# Calculating the flux of groundwater discharged into sea in the Yellow River Farm by cross-section method

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**Abstract:** In the area of the Yellow River Delta, due to the shallow water is salt and little research on hydrogeology condition results in impercipient of hydrogeology condition, although we studied on groundwater discharge nutrients into Bohai before, maybe the result we obtained is not very exact. This time based on other people's achievements, we constructed 13 boreholes which are 20-30 meters deep and took the soil in origin state to lab to analyze granularity and penetrability and so on. The fieldwork includes the experiment of pump water and penetrability, and also includes observation of groundwater level and groundwater temperature by CTD. Finally, we estimated that the amount of shallow groundwater in the Yellow River Farm area discharging into sea is 205.6 $m^3$, time distribution is consistent with the Yellow River's runoff but taking on lag effect, estimated that the amount of groundwater discharging into sea from the whole delta unconfined water is $3.6\times10^3$ $m^3$, which is 0.0002‰ of the Yellow River's total runoff. The amount of transport of silver sand between buried depth of 16 to 20 m is $2.67\times10^4$ $m^3$ in the Yellow River Farm area and is $46.6\times10^4$ $m^3$ in the total Yellow River Delta, which is 0.24‰ of the Yellow River's total runoff , but the value is much different from SGD mensurated by seepage instrument, the reason needs deep research.

**Key words:** the Yellow River Delta, submarine groundwater discharge, cross-section method

## 1. The Study Area

The Yellow River delta's scope is Ninghai of Kenli County in Shandong province for top, from Taoer Eestuary in north to Zhimai ditch of sector silt region in south. There are nearly 5212 $km^2$ on the land, and 350 km coast line on the Yellow River delta. The Yellow River farm is located on the second delta, the top of which is Yuwa and it faces yellow river on the west and north, Bohai Sea on the east, and an Xiaodao river on the south.(Diagram 1). The relief is getting lower slowly from the northwest to the southeast. The farmland is about 450 $km^2$, and the coast line is about 20 km in length.

The stratums were marine and continental facies stratums formed by invasion fore and after the Recent epoch, the thickness of which are about 26m. According to the change of lithofacies, the stratums were divided into Kenli set($Q_{3\text{-}4}k$), No.5 Zhuang set($Q_4w$) and Diaokou set($Q_4d$).

## 2 Aquifer Divisions and Hydrogeology Parametric Definition

There are 5 drills (N6～N10, given in Figures 1) constructed on the Yellow River farm. The aquifer is divided into two according to the spot drilling observation and record, the size analysis of undisturbed soil, and the penetrating experiment (Table1). The drilling depth of the first floor is 0.5-5.3 m, with an hydraulic conductivity between $1.3\times10^{-5}$ and $7.5\times10^{-5}$cm/s. The second floor which is confined aquifer belongs to river and lake sediments in Kenli set, the lithologic characters of which are fine sand and medium fine sand seam. The drilling depth is 16 or 17-20m, hydraulic conductivity is 0.5-$7.8\times10^{-4}$cm/s.

## 3 Estimating the Quantity of SGD With Cross-section Method

### 3.1 ESTIMATING THE QUANTITY OF SGD IN FLOOD AND DRY SEASON FROM

**YELLOW RIVER WITH CROSS-SECTION METHOD**

Tab.1 hydraulic conductivity of drill at different depth on the area unit:($\times 10^{-6}$cm/s)

| N6 | | N7 | | N8 | | N9 | | N10 | |
|---|---|---|---|---|---|---|---|---|---|
| Depth (m) | Hydraulic Conductivity | Depth (m) | Hydraulic Conductivity | Depth (m) | Hydraulic Conductivity | Depth (m) | Hydraulic Conductivity | Depth (m) | Hydraulic Conductivity |
| 2.2-2.4 | 13 | 2.2-2.4 | 68 | 4.7-4.9 | 22 | 2.2-2.4 | 75 | 2.3-2.5 | 6 |
| 4.3-4.5 | 32 | 4.3-4.5 | 1. 1 | 6.3-6.5 | 0.082 | 4.3-4.5 | 0. 5 | 4.5-4.7 | 230 |
| 6.3-6.5 | 0.16 | 6.0-6.2 | 0. 084 | 8.5-8.7 | 0.11 | 6.5-6.6 | 0. 06 | 5.3-5.5 | 3.9 |
| 8.4-8.6 | 0.084 | 8.2-8.4 | 0. 26 | 10.2-.4 | 0.068 | 8.6-8.8 | 0. 14 | 8.5-8.7 | 0.48 |
| 10.5-.7 | 0.055 | 10.3-.5 | 0. 042 | 12.2-.4 | 0.12 | 10.7-.9 | 0. 057 | 10.3-.5 | 23 |
| 12.5-.7 | 0.2 | 12.4-.6 | 0. 054 | 14.5-.7 | 0.1 | 13.3-.5 | 0. 043 | 12.4-.6 | 0.046 |
| 14.2-.4 | 0.12 | 14.1-.3 | 0. 27 | 16.2-.4 | 0.35 | 14.6-.8 | 0. 1 | 14.2-.4 | 0.075 |
| 16.2-.4 | 53 | 16.4-.6 | 4. 9 | 18.2-.4 | 750 | 16.3-.5 | 200 | 16.5-.7 | 0.36 |
| 18.0-.2 | 430 | 18.2-.4 | 610 | 20.0-.2 | 780 | 18.3-.5 | 330 | 18.3-.5 | 5 |
| 21.2-.4 | 22 | 20.3-.5 | 3. 6 | 20.3-.5 | 360 | 20.4-.6 | 8. 3 | 20.1-.3 | 1.7 |

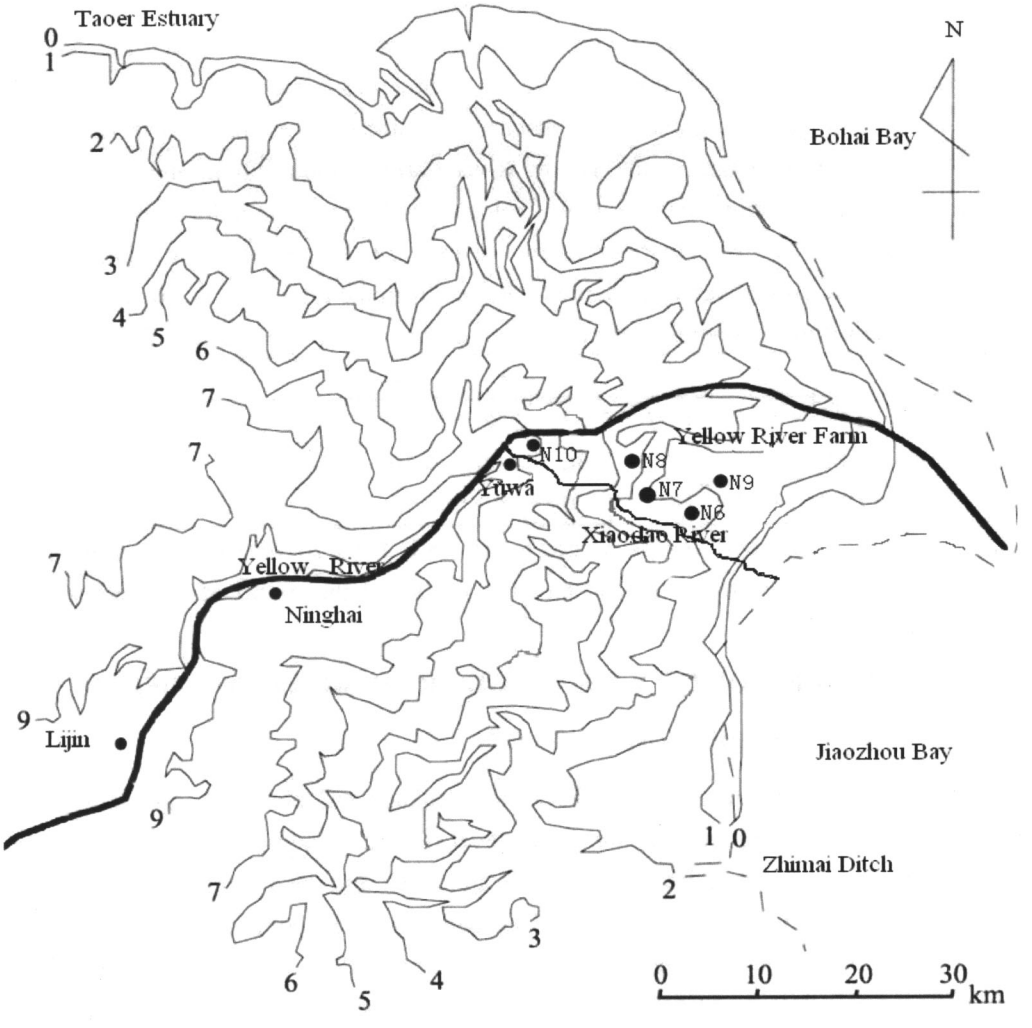


Fig.1 the locations of the boreholes and the contour map of the Yellow River Delta

Two hydrology cross-sections were set along the direction of the groundwater flow (N10 and

N9).The average distance of which is 15.8 km, and the average permeability coefficient is 0.043 m/d.

Cross-section method use Darcy's equation to calculate the level seepage discharge of groundwater according to the geologic and hydrogeologic conditions,

$$Q = KI\,\omega = K\,\frac{h_1 - h_2}{L}Bh$$

where **Q** is the groundwater discharge; **K** is the average horizontal hydraulic conductivity;

**I** is the hydraulic gradient of the cross-section, $\omega$ is the discharge area;

**B** is the width of the cross-section; **h** is the average thickness of the phreatic aquifer;

**h1,h2** are the thickness of the phreatic aquifer at the upper section and the downstream section respectively; **L** is the average distance between the upper section and the downstream section

The monthly average SGD Q($m^3$) of Yellow River farmland from 2003 October to 2004 December were calculated by the Darcy's formula according to monthly average groundwater lever supplied by CTD. The relation between it and monthly flow measured on Yellow River hydrologic station is shown as follow:

The monthly variation extent of runoff of Yellow River is remarkably larger than that of phreatic aquifer, but the flux of phreatic aquifer to the sea is much more steady. The yearly variation regulation of the runoff of Yellow River is similar to that of the discharge from phreatic aquifer to the sea. However, compared with the runoff variation of Yellow River, the variation of phreatic aquifer transport to the sea has a relative lag, taking on a hysteresis.

There is 205.6 $m^3$ phreatic groundwater discharged to the sea from the Yellow River Farm in 2004(tab.2). The coastline length of the Yellow River Farm is about 20km, and that of the total delta is about 350km. Providing that the geohydrologic condition of the delta's phreatic aquifer is approximately same as the Yellow River Farm, we can use the analogism to estimate that the amount of the phreatic groundwater discharge to the sea from the total delta is 3.6×103 m3.

Tab. 2 the mean flux monthly of phreatic aquifer in Yellow River Farm, 2004

| 月份 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I($\times10^{-4}$) | 2.14 | 1.96 | 1.81 | 1.97 | 1.67 | 1.80 | 1.52 | 1.61 | 1.44 | 1.59 | 1.67 | 1.59 |
| h(m) | 3.50 | 3.68 | 3.95 | 3.62 | 3.36 | 3.29 | 4.39 | 4.18 | 4.45 | 3.85 | 3.59 | 3.75 |
| Q($m^3$) | 20.0 | 18.0 | 19.1 | 18.4 | 15.0 | 15.3 | 17.8 | 17.9 | 16.6 | 16.3 | 15.5 | 15.9 |

The runoff of the Yellow River discharged to the sea is 1.98×1010m3 in 2004, while the ratio of the freshwater discharged to the sea by phreatic aquifer in the runoff of the Yellow River is 0.0002‰.

### 3.2 ESTIMATING THE MONTHLY MEAN SGD FROM SHALLOW COFINED WATER WITH CROSS-SECTION METHOD

The confined water flows up mainly in the form of leakage and then discharged to the sea. The thickness of leaky layer is about 11m; the water level on the coastline and on the 1500m away from the coastline to the sea is estimated by the N8 and N9s', and the average is considered as the shallow confined water level. The water level of sea bed is 0m. The permeability coefficient of the leaky layer is $2.67\times10^{-8}$m/s; the area is 20000m long and 1500m wide. At last, depending on Darcy formula we calculate the SGD from shallow confined water as follow in Tab.3.

The recharge from shallow confined groundwater is more than that from phreatic groundwater, the SGD from the Yellow River Farm arrives at $2.67\times10^{4}$m3, and that from the total delta arrives

at $46.6\times10^4$m3,but when compared with runoff of the Yellow River, it is very little, only 0.24‰ of the yearly runoff.

Tab. 3 the mean flux monthly of shallow confined groundwater in the Yellow River Farm, 2004

| month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I($\times10^{-2}$) | 4.49 | 8.79 | 13.8 | 8.75 | 3.35 | 1.70 | 20.2 | 16.0 | 20.6 | 10.8 | 6.96 | 10.7 |
| Q($m^3$) | 963 | 1762 | 2953 | 1815 | 717 | 352 | 4326 | 3428 | 4273 | 2323 | 1443 | 2292 |

## 4. Results and discussion

The findings about the SGD of the Yellow River Farm in recent years are shown in Tab.4. The second column in Tab.4 is the results by Zhang Quan etc, according to the boreholes data we can see that it is unsuitable to assign the thickness of aquifer to be 16m, and the permeability coefficient is too large. The third and the forth column are the results of this paper. The fifth is the result settled using seepage meter data in Sep, 2004, and estimated the SGD of total delta is $25\times10^8$ in 2004. However, the yearly mean runoff of the Yellow River is 198. $88\times10^8$m$^3$in 2004,which is 8 times of SGD. But in our opinion, the SGD is too high to believe, because the Yellow River Delta is mainly in the form of fine particle sediment and has a low hydraulic gradient.

The method of section is used to estimate the SGD from phreatic groundwater in the Yellow River Farm, and the results show that the flux of phreatic aquifer to the sea is much more steady and it has an intimate relationship with the runoff of the Yellow River but takes on a lag effect. The SGD from phreatic groundwater doesn't like the runoff of the Yellow River which has large transformation range, and the quantity is also very low, only 205.8 m3 in 2004. Using analog method to estimate that the amount of groundwater discharged into sea from the whole delta unconfined water is $3.6\times10^4$ m3, which takes 0.0002‰ of the Yellow River's total runoff.

The recharge from shallow confined water by leakage is more than that from phreatic groundwater, the SGD in the Yellow River Farm arrives at $2.67\times10^4$m3, and in the total delta it reaches $46.6\times10^4$m3, but the value is much different from SGD measured by seepage meter, and the reason needs deep research.

Tab. 4 results comparison of the SGD in the Yellow River Farm

| item | phreatic water (ZhangQuan.ect.) | phreatic water | shallow confined water（20m） | seepage meter |
|---|---|---|---|---|
| Caculated time | 2001 | 2003.9～2005.5 | 2003.9～2005.6 | 2004.9 |
| K(m/d) | 0.207 | 0.043 | $2.67\times10^{-8}$ | |
| I | 0.00012 | 0.00014～0.00024 | 0.017～0.206 | |
| B(m) | 20000 | 20000 | 20000 | 5000 |
| h(m)or width | 16 | 3.23～4.45 | 1500 | 1500 |
| Q($m^3$/month） | 241.8 | 13.88～23.42 | 352～4326 | 5754240 |
| Q($\times10^4m^3$/year） | 0.2901 | 0.021（2004) | 2.67 | 3596.4 |
| the Yellow River Delta ($\times10^4m^3$/year） | 7.77 | 0.36 | 46.6 | 251748 |