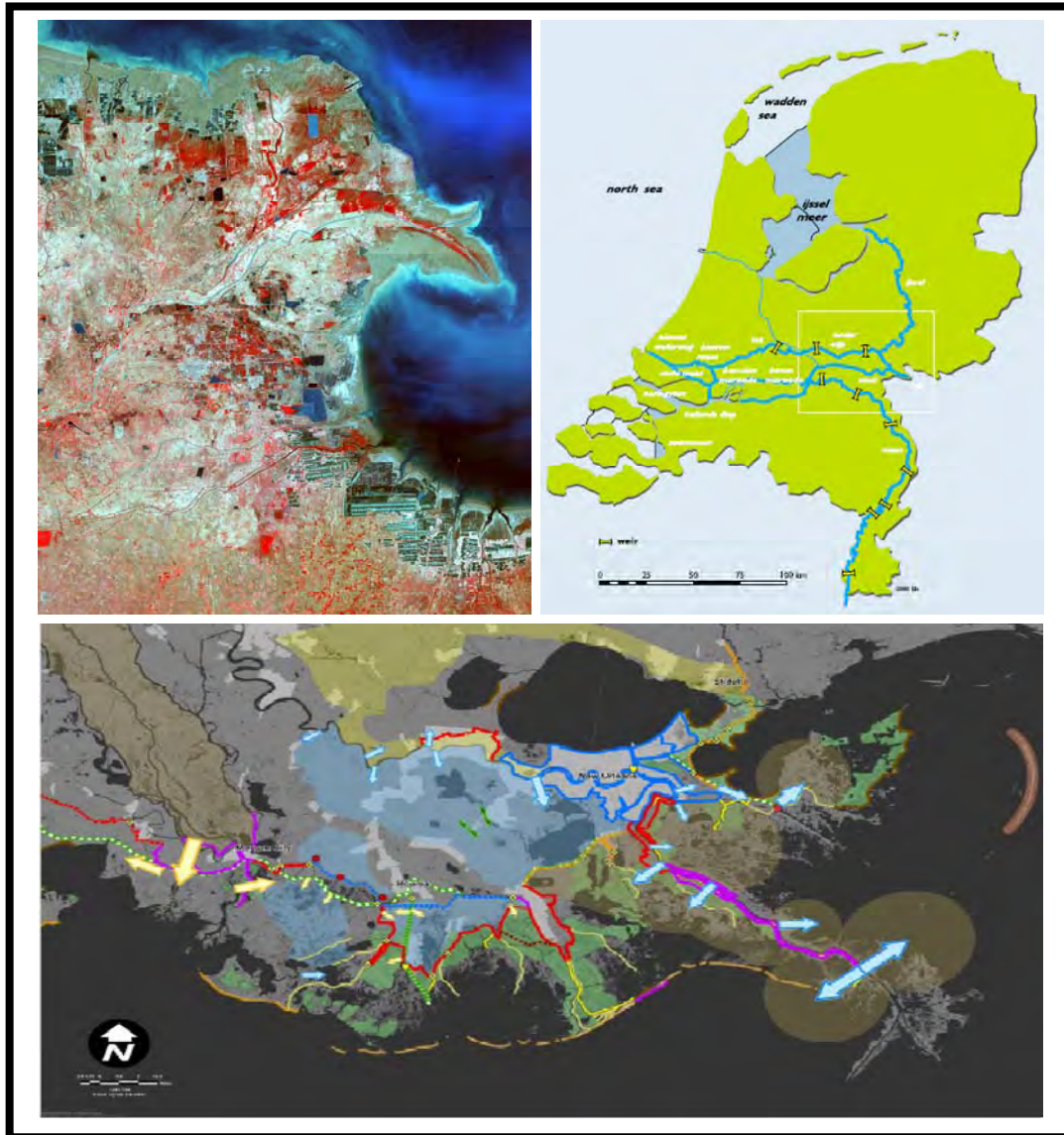


UNESCO-IHE
INSTITUTE FOR WATER EDUCATION



**Comparative Study of Flood Risk Management and
Land Use in the Deltas of Rhine River, Yellow River
and Mississippi River**

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Comparative Study of Flood Risk Management and Land Use in the Deltas of Rhine River, Yellow River and Mississippi River

Master of Science Thesis

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The findings, interpretations and conclusions expressed in this study do neither necessarily reflect the views of the UNESCO-IHE Institute for Water Education, nor of the individual members of the MSc committee, nor of their respective employers.

Abstract

The Rhine River in the Netherlands, the Yellow River in China and the Mississippi River in the U.S. are three great rivers in the world. Each of them is performing a significant role in the country. The delta area for each river, in particular, is served as the centre in importance and commonly the most developed region in the whole river basin. These three deltas are not excepted. All of them are the economic and cultural centre either in the district or in the whole country and all have a big harbour. However, because of the special location, near the sea and the river passing through, the delta area is always threatened both by river flood and the storm surge or hurricane. As a result, flood risk management is the main task for the local people and the government.

The objective of our study is focused on the flood risk management and land use in these three deltas, and a comparison is made on several aspects: physical, socio-economical, technical, organizational and institutional, legal and policy. First we would put forward the main problems on flood risk management existing in each region, then make an analysis for each problem, after that come up with possible solutions, at last a comparison between three deltas is discussed and recommendation is followed.

The whole report is composed by five parts, part A, B and C are separated for each delta. It includes the problems, analysis of the problems and possible solutions; part D and E are comparisons and recommendation respectively. The problems existing in each delta are similar in some extent or in a certain scope. The common problems are high flood from the river, storm surge (hurricane) from sea, land subsidence and land loss, coastal erosion, sea level rise, etc. In each delta area, there are common or special reasons for different problems and traditional or peculiar measures are carried out in problem addressing. These measures are very valuable for each other, and could be learned from their experience and lessons.

Keywords

River delta, flood risk, problems analysis, comparison, recommendation

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Introduction

1. Context of the study

1.1 Natural and social-economic changes in coastal area

- Coastal areas are increasingly playing an important role in maintaining the balance of the ecosystem and protecting the natural environment.
- Climate change, especially sea level rising and unpredictable extreme storm surges and hurricanes, make great impacts on the development of the coastal areas.
- Coastal areas, which are generally densely populated and relatively developed as well in most countries, usually play an important role in industry, transportation and recreation etc, thus it confronts more risks and threats due to flood problem as its increasing value in infrastructures and properties.

1.2 Needs for alternative options of regional development

As long as population growth, increases in standards of living, urbanization and industrialization in flood prone areas continues, flood management and flood protection provisions will increasingly be required. (Bart Schultz, 2006)

The development of the coastal area based on the climate change, flood protection, land use and water management is a global challenge. So, the search for effective measures to solve the problems between flood protection and regional development will be helped by more innovative approaches and solutions.

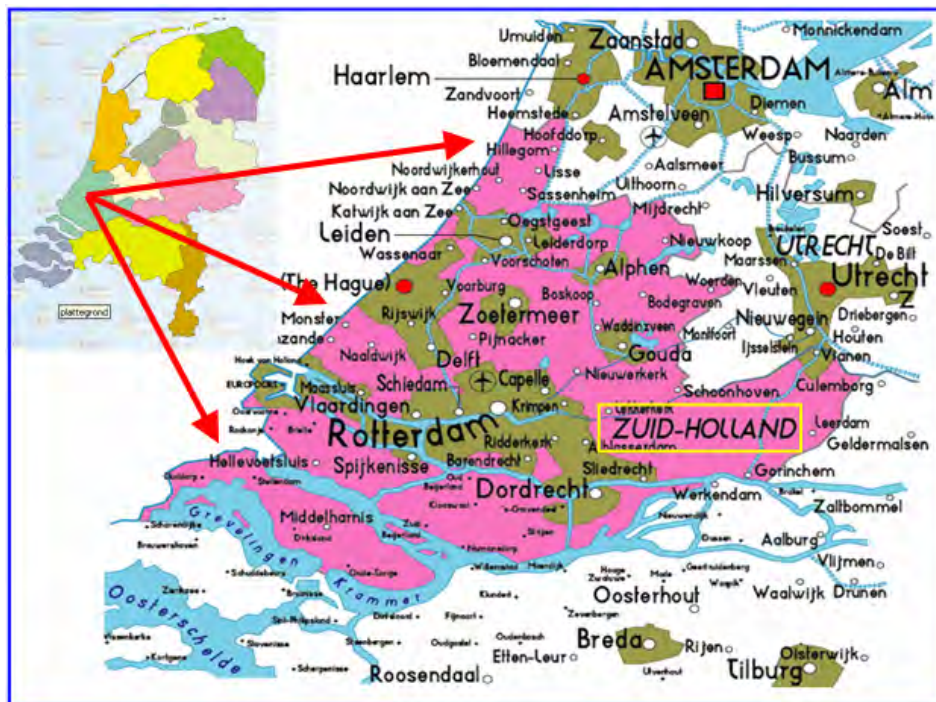
1.3 Interest of comparison of three regions in different countries

The delta areas of the three rivers (Rhine River, Mississippi River and Yellow River) face the same problems with other coastal zones, which have different natural, socio-economic features. The comparison of the practical or planning alternatives on how to solve the problems regarding flood management and land use will help us to find some optimal ways which could be used in the different coastal zones in the world.

2. The current practices and future perspective in three regions

2.1 Rhine River Delta

The Netherlands has been shaped by ages of level management and land reclamation. Climate changes and soil subsidence are threatening the country's existence. The water system is influenced by various claims on the available space and a changing use of this space. Dutch people have been forced to conclude that technological approach to water management has reached its limits. The drastic changes *from keeping the water out to accommodating the water* are mobilizing, developing, focusing, embedding and making applicable knowledge infrastructure to attune in a sustainable manner *living with water* with spatial developments in support of safety, welfare and the economy in the 21st century. (Rein van der Kluit, 2003)

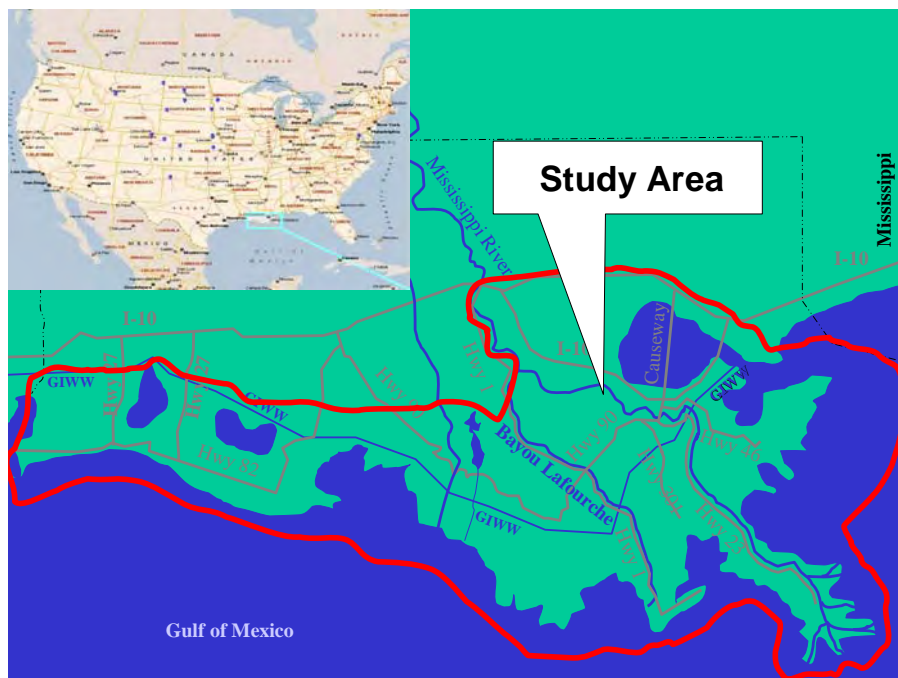


Study area – Zuid-Holland and Rhine River delta

2.2 Mississippi River Delta

Two specific cases of the entire flood control programme in the coastal zones of the lower Mississippi plain are the flood protection schemes of the urbanized area of New Orleans and the scheme to combat coastal erosion in the Mississippi delta. Over the past years there have been many and concerted efforts within the USA to balance structural solutions, as evidenced by activities stemming from the Association of State Flood Plain Managers and federal task forces. As technology continues to

improve and a clearer understanding is gained of environmental effects, so must the social-economic dimension related to floodplain occupancy be better understood? Now, broader and more intensive partnership are promoted and required, determining the success of any integrated management in the flood control related sector. It is obvious that no single sector can be expected to shoulder the management burden alone, and that far more integrative strategies need to be devised for each new project that is undertaken. No doubt, the events as caused by the hurricane Katrina in 2005 will accelerate further striking development (D. de Bruin, 2006). However, practically the process still is slow.



The study area in Mississippi delta

2.3 Yellow River Delta

The Yellow River Basin has been suffering severe water shortage from 1980s, due to the less rainfall and the dramatic growth of water use, even zero-flow occurs in the downstream in dry season. There is not so much flooding threat in Yellow River delta due to the large wetlands plain for flood release. The specific land use is oil field exploitation, which is well beneficial for regional development. The sediment transported by Yellow River produces more new lands where new oil wells could be built. Flood routes and ecological protection are the important issues. The planning of Yellow River Delta Development combines integrated measures and policies in terms of stability of flood route, regional development and ecological protection.



Yellow River Basin



Yellow River Delta

3. Set-up of the study

On the basis of the situation and problem above, several European countries around North Sea, in which Netherlands is included, have established a project named “Comcoast”, which is aimed on replacing the current flood-retaining line element with a flood-retaining zone, responsible for regional safety from flood and beneficial development. This scheme is based on the principle of reducing wave run-up. For USA, after experiencing the disaster caused by hurricane Katrina, they are facing the

reconstruction of New Orleans and planning the future water management merging into urban and rural planning with a sustainable environment people want to live in. In China, due to the water shortage and environmental deterioration, the Yellow River Commission have launched a long-term policy -“keep river healthy” and the composition planning for delta area.

Under this situation, we have more opportunities to exchange the ideas and cooperate with associates internationally, keep an open mind to look into the different factors which affect on the flood management and land use in the study areas in order to meet the expected objectives.

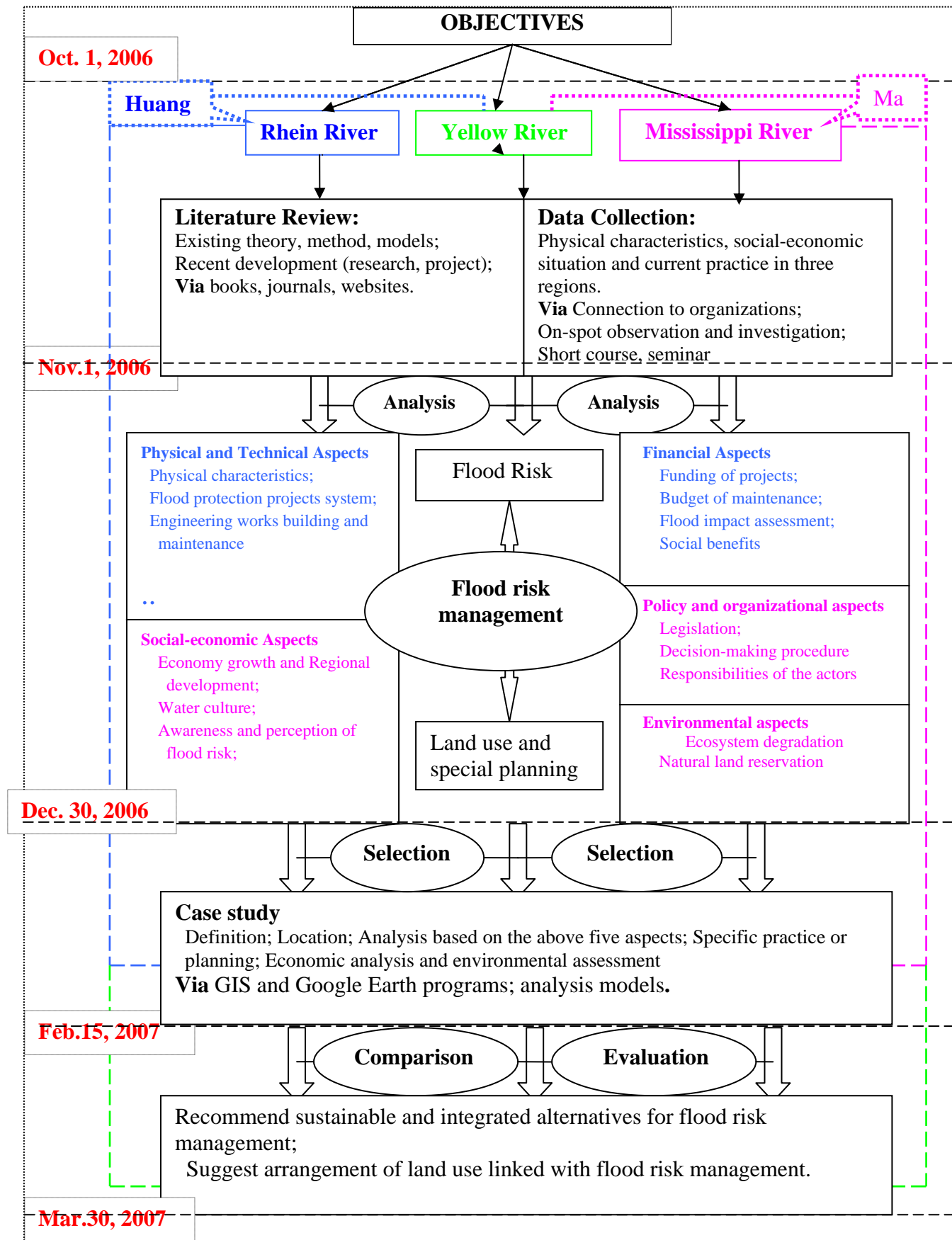
4. Objectives of the study

- Conclude the merits and bottlenecks in practical flood risk management in three deltas.
- Provide suggestions to wisely arrange land use and special planning linked with flood risk management.
- Provide recommendations to improve the present flood risk management
- Recommend the relevant alternatives to transitional approaches for future land use and flood risk management.

5. Methodology

- Data collection (literatures, websites, connection to related organizations, on-spot observation...)
- Data analysis
- Study criteria (flooding risk management, specific land use,)
- Comparisons of different aspects
- Recommendations for sustainable approaches

Research flow chart is shown below.



Part A: Yellow River Delta



1. Introduction

1.1 The Yellow River

The Yellow River, the second biggest river in China, rises from the Yueguzonglie Basin 4,500 m above sea level in the northern side of Bayankela Mountains, traverses nine provinces (one autonomous region), and flows into the Bohai Sea in Shandong Province. The River has a total mainstream length of 5,460 km, river basin area of 795,000 km², annual average runoff of 58 billion m³, annual sediment discharge of 1.6 billion tons and average sediment content of 35kg/m³. The upper reach of the Yellow River is from the headwater region to Hekouzhen in Inner Mongolia Autonomous Region. With a channel length of 3,472 km and a basin area of 428,000 km², the upper reaches mainly flows through the Qinghai Plateau and Inner Mongolia Autonomous Plateau. From Hekouzhen to Taohuayu in Zhengzhou City of Henan Province is the middle reach, which has a channel length of 1,206 km, a basin area of 344,000 km², and it mainly traverses the largest Loess Plateau in the world. The Loess Plateau is the major source area of flood and sediment of the Yellow River. From Taohuayu to the estuary is the lower reach with a channel length of 786 km, basin area of 23,000 km², and it flows through the alluvial plain of the Yellow River (Figure 1.1).



Figure 1.1 Yellow River Basins

Flooding and disaster are the main events all along the river's managing history. "Twice breaching in every three years" is the accurate illustration for the Yellow River before 1949. The downstream channel had changed its course repeatedly in the history, and there were 10 large-scale course changes according to the record. The river flown into the sea near Tianjin through a channel (the northernmost changing point) in 1048 and changed its course and seized the Huaihe channel (the southernmost changing point) in 1128, the changing scope covers more than 1000 km. Since 1855 the Yellow River has been flowing through the current channel (Figure 1.2).

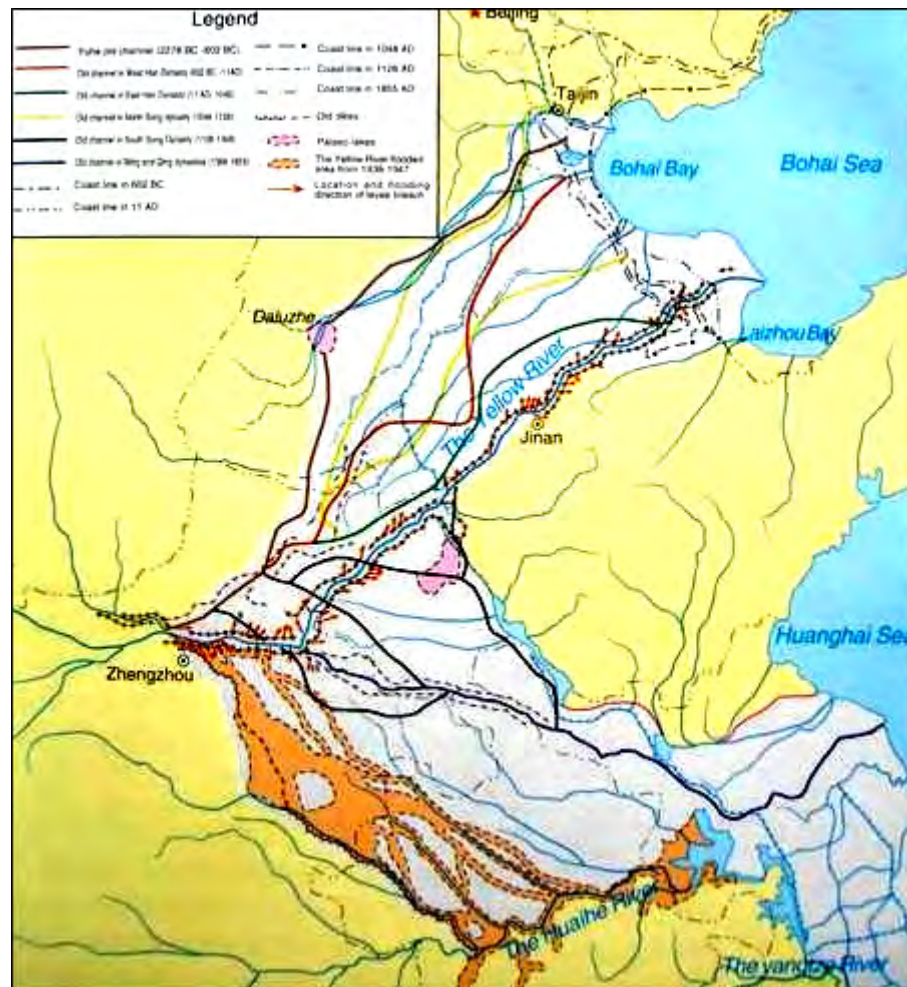


Figure 1.2 Course changes of Yellow River in history

1.2 Yellow River Delta

The Yellow River Delta is normally referred as the 'fan-shape' area, in which Ninghai town is served as the changing axis, and covers an area of about 6000 km² from north - Taoer River mouth to south - Zhimai Ditch mouth (see Figure 2). This area

approximately includes all the meandering scope of each changing course after the river breaching from Tongwaxiang, seized the Daqing River (the current course) and flown into the Bohai Sea in 1855.

During a very long period after the river breaching and changing to the current course in 1855, there had been no embankments along the river and the river changed its course freely in deltaic area. The river discharges a large amount of sediment to the sea, and then the riverbed rises, the channel embouchure stretches and at last changes its course. The evolution of embouchure channel always follows this periodic return “silting, stretching, swaying and course change” and then the Delta formed gradually (Figure 1.3).



Figure 1.3 Yellow River Delta (2004)

Land forming is the main characteristics for the Yellow River Delta. The total average sedimentation flowing into the sea is about 0.8 billion tons per year and the average area of land forming is about 25 km² per year. The total area of the new land formed from 1855 to 1996 amounts to 2400 km² and the new land area formed from 1976 to 1999 are about 405km² (Figure 1.4).

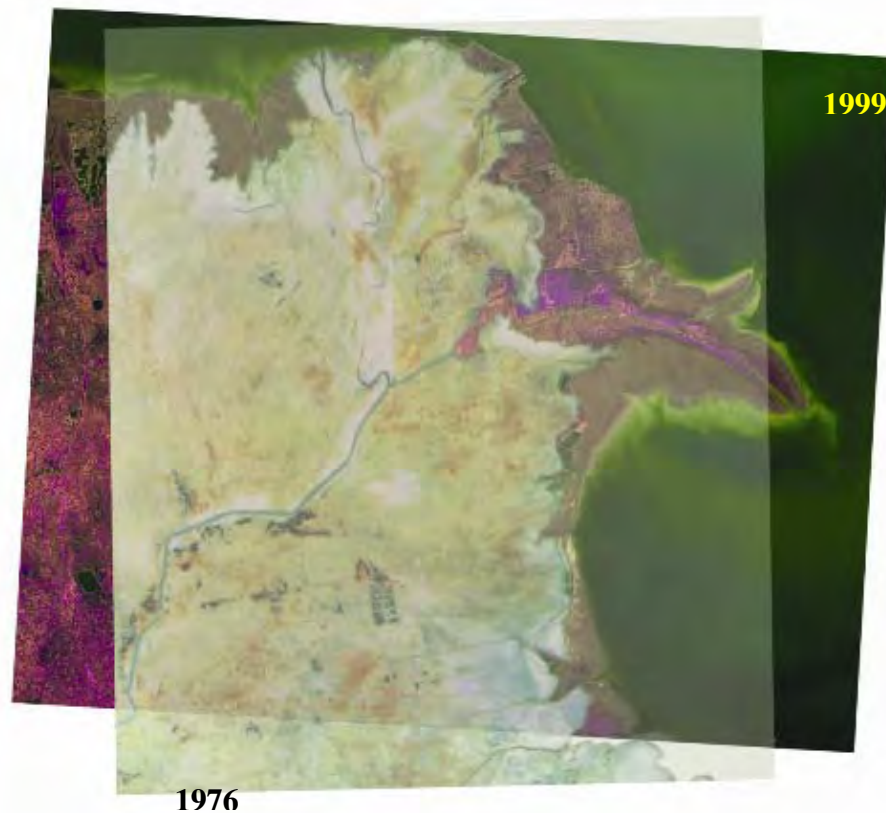


Figure 1.4 Overlapping Remote Sensing image of 1976/1999

1.3 Social-economic development in Delta

From 1949, the founding of the new China, the Yellow River Delta started its exploitation and development. Especially since 1961 when the second biggest oil field and energy base in China has been discovered in deltaic area. Subsequently a new oil city, Dongying was founded in delta in 1982, and now it has grown to be the economic center in the Yellow River Delta with a population of 240,000. Meanwhile the safety against flooding became the main problem with the requirement of regional development.

The estuary training is one of the important parts in the delta development. Great achievement in construction of infrastructure, hydraulic engineering works, river and sea dikes, and institutional, organizational development have secured the whole delta from flooding in the past decades. Whereas flood risk still exist and it reveals a rising trend with the increase of socioeconomic values and the climatic change, which could result in more extreme climatic events like flood in river and storm surge from sea. In our thesis

four main problems will be elaborated and analysed and possible solutions will be discussed as well.

2. Main problems on flood risk management

2.1 Relatively instability of the river course

The relatively instability of the river course is the primary problem in flood management in the Yellow River Delta. The river has changed its course in a large scale 10 times in the deltaic area from 1855 till now, from which three times are artificial changes in 1953, 1964 and 1976 respectively, in order to avoid flooding and property damages (Figure 2.1). The current course has been running for 30 years, the natural evolution process is still being followed, “silting, stretching, swaying and course change”, although the speed of channel silting and stretching have been dramatically slowed down due to the change of natural water-silt condition and intervention of artificial water-silt regulation. However, how long it could be maintained still uncertain. Therefore, how to extend the present condition in time as long as possible and secure from flooding is the main task and major problem, which will be confronted for a long period in the Yellow River Delta.

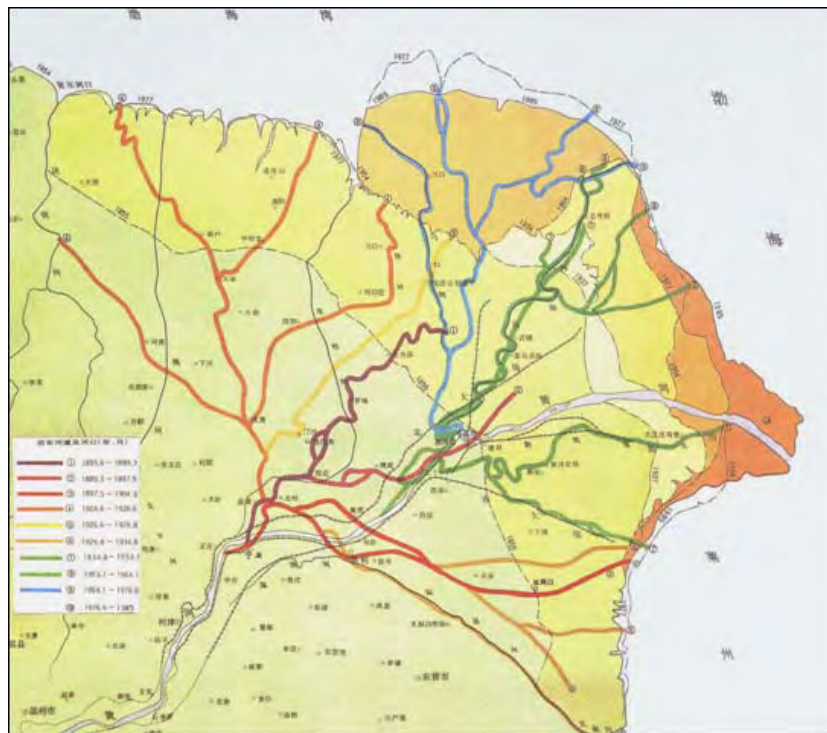


Figure 2.1 Course changes of Yellow River in history in delta area

The expected running life time of the current course has been investigated for a long time by several institutions, and the result varied from about 50 to 80 years (from 2000). The main reasons for this great difference are: a) different schemes of course management, such as artificial bifurcation in the end reaches b) some fundamental conditions are still uncertain, such as the natural changing of water-silt condition, the effects of reservoir construction (Xianglangdi Reservoir) in upper and middle reaches, and the relationship between riverbed rising and estuary stretching and its feedback impacts. The fact is that the sedimentation will continue, the current course is still relatively unstable, but comparing with the average running life time 13.4 years for each course, the current course can be kept relatively longer time (at least 50 years) as a result of river training, channel dredging, artificial bifurcation in end reaches and water-silt regulation, etc.

2.2 Continuous sedimentation and imperfect flood defense works

Continuous sedimentation of the river channel and then the rising of the riverbed is the primary threat of flooding in the delta area. The design discharge of the channel in the delta is $10,000 \text{ m}^3/\text{s}$ and the control condition for the current course is the water level in Xihekou (control cross-section in delta) should not exceed 12 m under the design discharge, otherwise safety can not be guaranteed and artificial course changing should be taken. The construction of the flood defence works in 1980 increased the river's discharge capacity, improved the river regime and stabilized the river course, thus to some extent increased the scouring of the river channel and slowed down the rising of the riverbed.

Whereas all these measures have not solved the problem completely, and the current situation is that with the continuous sedimentation of the riverbed and stretching of the channel the water level is rising with the same discharge; flood releasing capacity in the river channel has decreased from $5000 \text{ m}^3/\text{s}$ to $3000 \text{ m}^3/\text{s}$ from 1980 to now. It indicates the evolution trend that the discharge capacity of the channel is decreasing and the water level for the same discharge is rising. As a result, the flood risk is becoming high and the exploitation of the oil field and development of the local region are confronting more flooding threat.

The current standard of flood defence works is still very low and some reaches of the dikes cannot guarantee safety for the design discharge ($10,000 \text{ m}^3/\text{s}$). The current defence works are constructed from 1986 after the river changed its course in 1976 and most of them were used for water diversion at that time. Therefore the layout, scale and standard cannot reach the flood protection requirements; the river flow cannot get effective

control and improvement. There are 26.8 km of river dikes, 35% of the total length in the deltaic area, still didn't reach the design standard in height; some sections have high risk of seepage; the crest width of the total left bank (49.7km) are not satisfactory for the standard of class I (10m).

2.3 Storm surge hazard and disintegrated defense system

Storm surge is one of the main natural disasters in Bohai Bay, especially in the area near the estuary, because of its special topography (shallow sea area). According to the record of the last two hundred years, 7 huge storm surges happened in 1845, 1890, 1938, 1964, 1969, 1992 and 1997 respectively and the average tide height was more than 3 m. The biggest storm surge happened in 1969, the tide level was up to 3.75 m above mean sea level, invaded into the hinterland up to 40-50 km along the river, but the one happened in 1997, tide level 3.26 m, caused the biggest economic damage (2.6 billion Chinese Yuan) and casualties (1633 people) in the history.

The total length of tide defence along the coast amounts to 203 km. The first stage of the tide defence construction was started in 1960 and finished in 1987 by the Oil Company due to the purpose of protecting the oil field from storm surge hazard. The majority of the dikes have reached the standard of withstanding storm surge with probability of once per 50 years. The second construction stage was started in 1999 by the local government in order to protect Dongying city and the infrastructures with the design standard of withstanding the storm surge probability of once per 50 years. But the dikes constructed in different periods by different institutions and for different purposes have not formed an integrated tide prevention system with a uniform design standard.

Furthermore, with the seaward development of the oil exploitation, land reclamation, city growing and industrialization in the last decades, the flood risk and flooding damage by storm surge increase dramatically. Especially with the coast erosion, strokes by storm tide, lack of maintenance, subsidence of dike foundation, the quality of the dikes and protection standard have decreased and even some parts have totally lost defence function.

Besides of the defence work itself, the management for the storm surge prevention system also needs coordination. The current situation is that the Oil Company maintains the dikes constructed by themselves and the local water-management department is in charge of the remaining dikes. Because of lack of financial resources, equipments, forecasting and early warning systems, the management and maintenance of the dikes,

hydraulic works, and reducing the flood risk are very hard tasks for the local departments.

2.4 Land loss

Land loss is another characteristic accompanied with land forming in the Yellow River Delta. It has not got sufficient attention before 1990 comparing with the evident delta growing in size, but actually land loss has never slow down its pace and almost keep a constant scale in each year. From 1996 the net land loss is 7.6 km^2 per year for average in the whole delta, because of decrease of water and silt due to natural change in water-silt condition, affection of human activities and construction of Xiaolangdi Reservoir. The total land loss has been more than 100 km^2 since 1972 and the main area is near the old course mouth (Figure 2.2).

Land loss causes great impacts on oil extraction and sea dike maintenance. Many oil well platforms, pipes, roads and some other facilities along the beach are submerged or eroded. The oil company has to invest a large amount, about 50 million Yuan each year, to repair, rebuild and maintain those facilities. The sea dikes start to subside and become unstable due to the wave scouring to the dike foundation. The scouring is up to 4.5 m deep in some spots. It causes high risk of dike collapse or breaching and brings high cost in dike maintenance.

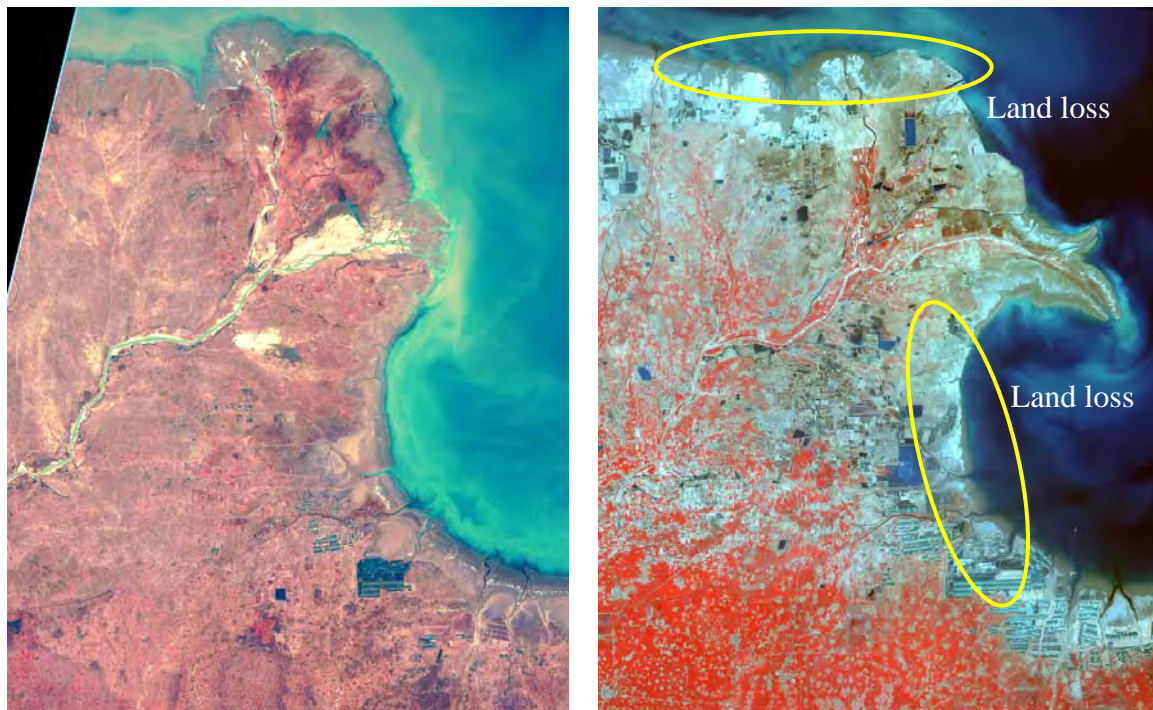


Figure 2.2 Land loss: Remote Sensing images of Delta in 1976 and 2000

Another aspect for 'land loss' is land salinization, although it has not any land loss in size but the land loses its function and become useless. The consequence or impact is almost comparable with the land loss in size. The current situation is that 30% of the total area in the delta has lost or partially lost its function because of soil salinization..

2.5 Competition between different interests in terms of land use and management

In the delta area, the majority of land are used for the river channel and flood passage, infrastructures of gas and oil extraction, nature reserves (wetlands, marshes), fishery and farming, and habitations (towns and villages), which are managed and maintained by different authorities such as the Estuary Bureau of Yellow River Commission, Shengli Oil Company, and the regional government.

- **Land for river and floods.** The Yellow River Commission needs a wide channel for flood diversion and for building river training works for river regime improvement. The most important is preserving the flood passage for changing the river course in the future.
- **Land for nature.** The wetlands and nature reserves in the Delta are very important for immigrating birds' flight passages and the habitation of rare birds and animals. However the natural area is shrinking rapidly due to climate change and human activity. Measures should be taken to maintain and restore the nature area.
- **Land for gas and oil exploitation.** China is facing a tense situation for energy due to its rapid economic development. Shengli Petrol Company is trying its best to extend gas and oil exploitation wherever, inland or near shallow sea for its maximum benefits.
- **Land for regional development.** Since the municipality of Dongying City was established in 1982, the delta area has achieved great development. Along with the progress of civilization and urbanization, more and more land has been reclaimed for agriculture, pasture, infrastructure and buildings. The projects of saline land improvement and enhancement of Dongying Harbor are under planning.

Usually, these different organizations just focus on their own developments according to their visions and policy without considering other organizations and overall development in the delta area, which leads to a conflict of different interests and sets up obstacles for future perspectives.

- **The uniform vision and target are not very clear** for the whole delta area development. There are no profound, integrated, systematic studies concerning the relationship and internal mechanism of estuary training, the Lower Yellow River flood protection, ecology protection and regional development, although some authorities have launched a lot of research and planning to address certain problems.
- **Confusion of investment and management.** The mouth training and flood protection works are built and managed by several parties such as the Mouth Bureau of YRCC, Shengli Oil Company and regional government on the basis of different policies, criteria and interests. Occasionally, the facilities built by one party might cause other parties difficulties. There are many problems in the operation and maintenance of facilities.
- **The managerial effectiveness and financial efficiency are reduced** due to lack of communication and cooperation, which affects the investors' confidence for the development of delta area.

3. Analysis of the problems

3.1 The characteristics of water and sediment

The Yellow River is well-known all around the world as sediment-laden river. The annual averaged delivery of sediment through Sanmenxia calculates approximately 1.6 billion t with averaged sediment content 35 kg /m³, however, the total volume of annual runoff is merely 58 billion m³ within the whole basin.

The water and sediment of the Yellow River is mainly characterized by

- **Less water and more sediment.**
- **Water and sediment come from different sources.** The water of the Yellow River mainly yields from the Upper Yellow River and the sediment mainly from the Middle Yellow River (Figure 3.1).
- **Great changes between water and sediment and uneven distribution in a year.** For example, the observed maximum flow at Sanmenxia is 65.9 billion m³ (1937), and the minimum is 20.2 billion m³ (1928), which differs 3.2 times in that; however, the annual maximum delivery of sediment is 3.91 billion t (1933) and the minimum is 488 million t (1928), which differs 8 times in that. Moreover, the water and sediment annual distribution is uneven as well, mostly concentrated in the flood season or even in a few flood events.

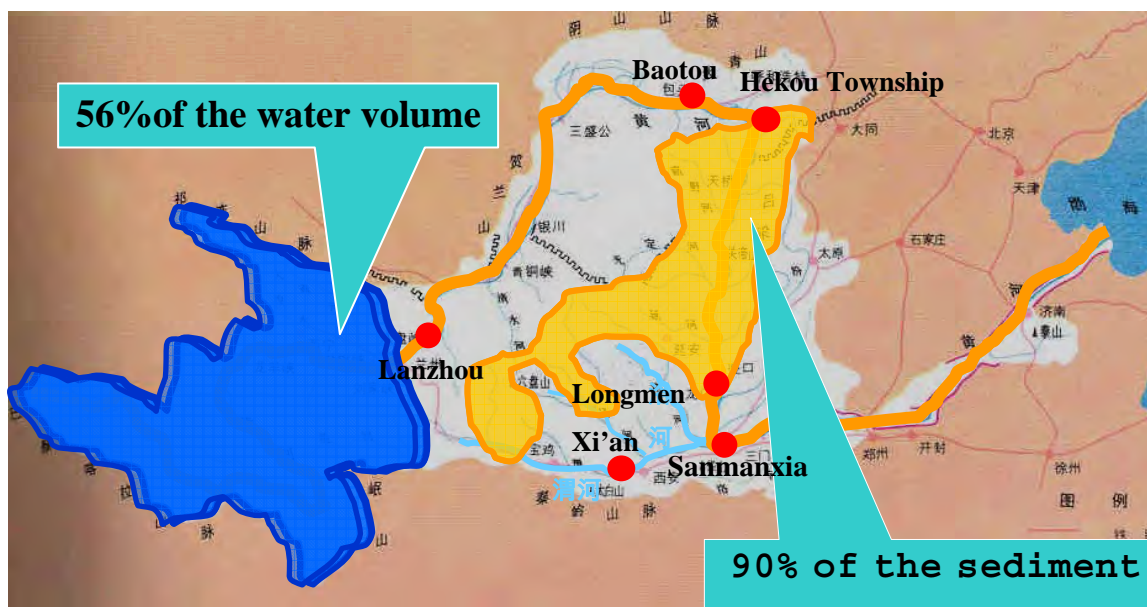


Figure 3.1 Different water and sediment origins
of the Yellow River

Water and sediment relationship in delta area follows the same trend with the upstream. From the statistics in a long run, the average water and sediment delivered to Yellow River Delta is 32 billion m^3 and 0.8 billion t respectively. The sediment content is 25 kg/m^3 . The annual water volume is 3.4% of that in Yangtze River delta, but the sediment volume is 1.66 times bigger. The water volume is 5.7% of that in Mississippi River delta; however the sediment volume is 2.33 times higher (Table 3.1).

Table 3.1 The comparison of water and sediment inflow to the delta
of the great rivers in the world

River	Total water/yr (billion m^3)	Aver. Discharge (m^3/s)	Total silt/yr (billion ton)	Sediment content (kg/m^3)
Mississippi	564	17820	0.34	0.6
Yangtze	948	30060	0.48	0.5
Nile	90	2830	0.12	1.4
Ganges	371	11750	1.60	4.3
Yellow river	32	1015	0.80	25.0

3.2 The sedimentation in the Lower Yellow River and the delta area

3.2.1 “Hanging River”

According to the analysis based on the observed data, the sedimentation in the lower reaches had amounted to 9.2 billion tons from 1950~1998. The riverbed has generally risen by 2~4 meters since the 1950s. The river channel in Lower Yellow River is known as “Hanging River”, because the riverbed is generally 4~6 m higher, at some places even over 10 meters higher, than the land surface. For instance, the riverbed is 20 meters higher than the land surface in Xinxiang city and 13 meters higher in Kaifeng city.

In the recent two decades, due to the impact of natural factors and human activities, the extremely inharmonious water and sediment relationship has caused increasing sedimentation in the main channel (accounting for over 80% of total sedimentation(Figure 3.2), which has furthermore resulted in 3~5 m high “hanging channel in the hanging river” , called as “Secondary Hanging River” . It shows a situation of “channel is higher than beach, and beach is higher than the land surface” (Figure 3.3). At present, all the downstream channel of the Yellow River has become “Secondary Hanging River”, and river reach posing serious danger has reached 300 km. In these river reaches, the channel transverse gradient is bigger than the longitudinal gradient. Since the main channel has taken the shape of a “shallow dish”, it could hardly withstand even a medium and small flood. In August 1996, the water level at Huayuankou station with flood peak discharge $7600 \text{ m}^3/\text{s}$ was even 0.91 meters higher than in 1958 when the flood peak discharge was $22,300 \text{ m}^3/\text{s}$.

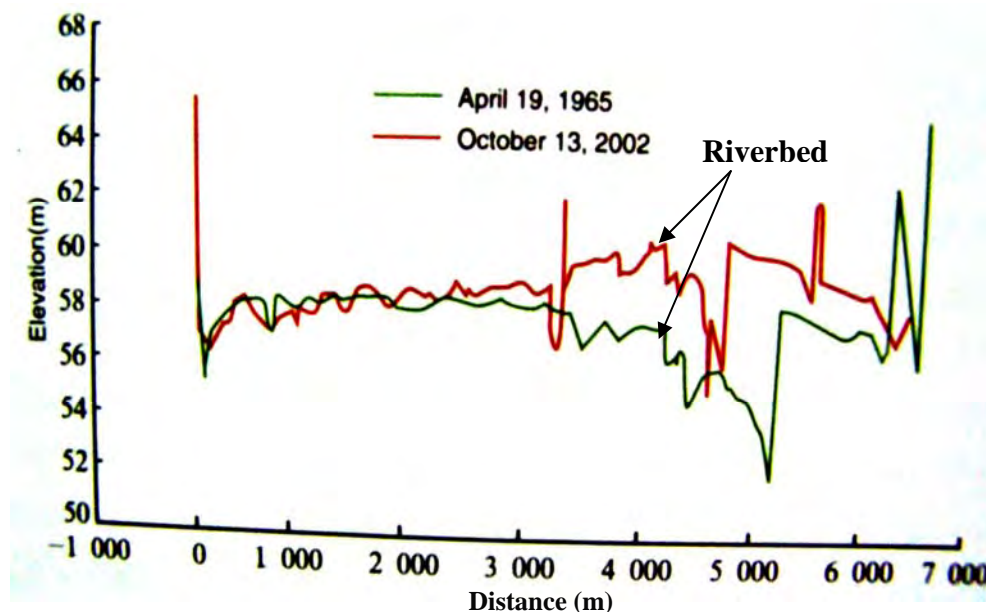


Figure 3.2 The sedimentation in the river channel of the lower Yellow River

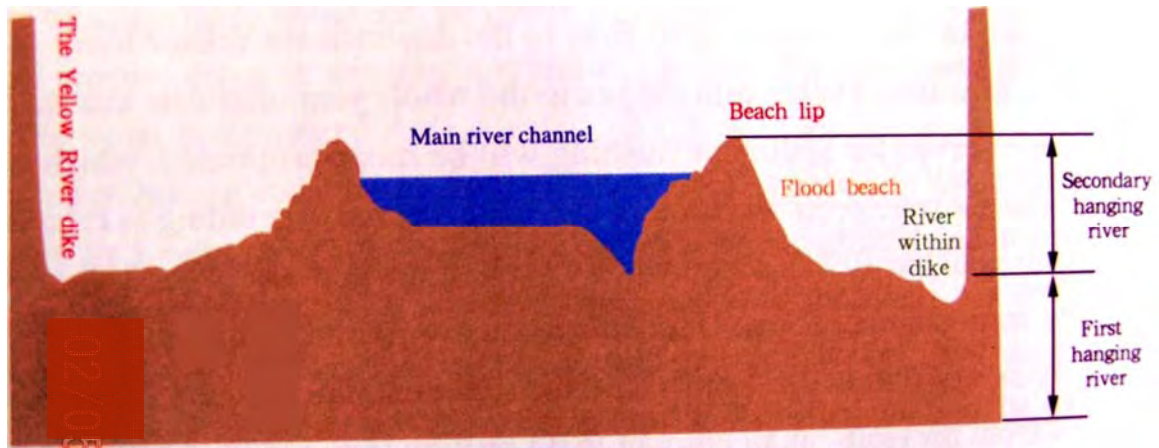


Figure 3.3 The sketch of “Secondary Hanging River”

In Yellow River Delta, due to frequent river course changing, the situation of “Hanging River” is not as severe as that in lower reaches. In general, the flood plain is higher than the surrounded land surface, but the river bed of the main channel is at the same level or a little bit lower than the land surface.

3.2.2 Interaction between the lower reaches and estuarial area in sedimentation and scouring

In estuarial area, the ocean dynamics is pretty weak with a tidal range of about 1 m in general and the area belongs to terrigenous estuary with weak tide, sand-laden flow and frequent swinging. Among the 1.6 billion tons of normal annual sediment flowing into the lower reaches of the Yellow River, 400 million tons is deposited into the downstream riverbeds, and the rest 1.2 billion tons in the estuarial area. And of 1.2 billion tons, 400 million tons is transported to deep-sea area, 800 million tons is silted up in littoral area below Lijin resulting in aggradations land and further extension of the estuary. Along with the extension of estuary and channel reach, backward sedimentation occurs in the upper stream channel, which causes the rising of flood level compared with the same water volume. When the flood level is higher than the ground elevation of the river lips, the ocean inlet flow path will swing, which furthermore will cause river course changing. During the initial stage after river course changing, the channel length is shortened, which will result in backward scouring, thus reducing the flood level in upper stream. We can create backward scouring by artificial intervention of the flow path to increase the sediment discharge capacity of the lower reaches (man-made river course changing).

No matter whether it is the sedimentation of the riverbed in the lower reaches or scouring, it will in turn affect the characteristics of evolution of the embouchure channel at the estuary by water and sediment inflow.

Therefore, the estuary harnessing is an important key link to the sedimentation in the lower reaches of Yellow River, though it is still controversial issue about how much sedimentation in the lower reaches due to the estuary situation and what is the mechanism. Estuary harnessing can not considered simply as estuary stands, but whole river basin view

3.3 Decrease of water and silt inflow to delta in recent years

3.3.1 Water and silt inflow

Since the 1980s, the water and sediment inflow from upstream have gradually decreased. The table 3-2 shows that, the annual water volume in 2000-2005 only is 24.8% of that in 1950s; the annual sediment volume is 11.7% as well. The sediment content keep stable, no significant trend before 2000. The sediment content greatly reduced from about 25 kg/m³ to 13.5 kg/m³ in 2000-2005 because Xiaolangdi reservoir started sediment retention since 2000.

Table 3.2 Water and sediment inflow in the Yellow River Delta in the years

Year	Annual water volume (billion m ³)	Annual sediment volume (billion t)	Sediment content (kg/m ³)
1950-1959	46.36	1.32	28.4
1960-1969	51.29	1.10	21.5
1970-1979	30.42	0.89	29.2
1980-1989	29.07	0.65	22.2
1990-1999	13.15	0.38	28.9
2000-2005	11.48	0.16	13.5
1950-2005	32.00	0.80	25.0

3.3.2 The causing factors

The decrease of water and sediment inflow at the delta can not be decided by the estuary itself, but affected by the natural and activities in areas in the upper, middle and lower reaches of the river.

- **Less rainfall and annual runoff.**

The average annual natural runoff of the Yellow River basin is 58.0 billion m³ from 1919 to 1975. Since 1986 the basin's rainfall and annual runoff has decreased by 10%.

- **Increased water diversion.**

While in contrast of less runoff, the water consumption by the rapid economic development and social progress within the basin has increased from 12.2 billion m³ in the 1950s to 30.7 billion m³ in the late 1990s by nearly 3 times (including 10.6 billion m³ consumption outside of the basin) (Table3-3). The increased water diversion along the river bank mainly is used for irrigation, industry, drinking and ecology.

Table3.3 Annual water consumption of the Basin in different years

Year	1950s	1960s	1970s	1980s	1990s
Water consumption (billion m ³)	12.2	17.8	25	29.6	30.7

This dramatic growth in water consumption in the last 50 years has directly resulted in the occurrence of zero-flow in the lower reaches of the Yellow River in the dry season period. However, the water demand will continue to increase. It is estimated that by 2010 the total water consumption in the basin and neighbor area will reach 52.0 billion m³ while the maximum water supply is 42.0 billion in a moderately dry year. The water shortfall by then will be over 10.0 billion m³.

- **Water storage and sediment retention by Xiaolangdi Reservoir.**

Xiaolangdi water control project has a total storage capacity of 12.65 billion m³, of which the sediment retention capacity is 7.55 billion m³. In the initial operation period, the project adopts the operating mode of “gradually raising the limited water level of flood season, and reasonably retaining the sediment (retain the coarse and discharge the fine). It will take about 30 years to form a high beach and deep channel sedimentation state, to accomplish the task of sediment retention of 10 billion tons and sedimentation reduction of 7.6 billion tons in the downstream channel of the lower reaches which is

equivalent to non-sedimentation in the channel bed of the lower reaches for 20 years. From the operation in Sep., 1999 to Sep., 2005, the sediment of 1.82 billion m³ has been retained in the reservoir.

3.3.3 The adverse impact

- Net land loss. The less sediment delivery to sea slowed down the new land forming processing; furthermore the land forming is smaller than land erosion along the shoreline.
- Increasing sedimentation in the main river course. Except the positive effect of sediment retention by Xiaolangdi Reservoir, the small discharge and lack of moderate flood caused the severe sedimentation in the main river course which decreases the flood passage capacity in river channel and raise the flood level in the same flood volumes.
- The water shortage in the estuarial area.
- The deterioration of eco-system.

3.4 Regional development and land use changes

3.4.1 Regional social-economic development

Since the water and sediment from Yellow River fed the estuarial area to create new lands in 1855, it is long time that only few people swelled in delta area due to the frequent flood without protection works and river course changing. Since 1961 oil was discovered in deltaic area, the development of Yellow River Delta is initiated. Especially since Dongying municipality was founded in 1982, the economic development has been rapidly growing and civilization progress has been accelerating.

▪ Population growth and urbanization

The total population has reached 1.95 million in 2005 with the density 246 head/km². The natural growth rate of population is keeping about 6‰. Along with the urbanization progress, 1.08 million people live in Dongying city or towns, 55% of the total population. The cities and towns dramatically expanded.

▪ The gas and oil extraction and production industry

As the second biggest oil field and energy base in China, the geological storage of 1.727 billion t gas and oil has been discovered in 36 blocks of the storage area 1222.1 km². Since 1963, 11,445 oil wells have been operated which accumulated 0.565 billion tons

with 50,000 t/day. Wherever one goes in deltaic area, the oil wells could be seen. The distribution of gas and oil field can be seen in the Figure 3.4.



Figure 3.4 Distribution of the gas and oil fields in delta area

According to the national investigation for gas and oil, the total gas and oil resources are 4.06 billion t in Yellow River estuarial area. Still there is 57.5% of the total storage, about 2.33 billion t for future discovery and extraction, in which 1/3 storage located near shallow sea area. Estimated annual production of oil is 1.7 million in next 10 year, 1.5 million in next 20 years.

Additionally, other economic sectors like agriculture, forestry, livestock and fishery have made great progress.

- **Infrastructure development**

Gas and oil industry and urbanization are pushing the development of communication and transportation and construction of infrastructure. The motorway linking towns has covered 4895 km; the railway connects to Jinan, the capital of Shandong province; Dongyi harbour is growing fast linked with highway; Dongying airport had the first flight in 2001.

3.4.2 Land use changes

The total area in Yellow River Delta is about 8,140 km². With the regional development, land use patterns have greatly changed from 1950s to 1990s (Figure 3.5 and Table 3.4).

- The land utilization rate increased from 39.75% in 1956 to 61.24% in 2005. It will reach 85.82% in 2010 in accordance with the regional development plan. The farmland has been keeping above the 37% as the main pattern.
- The pattern of land use tends to multiform. Except the ratio of reclamation land decreased, other patterns are growing gradually, especially land use for habitation, industry and infrastructure increasing from 1% in 1956 to 7% in 1996.
- The water area has a significant degradation trend after increase from 1956 to 1984, which from 22.5% in 1984 to 15.3% in 1996.
- The disused land is increasing after rapid reduction because of considerable reclamation from 1956 to 1984, and the salt and saline land have been increasing gradually.
- The total area of wetland is 3,500 km² including natural wetland and man-made wetland like rice field. Fresh wetland has reduced 50% compared with that in 1950s, in which, the area as the national nature reserve is 1530 km².

The patterns' transformation of land use is not only driven by regional development and gas and oil extraction, but also water and sediment inflow and river course changes. Water and sediment feed the sea to create new land and fertilize the beach and surround area when flooding. The decrease of water and sediment inflow in recent years and river course stabilization since 1976 caused deterioration of eco-system such as wetland shrink and expansion of salt and saline land.

Table 3.4 The change of land use patterns in Yellow River Delta
within 40 years

pattern	1956		1984		1996	
	Area (km ²)	% of total	Area (km ²)	% of total	Area (km ²)	% of total
tidal area	1257.8	15.45	262.9	3.23	236.3	2.90
farmland	1992.1	24.48	3417.4	41.99	3025.1	37.17
fruit trees land	2.3	0.03	11.3	0.14	92.7	1.14
forest land	212.1	2.61	279.5	3.43	284.3	3.49
grassland	936.9	11.51	687.7	8.45	767.9	9.44
habitation and industry	87.6	1.08	284.4	3.49	465.5	5.72
infrastructure	3.9	0.05	4.0	0.05	145.8	1.79
water area	1661.3	20.41	1833.6	22.53	1244.4	15.29
disused	1384.4	17.01	251.0	3.08	468.9	5.76
salt and saline	599.9	7.37	1106.8	13.60	1407.7	17.30
total	8138.5	100	8138.5	100	8138.5	100
Utilization rate (%)	39.75		57.56		58.75	
Reclamation rate (%)	24.51		42.13		38.31	

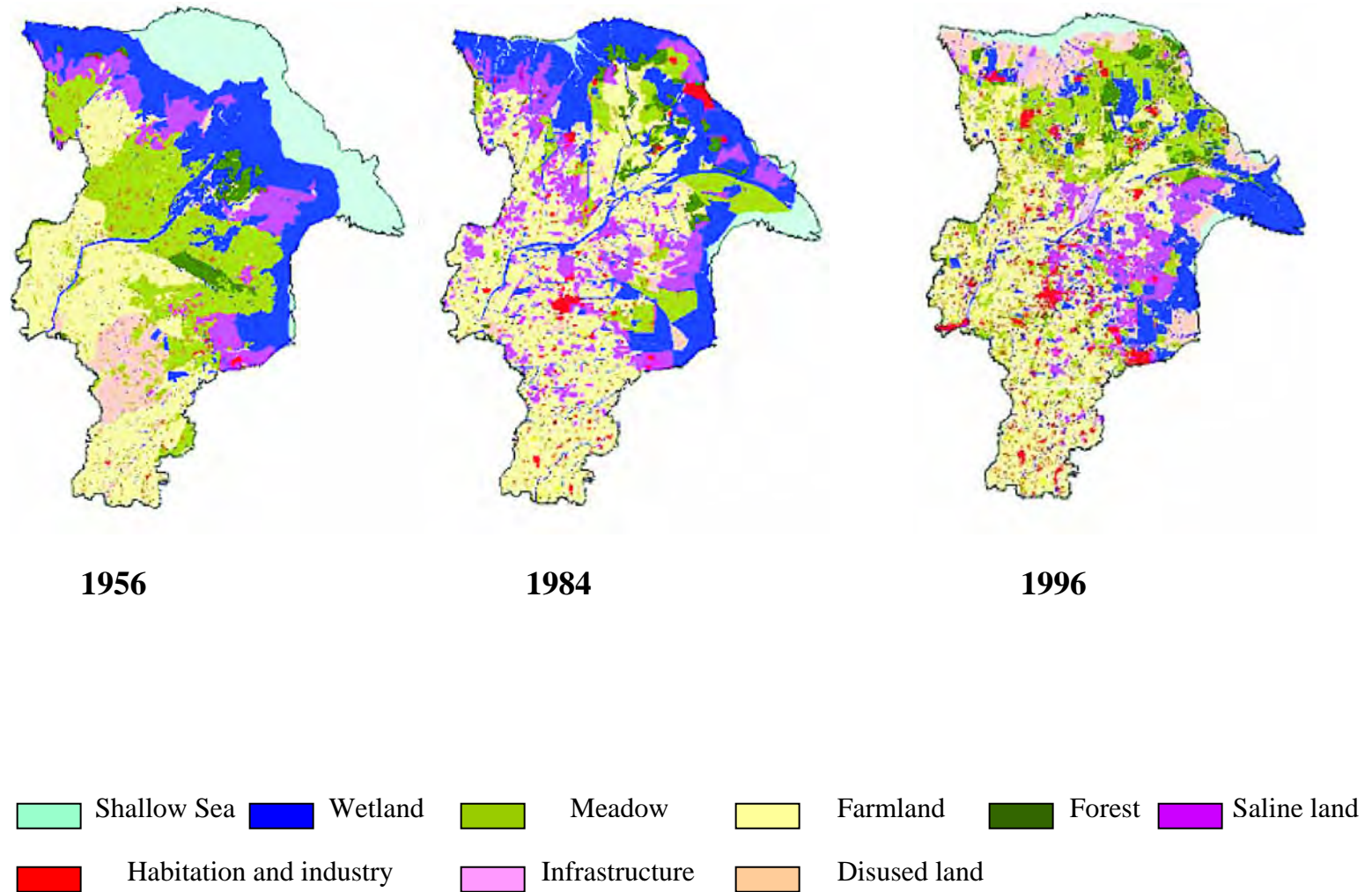


Figure 3-6 Land use change in Yellow River Delta from 1956 to 1996

3.5 Flood risk in the Lower Yellow River and the delta area

3.5.1 Flood categories

Flood threat of the delta mainly comes from the Middle Yellow River reaches, which can be divided into two categories of **ice and storm floods**.

Most ice flood occurs in February in the downstream sections. The river flows to northeast direction in Lankao of lower reaches to sea outfall, namely from lower latitude to higher latitude. When the ice flood flows to the lower reaches, it coincides with the season of peach blossom, so it is also called ‘Peach flood’. The damage of “ice flood “ is mainly reflected in breach of dykes due to elevated water table by ice jam or ice bar. In history, since it was not possible to control the flow rate and runoff plus it was freezing and cold usually when “ice flood” occurred it was extremely arduous to get earth by hands, so “ice flood” was difficult to control. There was a saying that “the river administrator is not guilty when breach is caused by ice flood”. The nearest ice flood breaches occurred in the delta area in 1951 and 1955.

The torrential rains in the Yellow River basin in July and August is frequent with high density, and major floods of the lower reaches occurred in July and August are habitually called “summer flood” while the floods occurred in September and October are called “autumn floods”. Since summer and autumn floods are very close, they are called “summer and autumn floods” in general. The recorded biggest discharge during summer flood was 22,300 m³/s at Huayuankou hydrological station in 1958 while the coincident discharge in delta area is 8,000 m³/s.

3.5.2 Origins of flood

The main flood problems in Yellow River Delta are caused by summer and autumn flood which are mainly originated from three regions in the middle reaches: Hekoucun-Longmen section, Longmen-Sanmenxia section and Sanmenxia-Huayuankou section (Figure 3.6), which form heavy or extremely heavy floods in lower Yellow River by combinations.



Figure 3-7 Three source regions in the floods of the lower Yellow River

3.5.3 Possible inundated area

At present the total flood control protected area on the Lower Yellow River is about 120,000 km², covering the five provinces of Henan, Shandong, Anhui, Jiangsu and Hebei, with over 90 million people living in the area, which include arable land 75, 000 km² as the important national crop production base and petrol, chemical and coal industries. (Figure3.7)

In the past, the flood problem in delta is not significantly caused by extreme flood, but by course changing because of scarce inhabitation near the river channel. With the regional development and gas and oil extraction in recent years, **the flood threat is caused by both river course changing and extreme flood.**

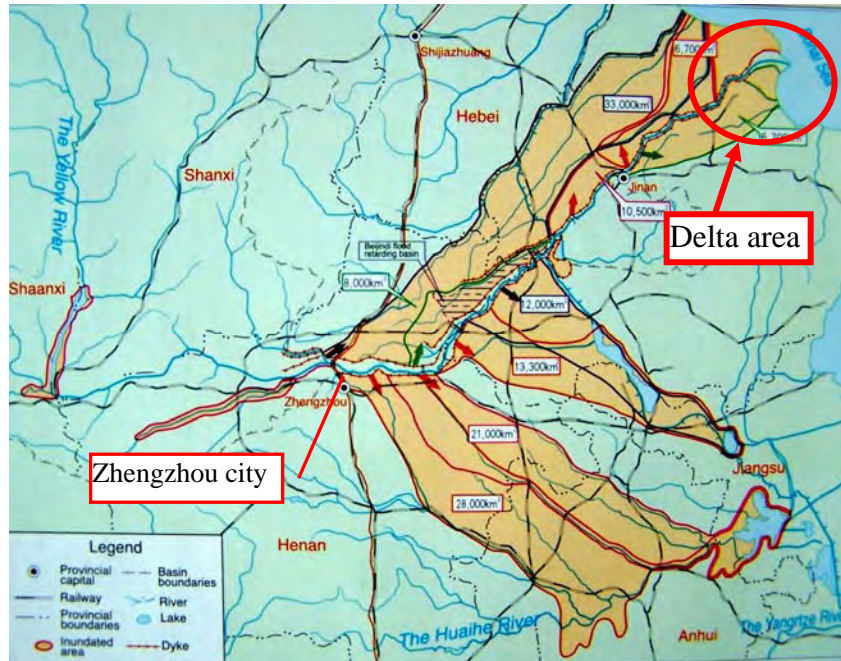


Figure 3.7 Flood protected area in the Lower Yellow River

The flood threat in delta is not very serious compared with the lower Yellow River because of the following reasons:

- The situation of “Hanging River” is not as serious as lower Yellow River because of river course changing in the years.
- The river channel is much wider than that of upstream, especially the Aisan section, which is the narrowest channel in the lower Yellow River. So, for the flood peak discharge in delta is determined by Aishan section.
- The flood peak discharge takes 5 days to run from Huayuankou in middle reach to delta, even more time if the floods occur after extreme drought. For instance, the flood spent 60 h from Huangyuankou to Sunkou (before delta) in 1958 but the duration was 111h in 1982. Therefore, there is enough time to do preparation for flood defense before the flood arrives.

3.6 Risk analysis of storm surge hazard

3.6.1 Origin of storm surge

Bohai Sea is surrounded by Liaodong and Shandong Peninsula and the water depth shallows from east to west. The water depth in the east part is more than 70m and the shallow water scope in the west part that less than 10m depths is up to 40km wide from

the coast. The whole Bohai Bay is a half closed super-shallow marine area, in which the area that water depth less than 20m amounts to 1/3 of the total. This special topography makes it easy to form intensive storm surge in Bohai Bay when the direction of strong wind coincides with the gradient direction of shallow water (Figure 3.8).

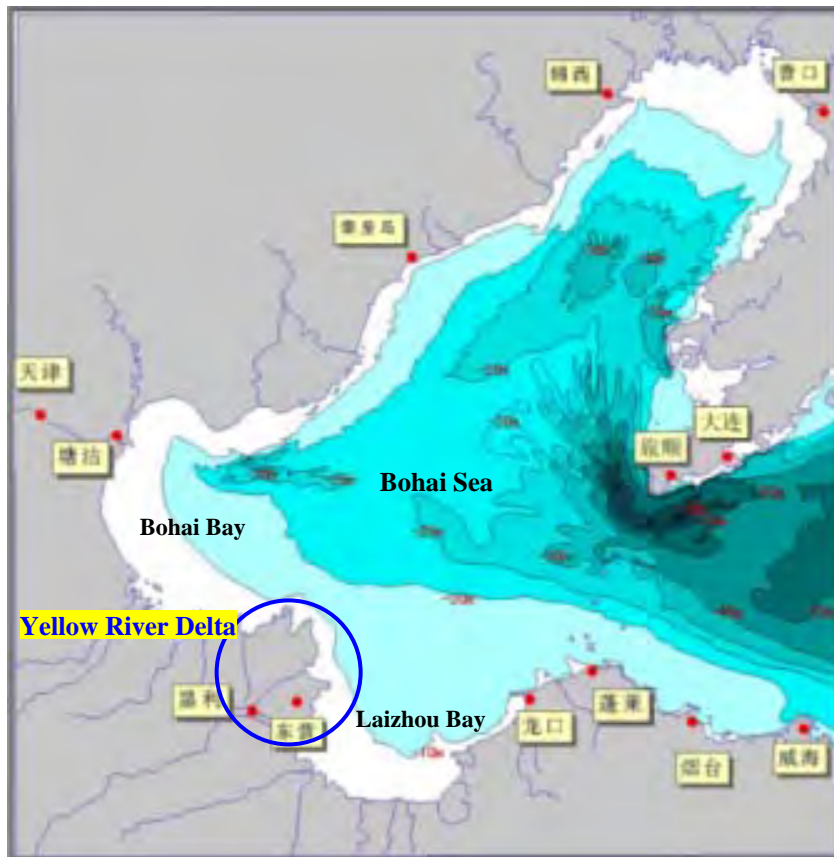


Figure 3.8 Bottom topography of Bohai Sea

Intensive temperature storm might form disastrous storm tide. Under this climate circumstance Bohai Bay is always controlled by continuous and strong east-north wind, and huge amounts of seawater are pushed into Bohai Bay from Huanghai Sea, the seawater level will cause obvious rising in Bohai Bay. If it is cooperated with the high astronomical tide, more than 2m high tide might be formed, even more than 3m. Most of the extra-large storm tides in Bohai Bay in history were occurred under this climate circumstance.

One of another reason that might cause larger or extra-large storm surge hazard in the Yellow River Delta is typhoon when it lands in the area near Bohai Bay. Although its frequency is not too high comparing with the intensive temperate storm tide, the strong wind, intensive rainfall, high wave and tide level, and its unpredictability always cause

great disaster. The storm surge hazards happened in 1960 and 1992 by typhoon caused 2.76 m and 3.59 m high tide respectively and caused great damage.

3.6.2 The characteristics of storm surge hazard

- Characteristic in regional distribution

The northern part of the Yellow River Delta is the main area affected by storm surge hazard. The intensity, scale, velocity and duration time of the storm surge happened in this area is always affected by the movement of regional astronomical tide, formation of regional coastline and topography of shallow sea bottom. Because of the Delta divides the west part of Bohai Sea into Bohai Bay and Laizhou Bay, the tide-level-difference is various in location. The smallest mean tide-level-difference is 0.9m near Dongying Harbor; the highest tide level is 2.6m after 1949, and then increases gradually in both sides along the coast. The point that has the biggest mean tide-level-difference is near Yangjiaogou about 1.4m; the highest tide level is 3.75m after 1949 (Figure 3.9).

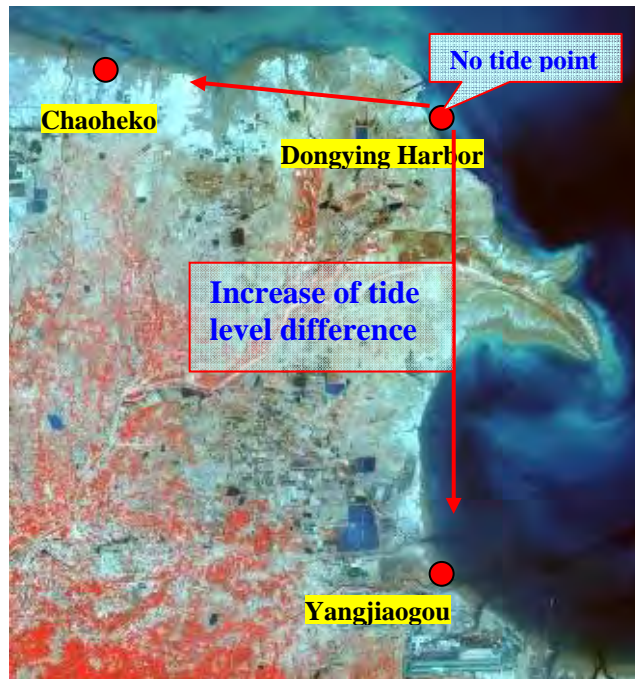


Figure 3.9 Increase of tide difference

- Characteristic in seasonal distribution

Most of storm surges happened in spring and autumn are affected by typhoon. In accordance with statistics, 671 times strong wind took place in the last 20 years, most of which are east-north direction and the mean duration time is about 1.2 day, the longest duration time is 4 days. Under the action of continuous and intensive east-north wind, a

large amount of seawater surge toward the west-south Coast of Bohai Sea and then cause serious storm surge near estuary area.

Probability of causing hazard (Figure 3.10)

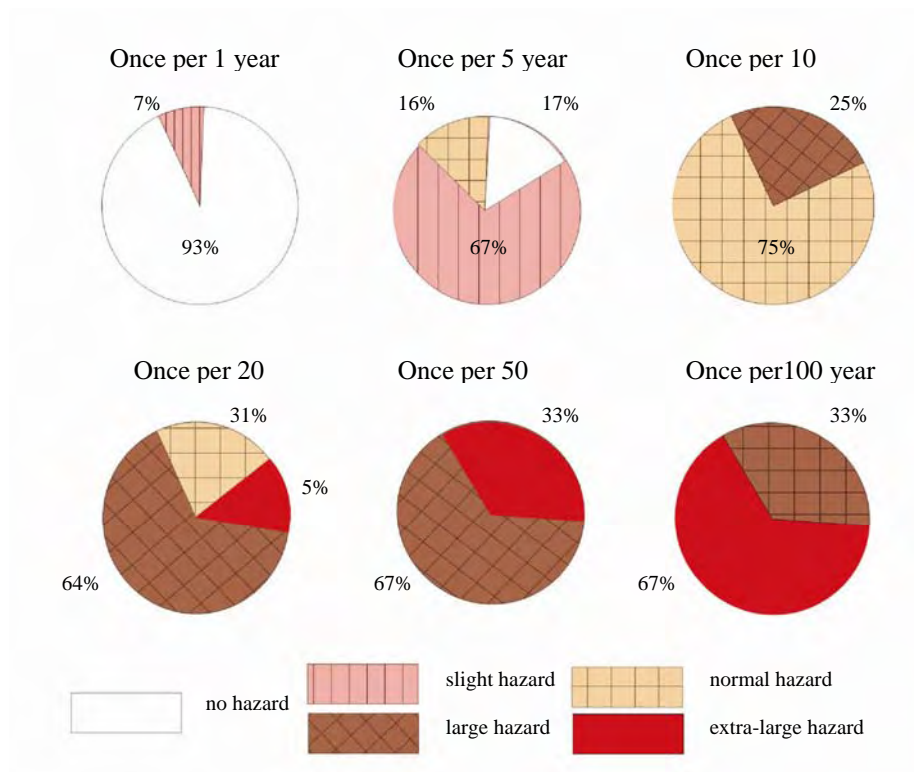


Figure 3-11 Probability of causing hazard for various storm tides

3.6.3 Storm surge frequency and hazard analysis

- Frequency analysis

The two processes of water quantity increase in Bohai Sea and tide level rise, which might cause storm tide, are resulted from different reasons and the overlapping tide level caused by these two respects are much various. Whether the storm surge can result in great damage or not, depends on if the water quantity increase and the tide rise can coincide. July to September is the high tide level period in estuary area, but storm surge normally happens in the beginning of spring and the end of autumn.

In accordance with the record of the high storm surge levels observed after 1949 and combining the analysis of larger and extra-large storm surge hazard after Ming Dynasty, a formulation is suggested to assess the tidal level that could result in disastrous storm tide.

$$Z_t = Z_{avg} - a_{loc} \cdot \ln \left(-b \ln \left(1 - \frac{1}{T} \right) \right)$$

In which: T (yr): reoccurrence period

Z_{avg} (m) :average multiyear high tide level

Z_t (m): high tide level corresponding to T

a_{loc} : parameter of location

$b = 2.6336$

Table 3.4 the tidal level along Dongying coast under various frequency

Point name	Z_{avg}	a_{loc}	P=0.002	P=0.01	P=0.02	P=0.05	P=0.1	P=0.2
Yangjiaogou	2.65	1.00	4.24	3.75	3.54	3.26	3.04	2.81
Shenxiangou	2.10	0.75	3.29	2.92	2.77	2.55	2.39	2.22
Chaohekou	2.45	0.91	3.90	3.46	3.46	3.00	2.81	2.60

- Hazard analysis

For the storm surge that tidal level over 1m and below 1.65m, could happen a dozen times in one year and most of which are below the mean high annual tidal level, therefore it doesn't cause storm surge hazard normally. For the storm surge that tidal level over 1.65m and below 2.65m could happen every year and the probability of causing hazard is very small (about 7%), the damage is also very slight. For the storm surge that tidal level over 2.65m and below 3m, could happen in every 3~5 years; under this tidal level plus the affection of wave, dike scouring or breaching could be happened and 67% of which could cause slight tidal hazard, 16% could cause normal tidal hazard (casualties). For the storm surge that the tidal level excess 3m and the reoccurrence period is more than 10 years, is the main disaster in the deltaic area and it always cause

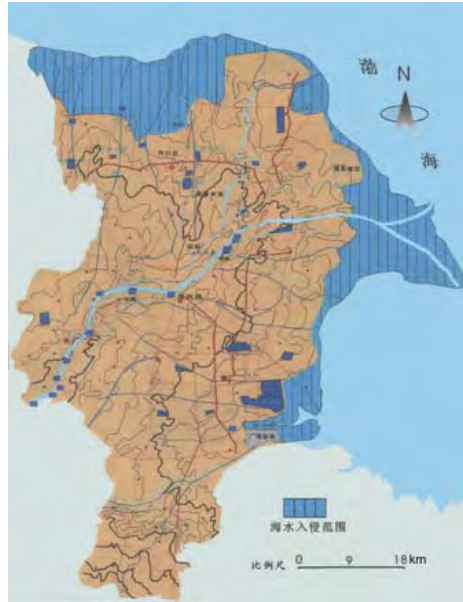
dike scouring and breaches. With the increase of the reoccurrence period the tidal level rises correspondingly and the degree of the storm surge hazard is great as well.

For the storm surge that the reoccurrence period less than 10 years normally have relatively less flooding area and small losses. The flooding area (about 1364 km²) is mainly the aquiculture field outside the dike and the tidal beach. For the extra-large storm surge that the reoccurrence period is more than 50 years, the damages are much great and the main losses are agriculture, aquiculture, oil wells and residential facilities. The city can be secured from this storm surge under the protection of the current defence works and the flooding area can be up to 2620 km² (Figure 3.11).

For the current defence works, the closed oil field can basically withstand the storm surge that reoccurred once per 100 years and the majority of the remained dikes can only resist once per 50 years storm surge and most of them have not formed into an integrated defence system. To guarantee the deltaic area secure from intensive storm tide, the current defence works need to be heightened to the requested level corresponding to the tidal level. The suggested dike crest height for resisting various frequency storm tides is in table 3.5.

Table 3.5 Suggested dike height with different frequency

Point name	P=0.002	P=0.01	P=0.02	P=0.05	P=0.1	P=0.2
Yangjiaogou	5.5	5.0	4.8	4.5	4.3	4.0
Shenxiangou	4.5	4.1	4.0	3.8	3.6	3.4
Chaohekou	5.1	4.7	4.5	4.2	4.0	3.8



Once per 10 years



Once per 20 years



Once per 50 years



Once per 100 years

Figure 3.11 Flooding area with different frequent storm surges

3.7 Flood control engineering system in the Lower Yellow River and Delta

3.7.1 Flood control engineering system

In Lower Yellow River, the river channel is wide in the upper sections and narrow in the lower sections. The widest channel is as much as 24 kilometers while the narrowest is only 275 meters. The flood transporting capacity is, therefore, bigger in the upper stream which is $22,000 \text{ m}^3/\text{s}$ and smaller in the lower sections where it is $11,000 \text{ m}^3/\text{s}$ in channel at Shandong. The channel regime roves and the trunk section swings frequently.

Through the long history of struggle against floods, the people along the river have got many experiences and measure to deal with flood. Especially since 1950s, Yellow River Conservancy Commission (YRCC) has been developing modern flood control engineering system to protect the lower Yellow River and Delta area from flooding. The principle thought is to control heavy and extremely heavy floods through “intercepting at the upstream and discharging at downstream while diverting and retaining on both banks”. Reservoirs have been constructed in upper and middle reaches and flood retention areas were opened up on both sides of the river channel in the lower reaches; the dikes of the lower reaches have been heightened and thickened for four times. The layout of the works is presented in Figure 3.12.

- Flood control reservoirs: Sanmenxia, Xiaolangdi, Luhun, Guxian. Sanmenxia and Xiaolangdi reservoirs are located on the mainstream and Luhun reservoir on the tributary of Yihe River and Guxian reservoir on the tributary of Luohe River as well. A joint regulation group of storage reservoirs are able to cut down dramatically the peak flows of floods with low recurrence probabilities in the lower Yellow River.
- Flood storage & detention projects: flood retention area at Dongpinghu Lake, flood retention area at Beijindi, flood extension area of Qihe River (to north), Kenli flood extension area (to south), Fengqiu flow backward area and Dagong flood diversion area.
- Engineering works along the river channel: dikes, river training works etc. The 1,371 km dike system in the lower reaches has been reinforced and heightened for four times, and at present they have met the requirement of water level protection set up in the year 2000.

Additionally, there are some division structures and sluices for water supply and irrigation.

3.7.2 The calculated flood discharge and design discharge

Through analysis and calculation of the flood at Huayuankou station and area without control (downstream of Xiaolangdi on the mainstream ,downstream of Lunhun and Guxian reservoirs on the tributaries and downstream of Huayuankou), the calculated values are presented in Table 3.7.

After joint operation of the existing flood control works, the flood peak rate once every 1,000 years entering the lower reaches is reduced from 42,300 m³/s to 22,600 m³/s (at Huayuankou station, the defense discharge rate is 22,000 m³/s)(Table 3.8).

Table 3.7 The designed floods at Huayuankou and areas without control works

Hydrological station or section	Catchment area (km ²)	Item	Frequency(%) and the designed value		
			0.01	0.1	1
Huayuankou	730036	flood peak flow rate (m ³ /s)	55000	42300	29200
		flood runoff of 5 days (billion m ³)	12.5	9.84	7.13
		flood runoff of 12 days (billion m ³)	20.1	16.4	12.5
Area without control works	27019	flood peak flow rate (m ³ /s)	27500	20100	12900
		flood runoff of 5 days (billion m ³)	5.51	4.02	2.55
		flood runoff of 12 days (billion m ³)	6.94	5.12	3.32

Table 3.8 Flood discharge rate and defense flow rate in the Lower Yellow River with the operation of flood control works

Hydrological station	Frequency(%) and flood flow rate(m ³ /s)				Defense flow rate (m ³ /s)
	3.3	1	0.1	0.01**	
Huayuankou	13100	15700	22600	27400	22000
Jiahetan	11500	15070	21000	26100	21500
Gaocun	11200	14400	20300	20000	20000
Sunkou	10400	13000	18100	17500	17500
Aishan	10000*	10000	10000	10000	11000
Luokou	10000	10000	10000	10000	11000
Lijin	10000	10000	10000	10000	11000

Note:*Dongping Lake flood retention area was put into operation;

**Beijindi flood retention area was put into operation

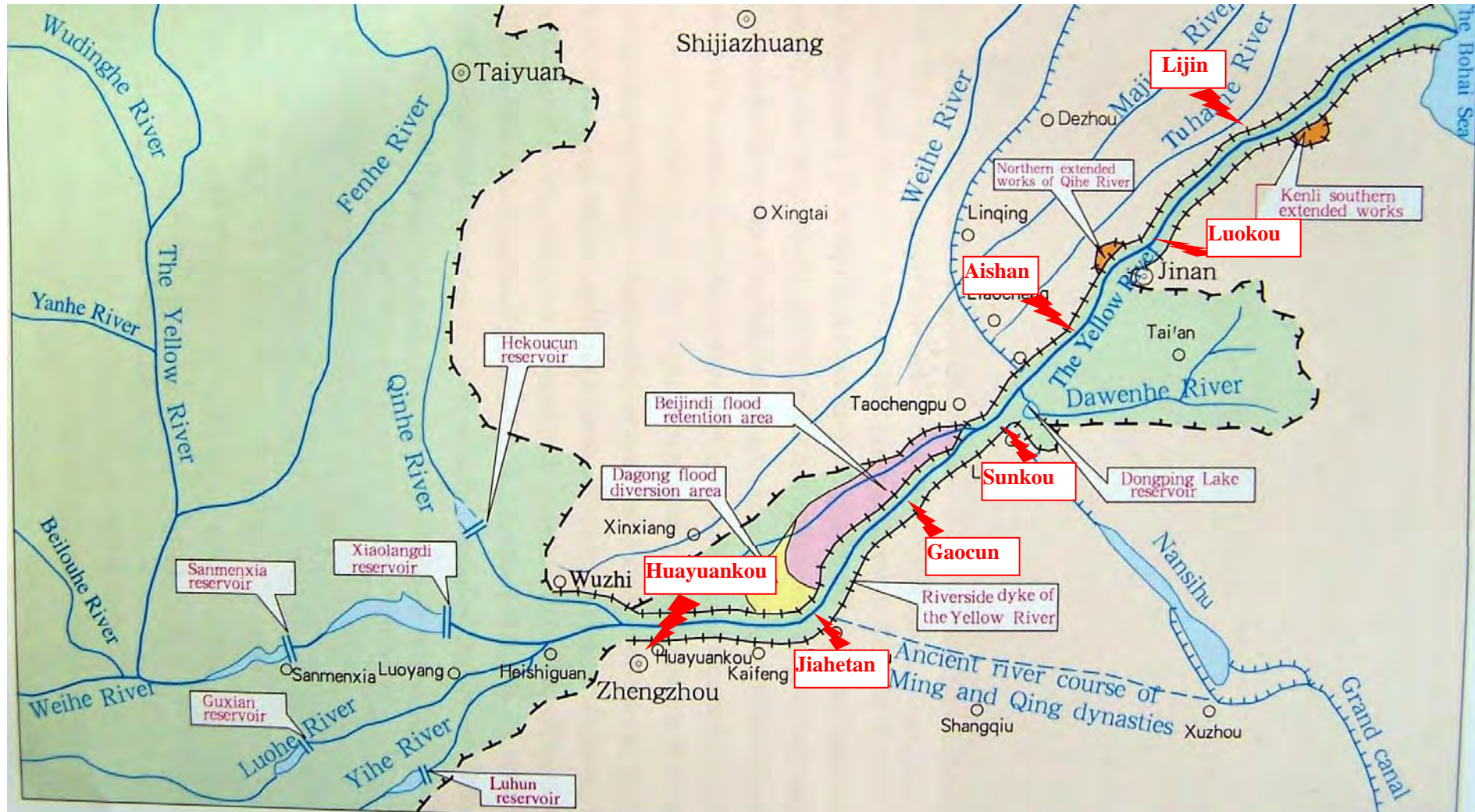


Figure 3.12 Flood control engineering system in the lower reaches of the Yellow River

The design discharge of the dykes downstream of Aishan in the lower reaches is 11,000 m³/s. As such, when the actually measured peak rate reaches 10,000 m³/s at Sunkou station and still has the trend of increasing, Dongping Lake flood retention area must be used. Therefore, the probability of operating Dongping Lake flood retention area is once 30 years, i.e. After Xiaolangdi reservoir is put into operation, the probability of using Dongping Lake flood retention area remains to be big. Beijindi retention area and Dagong division area are reserved for extreme situation like more than 1,000-year flood. Nanzhan and Beizhan detention areas are used to control the flood discharge to the narrow reaches under Jinan during ice flood. After Xiaolangdi project was put into operation, both Nanzhan and Beizhan detention areas are not used any more. As the river channel downstream of Aishan is concerned, its capacity to control floods needs to be strengthened.

At present, the design discharge at Huayuankou station is 22,000 m³/s, along with the gradual silting and elevating of the riverbed, if the height of the dykes remains the same, its design discharge will gradually decrease.

3.7.3 Possible types of the dyke breach

The dykes of the Yellow River were mainly formed in Spring-and-Autumn Period in order to prevent the floods in history. In the lower reaches, dyke breach happened in 543 years out of 2,540 years from 602 B.C. to 1938 A.D. sometimes, several breaches occurred in one year. There were altogether 1,590 levee breaches in history. This is what people usually referred to as “twice breaches in every three years”.

The total length of the dykes in the delta area is 206.33 km, and of this, the defensive dykes are 77.46 km including both the North Dyke and the South Dyke and the non-defensive dykes are 128.87 km. Of the defense dykes, 21.7 km of the North Dyke and 5.1 km of the Gudong Ring Dykes do not reach the designed standard. These account for 54% of the total length of the dykes on the left banks. Based on analysis, there is a high possibility of seepage collapse of all the dykes

Since 1986, the river training works have been built gradually to control and improve the river regime and protect the exploitation of gas and oil. However the works need to be adjusted in time because of continuous changing of the river regime. The new works have not been tested by the flood, so it is difficult to find the vulnerable points.

The dyke breaches can be classified into four types:

- **Due to overflowing:** when the flood level is higher than the elevation of dykes, the water flows over the dykes thus breaks the dykes.
- **Due to scouring:** under condition of “secondary hanging river”, once the flood breaks off the main channel, it will cause major change of river regime (rolling and swinging), leading to incidence of the “transversal channel”, “diagonal channel” and “rolling channel” (Figure 3.13) which directly scours the dykes, furthermore causes collapse of the dykes and dyke breach.
- **Due to collapse caused by hidden defects:** because the dykes have hidden defects, when flood arise and river flow reaches dyke, piping, seepage, leakage and collapse will appear, and when repairing work is not in time and immediately effective, the levee breach will happen.
- **Due to ice jam flood:** in the reaches of river flows from low latitude to high latitude, the river freezing starts from downstream to upper stream but ice thawing begins from upper stream to lower stream. If the ice slush blocks the river channel during icebreaking, it is quite easy to form ice dam that will raise the water level, thus causing levee breaching, or the water snuggles up to the dike causing piping and furthermore levee breaching. For example, this kind of levees breaches happened in the delta area in 1951 and 1955.

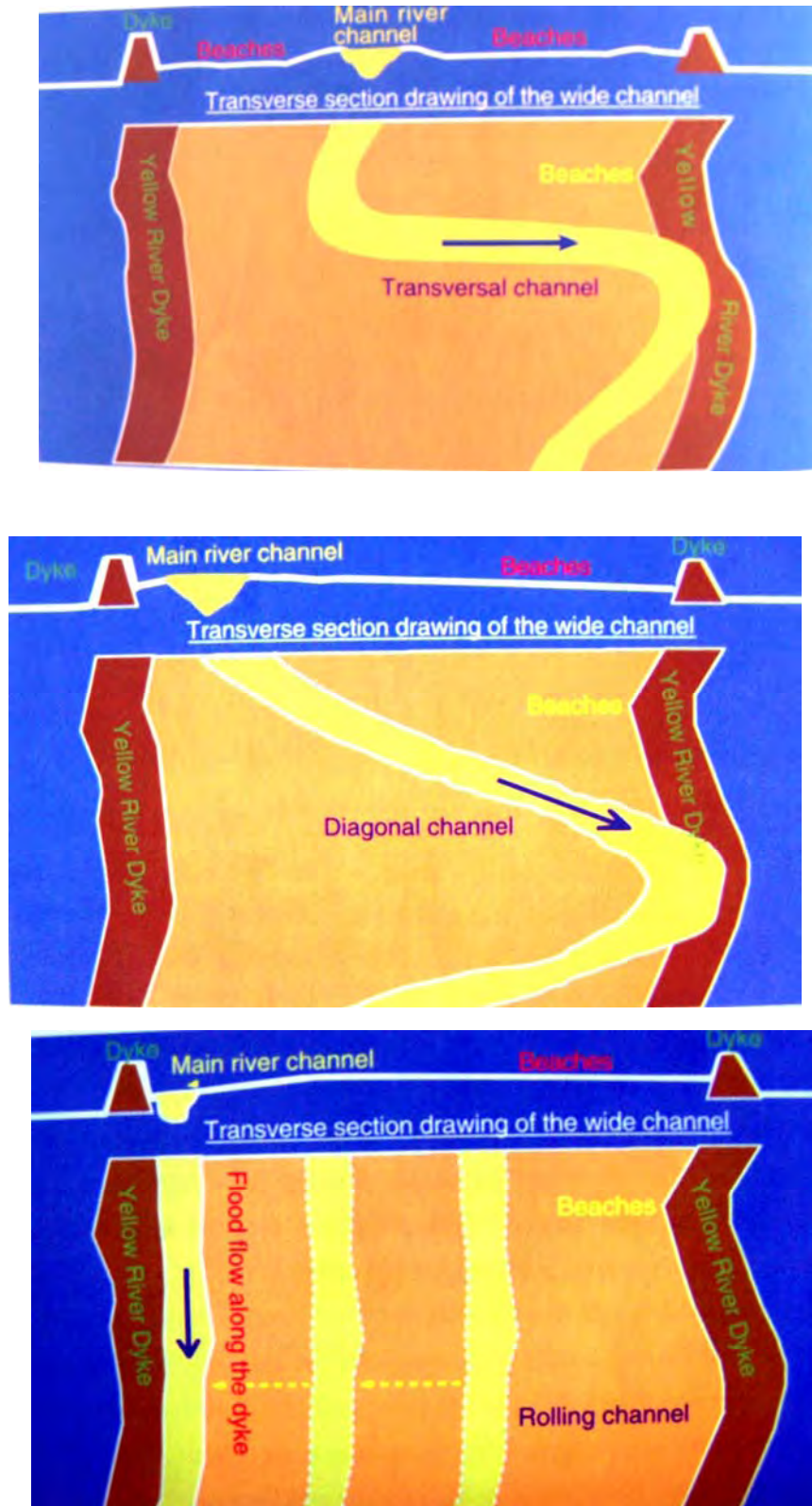


Figure 3.13 The sketches of “Transversal channel”, “diagonal channel” and “rolling channel”

The breach caused by ice flood has been basically solved through joint operation of Sanmenxia and Xiaolangdi projects. According to the operation experience of water control project in ice control, under circumstances of certain temperature, ice status and water situation, it is very effective to use reservoirs to regulate the water volume and water temperature so as to prevent ice jam in the river channel, create conditions for mild ice thawing and furthermore ensure the safety of the lower reaches

Levee breach due to overflowing is also basically solved after the completion of Xiaolangdi project. The designed standard for the dykes in the Lower Yellow River is flood peak discharge of 22,000 m³/s at Huayuankou cross-section in consideration of safe surcharge and wave run-up, which means the dykes meet flood control standard for 1,000-year flood.

So, we can draw the following conclusion: after Xiaolangdi water control project is put into operation, there are more scouring breach and collapsing breach than overflowing breach, which is determined by the drastic wandering channel of the lower reaches of the Yellow River. The priority work should be focused on prevention of scouring breach and collapsing breach through River training and dyke reinforcement.

3.8 Institutional aspects

3.8.1 Three phrases of development in the delta area

In the Yellow River Delta, due to the significant formation of new lands and frequent wandering of the river embouchure at the estuary, the economic and social development in the delta areas consistently lags behind those deltas of clear water river, such as the Yangtze River and the Pearl River. Relatively thin population and poor productivity inevitably lead to corresponding slow progress in development and harnessing of the Yellow River estuary. This area was not given any importance by the national government; some area was even used as an army base for reclamation.

Until the exploitation of the oil fields in the delta since the 1960s and the rapid emergence of Dongying City in 1980s, the river course management and regional development plan became more and more important, so 'The planning for the river course of the Yellow River in the estuary area' was formulated and implemented in 1990 while the construction of flood control and river training engineering works for estuary harnessing was launched in 1990 and finished in 1996. This planning and building of engineering works mainly served for gas and oil exploitation.

Since the 1990s, along with further regional development, water shortage and the deterioration of both the ecology and the environment have emerged and these tend to be becoming worse and worse. The former plan does not fit the new situation. Under the new idea of ‘keep the healthy life of the river’ and ‘maintain the harmony of nature and human’, the integrated plan needs to be tabled as an important agenda item. ‘The rules of management in the estuary area of the Yellow River’ have been posted and came into force in 2005. However, this regulation is still rough in approach, and not yet detailed or operational.

3.8.2 The responsibilities of different organizations

- Yellow River Conservancy Commission (YRCC)

Historically the Yellow River has always been directly managed by the central government. As the river basin management institutions assigned by the Ministry of Water Resources since 1946, the Yellow River Conservancy Commission (YRCC) is entrusted with the responsibility for unified management of the water resources, unified dispatching of water volume, and the direct management of the downstream channels and flood-control projects.

Though some engineering works have been built in the delta area since 1949, YRCC put more attention on flood control in the lower reaches, such as engineering works along the river channel and water control projects in the middle reaches, and carried out three river course changes in order to control the water level during floods in the lower reaches and the delta area.

Until the 1980s, in order to meet the requirements for gas and oil exploitation and regional development, the YRCC formulated ‘The planning for river course of the Yellow River in the estuary area’ to relatively stabilize the current river course and reserve the spare courses for the future, then set up the Estuarial Bureau and launched the construction of dykes and river training works to protect the oil field and regional development.

As mentioned above, the sedimentation and extension of the river course in the estuary area interact with the sedimentation in the upstream of the Yellow River, so river management and flood control in the delta area are important for the management of the overall basin. At present, facing a water shortage and deterioration of the environment, the YRCC will play an important role in relieving this situation through the unified dispatching of water volume and water-sediment regulation upstream.

- Shengli Oil Company

Shengli Oil Company is the second biggest gas and oil enterprise in China while the exploitation of gas and oil is the most important industry in the Yellow River delta. The majority of other industries are serving the production of gas and oil. Even now, more than half of the citizens in the towns are working in the oil industry.

As the huge national enterprise, Shengli Oil Company made a lot of effort for regional development, directly resulting in the establishment of Dongying City, literally 'Oil City'. In accordance with the Chinese political system, the president of Shengli Oil Company used to be the mayor of Dongying city, so the head of company and the government did not have a very clear dividing line. The company was involved in the construction of infrastructures and flood control engineering works and provided major funds. Some of the projects are serving for the exploitation of oil while others are not. Because it is national property, central government can affect the investment of the oil company.

Since the end of the 1990s, with the transformation of national enterprises and marketing economy policy, the Shengli Oil Company has been restructured as an independent company, and what is more, it is a listed company. Though the nation holds the majority of the stock share, the company can no longer give large sums of money for estuary harnessing like before. Construction of the facilities is not the responsibility of the Oil Company if they are not to serve their oilfield, because the Oil Company has paid taxes. Therefore the managerial group of the company should make decisions based on the profits for the stakeholders.

- Regional government

Since Dongying City was set up in 1982, the municipality has been devoted to balancing the relationship between the evolution of the river course and the exploitation of gas and oil, which is the key for regional development. The revenue of the Oil Company is the main income source of the municipality. In recent years however, although the exploitation of oil has potential development, the production of oil has gradually decreased since 1994 and the difficulties of extraction are increasing. In order to obtain sustainable development and economic growth, the regional government has planned to transfer the single industry to multiform enterprises in the next dozens of years, such as establishing a highly-efficient agricultural base, enlarging the Dongying Harbor, and facilitating the recreation area. All the development strategies should consider the river course arrangement and flood control system.

The regional government is responsible for the storm defense from the sea, including the integrated planning, designing and construction. Because of the lack of money and thin population along the shorelines, the storm defense system is not completed and has not reached the designed standard. The partial defense works were built by Oil Company to protect the extraction of gas and oil. So the regional government should play a dominant role in the construction of storm defense.

- Nature reserves agency

One of the important land uses in the delta is national nature reserves such as wetlands and forest, which is very critical for the ecosystem in the delta area. In order to preserve the nature lands, nature reserves agency will be involved in the land use plan and river course management, such as providing observed data and research about the evolution of nature lands under these changed conditions.

3.8.3 Imperfection of finance and management for flood control facilities

The 40-km long stretch from the edge of the sea to the estuary (below the 4th section on the north bank, below the 21st subsection on the south bank) is not under the jurisdiction of the Yellow River Conservancy Commission, which means it is not in the ranges of national investment. In the past few years, the estuary training works were built with joint efforts; ‘the Oilfield Company provides the funds, the Yellow River agency draws up the plans and Dongying City government maps out the policy’ based on the principle of ‘who benefited pays’ and ‘who built manages’. The oil company was in charge of construction, management and maintenance of these facilities. Because there was no flood in recent decades, due to the consideration for their own profits and lack of a professional group, until now the training works have not reached the standard of planning by the YRCC and are facing the absence of management and maintenance. This situation causes difficulties with river training in the whole of the delta area.

Meanwhile, the management and maintenance of flood control facilities in the Yellow River Basin are carried out under the new legislation. In the past, the YRCC or its divisions operated all the processes of construction, management and maintenance of the facilities, which caused overstaffed organizations, unclear responsibilities and low efficiency and quality. The finances for management and maintenance are sent together by Central Government, which make some confusion for the utilization of the finances. In order to adapt the development of the market economy and to solve the above problems, the divisions engaging in construction and maintenance will separate from the YRCC. The YRCC will more effectively carry on managerial function. So, this

transformation will make it easier for the maintenance of river training works built by the Oil Company.

The regional government is responsible for the construction, management and maintenance of the storm defense system. However the situation is almost the same as that of the river training works. Because there are not very serious storm problems and a thin population along the shorelines, the regional government has not financed large sums of money on a sea defense system, but the Oil Company built the majority of sea defense works to protect the exploitation of gas and oil and is also in charge of the management and maintenance. So the sea defense system is not uniform and integrated.

4 Possible solutions

4.1 Sediment reduction

4.1.1 Sediment retention in the reservoirs

Retaining sediment in reservoirs is not bottom-solution but temporary and most effective measure for sediment reduction in a short term. Seven trunk stream key projects are planned to build for water and sediment control and regulation, in which the Longyangxia and Liujiaxia projects in the upper reaches and Shanmenxia and Xiaolangdi projects in the middle reaches have been completed (Figure 4.1 and Table 4.1). The Shanmenxia reservoir for sediment storage has been silted up. Xiaolangdi project was put into operation in 2000 with a total water storage capacity of 12.65 billion m³. Its sediment capacity is 7.55 billion m³ which is equivalent to non-sedimentation in the channels bed of the lower reaches for 20 years.

Twenty years after the operation of Xiaolangdi project, the reservoir area will be reach the sediment balance state, so before that we should find proper time to construct other two trunk stream projects in the middle reaches, Guxian and Qikou. The designed total storage capacity of Guxian project is 15.3 billion m³, of which sediment retention capacity is 10.45 billion m³. It could reduce sedimentation 5.4 billion t in middle reaches which equivalent to sedimentation of 52 years and 77 billion in lower reaches which equivalent to sedimentation of 20 years. Furthermore, Qikou can prevent sedimentation in both the middle reaches and the lower reaches for another 20 years. From the perspective of establishing sediment and water regulation system, the reservoirs could keep non-sedimentation in the lower reaches for 100 years even more.

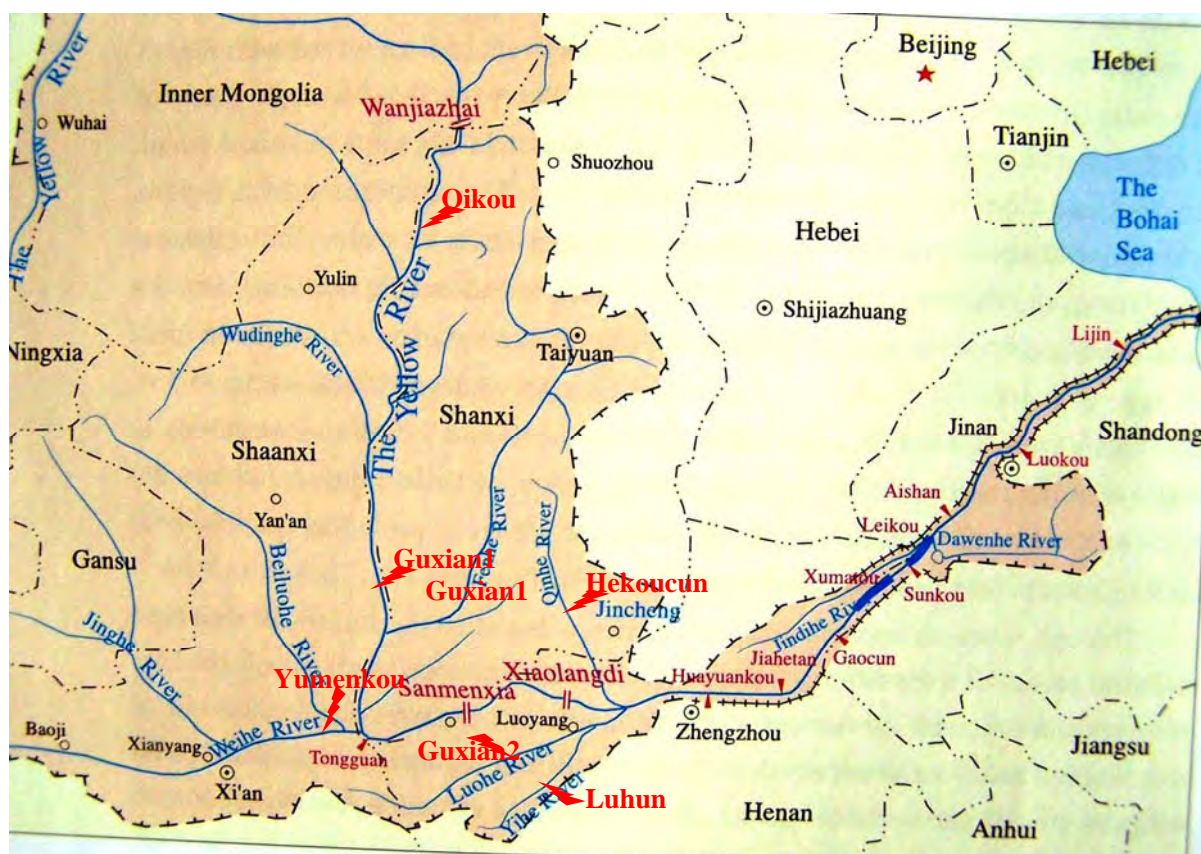


Figure 4.1 The locations of water-sediment regulatory projects

Table 4.1 Technological and economic indexes of water-sediment regulatory projects in middle reaches of Yellow River

Name	Total reservoir capacity (billion m ³)	Effective capacity (billion m ³)	Max. water head (m)	Dam height (m)	Installed capacity (million.W)	Annual average power generation (billion. kWh)
Wanjiashai	0.90	0.45	81.5	90.0	1080	2.75
Qikou	12.57	2.79	117.0	143.5	1800	4.70
Guxian1	16.57	4.78	174.0	199.0	2100	7.10
Yumenkou	0.07	0.04	23.5	48.5	140	0.61
Sanmenxia	9.64	6.04	46.0	106.0	400	1.30
Xiaolangdi	12.65	5.10	141.9	173.0	1800	5.84
Guxian2	1.18	0.96	63.6	125.0	60	0.18
Luhun	1.32	1.17	48.3	55.0	10	0.01
Hekoucun	0.35	0.26	68.0	156.0	20	0.08

4.1.2 Sediment diversion in the Xiaobeiganliu section

The sediment diversion in the lower reaches has been implemented in the past dozens of years, namely “discharging sediments for embankment consolidation”. But it seems to be impossible to do that considerably because of no ample space due to the economic development and social progress. Xiaobeiganliu section located in between Yumenkou and Tonguan of middle reaches with a length of about 130 km, which has wandering channel with broad beach area. It is ideal site to storage the sediment because of relatively uncivilized social-economic situation. If adopting the mode of siltation with dam, estimated sediment storage capacity in broad beach in the range of Xiaobeiganliu section is 10 billion t which means we will get another Xiaolangdi reservoir for sediment retention.

4.1.3 Water and sediment regulation through joint operation of reservoirs

- **The principle and objectives**

As mentioned above, the sediment retention in reservoirs is a temporary measure, the final purpose is transporting sediment to the sea which is beneficial for the lower river channel and delta development. The analysis based on measurement shows that the river channel of the Lower Yellow River generally has been in a state of sedimentation within a long period of time, but not unidirectional sedimentation, i.e., silting up occurred in some years and scouring occurred in other years instead. Such a sedimentation-flushing character is closely related to the conditions of water and sediment inflow. So is it possible to transport sediment once unbalanced sediment and water relationship is regulated to a harmonious one by joint operation of reservoirs? The testing of sediment and water regulation in Yellow River in 2002, 2003, 2004 has proved it is the effective approach to silt transport to the sea, sediment reduction of the downstream channel and even in downstream channel scouring. The Figure 4-2 presents the operational mechanism of water-sediment regulation.

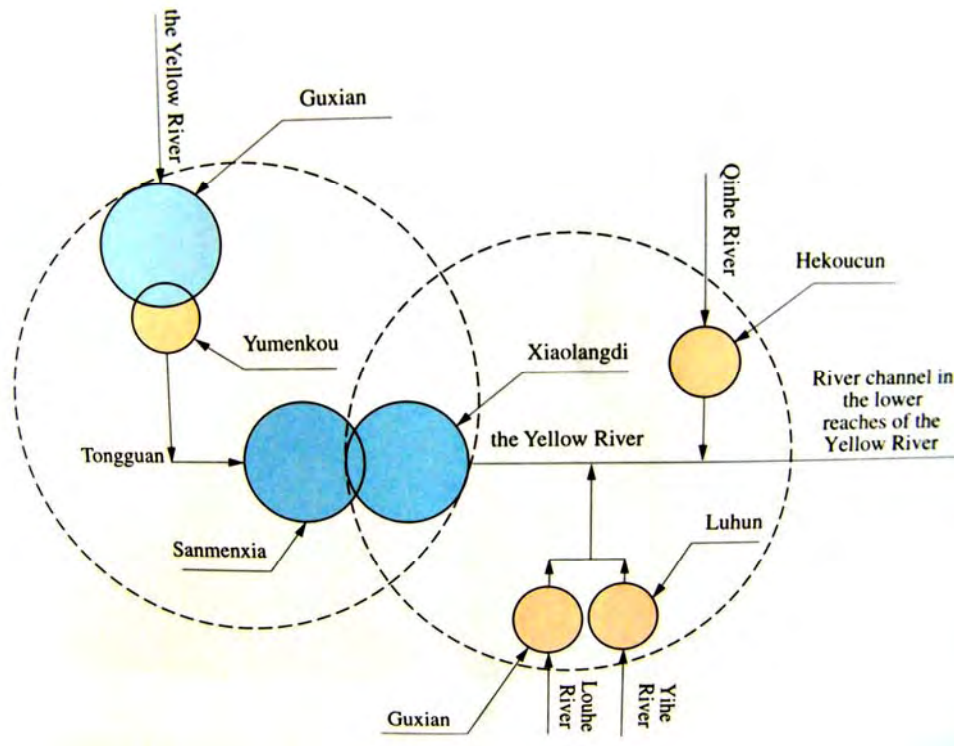


Figure 4.2 Water-sediment regulation project and its operational mechanism

Among the reservoirs in middle reaches, Xiaolangdi project is a most powerful function for sediment and water regulation at present, which is located in a key position controlling 91% of the runoff and nearly 100% of the sedimentation of the Yellow River. Except the water storage and sediment retaining, the reservoir have enough storage for sediment and water discharge regulation. When the reservoir's sediment retaining capacity is filled up in 30 years, the reservoir will turn into its normal operation period, and shall have a usable storage of 5.1 billion m^3 , of which 1.05 billion m^3 is designed for sediment and water discharge regulation. The only problem is the conflict with the other functions like power generation and irrigation because of stressed water shortage in Yellow River Basin. But we can choose the days just before flood season because the project should release excessive water storage volume above the flood limit water level before flood season due to the top mission of the project.

Except sediment reduction in the river of the lower reaches and enhancing flood passage capacity, sediment and water regulation have two other objectives:

Testing the adaptation of river training works

The river training works built in recent several years never encounter as big discharge as that during sediment and water regulation. The problems could be found during the sediment and water regulation, which helps engineers to redesign the river training works and planning.

Adjusting the silting form of sediments at the tail of Xiaolangdi reservoir and discharging sediment out of the reservoir to prolong the active operation life for water storage and sediment retention.

Through scouring by hydrodynamic force of the current discharged from Sanmenxia and Wanjiashai reservoirs and the measures of artificial perturbation of sediment in reservoir area, it is to eliminate the silt at the tail of Xiaolangdi reservoir that has occupied the long-term live reservoir capacity. Furthermore, it is to discharge as much sediment as possible out of the reservoir through the movement of density current in the reservoir (Figure 4-3 Li2 P) so as to reduce the silting of the reservoir area. The total discharged sediment is 14.9 million t.

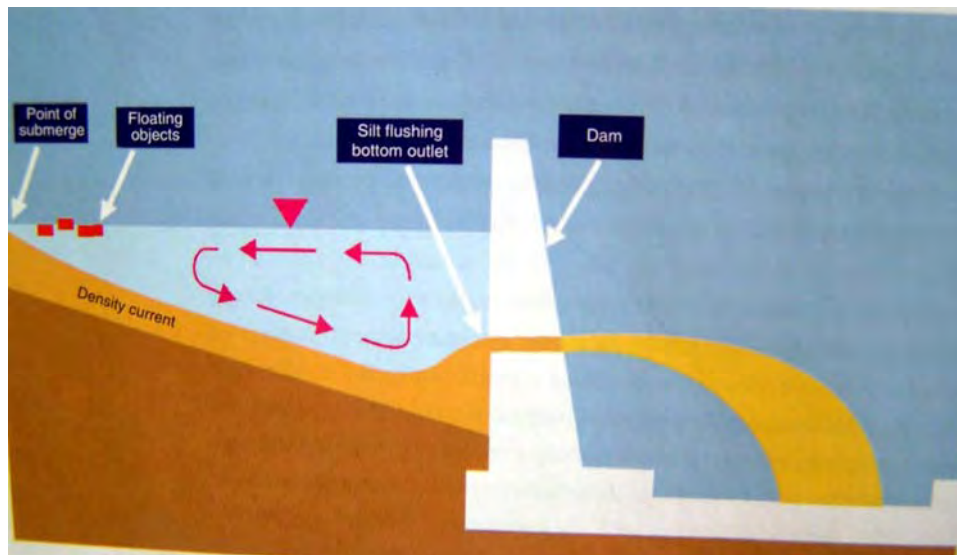


Figure 4.3 The movement of density current in the reservoir

Regulating components

Based on the alluvial pattern of the downstream channel of the lower Yellow River, the operation of sediment and water discharge regulation by Xiaolangdi Project usually takes the following two ways:

The first is to control the sand grain composition “retaining the coarse and discharging the fine”.

According to the statistics of the sediment in Sanmenxia reservoir and the main channel of the lower reaches, 80% are coarse sand and silt a particle whose grain diameter are larger than 0.05 mm, while larger than 0.025 mm of the grain diameter is 90%.

Since fine sand smaller than 0.025 mm can be generally transported into the sea, it is unnecessary to impound them in the reservoirs. On the contrary, the reservoir should by means of operational control intercepts only coarse sand larger than 0.05 mm that has serious risk to the downstream channel, which not only can prolong the reservoirs' operation life of sediment interception but also effectively reduces the sedimentation in the downstream channel of Yellow River.

The second is to control the three important factors: reservoir outflow sediment content, outflow discharge and the duration of discharge.

- 1) Sediment content. The analysis based on 145 floods during 1950~1990 in natural conditions shows that, the channels incur sedimentation when the annual average sediment content is bigger than $20\sim 25\text{kg/m}^3$, and that the channel attract scouring when the annual average sediment content is smaller than $20\sim 25\text{ kg/m}^3$. Therefore, it is concluded that $20\sim 25\text{ kg/m}^3$ is the critical threshold value of annual average sediment content related to downstream channel alluvial variation. So, it is certain that downstream channel faces sedimentation because annual sediment content of water flows into downstream channel is 35 kg/m^3 .

Xiaolangdi water control project during the stage of water storage and silt interception within the dead storage capacity, definitely undergoes a period of relatively clear water discharge during this period, the sediment ejection of the reservoir is mainly by density flow. The average sediment transport ratio under different water silt condition is about 10~20%, with fairly small outflow sediment content. Therefore, for the testing the average outflow sediment content is less than 20 kg/m^3 .

- 2) Outflow discharge. Analysis based on large amount of statistical data shows the situation with sediment content of less than 20 kg/m^3 , the whole channels of the lower reaches will be fully flushing if the discharge at Huayuankou control station is $2,600\text{ m}^3/\text{s}$ which is the critical discharge value. The flushing of the downstream channels has the greatest efficiency when the discharge at Huayuankou cross-section is $3,700\text{ m}^3/\text{s}$.
- 3) Duration of discharge. From Huayuankou to the sea outfall, each cross-section has a critical discharge value of alluvium variation. If the time duration of water discharge

is too short, the running flow will be weakened quickly by the retention of downstream channels and it will be difficult to provide appropriate flushing discharge for the next consequent downstream sections. Theoretical analysis shows that, the critical time duration for the river reach from Xiaolangdi Reservoir to the sea outfall is 6 days. In practice, the adopted time for releasing discharge was no less than 10 days considering the beaches flooding and the requirement that the water level should be under flood limit water level during sediment and water regulation period.

In order to control the reservoir outflow factors, different operating combination of the discharge facilities (for instance sand-flushing outlet, free flow outlet etc.) is set up at different Xiaolangdi Project. (Figure4.4)

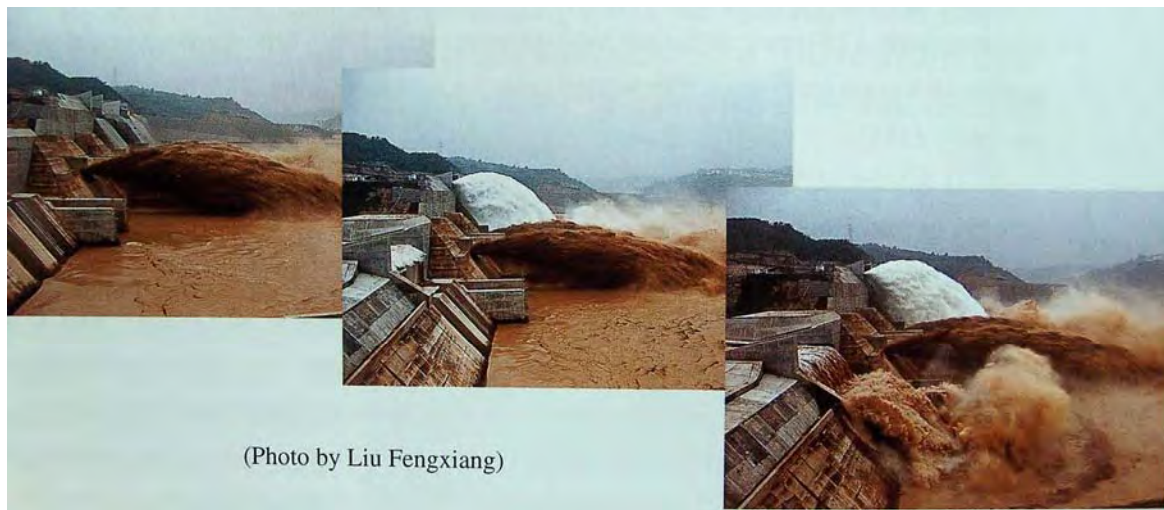


Figure 4.4 Sluicing of Xiaolangdi reservoir during the sediment and water regulation

- **Sediment perturbation in river channel downstream**

Additionally, the river regime (boundary condition like the width and elevation of main channel and beach, river training works) in lower Yellow River influences the three factors. That is why sediment content, outflow discharge and the duration of discharge are variable, not fixed, which should be adjusted coordinating with river regime. In the experiment of water and sediment regulation, fully using the energy of runoff with the assistance of corresponding artificial sediment perturbation can achieve the effect of silt reduction with only half the effort.

- **Observation and results**

The results of controlled factors and silt transportation are showed in Table 4.2 during sediment and water regulation in 2002, 2003, 2004, 2005, and 2006.

Table 4.2 The modes and results of sediment and water regulation

Time	Mode	Water storage volume in Xiaolangdi reservoir (billion m ³)	Releasing discharge (m ³ /s)	Sediment content (kg/m ³)	Water volume to sea (billion m ³)	Sediment amount to sea (million t)	Scoured sediment (million t)
07.04-07.15 in 2002	Based on operation by single Xiaolangdi reservoir	4.34	2600	20	2.29	46.4	36.2
09.06-09.18 in 2003	Based on Sediment and water confluence in spatial dimension	5.61	2400	30	2.72	120.7	45.6
06.19-07.13 in 2004	Based on the joint operation of reservoirs in trunk stream	6.65	2700	40	4.80	69.7	66.5
2005	Based on joint operation of Wanjiazhai, Sanmenxia and Xiaolangdi reservoirs	6.16	3000~3300	40	4.20	61.26	64.67
06.10-07.03 in 2006	Based on joint operation of Sanmenxia and Xiaolangdi reservoirs	6.89	3500~3700	40	4.81	64.8	60.1

The total sediment amount transported to the sea is 0.36 billion t and the total scoured sediment in lower Yellow River is 0.27 billion t. although the amount is much smaller than the annual sediment inflow 1.6 billion t, it lowered the riverbed by average 0.8~1.2 m in main channel along the lower Yellow River and increased the overall flood passage

capacity by average 1500 m³/s (from 2000 m³/s to 3500 m³/s) since mostly sediment scouring occurred in the main channel.

4.1.4 Water and soil storage in the middle reaches

The sediment of the Yellow River originates from the Loess Plateau in the middle reaches. It should be implemented continuously to store the water and sediment in the local area instead of flowing into downstream; relying on engineering means namely the construction of gully control and warping dam system, plantation and slope measures like terracing. But it will be a long way to solve the problem of water and soil loss in Loess Plateau due to financial and other factors.

4.1.5 Water transport project from Yangtze River for Sediment flushing

There are three contributing factors to sedimentation in the lower reaches of Yellow River: insufficient water, excessive sand and unbalanced water-sediment ratio. From the view of solving the problem of insufficient water, the South-to-North Water Transport Project from Yangtze River can add certain water amount into Yellow River by western route and supply water to adjacent area of Yellow River by eastern and middle routes, thus decrease water diversion from the river and increase the flow discharge.

Considering economic development and national strength at present and near future, It is not possible to include the water demand for sediment flushing in the lower reaches of Yellow River in the South-to-North Water Transport Project, which is aiming at addressing the problem of water resource shortage in northern China. But from long term vision, it is reasonable to take into account of integration of sediment reduction in Yellow River and water transport project. It is proven that we can reduce sedimentation in the lower reaches through sediment retention and sediment-water regulation by reservoir. But it will be impossible to carry out sediment-water regulation by joint operation of reservoirs if there is not enough water. Therefore we should consider the approach in advance.

4.2 Alternatives of extending the running life for current course

4.2.1 Alternatives of running mode for the river

The running mode research of Yellow River in delta means that what methods and forms are taken to let water flow into the sea and keep a relatively long time for one course, which includes the direction of river regulation, the aim of river training and the corresponding measures. From the evolution history of Yellow River estuary, each course has its special running mode and under the intervention of human even the same

course might have its special running mode as well. There are three alternatives of running mode for extending the running life of current course, which are researched by different institutes according to different materials they mastered and the difference in understanding. The three alternatives of running mode are as following (Figure 4.5):

- a) Long-term stabilization of Qingshuigou course (the current course);
- b) Running by turns between two courses (Qingshuigou and Diaokouhe);
- c) Relatively stabilization of the Qingshuigou course.

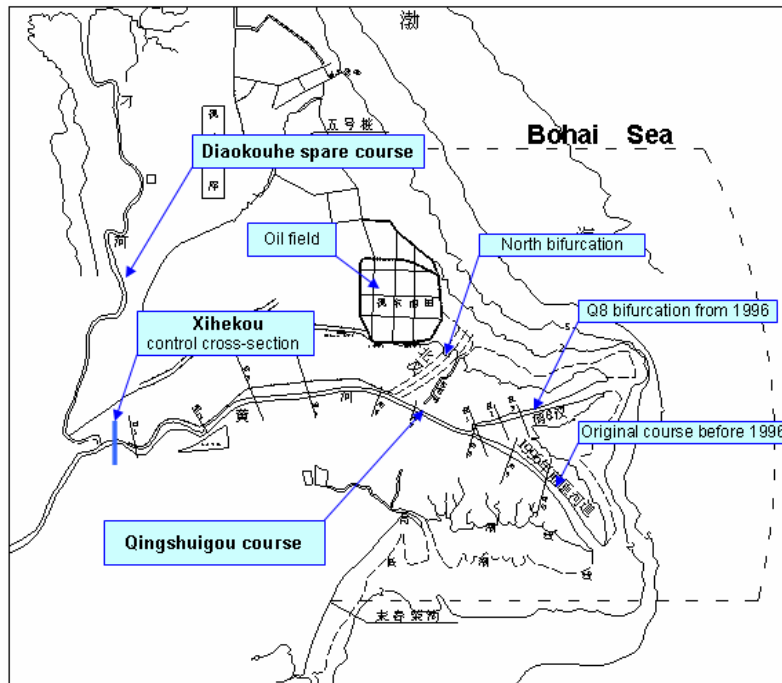


Figure 4.5 River course and bifurcations

Alternative I : Long-term stabilization of Qingshuigou course

The main principle of this mode is: one main and one supplementary course; fixing river by two courses; flood diversion of high water level; construction of flow guiding dikes into the sea. The specific meaning of this principle is: the current course is served as the main channel, constructing two flow guiding dikes along the channel and extending into sea till 3m seawater depth; the control discharge in the main channel is $3000 \text{ m}^3/\text{s}$ and constructing groynes to form compound riverbed; Diaokouhe course is served as the supplementary course and constructing a diversion sluice near Xihekou cross-section (discharge and water level control section in delta) with discharge of $3000 \text{ m}^3/\text{s}$; meanwhile persistent dredging and removing of possible silting in downstream of

Xihekou should be taken to ensure the stability of the river regime and the stability of navigation channel.

The aim of this running mode is hoped to fix the course, transport all the silt to the deep sea and realize long-term stabilization of estuary by utilizing two courses (Qingshuigou and Diaokouhe) and being supplemented by engineering measures such as two flow guiding dikes.

Alternative II: running by turns between two courses

The aim of this running mode is to control the development of channel stretching to the sea, delay the seaward extension of the coastline, slow down the channel sedimentation in upstream of Xihekou, reduce the pressure of flood protection and then realize long-term stabilization of the river course, in which the essence is to make full use of coastal zone conditions and be supplemented with engineering measures.

The two courses are Qingshuigou and Diaokouhe course. The specific plan is constructing a dam near Xihekou, regulating the Diaokouhe channel (old course running before 1976), and then make the two courses as main channel and flood diversion channel for each other and realize long-term course stabilization and safety at last.

Alternative III: Relative stabilization of Qingshuigou course (current course)

The main principle of this running mode is:

- a) To make full use of the resource superiority in deltaic area and promote sustainable socioeconomic development on the condition of the safety against flood and on the basis of preserving the ecological environment;
- b) Try to reduce the feedback impacts to downstream channel due to silting and stretching of the estuary and control the discharge and water level not excess 10,000 m³/s and 12m respectively;
- c) Try to full play the running potential and relatively stabilize the current course by necessary engineering measures before reaching the course changing condition. (The boundary condition of course changing is that the water level in Xihekou cross-section reaches 12m when discharge is 10, 000 m³/s).

The main point of view for this running mode is to make full use of the current course and keep as long running life as possible.

4.2.2 Comparison of three alternatives

Alternative I : Long-term stabilization of Qingshuigou course

The aim of this running mode is to fix the estuary and transport all the silt to sea by utilizing two estuaries and engineering measures such as constructing two flow guiding dikes, then the estuary will be stabilized for a long-term and will benefit the regional socioeconomic development. But there are following main problems:

- Long-term estuary stabilization is difficult to realize.

The Yellow River will remain to be a high silt content river for long period in the future and the mean silt amount coming to the estuary would be about 0.6 billion tons. According to the research result of The Hydraulic Science Institute of China, the sea transporting power for silt in estuary is only about 0.3 billion tons when the channel length reaches 80km(from Xihekou to river mouth) and the water level reaches 12m at Xihekou. Therefore it is impossible to avoid channel silting and stretching, and difficult to realize long-term stabilization of estuary. If continue use the channel through constructing flow guiding dikes when the channel stretching to a certain length, the channel certainly will continue its stretching and then it will cause feedback impact to channel sedimentation in downstream and increase flood risk as well.

- Impact of flood diversion sluice

The construction of flood diversion sluice near Xihekou will reduce the flood discharge in the downstream. It would be favorable to lower the flood level in coming short-term period, but because of the reduce of discharge in downstream and the decrease of silt entraining ability of the flow, the channel would be resulted in less scouring and more silting, furthermore, the feedback impact would be happened to the upstream from diversion point. Therefore, the construction of flood diversion sluice would be unfavorable to the downstream flood protection of Yellow River.

- Financial problem

The whole project of fixing the estuary costs too much. Only the first stage of the project, including flow guiding dikes, flood diversion sluice and regulation of Diaokouhe course would cost up to 3.5 billion Chinese Yuan, not accounting the cost of dredging every year.

Alternative II: running by turns between two courses

Advantages

- Two courses (Qingshuigou and Diaokouhe) running by turns can make full use of Bohai Bay and Laizhou Bay to transport silt away, complement fresh water and silt continuously to the offshore area and restrain coast erosion. It is favorable to protect the ecological environment of Yellow River Delta and especially to keep the nature reserve near Diaokouhe estuary in a good condition.

Disadvantages

- Running by turns between two courses has the same problem with the former running mode, which is the impact of the dam on the channel. The construction of the dam near Xihekou corresponds to establishing a new erosion datum and what the impact is to the downstream channel remains to have further research. According to the current understanding, the construction of damming works on accumulating channel exists inestimable negative impacts.
- There are still some specific problems need further research on this running mode such as how to take turns and what the criteria is for taking turns, etc.
- Two courses running by turns would make the population, farmland, oil wells and some other living and producing facilities that within two courses scope under continuous impact of course changing. Undoubtedly, this running mode would affect the local socioeconomic development. Moreover, the construction and management of two courses at the same time need great investments and are very complex in operation and management.

Alternative III: Relative stabilization of Qingshuigou course (current course)

This running mode, to some extent, takes into account both long-term stabilization of Qingshuigou course and running by turns between two courses. In long-term view the aim of this running mode is corresponding with running by turns, which is trying best to decrease the channel stretching and realizing safety against flood. Furthermore, the short and long term running plan of this mode is similar with running by turns, the only difference is changing frequent course changing (running by turns) into using the measures supplemented by engineering works, and quantifying the control conditions of course changing, which make planned course changing become more operable. Meanwhile, this running mode takes into account of the local economic layout and developing requirements, therefore to some extent (in long-term view) it also take the running mode I (long-term stabilization of Qingshuigou course) into consideration.

Conclusion

From the comparison above, it can be concluded that the alternative III is more practical and feasible, which is on the basis of trying to extend the running life of current course and ensuring safety against flood, not only satisfying the local requirements and decreasing the impact, but also taking the nature preserve and sustainable development into consideration. Therefore, the running mode of relatively stabilization is recommended to carry out for short and long term course running in Yellow River Delta.

The specific possible solutions and measures for running mode III are elaborated in the following.

4.2.3 Artificial bifurcating plan for Qingshuigou course

- Three possible bifurcations

In accordance with the designing ability of flood protection in estuary area, the control condition of bifurcating for Qingshuigou course is determined to be that the water level not exceed 12m under the Xihekou discharge $10,000 \text{ m}^3/\text{s}$, namely the control condition for each bifurcating or shifting between each bifurcation is the water level reaching or below 12m under the discharge $10,000 \text{ m}^3/\text{s}$ at Xihekou, and the control condition for final course changing is the water level reach 12m under the discharge $10,000 \text{ m}^3/\text{s}$ at Xihekou for all bifurcations.

In order to try to use the silt containing ability of offshore area near Qingshuigou estuary, the partial bifurcating plan for Qingshuigou course is envisaged in three directions. The three bifurcations are (Figure 4.5):

- a) The current bifurcation at the 8th cross-section (referred as “Q8 bifurcation”),
- b) North bifurcation and
- c) The original course before bifurcating in 1996 (referred as “Original course”).

- Four possible combined bifurcations

For the three bifurcations, there are four possible combined solutions and two respects are considered: a) try to make the channel length of Qingshuigou course as short as possible to lower the downstream discharge level; use the channel length 65km, which is the longest channel length ever took place from Xihekou to the mouth, as one of control condition for bifurcating during the running process; b) try to make the course relatively stable in order to be favorable to the local socioeconomic development and ecological

environment preserve; make the water level 12m at Xihekou (discharge 10,000 m³/s) as bifurcating condition or bifurcation shifting condition. The four possible combined solutions are as following:

Solution 1

Q8 bifurcation (12m)+ North bifurcation (12m) + Original bifurcation (12m)

—————→ Spare course

Continue using the Q8 bifurcation, and then change it to North bifurcation when water level reaches 12m (discharge 10, 000m³/s) at Xihekou; after that change it to Original course when water level reaches 12m in North bifurcation. At last change the river course to the spare course when water level reaching 12m in the Original course.

Solution 2

North bifurcation (12m) + Q8 bifurcation (12m) + Original bifurcation (12m)

—————→ Spare course

Change the Q8 bifurcation to the North bifurcation now, then change it to the Q8 bifurcation again when water level reaches 12m in North bifurcation; after that change to Original course when water level reaches 12m in Q8 bifurcation. At last change the river course to the spare course when water level reaches 12m (discharge 10,000 m³/s) at Xihekou in the Original course.

Solution 3

Q8 bifurcation (65km) + North bifurcation (12m) + Original bifurcation (12m) +

Q8 bifurcation (12m) —————→ Spare course

The process is similar with solution 1, but the first bifurcation change is according to the control channel length 65km not water level 12m and at last change to Q8 bifurcation again.

Solution 4

North bifurcation (65km) + Q8 bifurcation (65km)+ Original bifurcation (12m) + North bifurcation (12m) +Q8 bifurcation (12m) —————→ Spare course

The whole process is similar with solution 2, but the first two bifurcation changes are in accordance with the control channel length 65 km, and the last two changes are shifting to North bifurcation and Q8 bifurcation again.

4.2.4 Comparison of four combined bifurcations

▪ Comparison on running life

Yellow River Design Company and Hydraulic Science Institute of China calculated the running life of the course for each possible solution. For each solution there are two results in accordance with two preconditions, which are that the Guxian Reservoir will be or not constructed in 2020 (Figure 4.6).

(Guxian Reservoir plans to be constructed in the middle stream of the main channel in 2020, when the Xiaolangdi Reservoir will finish its silt containing capability; its main function is flood control and silt containing.)

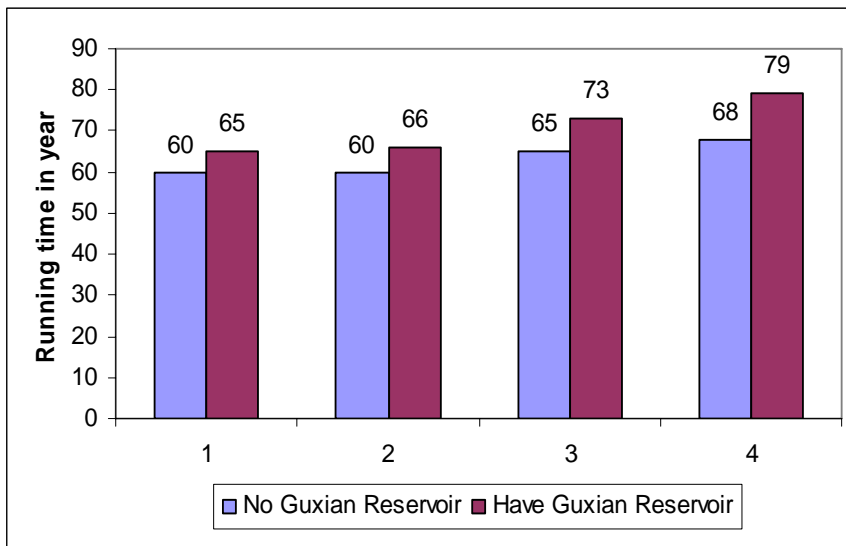


Figure 4.6 Running time for 4 solutions

Rank: solution 4, solution 3, solution 2 and solution 1

▪ Comparison on mean channel length from Xihekou to the mouth

The mean channel length from Xihekou to the mouth is one of the factors to reflect the feedback impact to the downstream of the river, because the stretching of the channel also means the decrease of riverbed gradient and thus lead to water level rise.

The mean channel length for each solution from 2004~2040 is 64.80km, 58.97km, 56.41km and 55.88km; from 2004~2060 is 64.0, 63.63, 61.86 and 62.32 respectively.

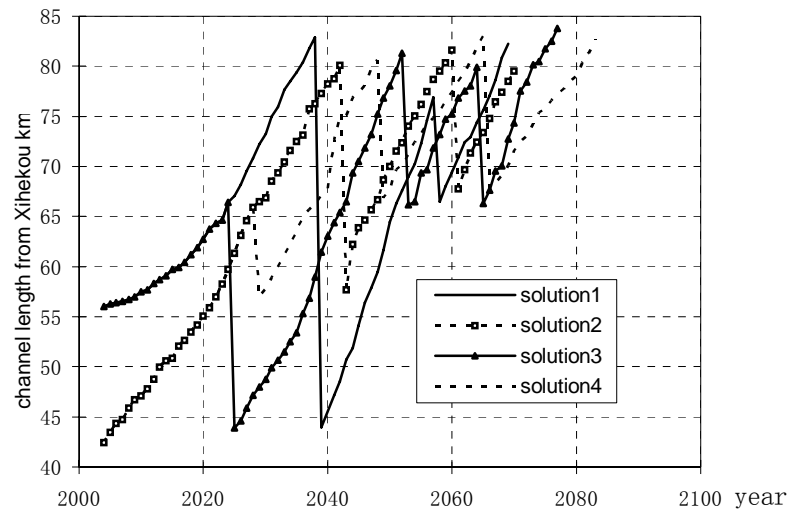


Figure 4.7 Mean channel length for four solutions

Rank: solution 3, solution 4, solution 2 and solution 1

▪ Comparison on mean water level at Xihekou

The one that first comes out the water level 12m when meeting 10,000 m³/s discharge at Xihekou is the solution 1, which comes out in 2038 and the latest time is in 2042 for solution 3.

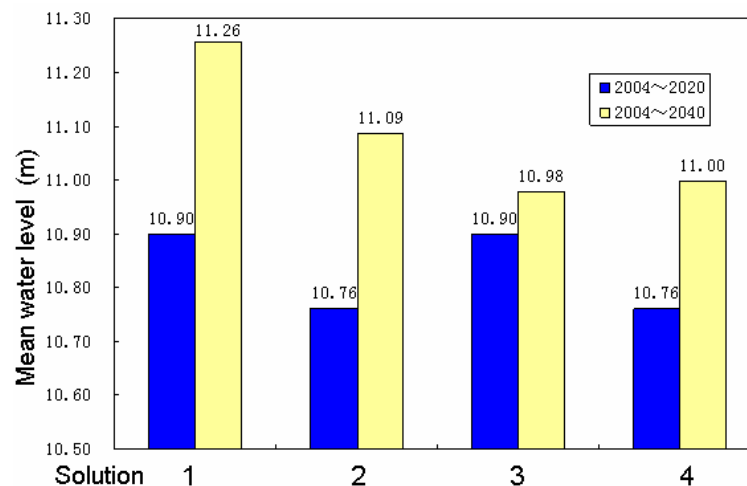


Figure 4.8 Mean water level for four solutions

Rank: solution 3, solution 4, solution1 and solution 2

▪ Comparison on accumulated sediments

The total amount of accumulated sediments in the 55km length channel upstream of Xihekou can reflect each solution's feedback impact of sedimentation for the downstream of the river. The total amount of the sediment for solution 4 is the least, and then is the solution 3. But according to the calculation of affected channel length, the solution 3 is the least in short-term 40 years.

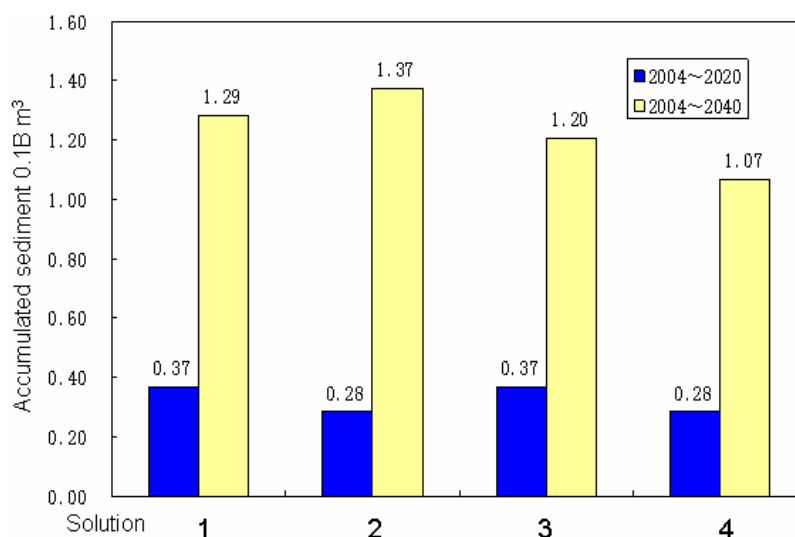


Figure 4.8 Accumulated sediments for four solutions

Rank: solution 4, solution 3, solution 1 and solution 2

▪ Comparison on running costs

The total costs for each solution include construction of flood defence works, bifurcating works, dredging, non-construction measures, construction management, and then according to the running mean running life for each course, get the annual cost for each solution.

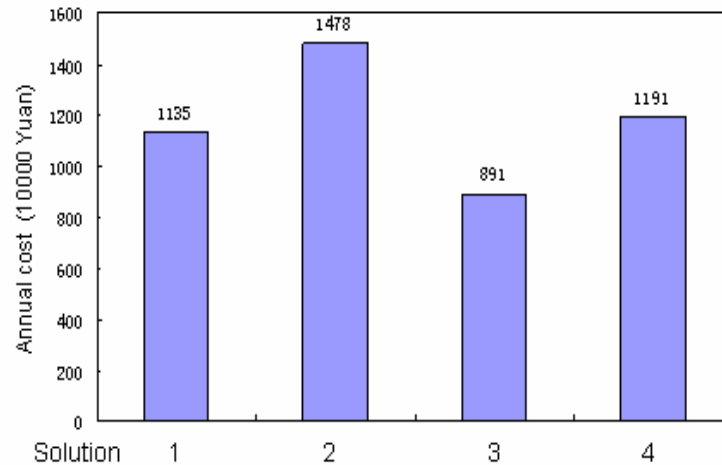


Figure 4.9 Running cost for four solutions

Rank: solution 3, solution 1, solution 4 and solution 2

Conclusion

From the comparison above in four respects, it can be concluded that the solution 3 is the best one in general. It has several advantages comparing with the other 3 solutions.

- (1) Reduce the channel length and keep relatively low water level at the same discharge in estuary. It has higher safety against flood.
- (2) Reduce the water level, the probability of floodplain flooding, and the natural breach. It keep relatively low water level, which has less feedback impact of sedimentation to downstream of the river.
- (3) On the basis of keeping high safety of flood protection, the invest scale of construction in short-term is relatively less; the flooding loss is relatively less as well.
- (4) As early as possible to shift to the North bifurcation from the current Q8 bifurcation, depositing silt and forming more floodplain in coast area near the North bifurcation mouth is favorable to oil prospecting and exploitation, and promoting the local economic development.

4.2.5 Measures for course training

The current course Qingshuigou has been running for 30 years and it will continue running about 50 years if adopting the combined bifurcation 3. But the realization of running life is established on the basis of under the control of engineering measures. It

cannot rule out the possibility of natural bifurcating or course changing in short term on the condition of natural evolution. So many courses changing in the history were not occurred at the end period of estuary development. Therefore, in order to relatively stabilize the current course, the construction of dikes and river training works must be intensified in the upstream of the 6th cross-section of Qingshuigou course and some supplementary engineering measures for river training are very necessary as well.

Many measures for river training were presented by some specialists in the past recent years, and several of which will be introduced in the following.

- Channel digging and dredging
- Divert high silt content flow for land-silting
- Draw seawater to scout riverbed
- Utilize maritime power to transport silt into deep sea

4.3 Spare course plan

The characteristic of less water and much silt for the current Yellow River have not had any great change, and the evolution of embouchure channel still follow the natural law of “silting, stretching, swaying and course changing”. Therefore, the spare course must be reserved in the deltaic area. Three spare courses are reserved on the comprehensive consideration of the historical condition of the course, the feature of marine area in delta, the past course plan and the socioeconomic development in deltaic area. The three selected spare courses are: Diaokouhe course, Maxinhe course and Shibahu course.



Figure 4.10 Spare course plan

4.3.1 Diaokouhe course

- Basic condition

Diaokouhe course had been running from January 1964 to May 1976, and now it has been stopped running for 30 years. During this period, the oil company conducted large-scale oil exploitation within the course scope and many oil and gas producing facilities were constructed; local government developed agriculture and forest industry as well. Although the original river course still exists now, the topography and landscape have changed greatly because of intervention of human activities and bad management.

During the running time, dikes were along the channel and the distance between dikes is about 8.6~14.2 km. But now most of the works have lost defence function. After course changing, 10 oil fields were discovered; large-scale infrastructures were constructed; 5300ha farmlands, 3300ha forests and 6600ha meadows were developed. 6751 farmers are living within the course scope and the national nature reserve is located at the estuary area

- Silt containing capability of the marine area

The marine area where Diaokouhe course located is close to the non- tide point, which belongs to high-speed sea-flow area, the largest flow velocity is up to 1.3m/s and the water depth is up to 20m. According to the measured marine topography, the silt influencing width is 50km and total silt containing capacity is about 14.5 billion m³.

- Possible running life

The channel length of the current Qingshuigou course would be about 80km after its full running life and the total length from Xihekou would be reduced 25km after the course changing to Diaokouhe. According to the design silt-water series condition, the annual mean silt amount coming to the estuary at that time would be about 0.58 billion tons. The calculating running life would be 31 years and 34 years respectively on the precondition of having and no Guxian reservoir.

- Construction quantity and costs

The main constructions include the guiding channel to the old course, dikes along the channel, channel regulation works, flow interrupting and guiding works, and some other rebuilding facilities. The total volume of earthwork and stonework would be about 42 million m³ and 0.69 million m³ respectively. The total cost would be about 1.1 billion Yuan.

4.3.2 Maxinhe course

- Basic condition

Maxinhe course is on the basis of the current Maxinhe River, the width of riverbed is 14.5~17m and the slope is 1:3. The planned Maxinhe course is basically widened on the basis of the Maxinhe channel. The total length from the changing point is 62km. The space between the dike for the planned channel is 3~4 km and all the dikes must be newly constructed, the left dike 53 km and right dike 54 km. 75 villages, 25.9 thousand people and 5.3 thousand hectare farmland will be affected.

- Silt containing capability of the marine area and running life

Maxinhe course is located at the west of Diaokouhe course, the water depth decrease from east to west and the largest depth is 20m. The offshore area that 24km far away at the west is where Dongfeng harbor and Binzhou harbor located, and 40km away at the west is the national harbor-Huanghua harbor. Therefore the silt containing marine area is about 30 km from the coast and total silt containing capacity is 39 billion m³.

The calculated running life is about 33~36 years according to the estimation of the mean annual silt quantity coming to the estuary is 0.58 billion tons and the silt depositing scope is 30km from the coast.

- Construction quantity and costs

The total volume of earthwork and stonework would be about 125 million m³ and 0.82 million m³ respectively. The total cost would be about 2.8 billion Yuan.

4.3.3 Shibahu course

- Basic condition

The Shibahu course is located at the south of the current course and flow into the Laizhou Bay. It is the shortest course that flowing into the sea in deltaic area, the course length is 32 km. Its north dike can be on the basis of the current south dike and the south dike needs to be constructed completely.

The course scope area is 150 km²; 14.2 thousand people and 3.2 thousand hectare farmland are concerned. No oil field is discovered as yet and no request for land forming from oil company. Moreover, an integrated storm sutgeprevention system has formed along the coast in this region.

- Silt containing capability of the marine area and running life

The marine area where Shibahu course located, the water depth is shallow; the largest depth is not more than 11m. It is the shallowest marine area around delta, the velocity of the tide flow is only 0.6m/s, and the function of sea power is weak.

The calculated running life is about 6 years according to the estimation of the mean annual silt quantity coming to the estuary is 0.58 billion tons.

- Construction quantity and costs

The total volume of earthwork and stonework would be about 16.5 million m³ and 0.57 million m³ respectively. The total cost would be about 1.4 billion Yuan.

4.3.4 Comparison of the spare courses and conclusion

Course length

The course length of Maxinhe and Shibahu are 30 km shorter than Diaokouhe course. It reduces the channel length and would cause effective feedback scouring for the downstream channel.

Marine condition

The marine condition of Shibahu course is the worst in the three plans, and it near Xiaoqing river mouth and Guangli harbor, which will be affected by silt deposition. Maxinhe and Diaokouhe course have relatively better marine condition, but Maxinhe course near Dongfeng harbor (24km), Huanghua harbor (41km) and Tuhai river mouth, which will be affected by silt deposition. Therefore, the Diaokouhe course is the best one in marine condition.

Running life

The running life of Shibahu course is only 6 years, because of the shallow marine area, which is about 20 years shorter than Diaokouhe and Maxinhe course. The running life of Diaokouhe and Maxinhe is similar.

Influence to socioeconomic development

The Maxinhe course runs through the relatively developed region in the delta and 25.9 thousand people and many oil producing facilities will be concerned. Whereas the Diaokouhe course is the old course running before 1976, which still keeps the original river form. Moreover, it has been clarified in the former “Courses for Yellow River” that Diaokouhe course is the spare course and the construction within the course scope is relative less; the affected amount of people is the least in three plans.

Total costs

The total amount of costs for the three courses is ranked as Maxinhe, Shibahu and Diaokouhe.

Conclusion

From the comparison above, it can be concluded that after the Qingshuigou course completing its running life, namely the running life of the three bifurcations, the prior plan to use the spare course is Diaokouhe course, then Maxinhe and Shibahu course.

4.4 Reinforcement of the river dykes and improvement of river training works

As mentioned in the Analysis chapter, there is more threat from scouring breach and collapsing breach than overflowing breach during flood, which is determined by the drastic wandering channel of the lower reaches of the Yellow River. So the priority work should be focused on prevention of scouring breach and collapsing breach through river training and dyke reinforcement.

- 1) Heightening and reinforcing the dykes which do not satisfy the designed standard.
- 2) Consolidating the dykes combining with dredging and discharging sediment in case of scouring breach and collapse breach when the flood runs near to the dykes.
- 3) Improving river training works to stabilize the river regime and control the main channel during medium flood, in order to make river course smooth and increase the sediment-flushing capacity.

4.5 Land use management

The law defines the land belongs to nation. The organizations or individuals have right to use, not possess the land. So the government has more room for readjust land use patterns.

- 1) In the middle Yellow River, changing land use from farming to planting the trees for water and sedimentation conservation with compensation and subsidy policy.
- 2) The defined land for flood defense and management along the dykes (10~50 m wide).
- 3) The limitation of land use and development in the spare river course.
- 4) Land management in flood plain (limiting building, relocation).

- 5) Keep the constant sum of farmland, encourage improving the saline lands.
- 6) Reservation and restoration of nature land.

4.6 Storm surge prevention system

4.6.1 General plan

The general tide prevention system along the delta coast is planned to establish two independent defence in north and south Yellow River systems on the basis of the current tide protection works. The Diaokouhe mouth, which plans to be used as spare course, will construct half opened tide protection dikes, which means the course mouth is open and two dikes will be constructed along the planned line of spare course dikes to against the tidewater invaded through the old channel.

The total length of planned dikes is 276.5 km, in which 140.5 km is the current dikes, 10 km is heightened and reinforced dikes and 126.5 km is newly constructed dikes. The tide protection standard is once per 50 years and the protection area is where the ground elevation below 4m (Huanghai Sea elevation), which amounts to 2153 km², accounting for 27% of the total area of the Delta.

4.6.2 Design criteria

- Design tide level

The investigated and real measured tide levels in the north and south Yellow River are 3.23m and 3.59m respectively and the calculated levels by different approaches are 3.35m and 3.64m respectively, which are very close to the real measured level. Therefore, the design tide levels in north and south Yellow River are determined as 3.5m and 3.6m respectively.

- Dike design

Design crest level of the dike

The design crest level of the dike is: the design tidal level + wave run-up + freeboard height 0.8m – the height of wave wall (1.0m).

The wave wall is concrete vertical wall and the height is 1.0m.

Unit: m

Section name	Design tide level	Wave run-up	Safety margin	Crest level		Top level of wave wall	
				Calculation	Design	Calculation	Design
North section 1	3.50	2.09	0.8	5.39	5.50	6.39	6.50
North section 2	3.50	2.09	0.8	5.39	5.50	6.39	6.50
North section 3	3.50	1.83	0.8	5.03	5.20	6.13	6.20
South section	3.60	2.65	0.8	5.95	6.00	7.05	7.00

Note: The tide protection dike in the north of Yellow River is divided into three sections by two river's mouths. So they are named north-section 1, 2, and 3 from west to east. The tide protection dike in the south of Yellow River is called south section here.

- Crest width

Considering the tide dike is also served as the road along the coastline, the crest width of the tide dike facing the sea directly is determined to be 9m, in which the road width is 7m; the crest width of tide dike along the old course is 7m.

- Dike slope and revetment

In general the outer slope is 1:3, and the revetment is concrete slab; the inner slope above the berm is 1:2, the berm is 1:3.

4.6.3 Non-constructional measures and institutional management

Establishing integrated observing, pre-warning and forecasting system is another main part to reduce flood risk and flooding damage. Recommend intensifying tide observing and research, establishing more observing station and getting more accurate tide data, and then improve the forecasting accuracy of storm surge intensity

Establish a uniform managing regime and a managing institution, which should be composed of local departments concerned and the oil company. On the basis of agreement, determine the specific dike sections that should be managed by each party and their clear tasks and responsibilities in dike maintenance and protection.

4.7 Improvement of the organizational and managing regime

4.7.1 Establishing the directorate to increase coordination

In the Yellow River Delta, there are several managerial parties with different responsibilities. In order to enhance the communication and cooperation of these parties, it is necessary to establish a directorate composed of these parties such as the YRCC, Shengli Oil Company, regional government and nature reserves agencies etc. The directorate will exert authority over the overall development of delta area, coordinate the relationships between the parties, supervise the development process and solve practical problems.

Central government should play the most important role in the directorate. Because the river course management is in the core position related to all the interests, therefore it is suggested that the Commissioner of the YRCC could be the president of the directorate.

4.7.2 Master plan for the future concerning the different interests

The common vision in the delta area is sustainable and multi-win development concerning the different interests, such as river management, exploitation of gas and oil, regional development, and nature reservation. The unified plan (Master plan) can provide the principle, procedure and approaches to guide the development activities in the delta area, avoiding a confused situation in investment and management.

4.7.3 Cost sharing for river management and flood control facilities

Because of concerning interests of several organizations, investment in the river management and flood control facilities should be shared by these organizations. Firstly, central government should supply the main funds for river management and nature reservation, which not only influence the delta area but the national environment, even the global environment. The estuary training works should be listed in the 'national capital construction plan'. It is the responsibility of central government. Secondly, the oil company should pay for the benefits from the river management and flood control, such as preventing flooding in the oilfield and transferring oil extraction from the shallow sea to land through land creation. The funds could be provided through taxes or flood control fees.

4.7.4 Clarifying management for flood control facilities

The flood control facilities should be managed by professional authorities. The flood control facility in the river channel of the Yellow River would be built, operated and

maintained by the Mouth bureau of the YRCC. The regional water resource bureau (under regional government) would be in charge of the building of a uniform sea defense system. The frame of the building and management for flood facilities is showed in Figure 4.11.

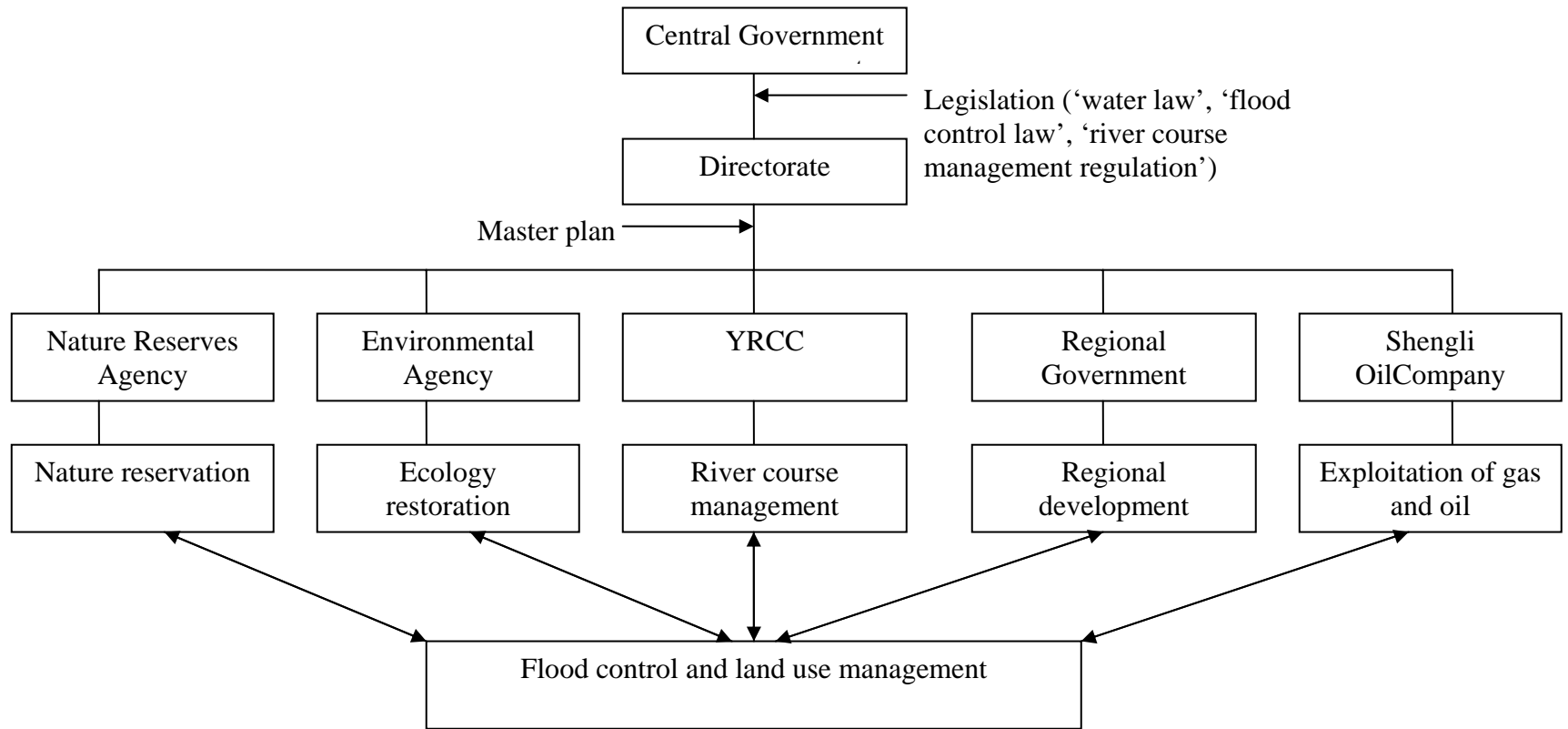


Figure 4.11 The structure of the managerial regime

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Part B: Rhine River Delta



1 Introduction

The Rhine is of great importance for the hydrology of the country, while the greater part of the surface water originates from it. High water levels occur regularly, and have been the cause of many cases of flooding, of which the impacts have increased due to land subsidence, population growth and the increase in value of buildings and infrastructure (Schultz, 2005).

1.1 The Rhine

The Rhine originates in Switzerland, with tributaries originating in the basin states: Switzerland, Germany, France and the Netherlands (figure 1.1). The Rhine flows through Germany and the Netherlands to the North Sea. The river has a length of over 1,320 km and its basin covers a surface of 185,000 km², of which 25,000 km² is in the Netherlands. The Rhine is both a rain-fed and a melt-water river. The relatively high water levels in summer are due to the regulating effect of the snowfields in Switzerland. In this period the surplus precipitation downstream of Basel, at the boundary of Switzerland and Germany, is low. In December the situation is reverse, and the river is fed by the precipitation surplus in the river basin downstream of Basel. The river is of great importance for the hydrology of the Netherlands, while the greater part (65%) of the surface water originates from it. The average discharge of the Rhine at Lobith - where the river enters the Netherlands - is 2,300 m³/s. At this discharge the water level there is almost 11 m + NAP (Dutch reference level, equal to Mean Sea Level) (Van de Ven, 2004; Schultz, 2005).



Figure 1.1 Rhine basin

Upstream from the Dutch-German border, the Rhine is a single river, fed by a large number of tributaries. Once in the Netherlands, the river changes into a system of Rhine branches: it fans out. The first bifurcation (the 'Pannerdaensche Kop') is found 10 km downstream from the border, where the Bovenijn splits up into the Pannerdensche Kanaal and the Waal. The second bifurcation (the 'IJsselkop') is that of the Nederrijn and the IJssel, 10km downstream from the first bifurcation. Further downstream, the Nederrijn changes its name and becomes the Lek. Further downstream again, the Lek and Waal join up in a number of water courses around Rotterdam, jointly known as the northern part of the Rhine-Meuse estuary. The IJssel discharges into the lake Ketelmeer, which in turn is connected to the lake IJsselmeer.

The River Rhine is divided into 5 reaches from its origins to the North Sea (figure 1.2):

Alpine Rhine and High Rhine: The Rhine has its origins in the Swiss Alps, where two tributaries (the Hinterrhine and the Vorderrhine) join together at Reichenau and flow as one river to Lake Constance. This part of the Rhine is called the Alpine Rhine. After leaving Lake Constance, the river down to the city of Basle is known as the High Rhine.

Upper Rhine: The reach of the river between Basle and Bingen at the Rhenish Slate Mountains is called the upper Rhine. This part of the Rhine was originally wide and dynamic, consisting of multiple channels and meanders.

Middle and Lower Rhine: Where the Rhine tries to find its way through the Rhenish Slate Mountains, the river is known as the Middle Rhine, and in the following stretch down to the German- Dutch border is called the Lower Rhine. The bed of the Middle Rhine is mostly rocky.

Delta Rhine: At the German-Dutch border, the Rhine changes from erosion to a sedimentation river, meaning that the Rhine Delta lies almost totally in the Netherlands. Just after entering the country, the river splits into three river branches: the Waal, the Nederrijn and the IJssel.

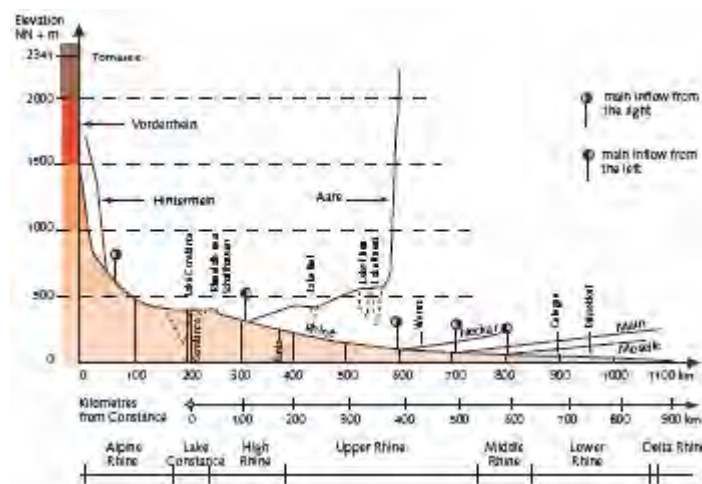


Figure 1.2 profile of the length of the Rhine

The Rhine is actually very modest in size, though it flows through an imposing list of countries. When compared with the top 10 of the world's largest rivers, it seems very insignificant, with an average annual discharge of 2300 m³/s. what makes the Rhine so special, however, is that it flows through the most densely populated areas of Western Europe. The Rhine is therefore one of the world's busiest shipping routes.

1.2 The Rhine Delta

The Rhine turns west in Germany and enters the Netherlands, where together with the rivers Meuse and Scheldt it forms an extensive delta. Crossing the border into the Netherlands at Spijk, close to Nijmegen and Arnhem the Rhine is at its widest, but the river then splits into three main distributaries: the Waal, Nederrijn ("Lower Rhine") and IJssel branches.

From here the situation becomes more complicated, as the Dutch name "Rijn" no longer coincides with the main flow of water. Most of the Rhine water (two thirds) flows farther west through the Waal and then via the Merwede and Nieuwe Merwede and, merging with the Meuse, through the Hollands Diep and Haringvliet estuaries into the North Sea. The Beneden Merwede branches off near Hardinxveld-Giessendam and continues as the Noord, to join the Lek near the village of Kinderdijk to form the Nieuwe Maas, then flows past Rotterdam and continues via Het Scheur and the Nieuwe Waterweg to the North Sea. The Oude Maas branches off near Dordrecht, farther down rejoining the Nieuwe Maas to form Het Scheur.

The other third portion of the water flows through the Pannerdens Kanaal and redistributes in the IJssel and Nederrijn. The IJssel branch carries one ninth of the water volume north into the IJsselmeer (a former bay), while the Nederrijn flows

west parallel to the Waal and carries approximately two ninths of the flow. However, at Wijk bij Duurstede the Nederrijn changes its name and becomes the Lek. It flows farther west to rejoin the Noord into the Nieuwe Maas and to the North Sea.

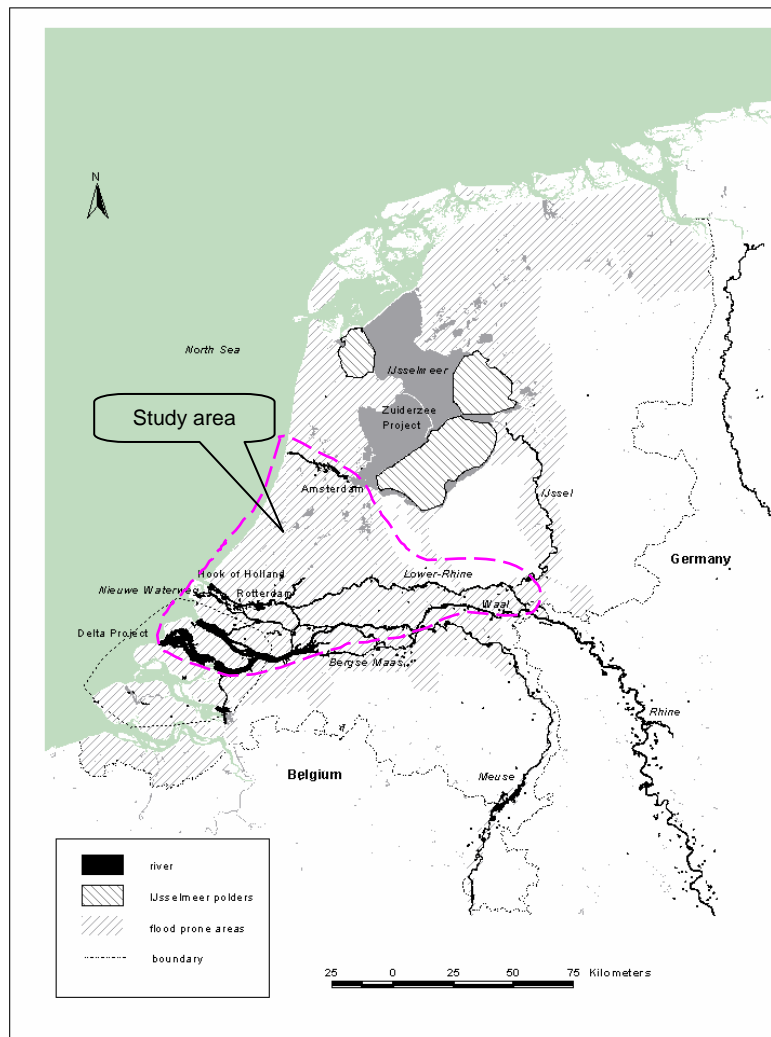


Figure 1.3 Rhine delta and study area

2 Main problems on flood risk management

2.1 Increasing flood risk

2.1.1 The flood of Rhine River

In 1993 and 1995, The Netherlands experienced periods of uncertainty when the Rhine and Meuse Rivers reached very high levels. In the Rhine River, only in 1926 had a higher discharge ($12,600 \text{ m}^3/\text{s}$) been recorded. Over 250,000 people were evacuated from a number of polders when the stability of the dikes seemed no longer guaranteed.

When the flood ceased, the discussions on The Netherlands' flood control strategy were intensified and extended to include climatic change as an additional relevant factor for the long term. Recent estimates of the change in the discharge regime of the Rhine River forecast an increase in the so-called design discharge (a peak discharge with a probability of 1/1250 years) from 15,000 m³/s in the 1990s towards 16,800 (minimum scenario) to 18,000 m³/s (maximum scenario) by 2,100. Additionally, in a downstream deltaic area, sea level rise may hamper the discharge. For The Netherlands, sea level rise is currently estimated as between 0.2 and 1.1 m above present. Finally, in deltas and alluvial plains both shrinkage and oxidation of extensive peat layers cause the subsidence of large areas, a process which in The Netherlands is enhanced and maintained by a history of over 1000 years of drainage (Fig. 2.1).

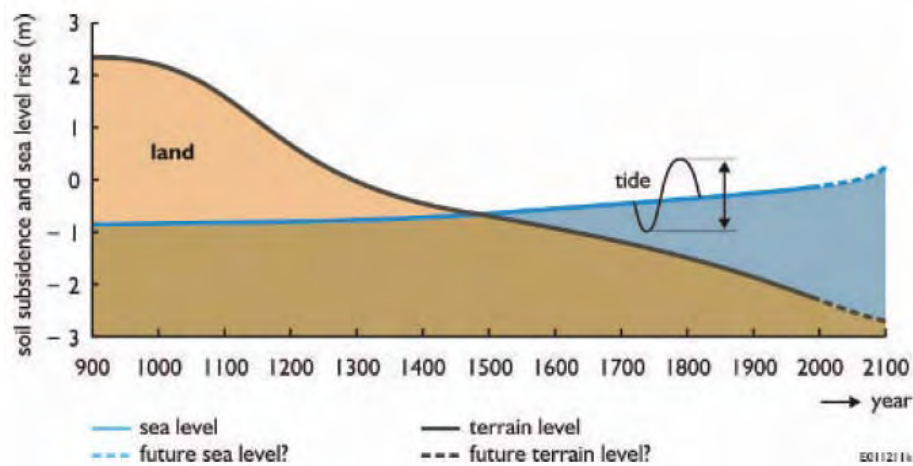


Figure 2.1 sketch of land level sinks and sea level rises

2.1.2 The storm surges

In addition to anticipating rising sea levels and soil subsidence, we will also have to take into account the increasing chance of heavy storms. And anticipation is an urgent necessity because nothing is as certain as the unexpected.

In the 1999-2000 winter, a relatively large number of storms raged across the North Sea and Western Europe. The question is whether there is a risk of severe material damage and victims as a result of such violent storms. Calculations have been carried out, for instance, for the Hook of Holland with the 1953 storm surge as a reference. The standard used is the water level of an event that has the chance of occurring once every 10,000 years (the safety standard). The calculations show that extreme high water levels along the Dutch coast with severe material damage or victims should not be ruled out. In its study, the Technical Advisory Committee for Water Defences ("from chance of exceeding to chance of flooding, June 2000) concluded that in the event of a sea level rise of 50 to 100 cm, the chance of

breaches in dykes and narrow dune ranges is a factor 2 to 4 or 6 to 15, respectively, higher than in the current situation (Fig. 2). As increasingly more investments are made in the low-lying part of the Netherlands, not only is there an increased risk of floods, but any consequences will also be more extreme – at least, if no countermeasures are taken (TAW 2000).

A calculated water level (m + NAP)

B difference from safety standard

A

B

I The maximum water level measured during the 1953 storm **3.85**

1.20 lower of 3.85 m above NAP. Since then, sea defences have been
(still safe) reinforced, so that this water level can be checked safely
in the current situation

II Due to a rise in sea level and soil subsidence since 1953, **4.05**

1.00 lower the water level during a storm similar to the one in 1953
(still safe) would already be approx. 20 cm higher

III In 1953, not all circumstances were equally unfavorable. **4.80**

0.25 lower

If, during the next storm, the spring tide is slightly higher
(still safe) and the direction of the wind slightly less favorable,
the water level will rise by an additional 75 cm.

IV And assuming the storm were 4% more severe, **5.05**

equal the water level will equal the current safety standard

V If the storm were 10% more severe, the water level **5.45**

0.40 higher would be approx. 40 cm above the level of the sea defences,
(dangerous) flooding of the hinterland is then possible.

2.1.3 The increasing socioeconomic development

Apart from these environmental changes, social changes are also relevant. The demographic and economic development of The Netherlands is such that the number of people possibly affected by a river flood has increased. By 1900 the population of The Netherlands amounted to 5 million inhabitants, whereas in 2001 the figure was over 16 million. In 1900, people lived very concentrated in relatively few cities however, whereas nowadays changing desires concerning the available room for housing; economic activity, leisure infrastructure, etc. have resulted in a spread over vast areas, and continuously high pressure on land-surface area.

Thus, the pressure on protected alluvial plains is becoming more intensive (Figure 2.2). The estimated financial loss through flooding of the largest dike-ring along the rivers was estimated at less than €7 million in 1990, but has risen to over 10 million

€ within 10 years merely as a consequence of economic development. The current mean economic growth rate of 2–2.5% will imply a steady doubling of the potential flood-damage each 35–28 years. In a century, this means an increase by a factor 8 (Frans Klijn, et al. 2002).

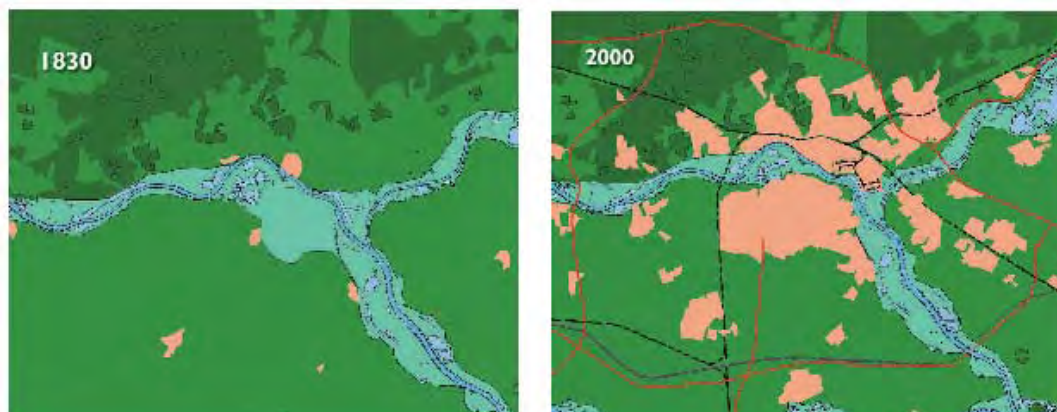


Figure 2.2 Floodplain area and land-use intensity around Arnhem in 1830 and 2000.

(Source: WL/ Delft Hydraulic)

Therefore, the design water levels in the rivers will probably rise because of higher peak discharges and a higher sea level, whereas the vulnerability of the protected areas will increase through population growth and economic development, aggravated by land subsidence. This calls for a change of strategy in the policy fields of both integrated river management and physical planning.

2.2 High cost in defense maintenance

The future will bring possible fundamental climate changes by which the normal loading on flood water defenses could increase. The increase in loading will consist on the one hand of an increase in Normal High Water (NHW) that is caused by an increase in river output as well as an increase in sea level. On the other hand structural ground subsidence is expected to occur in areas with weak soil layers (peat and some clay layers). Depending on the location in the next century, the NHW increase and ground subsidence could be up to 75 cm and 90 cm, respectively. In addition to a decrease in the defensive heights of the dikes, these changes will affect the behavior of the dikes and thus protection against flooding.

For dikes, a planning period of 50 years is currently used, which means that during this period the safety of the hinterland is guaranteed. This results in dike strengthening activities that theoretically follow each other every 50 years, which causes disturbance to the surroundings again and again and high cost in land use. Furthermore, with social developments in the future, more claims will probably be made on space for functions other than safety against inundation, such as the

landscape, the environment, nature, inhabitation, industry, etc. Because of this, traditional dike strengthening every 50 years will come up against greater social objections.

As a result of the future perspectives, the question has been raised as to how the dikes can continue to guarantee protection against flooding in the future. Is traditional dike raising by adding soil still possible or have we reached some technical or social limits?

3 Analysis of flood risk

3.1 Characteristics of Rhine

3.1.1 Discharge deviation

The Rhine is not only a rain-fed river, but is also fed with melt water from its source in the Alpine massif. This contribution to the total discharge certainly makes an impression on the annual discharge curve. The lowest discharge is generally in the autumn, when precipitation in parts of the river basin falls as snow. Melting of this snow then often results in the highest discharges of the year in early spring (figure 3.1): strikingly, high Rhine water discharge occur during the combination of plentiful rain and the release of large quantities of melt water. Approximately half of all the water entering the Netherlands at Lobith, comes from the Alps. In dry summer, this share of Alpine melt water can even run up as far as 95%.

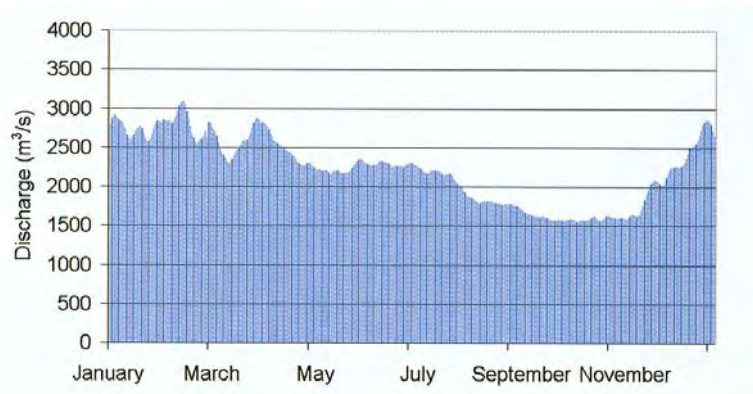


Figure 3.1 The average annual discharge curve of the Rhine at Lobith over a 50-year period (Source: RIZA)

The Rhine discharge is very variable over the course of a year, and from year to year. This has been very apparent in recent years: in 1994 and 1995, peak discharge of up to 5 times the average annual discharge occurred. The high water of 1995 was the second highest Rhine discharge of the past century, with no less than 12,000 m³/s at the German-Dutch border. The highest was 12,600 m³/s in 1926. Extremely low

discharge has also occurred in recent years, such as in the dry summer of 2003, when it was slightly less than $800 \text{ m}^3/\text{s}$.

The average discharge flowing into the Netherlands at Lobith is $2300 \text{ m}^3/\text{s}$. The greater the deviations from this discharge, the less likely it is to occur. Very low and very high discharges are therefore scarce. It means the occurrence of an extreme flood has a long repetition period or very slight probability. The high water of 1998, for example, had a peak of more than $9000 \text{ m}^3/\text{s}$ and its occurrence is at least once every 5 years on average. The flood of 1995 is considerably less common, while a flood of at least the scope of that of 1997, where the floodplains were only marginally flooded, occurs nearly every year (Wilfried Ten Brinke, 2005).

3.1.2 Discharge distribution and regulation

▪ Discharge distribution

The form and layout of the riverbed, up to approximately 25 km from the bifurcation point, almost entirely determines the distribution of discharge over the branches. Form and layout mean: height of the bed in the main channel, elevation and width of the flood plains, presence of embankment, overflows, abutments, vegetation and so on.

The distribution of the discharge over the Rhine Branches and thus also the design water level along the Rhine Branches are therefore bound to the river layout around the bifurcation points. Disruption of this distribution may bring immediate risks for the safety against flooding. The river manager therefore focuses a greater deal of attention on the management and maintenance of the river around the bifurcation points. If a change in the design of a Rhine Branches could lead to an adjustment on the discharge distribution, then compensatory measures must be taken in the same or other Rhine Branches.

Of the amount of water that enters the Netherlands at Lobith under representative circumstances, nearly 65% continues its journey via the Waal. More than 20% flows further via the Neder-Rijn and Lek, while the IJssel processes 15% of this distribution. For the most part, this distribution follows the pattern that was agreed upon during a convention between the province of Gelderland, Overijssel, Utrecht and Holland in 1771: 6/9 of the undistributed Rhine discharge via the Waal, 2/9 via the Neder-Rijn and 1/9 via the IJssel. This roughly sketched discharge distribution of the Rhine Branches is valid when considering the current discharge distribution of $15,000 \text{ m}^3/\text{s}$ at Lobith, yet remains nearly unchanged with an increase in the design discharge. One must keep in mind that the named percentages are the result of model calculations. Tests could not be performed since no design discharge has ever been confronted. This means, however, that the distribution of the design discharge

is still somewhat enshrouded in uncertainty. It is worthy of attention, since significant aspects of the safety along the Rhine Branches are based upon that calculated discharge distribution.

- Discharge regulation

River engineering constructions in the Dutch Rhine branches ensure that the Rhine water that enters the Netherlands is discharged to the sea in a regulated manner. The distribution of discharge among the branches in the upper course is regulated by weirs in the Nederrijn-Lek and by clever design of the shape of the branches themselves. Three weirs needed to be constructed in the Nederrijn for the purpose of improving navigation on both the IJssel and the Nederrijn-Lek and to increase the discharge of freshwater to the IJsselmeer Lake, one in the vicinity of the Nederrijn and IJssel branch in order to increase the IJssel discharge, and two further downstream in order to consequently keep the water level constant in the Nederrijn-Lek.

When the sluices in the Nederrijn-Lek are fully open, it is a free flowing river, just like the Waal and the IJssel. The ratio of discharges to the Waal, Nederrijn-Lek and IJssel is generally 6:2:1, at times of low Rhine discharge, the weirs are partially or completely closed. The most upstream weir (at Driel) determines the discharge through the Nederrijn-Lek. The weir is completely closed at Rhine discharges lower than $1500 \text{ m}^3/\text{s}$. it is completely open at Rhine discharge higher than $2350 \text{ m}^3/\text{s}$. in intermediate situation, the weir is gradually opened, step-by-step, as the Rhine discharge increases. When the Rhine discharge is less than $1500 \text{ m}^3/\text{s}$, there is a constantly low discharge through the weir: the central buttress of each weir complex also has a pipe to guarantee minimum discharge even if the sluice valves are completely closed. This discharge keeps the weir panels rinsed in order to maintain water quality. The minimum aim is $35 \text{ m}^3/\text{s}$ but this is not always possible if the Rhine discharge is very low: the lower limit is $20 \text{ m}^3/\text{s}$.

An increase in the Rhine discharge $1500 \text{ m}^3/\text{s}$ dams up the water upstream of the weir. When the discharge increases further, the weir gradually opens and the water level upstream drops again. The weir is completely open at a Rhine discharge of $2350 \text{ m}^3/\text{s}$. if the Rhine discharge increases even further, the water level will rise at same level as the discharge because of the river then flowing freely.

Sluice in the haringvlietdam allow for regulation of the discharge of river water to the North Sea. This is a combination of Rhine water and Meuse water: the water from the lower courses of Rhine and Meuse has joined forces at this point and forming a freshwater lake. The purpose of this sluice is sluicing the collected river water and against the seawater entering the Haringvliet. The sluice gates have two

slice valves, one on the seaside and one on the riverside. The general terms of the drainage programme are as follows. The sluice valves are closed at Rhine discharge up to approx. 1100 m³/s. at Rhine discharge between 1100 m³/s and 1700 m³/s, the sluice valves are open 25m² if the outer water level is lower than the inner water level. This maintains an average drainage discharge of around 50m³/s per tide. When the Rhine discharge is between 1700 m³/s and 9500 m³/s, a certain sluice opening is selected, depending on the discharge, so the greater the discharge, the larger the opening. Once again, sluicing only takes place when the outer water level is lower than the inner level. At Rhine discharges in excess of 9500 m³/s, the sluice valves are completely open (6000 m²) if the outer water level is lower than the inner water level.

3.1.3 Erosion and sedimentation

▪ Erosion

The elevation of a riverbed is not stable, and the bed can be lowered due to erosion or silted up due to sedimentation. Rivers that are fixed by means of dikes and groynes often show erosion of the bed. The fixing of the river often means that it is narrowed at the same time. The river will react by looking for space lower down to discharge its water. This will result in erosion and a decrease in the average elevation of the riverbed. In large sections of the Rhine branches, this erosion amounted to one to several centimetres a year for decades. In the previous century, this led to riverbeds deepening by as much as two metres.

Figure 3.2 shows the development of the bed level of the Bovenrijn and the Waal in three large time steps, starting from 1934 and ending in 1999. For each period, the amount of erosion and sedimentation has been indicated relative to the riverbed levels at the start of the period. It can be clearly seen that the colour of the picture turns increasingly more blue as time goes. In the first period, the riverbed did not become much deeper or shallower. In the second period, the bed level dropped due to erosion, especially in the upstream section, while sedimentation took place in the lower course. In the third period, the bed level dropped along the entire section of the Bovenrijn and the Waal. The bed fell several centimetres every year. This means that the riverbed came to lie 1-2 metres deeper during the past century. The main causes: a lagging reaction of the river to its being of shallows for the shipping traffic. Especially in the most recent period (1975-1999), dredging had a huge impact on the lowering of the bed.

Figure 3.3 shows the development of the bed level of the Pannerdensch Kannaal and Nederijn-Lek. From the figure, it can be seen that a great deal of blue in especially the two later period, so from 1950 on. But there is a special effect in the picture. Of

the total section of the Pannerdensch Kanaal-Nederfijn-Lek, the section of the Nederfijn-Lek is dammed up. A total of three weirs have been built in a channel section in the period between 1954 and 1970. On completion of the weir, the river was guided through the channel section, which, in all three cases, was lower than the original channel. Thus, the depth of the river after completion of the weir was monitored in a different and lower section of the river than before its completion, leading to a lowering of the bed that is artificial (Wilfried Ten Brinke, 2005).

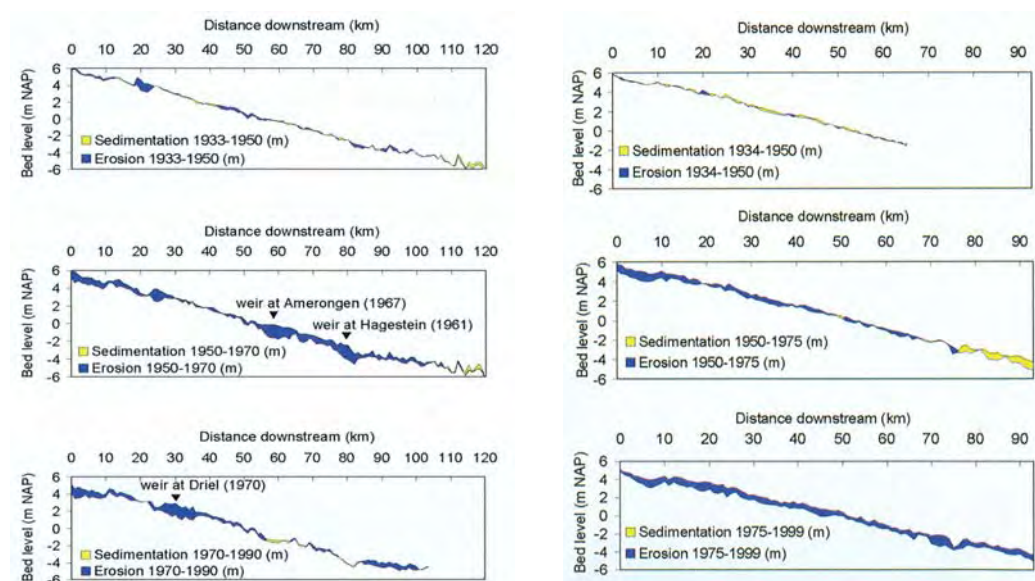


Figure 3.2 (left) changes in the bed level of the Waal during the past century

Figure 3.3 (right) changes in the bed level of the Nederrijn-Lek
during the past century (Source: TNO-NITG)

■ Sedimentation

The river on a permanent basis entrains sediment. Sometimes, the sediment flow expands because erosion of the riverbed or banks adds extra sediment to the flow. At other times, the flow will diminish due to sedimentation in the riverbed, groyne section and on the floodplains. The load of sediment that enters a river upstream is therefore not the same as the load that leaves it again downstream. To map the sediment flows upstream and downstream in the Dutch Rhine branches, it is necessary to take stock of all exchanges of sediment, all sources and losses, for riverbeds, banks and floodplains. This is represented in diagram form in Figure 3.4.

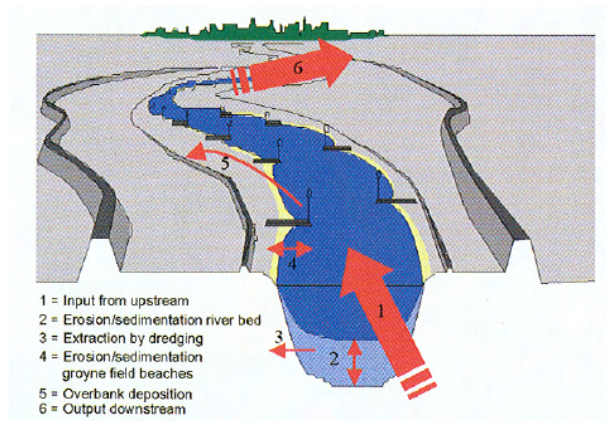


Figure 3.4 the sediment balance of the Rhine

For the system of Dutch Rhine branches, stock has been taken in the manner described above for each Rhine branch individually, and subsequently the results have been brought into line. In this way, insight is gained into the flows of gravel, sand and silt running through the Dutch Rhine system. Various situations can be put into the picture. The most interesting ones are those of the flows for an average year and the patterns for a flood: Figure 3.5 shows the outcome of this for gravel and sand.

The annual average picture (Figure 3.5 A) shows the sand and gravel flows per year, calculated as an average for a period of 20 years. Measurements show that about 570,000 m³ (855,000 tons) of sand and gravel enters the Netherlands from Germany every year. This comes down to roughly one truckload every 10 minutes. Almost all this sand and gravel is entrained to the Waal: a small part turn right at the point where the Bovenrijn bifurcates into the Waal and the Pannerdensch Kanaal and is distributed, further downstream in the Pannerdensch Kanaal, among the Nederrijn-Lek and IJssel. What stands out is that the amount of sand and gravel leaving the downstream side of the Rhine branches exceeds that which comes in upstream. This is the consequence of the lowering of the riverbed of the past few decades: due to erosion, extra sand and gravel has been added to the sediment flows.

The flood picture (Figure 3.5 B) shows how much higher the entrainment of sand and gravel is at high river discharge levels as compared to the rest of the year: in just a few weeks' time the river shifts a load of sand and gravel amounting to half the load shifted on average in a whole year.

The silt washes, as it were, through the river: whatever comes in from Germany flows on to the lower courses, where it settles. While it flows through the Rhine branches, the silt is evenly divided in the water. This means that the amounts of silt distribution among the Rhine branches are in proportion to the distribution of discharge among these branches. With silt flows, large volumes are involved. Figure

3.6 shows the flows of silt on an annual basis, together with the flows of sand and gravel for comparison (Wilfried Ten Brinke, 2005).

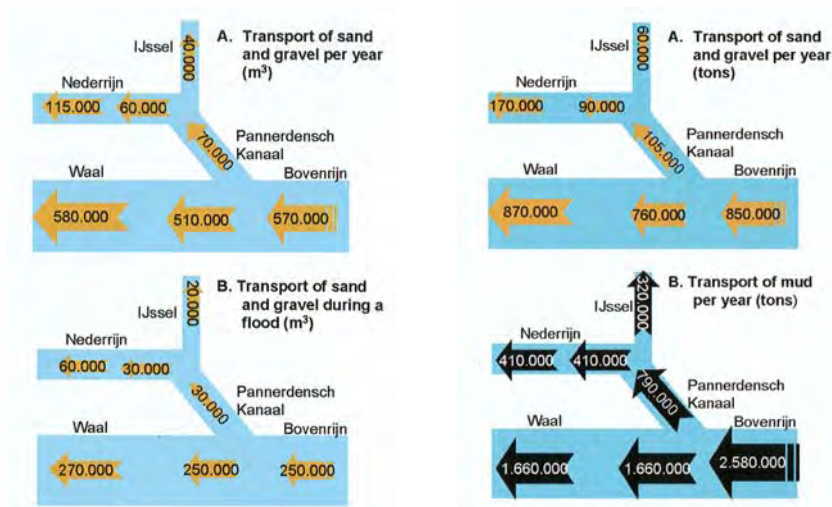


Figure 3.5 (left) the flows of sand and gravel through the Rhine branches, for the total volumes per year (above) and per flood (below)
Figure 3.6 (right) the flows of sand and gravel (above) and silt (below) through the Rhine branches, per year
(Source Wilfried Ten Brinke, 2005)

3.2 Flood defense standard (Rhine): design discharge and water level

3.2.1 Design discharge at Lobith

The design water levels are associated with the Rhine River discharge in terms of its 1/1250 annual probability of entering the Netherlands at the town of Lobith. This 'design discharge' is currently 15,000 m³/s at Lobith. This value was the result of research conducted by the Boertien Commission, a commission installed in 1992 by the Minister of Transport, Public Works and Water Management in response to the growing unrest and resistance within Dutch society to proposed dike reinforcements. For the sake of clarity: this design discharge does not yet take into account the flooding incidents of 1993 and 1995.

In the past, the design discharge has been subject to several variations, having been influenced by advancing scientific insight, as well as varying ideas concerning the best safety norms to be used. As a result, the river dikes along the Rhine Branches were adapted after the flooding of 1926 to correspond to the highest known discharge up to that point in history (roughly 12,500 m³/s at Lobith). The disastrous flooding of 1953 served to reinforce the existing doubts concerning the hydraulic capacity of the river dikes: in 1956, the design discharge of the Rhine was boosted to 18,000 m³/s with a probability of occurrence of 1/3000 per year. The consequence

of this was that the river dikes required major reinforcement. The unrest and resistance that arose in Dutch society as a result served as an impetus for the Minister of Transport, Public Works and Water Management to set up the Becht Commission in 1975. The most important conclusion reached by this commission was that it would be justified to take action based on a lower safety norm, specifically 1/1250 per year. The applicable design discharge was then adjusted to 16,500 m³/s. For the Rhine Branches Neder-Rijn, Lek and IJssel, this lower discharge led to lower design water levels, however this was not the case for the Branches Boven-Rijn and Waal. Worse still, they ended up with significantly higher discharge levels. Ultimately the Boertien Commission concluded in 1993 that the design discharge could be lowered to 15,000 m³/s; the safety norm of 1/1250 per year remained unchanged.

The significance is that the dikes along the Rhine Branches that have been reinforced over the course of time were not all adjusted using the same design discharge. The minimum discharge level that the dikes must be able to withstand is 15,000 m³/s (the current design discharge) but particularly along the IJssel River (upstream from Wijhe), the dikes are designed for a higher discharge.

3.2.2 The calculation of design discharge

The design discharge is derived using a statistical analysis of discharge peaks that have occurred in the past. In the Rhine at Lobith, measurements have been taken since the year 1901. First, they begin with the so-called homogenization of the flow measurement series. The Rhine catchment area has undergone a great deal of change over the course of time, which has resulted in changes in the discharge characteristics of the Rhine: the same precipitation pattern in the catchment area has now led to a different flood wave at Lobith, in terms of height as well as shape, than that seen at the beginning of the 20th century.

The canalization of the Oberrhein in the south of Germany represented an important change in the period 1928 – 1977, during which a total of 10 weirs were built and dikes were constructed close to the main channel of the river. As a result of this canalization, 130 km² of flood plain was eliminated, approximately 60% of the area present prior to these activities. The result of this is that flood waves that arise due to abundant precipitation in the south of Germany reach The Netherlands more rapidly and acutely than previously. The canalization of the Oberrhein causes an increase in the discharge peaks of approximately 250 m³/s at Lobith, averaged over a large amount of floods, but extremes of 700 m³/s have been known to occur. Floods that occurred before 1977 must thus also be corrected to compensate for the (partial) discharge-increasing effect of the canalization.

Other changes in the catchment area involve land use. This includes, among others, the increase in the urban (paved) surfaces and the intensification of agriculture, which is generally accompanied by drastic drainage measures. During extremely high periods of discharge however, both situations are actually of minimal importance. Such discharges normally occur after lengthy periods of heavy rainfall, sometimes in combination with frost in the ground. The absorption capacity of the ground is then either completely utilized or dramatically reduced: to a certain extent, the ground resembles a paved surface and precipitation results almost immediately in runoff. Finally, deforestation is often blamed as a factor that has led to higher river discharges. In the period up to the 19th century, this may have played a role. After this point in time, however, extensive reforestation activities, particularly in Switzerland, have been carried out.

The homogenization of the flow measurement series for the effect of the Oberrhein canalization is followed by a statistical analysis. The result of this is a graph with the probability of a flood along the horizontal axis and the height of the discharge on the vertical axis. The line that can be drawn for the occurring discharge peaks since 1901 is called the work line. By lengthening this, the discharge with a 1/1250 probability of occurrence can be read. The current work line is thus that of 15,000 m³/s at Lobith.

3.2.1 Design water level and design dike height

- Design water level

The last time that the design water levels were calculated and then established was in 1993 and 1996, respectively. The determination in 1996 coincided with the enforcement of the Flood Management Legislation in that year. The next determination took place in 2001. Incidentally, the calculations of the design water levels in 1993 were based on field data for the level of the low flow channel bed dating back to around 1980.

If the design discharge at Lobith is known, then the design water levels on the Rhine Branches can be calculated. Two-dimensional computer models are used to do this in which the discharge of the water and the water levels in the river are simulated. The design discharge is set at the upstream boundary of the model, which is at Lobith. The model then calculates the discharge across the three Rhine Branches and the corresponding water levels. The water levels are calculated across the total length of the Rhine Branches and the total width of the riverbed. The water levels in the middle of the main channel are then considered the design water levels. In particular, the water levels at the inner and outer edge of a river bend can differ, which is of course of interest for dike heights.

For a specific discharge the water levels are mostly determined by the space that is present in the riverbed and by the flow resistance that water encounters around summer embankments and over vegetation, for example. The relation between design discharge and design water levels is therefore not fixed. It is for this reason that widening and deepening of the riverbed by, for example, the lowering of the flood plain, with the same design discharge can, lead to lower design water level.

- Design dike height

In terms of height, width and slope, dikes are designed so that they can stem the discharge of floodwater for a pre-determined length of time. This water level has a certain probability of occurring that corresponds to the level of protection that has been chosen for the various dike ring regions. These levels of protection – which may also be considered safety norms – are laid out in the Flood Management Legislation. The dike rings in the study areas have a protection level of 1/1250 and 1/2000. In the western part of the Netherlands, the protection levels are significantly higher: 1/4000 up to 1/10,000 in the dike ring ‘Central Holland’, for example, a region including the cities of Amsterdam, The Hague and Rotterdam, and the area in-between (Figure 3.7). This is associated with to the larger economic interests and population densities, but also the difficulty in prediction of a storm at sea, which carries with it a higher probability of victims, and the fact that seawater is salty and brings with it greater degrees of damage in the event of flooding.

Wind set-up and wave run-up are also taken into consideration when determining the height of a dike. Extra height, so-called freeboard, is given to the dike in connection with uncertainties that may arise in the calculation of the design water levels, in order to keep the dike passable so it may be used as an inspection path, and to compensate for any subsidence of the embankment. Additionally, the dike must be wide enough to make up for differences in carrying capacity of the subsoil and in ground water discharge under and through the dike by which weakening and, in the longer term, sliding can occur.



Figure 3.7 dike rings and safety levels along the lower Rhine River

3.3 Floods and causes of the river

3.3.1 Causes of a flood wave

The main cause of a flood wave is by rain that falls on the Rhine catchment area. But that is not the only factor. Important issues are where, in which sections of the catchment, and when the rain falls. In short is the pattern of precipitation. Several aspects have influences on the generating of flood, such as whether it rains for an extended period causing the subsoil to become more or less saturated, barely able to absorb rain, whether the subsoil frozen leads to rapid run-off of precipitation, or the temperatures, instead, relatively high which causes snowfall to melt. This means that nearly every flood at Lobith has been caused in a different manner. A decisive factor in the height and form of the flood wave at Lobith is the interplay of inflow from the tributaries to the Rhine River and the discharge on the Rhine itself. This concept is illustrated below in light of the two most recent floods.

- The flood of December 1993

In 1993 on the border of the Alpine region, an average discharge developed and merged with the Neckar River to become a flood wave with a recurrence interval of approximately two years; in other words, a flood wave with an average probability of occurrence of once every two years. Simultaneously, the Neckar transported a flood wave with a recurrence interval of 50 years. With the contributions of the Main and the Nahe, a flood wave developed on the Rhine with a recurrence interval of 35 years. At Koblenz, the discharge peaks of the Rhine and Moselle nearly coincided. The discharge from the Moselle, at 4,200 m³/s, the highest since regular measuring began in 1817, generated a flood wave on the Niederrhein that, based on height alone, had only occurred once in the 20th century. At Cologne (Köln), the wave was so high and lengthy in time that the dike around the city center was flooded for 70 hours. High dikes downstream from Cologne were able to prevent further disasters in those areas. The flood of 1993 thus arose in the central and southern parts of the Rhine catchment area.

- The flood of January 1995

The origins of the flood of 1995 were also not to be found in the extreme discharges from the Alps. In 1995 the recurrence interval of the discharge peak on the Alpine border was 20 years, but the peak did not last long. After only one day, the river returned to its average high water situation locally. Due to the fact that the contribution of the southern German tributaries was relatively small, the Rhine discharge from Mainz upstream had a recurrence interval of less than 10 years. Thanks to an extreme discharge from the Main, the discharge on the Central Rhine in 1995 however was higher than that of 1993. The situation in Koblenz was less dramatic since the discharge peak from the Moselle was approximately 600 m³/s less than in 1993, resulting in a 31 cm lower water level in Koblenz than in 1993. However, heavy rainfall in the sub-catchments north of the Moselle led to such an increase in the discharge from the Rhine that the water level at Cologne was 6 cm higher than in 1993, thus rendering it equal to the highest registered water level in the 20th century (1926) (figure 3.8).



Figure 3.8 flood of January 1995 (Source: IRMA, RIZA)

3.3.2 Changes of river system

In the ninth century the pattern of the Rhine was fixed for the greater part. It flowed to the sea in wide beds full of shallows and sandbanks. The discharge was distributed among several river branches as a result; in normal circumstances, many river arms carried little water. Still, it was not unusual for the river to overtop its banks when the water level was high. From 1100 onwards, as a result of reclamations in the river basin, the regime of the river became more irregular, causing more extreme high water levels. The water of the Rhine flowed to the sea via two river systems. The Lower Rhine system - consisting of five branches - flowed to the West and discharged in the North Sea. The other system - consisting of two branches - flowed into the Almere lake, which later on grew, became an estuary of the North Sea and was renamed as the Zuiderzee. After the completion of the Enclosing Dam in the mouth of the estuary in 1932 the Zuiderzee was transformed into the IJsselmeer.

Between 1000 and 1250 many changes occurred in the river system. Several branches were dammed up. There are no direct records of river floods before 1200, because at that time rivers were non-diked. The overtopping of the banks by a river was not considered a disaster. The first river flood that has been recorded in historical sources is the bursting of the northern dike along the Lower Rhine system in 1233. About 1200, the surface level of the peat land north of the Lower Rhine system had already dropped considerably as a result of age-long, gradual land subsidence and oxidation (De Bruin and Schultz, 2002). In the case of collapse of the northern dike along the Lower Rhine system, a very large area in the present

provinces of Utrecht and South-Holland would be flooded (Figure 2). Apart from the construction of dikes, another possibility of controlling rivers was the upstream damming up of river branches. This not only shortened the dike rings but another major advantage was that only the water from one's own region needed to be drained by such a dammed up branch of the river.

At about 1300 the system of rivers was still largely intact. In the period between 1250 and 1600 by damming up branches of the rivers in this system the branches suffered from the increased influence of the sea in the Southwest. As a result of this influence several branches disappeared in the extending sea arms. Further inland the encircling dikes were closed at about 1300. Until well into the nineteenth century attention was mainly focused on the prevention of river floods.

In 1809, 1820, 1855 and 1861 large parts of the river area were flooded. The floods were caused by three imperfections of three rivers. The riverbeds were in a bad state, there were too few river mouths, and, in the Lower Rhine system, the upstream mouth of one branch, the Old Rhine, was not closed off. Because of the bad state of the riverbeds it was impossible to carry large amounts of water to the sea. At some locations the dikes on both sides were situated very close to one another. Often they showed sharply receding and protruding angles. Through the years the course of the dikes became increasingly irregular because, when a dike did burst, the waters swirling through the breaches scoured out deep pools and when a dike was repaired it had to make a detour around such pools. Besides, within the river forelands there were many obstacles that obstructed a regular discharge. The so-called summer dikes - shallow dikes - had been built higher to protect the river forelands against the water for as long as possible. The river forelands were also planted with woods and reeds. Even in the actual base flow beds the flow met with all kinds of obstacles in the form of islands and sandbars. The first thing to be done was to regularize the river. This meant giving the riverbed the required regular form at low and high water in a vertical and horizontal direction over a short and long distance. When a river had been regularized it could still, depending on discharge and bends, determine its own width and depth.

The process of making a river suitable for navigation was the second stage of river improvement. By constructing groynes and jetties the channel profiles were narrowed, in order to get a certain water depth (Figure 3.9). There were too few river mouths to discharge the water adequately to sea. The main branch of the Rhine - the Waal - coalesced at some places with the Meuse. As the Waal carried down a lot of water until the end of June, it was impossible for the Meuse to discharge water into the Waal in the spring months. In winter this confluence had even more serious consequences: ice dams were regularly formed, pushing up the water, overflowing

dike sections, which were subsequently washed away. Another problem was the deplorable discharge of the Meuse and the Waal waters towards the North Sea. According to an agreement obligation with Prussia (in Germany), the upstream mouth of the Old Rhine near Lobith had to remain open. In 1800 an osier dam (spillway) was made here with a height of 11 m+NAP. This dam had to decrease the inlet of water into the Old Rhine. The lateral diversion via the spillway was rather disadvantageous during high water levels with ice drift. In the main river downstream of the lateral diversion the current velocity decreased in such a way that ice could be stuck here and ice dams were formed.

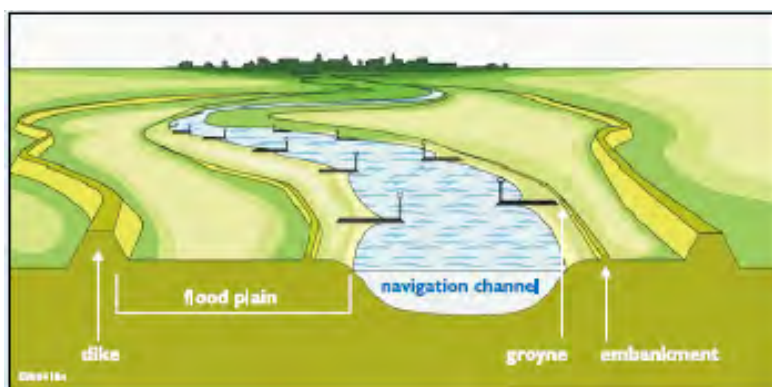


Figure 3.9 Current river system (Source: IRMA, RIZA)

Apart from shortcomings in the river system itself, the dikes too were in a bad condition. They were low, the crests were not very wide and the dike slopes were too steep. Especially the northern dike along the Lower Rhine system caused much anxiety. This was of poor quality and was located on a weak subsoil of peat and quicksand. As there was a relatively large difference in height in the direction of Central Holland, a dike burst would flood large parts of Utrecht and Holland (Bart Schultz, 2006).

3.3.3 Increase of land subsidence

Independent of the changing climate and the isostatic land subsidence, the Netherlands is also confronted with a subsidence in peat areas. Since the Middle Ages as much as 2–3 m of land subsidence has occurred in some peat areas. This land subsidence is correlated with the drainage of the peat; as a result the peat shrinks and oxidizes, disappearing as carbon dioxide (CO₂) into the atmosphere. Depending on the water level, this land subsidence can be up to 1 cm per year. At this rate, a subsidence of 0.5 m will occur in some of the peat areas until 2050 (Figure 3.10). If land subsidence continues, areas with thick layers of peat – in particular in the western parts of the Netherlands, where there are local depositions of peat up to 12 m thick – could, over the long term, be subjected to increased flood effects, increased surface water salinity and a water system that is increasingly

difficult to manage. In several areas (for example, around Slochteren in the north-eastern part of the country) land subsidence also occurs as a consequence of gas extraction. In these areas an extra subsidence of about 60 cm is expected by 2050.

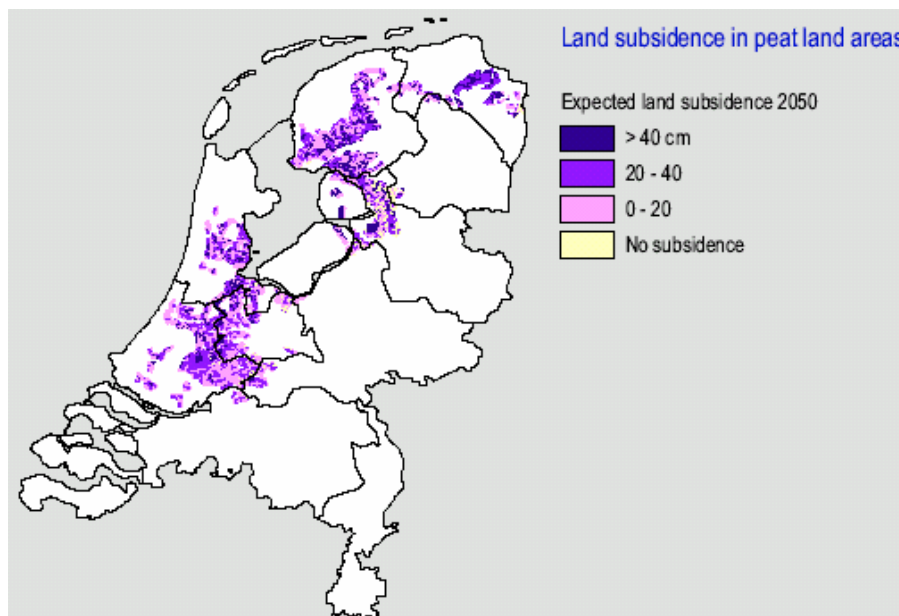


Figure 3.10 Land subsidence (Source: MNP)

The rising temperature, the longer summer season and a greater difference between wet and dry conditions (oxidation pump) will most likely result in a faster oxidation of peat. This in turn may lead to accelerated subsidence.

The rates of land subsidence are the same everywhere due to variation in peat soils and differences in water management. For example, agriculture requires a relatively deep drainage level, whereas urban areas in peat areas require a relatively high water table in order to prevent wooden pile foundations from decaying. Land subsidence in the peat areas therefore leads to an increasingly fragmented water management system, to a stronger salt seepage (detrimental for agriculture) and to damage resulting from the subsidence of roads and buildings. Various provinces – especially in the western part of the Netherlands – have consequently included measures to counteract land subsidence (Figure 3.10). These measures, however, only affect 4% of the total peat land area (M.M. Berk, G.J. van den Born, L. van Bree, et al. 2005).

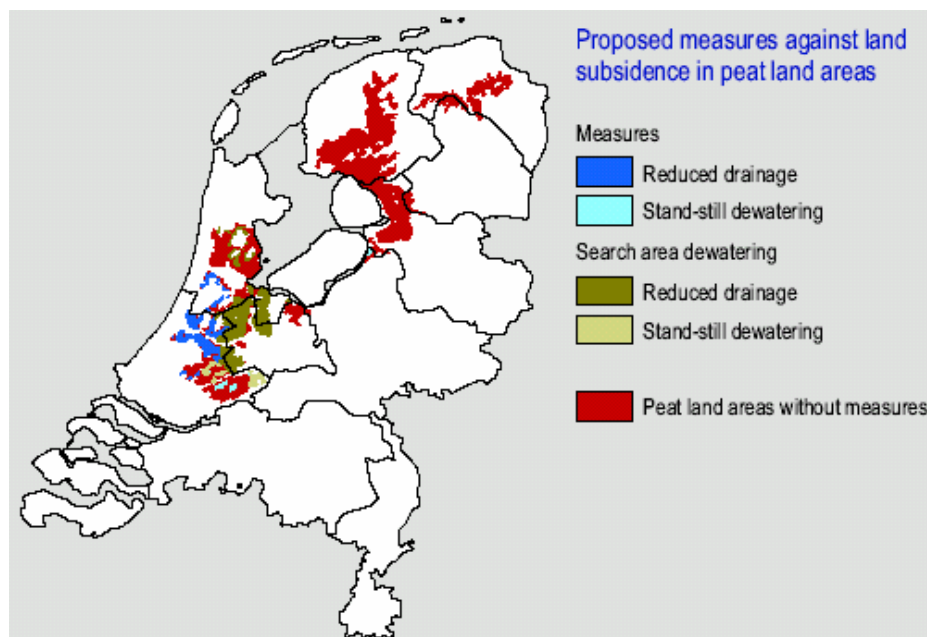


Figure 3.10 Proposed measures against land subsidence (Source: MNP)

3.3.4 Consequences of sea level rise

For the last 100 years, water levels measured along the Dutch coast have become higher and higher. The cause is not only that the sea level rises in the absolute sense of the word, but also that the coastal area is sinking. The combination of these two effects is called relative sea level rise. This amounts to some 20 cm per century. The expectation is that this trend will continue along the same line in the near future.

Additionally, just as with the river discharges, the consequences of climate change must also be taken into account. There are also various scenarios developed for this situation. The mid-range estimate of a 1°C increase in temperature around the year 2050 assumes a relative sea level rise of 25 cm. The upper estimate of a 2°C increase coincides with a sea level rise of 45 cm around 2050. The sea level rise in 2015, can be derived from these previous figures; the upper estimate will then total around 15 cm. Higher sea levels do not have to irrevocably lead to higher design water levels. By adjusting the management of the flood protection barrier on the New Waterway, the effect of sea level rise can be mitigated.

The consequences of all of this for the Rhine Branches can be illustrated that: the high estimate of 45 cm rise in sea level in 2050 would result in an increase in the design water levels of approximately 10 cm in the Lek River at Schoonhoven, and about 5 cm in the Waal at Gorinchem. If we combine this upper estimate for the rise in sea level with an increase in the Rhine design discharge at Lobith of up to 18,000 m³/s in 2050 and we leave the lay-out of the river region unchanged, then this rise at both locations would become approximately 80 cm. Therefore, the increase in the

water levels at the downstream of the branches is caused chiefly by a higher Rhine discharge and to a lesser degree by a rise in sea level. What is not taken into account in this situation is the fact that the rise in sea level can also have indirect influence on water levels via riverbed development in the lower river regions. If the average water level increases due to a rise in sea level, then the riverbed can rise due to sedimentation. Given the same scenarios described above for sea level rise and Rhine discharge, the bed level in the lower river region in 2050 will result in an approximately 25 cm higher water level at Gorinchem and Schoonhoven.

3.4 Storm surge hazard

Since 1962 the number of storms per year has decreased. Figure 3.12 shows the distribution of the 700 most extreme storms in the Netherlands over the past 41 years. The wind speed associated with these storms was, depending on the location within the country, more than 11–16 m/s; this is equivalent to a wind force of 6–7 on the Beaufort scale. Moreover, even if only the 300 or 500 most exceptional events are considered (heavier storms), the picture does not change: the number of storms in the Netherlands is decreasing. To what extent this decrease is correlated with rising temperatures is not clear.

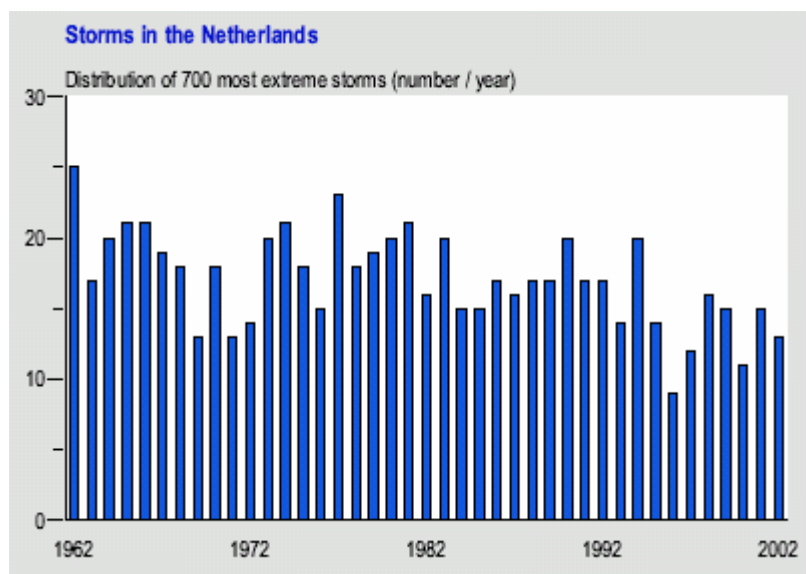


Figure 3.12 Distribution of the 700 most extreme storms in the Netherlands over the past 41 years (Source: KNMI)

The large uncertainty in the effect of climate change on the storm patterns in the Netherlands means that an understanding of changes in the likelihood of storm floods is far from complete. Recent research with large-scale models indicates a possibility of ‘super storms’ occurring within the orders, with the chance of significantly higher wind speeds than the Netherlands have experienced in the 20th

century. Further research with more refined models is necessary in order to understand the underlying processes (M.M. Berk, G.J. van den Born, L. van Bree, et al. 2005).

3.4.1 Storm surges in history

The primitive dykes of the early Middle Ages provided very poor protection against the sea. Each century had its floods. There were 111 serious or very serious floods in the West Netherlands between 1000 and 1953. Many were named after the saint's days on which they occurred. They included the St Agatha flood (1288), the St Elizabeth flood (1421), the St Felix flood (1530) and the All Saints' flood (1570).

The storm surge of February 1st 1953 caused one of the biggest natural disasters in the history of the Netherlands. The death toll of 1,853, an unprecedented high figure for Dutch standards, made a profound impression and roused emotions. The water levels that occurred during this storm surge at Hoek van Holland are the standard for the northern part of the delta area, and showed a highest water level of 3.85 m+NAP, which is 0.57 meters higher than the highest recorded water level of 3.28 m+NAP in 1894. A frequency analysis of the highest levels over a period of about 100 years shows that the water level of 1953 has an average chance of occurrence of one in about 300 per year. Such high water levels will probably have occurred more often in the past thousand years and there are significant indications that the well-known storm surges of 1421 and 1570 must have just as serious (Figure 3.13).

The Netherlands was not prepared for a storm surge of such magnitude, although the Storm Surge Commission had already expressed its doubts about the quality of the dikes in 1942. The destruction as a result of the disaster was enormous. No less than eight hundred kilometers of dikes had been severely damaged and about one hundred tidal breaches were made. In the fine-grained sandy soil of the gullies, erosion soon occurred making the breaches wider and deeper, sometimes up to 20 meters or more. 2000 km² of land were flooded, for the greater part with saline water. More than three thousand houses were destroyed and 43,000 were damaged. 72,000 people had to be evacuated. The total material damage was assessed at €450 to 680 million in the currency of those days. The cost of the repair was estimated at around €450.



Figure 3.13 Flooding areas in 1953

The investigation into the causes yielded important information. Dikes had collapsed because their crests turned out to be lower than the level of the outside water, so that the water could flow over the dike and for a considerable period of time scoured out the inner slope. This happened predominantly in harbors where the dikes were relatively lower than elsewhere, because the waves did not usually have access there; hence they were not designed to withstand the uprush of waves against the outside slope. The largest tidal beaches occurred here. In places where the crest was situated above the highest level of the outside water, the breach in the dike turned out to be caused by waves rushing over the dike, washing away the inner slope. In most cases it appeared that the outer slope, with the protective stone revetment had remained practically undamaged.

3.4.2 Storm surge protection system (the Delta project)

A disaster of the scale that occurred in 1953 had to be prevented in the future. That was something everyone agreed on. The specially appointed Delta Committee came up with a plan in the same year. They recommended strengthening the flood defences and cutting the coastline by 700 kilometres. The shorter the coastline, the easier it would be to protect it.

The plan was not new. Long before the 1953 disaster, the government had conducted studies into ways of defending the delta area in the southwest Netherlands from onslaughts by the sea. And Dutch hydraulic engineers already had some experience reducing coastlines. In 1932, they constructed the Barrier Dam to cut the Zuyderzee off from the North Sea, creating the IJsselmeer. In one fell swoop, the Dutch coastline was shortened by 360 kilometres, and the danger of flooding was considerably reduced.

The Delta Committee proposed closing off all the inlets in the delta area, and raising all flood defences to delta level, five metres above AOD at Hook of Holland. This would reduce the risk of flooding to 1:4,000 a year in the delta area and the north, and 1:10,000 a year in the Randstad. The New Waterway and the Western Scheldt would remain open to shipping, given the economic interests of the ports of Rotterdam and Antwerp, but the dykes on these waterways would also be raised to delta level.

The Delta Act, based on the plans put forward by the Committee, was finally approved by Parliament in 1957. Besides providing protection against the sea, the Delta Project would improve water management in many parts of the country, reduce salinization, produce freshwater reservoirs and create new recreational areas, while the new dams would greatly improve access to the southwest Netherlands.

The Delta project (Figure 3.14)

Hollandsche IJssel storm surge barrier (1958)

Construction of the Hollandsche IJssel storm surge barrier marked the start of the Delta Project. The Hollandsche IJssel runs into the New Waterway and the Maas forming an open passageway to the sea. The storm surge barrier, constructed to the east of Rotterdam, was completed in 1958 to protect the lowest-lying part of the Netherlands - at 6.5 metres below AOD - from flooding. The barrier is eighty metres long and comprises four piers that tower 44 metres above AOD and support two huge gates. In normal conditions, the gates are suspended high above the water, forming no obstacle to shipping. If the water rises to dangerously high levels, the gates can be lowered, damming the river. Ships can then pass through the lock.

Zandkreekdam (1960)

Shortly after the Hollandsche IJssel storm surge barrier was completed, the first sea inlet in Zeeland was closed off by dams. The Three Island Project, as it was known, was launched in 1953 with the aim of constructing two dams to connect the islands of Walcheren and North and South Beveland. In 1959, construction began on the smaller of the two, across the Zandkreek between North and South Beveland. The Zandkreekdam, which is 830 metres long and has a lock, was closed off with caissons in 1960.

Veerse Gatdam (1961)

A different approach had to be adopted to the Veerse Gat dam between Walcheren and North Beveland. The Veerse Gat is broader than the Zandkreek and at every tide more than 70 million cubic metres of water pass through it. Sluice caissons were used here instead of conventional caissons. The foundations of the dam were

constructed on the shallows of an existing sandbank. A stone sill spanning the entire 320-metre-wide inlet was then built to support the sluice caissons, each of which was as big as a seven-storey block of flats. The caissons were left open as they were put in place to allow the water to pass through. They were closed off at slack water between low and high tide, when the sea is relatively calm. The dam was finished off in 1961. The first inlet in the Delta was now completely closed and the salt water turned brackish. Zeeland also had a new lake, the Veerse Meer, now a popular leisure area.

Grevelingendam (1965)

Work on the Grevelingendam between Schouwen-Duiveland and Goeree-Overflakkee started in 1958. At six kilometres, this dam is longer than both the Zandkreekdam and the Veerse atdam. New technologies and materials were needed to build it. Part of the dam was constructed by raising the Oude Tonge sandbanks, leaving two channels open. Caissons similar to those used for the Zandkreekdam were put in place to close off the narrower of these two channels. But to close off the wider channel, the engineers came up with a new technique: gondolas on a cableway that dropped huge blocks of cement into the water. The Grevelingendam was completed in 1965.

Volkerakdam (1969)

The Volkerakdam separates the Hollands Diep and the Haringvliet from the waters of the southern Delta. Launched in 1957, the project comprised three elements meeting at the Hellegatsplein junction in the centre. Two dams were constructed, one to Goeree-Overflakkee over the Hellegats sandbank and one to North Brabant, across the Volkerak, and a road bridge was built across the Haringvliet to the Hoekse Waard. The dam in the Hellegat was constructed completely of sand. Twelve sluice caissons were used to close off the Volkerak in 1969. Since the Volkerakdam traverses the main shipping route between Rotterdam and Antwerp, it has three huge locks and a separate lock for pleasure craft. Haringvlietdam (1971)

Construction of the 4.5 kilometre Haringvlietdam between Goeree and Voorne took fourteen years. This dam not only protects the area behind it from flooding at high water, but also discharges excess water from the Rhine and Maas into the North Sea. That is why work on it started with the construction of seventeen drainage sluices and a lock. The sluices have steel gates which can be opened and closed to regulate the quantities of river water passing through Rotterdam's New Waterway to the North Sea. Because of its role in water management, the sluice complex is known as the Netherlands' safety valve. Once the sluices had been built, the channels on either side had to be closed off using the cableway that had been designed for the

construction of the Grevelingendam. The road over the dam was opened in 1971. The construction of the Haringvlietdam closed off the second inlet from the sea.

Brouwersdam (1971)

The closure of the 6.5-kilometre-wide and 30-metre-deep inlet between Goeree and Schouwen was a dress rehearsal for the final tour de force of the Delta Project: construction of the eastern Scheldt dam. Sand dams were constructed on two banks in the Brouwerhavense Gat, and the northern channel was closed off using sluice caissons. Another cableway was used for the work on the southern channel. The dam was completed in 1971, creating the Grevelingenmeer. Changing ideas on environmental conservation in later years did away with plans to turn the Grevelingenmeer into a freshwater lake. In 1981, a sluice was built in the dam, allowing water from the North Sea to enter. This proved to be a big success: the water in the Grevelingenmeer is as salty as North Sea water, but because there is no current it is clear.

Eastern Scheldt dam (1986)

The original plan was to build a dam to close off the Eastern Scheldt. It was the most ambitious part of the Delta project. The dam would cover a distance of nine kilometres between Schouwen and North Beveland, in an inlet with an average tidal range of three metres, and a maximum depth of forty metres. Preparatory work started in 1967 with the construction of three work islands: Roggenplaat, Neeltje Jans and Noordland. A dam was built to connect Neeltje Jans and Noordland. Steel piers were constructed in the three remaining channels for the cableway from which the concrete blocks that would close off the inlet would be dropped. The dam - and with it the Delta Project - was to have been completed in 1978.

By 1973 five kilometres of dam had been built in the Eastern Scheldt. But the work was never finished. In the 1970s, growing environmental awareness led to appreciation of the unique environmental value of the Eastern Scheldt's tidal waters. Under pressure from scientists, the fishing industry and the environmental movement, parliament decided that further studies were needed.

The Eastern Scheldt was and is a unique natural habitat. The clean seawater provides a rich source of food for wildlife of all kinds. Fish use the inlet as a breeding ground, and oysters and mussels are farmed there. The inlet's mud flats, salt marshes and sandbanks form a habitat for many species of bird. If the Eastern Scheldt had been dammed, the seawater flora and fauna would have disappeared. Sea fishing and mussel and oyster farming would no longer have been possible. The public debate was fierce, particularly in Zeeland, where the 1953 disaster was still fresh in people's memories. Opponents of the dam ultimately received support in

political circles and in 1974 a compromise was proposed in the form of a dam built up of elements that would allow seawater through. In 1975 the government decided on a storm surge barrier, with sliding gates. This solution would protect against flooding, while conserving the ecosystem.

The Maeslant barrier

The original Delta Project involved sealing off as many sea inlets as possible in the southwest

Netherlands. But the Western Scheldt and the New Waterway had to stay open, to allow shipping to reach the ports of Rotterdam and Antwerp. Nonetheless, the land on either side of both waterways had to be protected from flooding, and a major dyke reinforcement operation was launched. The dykes on the banks of the Western Scheldt, the New Waterway and the Maas were raised. In the 1970s, however, city-dwellers came out against reinforcing the dykes, since it often involved the demolition of historic buildings. What is more, later estimates showed that the dykes would have to be raised even higher, at great cost. The solution was to build a storm surge barrier in the New Waterway.

In 1987, the Ministry of Transport, Public Works and Water Management organised a competition for the best design. Unlike the Eastern Scheldt barrier, the barrier on the New Waterway could not pose an obstacle of any kind to shipping. And it would have to eliminate the need to raise the dykes in and around Rotterdam. The barrier could only be closed when water levels were extremely high, no more than once or twice every ten years. The winning design had two curved gates, kept in docks on the banks most of the time, that can be pivoted out into the canal and sunk to form a barrier against flood tides. Building started in 1991.

The Maeslant barrier was completed in 1997 and comprises two gates each 210 metres tall, which normally lie in docks on either shore. If a storm surge threatens, these docks are submerged, so that the hollow doors float. Within half an hour they can be transported to the middle of the New Waterway. Once they meet, the valves in the walls open, so that they fill with water. The gates then sink and stop above the concrete sill on the bed. The powerful current under the gates flushes sludge from the sill, and within an hour the gates have landed on the clean sill, protecting the area behind them from flooding.



Figure 3.14 The revised plan of 1986 for the Delta project with the names of the completed and newly designed work

3.4.3 Impacts of the Delta project

The protection level of the Netherlands against natural disasters has become very high thanks to the Delta project. Due to these projects substantial possibilities for water management have also been created. Because the saline water wedge in the southwestern part of the Netherlands has been driven back, the water of the Rhine can now be used for counteracting salinization in the North.

With the completion of the Delta project, not all water management problems have been solved. Closing the four main arms of the estuary brought an end to the nature transitions between fresh, brackish and salt water. Sediment transport stopped and large changes in the morphology began to develop. The original natural habitats disappeared, and were exchanged for man-made habitats. This was reflected in the biodiversity. Characteristic estuarine species disappeared, as was the case with species that traveled between the rivers and the sea. Species of more stable habitats established themselves. To find a solution for these problems studies are being made, including investigations into the possibilities of developing new saline and brackish environments in the coastal waters.

Furthermore, the solution to cut off the estuary from the sea by large dams, is irreversible. The costs were so high that a reversal would mean a tremendous write-off of the investment: you can't do the same job twice. Secondly, changes in the use of the lake-like compartments of the branches behind the dams were far-reaching. New strong economic interests grew profiting from fresh water for agriculture and extensive tide-free shipping routes. These interests resist attempts to change the situation. Thus, the decision to build the large structures such as the dams, determines the pathway for the future. Rising sea levels will be countered by heightening the dams, thus increasing the potential damage (Henk saeijs, Toine Smits, Willem Overmars, and Daphne Willems, 2005).

3.5 Expectation of sea level rise and river discharge increase

3.5.1 Sea level rise

The expectation for 2100 is that climate change will lead to a further rise in sea level at the Dutch coast in the order of 20–110 cm relative to ground level. This prediction is based on an average land subsidence of 10 cm per century and takes into account both land subsidence as a consequence of time lag effects from the last ice age – to which the NAP is also subjected – and the average value for fall in the ground level due to the settling of clay and peat. However, considerable local differences in ground subsidence can occur. Note that there is a large time lag between the warming up of the oceans and the temperature rise in the atmosphere. This implies that if the average temperature of the atmosphere would be limited as a result of reduced emissions, an effect on sea level would only be realized after many centuries.

One consequence of the expected rise in sea level is the need for more and larger volumes of sand to be added as beach nourishment to the coastal system to compensate for the losses of sand that now occur and to maintain current safety levels. The addition of sand to the coastal system will also ensure that the coast, estuaries and the Wadden Sea keep pace with the rise in sea level. In the future, stronger and wider dykes will be needed to offset the greater pressures arising from the rise in sea level.

Over the next 50 years, the additional costs for coastal management are expected to be no more than 0.13% of the gross national product. In the case of a further rise in sea level after 2050, the costs for coastal management could increase to (much) more than the present spending level. Next to the influence of sea level rise, the occurrence of flood levels is strongly determined by the occurrence of storms on the North Sea. However, it is not yet clear how the frequency and intensity of storms will change in the future (M.M. Berk, G.J. van den Born, L. van Bree, et al. 2005).

3.5.2 River discharge increase

Due to global warming, changes will occur in the precipitation pattern in the Rhine basin area. It is expected that the Rhine, at present a combined rain and melt-water river, will increasingly become a rain river with high discharges in the winter and low discharges in the summer. The increasing winter precipitation will affect an increase in the discharge of the Rhine in winter. Summer discharge will decrease as a result of a reduced amount of melt-water and a strong increase in evaporation, the latter outweighing the effect of the smaller increase in the average rainfall in the summer.

Figure 3.15 shows that in all of the climate scenarios (low, medium, high and dry) the expected winter discharge of the Rhine will increase even further and the summer discharge will decrease even further relative to the present discharge.

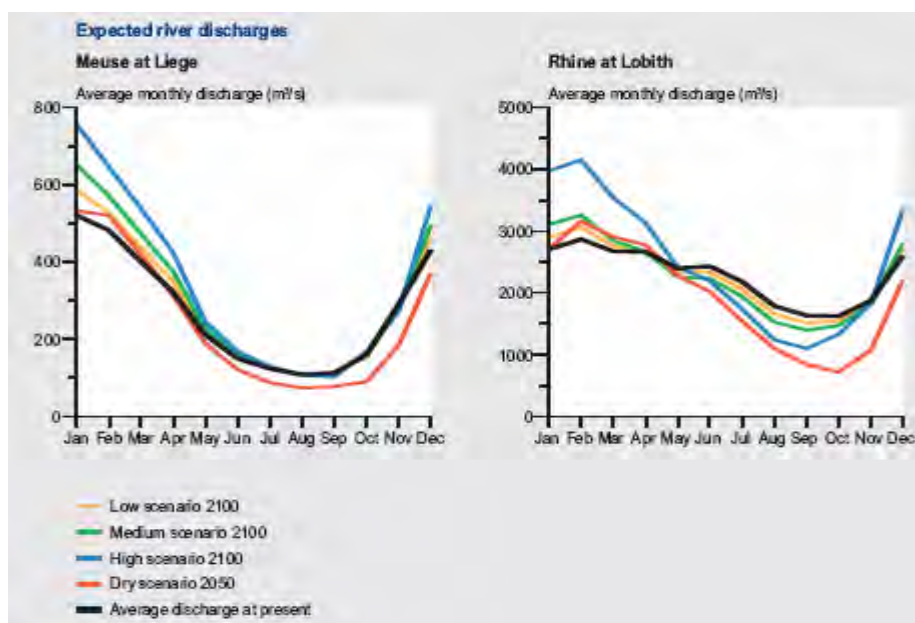


Figure 3.15 Expected river discharge with four climate scenarios
(Source: Beersma et al., 2004)

The design discharge, which is used as the basis for the legal safety standards in the Flood Defences Act, is indicative for extreme discharges. In the Rhine/Meuse area, the design discharge is based on a discharge quantity, which occurs on average once every 1250 years. In legal terms, this is the maximum quantity of water the river must be able to discharge without the hinterland becoming flooded. The dykes, flood plains, main channel and other related factors are dimensioned on this discharge.

Following the high water levels in the Rhine/Meuse system in 1993 and 1995 the design discharge for the Rhine was adjusted from 15,000 m³/s to 16,000 m³/s. The

direct consequence of this adjustment is that the current situation in the Rhine/Meuse area no longer satisfies the legal safety standards.

According to the climate scenarios, in 2050 the design discharges of both the Rhine and the Meuse will have increased: the Rhine by 3–10% and the Meuse by 5–20%. This means that additional measures in the Rhine/Meuse area will be necessary to ensure that the legal standard is still met (Figure 3.16) (M.M. Berk, G.J. van den Born, L. van Bree, et al. 2005).

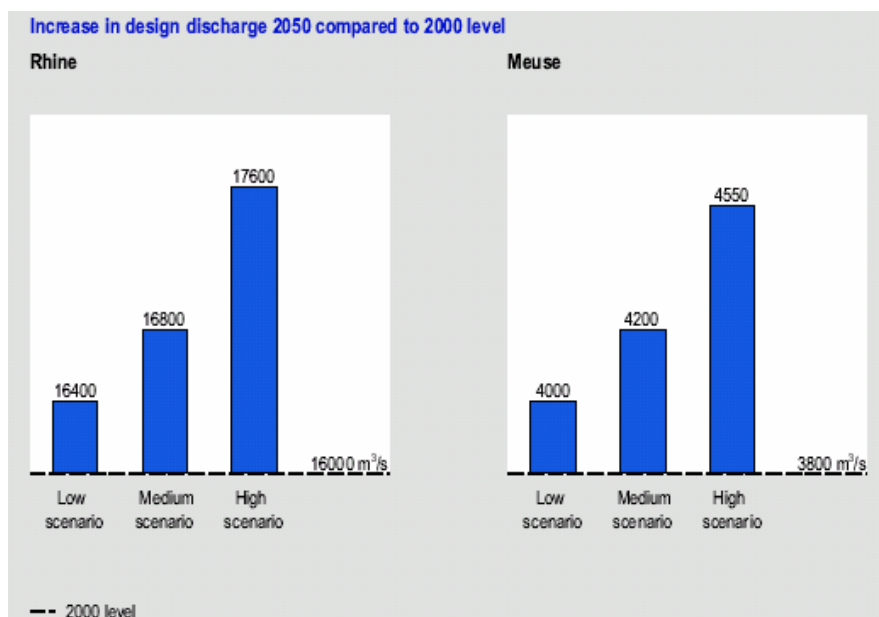


Figure 3.16 Increase of design discharge in 2050
(Source: Buiteveld and Schropp, 2003)

3.5.3 Coinciding storm surges and river flooding

In the Rhine Branches high water levels may occur in the winter months only. High water levels in two of the branches of the Rhine can be noticed as far as halfway the polder Alblasterwaard – southeast of the city Rotterdam – west of which is the ‘delta-area’. The river channel of further downstream is very wide and there are several branches, thus the discharge capacity is much bigger than upper branches and the high upstream water levels have hardly any influence in these reaches. However the delta area is a transitional zone which both affected by storm surge and high discharge. When a storm surge coinciding with a high discharge of the river, this area will cause high water level such as Rotterdam and Dordrecht, although the probability is extreme low, as storm surges occur in quite different weather conditions than high discharges of the rivers. But another condition also might cause high water level in this area. It is a storm surge, not extreme but still very high, holding for 2 or 3 tides and the storm barrier have to be closed. In this situation the accumulated water will in cause high level in the delta area. The probability of a

relatively intensive storm surge coincide a high discharge is still possible, because both are in the same season around January to February. Therefore, the storm design and the safety standard in the delta area should be taken more attention.

3.6 Flooding and measures taken

Between 1250 and 1600 bursting of dikes did not only occur more often but the flooded area became increasingly larger. This was partly as a result of the land subsidence in the peat areas. Before the reclamation the peat moor cushions could still stem the inflowing water. If the ground level in a large area had dropped to only some dozen centimeters above mean sea level, this entire area might be flooded in the case of a dike burst. Apart from large cases of flooding, there were a lot of local cases of flooding, too. From the dozens of floods, which swept the Dutch coast between 1250 and 1600, at least about twenty led to large disasters. The worst disaster to have ever hit the Netherlands was the All Saints Flood of November 1st 1570. This flood hit the entire coastal area. Following this flood many dikes were strengthened and in many areas measures were taken to improve dike management (Van de Ven, 2004).

Because of the heightening of the dikes flooding became less frequent, however, those that did occur became disasters. Only in the sixteenth century an accurate description was found of a flood disaster, at which occasion there was quite a chain of related dike bursts and the entire river area was flooded. Similar disasters occurred repeatedly in the following centuries. Around 1800 severe flooding hit the river area practically every decade.

At an earlier date the problem of the distribution of water among the various Rhine branches had been solved. In the course of the seventeenth century more and more water flowed into the Waal, by the end of this century even 90%. Due to the strongly decreased inflow into the Lower-Rhine and the IJssel the beds of these rivers were no longer scoured out so that their discharge capacity decreased sharply. The consequences were especially felt in spring. The water rose quickly and the river dikes proved to be too low, which caused a number of dike bursts and flooding. To end this hazardous situation the authorities of the present provinces of Gelderland, Utrecht and Overijssel joined forces and together they had the Panterden canal - from the Rhine towards the Lower-Rhine and the IJssel - dug in 1707, to increase the discharge over the other branches. This canal functioned well enough, but many concomitant works were required to perfect the total works. By the end of the eighteenth century a well-balanced distribution had been achieved. Six ninths of all the water flowed into the Waal, the remaining amount of water split south of Arnhem and flowed into the Lower-Rhine (two ninths) and into the IJssel (one ninth).

During the eighteenth century many plans were developed to counteract the danger of flooding, among others by making lateral diversions. By making overflows it was hoped to prevent unexpected dike breaches. The overflow was also intended to guard regions with a high population density against flooding by discharging the water over less important regions. Lateral diversions proved to be a bad solution, because they only shifted the difficulties to somewhere else. It became clear from the many dike breaches that even a breach that resulted in a natural lateral diversion did not make a further dike breach downstream impossible. There have, however, been many propositions for lateral diversions. Most of them were designed to save the northern dike along the Lower Rhine system.

River flooding was of great concern in the first half of the nineteenth century. Several times broadly based commissions were set up that had to investigate how such disasters could be prevented. Unfortunately these commissions did not stimulate real river improvements. River improvement was a long-term affair. The commissions contributed their share, however, to stimulate the discussion about river improvement and plans were made for river improvement that were executed in the second half of the nineteenth century. After the flooding of 1809 the 'Central Committee for Water Management' was set up. In a follow-up of the plans that were already developed in the eighteenth century, the commission investigated whether a number of side overflows would be possible. Many of the ideas were considered to be impractical. Only some improvement works were implemented. As a result of the flooding disaster of 1820, a year later a new commission to examine the best river diversions was installed. The commission was assigned to investigate all plans concerning river diversions that had been made at that time. This was quite a number. The proposals for improvement, which were finally formulated by the commission, were modest in comparison with the ambitiously investigated plans. The commission attached great importance to a careful and regular river management. Also, in its proposals for the execution of certain works in the rivers, the commission was very modest. It was proposed to undertake a number of works from downstream to upstream along the rivers. All proposals of the commission were tested extensively on their practicability before they were submitted, and it was examined whether certain interests would not be disproportionately affected. Only when these measures turned out to be insufficient, did the commission advise carrying out still more works. The commission did not propose a large number of lateral diversions. It pleaded for dike strengthening and for cleaning up the river foreland. The commission was also careful in the remaining recommendations. It stated that a general improvement of the rivers would have to be the result of guiding the flow, which had to be done step by step. In addition, the river dikes had to be strengthened at both sides. To enable control of activities in the river foreland,

the commission gave the advice to make river maps on a scale of 1:10,000. After 1850 these river maps appeared to be necessary for the design of river improvement works. The report as brought out by the commission in 1825 led to in depth discussions. For the major part, the objections were not against the whole plan, but there were protests of interested parties who had the feeling that the execution of certain facets would considerably harm them. As a result of all the protests and new plans, a new river commission was installed in 1828. This commission came together only a few times because of the difficult political situation. Finally in 1848 the report was ready, but it was only published in 1854. Also during this period structural measures were taken to prevent flooding. For example, the dike managing water-boards (public bodies in charge of local water management and flood protection) along the rivers heightened and strengthened their dikes.

Not only were the dikes strengthened, but also the riverbed was improved during this period. In 1849 two inspectors of Rijkswaterstaat were assigned to study the plans of the two river commissions and the extensive literature on this subject. Their recommendation was that any river had to be brought in such a state that it could independently discharge the upstream water and ice. This situation could not be realised at once, but would have to be achieved in the course of years by a series of activities. For that purpose they introduced the so-called standard width for the rivers. They determined the optimal width a river would have to fulfill. This width increased in the direction of the mouth. So the width of the Waal would have to be 360 m at the upstream, and 600 m downstream. These standard widths were based on practice. The works which would have to be carried out in the river sections, would also have to scour away the islands and shallows. In short, any river would have to be brought to a standard width and have only one continuous bed.

After 1848 due attention was given to river improvement. The increase in prosperity in the rural areas helped to promote a better maintenance of the dikes. The value of land had increased, which resulted in higher revenues for the water-boards. These additional funds were used to strengthen and heighten the dikes. It was now possible to execute river improvement works. From 1850 onwards, large improvement works were carried out in the rivers. These works aimed both at making the rivers suitable for the discharge of peak flows and ice, and at redesigning them into adequate shipping routes. The river dikes were substantially strengthened. These dikes were not only heightened and widened, but also given a basalt slope at dangerous places. The reasons for these dike reinforcements were the flooding disasters of 1855 and 1861. The idea was that by the dike reinforcements and the river improvements the danger for flooding from the side of the rivers was taken away for the greater part. This vision was too optimistic, which became clear from the flooding of 1926. As a consequence of this flooding, another large-scale strengthening of dikes took place.

It was decided that all dikes along the Waal and the Lower-Rhine should be heightened to one metre above the highest water level of 1926.

Large-scale dike reinforcement started again after the flooding disaster of 1953 when large parts in the southwest of the Netherlands were flooded and 1,835 people died. The so-called Delta Project included the closure of coastal inlets and estuaries. Along whole coast and in the region of the downstream rivers the flood protection structures were strengthened in an unprecedented way. For the first time the level of protection in a certain region was normative. For Central-Netherlands the flood protection structures had to give a protection against a storm surge from the sea with a chance of occurrence of one in 10,000 per year. For the river region the opinion was that the dikes had to be strong enough to resist a flooding, which had a chance of occurrence of one in 3,000 per year. By that time this standard was considered to belong to a discharge of the Rhine of 18,000 m³/s at Lobith, which later on proved to be an extremely high discharge. From then on this new standard of dike reinforcement is referred to as 'Normative High Water'. A total of 550 km of dike had to be strengthened, which would have to be finished by 1998. In the river region there developed, however, a strong criticism with respect to the planned strengthening of dikes. The opinion was that the new dikes would have a very negative impact on the beauty of the landscape and cultural heritage. Because of this the standard was adjusted to a chance of occurrence of one in 1,250 per year. To this standard belonged a discharge of the Rhine of 15,000 m³/s at Lobith. Furthermore, at the execution of dike reinforcements due caution had to be exercised with respect to the existing nature and scenic values of the river area. However, there was still no large-scale strengthening of dikes in the river region. This had two causes. The central government did not make enough money available and there was much distrust between the water-boards, on the one hand who made plans for dike reinforcements, and the activists, on the other hand, which mobilized their forces for landscape conservation.

At the end of December 1993 and in January 1995, very high water levels occurred in the rivers. In 1993 there was especially damage in the Meuse valley in the province of Limburg. Here there were some low parts of the cities Venlo and Roermond, and there were some villages as well. Furthermore, several farms were spread over the valley and the land was used as pasture. These settlements were flooded from time to time during high river water levels. Because these periodical flooding was taken into account, only marginal damage occurred. Since 1960 many houses had been built in the Meuse valley; flower cultivation and vegetable growing in greenhouses had developed, and a hospital had even been built in the valley. The houses with precious furniture, modern kitchens and parquet floors were much more sensitive to flooding. The very high water levels of 1993 came as a big surprise. In

the Meuse valley about 180 km² of land was flooded, eight thousand people were evacuated and six thousand houses were damaged. The damage amounted to about € 115 million. At the same time, the water in several branches of the Rhine was very high.

By that time not all the dikes sections were strong enough, because the planned reinforcements had not been implemented. As a result of the flooding of 1993, a Royal Commission was established to examine whether it was possible to protect the Meuse valley better against high water levels. In 1994 the commission published a report in which it proposed to deepen the base flow bed and to partly dig out the floodplain. In addition, it proposed to surround the settlements with low embankments. In total about 60 km would have to be made. The idea was that, with these measures, the inhabitants of the Meuse valley would have a chance of occurrence of flooding of one in 250 per year.

In January 1995 the Netherlands were surprised again by very high water levels on the rivers. Again there was substantial damage in Limburg. The Rhine had a discharge of 12,000 m³/s at Lobith and in the branches of the Rhine the water level was even about 25 cm higher than in 1993. The safety of the dikes was not trusted, because certain dike sections still had a safety level with a chance of occurrence of only one in 100 per year. 240,000 people and one million cattle were evacuated from the river region. Fortunately the dikes did not fail. Since 1995 structural measures have been taken. An emergency act was passed in parliament, which was called Delta Plan Great Rivers. In this act it was laid down that the entire dike reinforcement programme along the rivers had to be completed before 2000. Based on this act the dikes in the river region were indeed strengthened very quickly at the previously prescribed chance of occurrence of one in 1,250 per year. Now they protect the river region against high water levels belonging to a discharge of the Rhine of 15,000 m³/s at Lobith. (Bart Schultz, 2006)

3.7 Flood defenses system and safety

3.7.1 Composition and classification

- Composition

Three systems play a role in flood defence, as set down in the Flood Defence Act (FDA):

- a) The system of the protected dike ring area;
- b) The water management system (outside the dike) bordered by the flood defenses;

c) The system of the flood defenses itself.

In the protection against high water distinct areas can be distinguished, each surrounded by an unbroken system of flood defenses, possibly in combination with high grounds. High grounds are grounds that are high and broad to a very satisfactory degree to allow them to retain outside water without management being necessary to maintain the situation. Encircled by flood defenses and any high grounds, such an area is called a dike ring area. In the Netherlands there are totally 53 dike ring areas (Figure 3.17).

The water management system outside the dike sets the preconditions for the loads that work on the flood defenses. The system of flood defenses around a dike ring area, including any dunes and locks, is called an encircling dike. The safety of people and goods in the dike ring area is dependent on the adequate performance of the whole encircling dike, perhaps in combination with the flood defenses that are situated in front of the dike ring area. The encircling dikes of dike ring areas. The encircling dikes of dike ring areas and any defenses situated in front of it, are called primary flood defenses.

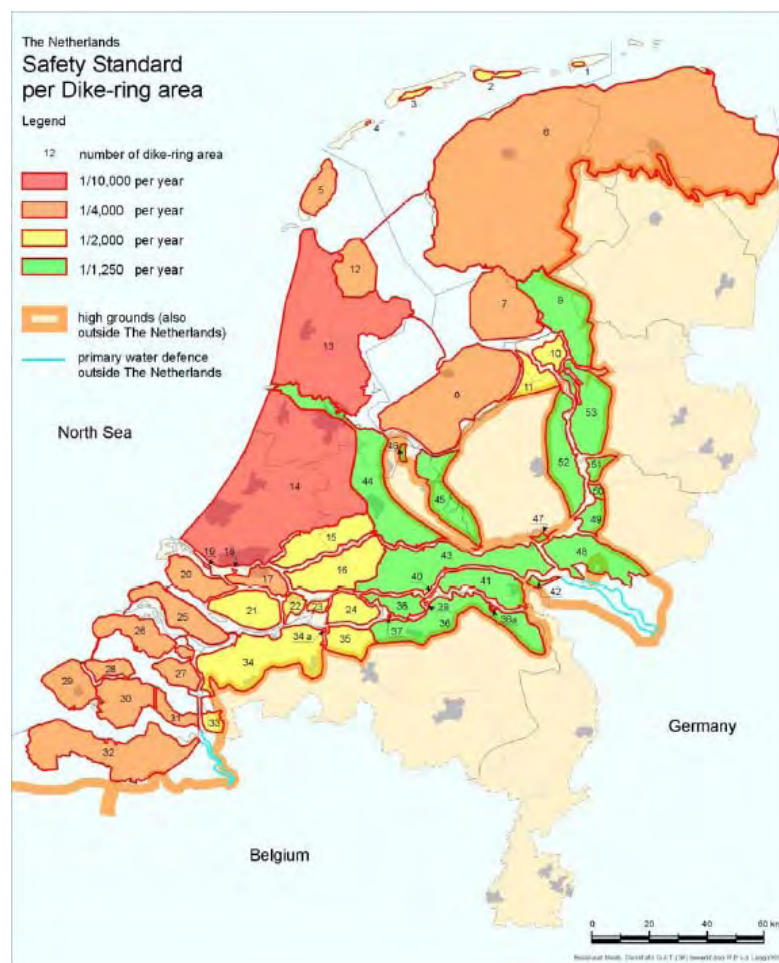


Figure 3.17 dike rings in the Netherlands

- Classification by category

In line with the Flood Defences Act, the primary flood defences can be subdivided on the basis of the following two characteristics:

1. A defence retains outside water or does not retain outside water. The concept outside water is limited within the Act to the surface water, the water level of which is directly influenced by high tidal floods, high surface water of one of the major rivers, high water of Lisselmeer or by a combination of these factors. Grevelingen lake for example, is therefore not outside water in the sense of the Act. Outside water accordingly indicates the most important threat. Inside water is all surface water except outside water.
2. A defence belongs to the system of flood defences that encircles a dike ring area or is located in front of a dike ring area

The combination of these characteristics leads to the following four categories of primary flood defences.

1. The flood defence belongs to the system that directly encircles the dike ring area and retains outside water;
2. As category 1, but not intended for direct retaining of outside water;
3. The flood defence is situated in front of a dike ring area and retains outside water;
4. As category 3, but not intended for direct retention of outside water.

No land is located behind the flood defences of category 3 and 4, but water. Examples of category 3 are the Lisselmeer closure dam and the Tidal Flood Barrier in the Oosterschelde, both of which retain high water levels on sea. In this context it makes no difference that the Lisselmeer closure dam always retains water and the Oosterschelde barrier only closes when the sea level is high. An example of category 4 is the northern part of Grevelingen dam, which has inside water on both sides. The function of flood defences of categories 3 and 4 is to prevent the occurrence of (too) high levels of water behind it, at least to greatly reduce the probability thereof. In doing so, they limit the loads on the flood defences that separate the water behind them from the land in front of them.

- Classification by type:

A large part of the Dutch coast is protected against tidal floods by natural dunes. The high grounds traditionally made of a combination of clay and sand, so-called soil bodies. The reason is obvious. The material is available in great quantities, is

easy to process, flexible, easy to maintain and adapt and very durable. In combination with grass, clay is reasonable erosion stable. Such structures as locks and cuts were designed in situations where the flood defence is crossed by waterways. In that way water retaining hydraulic structures, in the past most often made of wood and brickwork, were later also concrete and steel.

On the basis of the above, there are four main types of structure for the protection of a dike ring area against high water. These are (Figure 3.18):

- a) Dunes;
- b) Soil structures (dikes, dams);
- c) Special water retaining structures (including cofferdam, retaining wall, sheet piling);
- d) Water retaining hydraulic structures (including locks, cuts, tidal flood barriers, pumping stations).

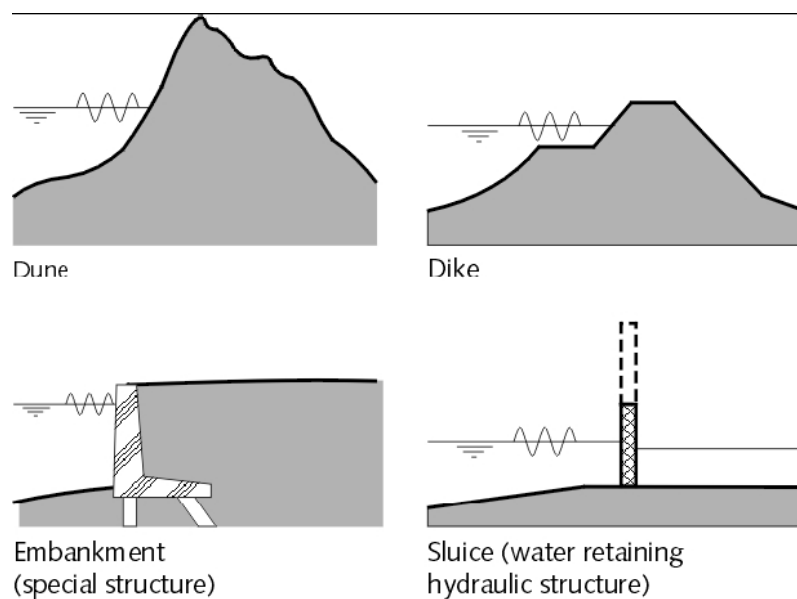


Figure 3.18 main types of flood defence

In addition, there may be objects in, on and alongside flood defence, such as pipeline, buildings and trees. These objects typically have no-water retaining function, but could influence the water retaining capacity. For all flood defences, it must be said that the water retaining capacity must be assessed using the height and firmness of the whole structure, including objects (TAW, 2000).

3.7.2 Safety principle

Before 1953 the risk estimates (safety definitions) were either formulated on the basis of intuition or experience. The 'highest known water level' on site played a

crucial role. The flood defence was designed at that level plus a certain margin. If a flood defence proved too low for a new and higher water level, then this automatically became the highest known water level and the dike was raised.

After the 1953 disaster the need for a more unambiguous approach, along the lines of the section above was adopted. The safety requirements in the prevailing guides placed on the flood defences have their origins in the Delta Committee's body of ideas, collated in its 1960 report. An econometric view was set up for Central Holland. The econometric optimum safety level was fixed at approximately 1/125,000 per year, assuming a complete loss of capital goods. The loss of human life and the breakdown of society was not collating in this view.

Assuming a flood probability of 1/125,000 per year this would mean about the same collapse probability for the flood defence. However, it was impossible to determine the probability of collapse of a dike with any precision due to insufficient numeric insight into the collapse mechanisms. As a result, partly in light of the other uncertainties, another approach was chosen. The requirement was that it must be possible to 'completely retain' a water level with an exceedance frequency of 1/10,000 per year (the design level, the Normative High Water, MHW). That was considered to be true when only 2% of the accompanying waves running up the dike were exceeding the crest of the dike.

For Hoek van Holland it was determined that a level of NAP +5m has an exceedance frequency of approximately 1/10,000 per year, the so-called base level of the Delta Committee. For Central Holland the design level (MHW) is the same as the base level. For other locations along the coast the base levels have been determined by assuming conditions with the same exceedance frequency. For the MHW along other parts of the coast an economic reduction was applied however, varying from 0.2 to 0.6m. The accompanying exceedance frequency of the MHW along the coast varies from approximately 1/4000 to approximately 1/1500 per year. The economic reduction was motivated by the fact that the consequences in the case of dike collapse are not always as serious as in Central Holland.

For the upper rivers area the River Dikes Committee (the Becht Committee) recommended an exceedance frequency of the design discharge (to which the MHW is linked) in 1977 equal to 1/1250 per year. The extenuating circumstances in the rivers area in relation to the coast included: fresh versus saltwater and announcements in the long term versus announcements in the short term. The loss of Nature values also played a role in the choice of this number. The Boertien Committee made a similar choice in 1993, the result of which was the same exceedance frequency of 1/1250 per year. This number was chosen in spite of the

fact that a material risk consideration would lead to a lower frequency (Boertien I Final Report, Toetsing uitgangspunten rivierdi/kversterkingen).

The concept ‘completely safe’ is worked out in the design rules. It should include a margin due to uncertainties in such matters as water levels, wave attack, soil & material characteristics and behaviour of the water retaining structures. The Delta Committee chose the freeboard for this margin, the difference between the crest height of a dike and the design level. This difference is decided in the design by such factors as the wave run-up, any fluctuations in the water level due to wind, estimated settlement of the flood defence and such like. The Delta Committee recommended that the freeboard, even when there is no wave attack to speak of, should be at least a couple of decameters.

3.7.3 Safety approach: from probability of exceedance to probability of flooding

- Exceedance frequencies- the current safety approach

The current safety approach is mainly a practical oriented approach. Each dike section has been designed to safely withstand a certain water level. This water level is called the design water level. By means of standard for each dike ring area, an exceedance frequency has been defined by law. These exceedance frequencies vary from 1/1250 to 1/10,000 per annum. This does not imply that when the design water level would be reached, the protected area would be inundated at once. Extra safety margins are built in, so that the final height and strength of a dike section is higher than strictly is required to exactly retain the design water level. In the design, the wave run up, the accessibility of the dike at high water stages and a reserve for uncertainties are included as well.

Technical handbooks and guidelines are available for the design and construction of a dike. In these guidelines it is for instance indicated how the dike should be shaped, depending on the subsoil, soil structure, the loads, etc. These guidelines, however, do not guarantee that a dike would never fail at lower water levels than the design water level. Therefore, uncertainties are included partially afterwards (adding safety margins to the crest level) and partially in advance (natural fluctuations in the water levels).

In the fifties, the political choices of the exceedance frequencies for the Netherlands were defined on the basis of the advice of the Delta Committee (1960). This committee followed two approaches with taking Central Holland as basic standard:

- Firstly it was investigated whether the water levels of 1953 could be exceeded. The conclusion was that there was no reason whatsoever to exclude the possibility of

water levels of (at least) $\text{NAP} + 5 \text{ m}$ at Hook of Holland (in 1953, the water reached a level of $\text{NAP} + 3.85 \text{ m}$). A water level of $\text{NAP} + 5 \text{ m}$ represents an exceedance frequency of 1/10,000 per year;

- Secondly, a study was made to the costs of greater safety in relation to the economic benefits. Based on the interests of the fifties, a financially optimal protection was established for Central Holland, whereby Central Holland would be inundated once every 125,000 years on average.

Both outcomes were related to each other by assuming that a water defence designed to safely retain a 1/10,000 water level, would probably only collapse at a 1/100,000 water level.

The final advice of the Delta Committee included a proposal to differentiate the protection level throughout the country in accordance with the (economic and other) interests to be protected.

Central Holland is the most densely populated area in the Netherlands, which is also threatened by the sea. In this area the largest investments have been made. It was therefore concluded that this area should be as optimal as possible be protected against flooding. For other coastal areas of the Netherlands, larger exceedance frequencies were considered acceptable, due to their lower economic value. For the provinces of Zeeland and Groningen-Friesland, for instance, it was determined that dike sections could be 2 to 4 decimetres lower than in Central Holland, which corresponds with an exceedance frequency of 1/4000 per year.

In a later stage, a standard was also set for the riverine area. The basic difference between floods from rivers and from the sea is that river water levels can be predicted well in advance: a matter of days instead of the few hours in case of a sea flood. This allows for taking precautionary measures. In addition, fresh water floods create less damage compared to floods from salt water floods. And thirdly, in case of a breach, the resulting erosion channels will be less deep compared to those in tidal areas. Because of these three reasons, a slightly lower safety level of 1/3000 for the river area was considered acceptable. In the intertidal area, where water levels are under the influence of sea and river, a transition zone was proposed, with an exceedance frequency of 1/10,000 on the sea side and 1/3000 on the river side.

In the seventies, the river dikes would be improved. However, strengthening (especially raising) the dikes up to the previously mentioned safety level would result in a lot of damage to the landscape, nature and the region's cultural inheritance. The resulting social protest led to a reconsideration of the safety levels. Following the advice of the River Dikes Commission (the Becht Commission, 1977) the original standard of 1/3000 was lowered to 1/1250 per year. In this way it was possible to partially leave the area around the dike to be reinforced.

In the eighties, the river dike reinforcement programme stagnated again. This time it was caused by a decline in social consensus. The Committee on testing different approaches of river dike strengthening (the Boertien Committee 1, 1992) advised to maintain the safety level at 1/1250 per year. However, the committee also proposed to apply another method for calculating the design water level. In this way the design dike height could be lowered with 3-4 decimetres (TAW, 2000).

- Probability of flooding

The method used to calculate probabilities of flooding mainly distinguishes itself from the current approach (exceedance frequencies) through:

- (1) the transition from dike section to dike ring approach. This approach results in the strength of an entire dike ring, which typically consists of dikes, hydraulic structures and dunes;
- (2) taking equal account of various failure mechanisms of a dike ring;
- (3) taking from the start of the calculation all uncertainties in a systematic and verifiable way into account.

The current safety approach is based on a design approach for each individual dike section. The calculation of the probabilities of flooding is based on the principle that a chain (dike ring) is as strong as its weakest link. The calculated probability of flooding of an area is the arithmetic sum of all probabilities of failure of dike ring elements. In this approach, the weakest link has the greatest impact on the calculated outcome: the flooding probability. The failure mechanism (Figure 3.19) taken into consideration when calculating the flooding probability is following:

The following failure modes were considered with the calculation of the flooding probabilities:

Dike:

- overflow and overtopping of water over the dike crest;
- sliding of the dike inner or outer slope;
- erosion of the dike revetment (e.g. grass, asphalt or basalt blocks), which might cause a breach in the dike;
- piping, causing water to run under the dike and erosion of the dike body from within.

Structure (like a sluice, pumping station):

- overflow and overtopping of water over the structure
- the collapse of the construction or the foundation due to high water and waves, collision or an extreme settlement
- piping and seepage, water streaming under or along a hydraulic structure
- not closing a hydraulic structure on time, allowing water to flow in.

Dune:

- Erosion under the influence of flow, wave action, wind or human action.

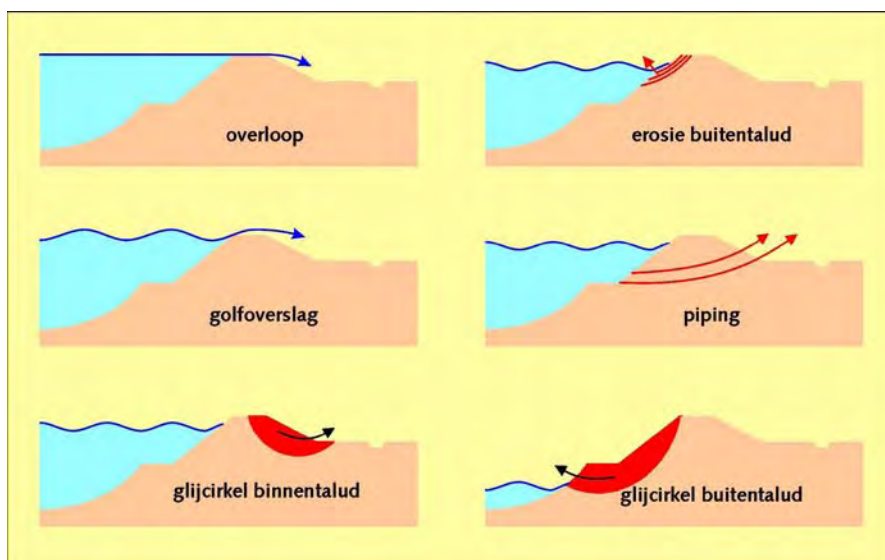


Figure 3.19 failure mechanisms of dike

The calculated flooding probability reveals all the weak links of the water defences of a dike ring. It also shows that not every weak link contributes in an equal manner to the total flooding probability. Bottlenecks can be of lesser or greater importance and thus contribute less or more to the flooding probability. This offers possibilities for a step-wise improvement of a dike ring, for instance by improving the dike crest or the dike body, by improving the construction of a hydraulic structure or its operation, or by reinforcing the dunes of the dike ring under consideration. The method is thus also a tool for analysing the bottlenecks themselves.

Addressing the weakest link firstly is the most beneficial measure to reduce the calculated flooding probability. It thus becomes possible to priorities: which part of the flood defence should be improved first and what can wait? This clarifies the difference with the current testing method, which does not focus on the coherence between and the prioritisation of bottlenecks.

When calculating flooding probabilities, several forms of uncertainty are taken into consideration in advance which has been discounted in the calculation in a systematic and verifiable way.

Uncertainties those are included in the calculation of the flooding probability:

- *natural uncertainties.* As just little is known on the behavior of nature in time and space. The location and occurrence of storm surges can be predicted with an certain accuracy. However, these remain predictions. The thickness of a clay layer in the subsoil may differ from place to place. Its accuracy can be improved by intensified measurements, but uncertainties can never be reduced to zero. Other uncertainties (e.g. long-term developments) can hardly be reduced, if at all;
- *model uncertainties.* A calculation model is never an exact reproduction of reality, but just an approach. Models can be improved by verifying their outcomes with reality and thus be improved, thereby reducing this type of uncertainty;
- *statistical uncertainties due to lack of measurement data.* This is especially relevant when working with extrapolations, for instance to predict unusual water levels. This type of uncertainty can be reduced partially if more measurement data are available; but uncertainties will always remain.

This is an important difference to the current approach of exceedance frequencies, which only considers one type of uncertainty in advance: the natural uncertainty in water level. After determining the height of a dike, a safety margin is added to include non-explicit uncertainties.

The calculation of the flooding probability includes uncertainties in water levels, in strength, in the calculation model and the lack of long-term measurement data.

The calculated flooding probability is always an approach to the actual flooding probability of an area. As the uncertainties in the models and the statistics decrease, the approach improves in accuracy. (TAW, 2000)

3.7.4 Safety assessment of primary flood defences (National Report on 2006)

The Flood Defences Act requires that those managing the primary flood defences test every five years whether the dikes, dunes and hydraulic structures, such as sluices and closable orifices in a dike, meet the statutory safety requirements.

The assessment of a flood defence can lead to three judgments: the flood defence ‘meets’ the standard, the flood defence ‘does not meet’ the standard or because there is insufficient information ‘no judgment’ can be made. An assessment of the

primary water defences was carried out for the second time in the period 2001-2006. This report summarizes and explains the results of the second safety assessment. The results were also compared with the results of the first assessment.

- Primary flood defence categories

The dikes, dunes and hydraulic structures are divided into various categories depending on their position and function. The assessment covered the primary water defences in categories a, b and c.

- Flood defences in category a (a defences) include dikes, dunes and hydraulic structures which provide direct protection against the sea, the major rivers, the IJsselmeer or the Markermeer lakes.

- Flood defences in category b (b defences), such as the Afsluitdijk or the Maeslant storm surge barrier, connect flood defences in either category a or c.

- Flood defences in category c (c defences) are defences, which provide indirect protection against flood water.

- Assessment process

The assessment bodies that manage the primary water defences carried out the assessment. The water boards manage 90% of the primary water defences and the Directorate-General of Public Works and Water Management manages the remaining 10%. These authorities send their assessment reports to the provincial authorities that make an assessment, which is then attached to the reports and submitted to the minister of Transport, Public Works and Water Management. Based on its independent position, the Transport and Water Management Inspectorate evaluates whether the assessment or management has been conducted in accordance with the regulations (this is known as the 'official judgment'). The results are summarized to create a national picture and an analysis is provided, together with its findings and conclusions. The Transport and Water Management Inspectorate submits this report to the minister of Transport, Public Works and Water Management.

Based on the summary report, the minister informs parliament about the state of the all the primary flood defences in the country and draws up a programme of improvements, known as the Flood Protection Programme, based on the results.

- Assessment

During the assessment the managing authorities check whether the strength of the flood defences meets the statutory requirements. The height and stability of the

flood defence contribute to its strength. During the assessment the water boards use the instruments specified by the minister of Transport, Public Works and Water Management, such as the calculation rules laid down in the Safety Assessment Regulations, and data on water levels and waves. Because normative water levels and waves can change over the course of time due to new insights and changes in the natural circumstances, such as average discharges and more storms, this data is revised every five years. Data from the Hydraulic Boundary Conditions 2001 (HR2001) was used for the second assessment of the flood defences.

From the assessment three different judgments about the flood defences could be made; that it: meets the standard ('meets'), does not meet the standard ('does not meet') or it was not possible to arrive at a judgment ('no judgment'). The standard lays down the prescribed level of protection against flooding. The assessment of 'no judgment' was therefore made when the managing authority, for whatever reason, was unable to gather sufficient data or the set of instruments available was insufficient to be able to fully carry out the assessment. Each authority was given the opportunity to include its own 'manager's judgment' in addition to the requirements of the Safety Assessment Regulations.

- Results of the assessment

The results of the assessment provide insight into the condition of the primary water defences in the Netherlands. On the basis of this, measures can be taken where necessary for the purpose of either further investigation or to make improvements. In some cases, for example, based on the initial assessment, it has been known for some time that improvements were necessary and measures are already in preparation. The results of this second assessment further underlined the necessity for these measures. This applies, for example, to parts of the rivers region and the 'weak links' along the coast. For a few other flood defences it was only further to this assessment that it became apparent that they do not (or no longer) meet the statutory standards.

The second assessment assessed the height and stability of the flood defences. During the first assessment mainly the height was tested. The comparison between the results of the first and second assessments must be seen in this light.

Results for defences in categories a and b (providing direct protection):

Figure 3.20 shows the assessment results for the dikes and dunes, which provide direct protection against flooding from the North Sea, the major rivers and the IJsselmeer and Markermeer lakes (categories a and b). These categories make the largest contribution to flood protection. The Netherlands has 2875 kilometers of such dikes and dunes.

The results for the category a and category b defences on the reference date of 1 January 2006 and compared with the assessment of 2001, can be summarized as follows:

- 1264 km meets the statutory standard. The percentage, which ‘meets’ the standard, is therefore 44%; in the previous assessment in 2001 this was 40%.
- 680 km does not meet the statutory standard. The percentage, which ‘does not meet’, is therefore 24%; in the previous assessment this was 19%.
- 931 km was labeled ‘no judgment’. The ‘no judgment’ percentage is now 32% and was 41%.

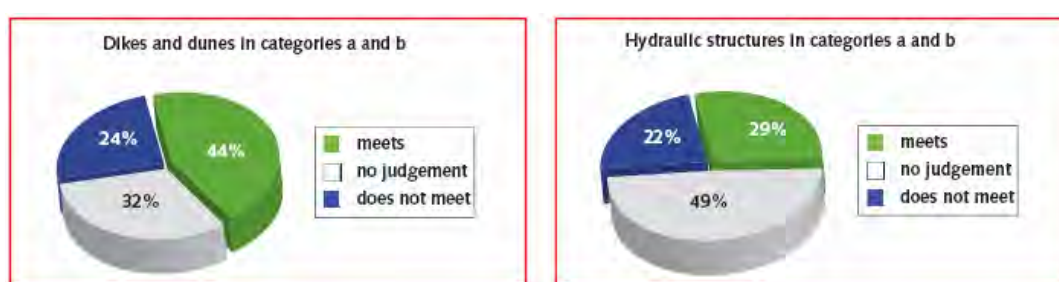


Figure 3.20 assessment of primary water defences 2006

Results for hydraulic structures in categories a and b

The results at the reference date 2006 can be summarized as follows:

- 277 hydraulic structures (29%) were labeled ‘meets’ the standard;
- 206 hydraulic structures (22%) were labeled ‘does not meet’ the standard;
- 459 hydraulic structures (49%) were designated as ‘no judgment’.

The percentage for ‘no judgment’ is high. For the assessment of a flood defence a wide range of data about its structure is necessary. Unlike in the first assessment, in many cases most of this data is now available but some details are still lacking to be able to reach a final judgment.

3.8 Organization and legislation about flood defences

3.8.1 Organization

The care of the flood defences in the Netherlands is spread over three administrative layers: the state, the provinces and the water boards. The municipalities are involved in spatial planning (as representative of other interests at flood defences like housing and traffic) and in the case of a threatened calamity.

A central role is reserved for the water boards. A water board is a functional administrative form, oriented to water management and flood defence management. The province has a regulatory task, both for the municipality and the water boards and can therefore take binding decisions in the event of a difference of opinion.

Division of tasks between administrative organs

Water board

Water boards are responsible for the construction, management and maintenance of primary flood defences that surround a dike ring area. Water boards are controlled by an elected representation of landholders: the parties with interests in the protected area. The water boards have the power to issue the by-law needed to secure the water retaining function. The management and maintenance is chiefly financed through taxation of landholders. The construction costs connected to the current round of dike reinforcement are too high for the majority of water boards however, and are therefore (largely) subsidized by the state. The construction subsidy for the river dike reinforcements were transferred to the provincial fund in 1993. The financing of integral flood defence management is a source of discussion, bearing in mind the limited terms of reference of water boards in the functional administration. It is expected however, that an integral vision on management will increasingly become common property and that financing will adapt to that. The aim is to form large and decisive water boards. This is connected to the ever increasing demands placed on the administrative and technical capacities of a water board, certainly in comparison to the situation just after the Second World War. In less than fifty years the number of water boards has been reduced from around 2500 in 1950 to less than seventy now.

Province

The provinces oversee the water boards. The Flood Defence Act distinguishes two specific tasks: (1) monitoring the technical quality of management, and (2) supervising proper harmony between municipal and water board policy. This last aspect is a guarantee within our polity for the adaptation of functional water board management in the general administration. The terms of reference of the water board is laid down by the province in the water board regulations. The plans for dike reinforcement and the flood defence manager's five-year report prescribed by the FDA on the hydraulic state of the primary flood defences must also be submitted to the Provincial Executive. The regulating function also includes the national flood defences in the province. Furthermore, the province plays an important role in the organization of the system of water boards, in the concentration of water boards mentioned for example. The setting of norms for drainage/discharge canal embankments and secondary flood defences are also provincial tasks.

State

The state has a number of responsibilities, including (1) legislation, (2) supreme control of the system of water boards, (3) the management of primary water defences that protect various dike ring areas (especially sea arm barriers) and the dune coast of the Wadden islands and (4) the management of the large waters and rivers. With respect to the sandy coast the state plays a specific role, of great importance to the flood defence managers along the coast. The state is responsible for maintaining the location of the coastline, one of the preconditions of the security of dunes and sea dikes. The river manager must ensure, among other things, that undesirable resistance is not created in the riverbed and that the water coming from upstream can be easily drained. The supreme control is expressed in the five-year report by the Provincial Executive to the minister of Transport, Public Works and Water Management on each dike ring area in its province, as prescribed in the tasks of the province.

Municipality

In the field of spatial planning the municipality draws up zoning plans, in which flood defences must find a place. Whereas water boards are oriented to protection against flooding, bearing in mind their functional administration tasks, the municipalities are oriented to the other functions of water defence. In addition, the municipality has responsibilities in the case of a flood, including drawing up a contingency plan, maintaining public order and security and ensuring public health.

3.8.2 Legislation

Article 21 of the Constitution calls the care of the habitability of the Netherlands a fundamental task of government. A number of legislative fields are especially important for flood defence management and improvement:

- Water management legislation (particularly the Flood Defences Act (1995), Water Control Act (1900), Delta Act (1958), Delta (Major Rivers) Act (1995), Rivers Act (1908), Water Management Act (1989), Water Boards Act (1992), provincial regulations and water board by-laws;
- Planning legislation, particularly Spatial Planning Act (1962), Expropriation Act (1857);
- Environmental legislation, including Environmental Management Act (1993), Soil Protection Act (1986), Pollution of Surface Waters Act (1971).

The main role of the Flood Defences Act (FDA, annex I) is to legally anchor protection from flooding by the outside water. The FDA is the legal foundation for construction, improvement and maintenance of flood defences and provides all dike

ring areas with a safety norm (see annex I). The management of the flood defences is also regulated in the provincial regulations and the water board by - laws.

The principal aim of the FDA is to guarantee security. It is a fact that social understanding of the risks of flooding decreases as the years elapse since the latest flood. Article 9 of the Act obliges the manager of the flood defence to report on the state of the defence in relation to the norm every five years. This is an attempt by the legislator to prevent the consequences of the process of a decreasing understanding of risks. The Delta Act regulates the damming of the sea arms in the South-West Netherlands and the improvement of the other flood defences along the whole Dutch coast (including the financing thereof). The Delta (Major Rivers) Act is an emergency act aimed at improving the weakest dikes along the great rivers in a short space of time after the high water of 1995.

The Rivers Act is oriented to ensuring that the water discharge function of the rivers continues to be guaranteed. This is also connected to the normative water levels for protection against flooding. A permit is therefore required for all works in (the winterbed of) the river.

The Water Management Act regulates in itself nothing with respect to flood defences, but the Fourth Policy Document on Water Management based on this act addresses in detail the relationship between water levels and the arrangement of the riverbed.

The Spatial Planning Act (SPA) is the basis of other zoning plans. A municipal building permit is needed for building of or on a flood defence, granted on the basis of the zoning plan. In the zoning plan the main purpose of the area of the flood defence is hydraulic. In turn, the water board draws up a by-law in which the permissible uses from a water retaining function are stated. The SPA set of instruments is also important at any building activities outside the dike.

The Expropriation Act regulates the legal procedures for ground acquisition, needed for improvement works, in the cases in which it is not possible to reach an amicable agreement.

The Environmental Management Act (EMA) regulates matters that are relevant to dike improvements. The EIA (environmental impact assessment report) procedure, which is mandatory at improvement projects, is based on the EMA. The EMA is also applicable in the final execution of improvement works.

Materials used in flood defences must fulfill the Building Materials Decree based on the EMA. If this is not the case then a permit must be requested on the basis of the EMA.

The Soil Protection Act (SPA) covers both preventative protection and curative decontamination of the ground. The latter comes into play when a flood defence must be reinforced on soil that is very contaminated.

The Pollution of Surface Waters Act (PSW) is applicable when there may be pollution in the adjacent surface water, such as at bank facilities and use of clay screens in dikes.

4 Possible solutions

4.1 Reduction of the flow of water to the Rhine Branches

4.1.1 Possibilities of reducing the design discharge at Lobith

The design discharge at Lobith is determined by the total quantity of water that is transported by the Rhine in the form of a flood wave. As was explained previously, the water flows down the river in the form of a wave. It is only possible to exert influence on the total quantity of water by changing the water balance in the entire catchment area, in other words, by allowing more precipitation to evaporate. This could be made possible by making adjustments in the use of the land. This is not possible for design circumstances, as will be explained further on. The height and shape of the flood wave can be influenced, but this is not simple. We will also elaborate further on this subject later.

The absolute quantity of water that ultimately flows down the river is determined by the water balance: how much precipitation falls and how much of this disappears again through evaporation. With frequently occurring and thus minor amounts of precipitation, there is a strong connection between land use and river discharge. Interception and evaporation as a result of vegetation and temporary storage in the bed play a large role during low amounts of precipitation. The more the paved surface area in the catchment area increases, the faster the smaller amounts of precipitation end up in the river. In order to prevent this, an adjustment in land use can be beneficial.

During extreme – and thus also more rare – circumstances, land use is less of a determining factor for river discharge. By extreme, we mean long periods of heavy rainfall, sometimes in combination with frost in the ground. Under similar circumstances, evaporation is practically nil and the absorption capacity of the ground is reduced to 0: precipitation results directly in runoff. Design circumstances for The Netherlands involve such extreme situations and for this reason land use in the catchment area becomes of minor importance.

The second point: the height of the flood wave. This is primarily determined by whether or not the peak discharges of the major tributaries of the Rhine coincide with that of the Rhine itself. The most important tributaries involved are the Neckar, Main and the Moselle. During the flood of 1993, the height of the flood wave was mostly determined by events in southern Germany and in 1995 by the coinciding of the peak on the Moselle with that of the Rhine. If the peaks on the Neckar and the Main had also coincided in 1995, then the discharge peak at Lobith would have been much higher.

As was determined by a commission of experts from the Rhine countries, during the last century the flood waves of many tributaries preceded those on the Rhine. This does not necessarily mean that slowing these waves down is desirable. In a broader sense, given the complicated timing of the discharge peaks on the tributaries and the main channel, it is incorrect to state that every measure that slows down the discharge on the tributaries is in and of itself a good measure.

One last point worthy of attention involves the period of time necessary for changes in land use to take effect during less extreme discharges. The expectation that the effect of increasing the absorption capacity in the catchment area of the Rhine by afforestation or nature development will be seen within 15 years is too high, given the expected necessary preparation time and the speed of growth of forest. It will sooner take 60 rather than 30 years before The Netherlands will see the benefit of such measures. If it is to be expected that sufficient measures are taken in The Netherlands within the next 15 years, in terms of maintaining the present level of safety that will bear fruit, then the Netherlands cannot wait. This does not mean that nature development in the catchment area should be advised against, on the contrary: measures in the catchment area can contribute substantially, but the length of time they require to prove their effectiveness falls far beyond the term that is currently considered acceptable in The Netherlands.

To briefly summarise: Limiting the absolute discharge through changes in land use under design circumstances is hardly possible and simply cannot be realized in the short term. By virtue of its complex phasing of discharge peaks from tributaries, discharge delay is not preferred. (IRMA, RIZA, 2001)

4.1.2 Detention measures

With regard to the shape and height of the flood wave that reaches The Netherlands, the location of the measures involving the peak-determining tributaries is significant. As a rule, the goal of detention measures along the tributaries of the Rhine is to protect a particular location against floods. By merging with other tributaries or the Rhine itself, a delay of the discharge of a tributary can lead to a reduction or

increase in the size of the flood wave on the Rhine, in proportion to the genesis of the flood wave in that portion of the catchment area. The following statements may be made about detention measures along the Rhine in Germany:

- Detention measures along the southern portion of the Oberrhein in southern Germany, upstream from the Neckar and Main, with a capacity of 290 million m³, can produce a reduction in an extreme flood wave of 25 cm. A reduction would have been negligible in the case of the flood wave of 1995 because this was largely determined by tributaries in the middle and north of the catchment area. The planned detention measures have no added value for Dutch design discharges since floods already take place along the northern Oberrhein.
- Between the mouth of the Main and Cologne, along the Mittlerrhein, detention is not possible because the river flows through a valley gorge at that location.
- Detention in Nordrhein-Westfalen, along the Niederrhein, can mean a great deal for The Netherlands because it is located just upstream from Lobith and there are no more large tributaries that flow into this area. Here 11 areas have been assigned which can provide room for the river. Four of these areas are actual detention areas (with a dike around them and a sill) with a total capacity of some 75 million m³. The remaining 7 are dike set-backs and they do not contribute substantially to a reduction of the flood wave that reaches The Netherlands. The manners in which the detention areas are designed and the water level at which they fill up determine whether or not The Netherlands may derive much benefit from them. The water level decrease that could realistically be achieved via all 11 measures combined is estimated at a maximum of 10 cm at Lobith (Figure 4.1).

In a nutshell: detention measures in Germany can provide a limited contribution to the lowering of the design discharge peak that reaches the Netherlands at Lobith. Therefore, detention in Germany does not provide an alternative strategy to measures in The Netherlands. This is sufficient reason to assuming a larger discharge, for example 16,000 m³/s, and to take some other measures. (IRMA, RIZA, 2001).

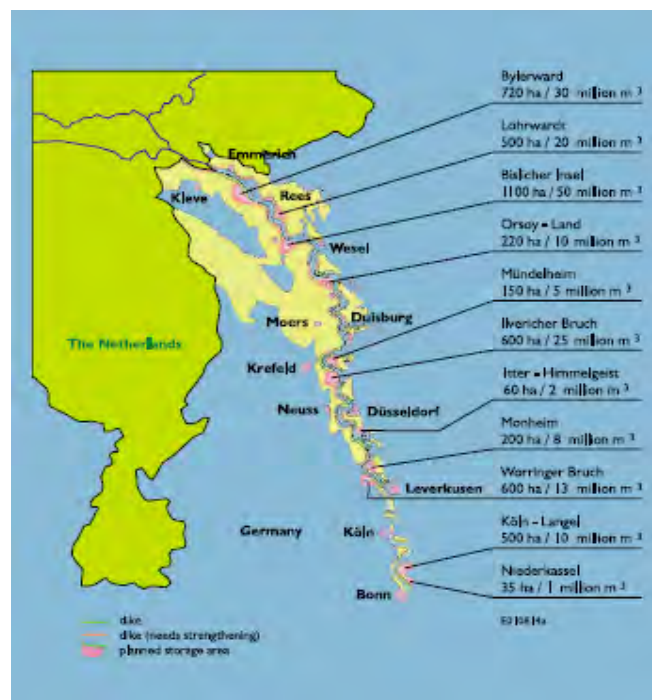


Figure 4.1 measures along the Nederrhein in Germany
(Source: Ministerium Umwelt, et al.)

4.2 Storage of water along the Rhine Branches

4.2.1 Detention measure

By detention it means that a segment of the discharge peak is shaved and is temporarily stored in a diked-in area. Once the worst has passed, the temporarily stored water is released again and discharged. Detention limits the quantity of water to be discharged for the section located downstream of one (or more than one) of the Rhine Branches. This means that detention must occur upstream if it is to fulfil its purpose. For The Netherlands, this translates into as close to Lobith as possible.

In a detention basin, the top of the flood wave is shaved off as it were. The quantity of water that is present in this 'wave top' is left behind in an area surrounded by a sufficiently high dike via an overflow or other type of construction. The total storage capacity of this area must be enough to be able to store the total volume of water from this 'wave top.' The intake must be large enough to convey the difference in discharge between the wave top and the amount of water that remains in the river.

This may be understood as follows: the difference between the current design discharge of 15,000 and the expected discharge of 16,000 m³/s is 1,000 m³/s. In order to prevent dike raising downstream exclusively through the use of detention methods, this amount of 1,000 m³/s must be allowed in via intakes into one or more

detention areas. The total storage capacity necessary is determined by the difference in the height of both tops in relation to the shape (and especially the duration) of a flood wave. In this way, it may be calculated how much water must temporarily be stored within one or more dike rings.

For the 1,000 m³/s mentioned here, a storage capacity of some 170 to 200 million m³ is required for a flood wave lasting several days and having an ‘average shape.’ At a depth of 5 metres, this means a necessary surface area of some 3,500 to 4,000 hectares. Similar depths are conceivable in the relatively low-lying areas within the dikes along the Boven-Rijn and the Waal, but along the Neder-Rijn and IJssel much shallower water depths would have to be realised. The higher the storage areas lie, the less the water depth will be and proportionately larger the surface area will be. (IRMA, RIZA, 2001).

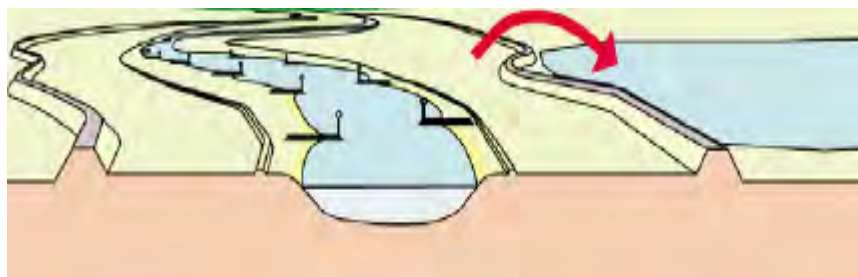


Figure 4.2 Detention for temporary storage



Figure 4.3 Layout of a detention area along the Oberrhein
(Source: Hochrhein)

4.2.2 Location of detention basin

If assuming the strictest definition of ‘detention,’ then a clear preference lies with upstream location. The attenuation and temporary suppression of discharge peaks is particularly beneficial to the section of the rivers or branches located downstream. It

is for this reason that the construction of detention areas just across the German border in Nordrhein-Westfalen can be so advantageous for The Netherlands.

If aiming to realise detention basins to assist with flood problems on the territory of the Netherlands, then these must be located as close to Lobith as possible, in terms of preference. According to an exploratory study, there are two areas that qualify for this:

- the Rijnstrangen area, in which the Boven-Rijn can be attenuated with positive results for all three of the Rhine Branches, including the lower river regions; and
- the Ooijpolder/Duffelt, by which the discharge from the Boven-Rijn and the Waal may be reduced, depending on the location of the intake.

These areas have a storage capacity of more than 150 and 65 million m³ respectively, with surface areas of over 3,100 and almost 1,400 hectares. In theory, these amounts combined are enough to attenuate a discharge of 16,000 m³/s for a sufficiently long period of time. (IRMA, RIZA, 2001)

4.2.3 Consequence of a detention area

First of all, an area may only be used as a detention area if an enclosure dike of sufficient height can be built and a sizeable and adjustable intake is in place. For the Rijnstrangen area, this means that several kilometres of dike must be raised and partially rebuilt. At present, the Rijnstrangen area runs up through the Pannerdensch Canal, but the dike there is currently more than a metre lower than would be necessary for a basin with a horizontal water surface since the river slopes. Also, dikes must be either reinforced or built on both sides of the area, particularly when one considers the substantial water depth. On the downstream side of the Rijnstrangen area, a water depth in the detention area of some 9 metres must be counted on.

Land owners must be compensated for any damage occurring during incidental flooding. Houses and other structures situated at these inundation depths must be bought up. In future, land use in the area will most likely be adjusted. And there will definitely be limitations that will apply in terms of investment. All of this influences the cost of such projects, which total at least 0.2 billion Euro for the Rijnstrangen area, and a minimum of 0.1 billion Euro for the Ooijpolder. These very global cost estimates do not yet include plans that are at this moment either being prepared or are in progress, such as the extension of the Rijksweg A15 (motorway) through the Rijnstrangen area, nor the construction of the Betuwe railway, both of which also pass through this area.(IRMA, RIZA, 2001)

4.2.4 Risk of using detention areas

Risks are possible when on the subject of the detention function because the operation of detention areas requires precision. In the first place, they must not fill up too soon, because they run the risk of being full before the actual discharge peak has arrived. Then there is no longer any room for the peak, which flows on ‘unhindered.’ A similar danger exists during a very lengthy – flattened as it were – wave, or during a second peak that occurs soon after the first and the detention area has not (completely) emptied. In this case, a detention area would no longer contribute to a reduction in the discharge.

Detention basins must also not fill up too late, because the discharge peak will already be over. This means that the timing of this filling up requires a high degree of precision. In the case of an intake with a regulating mechanism, this also means that we must be able to accurately predict the discharge pattern, which is currently possible for a period of 2 days in advance.

An entirely other issue involves the nature of the application of detention. If detention is considered a structural measure in order to attenuate discharges above 15,000 m³/s, then these same areas can no longer perform a function for discharges above the design level of 16,000 m³/s. In other words, application of the same overflow area as a temporary measure (‘calamity polder’) for discharges above the design is then no longer possible. (IRMA, RIZA, 2001).

4.3 Discharge of water via the Rhine Branches

In comparison with storage, the most important difference is with storage, the amount of discharge is reduced; and with measures to increase the discharge capacity, only the water level is lowered while the discharge remains the same. Storage, provided it is carried out for long enough, is beneficial for the region downstream of where the measure is being implemented and for only a very short distance upstream. Increasing the discharge capacity is advantageous for the section of river upstream from where a measure is being executed. The reason for this is that the backwater effect of a narrowing, another type of obstruction, or a substantial ‘hydraulic roughness’ is diminished, or that the cross-sectional profile is increased. The creation and implementation of measures which increase the discharge capacity must be first carried out downstream, with subsequent measures carried out in an upstream direction.

There are many measures to achieve the purpose, we can divide these up into three large groups and treat them in succession:

- measures in the low flow channel;

- measures in the flood plains; and
- measures in the areas protected by the dikes (setting back dikes, etc.)

Within each group there are then separate types of measures.

4.3.1 Measures in the low flow channel

- Lowering of low flow channel

The bed of the low flow channel in the upstream sections of the Rhine Branches has experienced substantial erosion in the past due to interventions. And the bed continues to erode. Because of the negative consequences of this, attempts are being made to halt this process. So to deepen the low flow channel is an option that is not very well-received. In downstream sections, on the contrary, siltation takes place. This is then regularly dredged. If other measures cannot provide a solution for this area, then low flow channel deepening in the downstream sections could be considered. For the three Rhine Branches, research has been conducted to determine how much reduction of the water level can be realised in the downstream sections with a low flow channel bed deepening of a ‘standard’ of 1 metre.

From these calculations it appeared that dredging of the low flow channel bed can produce a water level reduction between 20 and 30 cm over a distance of some 50 km. Low flow channel bed dredging could however be accompanied by undesirable consequences for the ground water conditions and salinity intrusion from the sea could occur. Further research is required to provide more information on both topics. (IRMA, RIZA, 2001)

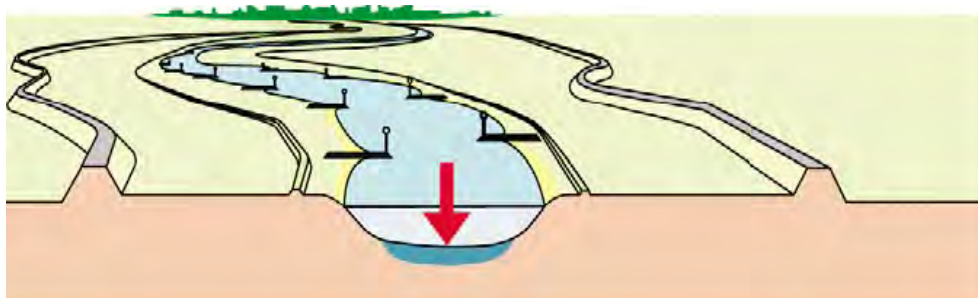


Figure 4.4 Lowering of the low flow channel

- Lowering of groynes

As was mentioned above, the riverbed is lower in the upstream sections due to erosion, while flood plains have become higher. Through erosion in the low flow channel, for a considerable part of the year the groynes currently lie higher above water than in the time that they were first constructed. This is particularly the case upstream. Therefore, during floods, they form an important obstacle.

Based on measurements of the groyne height above the low water mark, and taking into account adequate functioning that will keep the navigation channel at the proper depth, the maximum possible amount of groyne height reduction is determined for every section. Upstream there is a possibility to reduce them by more than 2 metres, but in the downstream sections such reduction is not possible at all; the bed is not eroded there and the backwater effect from the sea and the IJsselmeer is erceptible.

The number of groynes that may be reduced in height per section varies from about 90 to more than 400, depending on the length of the section and the degree to which groyne were constructed in the past. All together, there are more than 1800 groynes that could possibly be reduced in height.

Calculations have been made to determine which decreases in water level correspond to the different groyne height reductions. To this end, all groynes within one section are reduced in height equally; in the upstream sections by more than 2 metres, in the middle sections by less than a metre, and not at all downstream. Because the groynes differ in length and the reduction varies greatly in metres, the consequences for the water level per section also vary significantly. Along the Waal, the groynes are in general relatively long and along the IJssel quite short. However, where the river and/or flood plain is relatively wide, the effect of groyne height reduction on the water level is quite minimal; after all, relatively little water flows over groynes. The calculations show that groyne height reduction can contribute to a reduction in the water level on the Waal and the IJssel varying from 5 to 15 cm. On the Neder-Rijn, this is a maximum of 10 cm. This may not seem like much, but on the other hand, the costs of groyne height reduction are relatively low. Thus we may conclude that the efficiency of this measure is high.

By reducing the height of groynes, more water flows over them and less flows through the low flow channel. This can result in a decrease in erosion and a delay in the occurrence of erosion in the low flow channel. The contribution of groyne height reduction to counteracting unwanted erosion is then considered a favourable incidental circumstance. (IRMA, RIZA, 2001)

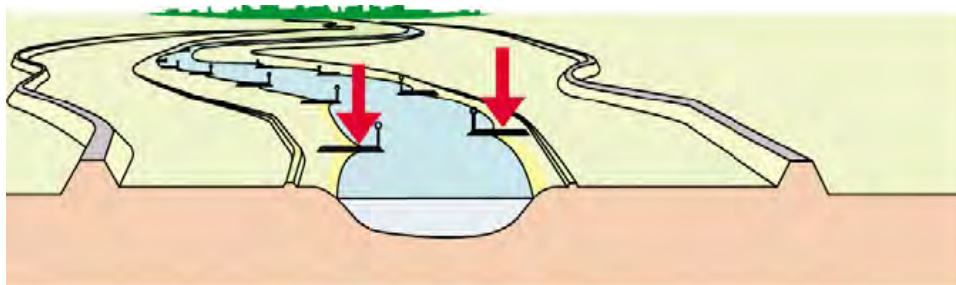


Figure 4.5 lowering of groynes

4.3.2 Measures on the flood plain

- Possible solutions on flood plain

The possible solutions on flood plain compose a list of measures and in this case, these are also split up into categories. With flood plains the following must be considered:

- excavation of the flood plains
 - landscaping plans of flood plains
- removing hydraulic bottlenecks

Flood plain excavation is a measure by which the gradual development of heightening by sedimentation on flood plains may be counteracted. This heightening is for the most part caused by the construction of dikes, ‘normalisation’ of the river and by the construction of summer embankments. Flood plain excavation may be combined with clay mining, as was recently applied within the framework of the most recent dike reinforcements, and/or with nature development. Aside from performing other functions, the latter plays a role in the fact that far-reaching flood plain excavation makes land less profitable for agriculture, particularly if the summer embankments are also removed in the process. Moreover it has appeared from practical examples – the Duursche Waarden, Millingerwaard and Blauwe Kamer flood plains among others – that due to this mining process, nature development produces a result that is valued by many.

The removal of ‘hydraulic bottlenecks’ implies that every type of obstruction that interferes with flow is removed or adapted to promote the continuation of flow. There are many types of hydraulic bottlenecks, all of which are first inventoried by depicting the water levels in the river on a graph; this is the so-called water level slope line. From this water level slope line, it appeared that flow obstruction was caused by things such as ferry ramps, bridge abutments, flood-free areas, summer embankments that are high and/or perpendicular to the flow direction, narrowing of the flood plains (in particular by dike stretches that locally are located close to the low flow channel), etc. (IRMA, RIZA, 2001)

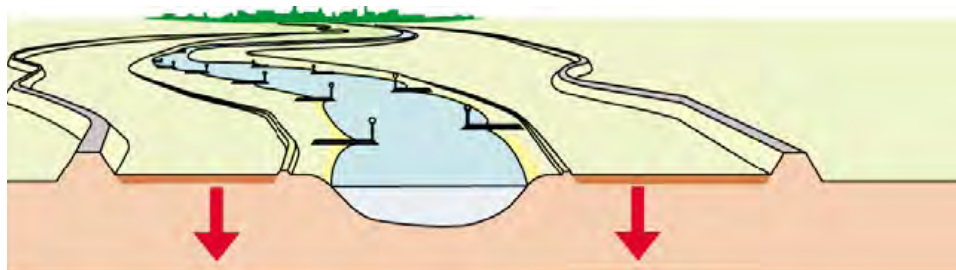




Figure 4.6 Lowering of flood plain (Source: RIZA)

- Landscaping plans of flood plains

There have been more than 150 plans for redesign offered by provinces, water boards and city councils. All of them were ‘nature development plans.’ These plans consisted of a type of ‘map’ which detailed the type of nature they had in mind for different areas. In only a very few cases the extent of flood plain excavation that was envisioned for the execution of their plans was indicated. For this reason, to conduct the research for each plan, in addition to a 0-variant, three other variants were distinguished for excavation, which resulted in the following:

- Plan variant 0: a plan without excavation;
- Plan variant 1: a plan with ‘maximum excavation’ without endangerment to the desired nature development;
- Plan variant 2: a plan with extra excavation, by which a portion of the ‘dry and humid nature’ was replaced by ‘wet nature’ and extra open water was realised;
- Plan variant 3: the same as variant 1, but with vegetation management aimed at preventing high, bushy vegetation development that would interfere with flow (for example, intensive grazing, which would allow pastures to remain intact).

Some sections of the flood plain have been protected from excavation: protected nature reserves, strips of land along the dike (meant to prevent the dikes from becoming unstable), and strips of land along the low flow channel (meant to prevent the low flow channel from shifting its position). These sections are called ‘keep out areas.’ (IRMA, RIZA, 2001)



Figure 4.7 excavation and nature development in the Baarsemwaard flood plain along the Neder-Rhine Left: before implementation Right: in progress (1999)
(Source: Draex)

- Removal of hydraulic bottle necks

Based on the water level slope line in all three Rhine Branches, it was first determined where the hydraulic bottlenecks were to be found. Using this method, 254 bottlenecks were found. Next, with the aid of topographic maps, these were identified as flood-free areas, bridge abutments, ferry ramps, etc. Some of these bottlenecks comprise a considerable surface area, such as floodfree (factory) areas. Ferry ramps, bridge abutments and summer embankments are, conversely, much smaller.

Not all bottlenecks qualify for removal, for example a flood-free area with a still-functioning brick factory or a narrowing in the river in the middle of a city. These so-called urban bottlenecks have been intentionally excluded from consideration because the administrative feasibility of measures in these areas seemed remote. Ultimately it was determined what water level decrease would be possible with removal for 126 ‘bottlenecks.’ Of these 126 bottlenecks, there were 31 cases of narrowing of the flood plain, for example due to dike stretches that are locally located close to the low flow channels. In this type of location, only setting back a dike will offer relief, which in actual fact is a measure for dike-protected areas. Because it usually involves a relatively small dike-protected area, and the water-level lowering effect of measures on all hydraulic bottlenecks is determined fairly effortlessly, these ‘small-scale setting back of the dikes’ efforts are included here.

For every bottleneck it was calculated what degree of water level decrease may be realised. At the same time, the costs of approaching every bottleneck were budgeted. The costs of widening and deepening the bridge abutments and the removal of ferry ramps vary from less than 2 million Euro to more than 60 million Euro for a

highway bridge. The costs of excavation of embankments and small-scale setting back of dikes are usually in the order of 4 million Euros per project, but it can run up to over 15 million if many houses must be expropriated. The removal of flood-free areas can amount to some 25 million Euros, especially in those cases where uncertainties concerning contaminated land play a role.

The water-level lowering effect of the measures varies so much that the efficiency also differs greatly. At that point, two criteria were applied to select 60 measures (including 18 small-scale dike relocations) that were taken into consideration in the further study, namely:

- A water-level reduction effect of at least 1 cm ('otherwise it's not worth the effort'); and
- An efficiency grade of at least 2 mm/million Euro ('otherwise it is a relatively expensive measure').

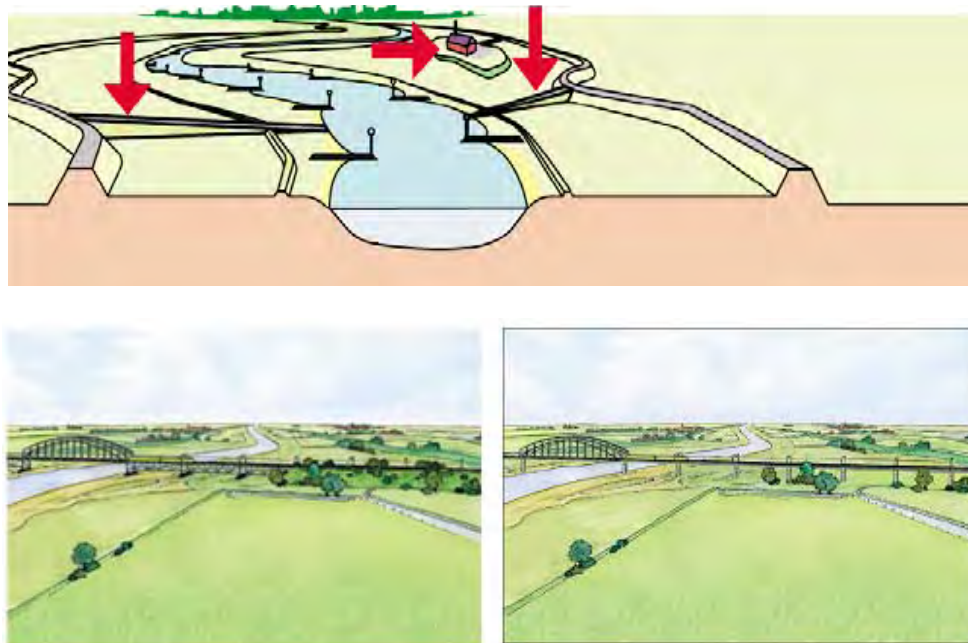


Figure 4.8 Removal of hydraulic obstacles (Source: K.Nuijten)

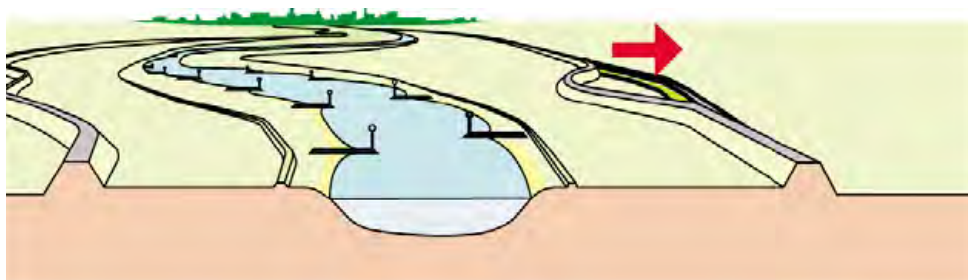




Figure 4.9 Setting back the dikes locally (Source: K.Nuijten)

4.3.3 Measures in the dike-protected areas

- Large-scale setting back of dikes

The options for setting back dikes are rather expensive, but sometimes also extremely effective. Despite the costs which vary from 4 to 50 million Euro, the setting back of dikes all surpass the efficiency level of 2 mm water level reduction per 1 million Euro. The achieved water level reduction of individual setting back of dikes can run into several tens of centimetres, but in contrast there are measures in this category that only produce several centimetres worth of reduction; nevertheless, these also satisfy the criteria that were formulated earlier as the minimum for measures at hydraulic bottlenecks.

Setting back dikes is particularly effective in cases of real narrowing of the flood plain which cause backwater effects quite a distance upstream. This is why the consequences of setting back dikes for the water level also continue to work relatively far upstream. A local reduction of some 10 to 20 cm is realisable per measure. Along the Waal and the Neder-Rijn/Lek, all of the settings back of dikes together can result in a maximum reduction of 60 cm. (IRMA, RIZA, 2001)

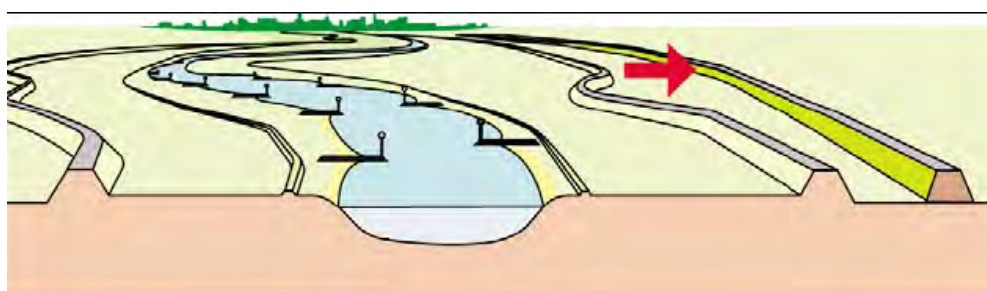


Figure 4.10 Large-scale setting back of dike

- Green river for urban bottlenecks

River widening and deepening measures upstream of such a narrowing do not offer a solution, since widening and deepening as it were occurs in or around a

‘reservoir,’ without the valve which empties the ‘lake’ being opened. Measures downstream of such a narrowing have little effect on the water levels since this would be comparable to drawing water using a closed valve. And even this does not help. This means that the urban bottlenecks do harm the effectiveness of the other measures and may work unfavourably in terms of the costs of combined alternative strategies.

The following urban bottlenecks have been identified:

Along the Waal

- the city of Nijmegen
- the city of Zaltbommel

Along the Neder-Rijn/Lek

- the city of Arnhem

It is obvious that the only thing that can offer relief for these urban bottlenecks are measures in the dike-protected areas; after all, flood plains are (almost) entirely lacking. As has been mentioned, similar measures were not taken into consideration in an earlier stage in connection with the expected futility of administrative feasibility, seeing as the measures involved would have to be executed in a relatively densely built-up area. For this reason, the *green rivers* have been created for measures involving urban bottlenecks.

Green rivers are in fact flood plains between two (guiding) dikes where water does not flow through during low discharges, but does flow during floods. They may be used for agricultural purposes or may be designed for nature and/or recreational areas: they are, in short, ‘green.’ (IRMA, RIZA, 2001)

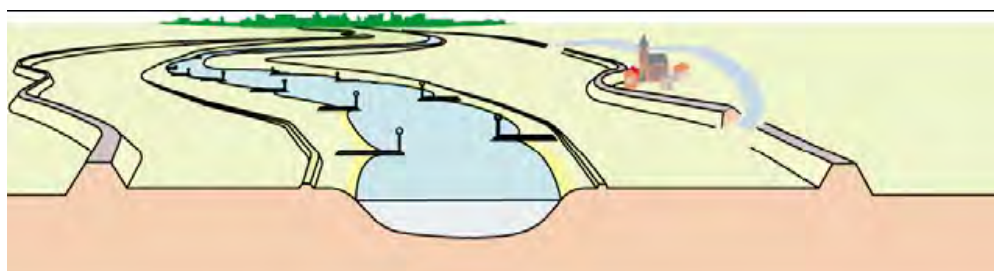


Figure 4.11 Urban bottleneck



Figure 4.12 Green river: low water (left) and high water (right)
(Source: WL/Delft Hydraulics)

4.4 ComCoast

4.4.1 Concept and aims

ComCoast – “Combined functions in Coastal defence zones” is a European project, which develops and demonstrates alternative solutions for flood protection in coastal areas, trying to address new functions to those areas. Rijkswaterstaat, a part of the Dutch Ministry of Public Works and Water Management, is the leading partner; other participating countries besides the Netherlands are Denmark, Great Britain, Belgium and Germany.

In the coming years climate change will increase the physical loads on coastal defences all over the world. Traditionally the Netherlands has protected itself against the growing threat of flooding, by heightening the dikes. However, with the continuing sea level rise, it becomes more and more evident to find alternative and innovative strategies, without just heightening the dikes. ComCoast develops such flood risk management strategies, with gradual transitions from sea to land, in order to create integrated defensive zones including wider environmental functions, such as recreation, fisheries, tourism and nature creation.

The ComCoast concept aims to create multifunctional flood management schemes with a more gradual transition from sea to land, which benefits the wider coastal community and environment whilst offering economically sound options. The concept focuses on coastal areas comprising embankments,

- to provide economical and sustainable alternatives to the traditional single line flood defence strategy of step by step raising the crest level of the embankments,
- to create a win-win situation for both flood management over a wider coastal zone and multi-functional land use and
- To adjust to spatial developments and needs in the coastal zone.

The aim of ComCoast is as following:

- to explore the spatial potentials for coastal defence strategies for current and future sites in the North Sea Interreg IIIb region
- To create and apply new methodologies to evaluate multifunctional flood defence zones from an economical and social point of view.
- to develop innovative technical flood defence solutions to incorporate the environment and the people and to guarantee the required safety level
- to improve and apply stakeholder engagement strategies with emphasis on public participation
- to apply best practice multifunctional flood management solutions to the ComCoast pilot sites
- To share knowledge across the North Sea region.

4.4.2 Technical functions and components

The ComCoast project searches for alternative coastal defensive solutions using a multiple line of defence strategy. In comparison with a single line defence, a coastal defence zone has a range of components (lines) each with its own function. First these technical functions and its components are formulated from which the main ComCoast solutions can derived.

Water retaining

The primary dike retains high sea levels and wave run-up, up to the design level. The inner slope can have an overtopping-resistant revetment, which permits a greater overtopping discharge.

Water storage

The area behind the primary dike is a transitional area able to store the overtopping seawater. A secondary dike or higher grounds, encircles the transitional area. Or the water is handled by large ditches or pumping stations.

Water control / management

During storms and in normal weather conditions the coastal defence zone should be able to drain off water when necessary. First, a drainage system facilitates water control in the transitional area. For larger quantities of water, a pump installation can be installed to support the discharge of water by the drainage system. If desired, a culvert can be added to increase tidal influence in the transitional area. A culvert can also be used to drain off excessive salt water after a storm.

Wave reduction

Several elements in front of a dike yield wave reduction. First, a shallow foreshore creates a moderate wave climate in front of the dike. In addition, wave reduction can also be achieved when there is a previously constructed lower dike, a breakwater or a summer dike.

Multifunctional use of area

The transitional area can be used for several purposes, for example aquatic sport, recreation, the development of aquatic areas and to enhance environmental values. This is only the case when the area is flooded regularly. This can also be obtained by Managed realignment.

4.4.3 Comcoast solutions

The distinguishing of the functions and components as discussed in the previous paragraph has led to five main ComCoast-concepts:

Landward solutions (figure 4.13):

- Regulated tidal exchange is the regulated exchange of seawater to the an area behind fixed sea defences, through engineered structures such as sluices, tide gates or pipes to create saline or brackish habitats.
- Managed realignment involves the placement of new Managed realignment flood defence landward of the existing flood defences. This would be achieved trough the partial or complete removal of the existing flood defences.
- Overtopping resistant dike involves the replacement of the top of the dike and its inner slope with a revetment that will not wear away by severe overtopping. The overtopped sea water will be handled in the coastal zone at the landward side of the dike (drainage/storage)

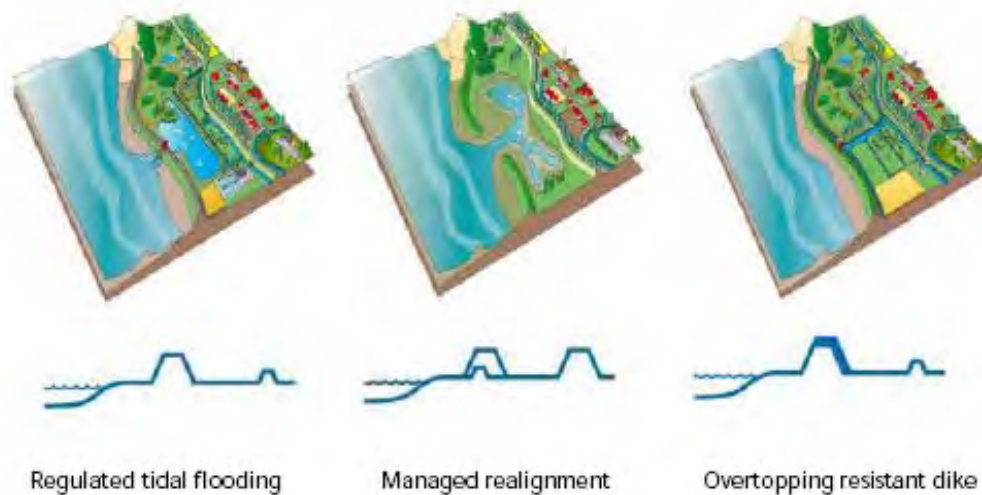


Figure 4.13 landward solutions

Seaward Solutions (figure 4.14):

- Foreshore protection involves reclamation works to maintain or to create higher ground and in some situation small dikes in front of the primary dike, which act as breakwaters in case of a big storm
- Foreshore recharge involves the placement of material in front of the existing coastal defence system. It includes to restore the coastline and to advance the line.
- Restore the coastal line means replenishing the foreland with environmentally safe dredge spoil. Advancing the line requires raising the foreland by coastal nourishment.

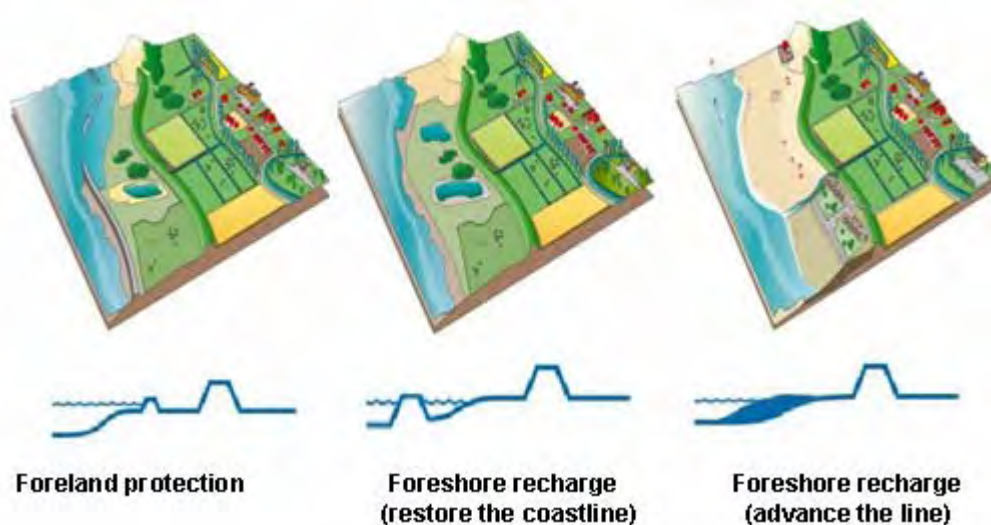


Figure 4.14 Seaward Solutions

4.5 Live on mound

Living on mound is a very traditional solution which was in use in the early Middle Ages in the Netherlands. These are artificial hills which are high enough to remain dry during floods.

Rotterdam is a good example in such way. Rotterdam is the largest port in the world, and the combination of the harbors along the Westerscheldt in both the Netherlands and Belgium could be considered the second-largest harbor in the world. So, huge investments have been made in this area. But they have shown that captains of industry will not accept any risk of flooding at all. Refiners, oil terminals, nuclear plants, chemical industries, container terminals had to be entirely secure. If the darkest situation occurs, and the safety limit of the dams (one in 10,000 years near Rotterdam and 1:4000 years in other areas) is overtaken by an enormous storm, even these dams will break and the lands behind will become drowned in water meters deep. The damage will take many months to repair and the losses would be amazing great. However, the industrial complexes on their artificial mounds, in the same worst case scenario, suffer a few centimeters of flooding during the few hours of high tide (figure 4.15).

The industry made a partial return to the safest possible strategy for flood prevention: large-scale artificial mounds. Why don't use this measure in urban planning?



Figure 4.15 Refiners on artificial mound in Rotterdam
(Source: Rijkswaterstaat)

4.6 Living with flood

Living in close proximity to water is attractive but has come at the price of land that could have been allocated to water. The possibilities of living near water are good, as long as the demands for safety and water storage are taken into consideration, now and in the future. With the increase of population and development of society and economy, more land and space are claimed for industry, housing and recreation. The area which has relatively high risk of flooding should keep preparation to live with flood by taking some individual measures, although the dike system has keep a certain safety level.

Inhabitants of high-risk area can take precautions to protect their homes and property and prevent a great deal of damage. In addition to the efforts extended by different level of government citizens themselves must protect their property or even take into account the heightened risk of floods in the design of buildings. Examples given include (figure 4.16):

Raising the elevation of the ground floor: building the house on the pile or on a heightened foundation according to the suggestion of the local flood protection department;

- Installing indoor heating, power and telecommunications systems as high as possible;
- Use of water-resistant building materials;
- Making cellars water proof.



Figure 4.16 Living with flood

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Part C: Mississippi River Delta



1. Introduction of Mississippi River Delta

1.1 Mississippi River system



Figure 1.1 The Mississippi River Basin

The Mississippi River drainage basin ("catchment") is the third largest in the world, exceeded in size only by the watersheds of the Amazon River and Congo River, about 1,243,700 square miles (4,760,000 km²), and includes 41% of the contiguous United States (portions of 31 states) and parts of two Canadian provinces (Figure 1.1, Table 1.1). The Mississippi basin stretches from the Rocky Mountains in the West to the Appalachian Mountains in the East. From its headwaters in upper Minnesota at Lake Itasca, the Mississippi runs 3700 km to its mouth in the Gulf of Mexico. If measured from the head of the Missouri, the length of the Missouri-Mississippi combination is approximately 6,270 km (3,900 miles), making it the 4th longest river in the world. It is a valley 20 percent larger than that of China's Yellow River, double that of Africa's Nile and India's Ganges, fifteen times that of Europe's Rhine (*Rising Tide*, John M. Barry, 1997). The average discharge of Mississippi is 16,200m³/s, carries an average of 436,000 tons of sediment each day. Over the course of a year, it moves an average of 159 million tons of sediment. Averages have ranged from 1,576,000 tons per day in 1951 to 219,000 in 1988. Eight principle tributaries are Missouri, Ohio, Upper Mississippi, Arkansas, Red, White, Yazoo, and St. Francis in order of the magnitude. The Ohio and Missouri are the second and third largest rivers in the United States, as well as numerous smaller, yet

still imposing rivers. Though the Missouri contributes only 13% of the Mississippi's eventual maximum flow, it brings to the system the major share of its sediment load, eroded from Midwestern farmlands and Western mountains and prairies. The Ohio doubles the magnitude of the discharge from the upper stream.

Table 1.1 Major Mississippi basin catchment areas

Catchment	River length (km)	Mean Flow(m ³ /s)	Catchment area (km ²)
Upper Mississippi	2,120	5,918(Thebes)	390,000
Missouri	4,090	2,300	1,371,000
Ohio	2,100	7,870	419,000
Lower Mississippi	1,580	16,510 (Vicksburg)	269,000
Arkansas	2,350	2,067	608,000
Red	2,080	687(Shreveport)	244,000

The Mississippi river can be divided into two segments: **the upper Mississippi** from its headwaters through Minneapolis and St. Louis to the Ohio, 2120 km, and **the lower Mississippi**, from the Ohio at Cairo, Illinois to Head-of-Passes in the Gulf of Mexico, 1580km. From Lake Itasca (440 m above MSL) to Minneapolis, the upper Mississippi meanders through glacial outwash, plains and moraines. From Minneapolis south it flows in a relatively well-defined channel through a bluff-lined valley 2~10km wide. The lower alluvial valley begins just below Cape Girardeau, Missouri, just north of the junction of the Ohio and the Mississippi, which is roughly 600 miles in length, varies in width from 25 to 125 miles, At a distance of 485 km above the Mississippi's mouth at the Gulf of Mexico, the Mississippi flows are shared with its principal distributaries, the Atchafalaya River. The Atchafalaya receives, on an average, approximately 30 percent of the flow at that latitude while the remaining 70 percent is carried by the Mississippi.

Without question, the Mississippi called "Great River" or "Father River" has made major contributions to the physical and economic growth of the nation. It is a navigation artery of great importance to the nation's transportation system, carrying an ever-growing commerce. Coursing through the heart of America, it supplies water for the hundreds of cities and industries that have located along its banks. Most notable among the large cities are Minneapolis and St Paul in Minnesota, St. Louis, Missouri; Memphis, Tennessee; Vicksburg, Mississippi; and Baton Rouge and New

Orleans, Louisiana. They range in population from 3 million in the Minneapolis-St Paul metropolitan area in New Orleans to under 50,000 in smaller cities like Vicksburg. More and more the Mississippi's importance is emphasized as America continues to grow. This great river is, truly, one of the Nation's outstanding assets. Uncontrolled, it would be just as great a liability.

1.2 The forming of Mississippi River Delta

Through a natural process known as deltaic switching the lower Mississippi River has shifted its final course to the ocean **every thousand years** or so. This occurs because the deposits of silt and sediment raise the river's level causing it to eventually find a shorter and steeper route to the Gulf of Mexico. After abandonment of an older delta lobe, which would cut off the primary supply of fresh water and sediment, an area would undergo compaction, subsidence, and erosion. The old delta lobe would begin to retreat as the gulf advanced, forming lakes, bays, and sounds. This process has, over the past 5,000 years, caused the coastline of south Louisiana to advance toward the Gulf from 25 to 80 km. The river occupied seven different deltas (deltaic lobes) and more than 30 main channels, all in coastal area of south of Louisiana (Shown in the Figure 1.2).

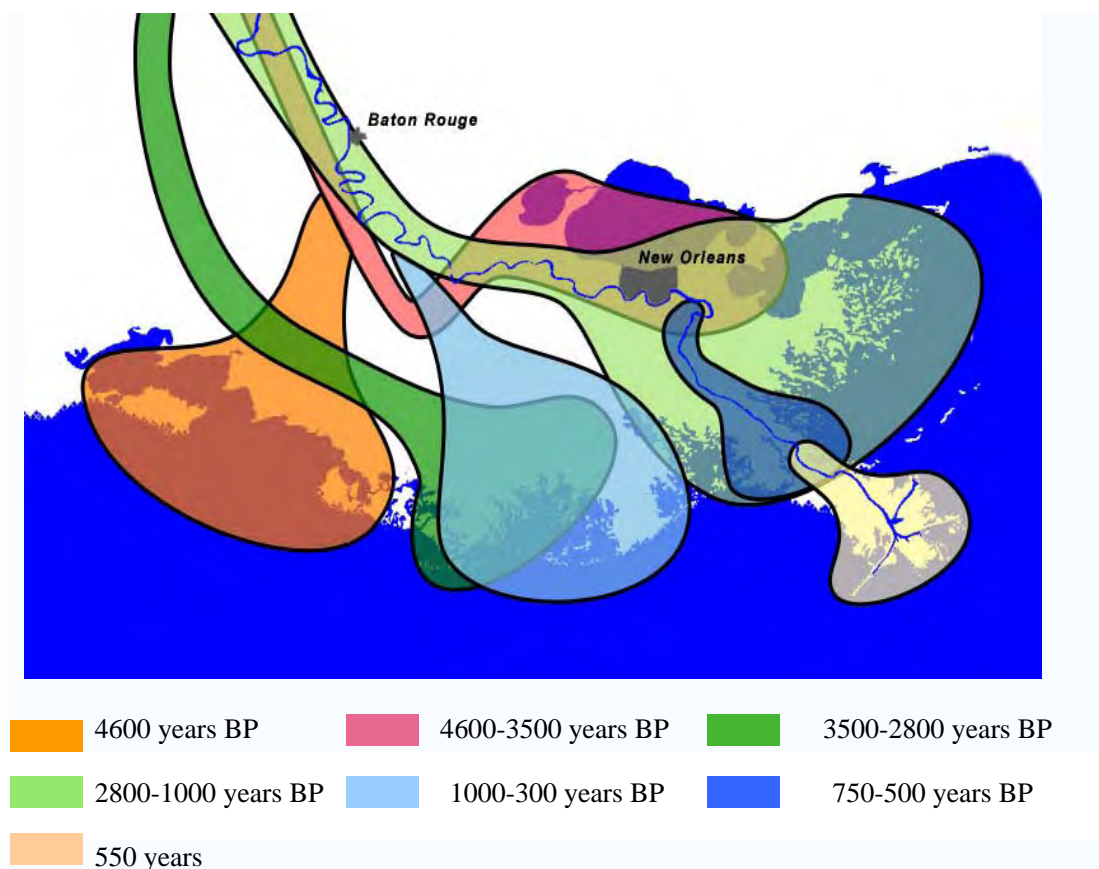


Figure 1.2 Mississippi River Delta Lobes (Wicander and Monroe, 1993)

750 years ago, the Mississippi abandoned its main course through the Lafourche Bayou and began flowing in the current direction to the area where New Orleans is located. 550 years ago, it began extending further out into the Gulf of Mexico, forming the present-day coastal plain.

The modern active delta is called “bird foot”. At Head of Passes—River Mile 0—the channel trifurcates into a birdfoot-shaped embouchure known as the Balize Delta or Plaquemines Complex. In terms of spatial extent, the modern Mississippi delta is not largest on earth; the Ganges and Mekong span about triple the size, and the Amazon’s delta is sixteen times larger. But it is probably the world’s most outstanding example of an elongated, river-dominated delta, as opposed to those dominated by waves, tides, or combinations of the three factors. Delta are dominated by rivers when the flow of fresh water and sediment is substantial and the receiving sea is slow-moving and placid, as is the Gulf of Mexico. The resulting formation is a “well-developed delta plain with several distributaries projecting seaward in a digitate, “bird’s-foot” configuration.” The Mississippi’s birdfoot formation comprises six sub-deltas, numerous splays and lobes, and three major passes: Southwest Pass (50 % of flow and the route of most navigation activity), South Pass (20%) and Pass a Loutre (30%), which branches into North and Northeast Pass.

In the last 100 years or so, the river has been diverting more of its flow to the Atchafalaya River, which branches off some 60 miles (95 km) northwest of New Orleans. In the 1950’s, engineers observed that the Mississippi would soon abandon its current channel as the mainstream, and instead migrate to the Atchafalaya. Because there is a considerable amount of economic development along the current path of the Mississippi, and because extensive flooding and evacuation would occur in the new area, Congress instructed the Army Corps of Engineers to maintain the then-present 70% / 30% distribution of water between the Lower Mississippi and the Atchafalaya River channels respectively. They did so by building the Old River Control Structure which consisted of massive floodgates that could be opened and closed as needed at the entrance to the Old River in 1954-1962.

“Lower Mississippi Delta Region” includes a total of 308 counties and parishes in 7 states of Illinois, Kentucky, Missouri, Tennessee, Arkansas, Louisiana, and Mississippi, which is the alluvial valley stretching at the junction of the Red, Atchafalaya, and Mississippi Rivers in natural resource terms. The junction is the head of delta. Below this point is found the first of the bayous which fed by the Mississippi, discharge into gulf. Below this point, the Mississippi receives no appreciable increase from tributaries. **In this study, “Mississippi delta area” refers to the southeast of coastal Louisiana.** (Figure 1.3)



Figure 1.3 The study area in Mississippi River Delta

1.3 Physical conditions

1.3.1 Geology and topography

Southeastern Louisiana is the youngest region of its size in the nation, whose landscape comprises the alluvium, delta plain, passes, bays, bayous, lakes and natural levees (Figure 1.4). The majority of the area is lowland which is only several feet above sea level, even below sea level (Figure 1.5). Most of the population occupies narrow peninsula-like natural levees barely above the marshes and swamps.

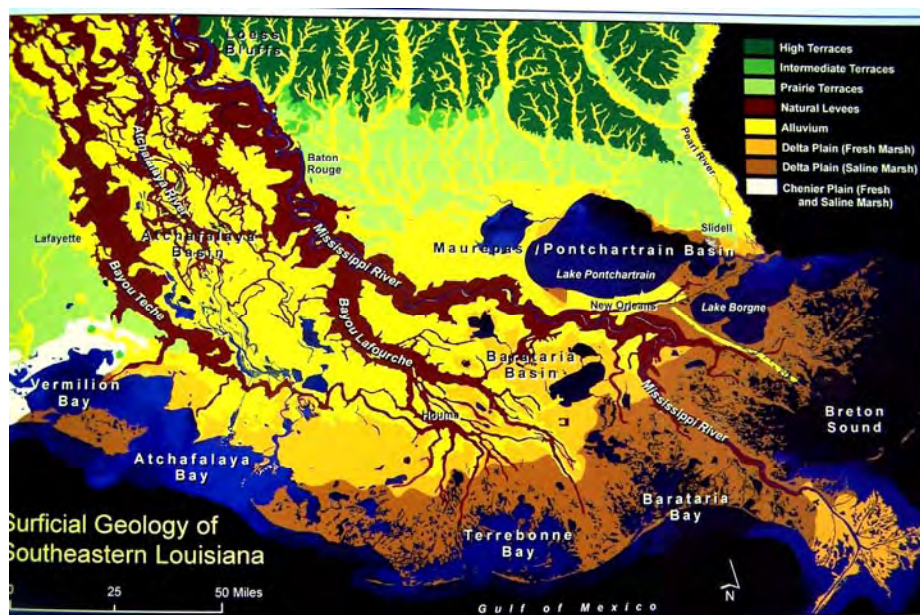


Figure 1.4 Surficial geology of Southeastern Louisiana

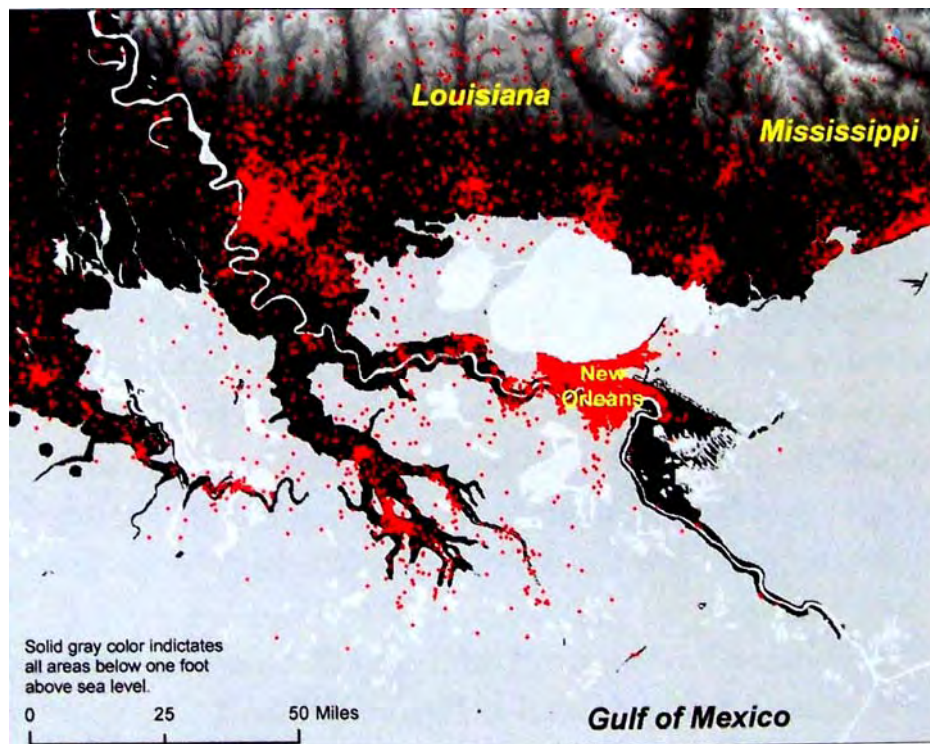


Figure 1.5 The low elevation of southeastern Louisiana

1.3.2 Climate

In the Mississippi River delta region, at about 30° north latitude, Mean monthly temperatures range from a December-January low of about 14°C to a midsummer high of about 30°C. Because of the moderating effect of the water bodies and high humidity, midday temperatures seldom exceed the low 30's (Celsius) despite the high isolation. Annual precipitation, usually as rain, averages is about 1500 mm. October tends to be the driest month and July the wettest, but torrential rains are common at any time. Ten to fifteen percent of the rainfall is from infrequent, severe tropical storms and hurricanes.

1.4 Social-economic development

Society and culture

People have lived in south Louisiana for over 12,000 years, using the abundance of the rivers and coast to extract resources and facilitate trade. When New Orleans was founded 300 years ago, it quickly became a center of international commerce, attracting people from around the world. These diverse peoples lived in proximity while retaining their own identities, a trend that defied typical melting pot dynamics. Thus, a new and multi-faceted culture was created in south Louisiana that continues to this day. The Chitimacha people have lived on Louisiana's coast for at least 2,500 years, and state as part of their beliefs, "We have always been here." The regard of

land and family expressed by this sentiment is one that many residents of south Louisiana share. In fact, according to the 2000 Census, Louisiana has the highest percentage of native born residents (79.4%) of any state in the nation. The richness of Louisiana's culture, a richness in part driven by the history that is present throughout the state, is also a tremendous attraction to the Nation and the world. It is this indefinable richness that has made tourism such an important contributor to Louisiana's economy, whether this richness comes from historic architecture, food, music, language or culture. According to the Louisiana Department of Culture, Recreation & Tourism over \$4.4 billion of visitor spending in Louisiana in 2004 was from New Orleans and Lake Charles.

According to 2000 census data, approximately two million people, or over 65% of Louisiana's citizens, lived in Louisiana's coastal parishes. Louisiana's economy is concentrated in the southern region of the state. This includes 73.5 percent of total state employment, almost 60 percent of oil and gas employment, 77 percent of pre-Katrina/Rita construction employment, and 67 percent of all manufacturing employment in the state (Richardson et al., 2004). Nationally important industries directly tied to locations on the coast and major waterways include not only the production of oil and gas, but offshore oil and gas exploration, development and transport; shipbuilding and other manufacturing of transportation equipment; petroleum and chemical refining; and waterborne transportation, as well as seafood production and harvest.

National Resources in coastal Louisiana

The Mississippi River is the lifeblood of coastal Louisiana's industries, infrastructure, ecosystem, and culture. The Mississippi river delta greatly contributes to the Nation's economic development.

Wetlands. Louisiana's coastal zone contains 41% of U.S. coastal wetlands and 25% of all U.S. wetlands (12,000 km²), making it one of the Earth's largest and richest estuarine areas: Coastal habitat for millions of birds and animals; 70% of Nation's migratory waterfowl of Mississippi Flyway over winter in Louisiana coastal area.

Energy infrastructure. The oil and gas industry has established a concentration of coastal and offshore infrastructure and refining capacity in and near south Louisiana. Nearly 9,300 miles of pipelines cross the marshes of coastal Louisiana (USACE 2004). The Henry Hub in Erath, Louisiana, is the pricing point for natural gas throughout North America, and Port Fourchon provides a port and supply point for hundreds of offshore drilling operations in the Gulf of Mexico. The network of energy facilities located in and around the wetlands produces or transports nearly one-third of the nation's oil and gas supply, and is tied to 50% of the nation's

refining capacity (DNR, 2006). Barrier islands and wetlands help buffer this infrastructure from storm damages.

National and international commerce. Ten major navigation routes are located in south Louisiana. Five of the busiest ports in the U.S., ranked by total tons, are also located here, handling approximately 469 million tons of waterborne cargo each year. This represents 19% of annual U.S. waterborne commerce (USACE 2003). Without barrier islands and wetlands, all of this infrastructure would be at much greater risk when storms come ashore. Each year, the Port of South Louisiana and the Port of New Orleans together account for \$150 billion and 20% of the U.S. import/export cargo traffic. (Dept. of Commerce Service Assessment, 2005).

Fisheries and wildlife habitat. No other region in the U.S. supports the diverse fish and shellfish species seen in south Louisiana's estuaries and bays. Louisiana is by far the nation's largest shrimp, oyster, and blue crab producer and provides 26% (by weight) of the commercial fish landings in the lower 48 states (US Department of Commerce 2005). In fact, Louisiana is second only to Alaska in annual volume of seafood ports by volume are in Louisiana (US Department of Commerce 2004, 2005). These resources are processed and shipped throughout the world, providing jobs for 40,000 Louisiana citizens.

The North American Flyway passes directly over south Louisiana, and more than five million migratory waterfowl spend the winter in Louisiana's marshes (DWF 2000). In addition, the coastal landscape provides stopover habitat for millions of neotropical migratory birds on their journeys across the Gulf of Mexico. Hundreds of fish and wildlife species, as well as the jobs and recreational opportunities associated with birding, hunting, fishing, and eco-tourism, all depend on the barrier islands and wetlands found in south Louisiana.

Vulnerable region

However, coastal Louisiana is one of the poorest areas in the United States, with nearly a third of the population living in poverty. Of these, over 50 percent are African-Americans and growing numbers of other people of color. The Delta is characterized by a persistent poverty, sluggish economy, high unemployment rates, and problems arising from a legacy of racial segregation. Taking the city New Orleans as an example, declining steadily since its 1960 peak, the city's total population is now at depression-era levels (Fig.1.6). After hurricane Katrina, many people lived in inundated communities displaced. The population and society will have a big change.

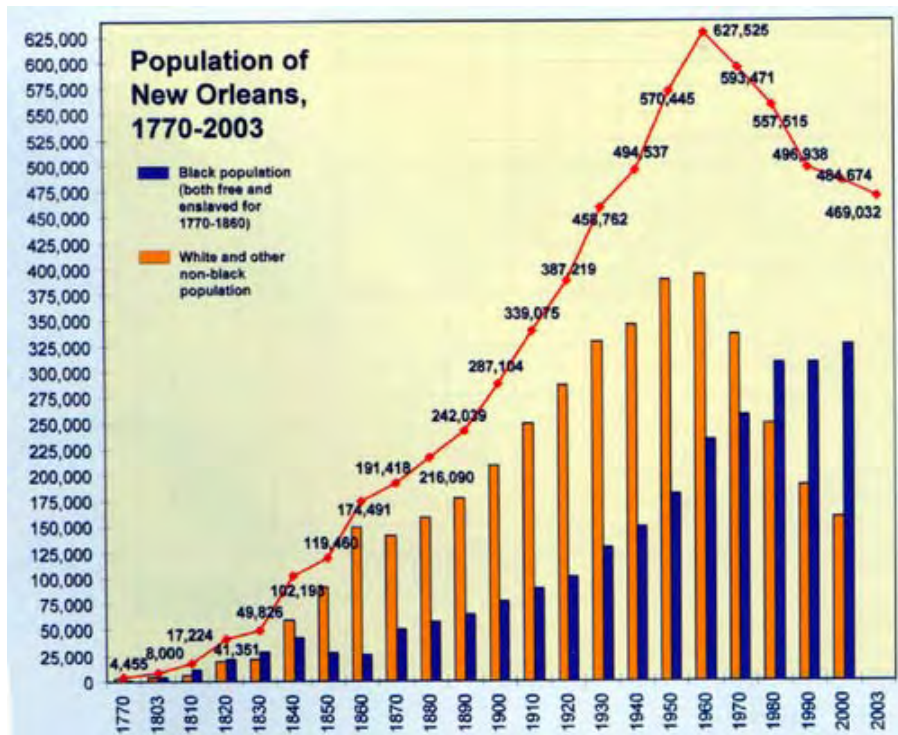


Figure 1.6 the population change in New Orleans from 1770 to 2003

Meanwhile, the Mississippi River Delta represents one of the most vulnerable regions of the Gulf Coast. The combined effects of engineered and altered landscapes, natural subsidence, and climate change had tremendous consequences for human well-being, natural resources, and biodiversity.

2. Problems identification

2.1 Flood threat from the Mississippi River

The lower Mississippi river valley is alluvial floodplain. In a long time history, it has been suffering frequent floods from the river. The earliest recorded flood in history of the Mississippi occurred in 1543. Explorer Hernando Desoto encountered a flood on the Mississippi near Memphis, Tennessee that extended over 40 days.

Major floods occurred in 1849, 1850, 1882, 1912, 1913, 1927 and 1973 in the near two century. The flood of 1927 was the most disastrous in the history of the Lower Mississippi Valley. This event devastated the levee protection system and resulted in flooding of over 67,340 km² of land, displaced more than 600,000 people from their homes, took over 200 lives and cost over \$10 billion in 1998 dollars (Barry, McCormick).(Figure 2.1)



Figure 2.1 The inundated area in the great flood of 1927

Fortunately, the city New Orleans avoided inundation of the flood 1927 after hard fighting on the levee. However, the high water in the river still threatens the city now.

The rate of flow through New Orleans typically ranges from 450,000 to 535,000 CFS at normal river stage, but can triple that volume during high water: it swelled to a frightening 1,557,000 CFS during the Great Flood of 1927. A peak discharge of approximately 1,250,000 cfs occurs on the average of once every 16 years downstream of New Orleans. Since consistent measurements have been kept, river stage in New Orleans has run as low as 0.71 feet above mean gulf level (Feb.11,1977) and as high as 19.98 feet (Feb.10,1950), averaging about 10 feet above the sea. This means that the river surface is almost always higher than 56% of greater New Orleans, usually higher than 95%, and occasionally higher than 99.5% of the land surface (everything except the artificial levees).

Although the complete flood protection system was established by Army Corps of Engineers since 1950s, there are still flood risks by high water stage or levee crevasses. Especially along with the climate change at present and subsidence of the land, the extreme events increase the uncertainty of flood risk. Does the present protection standard satisfy the future extreme events? Obviously, it is uncertain.

2.2 Frequent hurricane and tropical storm and imperfect hurricane protection system

Louisiana and Mississippi River Delta is highly susceptible to a direct hurricane impact according to the previous hurricane records. As the residents' words in coastal Louisiana, "hurricane is the fact of life". (Fig.2.2)

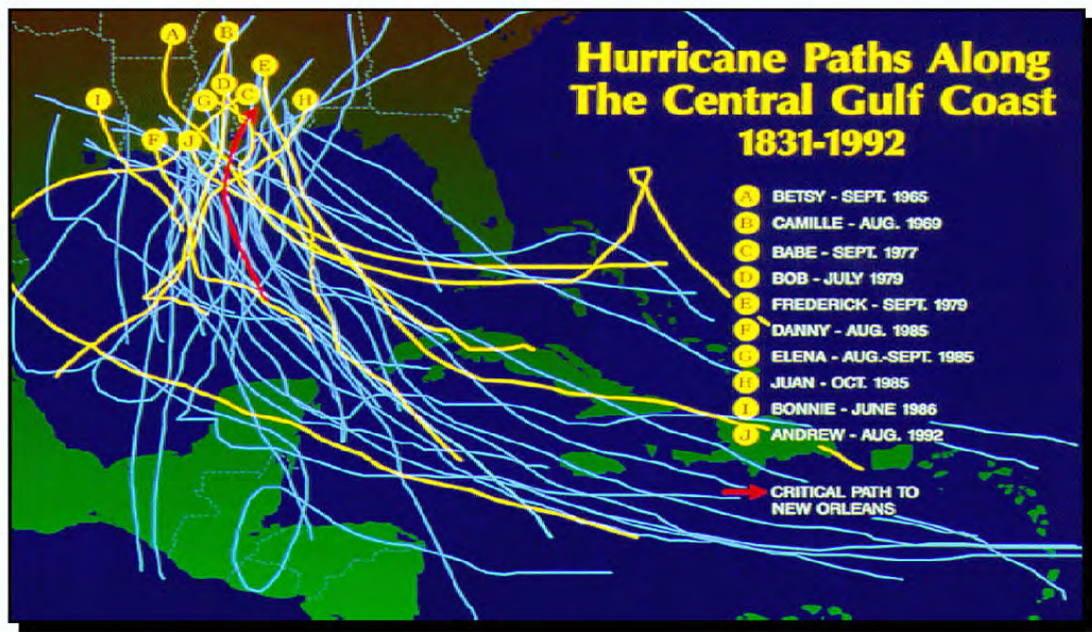


Figure 2.2 Hurricane paths along the central gulf coast from 1831 to 1992

As development and economic activity in Louisiana coastal areas has increased, so, too, has societal vulnerability to coastal hazards. Global climate change will likely exacerbate that vulnerability. Especially the area south of New Orleans, which is highly developed for residential, industrial, and tourism uses, as well as the international seaports of New Orleans and Baton Rouge, which function as important transportation hubs, and other smaller docks are at risk. Much of the immediate coastal fringe of Louisiana is rural and not overly developed, but the low-lying areas face growing challenges from sea-level rise.

Large portions of the city of New Orleans lie near or below sea level, an average elevation of 1.8 meters below sea level, a fact that has posed complex flood management problems since the city's founding in 1718. From the view of topography of the city, New Orleans lies in a bowl with the downtown area under about 3 m below mean sea level. (Fig. 2.3) the storm surge created by hurricane can threaten the city from the sea and from the tidal Lake Pontchartrain to the north. During Mississippi floods the river itself threatens the city. The entire urbanized area is surrounded with levees, floodwalls and steel gates (to be closed above a critical level).

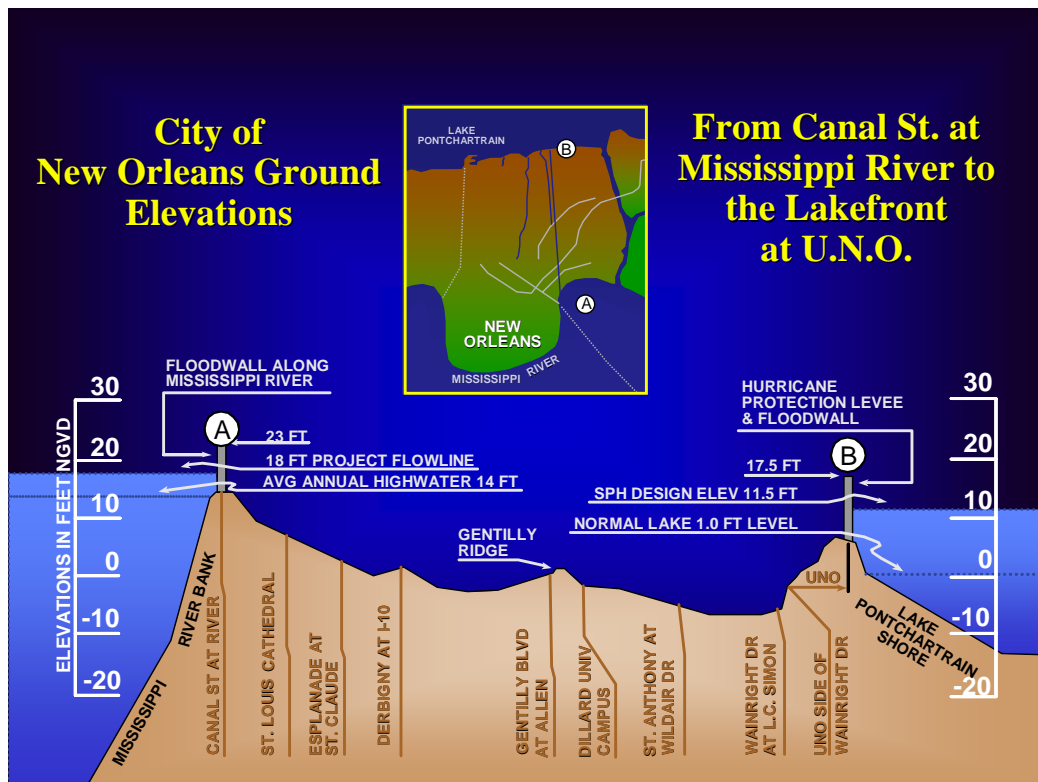


Figure 2.3 Ground elevations of New Orleans

Hurricane Katrina and Rita in 2005 catastrophically affected the coastal Louisiana and drown almost entire city of New Orleans, which became the most serious disaster caused by hurricane in history (Tab. 2.1). Over 1,400 Louisiana residents died, 200,000 homes sustained major or severe damage, and approximately 440,000 Louisiana citizens were still displaced from their homes one year after the storms.

The Congressional Budget Office estimated that losses of physical capital totaled between \$70 and \$130 billion. Approximately 45% of these losses involved business structures or equipment, including resources owned by national concerns. Loss of crude oil and natural gas production in the Gulf of Mexico, along with significant disruptions to 20% of the U.S. refining capacity, significantly increased gasoline and heating oil prices for households throughout the nation (Congressional Budget Office, 2005). Disruptions in offshore oil and gas production reduced supply and forced withdrawals from the Strategic Petroleum Reserve. The temporary closure of the Port of New Orleans slowed grain shipments from the Midwest, which had ripple effects on world agricultural markets.

The consequence of the hurricane Katrina exposed that the existing hurricane protection system is not competent to ensure the security of the city. Because of various aspects like technical issues, environmental concerns, legal challenges, and local opposition, the hurricane protection system which started building in 1965 is

incomplete, inconsistent and no redundancy. It needs to be planned for repair, redesign, reconstruction and improvement after Katrina.

The storm surge and economic appraisals have demonstrated that, under existing conditions, the areas vulnerable to flooding with a 1 percent annual probability includes over 430,000 residencies, with potential economic consequences (damages) of over \$34 billion coast-wide. The 0.2% probability risk area includes over 871,000 residencies, with potential economic consequences (damages) of over \$157 billion coast-wide. A surge of the same magnitude as Hurricane Katrina's in New Orleans has a 0.25% chance of occurring in any given year, or an average of once in 400 years. Similarly, a surge of the same magnitude as Hurricane Rita's in New Orleans has a 1.1% chance of occurring in any given year, or an average of once in 90 years.

Table 2.1 Hurricane Katrina and Rita and their impacts

Sources:NOAA,FEMA,LAGIC,LD HH, LDOL,LDED,&ISO	HURRICANE KATRINA Aug.23-31,2005	HURRICANE RITA Sep.2-31,2005
US states impacted	Florida,Louisiana,Mississippi, Alabama, and Tennessee	Louisiana and Texas
Strength of land	Category 4	Category 3
Minimum barometric pressure	902 mb(32mile wide eye)	897 mb
Winds of landfall	140+ mph	120+mph
Rainfall	12in-16in	6in-12in
Storm surge	4-32feet	4-16feet
Area impacted	108,456 sq.miles	85,729 sq.miles
Casualties	Total:1,299+ Louisiana:1,070+	Total:119 Louisiana: 0
People impacted	2,500,000 households request individual assistance	460,000 households request individual assistance
Left homeless	Total : 527,000 Louisiana: 288,700	Total:76,500 Louisiana:76,500
Businesses impacted	71,000 in Louisiana	10,000+ in Louisiana
Job losses	400,000+in Louisiana	45,000+in Louisiana
Damage estimates	Total \$34.4 billion; Louisiana \$22 billion (source: ISO properties report 10/7/05)	Total\$4.7billion; Louisiana \$2.4billion (source: ISO Properties Report 10/7/05)

- Approximately 75% of New Orleans Population displaced.
- Approximately 60% of City Still Without Utilities.
- Approximately 80% of city flooded with 4 feet or more water.

2.3 Tremendous coastal erosion

During the 20th century, coastal Louisiana has lost over 4800 km², an area more than 25 times larger than Washington, D.C. During the decade of 1990 to 2000, land loss

wetlands reduce storm surge by an average of 0.3 meter. In Louisiana's flat, low-lying coastal areas, these reductions in storm surge can mean the difference between an area that survives a storm and one that suffers significant damage.

•**Effect on infrastructural and industrial development.** A 2004 study of Louisiana's coastal infrastructure indicated a total asset value of approximately \$96 billion. As wetlands and barrier islands disappear, the wells, pipelines, ports, and roads that make the oil and natural gas industry possible will be exposed to open water condition. These facilities will need to be replaced at a high cost, and the potential for damaging oil spills will increase. It occurs that significant reduction in the \$20 billion per year shipping export industry that depends on Louisiana's ports and the fish catch that depends on Louisiana's coastal waters.

•**Threat to unique, world renowned ecosystem.** Ecosystems of coastal Louisiana wetlands provide habitat for internationally significant migratory waterfowl concentrations. The threatened habitats, which cover almost 3,000 square kilometers, also support large nesting concentrations of other birds, including threatened and endangered species such as the eastern brown pelican and the bald eagle. These areas also include 12 national wildlife refuges, Jean Lafitte National Park, and several state wildlife management areas, with land holdings totaling almost 300,000 hectares (National Park Service 1993; U.S. Fish and Wildlife Service 1996).

2.4 Land subsidence

The combined effect of the worldwide rise of sea level resulting from glacial melting and subsidence or land sinking results in relative changes between the elevation of the land and the sea (relative sea level rise).

Subsidence rates in some areas of coastal Louisiana have increased significantly during modern decades (Van Beek et al. 1986; Penland et al. 1988). A small part of this change can be attributed to worldwide increase in sea level. Based on sequential land surveying measurements, the combined subsidence/sea level rise rate in some of the most severe subsidence areas is more than 3.0 feet per century (average 9mm/year). Since the present world wide average rate of sea level rise is only 0.394 foot per century, it appears that the land elevation in some areas of coastal Louisiana is being reduced in elevation eight times faster than the sea level rise rate. Studies conducted by Shea Penland and others (Ramsey and Moslow 1987; Penland et al. 1988; Penland et al. 1989; Penland and Ramsey 1990) have led to the conclusion that the subsidence rate for the Deltaic Plain is 3.0 to 4.3 ft/century (0.9 to 1.3 cm/yr) and for the Chenier Plain it is 1.3 to 2.0 ft/century (0.4 to 0.6 cm/yr). The difference is related to the combined effects of fault movement and sediment compaction. The areas of highest subsidence appear to be related to fault movement and are found in

the lower Deltaic Plain within the fault-bounded triangle described above. Subsidence in the blocks bounded by these faults is high (2.1 – 3.5 ft/century). The area of highest rates (> 3.5 ft/century) is found in the lower delta below the Forts fault. (Fig. 2.5).

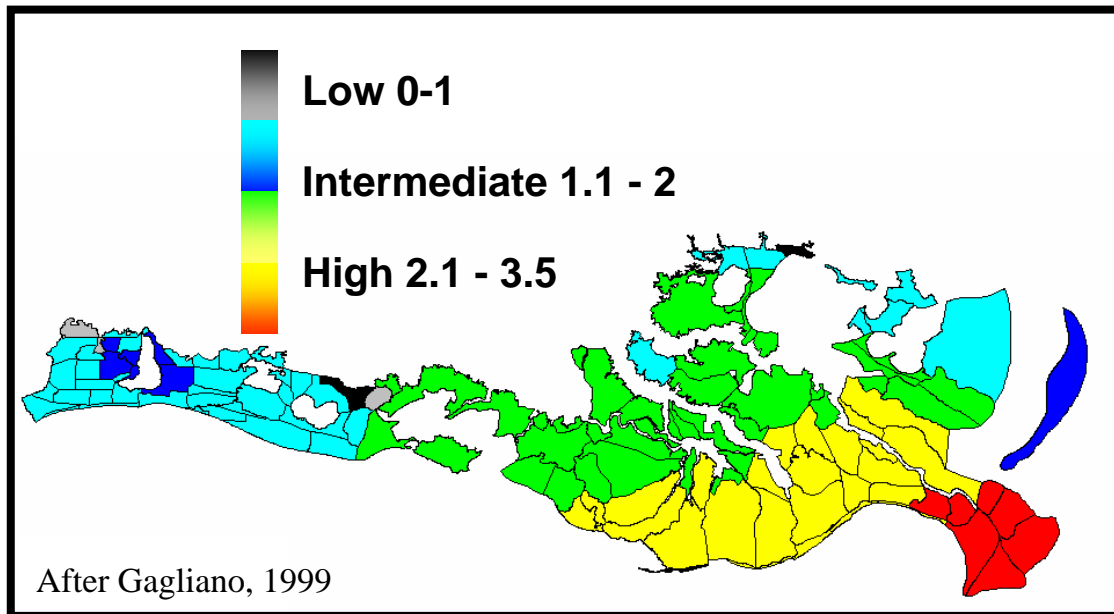


Figure 2.5 The subsidence in southern Louisiana (foot/century)

The subsidence of the land directly leads to the submergence and transformation of wetland to open water. The recent topographic survey to the elevation of the land surface in New Orleans indicates” Considering the rate of subsidence and sea level rise, the area of New Orleans and vicinity that are presently 1.5 to 3 m below mean sea level will likely be 2.5 to 4.0 m or more below mean sea level by 2100.” The sinking land surface threatens New Orleans’ infrastructure and handicaps the city’s ability to survive the lake and gulf surges of powerful hurricane.

2.5 Insufficient institutional attention and imperfect management

As mentioned above, coastal Louisiana is threatened by severe floods and storms and tremendous wetland loss. Meanwhile, it is so important for the state and the nation in energy supply, economy, nature resources and culture. But the federal government, even the state did not pay sufficient attention on the issue either in funding and projects planning and implementation.

For example, Lake Pontchartrain and Vicinity hurricane protection project to protect the city New Orleans was authorized by Congress in 1965, during the construction of what has become known as the “barrier plan,” project delays and cost increases occurred as a result of technical issues, environmental concerns, legal challenges,

and local opposition to various aspects of the project. As May of 2005, it is finished by 60%-90% of the whole project in different districts. The estimated completion date was 2015. This means the project of 125 miles of protective structures will take 50 years to build.

There are some problems in maintenance and management of the protection structures. Local levee districts (like water boards in the Netherlands) are in charge of the daily maintenance and operation. Before hurricane Katrina, there are many levee boards, dozens even hundreds. They were working for their own communities, no uniform standard to follow; even they had fighting between them during flood events. Good protection in one side or section will push or heighten water in the other side or next section. This situation leaves some obvious weak point in the protection system, such as the crevasses in the junction of the bridges and levees, which could lead to ineffective protection and failure of the whole system. After Katrina, in New Orleans these levee boards merged to two big levee districts--West Bank Levee Districts and East Bank Levee District. The efficacy of maintenance and management should be much better than before. (Prof. Battjens, Technology University of Delft)

Oil and gas exploitation and refinement is the most important industry in coastal Louisiana, which account for about 20% energy supply of the nation. It is also one of the contributions to wetland loss and land subsidence. Although there is no detail data, the estimated portion of the contribution is 30% (Prof. J. Alex McCoquodale, the University of New Orleans). But oil and gas companies put less than 2% of the revenue to coastal protection and restoration except normal tax. They should take more reasonable bills for restoration projects. There seems no voice from the federal or the states to restrict them or interfere the issue. (D. de Bruin, retired from RWS).

Another reason of no enough attention to coastal Louisiana from the federal is that the society of Louisiana consists of multiple ethnic and most poor-educated people which are a relatively weak group.

3. Analysis

3.1 Climate change in Coastal Louisiana

Coastal Louisiana's climate has always been variable and sometimes extreme—and climate change may intensify this historical pattern.

Temperature. Average state temperatures have varied substantially over the past century, with a warming trend of about 1°F since the late 1960s. 3-10°F rises in winter lows and 3-7°F rises in summer highs. July heat index—a measure combining

temperature and humidity-could rise by 10-25°F. The freeze line is likely to move north.

Rainfall. Extreme rainfall events, primarily thunderstorms, have increased during the 20th century. While rainfall totals have changed little, seasonal trends are apparent—winter average rainfall has increased slightly and summer totals have decreased somewhat.

Hurricane intensity (characterized by maximum wind speeds and rainfall totals) could increase slightly with global warming. Recent assessments show that in the North Atlantic there has been a significant increase in hurricane frequency since 1995 (Webster et al., 2005). This analysis also indicates an increase in the number and proportion of strongest category 4 and 5 hurricanes in the late 20th Century. Even if storm frequencies and intensities remain constant, the damages from coastal flooding and erosion will increase as sea level rises.

Sea level rise. As the most recent report of the Intergovernmental Panel on Climate Change (IPCC) makes clear, scientists are in all but unanimous agreement about the reality of global warming. There is, however, still debate over how the new trends are manifesting. Sea level trends are more certain. Since the beginning of high-accuracy satellite altimetry in the early 1990s, tide gauges and altimeters have shown global mean sea level to be rising at a rate of just above 3 mm/year, compared to a rate of slightly less than 2 mm/year over the previous century (IPCC, 2007). The IPCC's 2007 report further estimates that in the next century, future sea level rise rates may be anywhere from 2 to 6 mm/year higher than present rates. The best estimate of sea level experts is that the level of the world's oceans will increase 8 inches (20 cm) over the next 50 years (Fig. 3.1).

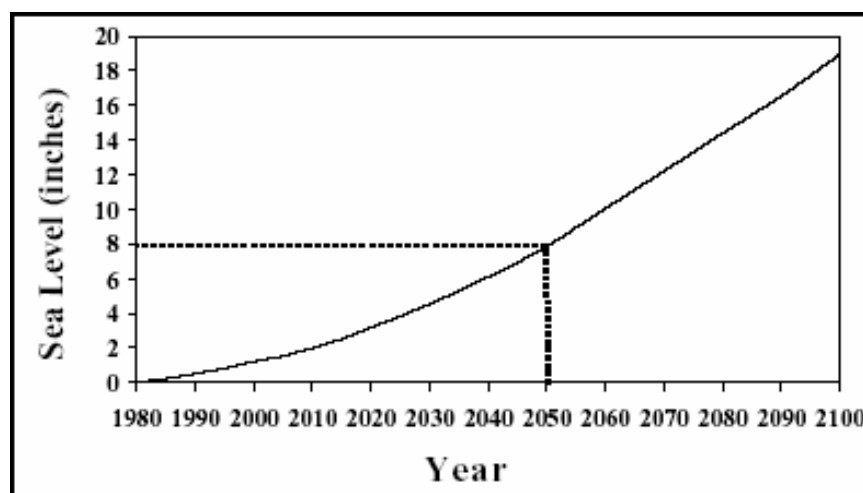


Figure 3.1 Projected best estimate of worldwide rise in sea level
(Wigley and Raper 1992)

Louisiana's rate of relative sea-level rise is the highest in the United States. Water levels along the Louisiana coast—from Holly Beach to New Orleans to the Chandeleur Islands—have risen by up to 40 inches over the past 100 years due to a combination of globally rising seas and substantial local sinking of the land (subsidence). The average rate of sea level rise is currently 0.39 ft/century (0.12 cm/year). Until recently, the sea level rise rate has been low, accounting for only a small component of the change along the Louisiana coast. Most of the recorded relative sea level rise has been related to subsidence. Sea level will increase at a faster rate over the coming century.

By 2100, ocean levels around Louisiana could be 24–47 inches higher than today, based on a continued average subsidence rate of 8–31 inches per century and a mid-range sea-level rise scenario. Even a relatively small vertical rise in sea level (a few inches to 1 foot) can move the shoreline inland by substantial distance (several tens of feet) along low-lying, flat coastal areas.

3.2 Flood protection system in the Lower Mississippi River

The most significant floods on the Mississippi River result from regional rainfall and snowmelt events that cause slow rise on the rivers and extend for days or weeks. Because of the influence of tributary flow (including the major tributaries, the Ohio, Missouri and Arkansas Rivers), the magnitude of flooding increases moving downstream from the headwaters to the mouth. The largest flood flow recorded on the lower Mississippi was 64,500 m³/s. Short, intense rainfall events can cause flash floods or quick rise and fall floods on the tributaries, but do not normally affect the mainstream.

Table 3.1 provides long-term average values of flow for annual minimum, mean, and maximum flow in the Mississippi River for the period of record 1930–2005 at the Tarbert Landing Gage maintained by the U.S. Army Corps of Engineers. The same table provides flow parameters for each month of the year for the same period of record. The months of March, April, and May provide highest average flows, and the months of August, September, and October provide lowest average flows. However, the average flows could be significantly different in any given year.

Table 3.1 Mississippi River Tarbert Landing Discharge,
Period of Record 1930 – 2005

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Min.	120	170	270	290	280	180	125	120	115	100	100	105
Ave.	520	620	730	770	710	580	420	290	240	250	290	410
Max.	1240	1390	1380	1480	1440	1290	960	795	550	735	710	1000

Note: Compiled from U.S. Army, Corps of Engineer District, New Orleans, Stage and Discharge Data. Discharge values in 1000 cubic feet per sec (cfs); Values are averages for the months for period of record; Average Annual Minimum –165,000 cfs; Average Annual Average –486,000 cfs Average Annual Maximum –1,081,000 cfs.

Like other alluvial rivers around the world, the people naturally built the levee to prevent the flood from Mississippi river. For over two centuries, structural measures dominated the US response to flooding. From the settlements in Louisiana in the early 1700's until the early 20th century, the country, the principal and frequently only approach to flood damage reduction was the construction of levees. In the early 20th century, levees were augmented by channel work to speed floodwaters to their ultimate destinations.

Levee building began in the early 18th century, and was followed by a continual increase in heightening and strengthening (Fig.3-2). Some breaches (“crevasses”) occurred, also during each major flood prior to 1927; it created relief corridors behind the levees parallel to the main stream on either side.

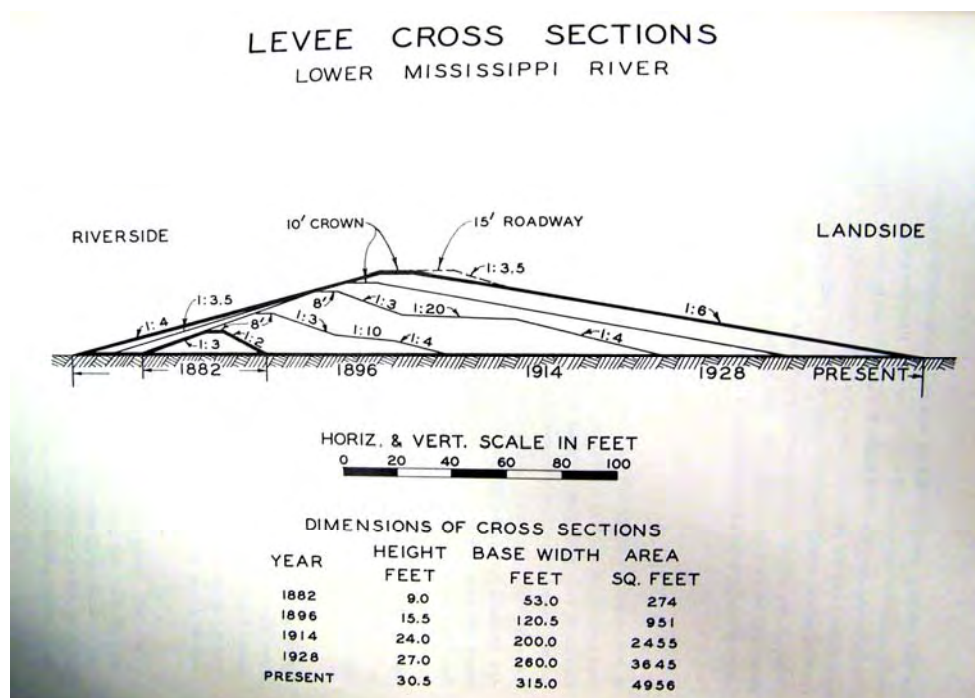


Figure 3-2 The heightening and strengthening of the levee in years

Until the 1927 flood, the most disastrous in the history of the lower Mississippi valley, demonstrated quite clearly the bankruptcy of the “levee-only policy”. It brought national attention to the need for federal involvement in flood damage reduction. Out of it grew the Flood Control Act of 1928, which committed the federal government to a definite program of flood control. This legislation authorized the Mississippi River and Tributaries (MR&T) Project, the nation's first comprehensive

flood control and navigation act. The flood control system and strategy gradually formed since that time.

3.2.1 The Project Flood

The flood control system is designed to control the "project flood." It is a flood larger than the record flood of 1927. At Cairo, the project flood is estimated at 2,360,000 cubic feet per second (cfs). The project flood is 11 percent greater than the flood of 1927 at the mouth of the Arkansas River and 29 percent greater at the latitude of Red River Landing, amounting to 3,030,000 cfs at that location, about 60 miles below Natchez.

3.2.2 Flood control engineering system

The four major elements of the Mississippi River and Tributaries flood control Project are: *levees* for containing and transporting flood flows; *floodways* for the passage of excess flows past critical reaches of the Mississippi; *channel improvement* and *stabilization* for stabilizing the channel in order to provide an efficient navigation alignment, increase the flood-carrying capacity of the river, and for protection of the levees system; and *tributary basin improvements* for major drainage and for flood control, such as dams and reservoirs, pumping plants, auxiliary channels, and the like.

Main Stem Levees

The Mississippi River levees are designed to protect the alluvial valley against the project flood by confining flow to the leveed channel, except where it enters the natural blackwater areas or is diverted purposely into the floodway areas.

The main stem levee system, comprised of levees, floodwalls, and various control structures, is 2,203 miles long. Some 1,607 miles lie along the Mississippi River itself and 596 miles lie along the south banks of the Arkansas and Red rivers and in the Atchafalaya Basin.

The levees are constructed by the federal government and are maintained by local interests, except for government assistance as necessary during major floods. Periodic inspections of maintenance are made by personnel from the U.S. Army Corps of Engineers and from local levee and drainage districts as it is essential that the levees be maintained in good condition for their proper functioning in the flood control plan.

Following each major flood, the Army Corps of Engineers has evaluated the project flood flow line and has modified the levee heights required to pass a new project flood that takes into account the most recent flood event. Between 1928 and 1999,

this has resulted in several increases in levee height. Analysis of the 1973 flood indicated that some sections of the levee system in lower Mississippi would have to be raised as much as 1.5 meters in order to safely pass the expected maximum flood.

Floodways

From Cairo to New Madrid, Mo., the east bank bluffs and the levee as originally built on the west bank left only a narrow channel through which the river could flow at flood stage. To protect communities along the Mississippi and Ohio rivers and to reduce the flood heights to which the controlling levees on the Missouri side would otherwise be subjected, the project provides for a setback levee about 5 miles west of the riverfront levee through this reach. The strip between this setback levee and the levee adjacent to the river forms what is known as the Birds Point-New Madrid Floodway with the capacity of 550,000 cfs (15,580 m³/s) operated only at extremely high stages. Water enters the floodway through lower levee sections or "fuse plugs" in the old front levee below Cairo and reenters the main river just above New Madrid. The floodway was operated in 1937 and was of material aid in reducing flood heights at and above Cairo.

At the latitude of Red River Landing, the project flood is estimated at 3,000,000 cfs. The project provides for dividing this great quantity of water, with 1,500,000 cfs of the flow continuing down the main river channel, the remaining 1,500,000 cfs being diverted to the Atchafalaya River via the Morganza and West Atchafalaya floodways, and the Old River Control structures.

Of the 1,500,000 cfs flowing down the main channel below Morganza Floodway, 250,000 cfs (7080 m³/s) are to be diverted to Lake Pontchartrain and the Gulf through the Bonnet Carre' Spillway, located about 25 miles above New Orleans. The remaining 1,250,000 cfs will continue down the river to the Gulf. (Fig. 3-3).

That portion of the flow diverted from the main channel near Old River is carried by the Atchafalaya River, the Morganza Floodway, and the West Atchafalaya Floodway. The Morganza and the West Atchafalaya floodways follow down on opposite sides of the Atchafalaya River until the end of the levee system along the Atchafalaya River is reached; there they merge into a single broad floodway that passes the flow to the Gulf through two outlets, Wax Lake and Berwick Bay. In major floods, the Morganza would be the first of these two floodways to be used, with water entering it through a control structure just above Morganza.

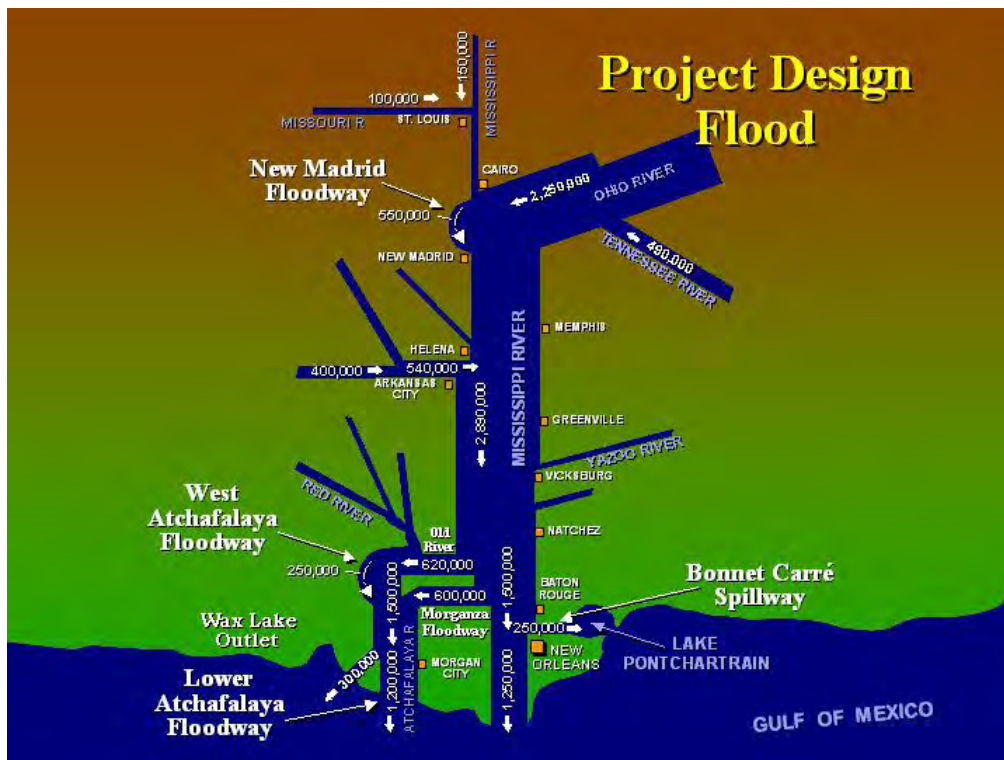


Figure 3-3 The distribution of the project design flood in the lower Mississippi river

Channel Improvement and Stabilization

Stabilization and protection of the riverbanks are important to the flood control and navigation plan, serving to protect flood control features and to insure the desired alignment of the river's navigation channel. This is accomplished by:

Cutoffs: Shortening the river and reduce flood heights, Because of the degradation of the river stability caused by the cutoffs built in the 1930's, further use of this approach was halted.

Revetment: Controlling the river's meandering;

Dikes: Directing the flow;

Improvement Dredging: Realigning the channel;



The Corps Dredge Jadwin at work

Mississippi River revetment construction

Principal Tributary Basin Improvements

The Flood Control Act of 1928 authorized work that would give the various basins protection against Mississippi River floods only, although the tributary streams within the basins caused frequent flood damage that could not be prevented by the main stem Mississippi River protective works. Later amendments to this act have authorized work that provides alleviation of the tributary flood problems.

There are four major drainage basins in the lower Mississippi River Valley Project: St. Francis in east Arkansas; Yazoo in northwest Mississippi; Tensas in northeast Louisiana; and Atchafalaya in south Louisiana. There are five flood control reservoirs in the tributary basin improvement plan: Wappapello Lake in the St. Francis Basin, and four lakes -- Arkabutla, Sardis, Enid, and Grenada -- in the Yazoo Basin.

Old River Control One of the most important modifications to the project was made in 1954 when Congress authorized the feature for the control of flow at Old River to prevent the capture of the Mississippi by the Atchafalaya River.

The first two features completed were the low-sill and overbank structures, the former to pass low and medium flows from the Mississippi to the Atchafalaya River in a controlled manner, and the latter to pass flood flows to the Atchafalaya in conformance with the flood control plan. Inflow and outflow channels were constructed connecting the low-sill structure with the Mississippi and Red-Atchafalaya rivers. A third facility -- called the Auxiliary Structure -- was placed in service late in 1986. (Fig. 3.4).

As the closure of Old River would cut off an important shallow-draft navigation artery, a navigation lock was constructed just south of the junction of the Old and Mississippi rivers. This navigation lock is one of the most modern in the nation's inland waterway system. Channels were dredged connecting the lock to the Mississippi and Old Rivers, and this feature was opened to navigation in 1963.

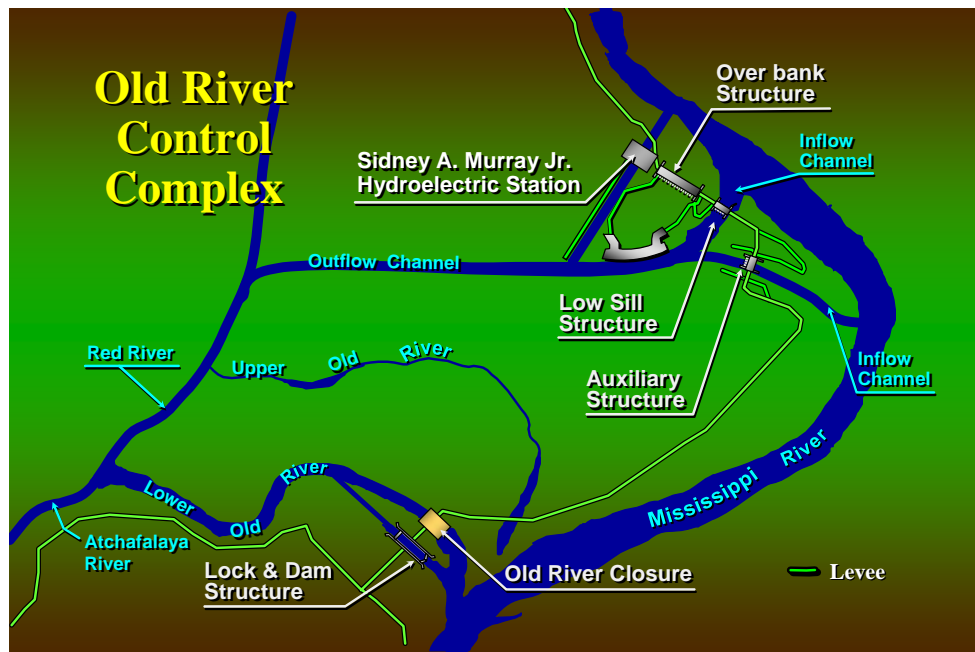


Figure 3.4 Old river control complex

3.2.3 Efficacy of flood control projects and new approaches

Flood control projects have over the years prevented significant flood damages. In the 1993 Mississippi River flood, the presence of federal projects prevented over \$18 billion in damages in the upper Mississippi and Missouri basins. The lower Mississippi River flood control project has cost over \$10 billion but has prevented over \$244 billion in damages. However, in spite of these statistics, annual flood losses in the United States continue to increase. Average annual flood losses in the United States are currently estimated at \$6 billion representing a four-fold increase over the last century.

The occurrence of the major floods as well as increased attention to the environment caused the Mississippi River Commission to seek means to ensure that flood control and related channel improvement projects can be accomplished in a manner that not only supports attainment of project purposes but also preserves and enhances the natural environment. Examples include the following:

- To provide a freshwater supplies to vast wetland acreages near the Louisiana coast that had been isolated from these supplies by the construction of levees, the Corps has constructed two major structures in levees near New Orleans (and is planning a third) to permit, in non-flood periods, the diversion of Mississippi River waters into these areas and the overland flow of the waters into the Gulf of Mexico. The most recently completed project -- Davis Pond Diversion that cost nearly \$120 million, will divert, during non-flood periods, 301 m³/s of fresh water, nutrients and sediments from the Mississippi to the salt-threatened Bataria

estuary that connects with the Gulf of Mexico. The project is expected to provide over \$15 million in benefits to fish and wildlife each year.

- As part of a program to stabilize the river banks in the Lower Mississippi, articulated concrete revetment is placed on the banks. In a new program, the surface of the 1.2 x 7.6 meter sections that make up the revetment is being roughened to increase the production of aquatic macro-invertebrates. In 2001, over 70,000 of these new sections were placed on the banks.
- As levee heights are increased to comply with new flood lines considerable soil must be obtained from nearby areas. Not only must the height be increased but also the entire cross section. In accomplishing this work, every effort is made to concurrently increase the wetland habitat on the riverside of the levees. The areas used to provide material for the levees, borrow pits, are designed to provide irregular bottoms and small uncleared islands that improve fish and wildlife habitat.
- Tree screens, buffer strips of trees, are being planted along the riverbanks to shield levees from the adverse effects of river overflows and to provide habitat.
- Long-term environmental programs have been instituted to monitor the impact of both navigation and other river development activities, including flood control.

Additionally, more and more initial proposals were made for the use of non-structural measures, like relocation of the people in floodplain for flood storage, flood zoning, flood proofing, flood insurance, and response and evacuation plan for emergency. (Discussed in the following chapters)

3.3 The impacts of intervention of human on the river

While most water enters the lower Mississippi River via the Ohio, most sediment comes from the Missouri and other western sources. Continental-scale manipulation of the Mississippi River and its tributaries for flood control and hydropower has significantly influenced coastal ecosystems. After a major flood occurred in 1927, the U.S. Congress initiated a massive effort to levee the river, seal off the crevasses, and cut off long meanders to increase the gradient and accelerate runoff. Because of the levees, the river has built its present active delta to the edge of the Continental Shelf, where most of the sediments are lost in deep water and can no longer build land. A control structure constructed 480 kilometers above the mouth of the river has halted the imminent capture of the main flow of the Mississippi River by the Atchafalaya River; this structure limits the diversion to one-third of the combined flow of the Mississippi and Red rivers. The levee systems on both rivers limit overbank flow during spring floods to the lower Balize delta and to the Atchafalaya

bay and its adjacent marshes (Louisiana Coastal Wetlands Conservation and Restoration Task Force 1993).

Decrease of the sediment inflow

Before these artificial modifications, the Lower Mississippi River had an estimated average annual sediment discharge of 270 million cubic meters per year of suspended load, and bed load that may have been as high as 130 million cubic meters per year (Kesel et al. 1992). Since 1850, however, the sediment supplied by the Mississippi River and its tributaries has decreased by almost 80%. This reduction can be divided into three phases: a historical period before 1900, a pre-dam period (1932-1952), and a post-dam period (1963-1982). The suspended sediment load declined by 43% from the historical to the pre-dam periods and by 51% from the pre-dam to the post-dam periods. At the same time, the particle size of the suspended sediment load has decreased. At 170 kilometers above the mouth of the river, the sand fraction decreased by 72% from the late 1800's to 1983 (Kesel 1989). The particle size distribution in the bed load also declined during this period. Presumably, dams on the tributaries, particularly the Missouri River, act as sediment traps, especially for the heavier sediment fraction, and are partly responsible for the decrease in both load and coarse fraction delivered to the delta. Clearing of the watershed for agricultural and urban development undoubtedly contributed to the suspended load during the last century, but clearing may have occurred before there were good records of sediment loading rates. Efforts to reduce erosion from agricultural fields in recent years are not reflected in the record.

Figure 3.5 showed that the changes of the suspended sediment and discharge in the lower Mississippi River in 50 years of 1949 -1996. The discharge basically had no significant trend to rise or drop though there was some fluctuation, but the sediment content was keeping decrease from 900 ppm in 1949 to only 250 ppm in 1996. The sediment substantially reduced than before. In 1846, the river at New Orleans bore 890 mg/L of sediment; today, the figure is around 125 mg/L. The change is visible to the naked eye: waters that were once an opaque rusty brown are now a translucent, cloudy grey.

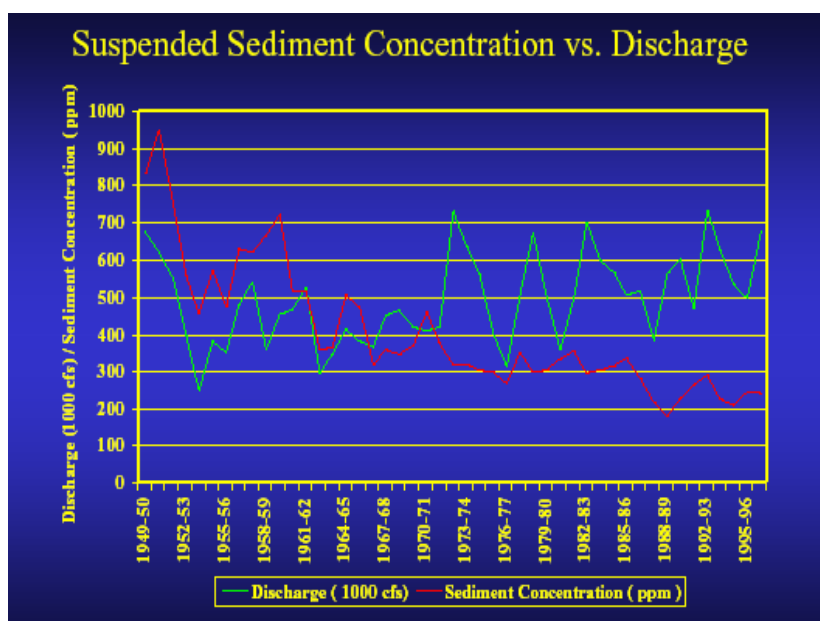


Figure 3.5 The changes of suspended sediment and discharge in years

Benefits and tradeoffs of the changes

Humans have altered Louisiana’s coastal ecosystem for centuries, and these changes have allowed the region and the nation to prosper. However, the effects of these changes have now reached a critical mass that threatens not just the health of the natural systems but life in south Louisiana as we know it. The decrease of sediment and no overland flooding directly affect deltaic processing and lead to the wetland loss and land subsidence. Table 3.2 describes the benefits and tradeoffs of the alteration by human.

Table 3.2

Change	Benefits	Tradeoffs
Levees and other structures built to control the Mississippi River.	Provided flood protection as well as navigation, and expanded the land available for development in areas such as New Orleans.	Reduced the flow of water and sediment into deltaic wetlands, thereby destabilizing coastal landscapes.
Canals and navigation channels dredged; rivers in deltaic plain straightened and deepened.	Allowed shipping as well as oil and gas production to flourish; provided for greater flood control; further established south Louisiana as an international center for trade and industry.	Changed the way water flows in the region, increasing saltwater intrusion, reducing retention of freshwater in the Chenier Plain, and accelerating land loss.
Forced drainage of wetlands	Increased land available for development.	Promoted rapid sinking of land, and increased the number of people and assets at risk.

3.4 The causes and distribution of the wetland loss

The causes of wetland loss

Many studies have been conducted to identify the major contributing factors and agreed that land loss and the degradation of the coastal ecosystem are the result of the cumulative effects of human and natural activities in the coastal area which severely impaired the deltaic processes and shifted the coastal area from a condition of net land building to one of net land loss.

- **Decrease of freshwater and sediment delivered from Mississippi River.** Until the late 19th Century, the Mississippi River's floods regularly spread water and sediment across southeast Louisiana, helping to expand the Delta Plain and replenish swamps and marshes, and creating an ecosystem that endured for thousands of years. But in the last century, the levees and associated navigational works of the Mississippi River prevent the overflow of fresh water and sediments into the adjacent marshes during spring floods. These structures extend to the river's mouth, where fresh water and heavy, delta-building sediments enter deep water on the edge of the Gulf of Mexico Continental Shelf. The wetlands do not receive the sediment and nutrients necessary to allow them to be sustainable.
- **Relative sea level rise and land subsidence.** As the sea level relative to the land surface is rising because the rates of coastal land subsidence are very high, wetlands sink beneath the intertidal zone, and barrier island systems move shoreward and become thinner. Some barrier islands have submerged entirely in the last 50 years, and more are on the verge of total submergence. Large winter storms and hurricanes resculpt the coastline and rapidly change habitats.
- **Saltwater intrusion from oil and gas exploration and navigation works construction.** Development activities in coastal area have helped shrinking of coastal delta ecosystems. Canals built for oil and gas exploration, pipelines, well maintenance, and transportation have also contributed to wetland loss. Artificial canals and their associated spoil deposits are directly responsible for at least 10% to 30% of the loss.
- **Other unknown contributing factors.** An additional but unknown percentage of loss may be attributed to their indirect effects.

The distribution of wetland loss

The distribution of the land loss sheds light on the causes (Fig. 3.6). The losses are not uniformly distributed, but rather are concentrated in a few areas. The two areas of highest loss are (1) within the Deltaic Plain in the lower Terrebonne and Barataria

Basins and the Mississippi Basin, and (2) in the Chenier Plain in the vicinity of Calcasieu and Sabine Lakes.

Net land loss for coastal Louisiana for the time period 1978-90 was 418.8 mile², which equals a loss rate of 34.9 mile²/year for the 12-year period. Net land loss for the time period 1956-78 was 862.4 mi² which equals a loss rate of 39.4 mi²/yr for the 22-year period. Land loss patterns have shifted between the 1956-78 and 1978-90 periods. Overall, the land loss rate has decreased from a high of 39.4 mi²/yr between 1956 and 1978 and is concentrated in the southern deltaic plain. Land loss patterns have shifted from loss of primarily large areas of interior lands in the 1956-78 time periods to also include loss of fringing marshes within the Terrebonne and Barataria Basins.

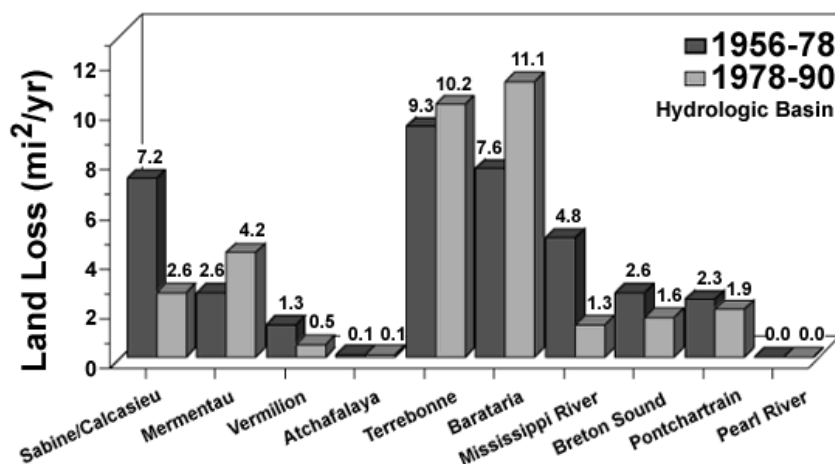


Figure 3-6 The land loss in the basin level

Land loss rates within coastal Louisiana, although decreasing; remain high at 34.9 mi²/yr for the 1978-90 time periods. The Deltaic Plain accounts for 80.7% of total coast-wide land loss, while the Chenier Plain accounts for the remaining 19.3% land loss for this time period. Loss rates are almost a magnitude higher within the Terrebonne and Barataria Basins than within all of the remaining basins and account for 61% of coast-wide land loss between 1978 and 1990. Much of the large areas of land loss occurring within the Chenier Plain appears to be related to impounded areas and therefore may be an artifact of managed water levels.

3.5 Coastal defense

3.5.1 The feature of Hurricane

A tropical system with origins comes from the coast of Africa. These are the long tracking systems, which move off Africa, form and trek across the Atlantic eventually threatening the Eastern Caribbean Islands and the US East Coast. The forming of a hurricane can be illustrated in Fig.3.7.

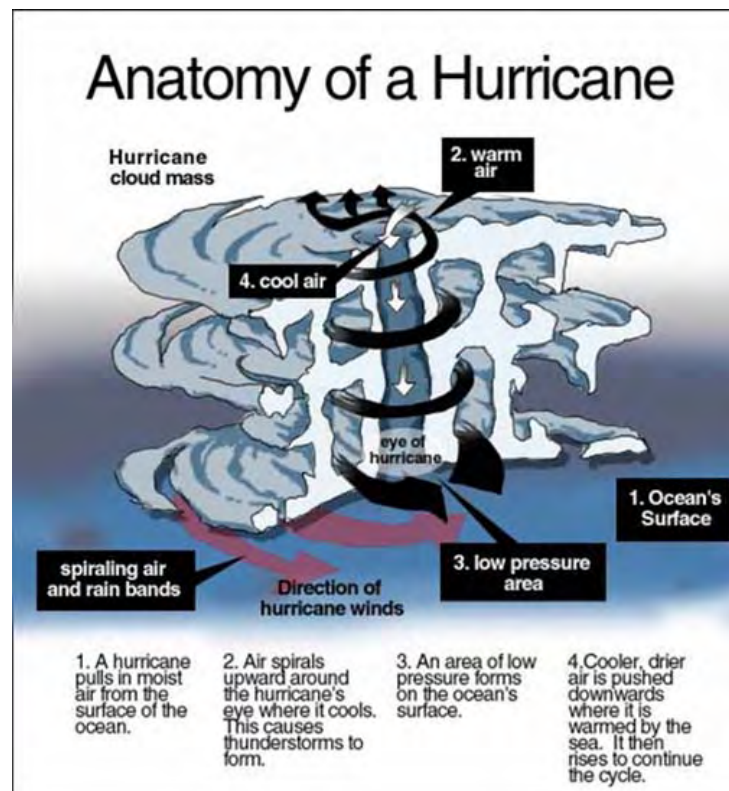


Figure3.7 The forming of a hurricane

Forecasting the hurricane has many limitations, no rational alternatives. The advisory for hurricanes approaching the coast must contain at least five elements: 1) current position, strength, and movement; 2) predicted time and position at landfall; 3) the strength at landfall; 4) peak hurricane tides and the area of inundation.; and 5) specific warnings for coastal area at risk. Of these, the most critical are the prediction of position and strength at landfall. If those two are known, the reminder can usually be observed or derived from data supplied by the customary hurricane-monitoring facilities—aircraft, weather satellites, and radar. A small shift in the expected landfall position can quickly change the requirement for evacuation and for other preparedness measures. A rapid increase in hurricane strength during the last 12 hours at sea can sometimes double the peak-surge heights and escalate the urgency for evacuation. In coastal Louisiana, hurricane can move along three tracks to hit the area at landfalls. (Fig. 3.8)

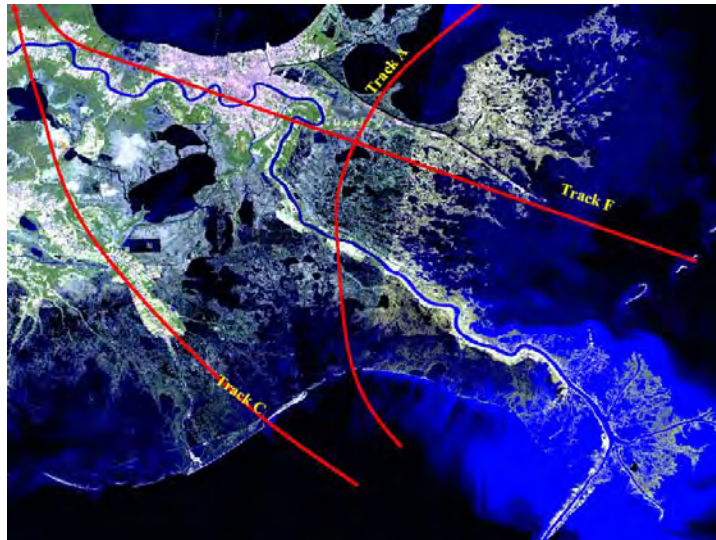


Figure 3.8 The tracks of hurricane hits in coastal Louisiana

Since 1717 when Andre Penicaut recorded the first known hurricane to strike the Mississippi Coast, the area has experienced 30 direct hits and at least 10 near misses. On average, that works out to one every six or seven years. The top deadliest hurricanes in the gulf of Mexican list in the Tab. 3.3.

Table 3.3 Top 10 deadliest hurricanes (Atlantic)

Rank	Hurricane Name	Year	Category	Deaths
1	Texas (Galveston)	1900	4	8000
2	FL (Lake Okeechobee)	1928	4	1836
3	Hurricane Katrina	2005	4	1336+
4	Florida Keys	1919	4	600
5	New England	1938	3	600
6	Florida Keys (Labor Day)	1935	5	408
7	Audrey	1957	4	390
8	NE United States	1944	3	390
9	LA (Grand Isle)	1909	4	350
10	LA (New Orleans)	1915	4	275

In hurricane business, average means nothing. The records of Mississippi coast reveal multiple strikes in a single season, hits in successive years and periods of inactivity totaling 10, 20 as in two cases, in excess of 30 years. The lesson of history is plain. Since hurricane can be neither prevented and nor predicted, major effort should be directed toward preparation for them.

3.5.2 “Multiple lines of defense” strategy for hurricane protection

Residents of coastal Louisiana have used a multiple lines of defense strategy for thousands of years, building homes and settlements on high ground that was protected by natural ridges, barrier islands, and more recently by levees.

Barrier islands, healthy marshes, natural ridges adjacent to bayous, and cypress swamps provide a natural buffer during storms by slowing down and reducing incoming surges of water. This function, combined with man-made levees and other flood control measures, has allowed Louisiana’s working coast to exist in a flood-prone area.

Coastal Lines of Defense

- Wetlands provide flood water storage
- Natural habitat features (forested ridges, marsh and islands) buffer the coastal area from storms and provide other ecosystem benefits (Fig.3.9)
- LA coast wetlands restoration supports coastal protection and recovery
- Surge reduction benefits more important in lower intensity storm events with more frequent return intervals



Figure 3.9 Natural lines of defense for coastal protection

Storm Surge Reduction

- The concept of natural lines of storm surge defense is based on the hydraulic principle that surge elevation is effectively reduced by the friction of flowing over a vegetated land mass.
- Historically an engineering “rule of thumb” has been used for estimating potential storm surge reduction in LA.
- The engineering “rule of thumb” for the effect of coastal wetlands in reducing storm surge elevation provides for an estimated one foot of surge reduction for each 2.7 miles of wetlands over which the surge must flow. (Fig.3.10).



Figure 3.10 The storm surge reduction by natural lines

3.6 The impact of Hurricane Katrina

The hurricane Katrina hit New Orleans on Aug.31, 2005 and led to catastrophic destruction. It became the most serious disaster in New Orleans.

The path followed by Hurricane Katrina, shown in Fig.3.11, caused severe surge and wave conditions on the east side of the hurricane protection system, from Lake Pontchartrain to southern Plaquemines Parish. It struck early on the morning of 29 August 2005, after building up water levels to the east of New Orleans for several days. Katrina was a Category 5 storm with up to 175-mph winds until it was approximately 170 miles from landfall. When it reached landfall at Buras, LA, around 06:30 hr, wind speeds were at 127 mph, but the long path through the Gulf had built up record levels of surge and waves, larger than any previous storm to strike the area, or the North American continent.(Fig.3.12)

Katrina (a Category 3 storm at landfall) generated substantially higher surges than Camille (a Category 5 storm at landfall) in the area where they both made a direct hit. Whereas the Saffir-Simpson scale is a good predictor of wind damage from hurricanes, it is not a particularly good predictor of the surge and wave generation potential for these storms. (Tab.3.4) Hurricane Katrina had much greater wave and storm surge generation potential than the Standard Project Hurricane storms used to design the hurricane protection system.

Table3.4 Saffir / Simpson Scale

category	Wind speeds(MPH)	Storm surge(Feet)
1	74-95	4-5
2	96-110	6-8
3	111-130	9-12
4	131-155	13-18
5	156+	19+

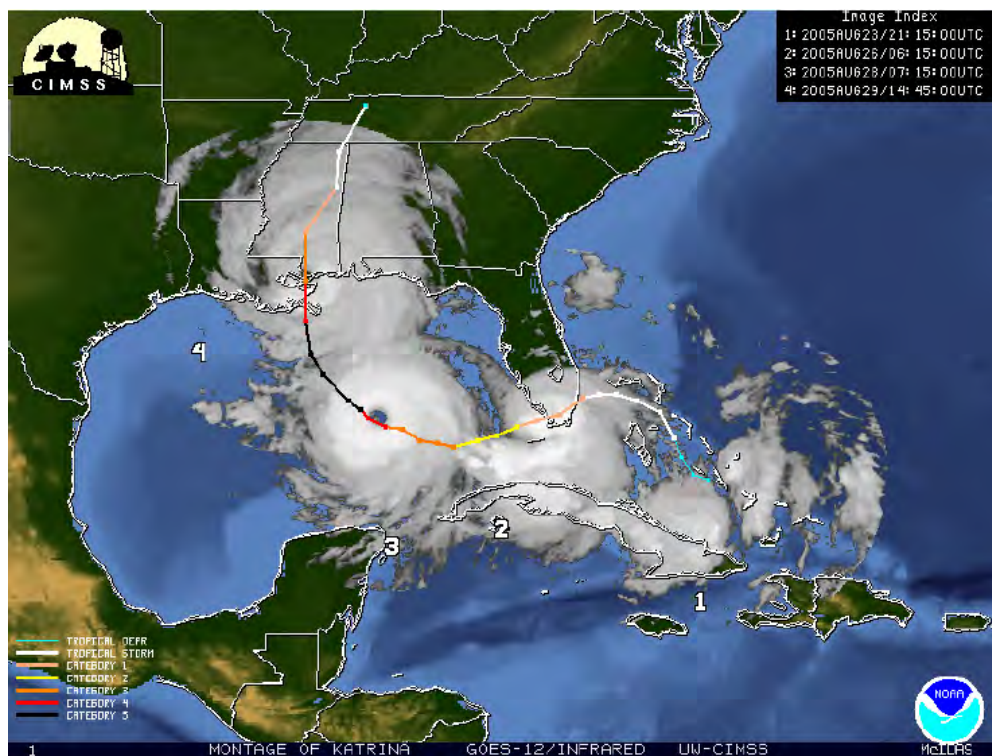


Figure 3.11 Hurricane Katrina path and intensity history

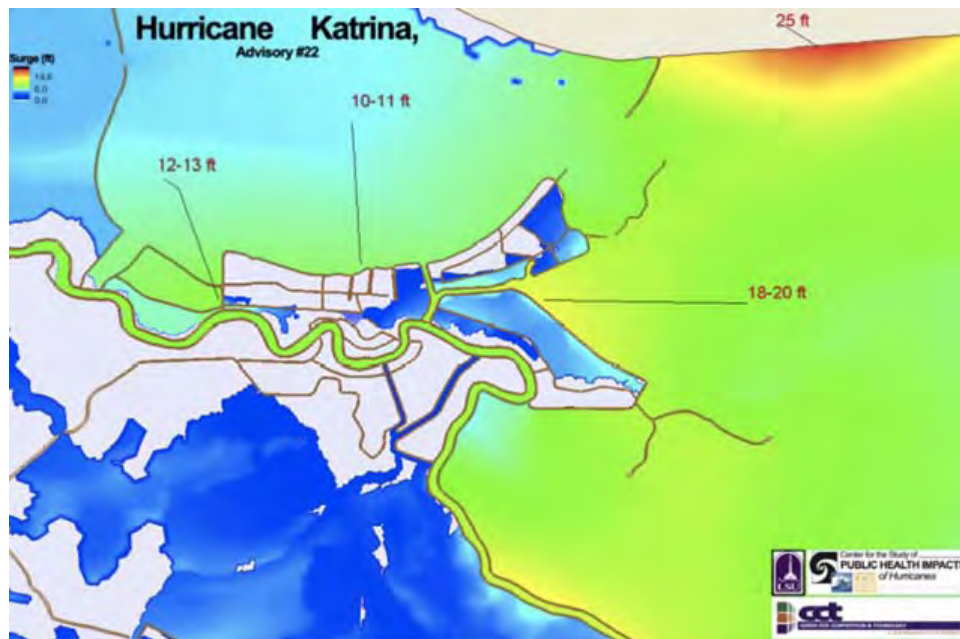


Figure 3.12 The height of storm surge due to hurricane Katrina

3.6.1 Existing hurricane protection system

Located in the low-lying Mississippi River delta in Louisiana, large portions of the city of New Orleans lie near or below sea level, a fact that has posed complex flood management problems since the city's founding in 1718. Historically, the greatest natural threat posed to residents and property in the New Orleans, Louisiana, area has been from hurricane-induced storm surges, waves, and rainfall, especially those associated with Hurricane Betsy in 1965, Camille in 1969, and Lilli in 2002. Although some hurricane protection had been provided to a few areas of New Orleans, it was not until Hurricane Betsy struck the city, killing 75 people and causing substantial damage and loss of property, that a comprehensive hurricane protection plan was initiated. Over time, three hurricane protection projects have been designed and partially constructed in New Orleans and the Southeast Louisiana region: Lake Pontchartrain and Vicinity, the West Bank project, and the New Orleans to Venice project. (Tab.3.5, Fig.3.13) The Lake Pontchartrain and Vicinity project is used here to illustrate the events that preceded Hurricane Katrina. (Fig.3.14)

Table 3.5 Existing Hurricane Protection Project

Projects	Level of Protection
Lake Pontchartrain & Vic (1965)	SPH *
W. Bank Hurricane Protection (1986)	SPH *
New Orleans to Venice (1962)	100-Year Frequency
Larose to Golden Meadow (1965)	100-Year Frequency
Grand Isle (1976)	50-Year Frequency

* Standard Project Hurricane equivalent to fast moving, low-strength Category 3 storm on critical path; Derived by the National Weather Service in 1957; Central Pressure: 931 millibars; Wind Speed: 177 km/h; Radius of Maximum Winds: 48 km; Forward Speed: 5–11 knots.

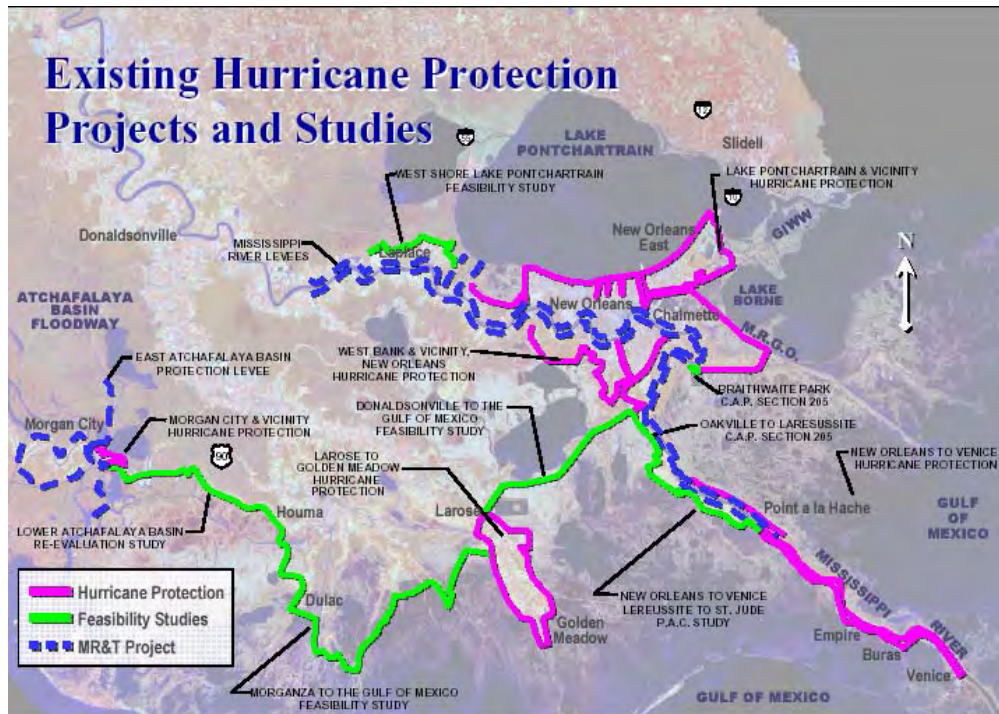


Figure 3.13 Existing hurricane protection projects

Lake Pontchartrain, LA and Vicinity Hurricane Protection Project:

- The project was originally authorized in 1965.
- The project is located in St. Bernard, Orleans, Jefferson and St. Charles Parishes on the East Bank of the Mississippi River.
- The project was designed to protect against the Standard Project Hurricane (SPH)
- The project consists of over 125 miles of levees, floodwalls and floodgates.

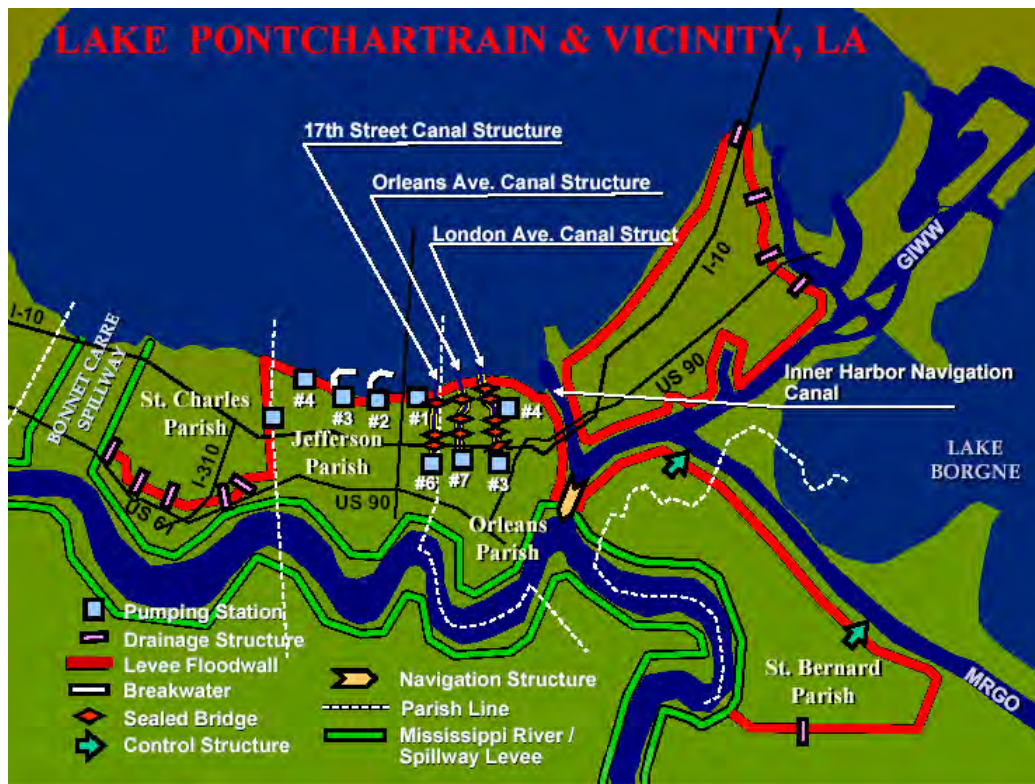


Figure 3.14 Detailed geometry and features of the New Orleans metropolitan area

Congress first authorized the Lake Pontchartrain and Vicinity hurricane protection under the Flood Control Act of 1965. The project was intended to protect areas around the lake (in the parishes of Orleans, Jefferson, St. Bernard, and St. Charles) from flooding caused by a storm surge or rainfall associated with a hurricane that would be roughly the same as what is today classified as a fast-moving “Category 3” hurricane. The basis for this was the standard project hurricane (SPH) developed by the Corps with the assistance of the U.S. Weather Bureau (now the National Weather Service). The model (assumed at that time to represent a storm that would occur once in 200-300 years) was intended to represent the most severe meteorological conditions considered reasonably characteristic for that region: winds up to 111-113 miles per hour and that can be expected to cause some structural damage from winds and flooding near the coast from the storm surge and inland from rains. Although federally authorized, the project was to be a joint federal, state, and local effort, with the federal government paying 70 percent of the costs and the state and local interests paying 30 percent. The Corps of Engineers was assigned responsibility for project design and construction, and the local interests were responsible for maintenance of the levees and flood controls.

The hurricane protection system, outlined on the map in Fig.3-13, includes approximately 350 miles of protective structures, 56 miles of which are floodwalls. The majority of the floodwalls are I-walls with some sections of T-walls and a small

amount of L-walls. Fig.3.15 provides a schematic of the basic geometry of these structures. The elevation of the current hurricane protection structures are significantly below the originally authorized heights in part from errors in initial constructed elevations and in part from rapid subsidence. Figure provides a general map of the New Orleans metropolitan area and the features of the hurricane protection system.

As of May 2005, the Lake Pontchartrain and Vicinity project included about 125 miles of levees, major floodwalls, flood-proofed bridges, and a mitigation dike on the lake's west shore. Progress on the project varied by area: 90 percent complete in Orleans Parish, 70 percent complete in Jefferson Parish, 90 percent complete in the Chalmette area, and 60 percent complete in St. Charles Parish. The estimated completion date for the entire project was 2015. In recent years, questions were raised about the ability of the project to withstand hurricanes with intensities greater than those assumed for the original design. In 2002, a pre-feasibility study on whether to strengthen hurricane protection along the Louisiana coast was completed. A full feasibility study was estimated to take 5 years to complete.

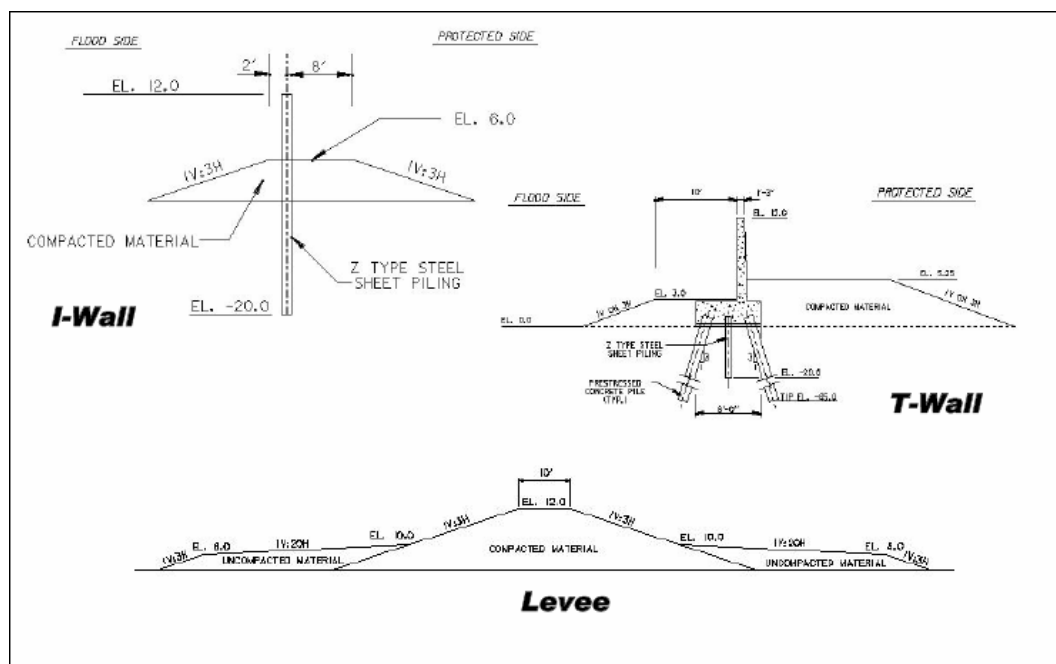


Figure 3.15 General Schematic of major hurricane protection structures used in New Orleans and vicinity

3.6.2 The performance of hurricane protection system during hurricane Katrina

The damage of hurricane protection system

Katrina-generated surge and waves:

- Caused 50 major breaches in the HPS, causing a dramatic reduction in protective elevation and losing the ability to prevent the inflow of external water.
- Significantly damaged 34 of 71 pumping stations designed to move water out of the city, approximately 169 of the system's 350 miles of protective structures, such as levees and floodwalls.
- Severely damaged 41 miles of protective structures.

Fig. 3.16 shows the locations of the most severe damage to the hurricane protection system. Of the 50 major breaches, four were caused by foundation-induced failures and the remainder from a combination of overtopping and scour. Three of the four foundation breaches occurred in the outfall canals and one in the IHNC. I-wall structures were particularly vulnerable as were levee sections created from hydraulic fill and transitions where either elevation or strength differences occurred from changes in structure type or capability. (Fig.3.17, Fig.3.18, Fig.3.20, a crack forming along the front of the I-wall introduced high forces down the face of the sheet pile, resulting in lateral movement of the floodwall along a shear plane in the weak clay foundation).

The flooding resulting from the overtopping and breaching was catastrophic. Figure 3.19 shows the extent and depth of flooding for the metropolitan area where almost 80 percent was inundated.

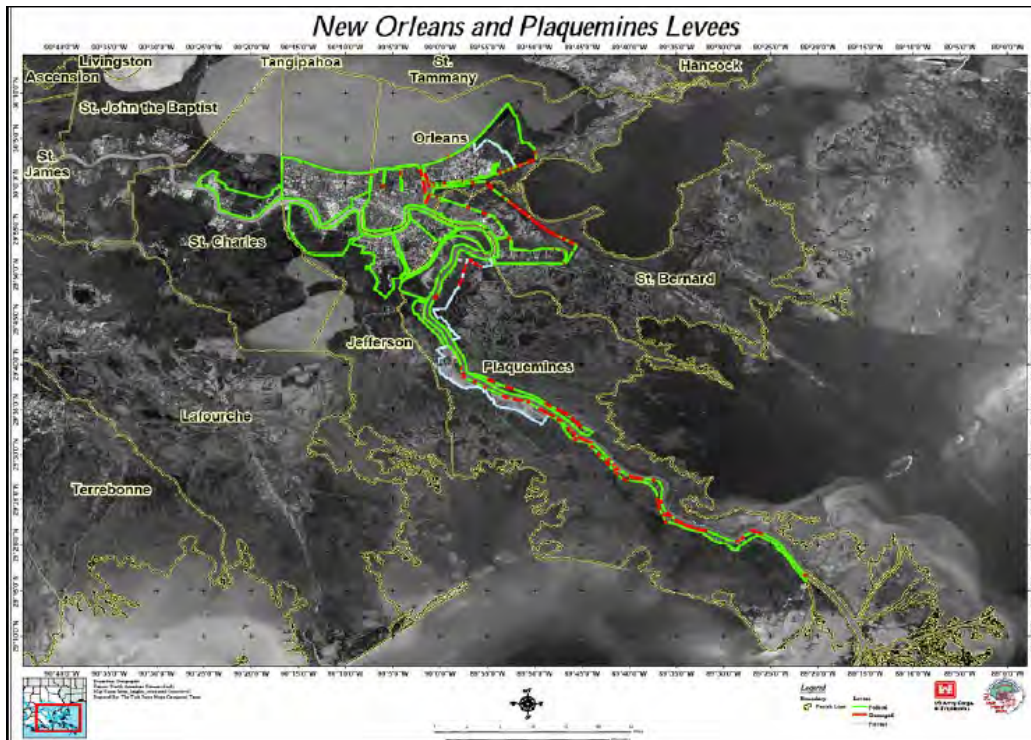


Figure 3.16 Locations (in red) of severe damage to hurricane protection structures

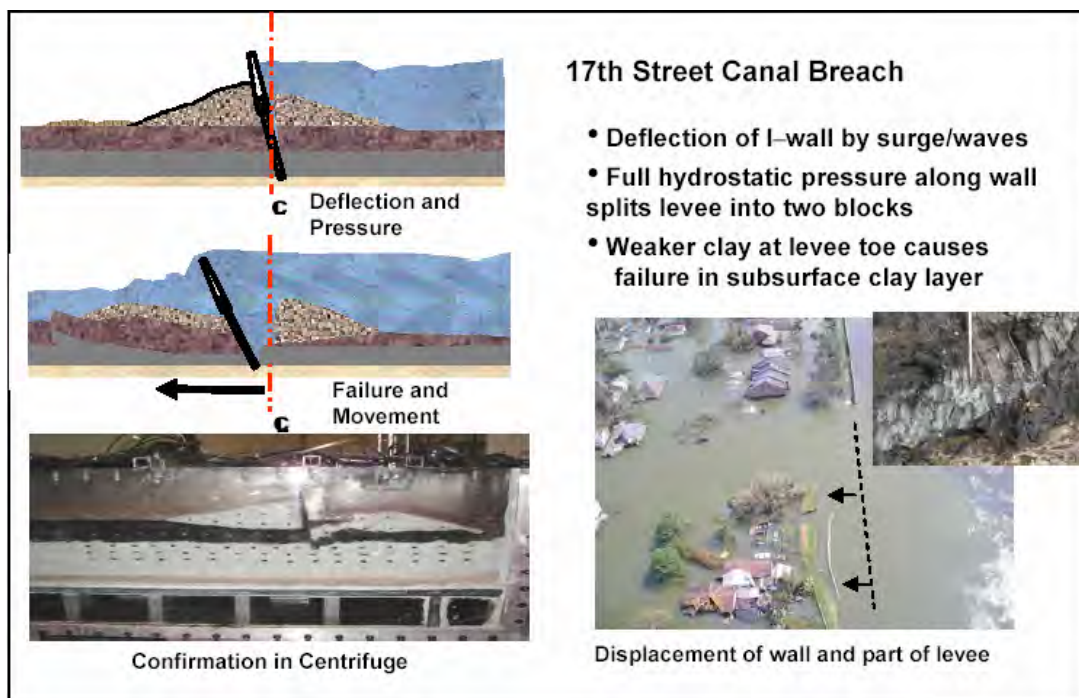


Figure3.17 Depiction of failure mechanism for 17th Street and IHNC foundation failures



Figure 3.18 Example of breach along IHNC (east side) from overtopping and scour (top) and scour behind adjacent section that did not fail (bottom)

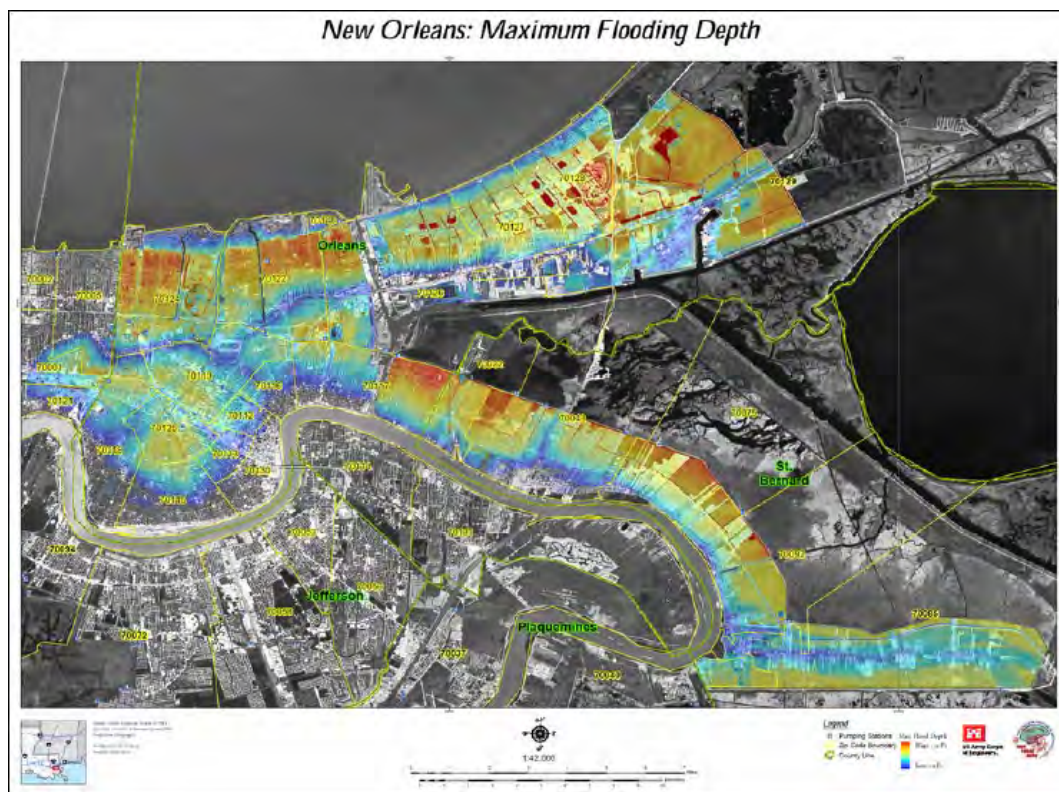


Figure 3.19 Map of maximum depths of flooding from Katrina

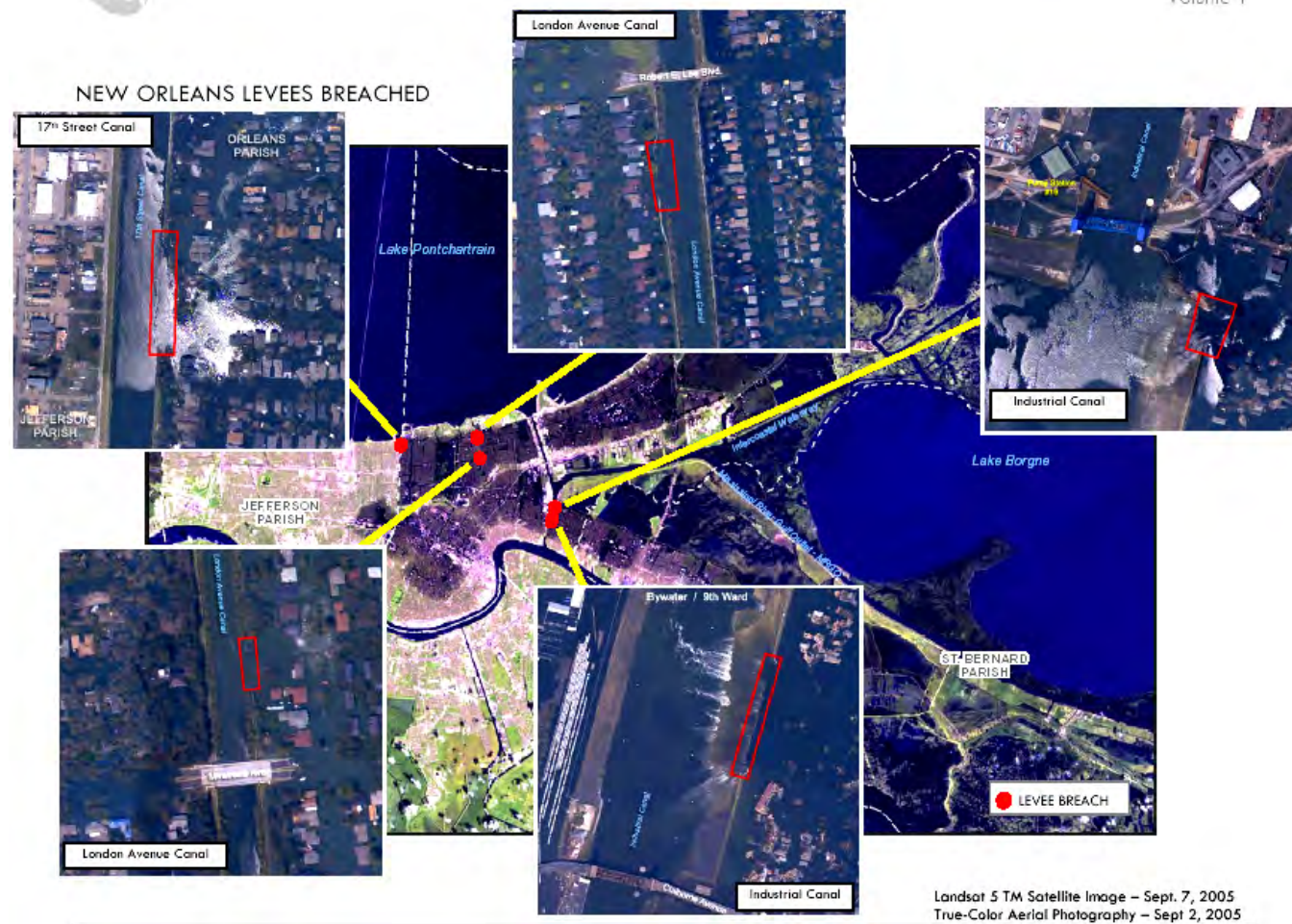


Figure 3-20 The levees breaches in New Orleans

3.6.3 Analysis of the failure of hurricane protection system

The system did not perform as a system. The hurricane protection system (HPS) in New Orleans and southeast Louisiana was a system in name only. The system's performance was compromised by the incompleteness of the system, inconsistency in levels of protection, and the lack of redundancy.

Incompleteness: The HPS was scheduled for completion in 2015. Some sections of the system were not finished, and transitions between complete and incomplete sections or different types of protection created weak spots in the system. Given that hurricane protection is typically a series system; the failure of the weakest component causes the failure of the system.

Inconsistency in levels of protection: Because of differences in the quality of materials used in levees, differences in floodwall designs and variations in elevations of protective structures due to subsidence and construction below the design intent (due to error in interpretation of vertical elevation datum information), protection system-wide was not uniform.

Lack of redundancy: Redundancy — components of the system backing each other up so that failure of one component does not cause the whole system to fail — were not included in the system's design. Pumping is a form of redundancy; however, the pumping stations are not designed to operate in major hurricane conditions nor are they part of the hurricane protection system. Armoring the back sides and crests of levees and the protected side of floodwalls would have added significant redundancy and reduced breaching. Surge gates at the mouths of the outfall canals are also an excellent example of providing redundancy.

While overtopping and significant flooding were inevitable with a large, powerful storm like Katrina, a complete system providing consistent levels of protection and incorporating redundancy would have reduced loss of life and curtailed damage to property.

The consequences of the flooding were enormous, dwarfing the losses from previous disasters. This graphic correlates primarily to elevation (depth of flooding) and concentration of assets. When coupled with the approximately \$4.5 to \$5.6 billion in public infrastructure damages, the total direct property losses for New Orleans alone reach nearly \$25 billion. In contrast, Figure 23 shows the hypothetical percentage loss for the scenario of having no breaching (just overtopping) and full pumping capacity. While this scenario is not realistic for the time of Katrina, when added to the relationship

shown in Fig. 3.20, it is a testimony to the value of having a resilient hurricane protection system.

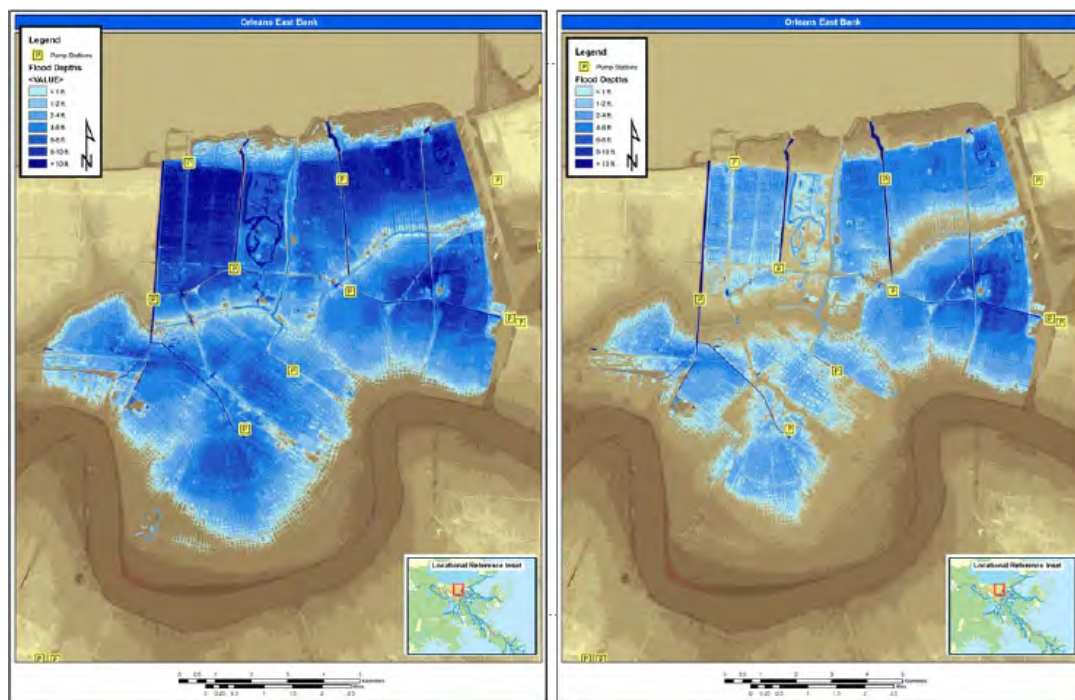


Figure 3.20 Comparison of flooding from Katrina (left) to hypothetical condition of no breaching and full pumping capacity (right) for Orleans East Bank

3.6.4 Wetland Losses impacted by hurricane Katrina

Hurricanes Katrina and Rita converted approximate 217 mi² of marsh to water. Of this total, 98 square miles of land were lost in southwestern Louisiana, and 119 square miles were lost in southeastern Louisiana.

Caernarvon Mississippi River diversion project was invested Multimillion dollar to create new wetlands in Breton Sound Region in 1991. As preliminarily estimated, Hurricane Katrina led to 26 % loss (133 mi²) of wetlands which caused by wind & wave, saltwater intrusion, increased susceptibility to storms. (Fig. 3.21)

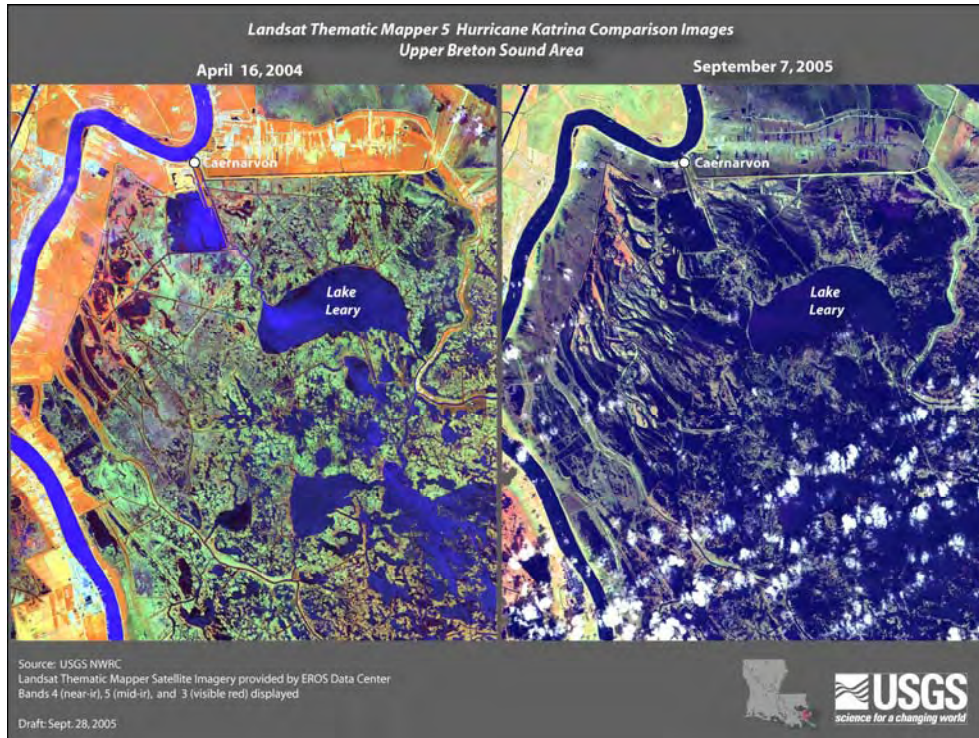


Figure 3.21 The changes of marsh in Upper Breton Sound Area pre-and post-Katrina

3.7 Flood and storm mitigation (non-structural measures)

Non-structural activity has played a relatively small role in flood damage reduction activities on the Mississippi River. In the mid 1950's, initial proposals were made for the use of non-structural measures to reduce flood damages and a slow movement in that direction began. Until recent years, more and more states along the river started to prefer to implement non-structure measures to reduce flood damage.

Non-structure is more important for hurricane and tropic storm protection than flood mitigation in the river, because they are rapid and vigorous and difficult to predict the detail stage.

Data and information collection

The federal government provides a vast array data collection, storage and dissemination in support of integrated flood management. The US Geological Survey is charged with providing baseline information on US water resources and operation of gauging stations on most US rivers. There are 84 sites on the lower Mississippi and its tributaries. The Corps also remotely operates and monitors selected gauges in the Mississippi basin for use in water control activities. The National Oceanic and Atmospheric Administration

make weather forecasts and flood stage data as well as historic data available on the web.

Flood warning

Flood notification systems have been in use for decades to inform the public about the threat of flooding and provide residents the opportunity to clear the hazard area and move valuables to higher ground. The residents rely primarily on the media and access to flood information on the Internet to get information about the timing of flood stages.

Flood response and evacuation

Federal Emergency Management Agency and local government will be the first responder for flood events. During extreme situation, more organizations at the federal, state and local level like US Coastal Guard, the Army Corps of Engineers will participate the flood fighting, evacuation activities. United States have National Response Plan and the National Incident Management System to coordinate the response to emergency and accident, which involved all levels of American government.

By most accounts, the response to Hurricane Katrina was a failure. During the crisis, many organizations suffered from a lack of leadership. In many cases, there was no obvious leader to coordinate the emergency response. All relevant organizations must know about prescript plans. In New Orleans, guidelines set in documents such as the National Response Plan and the National Incident Management System were not followed.

The state-directed evacuation of New Orleans was considered a success. Approximately 1 million people left the region in 36 hours. However, more than 100,000 remained for various reasons. Effective coordination was demonstrated by the contra-flow system used during the initial evacuation of New Orleans. The Senate report noted this approach required careful planning and the cooperation of many organizations because evacuating New Orleans is particularly difficult for at least four reasons. First, evacuating the area requires at least a 45- to 80-mile trip. Second, there are only two or three ways to exit the metropolitan area. Third, one of those ways out of the area runs into Mississippi, requiring that state's cooperation. Fourth, because of the limited number of ways to exit the metropolitan area, the northernmost parishes within the area must wait patiently for the southernmost parishes to evacuate first.

Flood management in floodplain

On the upper Mississippi (as well as throughout the nation), following the 1993 flood the federal government increased its support of relocation activities. Since 1993, over 13,000 homes have been relocated or removed from the floodplain in the upper Mississippi-Missouri region (over 25,000 nation-wide). One community in Illinois was relocated in its entirety. State and federal governments and private organizations have voluntarily acquired several hundred thousand acres of frequently flooded agricultural lands from willing sellers. These now serve as flood storage areas. Increased attention in planning is given to upland wetland restoration and improvement of farming practices. Federal funding support is now provided for farmers to voluntarily place land in conservation reserve to provide habitat and flood storage.

Advisory Base Flood Elevations

Elevating is the one measure of reducing the damage from flooding. Federal Emergency Management Agency (FEMA) developed Advisory Base Flood Elevations (ABFEs) to provide communities with recommended building elevations for use in the reconstruction process to avoid future flood damages until more detailed data become available. ABFEs are based on a new flood frequency analysis that takes into account Hurricanes Rita and Katrina, as well as additional tide and storm data from other events that have occurred during the more than 25 years since the existing Flood Insurance Rate Maps (FIRMs) were developed.

$$\text{ABFEs} = \text{Advisory SWEL} + \text{Wave Height}$$

Where Advisory SWEL=1%-annual-chance stillwater elevations;

$$\text{Wave Height} = \frac{1}{2} \text{ stillwater flooding depth (relative to the ground surface).}$$

Updated SWEL is determined through the analysis of tide gage data and estimated High Water Marks (HWMs) across the inundated area.

FEMA provides detailed ABFEs maps in different communities to the state and local officers, the house owners as well, to identify the flood risk and inundation caused by storm surge. The people can easily get the information to prepare defending the storm.

Flood insurance program

According to FEMA (Federal Emergency Management Agency), a home has a 26% chance of being damaged by a flood during the course of a 30 year mortgage, compared to a 9% chance of damage from fire, And because of its low lying topography, Louisiana has the highest rate of repetitive flood losses in the nation. Given the base risk, all

residents of coastal Louisiana should invest in flood insurance, even if they live inside of a hurricane protection system. Public education about flood risks and the need for insurance is available through the Community Rating System Program.

In 1969, the federal government instituted the National Flood Insurance Program (NFIP), which combines subsidized flood insurance with requirement for participating communities to regulate land use in the floodplain. Yet only 20%-30% of those eligible for insurance participate in the program. Some floodplain zoning has taken place as a result of community participation in the flood insurance program. Relocation of flood prone homes and activities has concurred and its use is growing.

During hurricane Katrina, flood insurance companies seem not doing their work well. Many claims from the people who participated the insurance did not get proved or a little partially get proved by the insurance companies. Because of extensive damage, the insurance can not afford a bulk of budget, and then they checked very carefully the claims and try to escape the responsibility. Insurance companies regarded the most flooding damages as negligence of the state for hurricane protection (levee breaches) because they assumed the levee was strong enough to protect the communities. They would like to pay for overtopping flood and wind damage. According to the local people word “they (insurance companies) do not like to pay for my damage”, the insurance companies got many complains from the people. So after Hurricane Katrina, the flood insurance program maybe will lose more and more participants. The reason is that people will not trust insurance company any more, and the insurance companies will raise the charge for insurance in order to meet the current inadequate flood protection as well.

3.8 Legislation, finance and institutions

3.8.1 Legislation

Policy for flood management in Mississippi River

For a long time, the floods had been viewed as regional problem in US. In the mid-19th century, Congress was still debating whether flood control could be justified as a federal function. During the floods in 1882, 1912 and 1913, many losses were suffered and tremendous damage caused. It drew attention to the need for federal relief legislation. In 1917, Congress passed the first Flood Control Act. The flood of 1927 brought national attention to the need for more federal involvement in flood damage reduction. Out of it grew the Flood Control Act of 1928, which committed the federal government to a

definite program of flood control. This legislation authorized the Mississippi River and Tributaries (MR&T) Project. The 1936 third Flood Control Act recognized that flood control was a proper activity of the federal government in cooperation with states, their political subdivisions, and localities thereof. While this Act remains in force, over time, it has shifted from a program of almost full federal funding to one in which states and local sponsors share the costs of both structural and non-structural activities. The ability of federal agencies to operate under the Flood Control Act has been modified by the enactment of other laws governing the environment and flood mitigation.

In nearly three centuries of flood management activities on the Mississippi the US federal government policies and activities to deal with flooding have shifted from 'let the locals do it' to full federal responsibility for an essentially structural only approach, to a federally led, locally shared mix of structural and non-structural elements that are gradually being combined with other water resource activities in a an integrated and comprehensive approach.

Policy for hurricane protection and coastal restoration

The federal government's traditional way of building hurricane protection and coastal restoration projects works well for endeavors that are localized and relatively narrow in scope. The Congressional authorization and appropriations processes present large challenges. For example, the Water Resource Development Act is the primary vehicle used to obtain authorization for restoration projects, but Congress has not reauthorized this act in seven years. In addition, before a project can move from planning to design to construction the Executive Branch is required to give approval and Congressional action is needed. At each juncture therefore, a project can meet with delays lasting months or even years. Such restrictions will effectively hamstring Louisiana's coastal restoration and hurricane protection program before it. Specific recommendations for improvement of intergovernmental coordination.

3.9.2 Finance

Levees and floodwalls that protect against flooding from both Mississippi River and hurricanes are built by the Army Corps of Engineers and are maintained by local levee districts. The corps and local districts share the construction cost of hurricane levees, while the Mississippi River levees are a federal project. Levee districts also build and maintain non-federal, low-elevation levees with construction money from each districts' share of property taxes and state financing.

The state's Coastal Protection and Restoration Fund receives \$25 million in state funds annually to address coastal protection and restoration issues, and the federal government dedicates approximately \$50 million per year through the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) program. These funds support efforts that have been the cornerstone of Louisiana's coastal restoration efforts to date. Funding for hurricane protection projects and other coastal restoration activities comes through annual federal and state appropriations processes, and as such, the dollars allocated are determined by fluctuating fiscal priorities. As a whole, this level of funding is less than what will be required to build the whole projects for coastal protection and restoration.

The Energy Policy Act of 2005 created the Coastal Impact Assistance Program, which will provide \$540 million through 2010 to Louisiana and its coastal parishes. The funding is designed to support coastal restoration and infrastructure projects that mitigate the impacts of offshore oil and gas activities. The program will be an important asset as Louisiana ramps up its coastal restoration effort. However, most successful national civil works programs, such as the construction of the Interstate Highway System, were built because they were supported by a more stable long-term funding commitment. A similar national commitment, buttressed by strict standards of accountability, must be made in order to save Louisiana's coast. In December 2006, the U.S. Congress passed legislation regarding the sharing of outer continental shelf revenues. This will provide the state and coastal parishes approximately \$20 million per year until 2016; the amount Louisiana receives will increase to \$300 to \$500 million per year thereafter. Similar commitments of federal funds will need to be applied to this effort.

3.8.3 Institutions Responsible For Flood Management

The Corps of Engineers and the Federal Emergency Management Agency are the lead federal agencies in flood management.

U.S Army Corps of Engineers

The Corps role is to lead in the development of comprehensive plans for flood damage reduction, and then as authorized by the Congress and the President, to carry out flood damage reduction projects, both structural and non structural. In 1779, Congress passed a resolution forming a (military) unit known as the Corps. After a few years, military and engineers were separated in 1802 when President Jefferson was authorized by Congress to establish a "Corps of Engineers". In 1824, the Corps of engineers was given

official responsibility for civil works projects in the United States; it was assigned the task of snagging and clearing the Ohio and Mississippi River for navigation purposes.

By the year 1879, the need for improvement of the Mississippi River had become widely recognized. The necessity for coordination of engineering operations through a centralized organization had finally been accepted. Accordingly, in that year, the Congress established the Mississippi River Commission and assigned it the duties. . . " to take into consideration and mature such a plan or plans and estimates as will correct, permanently locate, and deepen the channel and protect the banks of the Mississippi River, improve and give safety and ease to navigation thereof, prevent destructive floods, promote and facilitate commerce, trade, and the postal service." The Commission was to consist of three officers of the Corps of Engineers, one of whom would be President; one member from the U.S. Coast and Geodetic Survey; and three civilians, two of whom would be civil engineers. All appointments would be nominated by the President of the United States, subject to confirmation by the Senate.

Federal Emergency Management Agency

FEMA is charged with preparing for and responding to all natural disasters and operation of the National Flood Insurance Program (NFIP). Parallel state agencies perform similar functions at their level. Other federal and state agencies dealing with housing, economic development, agriculture, transportation, energy, and the environment collect and provide data, support post-disaster reconstruction, advise the Corps and FEMA on the impacts of their activities and support actions by communities and sectors to reduce their vulnerability. The most challenging responsibilities fall to local governments that must ensure, through zoning or other land planning, the proper use of the floodplain and, in the event of a flood, must become first responders to the hazard situation. Typically, local governments have more responsibility than resources needed to deal with the challenges.

The Public's role and involvement

The public as taxpayers played an important role in flood management. During the development of plans for flood damage reduction or mitigation by any federal or state agency there is ample opportunity for public comment and participation in the planning process. The planning team will hold dozens of meetings with citizen and stakeholder groups to seek their ideas as the initial draft plan is developed.

During the implement and maintenance of the projects, the public is monitoring and supervising the process. They can give the comments and complains.

Like the master plan for coastal protection and restoration, a Preliminary Draft Master Plan was released for public comment on November 29, 2006. Nine public meetings were held across coastal Louisiana to gather citizen input, and two meetings were held to facilitate scientific and technical review. Comments received were used to create this document, the Draft Master Plan, which will be open for public review through March 2007. The planning team will make further revisions based upon these comments and present the final Master Plan to the Louisiana Legislature in April 2007.

On the other hand, sometimes the much involvement of the public could delay or extend the progress of the projects and make implement and construction become complicated.

4. Possible solutions

4.1 Make a Master Plan for coastal protection and restoration

As demonstrated above, Mississippi River Delta area is facing a crisis that extreme rates of land loss compounded with inadequate hurricane protection measures threaten the viability of south Louisiana's communities and infrastructure. Scientists, engineers and policy makers have long worked to improve wetland restoration and hurricane protection in the region, even as the wetlands converted to water at a rapid rate. Hurricanes Katrina and Rita intensified these urgent needs.

Creating a sustainable coast

To correct the root causes of these problems, the efforts should be done to create a sustainable coast. As Hurricanes Katrina and Rita made clear, this goal can not be achieved unless we return the wetlands to health, change the way we manage and live in this dynamic landscape, and improve our hurricane protection systems. A healthy landscape is essential to achieving both a sustainable ecosystem and reliable flood protection.

Furthermore, the levees and wetland restoration projects can no longer be constructed in separate spheres. Instead, flood control and wetland restoration projects must be designed and built in tandem, while taking into account how individual projects interact with each other.

Long term guidance for the future of Coastal Louisiana

In order to achieve a sustainable solution for comprehensive hurricane protection and coastal restoration, projects and plans will be integrated and evaluated on a long-term

like 50-years or 100-year planning horizon to understand future implications of current actions, and provide a basis for follow-on decisions regarding redevelopment of south Louisiana.

Concerning diverse interests

The mater plan should provide a context within which to evaluate other activities in the coastal zone, including: transportation, navigation, and port projects; oil and gas development; groundwater management; and land use planning. It will be developed and implemented with the participation and input of the numerous and diverse interests that live, work, and play in coastal Louisiana, along with national interests who depend upon coastal Louisiana's continued health and existence.

Uniform plan and implementation

In recent years, many institutions are working for coastal protection and restoration and many programs are going on at the local, state and federal levels, including the Coastal Wetlands, Planning, Protection, and Restoration Act (CWPPRA); the Louisiana Coastal Area (LCA) Ecosystem Restoration plan; the Coastal Impact Assistance Program (CIAP); hurricane protection proposals; and the US Army Corps of Engineers (USACE) Louisiana Coastal Protection and Restoration (LACPR) Study.

The Master Plan should builds on past efforts and existing programs to provide this comprehensive vision, and serves to unite the work in order to keep the uniform criteria and effectively use the resources. (Fig.4.1).

Dividing the Planning Units

The term “Louisiana coast” might sound like a reference to a homogeneous ecosystem. In reality, Louisiana’s coastal region contains diverse landscapes, including forested wetlands, barrier islands, marsh, and ridges .where humans have lived for centuries. Louisiana coast could be divided the coast into five distinct areas, or planning units. Within each planning unit, the plan offers a strategy for hurricane protection and coastal restoration.

The Master Plan must consider the unique nature of each region when it proposes solutions. The Master Plan thus defines five separate planning units (Fig.4.2), each representing a distinct hydrologic area.

Planning Unit #1: Pontchartrain Basin (area east of the Mississippi River);

Planning Unit #2: Barataria Basin (from the Mississippi River west to Bayou Lafourche);

Planning Unit #3a: Eastern Terrebonne Basin (from Bayou Lafourche west to Bayou de West);

Planning Unit #3b: Atchafalaya Influence Area (from Bayou de West to Freshwater Bayou Canal);

Planning Unit #4: Chenier Plain (from Freshwater Bayou Canal to the Sabine River);

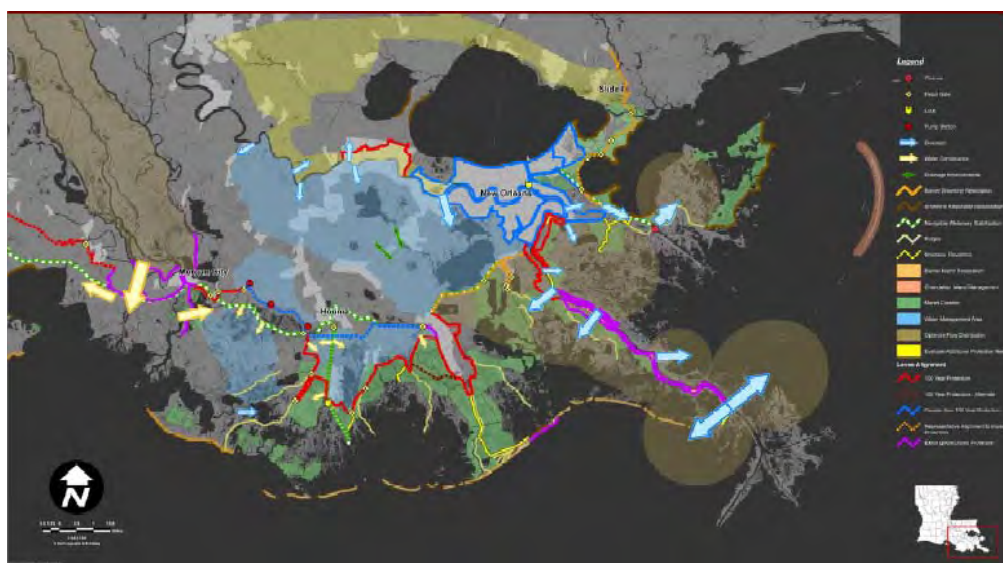


Figure 4.1 Conceptual depiction of the comprehensive measures in Delta Plain

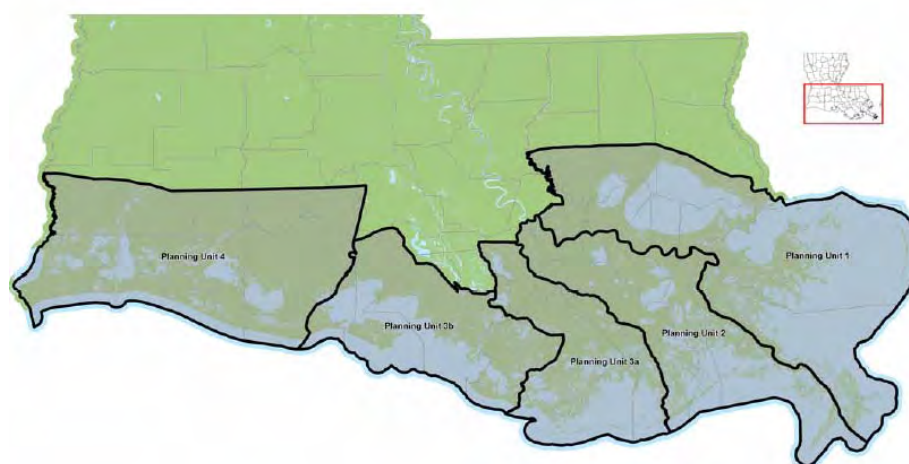


Figure 4.2 The Five Planning Units

4.2 Block the openings of hurricane protection in New Orleans

“Holes” in the South shore of the Lake Pontchartrain

The comprehensive coastal protection and restoration is a long-term plan, which will take several even dozens of years into effect. Before next hurricane comes, it is better to consider how to protect most important urbanized area --New Orleans from storm surge. The effective measure is to cut the accessible passage of the storm from the gulf. The protection levee along the South shore of the Lake Pontchartrain, our city's North side has four big holes in it, not counting Bayou St. John. Three holes are at the mouths of the outfall drainage canals: 17th Street, Orleans and London Avenue. The fourth opening is the north end of the Industrial Canal. (Fig.4.3)

Using jetties, specialized barge/thruster pumps, a dam, and in few years, new pumping stations, we can close the weak points in our defenses against storm surge from the Lake.



Figure 4.3 The openings to storm surge near New Orleans

MRGO Closure

Mississippi River Gulf Outlet (MRGO) is generally thought to contribute greatly to the storm surge effect by channeling water into both Orleans and St. Bernard. It is also

maligned by environmentalist for destroying marshland, nature's barrier to storm surge. It also provides a navigable waterway for boats of all types, including oceangoing ships that need access to various docks on the Industrial Canal. (Fig.4.4).

The closure structure or other flood control structure should be built on this canal. The channel will no longer be used for deep draft navigation. In addition, an important alternate route for the Gulf Intracoastal Waterway would be lost if the channel is closed with an earthen plug. The public is concerned that navigation considerations may slow closure of the channel.

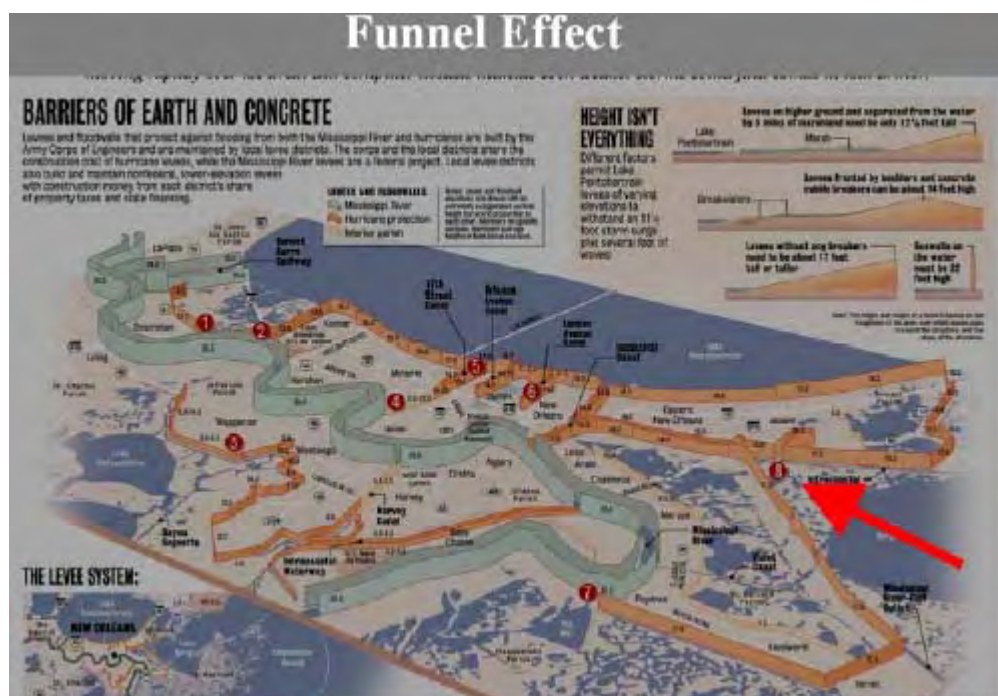


Figure 4.4 The Funnel effect in MRGO

Lake Pontchartrain Barrier Plan

Right now, the area's hurricane protection projects do not provide enough protection to New Orleans, and they cannot be retrofitted to substantially increase protection beyond the 100 year level. In addition, the North Shore of Lake Pontchartrain and other areas surrounding the lakes have no protection from storm surges entering from the Gulf. To address these deficiencies, an outer barrier must be built to supplement projects already on the ground or in the planning stage.

In the 1970s, a plan, called the Lake Pontchartrain Barrier Plan, was proposed to put flood control structures in the Chef and Rigolets allowing normal water flow at normal

times and closure at threatening times. The proposed control structure also functioned as an automobile bridge. When closed, the flood gates would keep storm tides out of the Lake. (Fig.4.5)

A levee connecting the high ground in St. Tammany Parish to the Rigolets and then following the highway right-of-way to the Chef, was to connect to a levee system continuing on, with a lock on the Intracoastal Waterway, to St. Bernard Parish.

The project will affect hydrology in and around the lake as well as the habitat of important species. The cost of the project is a big amount. So the plan has been held for dozens of years. Additionally, from cost-benefit analysis view, the further analysis needs to judge the contribution of swollen saltwater from Gulf or wind force to storm surge in Lake Pontchartrain.

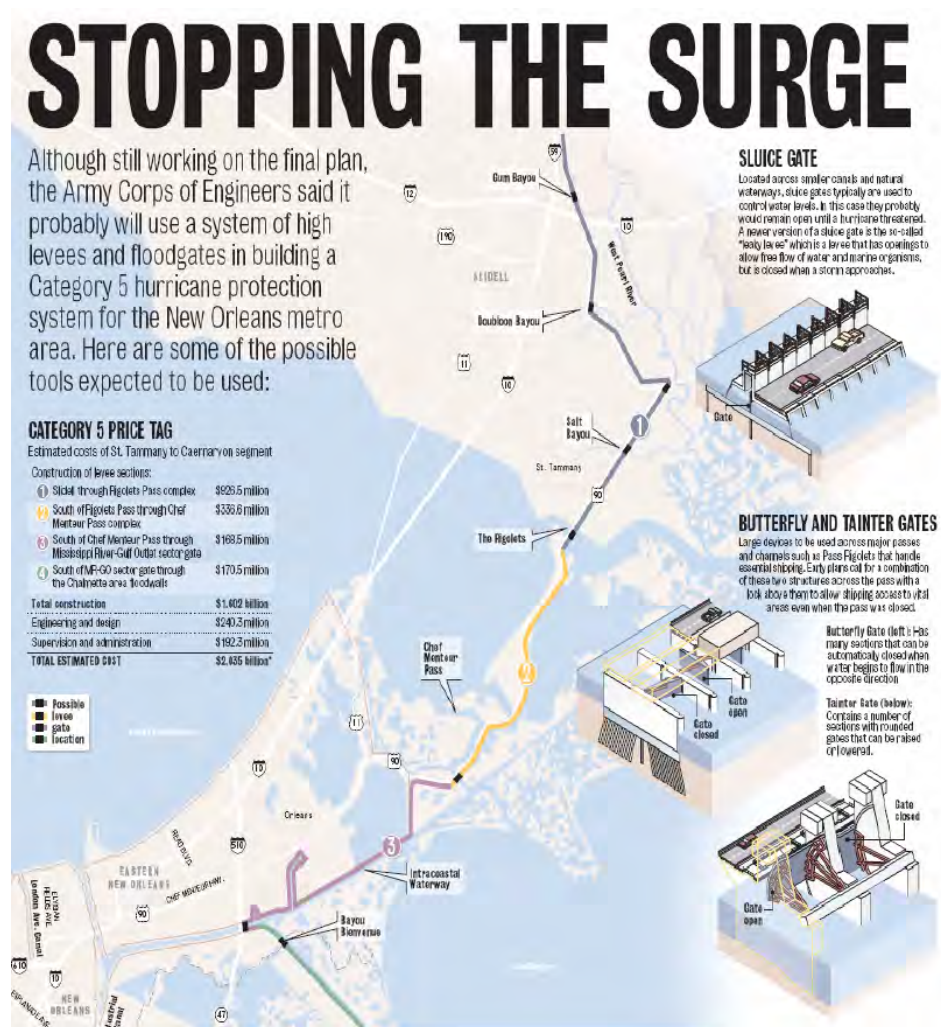


Figure 4-5 Lake Pontchartrain Barrier Plan

4.3 A New Approach to Levee Building

As hurricane protection options are considered for the coast, a balance must be struck between two urgent needs. On one hand, residents need storm protection. These communities could not exist without levees. In recognition of the need for structural protection, levees are recommended in high risk areas that must be protected if we are to avoid severe consequences for the state and nation.

On the other hand, there is legitimate concern that building levees across wetlands can stop the natural flow of water, creating impoundments that flood communities and lead to further land loss. Finding the right mix of options requires that innovative technologies to build modern flood protection systems. It bears little similarity to the traditional earthen levee embankments that have historically dominated Louisiana's flood protection plans. Levees must be built with innovative designs, since we now recognize the importance of tidal exchange and natural hydrology in sustaining wetland ecosystems. If a levee is deemed appropriate for an estuarine basin, we must do the following things:

- Use innovative levee designs and reduced levee footprints to minimize disruptions to the basin's tidal regime and hydrology;
- Keep the entire basin system functional and sustainable by using the levee in tandem with other measures, such as landward diversions and drainage structures. These areas must be managed to ensure that protection and restoration actions do not induce flooding in low-lying communities that are landward of levees. For example, once a levee is built, water flow through wetlands that are landward of the levees must be maintained, and even enhanced where necessary, to maintain natural cycles of water and sediment exchange. Levees built landward of wetlands are more resilient than stand alone structures because the adjacent marsh helps buffer storm surge and wave energy.
- Ensure that strict land use controls are enforced. Wet areas must stay wet, and community growth must be managed to minimize impacts on wetlands as well as risks to life and property.

4.4 Land use management for smart development and minimizing risk

Levees and restored wetlands cannot eliminate all flooding risks, whether from storm surges, rivers, or rainfall. Nor do levees protect against wind damage. In many areas,

non-structural solutions will provide more protection more quickly than will massive building projects that take years to be constructed. For these reasons, storm related risks will remain facts of life in south Louisiana, regardless of how many levees are built and wetlands are restored. The measures described below are thus urgent aspects of making south Louisiana a viable place to live and work. In addition, these measures can be implemented now, while larger flood protection structures are being planned and built in the coming years.

Land use planning and zoning

Wetland areas inside the hurricane protection system need to remain intact and undeveloped. The most state of the art hurricane protection system can actually increase the assets at risk if it encourages development in wetlands or areas near the levee footprint. Such action would not only be risky from a safety and economic standpoint, but it would also degrade wetlands and eliminate interior flood storage capacity. Once a national and state commitment to building a levee is made, local governments must enforce appropriate land use planning and zoning regulations to ensure that the system, once built, contributes to the long-term sustainability of the region. For example, the Louisiana Coastal Resources Program and the Louisiana Coastal Zone Management Plan should be strengthened. Zoning actions by local governments, though not popular in Louisiana, are another means of protecting coastal wetlands. State legislation as well as departmental policies should provide incentives to local governing bodies to enact region-wide land use zoning, following the lead of some Louisiana communities which have already done so.

After hurricane Katrina, there is approximate 65% population displaced to other place. Many houses are abandoned and many communities still are empty. Maybe it is good time for government to consider the redevelopment of the city, which can concentrate the people within the hurricane protection and make the city smaller in order to reduce the flood risk and effectively implement hurricane protection projects.

Address processes to acquire land rights

Approximately 80% of coastal Louisiana is privately owned, and the rights of these landowners, including mineral rights, must be honored as components of the project planning are constructed and operated. Through many years of working on projects in coastal Louisiana, the Department of Nature Resource (DNR) and the Department of Transportation and Development (DOTD) have built strong working relationships with

most of the coast's major landowners. In order to complete the protection and restoration measures in a timely fashion, these relationships must be fostered and strengthened.

Land ownership has many faces in coastal Louisiana. Often, large tracts of land are owned by a single entity. In other cases, single parcels of property may be owned by hundreds of individuals that are either difficult to contact or, in some cases, unknown. This is particularly true when land has been passed down through generations. Situations will also arise in which multiple parcels of land will be needed to implement very large projects. In any of these cases, a single landowner's desire not to participate can cause a project to be delayed indefinitely or even terminated.

Multiple options must be available to reach fair and equitable solutions for building projects on private lands. The first course of action would be to acquire the necessary easements to construct the project. Another option would be to allow for separation of surface rights from mineral rights. The state could then purchase the surface rights to the land, while the original landowner would retain all subsurface (including mineral) rights.

In cases where such an agreement cannot be reached, expropriation is an option. Both DNR and DOTD have the capability to expropriate under Title 19 of the Revised Statutes. However, expropriating involves filing a lawsuit, which must be resolved prior to initiating project activities. This is a long and contentious process, and is clearly not a desirable outcome. Another choice for acquiring the necessary land rights to construct projects that are in the best interest of the public is an authority known as "quick take." When a negotiated settlement cannot be reached between the implementing agency and the landowner, quick take authority allows the agency to place the offered compensation in the court registry and file a lawsuit against the landowner. Progress toward project construction is not hindered by that action or the suit, and whatever compensation the landowner will ultimately receive, is settled at a later date. DOTD has this authority for roadway construction, and levee districts have this authority for levee projects. DNR only has quick-take authority to acquire lands for coastal restoration projects on barrier islands if a settlement cannot be reached. No further quick-take authority legislation has been passed for coastal restoration projects because of legislator and landowner opposition and because of technical complications caused by land reclamation issues.

To date, DNR has never entertained the idea of using either form of condemnation and considers both to be options of last resort. However, in order to ensure that large-scale projects are built on time, these options must be available, particularly in cases where property would be damaged or destroyed in order to build project features. Thus,

although it is the state's clear preference to work in partnership with landowners, passage of legislation to provide DNR and DOTD with "quick-take" authority for the implementation of coastal protection and restoration, similar to that already provided to DOTD for highways, is necessary at this juncture.

Relocation of the communities in low-lying areas

Not every south Louisiana community that wants levee protection from the largest of storms will get it. In some areas of the coast it would be difficult if not impossible to build and maintain these types of structural protection systems. In addition, there are simply not enough federal or state dollars available to make this solution feasible. As a result, communities where there is a dense concentration of assets at risk, such as New Orleans, Houma, Lafayette, and Lake Charles, will receive a greater level of structural protection than will other communities.

The centuries old tradition in south Louisiana was to build and live on high ground and leave wet areas wet. In recent decades, this tradition held less sway, as people began filling in and developing low-lying areas, sometimes all the way to the base of levees. Allowing development of low-lying areas within protection systems not only increases exposure to damages in the event of a system failure, but also diminishes effectiveness of the protection works themselves by removing water storage areas from the system.

The government should support and promote close coordination among all jurisdictional authorities to encourage strict enforcement of laws and regulations. Appropriate easements will be obtained in wetlands landward of hurricane protection systems to maintain these important natural buffer zones. For example, the National Flood Insurance Program's Community Rating System can lower flood insurance premiums up to 45% for residents of communities that adopt flood preparedness measures, from floodplain management and buy-out programs to drainage system maintenance. The Community Rating System gives a substantial incentive to communities that zone floodplains with low density uses (Activity 430LZ Low Density Zoning, CRS Coordinator's Manual).

Elevating and retrofitting structures

In coastal Louisiana, most of the people's houses are made of woods, even no any protection for the roof. Maybe it is local material and more economic, or it is tradition. But they are much weaker than brick and concrete to against the flooding and wind strength.

Residents of south Louisiana must now meet improved building standards, including raising their homes to avoid damage from storm surge. Hazard mitigation funds are available to citizens through their local parish Emergency Preparedness Offices. These funds can be used to elevate, retrofit, or buy-out homes that have suffered damage from flooding (see www.FEMA.gov). State-wide mandated freeboard standards (meaning standards that require homes to be built one to two feet above FEMA base flood elevation) could be another tool that helps residents adapt to flood risks. Adoption of these kinds of measures would have the added benefit of lowering flood insurance premiums for homeowners (FEMA Louisiana Floodplain Management Desk Reference, p. 17-2) as well as reducing storm damages.

Backfill and/or Plug Non-Essential Oil and Gas Canals

This measure will close non-essential oil and gas canals coast wide to restore natural hydrology to wetland areas that have been adversely impacted by canal construction. Abandoned location canals, and other canals that can be eliminated without adversely impacting ongoing production operations, will be identified for restoration to mitigate the adverse effects of unchecked tidal exchanges. Restoration operations could include permanent plugs, spoil bank degradation and marsh creation by backfilling through dedicated dredging projects.

4.5 Relocation of freshwater and sediment for wetland restoration

This measure will identify and evaluate features that would greatly increase the deposition of Mississippi River sediment in shallow coastal areas and restore deltaic growth in the Mississippi River Delta Plain. Creating a sustainable deltaic system requires to reestablish the processes that originally created the landscape. Two types of projects, large diversions (greater than 50,000 cfs) from the Mississippi River and alternative navigation channel alignments will be investigated. The large-scale river diversions could potentially maximize the river's sediment and freshwater resources available for ecosystem maintenance. Diversion sites, capacities, and outfall management measures would also be assessed to help optimize diversion plans while accommodating navigation needs. (Fig. 4.6).

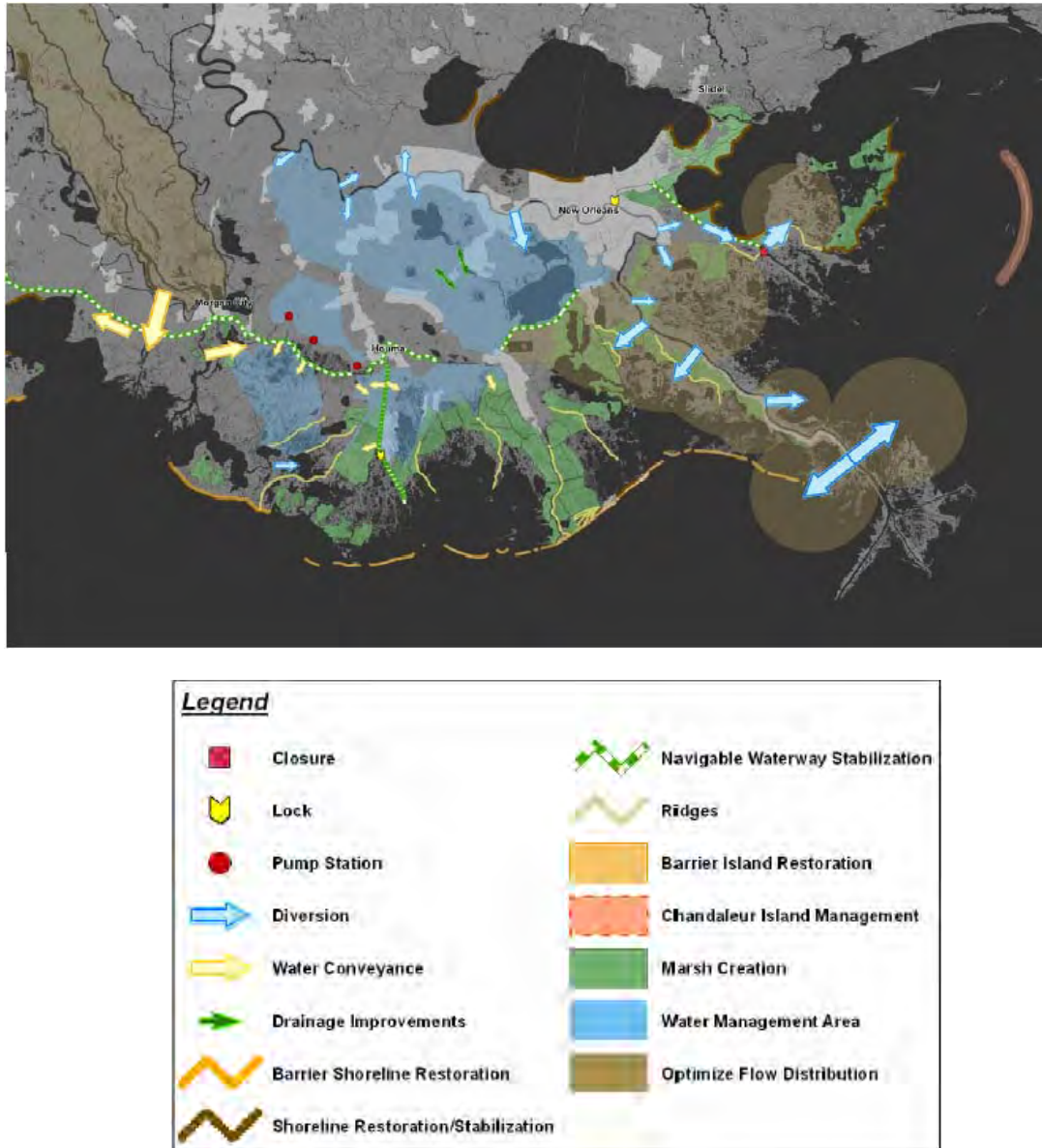


Figure 4.6 Restoring and Maintaining Critical Landscape Feature

Freshwater and sediment diversion

The most practical large-scale solution to coastal erosion and wetland loss is the diversion of Mississippi river waters into the wetlands through control structure or crevasses in the levee. The freshwater pushes back the encroaching saltwater wedge and coat the subsiding wetlands with new sediments. The impact areas of the first two major river diversions, Caernarvon and Davis Pond, have been operated.(Fig.4.7). Others diversions, crevasses, and siphons are planned for the near future.



Figure 4.7 The impact area of two major river diversions of Caernarvon and Davis Pond

The Caernarvon freshwater diversion structure diverts up to 8,000 CFS from the Mississippi into the marshes of Plaquemines and St. Bernard parishes. In its first dozen years of operation since opened in 1991, “Caernarvon has increased over seven-fold the size of freshwater plant communities, reduced the area of saltwater vegetation by over 50%, rejuvenated fish and wildlife population, and created some new land.”

In 2002, the Davis Pond Freshwater Diversion Structure opened near Luling, 22 miles above New Orleans, designed to release a maximum capacity of 10,650 CFS into 777,000 acres of Barataria Basin marshland. It is the largest coastal restoration project of its type in the world, and together with Caernarvon and other currently on-line structures, can divert up to 6% of Mississippi river flow when operating at full capacity.

Where gated diversions are not practical, pipelines are used to siphon high river water over the levee to specific locations in the low-lying backswamp. Less costly to install but difficult to maintain suction, siphons are proposed to rebuild wetlands in eastern Orleans Parish, the only planned marsh creation that falls within New Orleans’ limits. Where circumstances allow for a more natural approach, an old-fashioned crevasse is opened in the levee, sans gates or pipelines, allowing the water to spill through

unimpeded. One such manmade crevasse is the West Bay Project, a 25-foot deep cut in the levee about 5 miles downriver from Venice, through which up to 20,000-50,000 CFS of river water will pass. Currently under construction, West Bay promises significant land-building because of its large and unimpeded flow, and because it taps into a large quantity of high-quality suspended sediments, not just the surface-level particles that controlled diversion use. Many more openings, part of the Delta-Wide Crevasses Project, are planned for lower Plaquemines Parish, near the mouth of the Mississippi. In all, as of August 2003, the Army Corps of Engineers, the state of Louisiana, and other federal agencies oversee 25 gated diversions, siphons, crevasses, and auxiliary projects in planning, construction, or operational phases throughout southeast Louisiana.

Beneficial Use of Dredged Materials

The beneficial use refer to the physical act of building wetlands with dredged material rather than the programmatic aspects which would result in project development and construction. It is a very promising option for restoring coastal wetlands and reducing land loss. The U.S. Army Corps of Engineers, New Orleans District (USACE-MVN) has the largest annual channel Operations and Maintenance (O&M) program and dredges an average of 60 million m³ of material annually during maintenance dredging of navigation channels. Not all of this material is available for beneficial placement in the coastal ecosystem; however, there is the potential to use up to 25 million m³ annually to enhance coastal wetlands through marsh creation, wetland nourishment, barrier island restoration, ridge restoration, and other techniques.

Additionally, Dedicated Dredging is a viable strategy across the coastal zone to build land where traditional marsh building processes do not occur or are infeasible. Its purpose is the utilization of dredged material to restore, create, or enhance coastal wetlands.

Availability of Mississippi River resources

The annual quantities of sediments available from the Mississippi River are significantly reduced from the quantities delivered by the river 50 to 60 years ago. Future rebounding in magnitude of annual supply of sediments is not a reasonable expectation. It is further noted that the majority of the sediment delivered is currently being carried out to the deep waters of the gulf and is unavailable for use. Plans to better utilize available Mississippi River resources should recognize:

- The maximum water available for simultaneous diversions is generally limited to 500,000 cfs in the winter, spring and early summer. Late summer and early fall will

generally offer limited to no availability.

- The magnitude of water available for diversions along the river must consider that the total flow of the river at Head of Passes must be maintained at or above 250,000 cfs to control the salt-water wedge at Head-of-Passes.
- Multiple diversions from the river must be coordinated so that maximum benefit from the available sediment and fresh water is obtained.
- There should be much more diversion capacity built than can be diverted at any given time to allow pulsing and timing of the diversions for land building and habitat benefits.
- On average, there are about 94.3 million cubic yards of measured suspended sediments and an estimated 18 million cubic yards of unmeasured sediment load available for wetland restoration purposes. Suspended sediment can be captured and used by diversions. However, diversions must have deep intakes and be located in sediment rich areas of the river to divert the unmeasured bedload.
- The most effective way to utilize the bedload is by direct delivery/dredging or very large diversions near the mouth of the river.

Plans that fail to utilize the resources of the Mississippi River will not accomplish a sustainable Louisiana coast.

4.6 Improvement of cooperation of different organizations

The nature of the US federal organizations (sector stovepipes) creates the potential for lack of coordination. Comprehensive and project planning activities of the agencies is less well coordinated than activities that take place during or immediately following a major flood. On the occasion of a major flood, the President will typically name a senior member of his cabinet to ensure coordination of the federal agencies. For smaller floods, the Director of FEMA assumes this role.

Since 1990s, several organizations at the local, state and federal level started to study and plan the projects and programmes for coastal protection and restoration from comprehensive vision, including the Coastal Wetlands, Planning, Protection, and Restoration Act (CWPPRA); the Louisiana Coastal Area (LCA) Ecosystem Restoration plan; the Coastal Impact Assistance Program (CIAP); hurricane protection proposals; and the US Army Corps of Engineers (USACE) Louisiana Coastal Protection and Restoration (LACPR) Study. They made

dozens of proposals and reports like Coast 2050, and some projects are on-going. Most of projects still stay on the paper. These projects and programs should be unified to integrated project in order to effectively utilize the funds and keep the uniform standard. It needs the cooperation of different organizations and participation of the public.

Implementing comprehensive solution will require one of the largest public works programs the nation has ever attempted. And while Louisiana is willing to pay its fair share of the cost, federal funds will also be needed. Such assistance is not a handout, but rather an acknowledgement that south Louisiana's coast was altered so that it could better serve national energy and navigation interests. It only makes sense, therefore, that having benefited from Louisiana's geography and resources for over 100 years, the nation will invest in restoring the ecosystem and protecting the coast's defenses.

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Comparison and Recommendations





Comparison

1. Physical condition

Yellow River Delta	<ul style="list-style-type: none"> Alluvial plain, in Northeast of Shandong Province in China; new land forming since 1858. Annual average precipitation: 560 mm; evapotranspiration: 1167 mm; Land use types: wetland, nature reserves, farmland, meadow, town Topography: several meter above mean sea level in the whole region Annual average discharge of the river is 1015 m³/s, the maximum is 22,300 m³/s; the maximum discharge at the delta is 10,400 m³/s; Discharge deviation: minimum in winter is 0; maximum in summer is 10,400 m³/s; High sediment content: average 25 kg/m³. Storm surge and typhoon occur in Jul.-Sep. of the summer time.
Rhine River Delta	<ul style="list-style-type: none"> Alluvial plain, in western Netherlands. Land use type: harbor, grassland, big city and many small towns Annual average precipitation: 750 mm; evapotranspiration: 475 mm; Annual average discharge of the river is 2300 m³/s, the maximum is 12,600 m³/s; Discharge deviation: minimum in summer 623 m³/s (1947); maximum in winter 12,600 m³/s (1926); Silt content: average 0.04 kg/m³ Water distribution: water distribution 6:2:1 among Rhine branches of Waal, Nederrijn-Lek and IJssel. Storm surge usually occurs in Dec.-Feb. of the winter time.
Mississippi River Delta	<ul style="list-style-type: none"> Alluvial Plain, in southeast of Louisiana, USA; modern delta forming started 750 years ago. Land use type: wetlands, marsh, lakes, cities Annual average precipitation: 1500 mm; Annual average discharge of the river is 13,800 m³/s, the maximum is 30,600 m³/s (1926); Design discharge: 35,400 m³/s; Silt content: average 0.6 kg/m³; Hurricane usually occurs in Aug.-Sep. of summer time.

Conclusion

- From the view of basin area and the length, Yellow River and Mississippi River are one of the greatest rivers in the world. Rhine River is much smaller than other two rivers, but it is an international river, which increase the difficulties in river basin management.
- Sediment content in Yellow River is much higher than others although it has decreased in recent years. High sedimentation is the vital problem in Yellow River Delta, it is the main source of water level (river bed) rising and course changing, namely flood risk.

Sediment in Mississippi River used to be substantial, but now it is greatly decreased because of human intervention. There is very little sediment in Rhine River, which cause low flow channel erosion. The decrease of sediment flow to the three Deltas has become one of the main factors of coastal erosion or land loss.

- Three rivers have different flood season. High water is in summer in YRD, and in winter in RRD and in spring in MRD as well. Flood fighting in winter in RRD is more difficult than that in spring or summer in YRD and MRD.
- The difference between the maximum and the minimum discharge in YRD is very big. Sometimes, the drought and flood problem exist in the same year. The discharge in MRD changes in different seasons not as much as that in YRD. RRD has a relative small change in summer, but normally the deviation is not very big.
- There are wetlands or marsh area along the shoreline in YRD and MRD. It is the natural storm surge defense. The population is very thin and the main industry is agriculture and fishery in the coastal zone of these two deltas, while the RRD is a very populated and industrialized region, and all distributed along the coastline, no transition or buffer space against storm surges.

2. Social- economic aspects

Population	
Yellow River Delta	<ul style="list-style-type: none"> • 240,000 residents; • Low density compared with the whole country. • Increasing population.
Rhine River Delta	<ul style="list-style-type: none"> • Above 1/3 population of the Netherlands; • The highest density in the country. • Increasing population.
Mississippi River Delta	<ul style="list-style-type: none"> • 2,000,000 residents; • Concentrated in several cities like New Orleans.
Development level	
Yellow River Delta	<ul style="list-style-type: none"> • Economy is developing rapidly since 1980s; • Annual growth rate of GDP is about 8%, average level in the nation; • Expected development is more urbanized and industrialized.
Rhine River Delta	<ul style="list-style-type: none"> • Developed, urbanized, industrialized area; • Total gross production accounts for 80% of the Netherlands; • Steady growth
Mississippi River Delta	<ul style="list-style-type: none"> • Sufficient national resources; • Regional development is relatively slow, even declining; • Many social problems like high unemployment and crime rate; • The future development is uncertain, especially after hurricane Katrina.
Economic types	
Yellow River Delta	<ul style="list-style-type: none"> • Oil and gas exploitation, accounting for more than 50% of economy development; • Fishery; • Farming and pasture; • Harbor.
Rhine River Delta	<ul style="list-style-type: none"> • Harbour and navigation; • Chemical industry; • Greenhouse industry; • Pasture and dairy industry; • Tourism.
Mississippi River Delta	<ul style="list-style-type: none"> • Oil and gas exploitation; • Chemical refinery; • Harbor and navigation;

	• Fishery; Tourism.
Conclusion	
<ul style="list-style-type: none"> • All of three river deltas are important economy and national resource bases. • Three river deltas are in the different developing levels and stages. Rhine River Delta is developed area with steady growth, which has a relatively small space for future development. Yellow River Delta is developing very fast and the potential development is expected. Mississippi River Delta is developing slowly and has uncertain future. • Oil and gas exploitation and refinery are the important industry in Yellow River Delta and Mississippi River Delta, while Harbour and Navigation is the important industry in Rhine River and Mississippi River. Yellow River Delta has a small navigation activity in the sea and no navigation in the river. Rhine River Delta has no oil and gas extraction activity but it is the main chemical industry base in EU. • Mississippi River Delta has sufficient national resources and great contributions to the nation, but the regional development does not match this importance. 	

3. Main problems

Flood risk from the river	
Yellow River Delta	<ul style="list-style-type: none"> • Mainly caused by river course changing; • Summer flood, caused by the rainstorm in the middle reaches of the river; • Ice flood, caused by ice jam because of different latitudes in upper and lower reaches; • River channel is higher than ground surface because of severe sedimentation. • The sedimentation in the channel of Delta leads to backward sedimentation in the upper stream channel.
Rhine River Delta	<ul style="list-style-type: none"> • Increasing discharge due to climate change; • Increasing difference between ground level of inner bank and flood plain of outer bank due to land subsidence and floodplain sedimentation; • River and sea transitional area much be affected by tidal level; • 1993 and 1995 high flood occurred.
Mississippi River Delta	<ul style="list-style-type: none"> • Spring flood, caused by regional rainfall and snowmelt; the largest flood flow recorded was 64,500 m³/s; • Frequent floods in the history; the most disastrous flood occurred in 1927; • The biggest city New Orleans in Louisiana is under the water

	level of the river.
Sea storm	
Yellow River Delta	<ul style="list-style-type: none"> • Frequent storm surges caused great damage in the past; • All the land is above sea level; the recovery after flooding is relatively fast; • The highest tidal level is 3.75 m occurred in 1969; • The main losses are oil facilities, fishery, agriculture and public infrastructures; • Each storm surge could cause victims or damages.
Rhine River Delta	<ul style="list-style-type: none"> • Storm surge is the main threat; • All the delta area are below sea level; • The highest tidal level is 3.85 m occurred in 1953; • The potential losses due to extremely small probability storm flooding are still astonishing big; • The recovery after flooding is very difficult; • Intensive storm surge could cause damages and losses but nearly no victims at present.
Mississippi River Delta	<ul style="list-style-type: none"> • Frequent hurricane and tropical storm and increasing category due to climate change; • Most part of the ground level of the biggest city New Orleans in Louisiana is below sea level, vulnerable to the storm surge; • Inadequate hurricane protection system;
Coastal erosion	
Yellow River Delta	<ul style="list-style-type: none"> • Coastal erosion emerged in recent years due to the changes of river regime; • Land creation slow-down due to decreasing sediment inflow; • land creation transfers to land loss since 1990s; Average net land loss is 7.6 km² per year from 1996; • Land salinization caused by intrusion of saltwater;
Rhine River Delta	<ul style="list-style-type: none"> • Coast erosion is caused by frequent storm surges; • Coast erosion cause sea dike damage and increasing cost for dike maintenance;
Mississippi River Delta	<ul style="list-style-type: none"> • Wetland loss (lost 4,800 km² during 20th century, at the rate of 40-56 km² each year now); • Wetland loss reduces the natural defense to storm surge and increase the risk of hurricane hits; • Saltwater intrusion • Marsh salinization

Land subsidence	
Yellow River Delta	<ul style="list-style-type: none"> • No significant land subsidence and very little impacts for flood management.
Rhine River Delta	<ul style="list-style-type: none"> • As much as 2-3m of land subsidence in some peat areas since the Middle Ages; • Increasing land subsidence due to continuous drainage and soil compression and consolidation; • An expected subsidence of 20-60 cm by 2050.
Mississippi River Delta	<ul style="list-style-type: none"> • 3-9 mm/year; • Land subsidence tends to increase due to sea level rise and oil and gas extraction; • The elevation of land surface in New Orleans will drop from present 1.5-3m to 2.5-4.0m by 2100 below mean sea level.
Conclusion	
<ul style="list-style-type: none"> • The common problems in three Deltas are high floods from the river, storm surges from the sea and coastal erosion. Along with the regional development and climate change, the problems tend to be more serious; • Increasing land subsidence in Rhine River Delta and Mississippi River Delta causes flood risk increase. No significant subsidence happens in Yellow River Delta; • Because of relatively perfect flood protection system of the riverine, the main flood defense in Rhine River Delta and Mississippi River Delta is focusing on the storm from the sea. For example, hurricane Katrina exposed obvious inadequacy of hurricane protection; • In Yellow River Delta, the affected area and the losses from storm surge is smaller than the other two Deltas, and the flood problem from the river is mainly caused by riverbed rising and river channel silting. In the process of river course change, sedimentation plays an important role because of high sediment content in the river; • The elevation of the land is below mean sea level both in Rhine River Delta and Mississippi River Delta, so the people have to rely on the levees or dikes along the whole areas to protect storm surge. Their flood protection systems include drainage system to get water out of the low-lying areas. The land surface in Yellow River Delta keeps above mean sea level. The situation is much better than other two Deltas when flooding; 	

4. Human intervention on the river system and impacts

Human intervention	
Yellow River Delta	<ul style="list-style-type: none"> • The construction of flood protection works: reservoirs in the upstream, dikes along the river in the lower reaches, river training works. • Water and soil conservation in the middle reaches. • Rapid increase of water diversion, accounting for nearly 50% of annual runoff and cause water shortage in downstream.
Rhine River Delta	<ul style="list-style-type: none"> • Dike construction, damming, canalization and cut-off; • Urbanization and land reclamation occupied much space which used to be water retention area. • Dredging for shipping and navigation.
Mississippi River Delta	<ul style="list-style-type: none"> • The construction of flood protection works: levees, floodway, cutoffs, river training works, and reservoirs in the tributaries. • River canalization and dredging for navigation. • Old River Control, avoiding the Achafalaya river capture the main flow from Mississippi River and keeping river discharge flow to Achafalaya river and Mississippi River as 30/70 percentage.
Impacts	
Yellow River Delta	<ul style="list-style-type: none"> • Decrease of water and sediment inflow; even zero-flow in dry season of dry years. • Severe sedimentation in the lower reaches and formation of “hanging river”. • Slow down land building and cause net land loss. • Wetland shrink and degradation of ecosystem. • land salinization due to sea water intrusion.
Rhine River Delta	<ul style="list-style-type: none"> • Dike construction, damming, canalization and cut-off change the morphological process of the river. • Human intervention cause increase of flow velocity and channel gradient, then cause more erosion for riverbed; • Urbanization and land reclamation cause decrease of discharging capacity; • Dredging for shipping and navigation increase damage risk for the dike and hydraulic structures. • Construction of storm surge barriers change the eco-environment and cause decrease of biodiversity.

Mississippi River Delta	<ul style="list-style-type: none"> • Decrease of sediment inflow. • Reduced the flow of water and sediment into deltaic wetlands. • Destabilized coastal landscapes and increase saltwater intrusion. • Reduced retention and prevention of storm surge in the wetland, increase vulnerability of coastal communities. • construction of drainage canal in marsh area and oil extraction cause degradation of ecologic environment and biodiversity.
Conclusion	
<ul style="list-style-type: none"> • The river systems and landscapes in three river deltas are significantly changed by human activities because of the needs of flood safety and economic development. • These changes lead to the destruction of natural processing and deterioration of ecosystem; at certain extent, they do not reduce but increase flood risk in the coastal area. • High sediment content in Yellow River is a problem. Many measures are used to control sediment and reduce sedimentation in the river channel; On the contrary, in Mississippi River Delta people are worrying about the decrease of sediment, which is the main resource for wetland restoration. 	

5. The roles of the institutions in flood management

National level (Central Government, Federal Government)	
Yellow River Delta	<ul style="list-style-type: none"> • Ministry is responsible for finance, supervision, and investigation and approval for big projects. • Yellow River Conservancy Commission (YRCC) is authorized to implement flood management in the Yellow River Basin including the Delta. • YRCC is responsible for short-term and long-term flood protection plan for the river. • Finance (100%), build, manage and maintain flood protection works of the river, like reservoirs, dikes. • Coordinating flood protection in extreme events. • Defences recovery and rebuilding after flooding. • Formulate Master Plan of flood management for the Delta

Rhine River Delta	<ul style="list-style-type: none"> • The national government (Minister of the interior) has a supervisory and coordinating role and is responsible for multi-province emergencies; • Partially financing, building and improving of the main flood defence. • Recovery and rebuilding of the main defence after flooding. • National Government implements 5-yearly testing of the dikes, which is the basis for future construction and repairing.
Mississippi River Delta	<ul style="list-style-type: none"> • Mississippi River Commission is authorized to implement flood management in the Mississippi River Basin; the Army Corps of Engineers is authorized to build and management flood protection works. • Formulate flood protection plan for the river. • Financing, building and improving of flood protection works of the river, like reservoirs, structures and levees. • Manage and maintain the flood protection structures on the river. • Build main hurricane protection works and share the costs with the state and local (70%/30%). • Emergency relief (Federal Emergency Management Agency).
Province (state) level	
Yellow River Delta	<ul style="list-style-type: none"> • Directive for local development plan. • Finance, build some important sea defense projects. • Coordinate flood defense in extreme events. • Recovery and rebuilding after flooding.
Rhine River Delta	<ul style="list-style-type: none"> • The provinces have a supervisory and coordinating role and they are responsible for spatial planning in provincial level.
Mississippi River Delta	<ul style="list-style-type: none"> • Formulate hurricane protection plan. • Build and manage hurricane protection and wetland restoration projects. • Share the cost of hurricane protection projects.
Local Level (Municipality or local authority)	
Yellow River Delta	<ul style="list-style-type: none"> • Regional land use and development plan. • Building and maintenance of sea defense projects (local gov.). • Share the cost of sea defense works. • YRCC in this level is directly responsible for river defence construction, maintenance, operation, and recovery and rebuilding after flooding.

Rhine River Delta	<ul style="list-style-type: none"> • Municipalities are responsible for supervising and coordinating among water boards. • The water board is the main organization responsible for defences finance, construction, maintenance and operation; • Water board is responsible for recovery and rebuilding after flooding.
Mississippi River Delta	<ul style="list-style-type: none"> • Manage and maintain the levees along the river and hurricane protection structures.(levee boards) • Share the cost of main hurricane protection projects. • The first responder to flood events. • Recovery and rebuilding after flooding.
Local interests, The public (sector institutions, enterprises, companies, individuals)	
Yellow River Delta	<ul style="list-style-type: none"> • The main industry (oil and gas company) shared the river harnessing projects and built some sea defense projects. • The public neither be involved in the flood protection projects planning, nor pay for flood protection. • The enterprises, company and individuals provide materials or other resources contributing to flood defense during extreme events.
Rhine River Delta	<ul style="list-style-type: none"> • Take part in flood protection projects planning (comments or complains). • Pay the bills for construction and maintenance of the defences. • Take part in the flood defense in extreme events.
Mississippi River Delta	<ul style="list-style-type: none"> • Extensive participation for flood protection projects planning (public meeting, comments). • The residents share the costs of hurricane protection.
Conclusion	
<ul style="list-style-type: none"> • In YRD, the Central Government overwhelmingly dominates flood protection and management from projects planning, finance, build to maintenance; In RRD, the national government plays a very important roles on flood management, who funds and builds important and large flood defense projects; Compared to YRD and RRD, the Federal Government has less contribution to flood management in MRD, especially to hurricane protection, which is considered as “local problem”. • In MRD, the state government dominates hurricane protection and coastal restoration; The provincial governments in YRD and RRD are relatively less 	

involved, but the province government in YRD is much more powerful than that in RRD.

- In flood protection planning, the projects generally follow the cost-benefit analysis in MRD and RRD. There is not strict cost-benefit analysis during flood protection projects planning in YRD. Social effectiveness and welfare are more emphasized.
- In YRD, all levels of the governments do more things in recovery and rebuilding, such as providing special compensation, allocating the resources between provinces or regions to help enterprises and individuals. On the contrary, in MRD the governments only provide emergency relief; there is no large fund for individuals except flood insurance. That's why New Orleans is still in a massy and terrible situation until now when hurricane Katrina has passed for one and half years. In RRD, the governments do some things for communities' recovery and rebuilding, neither as much as that in YRD nor as less as that in MRD.
- In coordination and cooperation of institutions, there is better performance in YRD than other two Deltas. In YRD, different levels of the government easily reach the agreement because sufficient communication and significant orders of the leaderships among the levels of government. In MRD, the lack of coordination and cooperation often delays the implementation of the flood defense projects and prolongs the process of the construction, makes the situation complicated.
- In RRD and MRD, the public has opportunities to involve the flood protection projects planning and solutions, and give their opinions or comments. The people seem to be more involved in the planning in MRD. This is the process of decision-making and some kind of democracy. In YRD, the flood protection planning and building are implemented by the professional institutes. Local people are very less involved and have few channels to give comments, because the governments are completely responsible for flood security. This is some kind of centralization in China.
- In YRD, the Central Government is changing the overall funding for flood protection projects to cost-share policy and gradually releasing the responsibility of the building of the small-scale projects and maintenance of dikes to the local.

6. Flood defense system and flood risk management

Yellow River Delta	<ul style="list-style-type: none"> • Safety standard (river): 1/1000. • Storage of the flood in the Reservoirs upstream. • Discharge the flood relying on dikes along the lower reaches to the sea. • Retention and detention area for flood storage and peak discharge reduction. • Water and soil conservation in upper and middle reaches(Loess Plateau) to decrease sedimentation and river bed rising in lower reaches; • Sedimentation reduction measures, like sediment storage in the reservoir, flushing sediment through operation of the reservoirs, dredging. • Sea defence standard: 1/50 and part 1/100(oil field); • Storm surge protection system (sea dikes and barriers) and storm water drainage system (drainage canal or natural river with sluice and gate)
Rhine River Delta	<ul style="list-style-type: none"> • Safety standard (river): 1/1250 and 1/4000; • Dike strengthening and heightening to stipulated level; • Keep water in the field in original area (reforestation, detention for tributaries); • Store water along the Rhine Branches(detention measures); • Increase discharge capacity of the Rhine Branches: lowering of low flow channel, lowering groynes, lowering of floodplain, removal of obstacles, green river; • Comcoast: managed realignment, advance the line, hold the line; • General and individual flood resilience measures; • Live on mound. • Sea defence standard: 1/4000 and 1/10,000; • Storm surge protection system (dunes, sea dikes and barriers)

Mississippi River Delta	<ul style="list-style-type: none"> • Design flood: 67,000 m³/s at Cairo, based on historic flood; • Discharge the flood relying on dikes along the lower reaches; • Discharge high water by floodway; • Flood distribution by diversion works; • Sea defence standard: 3 category hurricane; • Storm surge protection system (sea dikes and barriers); • storm water drainage system (drainage canal and pump station)
Conclusion	
<ul style="list-style-type: none"> • Flood defense system in RRD against either river flood and sea storm is more complete than other two Deltas. • River flood protection system is relatively completed and perfect in YRD and MRD, but the sea defense system is incomplete and inadequate, and the protection standard is still very low which can not guarantee safety from more intensive storm surge or hurricane. • In YRD and MRD the river flood and storm surge or hurricane are not during the same season, so the threat is only by river flood or storm surge. While for RRD, the high flood in river and high tide from storm surge could coincide in the same time, although it has an extreme small probability. This situation has the highest risk of flooding or damage. • The major dredging activities in three deltas have different functions. In RRD, the dredging is for improvement of river regime and reduction of sediment contamination. In YRD, the dredging is to reduce sedimentation of river channel and increase flood-carrying capacity. In MRD, the dredging mainly is for the maintenance of navigation channel. Interests in “flood control” and “navigability” in RRD and MRD are integrated when deciding about intervening works in the main channel of both rivers. Also institutionally, both nautical and flood management were the two major responsibilities of one authority (Ministry of transportation, public works and water management in RRD, U.S. the Army Corps of Engineers in MRD). In YRD, there is no navigation function in the river. 	

7. Non-structural measures for flood mitigation

Yellow River Delta	<ul style="list-style-type: none"> • Reserve the spare course for future river course change. • Limit the development in floodplain. • Land planning and zoning for proper development. • Perfecting early alarm and forecast system; • Relocation of the people from floodplain or taking measures to improve security level (live on mound); • Improving flood risk perception for local people. • Execute flooding insurance and encourage people take part in.
Rhine River Delta	<ul style="list-style-type: none"> • Perfecting early alarm and forecast system; • Improving flood risk perception for local people • Land use planning: leave more space for water. • Population, urbanization and housing control and decrease land occupation. • General and individual flood resilience measures, decrease flood damage and losses like base elevation.
Mississippi River Delta	<ul style="list-style-type: none"> • Relocation of the communities from floodplain and low-lying areas. • “Multiple lines of defense” strategy, utilizing the retention and reduction function of wetlands, islands barrier. • Land planning and zoning. • Evacuation plan. • Advisory Base Flood Elevation for building elevating.
Conclusion	
<ul style="list-style-type: none"> • Along with the increase of the costs for construction and maintenance of flood protection engineering works and uncertainty of structural measures due to climate change, non-structural measures play more and more important role in three Deltas, which could be achieved significant efficacy in damage reduction. 	

8. Flood incident management

Yellow River Delta

Organization

- Command department for flood fighting: the command department is established according to the Flood Protection Law in each level (state, province, district and county). It is composed by the Government and Yellow River commission (Bureau) in each level and the director in each level is completely responsible for flood protection. The specific people, departments, responsibility and obligation are regulated explicitly for different big discharge or flood. They must be in place and organize, harmonize all the people, departments, materials concerned according to flood scenarios, which are updated every year.

Responsibility

- Command department of the Government is responsible for organizing and harmonizing all the local departments concerned and make decision in different situation. Each local department has specific responsibility, such as materials, transportation, communication, electricity, sanitation, media, climate forecast, insurance, security, etc.
- Command department of Yellow River Commission or Bureau is responsible for flood fighting scenarios and schemes, inspection and monitoring of flood protection works, technical schemes for flood fighting, management of flood fighting materials, technical training, etc.

Main composition of flood fighting team

- Local people: different scenario (discharge) has specific population, responsibility, and places where they are from.
- Professional people from Yellow River: most of the staff from Yellow River and the professional flood fighting team which mainly fighting for dangerous situation, like serious seepage, piping sliding, or overtopping, etc.
- Military: mainly for urgent, difficult, dangerous and serious situation, such as dike breaches, collapse, evacuating or rescuing people and protecting some important places.

Materials for flood fighting

- Nation reserved materials: national regularly available materials are exclusive materials. It is only used for flood fighting and managed by local Yellow River Bureau according to actual demands. Those materials are stored in local Yellow River Bureau base near river, like sand bags, wood pile, electricity generator, and great deal of stones and rocks are put on the dike shoulders near dangerous sections.
- Society and organization reserved materials: most of these materials are reserved or prepared by flood protection department before flood, such as equipments for flood fighting, vehicles, gases, food, life preserves, etc.
- Local masses reserved materials: used by themselves.



Well-laid rock on dangerous section

Specific flood fighting schemes

- There are 6 grades flood fighting schemes corresponding to the discharge at Huangyuankou gauging station. They are the discharge below 4000 m³/s, 4000~6000 m³/s, 6000~10,000 m³/s, 10,000~15000 m³/s, 15,000~22000 m³/s, above 22,000 m³/s respectively.
- Each scheme has a detail regulation for organization, people, materials, responsibility, defence measures, evacuation, etc.
- For each scheme also have specific sub-schemes for: flood gauging and forecast, people evacuation and rescue, guarantee for flood fighting materials, guarantee for traffic and transport, guarantee for communication, guarantee for electricity and lighting, guarantee for logistics.

Rhine River Delta

Organization

- All relevant authorities(water boards, municipalities, provinces, ministries) have incident plans that describe their response, including internal and external

communication, roles and responsibilities, stages and details regarding the actual operational response (pumps, sandbags, road blocks, etc).

Responsibility

- The main role for flood incidents is the water board. As long as high water levels are no real threat to public safety, the water board is the only organization with an active role in flood incident management, operating and maintaining defenses and pumps.
- When the head of water board has declared that he can no longer guarantee the functioning of the flood defenses, the Mayor takes over and the responsibility shifts from the field of flood management to public safety.
- The Mayor is in charge of emergency management in the Netherlands.
- The provinces have a supervisory and coordinating role and they are responsible for emergencies that exceed the area of a municipality.
- The national government (Minister of the interior) has a supervisory and coordinating role and is responsible for multi-province emergencies.
- Municipalities develop emergency plans and emergency response plans, in the framework of the Safety region.

Operational response

- This partly concerns pre-defined actions such as water level dependent closure procedures of locks and gates, or visual inspection.
- Temporary measures to increase the strength of the defenses as a direct response to a particular situation.
- Typical measures are reinforcement of embankments using geotextile, packs of straw or sandbags.
- For some materials such as sandbags, many water boards have long-term arrangements with contractors, to ensure that sufficient sandbags are available without having to store them. However, there is a risk that different water boards will count using the same sandbag during a incident and the quality is not guaranteed.

Mississippi River Delta

Organization

- There is no clear top leadership to organize the flood accident. National Response Plan and the National Incident Management System coordinate the

response to emergency and accident, which involved all levels of American government.

- On the occasion of a major flood, the President will typically name a senior member of his cabinet to ensure coordination of the federal agencies.

Responsibility

- The Corps of Engineers and the Federal Emergency Management Agency are the lead federal agencies in flood management. The Corps role is to lead in the development of comprehensive plans for flood damage reduction, and then as authorized by the Congress and the President, to carry out flood damage reduction projects, both structural and non structural. FEMA is charged with preparing for and responding to emergency events and operation of National Flood Insurance Program.
- Parallel state agencies perform similar functions at their level. Other federal and state agencies dealing with housing, economic development, agriculture, transportation, energy, and the environment collect and provide data, support post-disaster reconstruction, advise the Corps and FEMA on the impacts of their activities and support actions by communities and sectors to reduce their vulnerability.
- The most challenging responsibilities fall to local governments that in the event of a flood must become first responders to the hazard situation. Typically, local governments have more responsibility than resources needed to deal with the challenges.

Operational response

- In the situation of no clear leadership, all the level of government agencies response the flood by their internal organization. The communication and cooperation between agencies are big problem, which affect the effective response to the events.
- The Army Corps of Engineers repairs and prevent the damage of the flood protection works.
- National Coastal Guard uses their resources to inspect the danger and help evacuation and flood fighting.
- Most of people have to help themselves to escape from danger and avoid the damage of property.

Recommendations

General

- We should recognize and respect the natural process of the evolution of river system and ecosystem, leave enough space for nature and environment in order to reach the long-term safety.
- During flood protection planning, the careful consideration should be done to reduce or improve the adverse effect on ecological environment.
- The proper, wise and limited development strategy should be taken in vulnerable regions, which should adapt physical conditions and natural resources, in order to reduce flood damage and abuse of natural resources.
- Some measures should be taken to return natural processing and restore ecosystem. In Yellow River Delta, the unified water allocation and the operation of reservoir are implemented to guarantee the minimum flow to Delta for ecology restoration and river system; In Mississippi River Delta, freshwater and sediment diversion structures along the river have been built to prevent saltwater intrusion and restore wetlands.
- The forecasting and warning of river flood, sea storm and hurricane have the different response time. River flood have longer prediction period and relatively accurate. But during extreme events, especially when the evacuation or detention area is needed to act, it is very important for the accurate and longer time forecasting. But for sea storm and hurricane, the forecasting time is limited, sometimes within 24 hours, so it is necessary to leave the space and time for response to the evacuation and flood fighting. The infrastructure planning should be taken into account the dramatic increasing traffic for evacuation in flood prone area, and leaving extra space or road for evacuation.
- In three deltas, increased concern over water quality and the environment in river basin led the administrators to institute major initiatives to encourage development of comprehensive watershed plans that would not only address these issues but would also integrate other water resource development activities in the planning.

Integrated water management and the more specific integrated policies are developed in RRD and YRD, but not yet visible along the MRD. Institutionally, USACE's mandate is restricted to flood control, navigation and the environment,

concern for direct water quality aspects is not part of it.

- Flood control is essential part of integrated water management and more institutions are involved in different aspects. Technical solutions must be forwarded based on social policy papers in a phased realistic approach by consistent political help.

Yellow River Delta

Technical aspects

- Although people try to prolong the running time of the current river course through various technical measures, river course change can not be avoided in the future due to sedimentation in the river channel. So the spare courses should be considered in advance to avoid the damage by natural change.
- Sedimentation is the main source of riverbed rising and course changing, comprehensive measures should be taken and more investment is necessary for decreasing the river channel silting, like dredging or flushing.
- Since 1990s, there is no flood in YRD. Most of flood protection works built in recent years did not experience big flood test. Intensive inspection and improvement of the dikes should be strengthened before flood season.
- The current safety standard of the storm surge protection system is still very low and integrated planning, dike construction and heightening for storm protection is needed.
- Further study is needed on how to use maritime power to transport silt.
- Land loss and coastline erosion should be taken more attention. The solving of this problem should combine the water-silt regulation upstream and course changing or course bifurcating.
- The concept of Comcost is suggested in wetland area and potential oil extraction area, low overtopping dike preventing land loss.

Non-technical aspects

- Master plan and integrated measures for flood management and local development.
- Discharge deviation has an impact for every aspect, so keep a relatively stable flow and determine a minimum flow is significant for local development and

<p>ecological environment.</p> <ul style="list-style-type: none"> • In YRD, local interests are growing fast; Master Plan should be formulated to coordinate conflicts among economic development, nature conservation and river management. • Communication and knowledge improvement are very important to strengthen coordination and cooperation among institutions. In YRD, participation of the public should be introduced in the process of the flood protection planning to avoid the mistakes and unreasonable points. • Environment protection or improvement should be taken more attention with the river training and dike construction. • Water diversion is suggested for wetland conservation, although the current situation is water shortage in YRD. In long-term view, the shrink of wetland would contribute more impacts on flood risk and local economy development. • An integrated authority of flood management for the whole YRD is necessary, in order to enhancing the cooperation and coordination among all stockholders and interests.
<p>Rhine River Delta</p> <p><i>Technical aspects</i></p> <ul style="list-style-type: none"> • Dike strengthening and heightening to stipulated standard is still the main task in short-term of future, especially for some weak spots. Under present situation, most of the people consider safe enough, especially for some decision-makers, then most of the money are distributed in other fields, excepting dike reinforcement, so the projects involving flood defences are prolonged, delayed or facing complicated process. In some cases, it should be enforced to be implemented for some important projects. • With the expected increase of river discharge, integrated measures should be carried out other than traditional dike heightening only, which is already very “high” considering landscaping. Detention measures, green rivers, flood resilience measures are much more preferable in long-term view. • Although the safety standard of sea defence is very high now, storm surge is still the main threat comparing with the high flood from the river which is relatively predictable. Storm surge have much more uncertainties with the climate change,

especially for the area affected both by high water from river and high tide caused by storm. In this circumstance, flood risk is confronted. So, for these areas, like Rotterdam and Dordrecht, more attention should be taken and further risk assessment and technical measures are necessary.

- In long-term view, with the sea level rising and land subsidence, the flood risk in coastal zone is increasing, but further dike heightening on the basis of the present level should be avoided, higher dike means higher risk. So, integrated measures should be innovated, combining flood protection with landscaping, local development, environment improving, namely sustainable improvement on the basis of safety, leaving more space or field for future. Then the concept of Comcoast is much more preferable, such as “foreland protection”, “foreshore recharge”, “advance line”, “landward overtopping dike”, “controlled flooding”.
- Coastal erosion causes beach shrink and dike damage, and makes the dike more directly exposed to the storm surge. So it is necessary to add sand to beach and make an advance line in seaward dike, such as replenishing the foreland with environmentally safe dredge spoil or raising the foreland by coastal nourishment.

Non-technical aspects

- In RRD, proper and wise development should be adopted to keep steady growth and stable population to avoid increasing flood risk in low-lying area and stressing more pressure on flood protection.
- Much participation of the public and interests concerned can avoid some mistakes or faults, but sometime it makes the process much complicated and takes too much time and energy on interests coordination, and some of them are not from technical point of view. So, in some cases decision should be made much decisively for the decision-maker and should be more technical, especially for some crucial projects which is much significant for most of the public and probably affect less people's interests.
- Dutch people have been and are also focusing on flood defences in flood risk management. The safety is very high now, but unfortunately it is not zero, and no way forever. So how to solve the residual flood risk is also need to take more attention. It means what we can do before, during and after a flood incident. Much lessons we can learn from the disaster of Katrina. Preparation for flooding is very necessary before each flood season, such as preparation for flood fighting materials and equipments. If it is necessary to put the sand, stones and rocks on

or near the dangerous spot; if it is necessary to store sufficient sandbags, geotextiles or packs near the dike; during the flood incident, central or provincial government should take more actions other than only depending on the water board or local people; after flooding if the people can get the compensation according to the agreement in the insurance when a widespread flooding happened. Evacuation plan is also vital when a flooding occurs, the explicit description for schemes and responsibilities are very necessary.

Mississippi River Delta

Technical aspects

- Comprehensive planning should be done combining hurricane protection and wetland restoration.
- The building of hurricane protection projects should be unified with uniform criteria as a whole system.
- The building of levee in wetland needs innovation of approaches to avoid destruction of wetlands, like the construction with drainage system or diversion structures.
- Before the large scale freshwater diversions are built for wetland restoration, the study on sediment availability, composition and moving law should be done. For this aspect, they can learn from Yellow River.
- The critical hurricane protection should be built as soon as possible in case of next hurricane comes. For instance, the floodgates or barriers to prevent storm surge attack from drainage canals, industry canal and Mississippi River Navigation Outlet.
- During levee design and repair, geology and soil condition should be carefully considered to avoid the danger in flood events.
- If there is enough space, earth levee is the best choice to build. Although the maintenance is costly, it is more resilient.
- The dredging activities could be combined with flood protection and coastal restoration. The dredging materials can be used for consolidation of levees and nutrition of wetlands.

Non-technical aspects

- National government should dominate the building and financing for great flood protection projects, especially which can not be afforded by the local. So the Federal Government should be responsible for the building of integrated hurricane protection system in New Orleans in case that next disaster comes.
- In recovery and rebuilding after extreme events, the government should provide certain amount of compensation to effected people in order to keep sustainable development of the society, because flood insurance seems not efficacious and practical measure (For example, Flood Insurance Program in New Orleans).
- In MRD, under the situation that more than half population left the city after Katrina, the new land planning could be made to relocate the people from low-lying area or vulnerable region or concentrate the people in safer area to reduce flood damage from storm surge.
- The management and maintenance of the levees should be enhanced. Some measures should be taken to prevent negligence of levee administrator.
- The legislation should make clear leadership and responsibilities in flood incidence, especially extreme events, in order to strengthen coordination and cooperation of federal and state agencies (learn from Yellow River Delta).
- Federal agencies are directed to coordinate with each other and the relevant state agencies in the development of any actions within a watershed. Such watershed planning encourages the integration of flood management activities within the context of integrated watershed planning.