

## The Mechanism of Salty Tide Intrusion in Pearl River Estuary and the Sustainable Use of Water Resources in Pearl River Delta

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**Abstract:** Pearl River Delta is often intruded by strong salty tide and the safe drinking water of residents is continuously threatened in recent years, so Pearl River Water Resources Commission of the Ministry of Water Resources transfers fresh water to resist salty water for many times since the year 2005. According to the characteristics of salty tide activity in recent several years, such as more active movement, longer duration, wider upstream scope, more serious intensity, etc, the paper analyzes the mechanism of salty tide intrusion in Pearl River Estuary from such perspectives as the change of upland water, the change of river channel topography, the change of sea level, wind power, wind direction, etc. On the basis of the research on salty tide in recent years, the paper puts forward the methods to defend salty tide intrusion from such perspectives as the safety of water supply, the sustainable use of water resources, etc, for ensuring the sustainable development of water resources.

**Key Words:** Salty Tide Intrusion; Pearl River Estuary; Pearl River Delta; Water Resources

### 1. Research Background

Pearl River Delta is the frontal zone of reform and opening-up, with a large population, developed industry and high-degree urbanization. However, with the growth of population, and the quickening of industrialization and urbanization, there exist the continuously-expanding water supply demand, the weak adjusting ability of local water resources to salty tide and the more serious effect of salty tide upstream on urban water supply in Pearl River Delta in recent years. In addition, since the global warming causes the rise of sea level, the water demand in the middle and upper reaches of the water basin increases, quarrying sand gives rise to the downcut of riverbed in Pearl River Delta and Estuary Area, and dredging is carried out in the major launching-out navigable channels, the salty tide activity in Pearl River Delta is with the following characteristics: more active movement, longer duration, wider upstream scope and more serious intensity. Especially since the autumn of 2003, strong salty tide intrusion occurs frequently in Pearl River Delta, threatening the safe water supply of Pearl River Delta seriously, especially Macau and Zhuhai. Salty tide upstream results in serious economic loss and social effect to Pearl River Delta. In order to defend the salty tide intrusion and protect the safety of drinking water, Pearl River Water Resources Commission of Ministry of Water Resources successively organizes and executes the emergency water transfer project in Pearl River by transferring fresh water to repel salty water

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intrusion in early 2005 and early 2006, implements water transfer in the major reservoirs of Pearl River during the low flow period of the years 2006-2007, and carries out the unified water transfer in Pearl River during the low flow period of the years 2007-2016.

With the rise of global temperature and sea level, the salty tide has a more and more serious effect on the safe water supply of Pearl River Delta, which draws much attention. So studying the mechanism of salty tide upstream intrusion in Pearl River Estuary and exploring the effective measures of using the water resources of the whole water basin continually have a very important significance in ensuring the sustained development of water resources and the social stability of Pearl River Delta(Fig1).

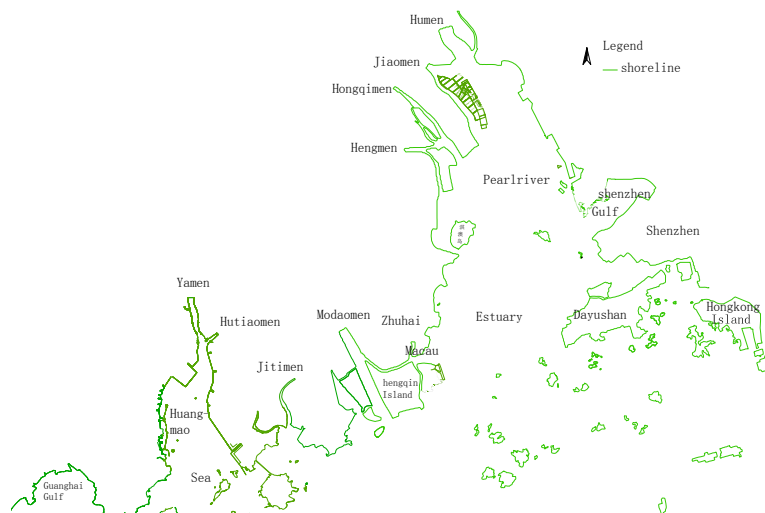


Fig1 Pearl River Estuary Sketch

## 2. The Analysis on the Mechanism of Salty Tide Upstream Intrusion

There are lots of zigzag river channels in Pearl River Delta. Salty tide activity is mainly controlled by runoff and tidal current. When the high saline water mass in the continental shelf flows up along the tidal channel of the estuary with the tidal flood current, the salty water scattering and the mixing of salty and fresh water make the water in the upper river channels become salty, so the salty tide is formed (or called salty tide upstream and salty water intrusion). When the chlorinity in the water of the river channel is more than 250mg/l, the water quality standard cannot be met and the urban drinking water supply will be affected. The other influencing factors consist of estuary shape, river channel topography, sea level change, wind power, wind direction, etc, in which the effect of the astronomic tide power is the most stable, with a certain periodicity. The tidal current in Pearl River Delta is irregular and semidiurnal, with two flood tides and low tides each day. On the first day and the fifteenth day of each lunar month, the tidal water level in the process of flood tide will be maximum, and the effect of salty tide upstream will be also relatively big.

### 2.1 The decrease of the runoff in the upper reach in low flow period

The runoff is the direct factor influencing salty tide. The larger the water quantity in the upper reach of the estuary is, the shorter the upstream distance of salty tide is and the less the effect of salty tide is. The salty tide upstream often happens in the low flow period. The observed

data show: when the flow quantity of the upper reach decreases, the salinity observed in the observation stations will increase; when the flow quantity of the upper reach increases, the salinity observed in the observation stations will decrease. In the recent several years, the incoming flow from the upper reach (the observed data obtained in Makou Station + Sanshui Station represent the incoming flow of West River and North River, respectively corresponding to Wuzhou Station + Shijiao Station of the upper reach) is less than 2000m<sup>3</sup>/s in the salty tide period, especially the most serious in springs of 1993, 1999 and 2004, and the least flow quantity is 1500~1600 m<sup>3</sup>/s. In the low flow period of 2002~2003 with weak effect of salty tide (not serious), the monthly flow quantities in Wuzhou Station and Shijiao Station are ample or calm to partially ample.

## **2.2 The change of estuary and river channel topography**

Since 1990s, there are more and more such human activities as quarrying sand in river channel, navigation channel dredging, etc, which leads to the riverbed downcut in Pearl River Delta and Estuary Area and the deepening of the deep pools of the major tidal channels. According to the data [2], the annual average incoming sand of the whole Pearl River Estuary is about 50,000,000 m<sup>3</sup>, but in the recent 15 years, the annual quarried sand is about 120,000,000 m<sup>3</sup> and the annual over-quarried sand is about 70,000,000 m<sup>3</sup>. Due to over-quarrying sand year after year, the incoming sand from the upper reach of Pearl River cannot supplement the quarried sand, which destroys the ecological balance of the river channel. The water in the no-sand river sections flows upstream, which causes the serious riverbed downcut and leads to the salty tide upstream. At present, some measures are taken to control the river sand.

## **2.3 The rise of sea level resulted from the global warming**

The global warming leads to the melting of polar ice, consequently the rise of sea level. According to a research finished cooperatively by 13 organizations of Chinese Academy of Sciences, etc in July 2003, the coastal sea level of Pearl River delta may rise by 30cm until 2030. If no preservation, Pearl River Delta will be intruded by more serious flood, storm tide, water logging disaster and salty tide [3]. The rise of sea level accelerates the intrusion of salty tide disaster to Pearl River Estuary. By calculating the change of the intrusion distance of salty tide in the estuaries of Lingdingyang Sea Zone, Modaomen Estuary, Jitimen Estuary and Huangmao Sea on the condition that seal level rises by 0.4 ~1.0m, Li Suqiong et al reach a conclusion that on the condition of high tide of low flow period, the intrusion distance of salty tide in Humen Waterway increases by 1~3km, and the maximum is about 4km; the maximum intrusion distance of salty tide in Modaomen Waterway increases by about 3km; the maximum intrusion distance of salty tide in Huangmao Sea Zone increases by about 5km [4].

## **2.4 The effect of wind power and wind direction on salty tide activity [5]**

For most rivers in Guangdong Province, the northwest section is high and the southeast section is low in topography, so wind has a great effect on salty tide activity. The different wind power and wind direction have a direct effect on the advancing speed and upstream distance of salty tide. If the wind direction is in accordance with the tide direction, the advancing speed of salty tide will be quickened and the upstream distance is longer. But the effect of wind power and wind direction varies from place to place. For example, East wind and Northeast wind can aggravate the salty tide disasters in Tanzhou and Shenwan of Zhongshan City, and Hongwan of

Zhuhai, meanwhile eases the salty tide disaster in the northeast of Sanzhao of Zhuhai. The different wind directions in the different seasons can have different effects on salty tide. Because of the different direction from that of salty tide, the northwest wind in winter can defend salty tide intrusion; But northeast wind is a unfavorable factor, which can accelerate the salty tide upstream and block the falling tide because the flow directions of Modaomen waterway and Hengmen waterway are both southeastward in the estuary of Zhongshan City; the southeast wind in spring can just accelerate the salty tide upstream. The salty tide upstream is the most serious in March and April of each year, mainly for the southeast monsoon prevails in Pearl River Delta in spring, the agricultural activity needs much water, and the spring is the low flow period.

### **3. On the sustained use of water resources in Pearl River Delta**

Salty tide results from natural and human factors. The intensity of salty tide activity is mainly controlled by tide activity and upper-reach runoff. The tide activity is a kind of natural phenomenon, which can be adjusted by human beings in a very limited degree. The upper-reach runoff is caused by the reduction of the incoming water quantity in the recent years, which belongs to both human factor and natural factor. However, the upper-reach runoff can be adjusted by human beings. In fact, the water-holding capacity the existing engineering facilities in the upper reach of Pearl River cannot ensure the safe water supply of Pearl River Delta. Some experts analyze that the water-holding quantity needed in the upper reach in winter and spring shall be 9,000,000,000 m<sup>3</sup>, while the current water-holding quantity is just 4,000,000,000 m<sup>3</sup>. Even though regardless of the safety of power network operation and the benefit of the enterprises, the problem of water supply cannot be solved either <sup>[6]</sup>. To solve the problem of water resources in Pearl River Delta shall be based on the unified dispatching and reasonable arrangement of water resources in the whole water basin.

Firstly, a fundamental approach is to construct a water-saving anti-polluting society. In the recent 20 years, the demand of urban and rural water supply increases quickly in Pearl River Basin, especially Pearl River Delta, for the rapid economic and social development and the quickening of urbanization, for example, the amount of water consumption in Pearl River Delta increases from 950,000,000 m<sup>3</sup> in 1980 to 10,250,000,000 m<sup>3</sup> in 2000. The increase of the discharge amount of waste and polluted water and the amount of water consumption worsens the water environment of the major waterways and river networks in Pearl River Delta further and reduces the utilization ability of local water resources. In order to defend salty tide effectively and protect the safe water supply for people in Pearl River Delta, the effective measures must be taken to control the increase of water consumption and water pollution. In the long term, Pearl River Basin shall consider constructing a water-saving anti-polluting society as the center, to establish the management system of water resources adaptable to the water right index control by executing the reform of water utilization system, to establish the economic structural system adaptable to the carrying ability of regional water resources by adjusting the economic structure and industrial structure, and to establish the hydraulic engineering system adaptable to the optimizing arrangement of wter resources by constructing water resources arrangement and water-saving projects. Only by these can the efficiency and benefit of water resources utilization be increased and the sustained development be realized.

Secondly, the hydraulic engineering construction shall be quickened. The hydraulic

engineering is the basis of water resources arrangement and water quantity dispatching. To solve the problem of water supply in Pearl River Basin, the hydraulic engineering construction in the basin shall be strengthened. At present, the development and utilization rate of water resources in Pearl River is less than 18%; the total reservoir capacity just accounts for 11% of the annual runoff amount of Pearl River, much lower than the national level; there are no hydrojunction projects with basin regulating and controlling capability in Pearl River, and there exists serious shortage of water with engineering character. So we shall quicken the pace of the comprehensive planning of water resources in the basin and the water supply planning of cities in Pearl River Delta, consider the safety of water supply in the basin, Pearl River Delta, Hongkong and Macau as a whole, and adjust the geographical distribution of urban water supply. The Dateng Gorge Hydrojunction is being constructed and to ensure the safety of water supply in Pearl River Basin. It is be considered as a major task. Meanwhile, all the cities in Pearl River Delta shall set up more water gates, pumping stations, reservoirs, water treatment plants, etc, enlarge the emergency water supply capacity, carry out the dredging, enlarging, maintaining and inforcing of the existing works, enhance the capacity of transferring and storing fresh water, and increase the guarantee rate of engineering water supply. Strengthening the engineering construction, we shall emphasize the infrastructural construction, such as hydrology, etc. and increase their modernization level, for serving the water resources management of Pearl River better, especially water quantity dispatching, flood prevention, etc.<sup>[7]</sup>

Thirdly, the function of the management organizations in the basin shall be given full play and the unified management of water resources in the basin shall be strengthened, to realize the unified dispatching of the key reservoirs in the basin. The unified management of water resources means not only the combination of water basin management and administration regional management, but also the unified management of water resources in development, utilization, arrangement, prevention, treatment, etc. The unified management of water resources accords with the characteristic of water and adapts to the national condition. To study the unified management of water resources in Pearl River Basin well, we shall base on the existing engineering system of Pearl River, emphasize the unified management of water resources in the whole basin, and ease the effect of drought and pollution by the scientific dispatching, for ensuring the safe water supply of Pearl River Delta and increase the utilization rate of water resources. Some experts think the unified dispatching is the key of exerting the maximum comprehensive benefit of water resources after the engineering facilities are established. Especially since the reservoirs established in the trunk streams of Pearl River belong to different administrative regions, departments and owners, and the economic benefit of the enterprises and the whole benefit of the nation need to be coordinated and balanced, to realize the unified dispatching needs the powerful legal basis and the realizable dispatching means and capacity.

Fourthly, the fundamental research of water resources management and the establishment of the relevant policies and regulations shall be strengthened. We shall solve how to deal with the benefits of all parties openly, fairly and justly at the same time of carrying out the unified dispatching of water resources according to the law. I.e. water resources shall be dispatched unifiedly and the benefits shall be distributed reasonably, with overall consideration. At present, one is to do the fundamental research well, and the other is to establish the unified administrative law of water resources in accordance with the present situation of Pearl River Basin as soon as possible. There are some successful experiences and practices in north rivers, such as Huanghe River short of water. The fundamental work is weak in Pearl River Basin in this aspect, so the

fundamental research shall be implemented as soon as possible and the specific approaches of managing and dispatching water resources of Pearl River shall be studied and established, changed into laws and regulations as soon as possible. In the near future, the establishment of the dispatching and management procedure of the key reservoirs in Pearl River Basin shall be quickened to standardize the dispatching principle of the reservoirs in flood prevention and drought resistance, for bringing the key reservoirs into maximum play in basin flood prevention and water resources arrangement. The mechanism and rule of salty tide activity in Pearl River Delta shall be studied further and the prewarning system of salty tide prevention shall be established, to provide the technological support for resisting salty tide and ensuring water supply<sup>[8]</sup>.

#### 4. The Conclusion

In recent years, due to the successive low incoming water, the change of river channels, etc in Pearl River Basin, the salty tide upstream becomes more serious in Pearl River Delta. The safe drinking water is endangered in Pearl River Delta (esp. Macau, Zhuhai and Zhongshan), which produces a unfavorable effect on the social and economic development.

It is predicted that in the future tens of years the economy of Pearl River Basin, especially Pearl River Delta, will increase continually and stably, and the population, the industry and urbanization will also increase, so the demand of water resources will increase in quantity and quality, the stress of the economic development on the regional resources and environment will rise further: on the one hand, the demand of high-quality water resources will increase; on the other hand, the discharge amount of pollutants will increase. So, facing the future, we must make a good preparation, seek for the relevant ways actively, and establish the reliable guarantee system of water resources. Accelerating the social and economic development Only by the sustained utilization of water resources can support the sustained development of economic society.

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