isotope; $A$ is the amplitude of the isotope change; $\varphi$ is the lagging phase; $t$ is sampling time.
Taking Momoge degraded wetland as an example, according to the above equations, using the nonlinear regression analysis to fit the measured stable $\delta^{18}$O data of rainfall and soil waters in different soil layers from June to September in the growing season. Through curve fitting, the model parameters were obtained to further estimate the soil water retention time of each corresponding soil layer. Based on the average residence time of soil water at different depths obtained in Table 4, and according to the plant requirements of soil moisture in different life cycles, it is helpful to calculate the optimum volume and timing for wetland recharge.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Mean value (‰)</th>
<th>Amplitude(‰)</th>
<th>residence time (d)</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall</td>
<td>-6.5103</td>
<td>10.64</td>
<td>-</td>
<td>0.38</td>
</tr>
<tr>
<td>0–20 cm</td>
<td>-8.04421</td>
<td>8.00</td>
<td>50.94</td>
<td>0.29</td>
</tr>
<tr>
<td>20–40 cm</td>
<td>-7.95047</td>
<td>5.79</td>
<td>89.60</td>
<td>0.52</td>
</tr>
<tr>
<td>40–50 cm</td>
<td>-7.78383</td>
<td>4.66</td>
<td>119.06</td>
<td>0.24</td>
</tr>
<tr>
<td>50–60 cm</td>
<td>-7.11428</td>
<td>4.52</td>
<td>123.68</td>
<td>0.89</td>
</tr>
<tr>
<td>60–70 cm</td>
<td>-8.45503</td>
<td>3.97</td>
<td>144.41</td>
<td>0.47</td>
</tr>
<tr>
<td>70–80 cm</td>
<td>-8.59227</td>
<td>3.72</td>
<td>155.56</td>
<td>0.63</td>
</tr>
<tr>
<td>80–100 cm</td>
<td>-8.59227</td>
<td>3.38</td>
<td>173.61</td>
<td>0.15</td>
</tr>
</tbody>
</table>

2.3 Ice/snow melting water resourced technology

The Sanjiang Plain is located in a seasonal freeze-thaw zone, which is frozen from November to May next year. The amount of snowfall is generally 40–80 mm with the maximum thickness of approximate 45 cm. In addition to evaporated and wind-swept snow, lots of effective snowfalls are accumulated on the land surface or in the soils, and then thaw along with the frozen layer in the following spring. Meanwhile the lower and middle soil layers have not yet been thawed and an effective water barrier is formed, which is conducive
to moisture accumulation. The melting water of ice and snow and spring precipitation converge together to become an important water source for the wetlands (Yin et al., 2003).

Since this work has just started, we have just completed the observation of the mild snow thickness on different underlying surfaces of wetlands. The preliminary results showed that the surface temperature curves of the different vegetation covers (ice, grass, shrub) were similar, with a slowly increasing trend. However, the variation of ground temperature showed great instability. The surface temperature of the grassland is higher than that of the ice and the shrub land, which may be due to the deciduous leaves and the snow covering the ground. During the whole observation period, the snow gradually melted and the snow cover became thinner. The daily changes of snow depth on ice, grassland and shrub land were roughly the same with the peak of ablation at the same time, which showed that the trend of thawing has nothing to do with the vegetation type as the temperature changes (Figure 6). Based on these collation and analysis of the data from the field experiments, ice and snow melting water resourced technology could be studied and developed further.

![Image](image.png)

**Figure 6** Soil temperatures and snow cover depths under different vegetation types

### 3. Agricultural technical measures

#### 3.1 Water-saving irrigation technology

For a long time, many irrigation experts believe that crop water requirement is immutable, and reducing irrigation will reduce production. Therefore, under the guidance of the theory of invariable crop water requirement, almost all water conservancy projects are
planned and designed according to the same agricultural water supply planning and engineering operation and management, and agricultural water-saving is mainly focused on water-saving irrigation projects (e.g. seepage prevention), while ignores irrigation management and agricultural water-saving measures. Practices have proved that water-saving irrigation can not only significantly reduce crop water requirement, but also not affect crop photosynthesis, which makes root development better and saves water, energy, labor and cost. Therefore, greater water productivity and economic benefits can be obtained (Jia et al., 2009). For example, intermittent and wetting irrigation significantly reduce the ecological water consumption of paddy fields with little effect on physiological water requirement. Compared with flooded irrigation, the inter-evaporation of intermittent and wetting irrigation decreases by 14.8% and 29.6% respectively; the paddy field leakage reduces by 22.7% and 31.8% respectively; and the total water consumption decreases by 13.9% and 20.2% respectively. Meanwhile, the water use efficiency increases by 35.7% and 50.0% respectively and the yield increases by 9.4% and 12.7% respectively (Nie et al., 2011; Nie and Wang, 2015).

3.2 Soil water capacity increased technology

The soils in the Sanjiang Plain generally have some water storage capacity, with the effective storage layer of 1–1.5 m and the storage capacity of 400–600 mm. The soil capacity still has the potential for transformation and expansion. One of the main existing water problems in the Sanjiang Plain is the uneven distribution of seasonal and interannual precipitation; therefore, dry and wet season or year are formed, with the coefficient of variation of 0.2–0.25 and the extreme difference of 1–2 times. The storage capacity of different soils is 140–300 mm. The inherent conditions of soil reservoirs in the Sanjiang Plain are poor. The groundwater depth (including the perched groundwater in vadose zone) is perennial or seasonally high, which restricts the soil regulated storage capacity especially in the low-lying land where the soil is heavy and without waterlogging and drought resistance. Therefore, most crop roots distribute within upper soils (< 40 cm). The thickness of soil moisture emergency layer is less than 50 cm, while that below 50 cm is basically unchanged. To increase the effective soil water storage capacity, comprehensive measures can be deployed including non-engineering measures, such as increasing surface coverage, leaving stubble, decreasing tillage even no-tillage, increasing the surface roughness, reducing precipitation loss and evaporation, deep tillage, ultra-deep tillage, application of organic materials and other soil improvers, artificially improving the physical properties of soil and enhancing soil water storage capacity (Deng et al., 2001).
3.3 Rainfed agricultural technology

Considering the semi-arid/semi-humid and humid climate in the Sanjiang Plain, only the precipitation resources is enough to meet or mostly meet the needs of rainfed agriculture with different paddy field and dryland planting ratios, in concert with local reservoirs (including soil, surface water and groundwater reservoirs). In the past, because of the small amount of annual irrigation and the low utilization rate of irrigation works and facilities, the water resource requirement is not too urgent. With the rapid development of paddy fields in recent years, the scale of irrigated agriculture has been expanding and water resource has become scarce. For drylands, rainfed has been achieved through the development of soil reservoirs and compensatory irrigation techniques such as ultra-deep tillage, ridge tillage, wet seeding and artificial rainfall. For paddy fields, the water-saving techniques (i.e. dry seeding, dry weeding, alternatively wet and dry, wet seeding, drought-resisting agent), the water consumption could decrease from shallow-depth-shallow (756 mm) to interplanting (395 mm) and to wet irrigation (409 mm), which means the actual water consumption can be reduced from the current amount of 600 mm to 300–400 mm that is similar with dry crops (280 mm for wheat, 400 mm for maize and 420 mm for soybean). The integrated utilization of these techniques can fully exploit precipitation resources, exert the regulation function of soil water reservoir, and overcome the uneven distribution of annual precipitation. Consequently, the canal irrigation proportion could be reduced gradually in the areas that are suitable for the rainfed agriculture development and the rainfed agricultural areas could be expanded (Xia et al., 2007; Jia et al., 2009; Yan et al., 2010).

3.4 Agricultural water conservancy engineering technology

For agricultural water conservancy projects involve a wide range of operations and complex operations, this report only recommends them as one of the technical systems without further review. Instead, this report focuses on making full use of local precipitation and transit water resources, combining irrigation and drainage, drainage and storage, and improving local water resource productivity.
Chapter VI Conclusion and recommendations

1. Conclusion

On one hand, wetland is one of the most valuable natural resources and the cornerstones of ecological civilization in the Sanjiang Plain. It is of great significance throughout Amur River Basin and even the whole world. On the other hand, the Sanjiang Plain will continue to serve as an important commodity grain base in China for a long time. The grain output and stable production in this area have become one of the mainstays of food security in China. This positioning based on natural resource endowments and national policies have determined the competitive relationship between wetlands and agriculture in this region, which becomes the source of the conflict between them.

The results showed that Heilongjiang Province, as a major grain-producing province in China, has consumed massive agricultural water resources to maintain the steady grain production in successive years. Between 2004 and 2015, the proportion of agricultural water increased from 72% to 88%, while the proportion of ecological water only hovered around 1% during the same period. Compared with the rest parts of China, the proportion of agricultural water in Heilongjiang is approximate a quarter higher than the national average, while that of ecological water is approximate a half lower than the average. The Sanjiang Plain, the most important grain-producing area in Heilongjiang Province, has unique surface and ground water resources. if there is no long-term unsustainable over-exploitation, it is difficult to cause the conflict of water resources between wetlands and farmlands. The natural resource endowments and the positioning of national policy determined the competitive relationship between wetland and agriculture. The total surface water storage in the Sanjiang Plain wetlands has decreased from $50.6 \times 10^8$ t in the 1980s to $9.3 \times 10^8$ t in 2010, and the total soil water storage has decreased from $93.4 \times 10^8$ t in the 1980s to $37.7 \times 10^8$ t in 2010. The total water storage of wetlands has decreased from $144.0 \times 10^8$ t to $47.0 \times 10^8$ t, which means that it has lost approximate 2/3 during the past 30 years.

No matter wetlands or their surrounding farmland, the water requirement can be divided into five parts: the actual evapotranspiration of vegetation after deducting precipitation, surface water storage changes, groundwater storage changes, soil water storage changes and plant water changes. The case study the Qixing River National Nature Reserve (QRNNR) showed that the wetland precipitation, evapotranspiration, groundwater recharge and
ecological water requirement were $1.04 \times 10^8 \text{ m}^3/\text{a}$, $1.54 \times 10^8 \text{ m}^3/\text{a}$, $0.15 \times 10^8 \text{ m}^3/\text{a}$ and $0.65 \times 10^8 \text{ m}^3/\text{a}$, respectively. For the surrounding farmlands in Friendship Farm and 579 Farm, the agricultural water requirement was $6.66 \times 10^8 \text{ m}^3/\text{a}$. When QRRNR and its surrounding farms were considered as a whole system, the total precipitation, evapotranspiration, groundwater recharge, groundwater extraction, and agricultural drainage were $12.50 \times 10^8 \text{ m}^3/\text{a}$, $14.77 \times 10^8 \text{ m}^3/\text{a}$, $2.30 \times 10^8 \text{ m}^3/\text{a}$, $4.27 \times 10^8 \text{ m}^3/\text{a}$ and $0.85 \times 10^8 \text{ m}^3/\text{a}$, respectively. Without the rapid development of paddy fields in the surrounding farms, the natural water resource endowment of Qixing River can fully meet the needs of the natural wetland ecosystems. Agricultural development for successive years, especially the dramatically increased requirement for water in paddy fields, intensified the water use conflict between wetlands and farmlands. The main reason for the local continuous decline of groundwater depth was that groundwater extraction was approximate twice as great as the total infiltration recharge from wetlands and farmlands.

The conflict between the use of wetlands and farmland is the result of a dual drive between the natural environment and socio-economic, which means that conflict is not unilaterally solved. Therefore, we must full encourage the enthusiasm of stakeholders such as ecosystems, markets, farmers and governments. We should take the initiatives to adapt to the human circumstances and take measures to increase the available water resources as well as reduce the unnecessary consumption as a whole. We will eventually achieve to the modern agriculture that is resource-saving and environment-friendly, and the ecological civilization that is harmonious development of people, nature and society.

2. Recommendations

2.1 Improvement of the right to speak of wetland water use to ensure that the minimum ecological water needs of wetlands

Encouraging water-saving irrigation in the forthcoming or promulgated laws of the central and local governments; and in the binding rules and regulations such as departmental rules and government documents; and increasing and improving wetland ecological environment water supply and recharge principles, procedures and systems, especially clearing the technical route, capital investment and the responsibilities and obligations of the relevant departments. Local governments should, as early as possible, restrict or at least discourage the development of paddy fields by adjusting agricultural subsidies, formulate and raise agricultural water prices to economically stimulate farmer to protect water resources.
Ensuring the minimum ecological water requirement of wetlands, maintaining the integrity of wetland ecosystems and improving the adaptability of drought and flood, through policies and regulations, market instruments, water-saving propagation and technical promotion.

2.2 Wetland surface-groundwater and wetland-farmland joint water resources management

Normalizing the implementation of wetland recharge project, making full use of flood, meltwater and purified farmland drainage to recharge wetlands to improve their ecological environment. Strengthening the investment and construction of farmland irrigation networks around wetlands to improve the utilization rate of transit surface water resources. For areas with better groundwater recharge and higher self-resilience, the wells need not be shut down completely. Instead, the timing of precipitation and agricultural water use should be taken into account and the “no-harvest period” should be set to give sufficient time to recover the groundwater depth. For the groundwater depression cones, artificial irrigation recovery should be carried out. For some isolated wetlands well recharge can be used to improve their ability to deal with extreme drought events and average the seasonal and interannual changes.

2.3 Encouragement and development of agricultural wetland irrigation system

Constructing the agricultural drainage collection-processing-irrigation wetland system (CPI-wetlands) in the sites adjacent to farmlands with suitable conditions. The system is generally composed of two types of wetlands that are connected each other in series: the first one is a constructed wetland that receives farmland drainage and is used for treatment of drainage pollution, usually with small area, limited surface water depth and high vegetation coverage; the last one is used to store irrigation water, usually with large size, deep surface water depth and low vegetation coverage. The drainage is collected, purified and stored through this system and can be reused for the irrigation. Smiley and Allred (2011) reported that in the Northwestern Ohio of the United States, the two types of CPI-wetlands support the biodiversity equally. In the wetland-farmland systems of the Sanjiang Plain, such projects should be encouraged and more similar or upgraded ones should be researched and developed.

2.4 Basin-scale water productivity assessment

The basin-scale water productivity can be used as a framework for assessing the requirement for balanced wetlands and agricultural water requirements to ensure an equitable distribution and allocation of water resources; i.e., the synthetic benefit accounting of water resources used for crops, livestock, fisheries, ecosystem services and the society. Although
there is no market exchange and the ecosystem service value cannot be easily realized at present and the basin-scale water resource allocation model based on the total economic value faces the practical operability challenge, wetland protection endeavour can be strengthened and the unconstrained requirement for agricultural water resources can be limited, under the background that ecological civilization construction is paid more and more attention nowadays.

2.5 Climate change adaptive water management

In developing a coordinated program of agricultural water use and wetland ecological water use, great attention should also be paid to the contribution of global climate change to the water balance of the basin. At present, influenced by the global change, seasonal frost area in the Sanjiang Plain is shrinking, the frost layer becomes thinner, and the freeze-thaw process becomes weaker, which is unfavorable to the formation of spring flood runoff. The increase of evapotranspiration caused by the increased temperature in summer and the decrease of winter snowfall will lead to the decreased water supply but increased consumption, which have led to widespread occurrence of wetlands and farmland water shortages, drastic runoff reduction and increased marsh river break-off days in the Sanjiang Plain. Therefore, greater importance should be paid and more actively response should be taken to mitigate the negative impacts of current and future climate change, through enhancing the adaptive capacities of both natural ecosystems and our societies.
References


