Results of Groundwater Group in Yellow River delta

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1. Introduction

The roles of "groundwater group" in the Yellow River Project (PL: Yoshihiro Fukushima) are to evaluate the interaction between groundwater - river water - sea water, and to evaluate the groundwater discharge and material transports into the Bohai sea, from the points of views of "Cutoff of the Yellow River" and the effects on Bohai sea. The studies have been made from 2003 to 2007 thorough five intensive field measurements and analyses. The groundwater monitoring in the delta, measurements of the Yellow river water, and measurements of coastal water have been done. Three of five field experiments have been made with the "Bohai group". This is the final report of the results from the groundwater group.

2. Groundwater flow system in the Yellow River delta

Field experiments and analyses have been made to evaluate the groundwater flow system in the delta, hydrogeology of the aquifer, and the distribution of the saltwater and fresh water. Core sampling to evaluate hydraulic and hydrogeologic parameters, saltwater/fresh water distribution by resistivity measurements, and measurements of groundwater potential have been made. As the result, the method by use of GPS to evaluate the elevation is useful for the groundwater survey in the flat area such as

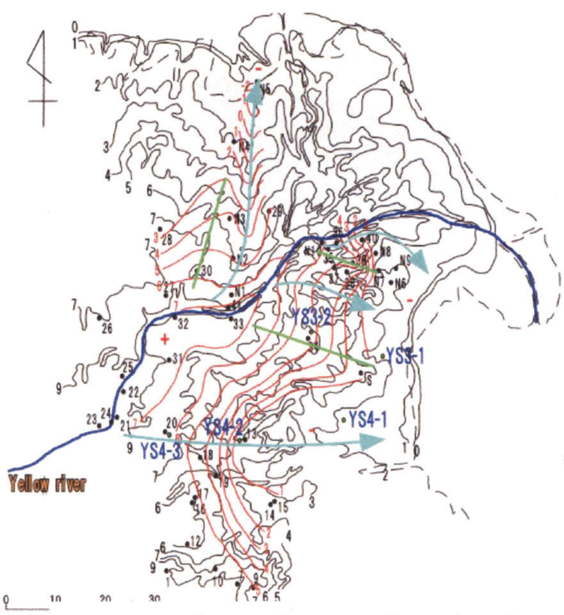

Fig. 1 : Groundwater flow in the delta (high flow, Sep. 2004).

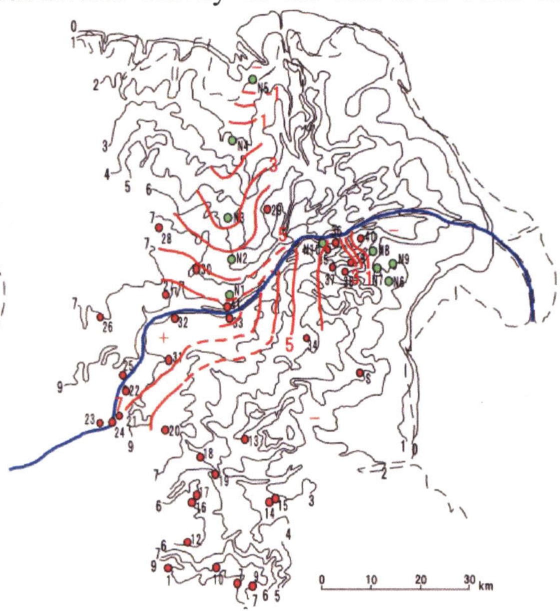

Fig.2 : Groundwater flow in the delta (low flow, May. 2005)

Yellow River delta. The Figures 1 and 2 show the groundwater table and direction of the groundwater flow on September 2004 (high flow) and May 2005 (low flow). The hydraulic gradient of the groundwater decreases during the low flow (similar to the condition of the "Cut-off of the Yellow River"), however the ratio of groundwater contribution increases during the low flow.

3. Interaction between Yellow River, groundwater and sea water

Three different waters, river water, groundwater and sea water, meat in the Yellow River delta. The magnitude and direction of the water have been examined to evaluate the effect of the cut-off of the Yellow river. As the results, the directions of the water were found to be from the Yellow River to groundwater and the groundwater to the Bohai sea (Fig.3). The replacement of the water has also been clarified from the results in the transect line from the Yellow river to the Bohai sea.(Fig. 4)

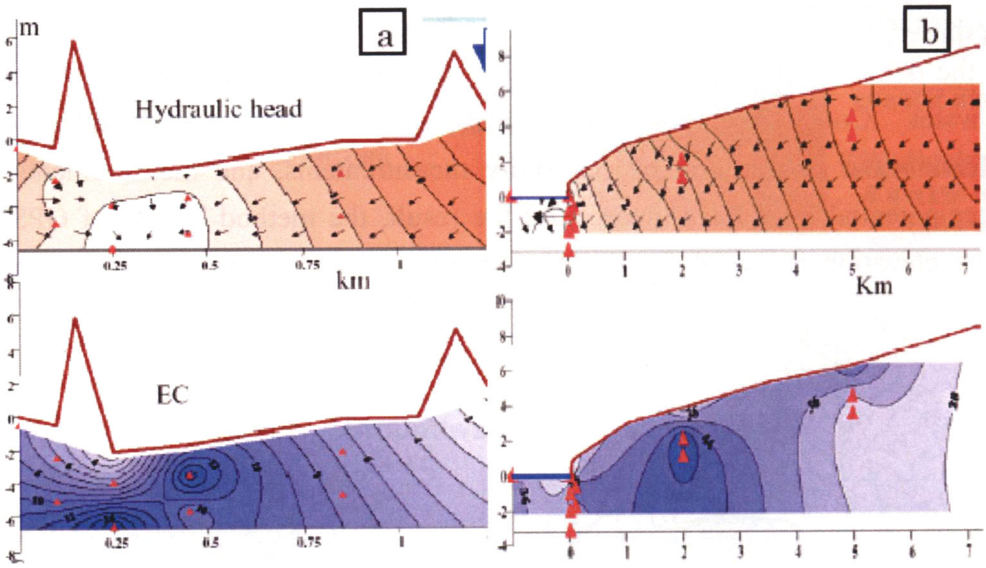

Fig. 3 Directions of the water flow,

Uppers: groundwater potential and direction

Lowers: Electric conductivity of the groundwater

Lefts (a) River-groundwater interaction (YR is located at the right side)

Rights (b): Groundwater-sea water interaction (Bohai sea is located at the left side)

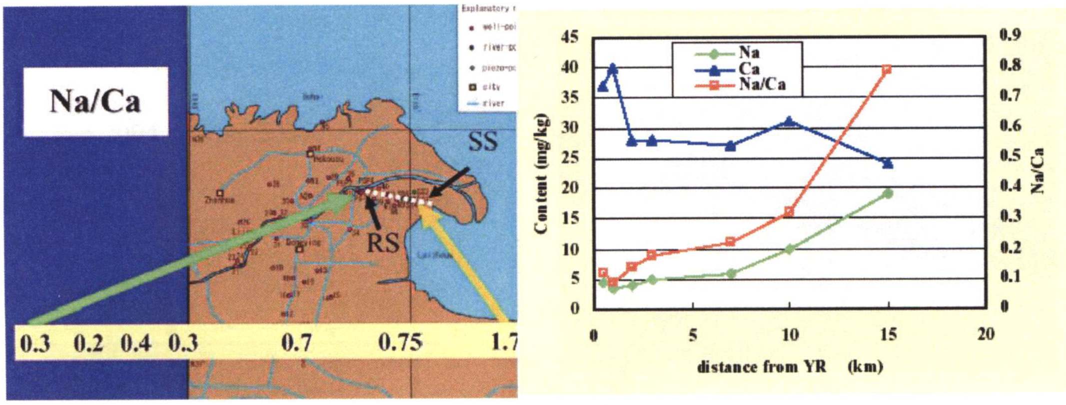

Fig 4 : Groundwater quality (Na/Ca) at RR (Yellow river) – SS (Bohai sea) line

4. Impact zone of the Yellow River

In order to evaluate the hydraulic continuity in the delta, the changes in groundwater level and discharge rate of the Yellow River have been analyzed. The correlation between the Yellow River discharge and groundwater level in the delta show that the impact zone (hydraulic continuity) of the Yellow river is more than 40 km.

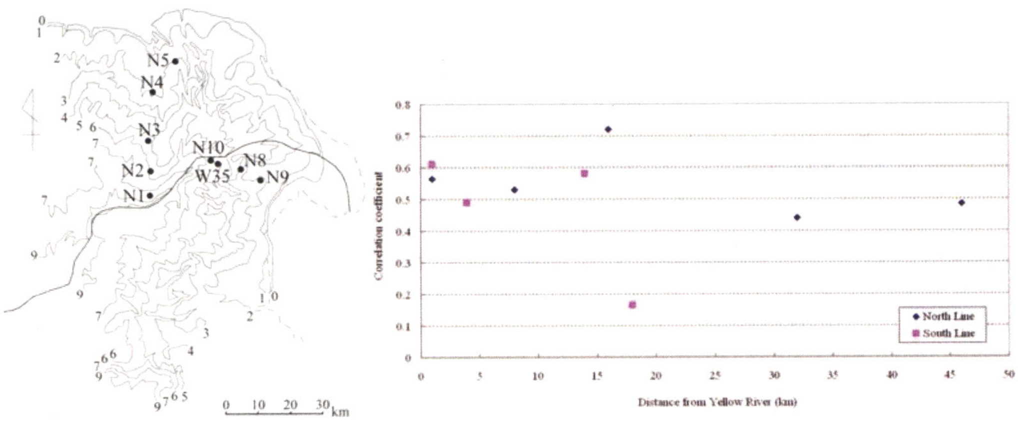

Fig5: Correlations between river discharge and groundwater level.

The analyses of the water balance in the lower reach of the Yellow River basin show that the 60 % of the water loss (total loss is 1.28 x 10^8 m^3/year) between Huayuankou and Lijin was irrigation, and that water transport through trans boundary from the Yellow river to the Qingdao and Tianjin was 20 % of the water loss.

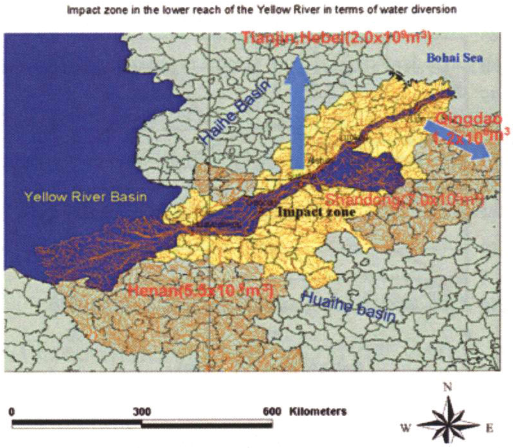

Fig.6 Irrigation area and trans boundary movement of water
From the Yellow River

5. Water and dissolved material transports from the delta to the Bohai sea

Spatial and temporal variations of submarine groundwater discharge (SGD) have been evaluated by automated seepage meters from the Yellow River delta to 7 km offshore in the Bohai Sea, China (Fig.7). We identified three zones from the coast to offshore based on different relationships between tidal and SGD changes. Our results indicate that the point of maximum SGD shifted 2 km offshore from September 2004 to September 2006 (Fig.8). This spatial change is thought to be caused by sediment deposition near the coast (Fig.9).

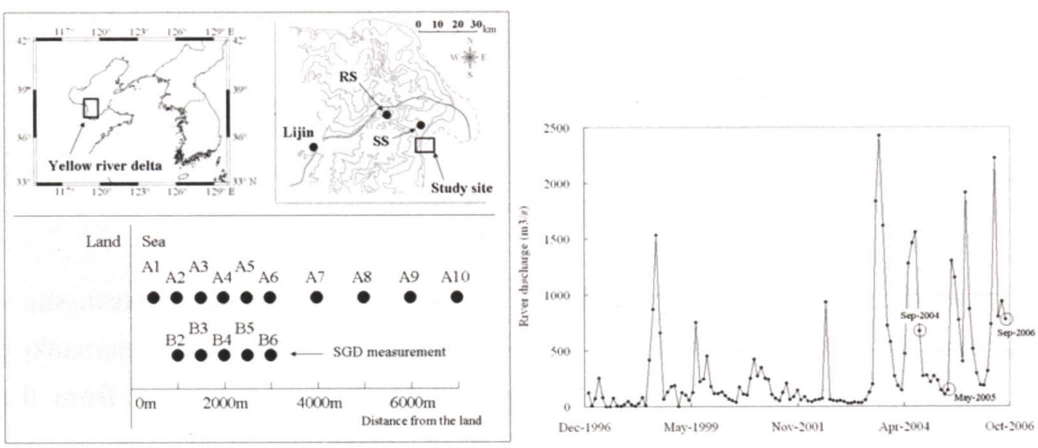

Fig.7 Locations of the seepage meters (left) and change in Yellow River discharge (right).

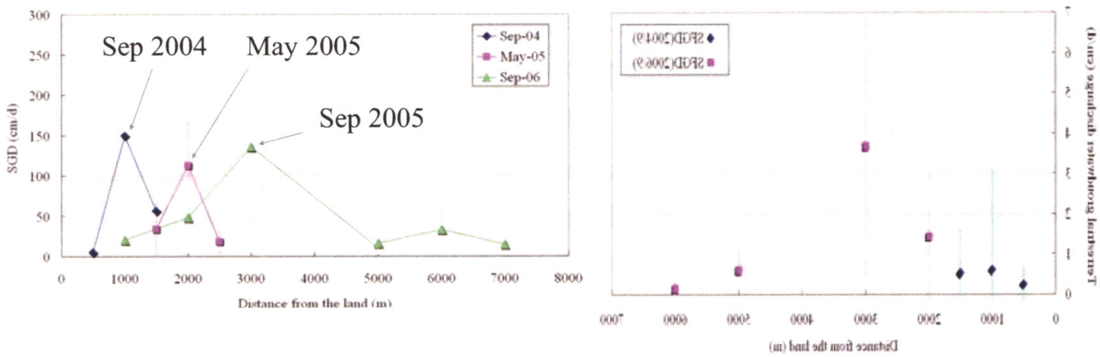

Fig.8 SGD (left) and SFGD (right) distributions

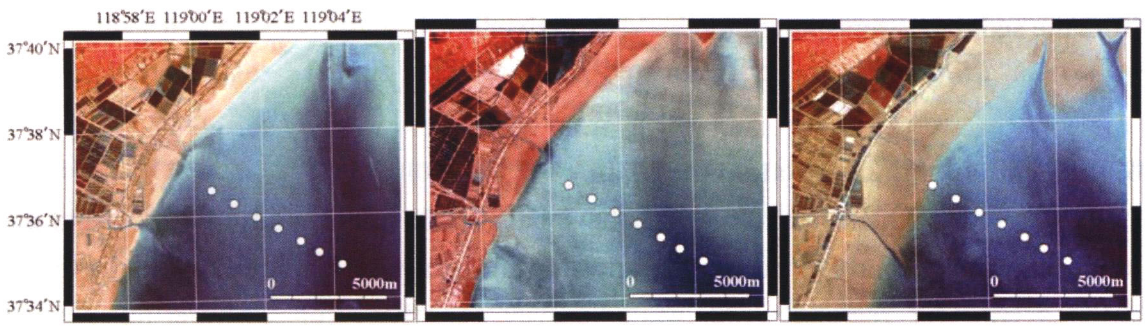

Fig.9 Locations of shoreline on Sep.2004 (left), May.2005 (middle) and Sep.2005 (right)

Assuming the seepage face extends 7 km offshore, the average integrated SGD of both the A and B lines per unit length of shoreline are estimated to be 2,300 m^3/m day and 304 m^3/m day in September 2004 and May 2005, respectively. The integrated SGD in September 2006 is estimated to be 3065 m^3/m day. Assuming the shoreline length of the Yellow River delta to be 350 km, the total SGD from the entire Yellow River delta is evaluated to be 9,300, 1,200, and 12,000 m^3/s in September 2004, May 2005, and September 2006, respectively. Since the Yellow River discharge in September 2004, May 2005, and September 2006 were 676, 145, and 778 m^3/s, respectively, the total estimated SGD from the delta are found to be 13.8, 8.5 and 16.0 times the river discharge into the Bohai Sea. Note that these numbers include both SFGD and RSGD.

Assuming the SFGD seepage face in September 2004 and September 2006 are 2 km offshore, the average SFGD in September 2004 and September 2006 are 18 and 28 m^3/m/day, respectively. Assuming the length of the coastline of the Yellow River delta to be 350 km and SFGD in the study area represents 3.6 times the average SFGD of the entire delta, SFGD is evaluated to be 110 and 170 m^3/s during September 2004 and September 2006, respectively. Therefore, SFGD represent about 4.5 % and 7.0 % of the Yellow River discharge during September 2004 and September 2006, respectively.

Comparison of these results with global data shows that the SFGD in the Yellow River delta is smaller than global average, but SGD is larger than the average, because of gentle slope in the coastal zone of delta.

Material transports by groundwater to by Yellow river were 100:60 for Phosphate and 100:50 for Silica, though fresh water discharge (SFGD) by groundwater to by Yellow river was 100:5. Therefore, the result shows the importance of groundwater discharge for Phosphate and Silica into the Bohai sea. On the other hands, nitrate discharge by groundwater to by Yellow river was 100:2.4. This small contribution by fresh groundwater discharge (SFGD) may be due to denitrophication. However, the nitrate discharge by recirculated seawater discharge may cause the dissolution of nitrate from the sediments transported by the Yellow river.

6. Integration of the evaluation methods

Integration of the different methods have been made in this study to understand the interaction between river water, groundwater and sea water. Geophysical methods, such as GPS for regional groundwater survey, resistivity for saltwater-fresh water distribution, automated seepage meter to evaluate submarine groundwater discharge, groundwater potential measurement to identify the impact zone of the Yellow river, and geochemical methods, such as stable isotopes and chemical composition analyses, were used and compared each other.

The groundwater group made three field experiments with Bohai group. This is not only for sharing data for the model by Bohai group, but also for improving their model itself. The interdisciplinary study by groundwater hydrologists and coastal oceanographers has been made in the Yellow River delta.

7. Conclusions

The conclusions of the groundwater group are as follows;

(1) The usefulness of GSP measurements in the flat area such as Yellow river delta is shown,

(2) The deep information on saltwater/freshwater distribution can be found remotely by uses of resistivity without borehole data.

(3) The directions of water movement in the delta are evaluated to be from the Yellow river to the groundwater, and from the groundwater to the Bohai sea.

(4) The hydraulic impact zone of the Yellow river was estimated to be more than 40 km by use of correlation between river discharge and groundwater level,

(5) Comparisons of the results of groundwater discharge into the Bohai sea between different river discharge periods showed that the role of groundwater discharge increases during low flow (similar to the condition of the cut-off of the Yellow River).

(6) The distribution of the SGD shifted 2 km offshore during two years because of the offshore shift of the coastal line due to the sedimentation.

(7) The ratio of SFGD (fresh component of submarine groundwater discharge) was 5-8 % of the Yellow river discharge, which was smaller than global average, however, SGD (total submarine groundwater discharge including recirculated sea water) was 8 to 16 times of Yellow river discharge, which is much larger than the global average. This is attributed to the gentle slope of the coast in the Yellow River delta.

(8) Material transports by groundwater to by Yellow river were 100:60 for Phosphate and 100:50 for Silica, though fresh water discharge (SFGD) by groundwater to by Yellow river was 100:5.

(9) The nitrate discharge by recirculated seawater discharge may be caused by the dissolution of nitrate from the sediments transported by the Yellow river.

(10) The 60 percentages of the water loss between Huayuankou and Lijin was used by irrigation in the lower reach of the Yellow River basin.

(11) The interdisciplinary study by groundwater hydrologists and coastal oceanographers has been made in the Yellow River delta.

8. Remained subjects

(1) Some hypnoses have been raised to explain the increase of nitrogen in the Bohai sea, however, no single reason was identified.

(2) The process of the SGD and SFGD were clarified, however, the process of recirculated seawater, in particular the entry process of the recirculated water was remained to be unclear.

(3) Geophysical and geochemical methods were integrated, however, the effects on the ecology in the coastal zone should be evaluated in the future.