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Hydrological adjustment and flooding control of wetlands in the Liaohe Delta

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Abstract: The function of estuary wetland on hydrological adjustment and flooding control is studied in this paper. It is estimated that the evapotranspiration in the reed field during growth season(June to October) is 722.9 mm, which is 37.5% higher than large water body(E_{601}: 525.9 mm). The water replacement rate in the reed field can reach 95% only when the rains continuously for 11 days and the precipitation reached 912 mm. For the water balance in the paddy field, the total water requirement ranges between 1920 and 1860 mm, among which, 31% is from precipitation, and the left is provided by reservoirs. The water usage efficiency is 0.35 at present productivity. Based on the landscape characteristics and functionalities on flooding control, 5 functional zones are designed for the Liaohe Delta: key protected area; underground storage area; flooding discharge area; flood diversion area in emergency; and flood control drainage area.
Keywords: hydrological adjustment; flood control; water replacement; water balance; landscape planning

Introduction

Wetland is the transition zone between open water body and dry land ,with some specific properties. Hydrology of wetlands includes water input, output, depth, current characteristics, and duration and frequency of inundation. The water input comes from precipitation, groundwater, flooding water and tide, while the water output includes evapotranspiration, surface flow, groundwater infusion, and tidal outflow.

Liaohe Delta locates on the transition zone between the Bohai Sea and the dry land, at the convergence of fresh and salty water affected by both the sea and inland. The complex driving mechanisms formed the complex and multiform wetlands and ecological environments (Ren, 1990), such as river wetland, estuary wetland, swampland, meadow wetland, and coastal mudflat wetland, as well as artificial wetlands including reservoir, paddy field and man-made salt marsh that influenced by intensive human activities.

These wetlands are playing important roles in hydrological adjustment, i.e. regulating the water storage, flooding, flush flow, and surface and ground water exchange by impounding, discharging and evapotranspiration. Taking Liaohe Delta as study area, this paper studied the hydrological adjustments of wetlands and their influences on human activities, and could serve as basis for the reasonable landscape planning and regional sustainable development.

1 General description of the research area

Liaohe Delta is located within the range of 121°35′—122°55′ E and 40°40′—41°25′N, with an area of about 4000 km^2. Several large rivers run into the sea here with 11.7 billion m^3 of water every year. Counteracted by sea tides, 76 million tons of sedimentation are accumulated in the delta annually. The reed marsh constitutes the main part of the delta, with an area of 900 km^2, which is the largest reed field in the world.

Climate of the research area belongs to temperate monsoon, with annual temperature of 8.3℃, and annual precipitation of 611.6 mm. More than 70% of the rainfall is in summer, with high evaporation and natural disasters such as draught, waterlogging, windstorm, hail, and storm tide. The wetlands in Liaohe Delta are mainly seasonal waterlogged (take 64% of the total), including paddy field (58%) and reed marsh (32.8%).

2 Methods

2.1 Water balance function and wetland storage capacity

The wetland hydrological conditions are mainly determined by water balance, landform, soil, geological and groundwater characteristics of the wetlands that can be described as below(Liu, 1996):

$$\Delta V = P_n + S_i + G_i - E_r - S_o - G_o \pm T,$$

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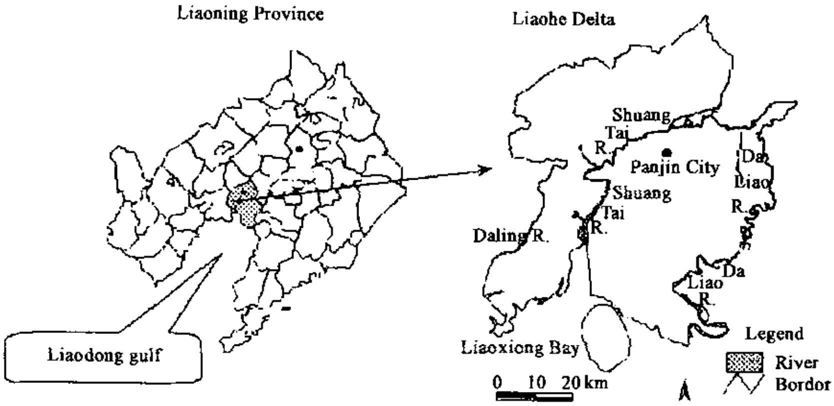

Fig.1 The location of study area

where, ΔV is the variation of wetland water storage volume; P_n is the available precipitation; S_i is the input of surface water including river flooding; G_i is the input from groundwater; E_r is the evapotranspiration; S_o is the surface discharge; G_o is the infusion to groundwater; and T is the tidal inflow (+) or outflow(−).

Dry land evaporation in wetland water balance can be calculated as:

$$E_i = P - R.$$

Where P is the mean annual precipitation, and R is the depth of runoff.

The dry land evaporation is constrained by the evaporation capability and water supply. They can also be obtained through practical measurement of evaporation capacity using 20 cm evaporating-dish after two steps of conversions. Firstly, convert the observation evaporation capacity values from small water bodies to the equivalent evaporation capacity values from E_{601} evaporation dish to estimate the evaporation capacities of large water bodies. Secondly, multiply a K value to convert it to dry land evaporation capacity. According to the water balance of its drainage area, we got the K value of Liaohe Delta as 0.58.

For the paddy field, we adapted the water balance equation as below:

$$P + I = E + R + S_p + \Delta W.$$

Where P is the precipitation; I is the irrigation amount of water; E is the amount of evapotranspiration; R is the total amount of surface runoff; S_p is the amount of seepage; and ΔW is the variation of soil moisture content. Generally, paddy field has no surface runoff, therefore, $R = 0$; soil moisture content is always in a state of saturation, therefore $\Delta W = 0$. As a result, the equation can be simplified as:

$$P + I = E + S_p.$$

2.2 The assessment of wetland hydrological adjustment

Reed marsh, paddy fields and shrimp pools are wetlands having functions of hydrological adjustment. The wetland hydrological adjustment capabilities are generally calculated based on the difference between the pondage of the flooding season in a high flow year when it harms the growth and production of crops and that of low water in a dry year, i.e. the biggest balance of pondages. The total wetland hydrological adjustment capability can be calculated as:

$$Q = \sum S_i \times D_i.$$

Where S_i is the area of the λ_i wetland type; D_i is the storage depth of λ_i wetland. The wetland hydrological adjustment values were estimated using shadow project method (hydrological adjustment value = the total wetland hydrological adjustment capacity × unit storage capacity cost(0.67 RMB Yuan/m^3)), Production Cost Method (local perennial average production cost of agriculture production), and Moving Cost Method(50000 RMB Yuan/family)(Wetland International, 1999).

3 Results

3.1 Wetland water storage capacity and reed field evapotranspiration

The potential ground surface storage of the delta region include the maximal runoffs of rivers, maximum storages of reservoirs, reed fields, salt pans, shrimp ponds, paddy fields, and high-flow year measurement or calculated storage cubage of ponds and canals. There are two rivers run over Liaohe Delta, Shuangtaizi River and Raoyang River, with lengths of 116 km and 71 km respectively and a total storage capacity of 209.3×10^6 m^3. There are 7 plain reservoirs in Liaohe Delta, with total storage capability of 139×10^6 m^3. The storage capacities of reed field, paddy field, and canals-ponds are $800 \times 10^6 m^3$, 237×10^6 m^3, and 366×10^6 m^3, respectively. Sum up those values above, the potential ground surface storage of the delta is 1763×10^6 m^3. The total water resources in Liaohe Delta is 8298×10^6 m^3, among which, the annual river runoff is 7204×10^6 m^3, about 86.8% of the total; depth of ground surface runoff is 78.3 mm; the annual surface runoff amount is 258×10^6 m^3, about 3.1% of the total; and the exploitable underground fresh water resource is 836×10^6 m^3, about 10.1% of the total.

The average annual precipitation of the study area is 611.6 mm, and the observation value of annual evaporation from small water body is 1636 mm. By conversion, the yearly water surface evaporation is 933 mm with 371.3 mm and 301.5 mm of evaporation in summer and spring, respectively. The dry land annual evaporation is estimated as 541 mm.

According to the field observations during the growth season (May—October) from 1997 to 1999 in Yangjuanzi reed farm, Panjin City, the daily average evapotranspiration from May to October is 4.6 mm, 5.8 mm, 6.9 mm, 5.2 mm, 2.9 mm, and 2.8 mm, respectively. The highest evapotranspiration appears in July due to the high temperature, the fast growth of the reed, and the high evaporation and transpiration. Comparison of the evapotranspirations between reed field and large water body is presented in Table 1.

Table 1 Comparison of evaporations among wetlands in Panjin City (mm)

Month	1997		1998		1999		Mean		
	Φ20 cm	E_{601}	Φ20 cm	E_{601}	Φ20 cm	E_{601}	Φ20 cm	E_{601}	Reed field
June	245.0	149.5	169.6	103.5	221.5	135.1	212.0	129.4	174.0
July	212.0	125.1	142.4	84.0	206.5	121.8	187.0	110.3	213.9
August	164.7	100.5	168.6	102.8	193.5	118.0	175.6	107.1	161.2
September	154.3	94.1	169.1	103.2	183.9	112.2	169.1	103.2	87.0
October	127.2	76.3	132.3	79.4	120.4	72.2	126.6	76.0	86.8
June-Oct.	903.2	545.5	782.0	472.9	925.8	559.3	870.3	525.9	722.9

Table 2 Calendar of wetland water replacement

Water replacement rate	Storage, C			
	< 5%	< 1%	< 0.5%	< 0.1%
0.1	29	44	51	66
0.2	14	21	24	31
0.3	9	13	15	20
0.4	6	9	11	14
0.5	5	7	8	10
0.6	4	6	6	8
0.7	3	4	5	6
0.8	2	3	4	5
0.9	2	3	3	4

In Table 1, we found that the evapotranspiration of reed field (including water surface evaporation, and reed transpiration) during the growth season from June to October was 722.9 mm, which is 37.5% higher than evaporation of large water body (E_{601}) (525.9 mm), due to the high reed plants and higher plant transpiration.

3.2 Water replacement rate

Water replacement rate is a criteria of wetland openness that directly affects the wetland chemical and biological processes. Water replacement rate represents the speed of water renewing in the wetland landscape, which reciprocal is the retention time of water in wetlands.

$$\beta = Q_i / V.$$

Where β is the replacement rate; Q_i is the rate of flow running through the wetlands; V is the storage capacity of the wetlands. Suppose the water retention time is t, rate of inflow $Q_i = V/t$, the first day storage is $(1 + 1/t)V$, and the storage of the nth day is $(1 + n/t)V$. If the water quality concentration in the wetlands is a and that of the inflow water is b, the water quality concentration of the wetlands after n

days is going to be changed to $(ta+b)/(t+n)$.

Suppose the wetland storage has reached the capacity C, i.e. $V = C$, then the average volume of water running through the wetland per day is C/t (Table 2).

The first day, the water will decrease by $1/t$ and left $(1-1/t)C$. By nth day, only $(1-1/t)^nC$ is left. When the defined replacement finished while the left water is 5% (or 1%), we can assign a value to t, and then calculate n. For example, let $t = 10$, i.e. the water running through the wetlands is 1/10 of the storage, then 29 days later 5% water remains, and approximately 44 days later less than 1% water remains.

We calculated the water replacement of the wetlands in Liaohe Delta on 21 Aug. 1997 as an example. The precipitation on August 20 was 92.7 mm, and the soil was saturated. Another rainfall on August 21 was 114 mm. The runoff from the apoapsis of the region to the estuary took about 24 hrs. So

Q_i = rainfall intensity $\times$ area $= 0.114 \times 3959 \times 10^6 = 4.5 \times 10^8 (m^3/d)$;

$C = 1.9 \times 10^9\ m^3$;

$Q_i/C = 1-0.24$.

Let $(1-0.24)^n < 0.05$; Then $n = 11$d (Soil seepage rate < 5% of rainfall intensity, ignored).

According to the calculation, unless 11 days of continuous rainfall and the precipitation reaches 912 mm, can water in the wetlands in the whole delta be replaced by 95%.

3.3 Water balance in the paddy fields

Four factors affect the water balance in paddy field: precipitation during the rice growing season (P); irrigation depth of water (I), evaporation and transpiration (E), and water seepage. The values for the Liaohe Delta are shown in Table 3.

Table 3 The water balance of paddy field in Liaohe Delta

Items	Irrigation area	
	Panjin	Yingkou
P, mm	579.2	572.8
I, mm	1347.3	1295.4
$P+I$, mm	1826.5	1868.1
P percentage of the total, %	31.7	30.7
E_r, mm	624.7	651.1
S_P, mm	1201.8	1217.0
S_P percentage of the total, %	65.8	65.1

During 1993—1996, the precipitation of the growing season (May-September) is 88.8% of the annual precipitation in Panjin Region. However, the range varied from 320 mm to 800 mm. The irrigation depth of water varied significantly as well, from 1140—1385 mm. The evaporation and transpiration of paddy field and water surface evaporation are significantly linearly correlated. According to the field experiments (Zhu, 1999), the linear regression equation can be described as $E_r = 0.4952E_1 + 18.557 (r = 0.868)$. Based on this regression equation, we calculated the paddy field evaporation as 625 mm in the Liaohe Delta. Since the growing season is 153 days, the average daily evaporation is 4.1 mm, which is 0.6 mm less than that of reed field (4.7 mm). In terms of the water balance equation, the seepage of paddy field is 1200 mm. Soil water permeability and field moisture management are main factors affecting the seepage. Soil parent materials of the study area are marine sediments, resulting in clayey soil texture, high groundwater, and low soil permeability. Therefore the seepage is quite low. In addition, the shallow and intermittent irrigation regime has been practiced so that returning water has been efficiently used. Therefore the real seepage (1.7 mm) is lower than the calculation.

The total water consumption during the rice growing season is around 1900 mm, about 30% of which is provided by precipitation. The rest is supplied by reservoirs. Apart from evaporation and transpiration, 65% of the total water consumption lost is by seepage. The year round distribution of precipitation, soil seepage intensity, and paddy field management can all affect the irrigation effect. The variation range of seepage is larger than evaporation and transpiration in the Liaohe Delta. The production efficiency of water consumption is 0.35 under the present productivity of 9.4 t/hm^2. Fig.2 presents the relationship between changes of precipitation and irrigation water consumption over several years.

4 Discussions

4.1 The assessment of wetland hydrological adjustment

Wetlands having functions of hydrological adjustment include reed field, paddy field, and shrimp/crab

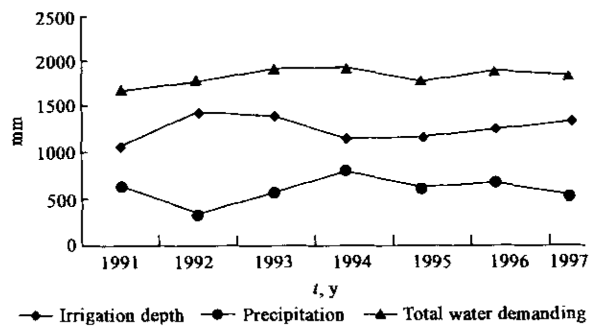

Fig.2 The relationship between water consumption and provision in the Liaohe Delta.

ponds with maximal storage capacity of 1m, 0.2m and 1m in depth, respectively. The total water adjustment capacity of wetlands in the study area is 10×10^8 kg. The investment would be 6.7×10^8 RMB Yuan if we built a reservoir equivalent to this capacity, according to the Shadow Project Method. Estimation of the farmland loss due to flooding using production cost method showed that the average affected area in 1985 and 1995's deluges is 3.64×10^4 km^2 in average. Grain output deduction is 2.18×10^8 kg, which would require 1.4×10^8 RMB Yuan investment to get the same amount of production. According to the moving cost method, 5.1×10^4 people (about 13800 families) were obliged to move during the floods, which cost 6.9×10^8 RMB Yuan. Summing up the results derived from the later two methods, the hydrological adjustment assessment is 8.3×10^8 RMB Yuan. This is quite close to the value derived from shadow project method. The final assessment is the

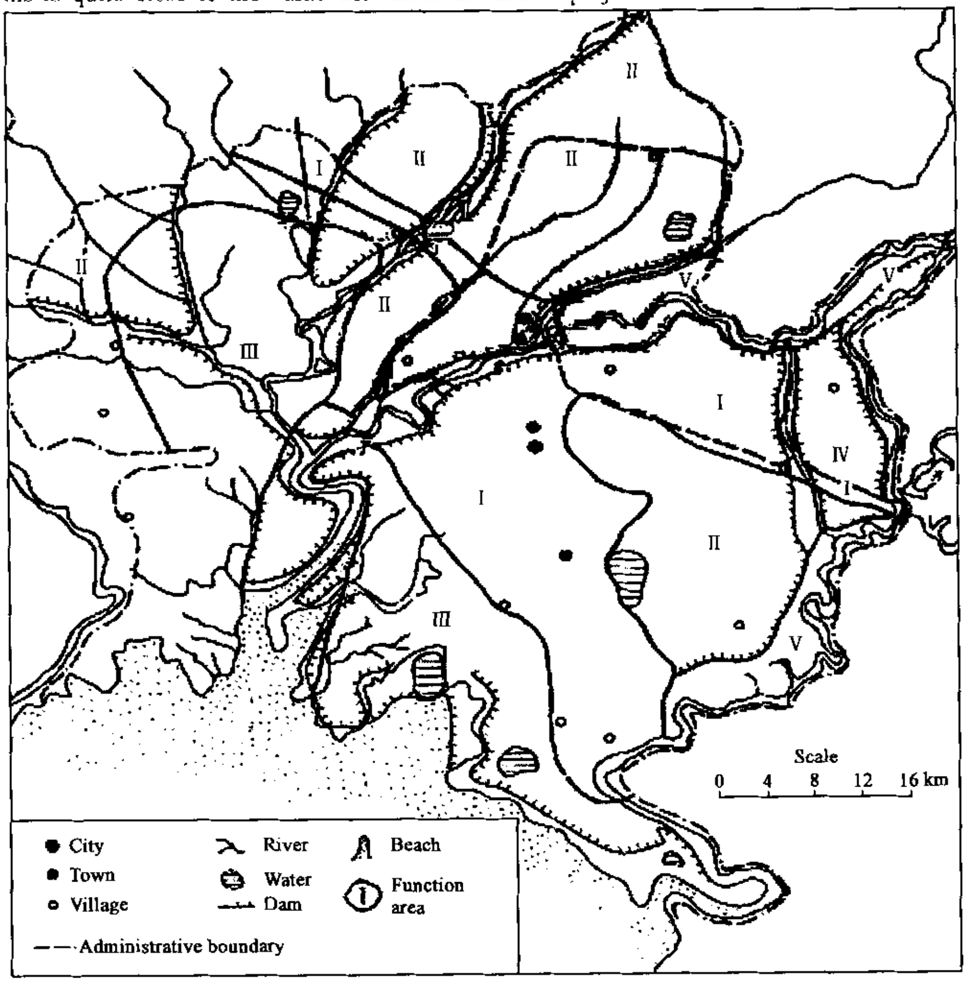

Fig.3 The partition of wetlands based on its flooding control function in the Liaohe Delta

Ⅰ. key area; Ⅱ. underground storage area; Ⅲ. discharge area; Ⅳ. emergent flood diversion area; Ⅴ. flood control drainage area average of the above two, which is 7.5×10^8 RMB Yuan.

There are 7 reservoirs in Liaohe Delta, with flood adjustment capability of 1.55×10^8 m^3. The total length of canals is 54432 km, which can store 1.25×10^8 m^3 of water. The 21 rivers have a flood adjustment capability of 0.6×10^8 m^3, suppose 10% of the flux can be used as flood adjustment. Summing up the above, we got 3.4×10^8 m^3 of flood adjustment capability in Liaohe Delta. Using shadow project method, the assessment of rivers and reservoir's flood adjustment is 2.3×10^8 RMB Yuan.

The areal hydrological adjustment of wetlands and water bodies is 2475 RMB Yuan/km^2, which is twice of the average in China, and 36% higher than the international average value.

4.2 The flood adjustment of underground water-bearing layer in the delta

The depth of the quaternary layer is between 200—500 m in the Liaohe Delta. The sediments mainly include sand, gravel, pebble and other coarse detrital stones covered by claypan with a depth of 21% of the whole quaternary layer. Accordingly, we can estimate the storage capability (the groundwater volumetric storage) of the quaternary layer as below:

$$V = S \times 0.79 \times H \times \mu.$$

Where S is the area of water-bearing layer (40.71×10^8 m^2); H is the depth of the quaternary layer (use the minimum value 200 m); 0.79 is the ratio of water-bearing layer to the whole; and μ is the gravity water yield (0.06). Suppose the falling of watertable is 2m per year, the underground spatial volume formed per year is 3.9×10^8 m^3.

Shallow layer groundwater in the south of the delta is salty or brackish with degree of mineralization of 1 g/L, and even up to 3—30 g/L in the estuary area. Permeability coefficient is usually less than 5 m/d. Although the depth of the underlying tertiary water-bearing layer is more than one thousand meters, the permeability coefficient is much lower.

4.3 Landscape planning for the flood control

The main threaten to the delta wetlands is flood. One of the primary purposes of landscape planning is to protect wetlands and human activities in the wetlands from the damage of flood. Wetlands in Liaohe Delta can be subdivided into 5 flood control domains according to the characteristics of landscapes and their functions in the flood control (Fig.3):

(1) Keystone protected area: main cities and towns, industrial basis and main transportation lines within the wetlands, the area of which is 1075 km^2, about 26.4% of the total wetland area; (2) Underground flood storage area: with elevation between 4—8m, mainly paddy field, 1278 km^2, 31.4% of the total wetlands. The drainage and irrigation systems can be used for draining the groundwater equivalent to 1.2×10^8 m^3 of flood; (3) Flood discharge area: reed fields with elevation less than 4m, and low population. The damage is small when inundated with flood. The area is 1229 km^2 about 30.2% of the total wetlands; (4) Flood diversion area in emergency: the area between the two rivers surrounded by dams. This is the best location for flood diversion when flood enters the wetlands from Liaohe River. Flood could be discharged into the farmlands in case of emergency to protect the cities. The area is 94 km^2, about 2.3% of the total; (5) Flood control drainage area: river flats with dams at both sides. For a successful flood discharge, buildings and forests within this area should be removed. The area is 395 km^2, 9.7% of the total.

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