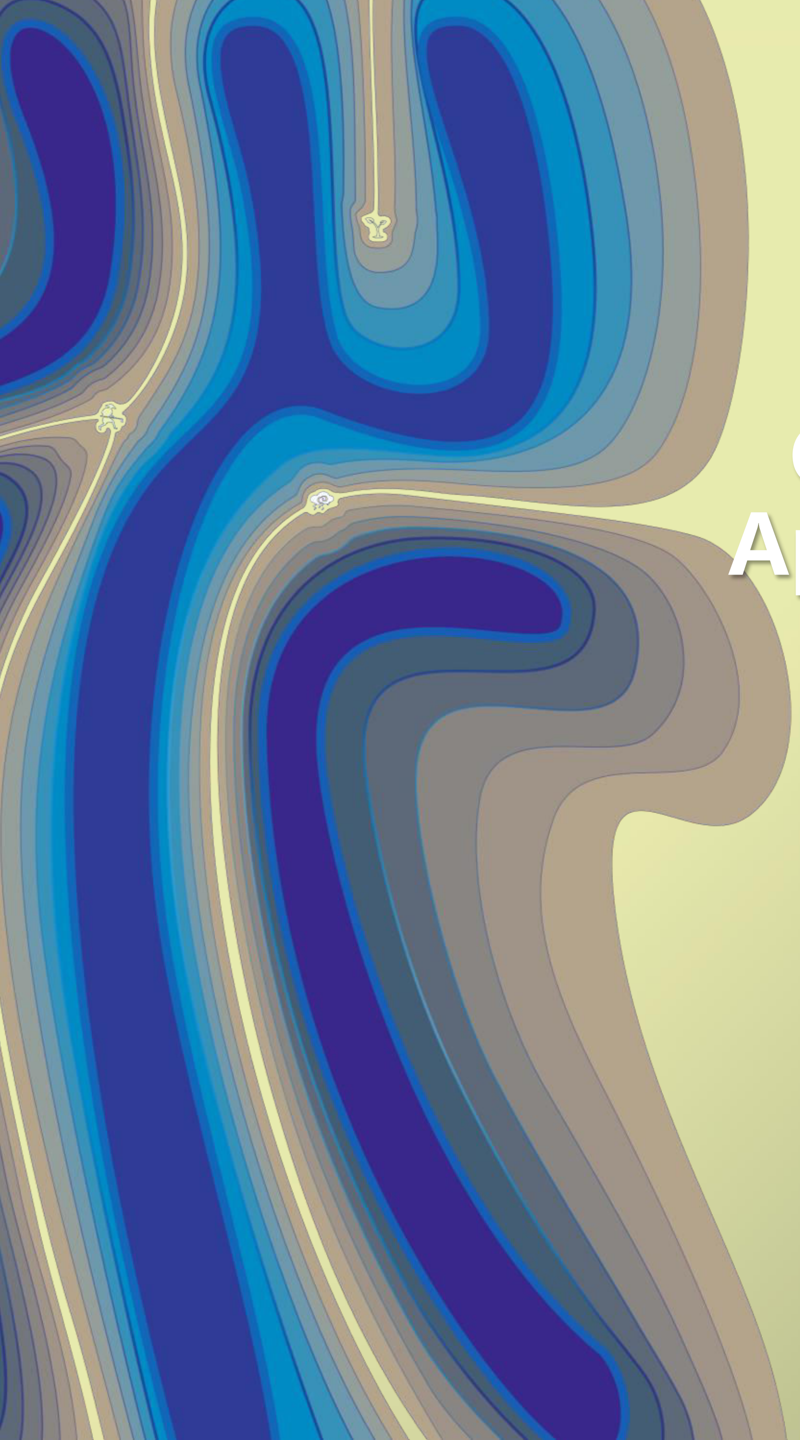

XVIII
World Water Congress
International Water Resources Association (IWRA)

Quantitative Evaluation of Groundwater–Surface Water Interactions: Application of Cumulative Exchange Fluxes (CEF) Method

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Institute of Disaster Prevention

XVIII
WORLD WATER CONGRESS
Water for All
Harmony between Humans and Nature

第18届
世界水资源大会
水与万物：
人与自然和谐共生

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Background： Groundwater – surface water interaction

Surface water (including rivers, lakes, reservoirs, wetlands, estuaries, etc.) interacts with groundwater almost everywhere on Earth. In the context of sustainable river basin management it is crucial to understand and quantify exchange processes between groundwater and surface water.

The core content: Stream-aquifer system

Two ways of GW-SW interactions

1.Losing stream
the stream infiltrates through sediment into the groundwater

2.Gaining stream
groundwater discharges into the stream

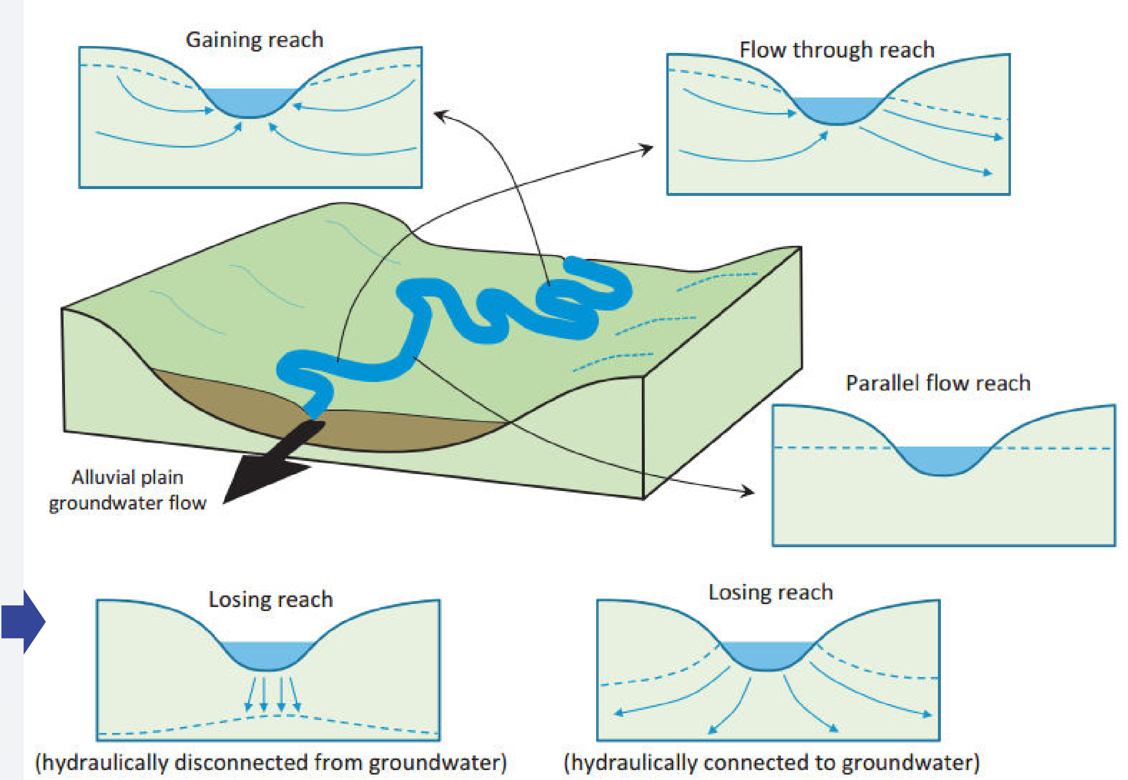
Controlled by five factors

1. Aquifer and riverbed Characteristics

2.Hydraulic gradients

3.Location and structure of the river

Else：Climatic factors and human activities



Five types of GW-SW interaction (Khan,2019)

Background： Groundwater – surface water interaction

Estimation of the fluxes of GW-SW interactions

Four basic methods

1.Direct measurements of water flux

Using seepage meters, the observation of the water flux is limited to point, may be affected by the resistance of the measurement itself

2.Heat tracer methods

Relies on a significant and stable temperature difference between GW-SW, interfered by daily fluctuations in surface water temperature

3. Methods based on Darcy’s law

Depend heavily on the choice of parameters, , such as hydraulic conductivity with higher uncertainty

4. Isotopic/geochemical-based methods

High costs, continuous dynamic monitoring is difficult to achieve.

No matter which method is used, uncertainty is inherent in the study

⬇

How to grasp the basic mode of regional GW-SW interactions before using various methods for research?

⬇

(1) Theory of Cumulative Exchange Fluxes (CEF)

Based on theory of surface water balance

(2) Case-study :Apply this method to a reach of the Taizi River Basin;

Theory of Cumulative Exchange Fluxes

Cumulative exchange fluxes is based on the theory of surface water balance

Volume change of the water body can be expressed by the difference between the downstream and upstream flow

$$Q_{gain} - Q_{lose} = \Delta Q = Q_{down} - Q_{up}$$

$$Q_t + Q_p + Q_r - Q_e - Q_d + Q_c \pm Q_o = Q_{down} - Q_{up}$$

The daily exchange fluxes Qc can be defined by daily equilibrium term and expressed as:

$$Q_c = Q_{down} - Q_{up} - (Q_t + Q_p + Q_r - Q_e - Q_d \pm Q_o)$$

Qt: flow of tributaries

Qp: recharge of precipitation to the stream surface

Qr: runoff volume produced by precipitation

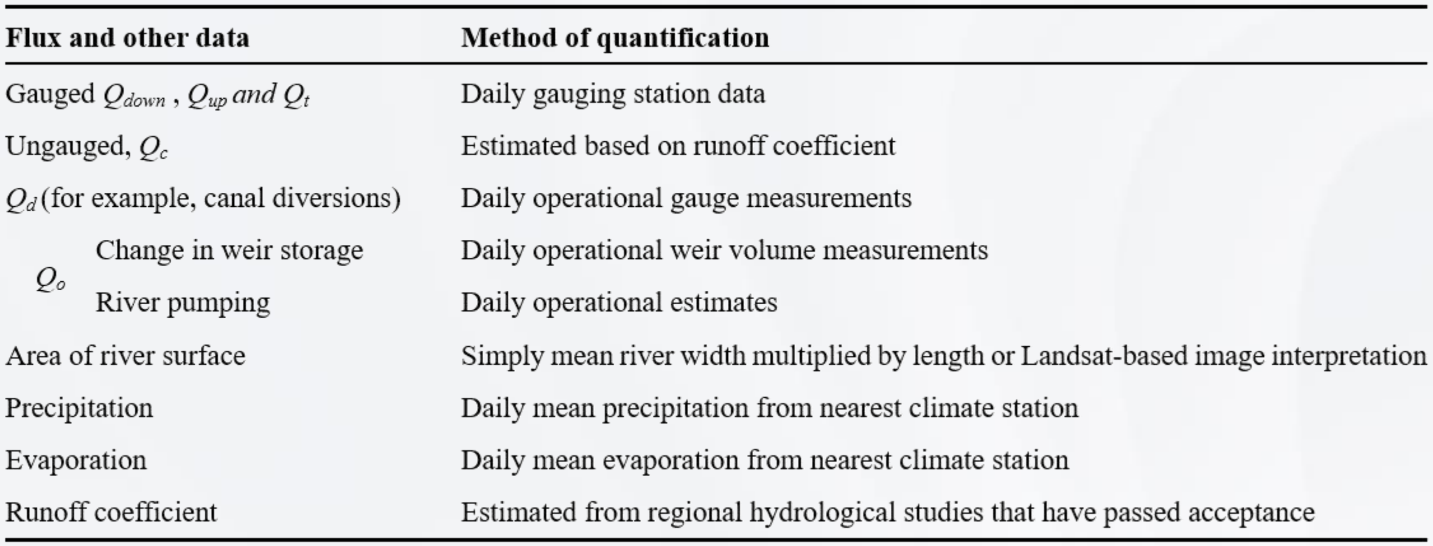
Qe: evaporation volume of the stream

Qd: diversion volume from the river to the outside

Qc: exchange fluxes between GW-SW

Qo: other water volume changes in the stream

Table 1 Methods for quantifying water fluxes in the reach water balances



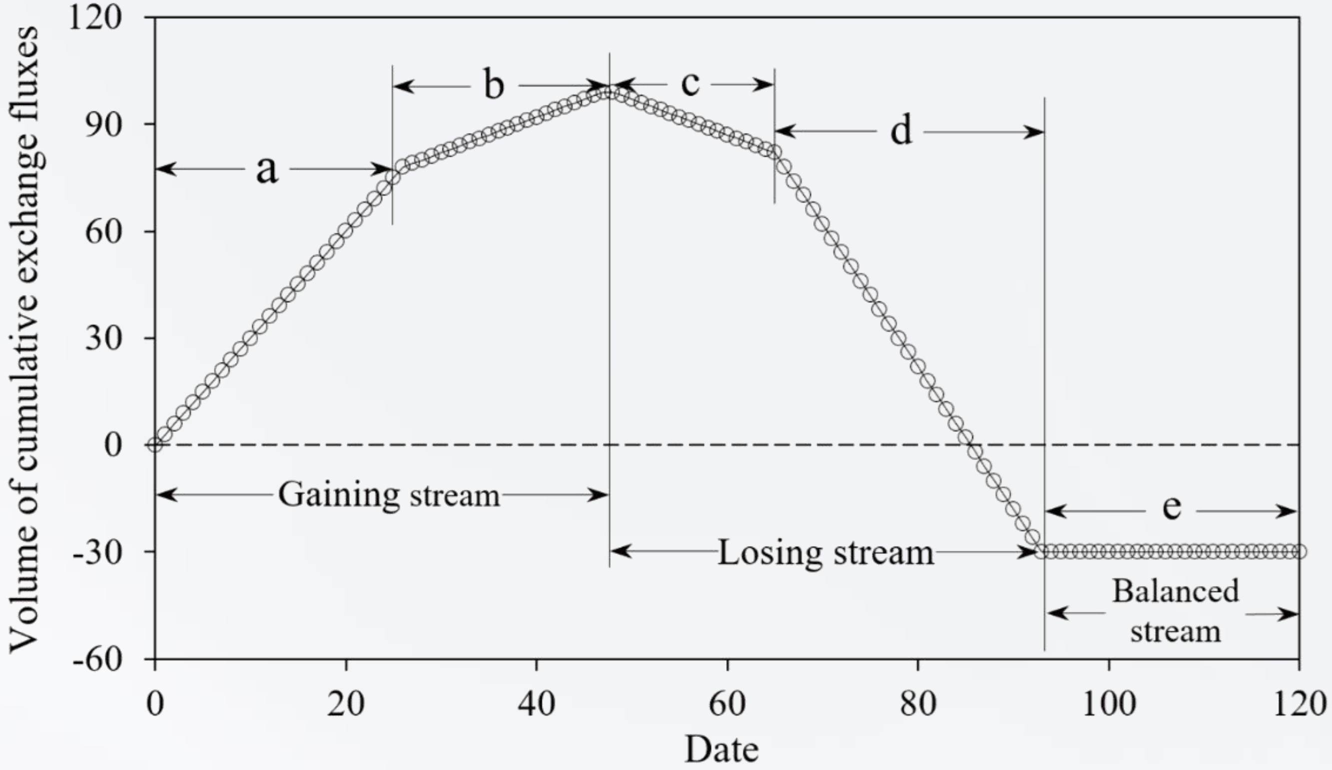
Flux and other data		Method of quantification
Gauged Q_{down} , Q_{up} and Q_t		Daily gauging station data
Ungauged, Q_c		Estimated based on runoff coefficient
Q_d (for example, canal diversions)		Daily operational gauge measurements
Q_o	Change in weir storage	Daily operational weir volume measurements
	River pumping	Daily operational estimates
Area of river surface		Simply mean river width multiplied by length or Landsat-based image interpretation
Precipitation		Daily mean precipitation from nearest climate station
Evaporation		Daily mean evaporation from nearest climate station
Runoff coefficient		Estimated from regional hydrological studies that have passed acceptance

Theory of Cumulative Exchange Fluxes

Cumulative exchange fluxes is based on the theory of surface water balance

The volume of the cumulative exchange fluxes for any n days (Qn cumulative) can be obtained as:

$$Q_{cumulative}^{n} = \sum_{i=1}^{n} Q_c^i = \sum_{i=1}^{n}\left[Q_{down}^i - Q_{up}^i - \left(Q_t^i + Q_p^i + Q_r^i - Q_e^i - Q_d^i \pm Q_o^i\right)\right]$$



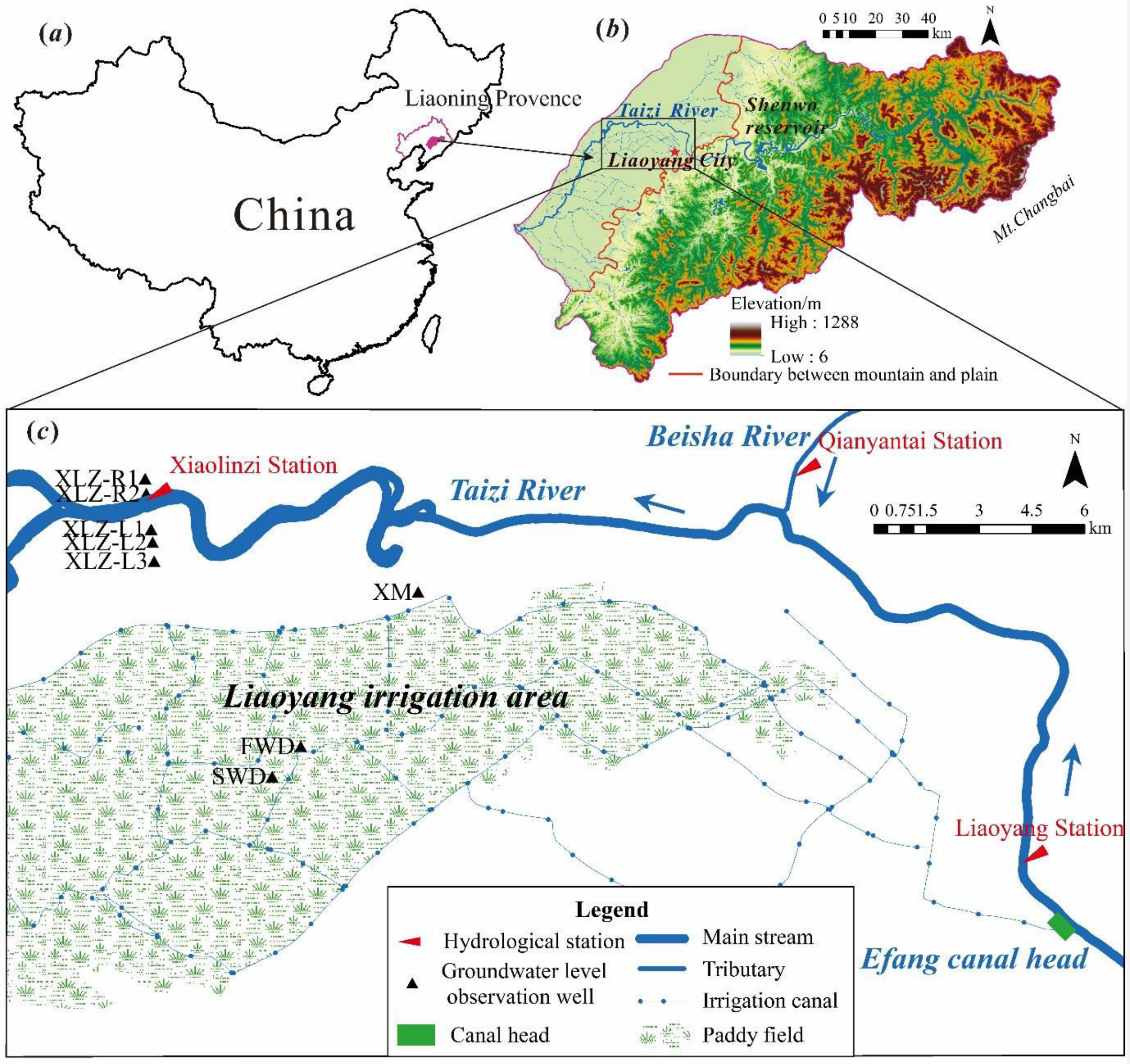
Schematic diagram of cumulative exchange fluxes

The equation can be represented by a "cumulative curve"

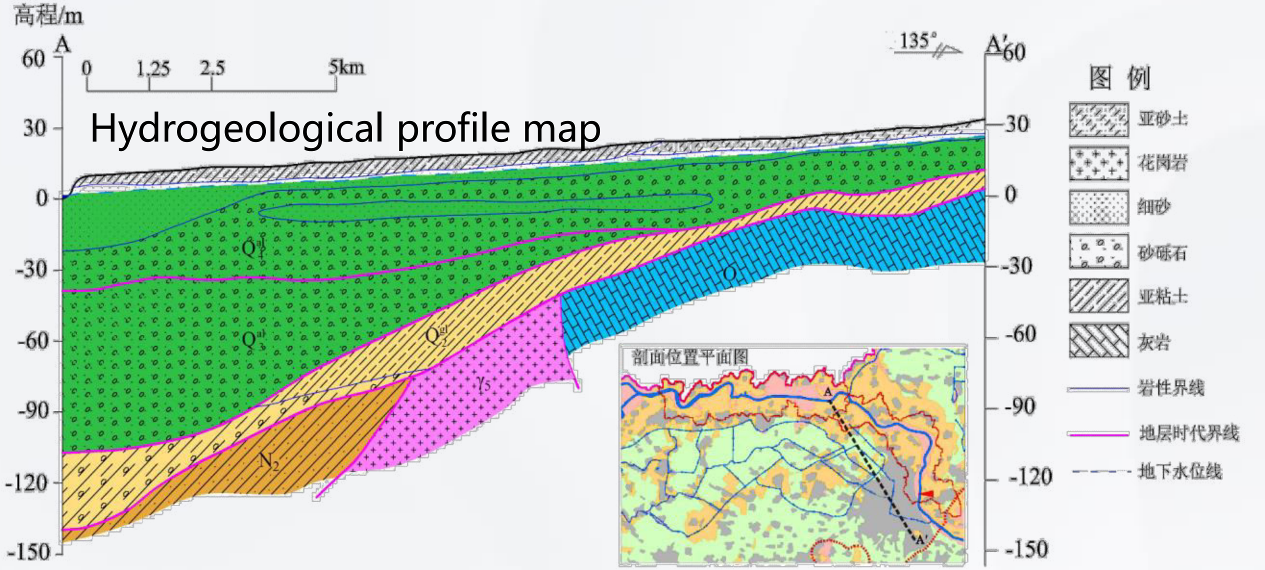
When Qn is in a continuously increasing trend , it indicates gaining stream;

On the contrary, when Qn is in a downward trend, it means losing stream.

Case-study: Study area

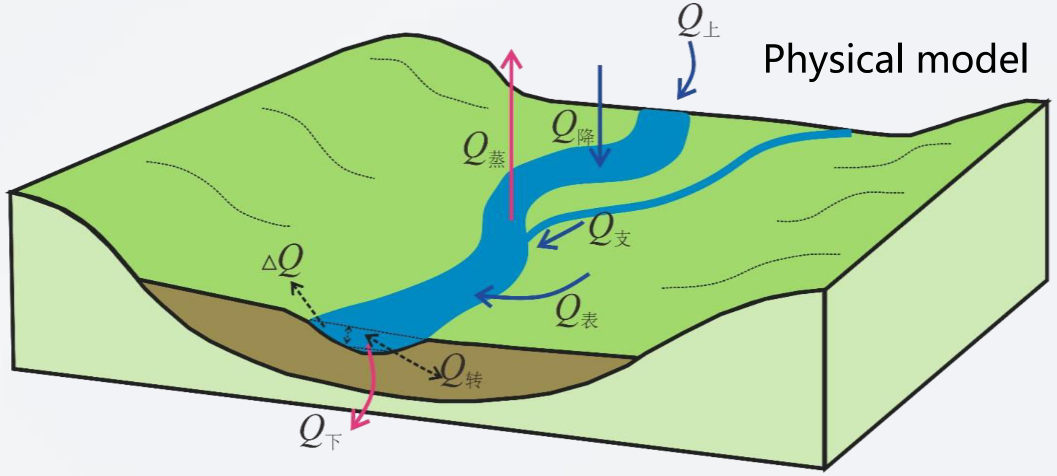


- The study reach is located in the alluvial plain of the Taizi River, downstream of the Shenwo reservoir between Liaoyang station, and Xiaolinzi station,
- One tributary is monitored by the Qianyantai station
- There is no water intake/outlet project in this reach.
- South of the reach is the Liaoyang Irrigation District


Hydrogeological profile map

Sand gravel aquifer lays the foundation for GW-SW interactions

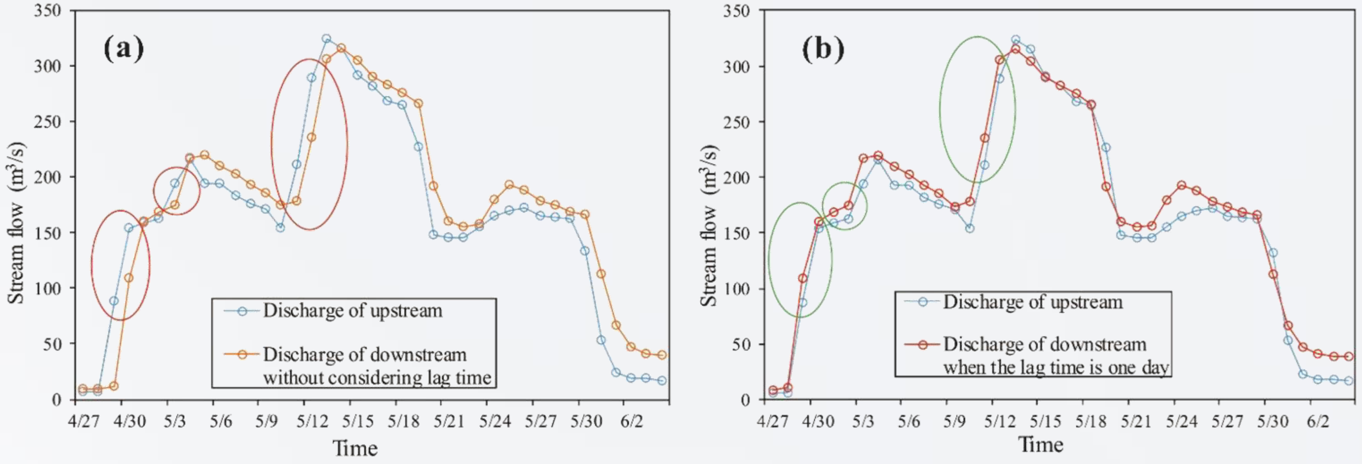
Case-study: Calculation of the Exchange Fluxes in 2016



Physical model

According to the actual situation and data from 2016

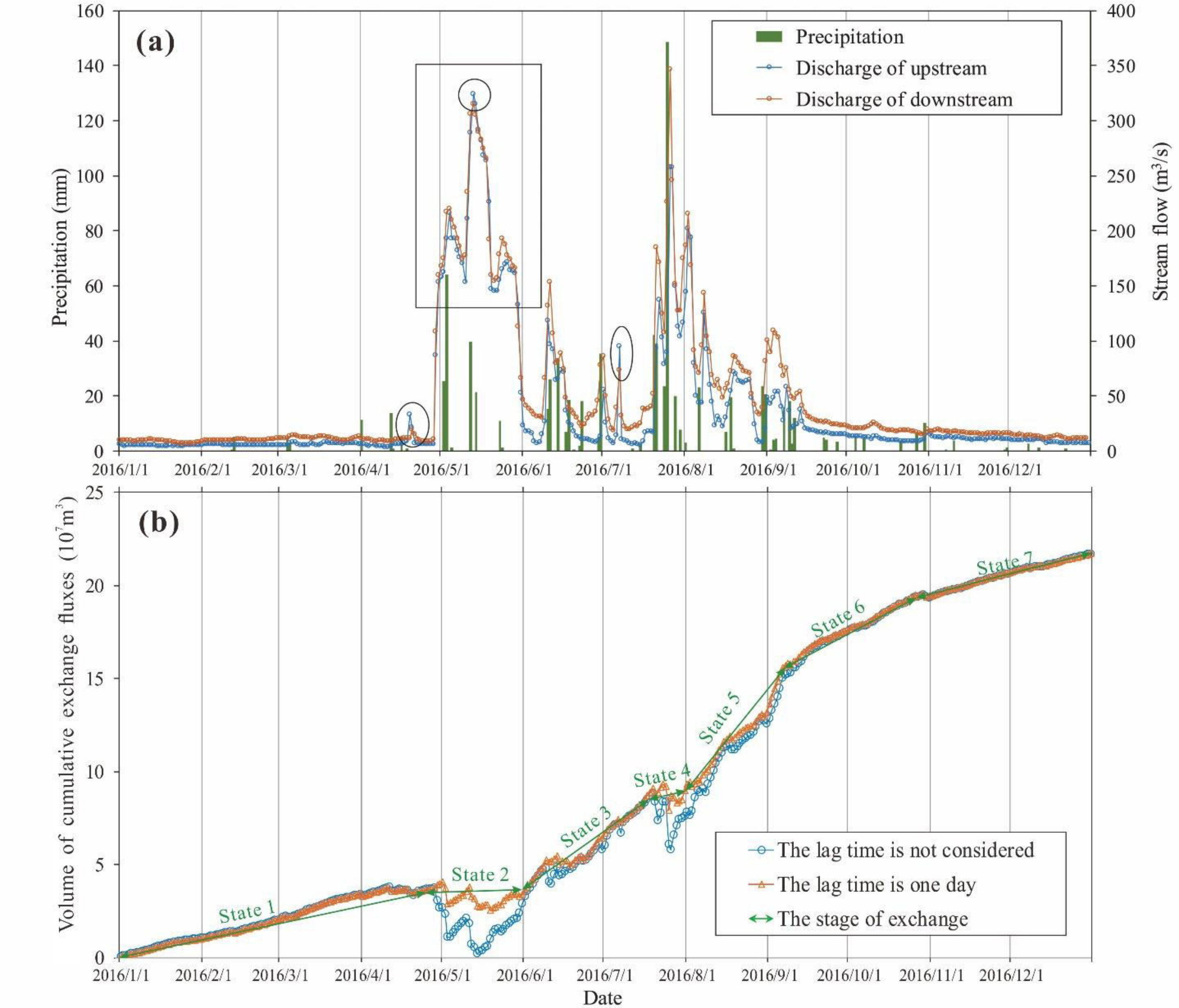
$$Q_{cumulative}^{366}=\sum_{i=1}^{366}Q_c^i=\sum_{i=1}^{366}\left[Q_{down}^i-Q_{up}^i-\left(Q_t^i+Q_p^i+Q_r^i-Q_e^i\right)\right]$$



70% of the flow peak points showing a lag time of one day between downstream and upstream, and considering a delay of 1 day can better represent the true situation of streamflow

$$Q_{cumulative}^{366}=\sum_{i=1}^{366}Q_c^i=\sum_{i=1}^{366}\left[Q_{down}^i-\boxed{Q_{up}^{i-1}}-\left(Q_t^i+Q_p^i+Q_r^i-Q_e^i\right)\right]$$

Case-study: Basic features



Results of cumulative exchange fluxes

- The amount of cumulative exchange fluxes showed an overall upward trend in 2016, indicating the occurrence of gaining stream, and the curve clearly shows 7 stages.

Stage1: River is recharged by groundwater in a stable rate, and can be considered as recharge under natural conditions,

Stage2-5: The periodic release of water from reservoir leads to fluctuations in the cumulative curve.

Stage6-7: The reservoir no longer releases water, and the curve gradually returns to its initial state

Case-study: Driving factors

The Relationship between the exchange rate and Upstream Runoff

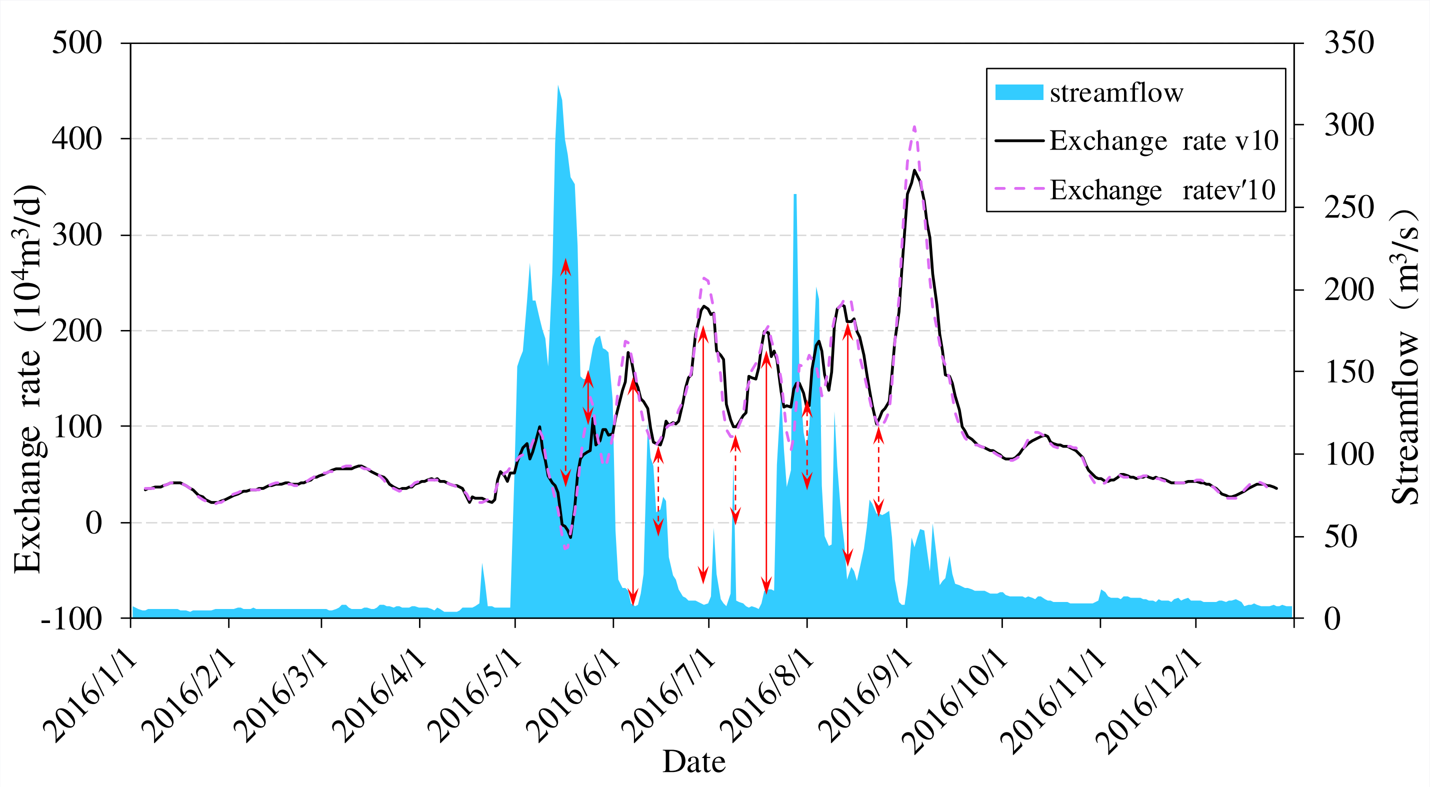
Two indexes are used to represent the exchange rate：

①10 days exchange fluxes moving average

$$v_{10} = \left(Q_{\text{day}}^{i} + \cdots + Q_{\text{day}}^{i+9}\right)/10$$

②Slope of 10 day curve

$$v'_{10} = slope\left(Q_{\text{curve}}^{i}, Q_{\text{curve}}^{i+1}, \cdots, Q_{\text{curve}}^{i+9}\right)$$

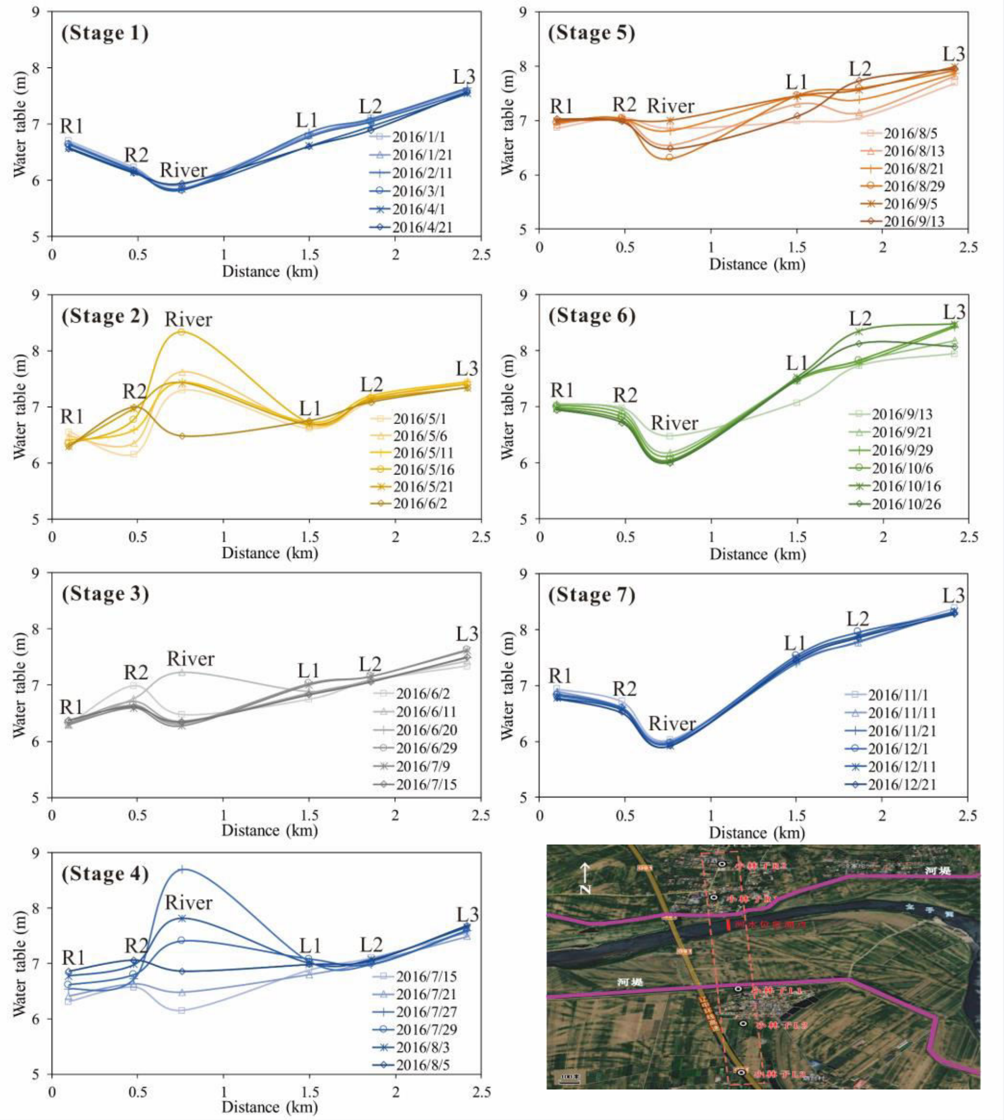


Exchange rate vs streamflow

- ■The exchange rate shows a "**steep increase & steep decrease**" trend.
- ■The "steep rise" occurs when runoff rapidly decreases after high flow.
- ■There is always a large exchange rate during the low flow period between two flood peaks, and the exchange rate decreases again when the runoff increases sharply.
- ■It can be seen that the regulation of reservoirs (periodic discharge) is the main reason for the fluctuation of exchange rate.

Case-study: Driving factors

Indications of water level changes on GW-SW interactions

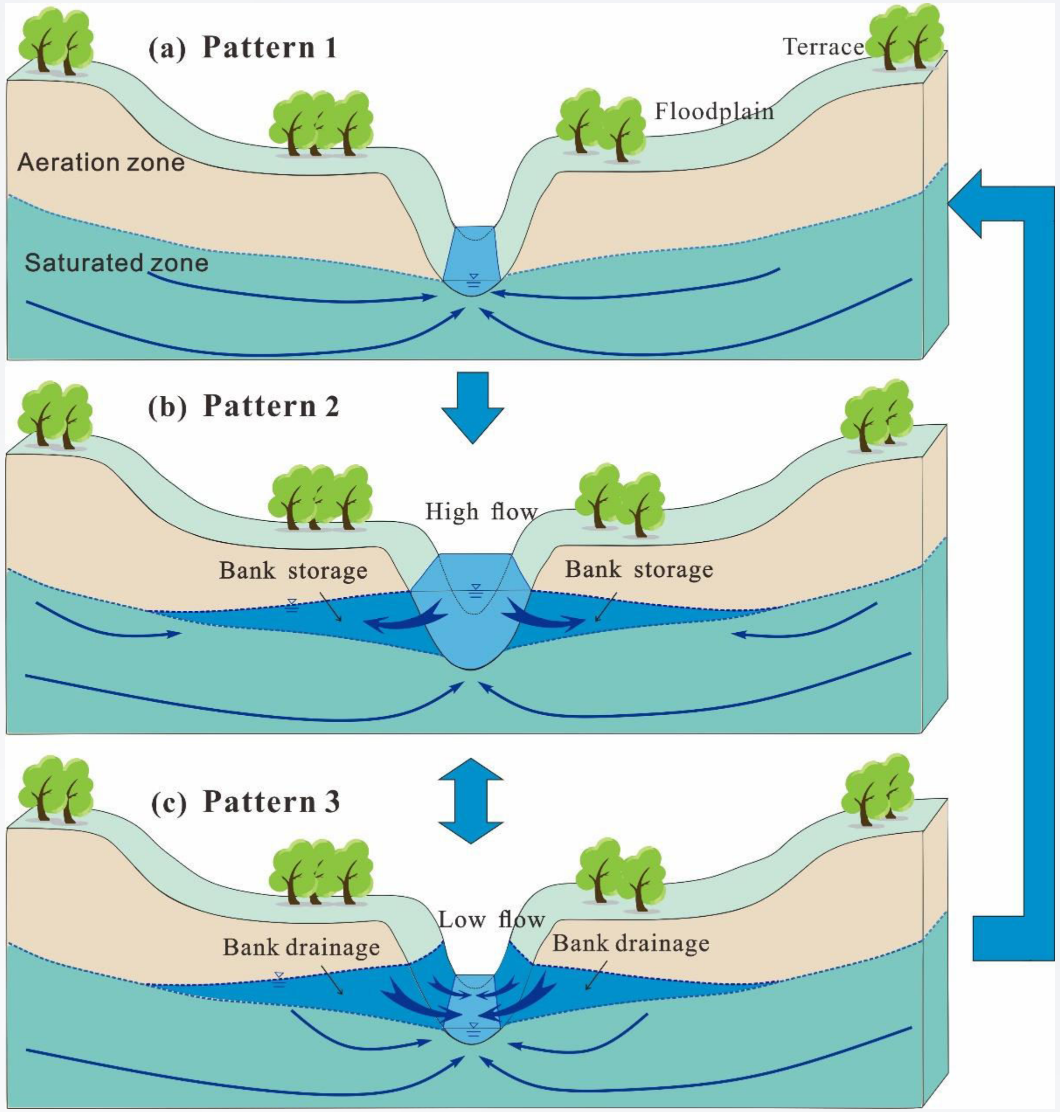


- The change of water level in stages 1, 6 and 7 is small, reflecting a relatively stable groundwater recharge process, which is consistent with the relatively stable exchange rate.
- Due to the release of water from the reservoir, the water level significantly changes in stages 2~5.
- The interactions change from simple gaining stream to alternating changes in gaining and losing during stages 2~5.
- After the middle of September, with the decrease of streamflow, the river level stops rising, and the GW-SW interaction return to gaining stream.

Monitoring data of groundwater and river water level at different stages

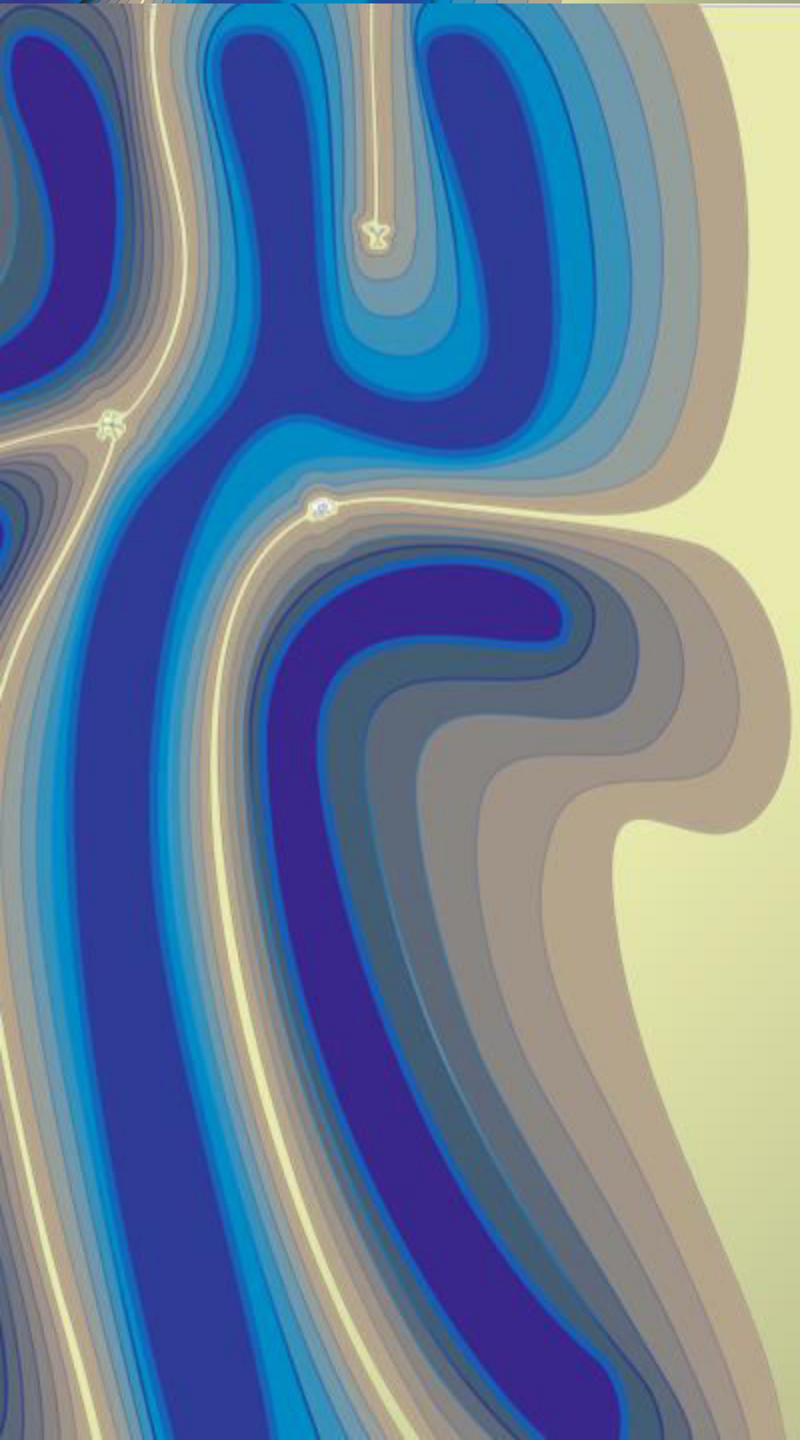
Case-study: Driving factors

Patterns of GW-SW interactions near riverbank areas



Finally, we summarized three patterns of GW-SW interactions near riverbank areas.

- Pattern 1 shows that groundwater is stably discharged into the river at a low speed in the form of basic flow;
- In pattern 2, the released water from the reservoir leads to the rise of river water level, and under the drive of hydraulic gradients, part of the river water seeps into the river banks and stored on the riverbank, called “**Bank storage**”；
- Pattern 3 occurs when the reservoir stops releasing water, at which point the water level rapidly decreases and the water in the riverbank storage area is released and discharged into the river.



Thanks for listening