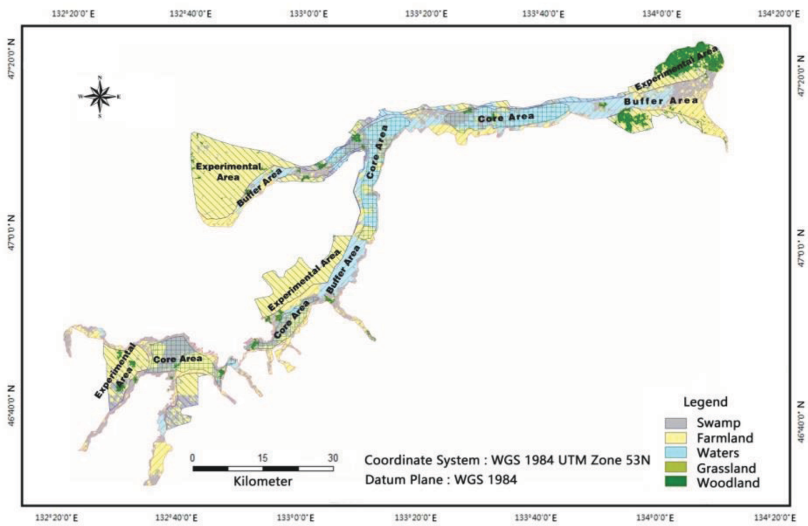

Fig.2. Land-use map of Naoli River Nature Reserve in 2013.

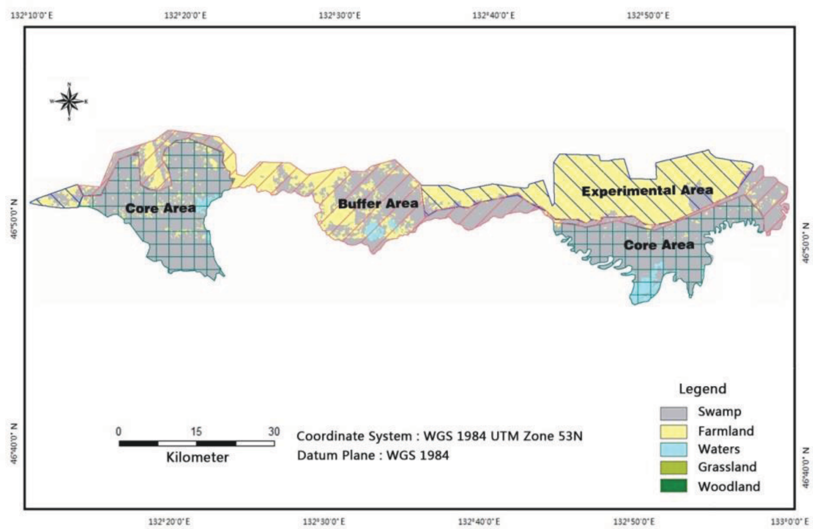

Fig.3. Land-use map of Sanhuanpao Nature Reserve in 2013.

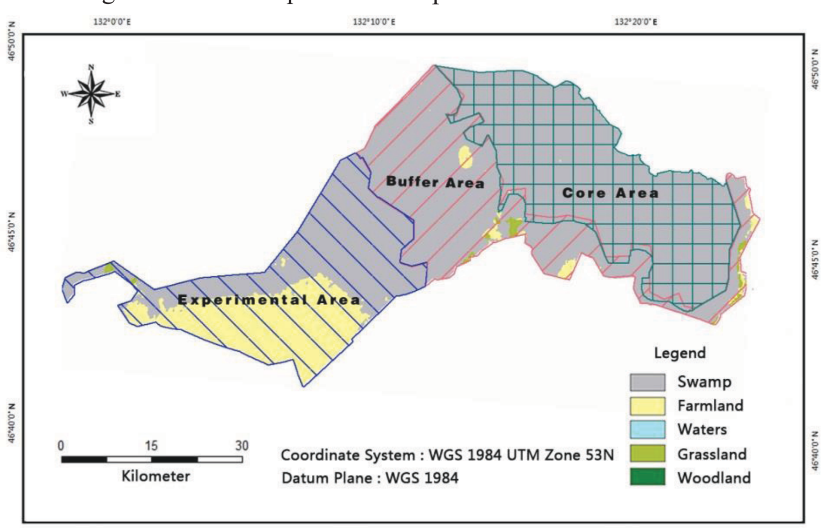

Fig.4. Land-use map of Qixing River Nature Reserve in 2013.

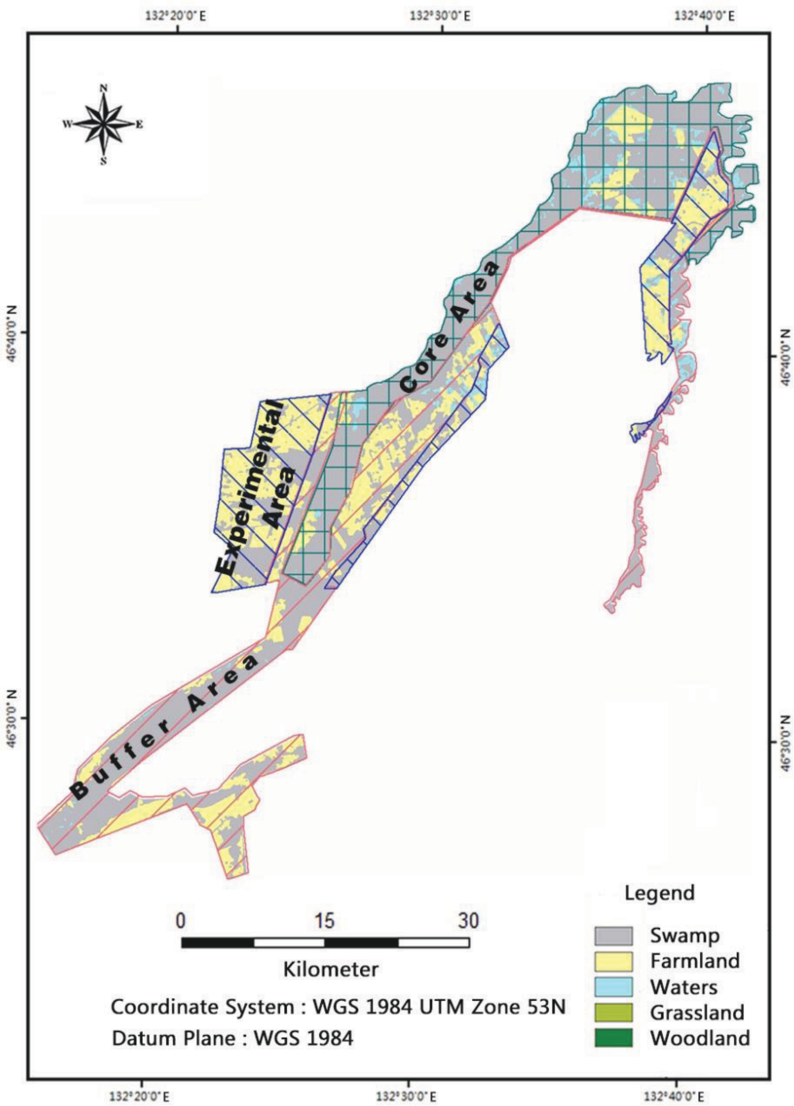

Fig.5. Land-use map of Dongsheng Nature Reserve in 2013.

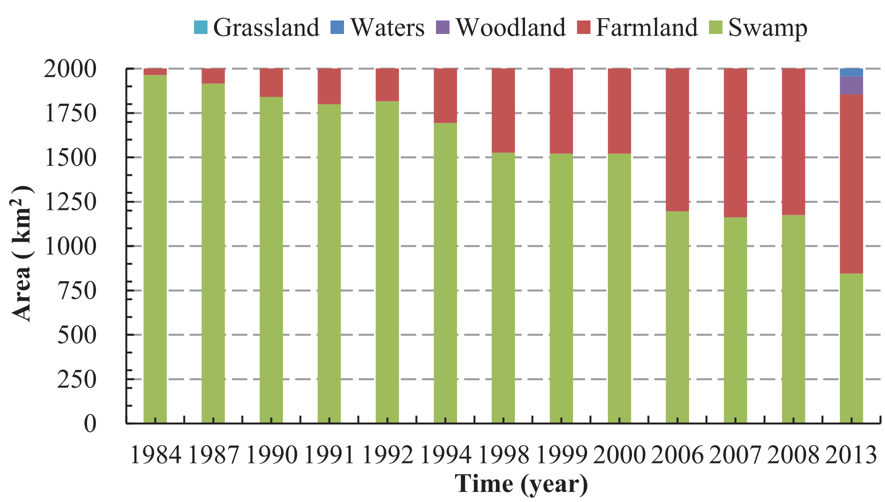

Fig.6. The change of land-use types in different periods of nature reserves.

Fig.2-Fig.6 show that the land-use types of the nature reserves are rich, including waters, farmland, swamp, woodland and grassland. The waters indicate the water surface, including reservoirs, bogs and rivers. The area of swamp decreased the most serious and decreased by 56.99% in 30 years from 1963.82km^2 in 1984 to 844.71km^2 in 2013. While the change of farmland area is the opposite of the change of swamp area, and it increased year by year. And the proportion of woodland, grassland and water area is relatively small and the change is not obvious. The changes of the land-use type area reflect that the wetlands are well preserved in the 1980s. With the passage of time, the wetlands are gradually destroyed and the area is gradually shrinking. At present, the wetland ecological environment is badly in need of protection and restoration.

2.2.2 Target Determination of Ecological Water Requirement

The maximum ecological water requirement is difficult to achieve in reality, due to the composition structure and actual demand of wetland ecosystem, aed the limited amount of regional water resources. Wetlands cannot be restored to near-original level even through water is transferred by the artificial conditions, so it has no practical significance. Therefore, the ecological water requirement of wetlands is divided into two levels: minimum and optimal. The minimum ecological water requirement is the minimum amount of water needed for the system to maintain its own development and prevent it from degenerating. Once below this amount, the ecological system will be destroyed or even disappeared. The optimal ecological water requirement is the amount of water that the wetland ecosystem can reach an ideal state.

1) Principles to Follow:

① the First Principle of Ecological Restoration- "the Core Area as the Main and the Buffer Area as the Secondary"

The core area is the essence of nature reserve, the core of the wetland ecosystem, and the minimum space where Huan, cranes and other rare birds inhabit and multiply, so it need to be strictly protected; In addition to the core area, the buffer area is less affected by human activities and maintains a good landscape. It is also the main foraging area and the resting place of the waterfowl during the spring and autumn migratory seasons. The buffer area mainly serves to isolate the core area and the experimental area, and it can play a good shielding effect for core area. Based on the project of returning farmland to wetland and vegetation restoration, the buffer area can be fully recovered and the ecosystem can be developed better. Therefore, the restoration of wetland ecosystem should focus on "the core area as the main and the buffer zone as the secondary". it’s the main target.

② the Principle of Equal Emphasis on Food Security and Ecological Benefits

Wetland ecosystem protection and management is a difficult project involving the complex relationship between natural system and human system. Under the goal of protecting and restoring the balance of wetland ecosystem, the construction of commodity grain base in Sanjiang Plain should also be guaranteed. Since 1949, with the rapid development of population and economy, the Sanjiang Plain experienced four land reclamation climax. In 1983, large-scale land reclamation basically ended, and the impact of human activities on land-use types weakened. Therefore, taking the equal importance of food security and ecological benefit as the principle, 1984 was regarded as the most original time point of wetland ecological restoration.

③ the Principle of Taking the Establishment Time of Nature Reserves as the Boundary

With the continuous degradation of wetlands and the increasing awareness of the importance of wetlands, a number of nature reserves were gradually established by the local government in the Sanjiang Plain. With the approval of the establishment of Nature Reserve and Protection Area Management Bureau, wetland management and protection work was carried out gradually. Management system construction, improvement of infrastructure, special rectification action and publicity and education activities basically curb the disorder development and construction activities on the destruction of nature reserves, and the impact of human beings on wetlands is gradually reduced. Therefore, the establishment time of each nature reserve is an important time point which related to the wetland area change. Before and after the establishment of the nature reserve, the wetland area change may be two different trends.

④ The Principle of Selecting Typical Years by Remote Sensing Image

The functional zoning of nature reserves is determined by the types of nature reserves, resource characteristics and distribution, focusing on natural conditions, the objects of protection. Therefore, the wetland area at the time of the nature reserve established does not necessarily correspond to the sum of the core area and the buffer area. If nature reserves are less affected by human activities or water inflow into wetlands is rich, the wetland area is larger than the sum of the core area and the buffer area when the nature reserve is established. If the wetland is protected well, the wetland area in the present year may still be larger than the total area of the core area and the buffer area; Similarly, if nature reserves are affected by human activities, or water inflow into wetlands is small, then when the nature reserves are established, the wetland area is certainly smaller than the total area of the core area and the buffer area. For the above situation, the principle of the establishment time of nature reserve as the boundary is meaningless. And based on the results of land-use at different periods after the interpretation of remote sensing image, using the method of typical year to select the typical year which is close to the area of wetland to be restored, ecological water requirement of wetlands at different level is determined.

⑤ the Screening Principle of the Regional Precipitation is not Unusual and Close to Multi-year Average

Natural precipitation and surface runoff are important recharge sources for wetlands, and natural precipitation is more important and the proportion is relatively large for wetlands. However, if precipitation is more or less than normal, it will have a certain impact on wetland ecosystem. If the wetland ecosystem can maintain its normal operation without damage during the normal year, the wetland ecosystem will reach steady state. Therefore, the target of ecological water requirement of wetlands at different levels should be determined according to the screening principle that regional rainfall is not unusual and close to multi-year average in long-term series or the rainfall under the 50% guarantee rate, so as to exclude the influence of precipitation anomaly on wetland.

2) Target determination

① minimum ecological water requirement

Calculation of minimum ecological water requirement should be to restore the core area. The nature reserve in the 1980s is protected better. The wetland area in the core area of Naoli River Nature Reserve accounted for 97.7% of the total area in 1984, while the other nature reserves are more than 99%. According to the analysis results of regional precipitation (Fig.3), the annual precipitation in

1984 is higher than the multi-year average and the precipitation under the 50% guarantee rate, but not belongs to the years of precipitation anomaly according to the climatic anomaly concept. Therefore, according to the principle of ① ② ④ ⑤, the recovery target of the minimum ecological water requirement is to restore the core area of wetland area near the state of 1984, so 1984 is selected as the typical year of the minimum ecological water requirement calculation finally.

② optimal ecological water requirement

Calculation of optimal ecological water requirement should be to restore the core area and buffer area. According to principles ③ and ④, the wetland area at the time of the nature reserve established and at different typical years, the relative error of total area with core and buffer area are shown in Table 2, in which the wetland area of Dongsheng Nature Reserve in 2004 was replaced by the area in 2002, because there was no corresponding remote sensing image in this year. According to Table 2, in addition to the Qixinghe Nature Reserve, the wetland areas of the Naoli River Nature Reserve, Sanhuanpao Nature Reserve and Dongsheng Nature Reserve are similar to the wetland areas at typical years when the nature reserves are established, and which is close to the total area of the core area and the buffer area.

At the same time, the area of wetland in the nature reserve changes little in successive years. Therefore, the typical year of ecological water requirement calculation of Naoli River Nature Reserve, Sanhuanbao Nature Reserve and Dongsheng Nature Reserve should be selected from 1998-2000, 1990-1992, 1994 and 1990-1992 respectively. The wetland area of Qixing River Nature Reserve in 2008 is the smallest in 13 typical years, but it still is larger more than the total area of the core area and buffer area $46.94km^2$, indicating Qixing River Nature Reserve are well managed and protected. But in the long run, in order to ensure that the wetland ecosystem is not degraded, the typical year of the optimal ecological water requirement calculation should be selected from 2006 to 2008.

Table 2 Wetland area of land-use in different periods.

Nature reserve	Area (km^2)	Wetland area of land-use in different periods					
		Founding time	Wetland area (km^2)	Ralative error (%)	Typical year	Wetland area (km^2)	Ralative error (%)
Naoli River	901.69	1998	1069.6	18.6	2000	1056.61	17.2
Sanhuanpao	210.33	1991	235.99	12.2	1994	209.69	-0.3
Qixing River	115.60	1991	191.79	165.9	2008	162.54	40.6
Dongsheng	135.36	2004	132.46	-2.1	1991	136.46	0.8
Total	1362.98	—	1629.84	119.6	—	1565.30	114.8

Area: The sum of the core area and buffer area

The analysis results of precipitation characteristics over the period of 34 years from 1980 to 2013 are shown in Fig.7. The annual precipitation in 1990, 1998 and 2006 is closer to the multi-year average and the precipitation under the 50% guarantee rate. According to the principle ⑤, the typical year of ecological water requirement calculation of Naoli River Nature Reserve, Sanhuanpao Nature Reserve, Qixing River Nature Reserve and Dongsheng Nature Reserve were determined in 1998, 1990, 2006 and 1990 respectively.

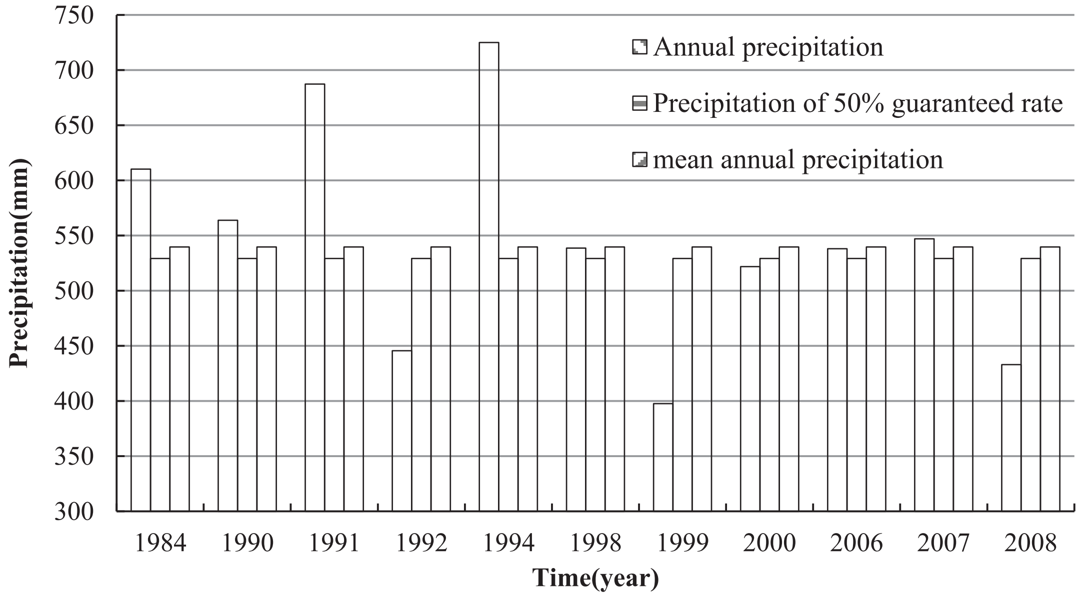

Fig.7 Analysis results of regional precipitation characteristics.

2.2.3 Calculation method of ecological water requirement

The calculation of wetland ecological water requirement is based on the water balance of wetland ecosystem. According to the actual situation, the wetland ecological water requirement is divided into consumptive water demand and non-consumptive water demand. The consumptive water demand includes the water requirement for water evaporation, for wetland vegetation, for wetland soil; the non-consumptive water demand includes the water requirement for biological habitat.

1) the water requirement for water evaporation

The water requirement for water evaporation is mainly consumed in the waters area of the nature reserves. Calculated as follows:

$$W_w = \sum AE \cdot 10^{-3} \quad (1)$$

Where: W_w is the water requirement for water evaporation, m^3; A is the waters area of wetland, m^3; E is the evaporation, mm.

2) the water requirement for wetland vegetation

The water requirement of wetland vegetation is the amount of water needed for the normal growth of vegetation. The water consumption of transpiration and soil evaporation are the main water consumption projects, which accounts for 99% of the water demand of plants (Liu et al.2007). Therefore, the plant water demand is approximately understood as the sum of the leaf transpiration of plants and the amount of soil evaporation, known as evapotranspiration. Calculated as follows:

$$W_p = E_p A \cdot 10^{-3} \quad (2)$$

Where: W_p is the water requirement for wetland vegetation, m^3; E_p is the vegetation evapotranspiration, mm; A is marsh area of the wetland, m^2.

3) the water requirement of wetland soil

The water requirement of wetland soil is closely related to plant growth, soil type, thickness and area, and soil water content is the basis for calculating the water requirement of wetland soil. Calculated as follows:

$$W_s = W_e H_s A_s \tag{3}$$

Where: W_s is the water requirement of wetland soil, m^3; W_e is the soil volume humidity; H_s is the soil thickness, m; A_s is soil area of the wetland, m^2.

4) the water requirement for biological habitat

The water requirement for biological habitat is the amount of water to provide the fish, rare waterfowl and other animal basic or normal space to survive and multiply. The wetland ecological system composed of water and swamp vegetation is an important habitat for waterfowl and other animals. At the same time, rare waterfowl and fish also have certain requirements on water depth. Therefore, the water depth and the flooded area (the sum of water and swamp area) are selected as the key indicator of the water requirement for biological habitat. Calculated as follows:

$$W_h = A_h H_h \tag{4}$$

Where: W_h is the water requirement for biological habitat; A_h is flooded area of the wetland, H_h is average depth of the wetland surface.

3. Results and Discussion

3.1. Calculation of water requirement

3.1.1. The water requirement for water evaporation

According to the hydrographic atlas of Heilongjiang Province, the measured evapotranspiration data of regional hydrological stations were converted into water surface evaporation and the average evaporation of water surface in the reserve was obtained by means of the arithmetic average method. The water requirement for water evaporation can be obtained by putting the water surface evaporation and water surface area into the formula (1). The results are shown in Table 3:

Table 3 Water requirement for water evaporation.($10^6 m^3$)

Level	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Min	0.1	0.2	0.6	1.4	1.3	1.4	1.4	1.2	1.0	0.9	0.4	0.1	10.1
Sui	0.7	1.4	3.7	8.3	8.4	8.4	8.3	7.6	6.5	5.1	2.2	0.8	61.5

3.1.2. The water requirement for wetland vegetation

There are many kinds of marsh vegetation in the reserves, and only the dominant vegetation species from all of marsh vegetation are selected. According to the report of scientific survey of the reserve and field investigation, reed is the single dominant vegetation in the nature reserves. Due to no actual reed evapotranspiration values in the nature reserves, the evapotranspiration of the reed marshes are replaced by that is measured in the Zhalong wetland, which is close to the nature reserves in latitude and longitude (Wang et al.2005). At the same time, according to the growth characteristics of reed in the north, the reed plants began to grow in May. And in October, reed begin to wither and lost the function of transpiration gradually. So the evapotranspiration of the reed was only calculated from May to October.

Table 4 Reed swamp evapotranspiration.(mm)

Month	May	Jun	Jul	Aug	Sep	Oct	Annual
Evaporation	154.2	169.1	167.7	147.3	111.0	89.2	838.5

According to the evapotranspiration of reed marsh and the marsh area of wetland, the water requirement for wetland vegetation in the nature reserves can be obtained by formula (2).

Table 5 Water requirement for wetland vegetation.(10^6m^3)

Level	May	Jun	Jul	Aug	Sep	Oct	Annual
Min	84.5	116.2	121.7	111.4	79.2	60.2	573.4
Sui	218.4	302.5	317.3	290.7	206.5	156.7	1492.0

3.1.3. The water requirement of wetland soil

The types of soil in the nature reserves include albic soil, marsh soil, black soil and meadow soil. The soil volume humidity is 0.45, and the soil thickness is 1 meter. Area calculated is the sum of grassland, farmland and woodland area. At the same time, it is the soil freezing period from November to April of the following year. Therefore, the water requirement of wetland soil is not considered during the freezing period. When the parameters and calculation area are brought into the formula (3), the water requirement of wetland soil can be contained, the results are shown in Table6.

Table 6 Water requirement for wetland soil.(10^6m^3)

Level	May	Jun	Jul	Aug	Sep	Oct	Annual
Min	0.4	0.4	0.4	0.4	0.4	0.4	2.4
Sui	29.9	29.9	29.9	29.9	29.9	29.9	179.2

3.1.4. The water requirement for biological habitat

The main protected objects in the nature reserves are the marshy wetland ecosystem and rare waterfowl, and Red Crowned Crane is the representative of waterfowl. According to the actual situation in the region, and taking the ecological habits of the Red Crowned Crane and fish as the main basis, classification of the water requirement level for biological habitat is determined by depth and flooding area (sum of the water area and the marsh area) under typical year for calculation of ecological water requirement. The results are shown in Table 7.

Table7 Water requirement for biological habitat.(10^6m^3)

Level	Flooded area (km^2)	Water depth (m)	Water requirement (10^6m^3)
Min	620.0	0.3	62.7
Sui	1611.5	0.8	1180.6

Total amount of wetland ecological water demand in consumption

Wetland ecological water demand in consumption should monthly be supplied based on the actual water demand; Wetland ecological water demand in non-consumption can be supplied flexibly according to the characteristics of regional water resources. After the completion of supply in the first year, the latter do not need re-supply.

Table 8 Total amount of wetland ecological water demand in consumption.($10^6 m^3$)

Level	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Min	0.1	0.2	0.6	1.4	86.2	118.0	123.5	113.1	80.7	61.5	0.4	0.1	585.9
Sui	0.7	1.4	3.7	8.3	256.7	340.8	355.4	328.2	242.8	191.7	2.2	0.8	1732.8

Table 8 shows that the water demand period in the whole year is mainly from May to October, which is also the growth period of the plants. In June and July, the plants grow vigorously, the water demand is bigger than other months.

3.2. Calculation of water supply

Precipitation and surface runoff are the main water supply source of wetland, which is affected by natural condition and human activities. In natural conditions, amount of water into the wetland directly affects the size of wetland area and determines the direction of wetland evolution. Therefore, for the minimum ecological water demand, precipitation and surface runoff under 75% and 95% guarantee rate in the core area of wetland under typical year for calculation of the minimum ecological water requirement are considered; for the appropriate ecological water demand, precipitation and surface runoff under 50% guarantee rate in the area of wetland under typical year for calculation of the appropriate ecological water requirement are considered.

3.2.1. Calculation of precipitation recharge

According to the data of observation stations around the reserves, the mean annual precipitation of wetlands is 539.7mm, and the precipitation is mainly concentrated in June to September. Farmland, woodland and grassland are part of the nature reserve, but they are not in the category of wetland and completely supported by rain. So the precipitation in wetland area is calculated. The annual precipitation at different frequencies and the monthly process are obtained by frequency analysis and typical annual distribution of precipitation (Table 9 and Table 10).

Table 9 Precipitation of different guarantee rate.(mm)

Frequency	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
50%	1.5	0.4	26.2	2.9	27.7	117.8	122.3	115.0	52.9	20.7	30.8	11.2	529.4
75%	8.6	4.8	26.7	22.6	28.9	25.2	68.8	153.8	57.4	34.7	8.8	20.4	460.8
95%	6.5	6.4	14.6	23.4	30.6	62.1	100.2	62.8	21.8	23.3	9.8	11.8	373.1

Table 10 Precipitation of different guarantee rate.(mm)

Level	Frequency	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Min	75%	5.3	3.0	16.6	14.0	17.9	15.6	42.7	95.4	35.6	21.5	5.5	12.6	285.6
	95%	4.0	4.0	9.1	14.5	19.0	38.5	62.1	38.9	13.5	14.4	6.1	7.3	231.4
Sui	50%	2.4	0.6	41.6	4.6	44.0	187.2	194.3	182.7	84.1	32.9	48.9	17.8	841.2

3.2.2. Calculation of surface runoff recharge

According to the process of natural runoff of Naoli River and Qixing River and other rivers, natural runoff process under different guarantee rates are obtained by frequency analysis. Available water supply of surface runoff to wetlands under different guarantee rates can be obtained after deducting ecological base flow and water consumption in other aspects (Table 11).

Table 11 Surface runoff of different guarantee rate.($10^6 m^3$)

Level	Frequency	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Min	75%	0.3	0.1	4.5	134.1	111.3	26.6	30.2	40.9	24.0	20.3	10.8	1.5	404.6
	95%	0.2	0.0	1.8	23.2	28.1	16.2	25.3	20.7	17.3	32.1	43.5	3.6	212.2
Sui	50%	0.2	0.4	1.7	45.0	60.3	53.7	23.5	90.1	105.7	91.9	33.4	7.8	513.7

3.2.3. Calculation of artificial recharge

Because precipitation in the farmland、grassland and woodland are not considered, the actual consumption of ecological water demand was obtained under different ecological targets after the water requirement of wetland soil is deducted from total amount of ecological water consumption of wetlands(Table 8). Combined with precipitation recharge and surface runoff recharge at different frequencies, the artificial recharge at different frequencies is determined by water balance analysis. The artificial recharge in some months is negative indicated that water is surplus and there is no need to be recharged, and this part of the excess water can't be used. The artificial recharge under different guarantee rates is shown in Table 12.

Table 12 Artificial recharge of different guarantee rate.($10^6 m^3$)

Level	Frequency	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Min	75%	0.0	0.0	0.0	0.0	0.0	75.4	50.3	0.0	20.7	19.3	0.0	0.0	165.7
	95%	0.0	0.0	0.0	0.0	38.7	62.9	35.7	53.0	49.5	14.5	0.0	0.0	254.3
Sui	50%	0.0	0.4	0.0	0.0	122.5	70.0	107.7	25.5	23.2	37.1	0.0	0.0	386.3

From the table 12, it can be seen that natural inflow of water at different frequencies can't meet the actual water requirements of wetlands. In order to make the wetland ecological environment reach a normal level, the artificial water transfer should be considered. Water is transferred from the Songhua River to the nature reserves by engineering measures. Under the 75% and 95% guarantee rate, the minimum artificial recharge is $1.66\times10^8 m^3$ and $2.54\times10^8 m^3$ respectively , and under the 50% guarantee rate, the optimal artificial recharge of the wetland is $3.86\times10^8 m^3$.

4. Conclusions

1) According to the results of image interpretation, the types of land-use of the nature reserves are rich, but the swamp area of wetland degraded seriously, from $1963.82 km^2$ in 1984 to $844.71 km^2$ in 2013, and decreasd by 56.33% in 30 years. While the change of farmland area is the opposite trend and the area of farmland is increasing year by year. The above indicates that the wetland is more affected by human activities.