DSD INTERNATIONAL CONFERENCE 2014

Climate Change Impacts on Urban Flood Risks

Adri Verwey
FloodConsult
Singapore / The Netherlands

ABSTRACT

This paper discusses in the first instance the expected sea level rise, partly based upon historic evidence. It presents an expected range of sea level rise of 40 – 100 cm during the 21st century. It further discusses the way sea level rise and changes in rainfall intensity have been tested in a sensitivity analysis as part of the Review of the Drainage Master Plan for the districts North and Yuen Long in Hong Kong. The values used in this study were already in line with the values reported in the 5th IPCC Report.

Subsequently, examples are given of phenomena perceived as resulting from climate change, while other factors play an important role as well. It points at the need to separate facts from myths.

Finally, the paper discusses way to mitigate the impacts of climate change and new visions on the management of floods.

1. INTRODUCTION

The successive reports published by the IPCC (International Panel on Climate Change) leave no space for wishful thinking. The recently adopted IPCC 5th Report is clear: climate changes due to the increasing release to the atmosphere of gases that aggravate the greenhouse effect are a fact. Impacts on urban drainage systems are increasing river and sea water levels, increased rainfall intensities and storm depths and possibly changing wind conditions, in particular impacting coastal cities.

Far less certain is the magnitude of the changes that can be expected. Results of a variety of climate change models show a distinct trend, though also significant spreading in the magnitude of changes, which leads to assumptions of low, medium and high climate change impact scenarios in urban planning.

Climate changes emphasize the need for urban master planning of which the development and regular updating of urban drainage master plans forms an essential component. A lack of early planning of the urban drainage system leads to costly remediation measures to handle increased peak drainage discharges. For most cities these result from urban expansion and a lack of vision to reserve sufficient space for at least the primary drainage network at an early stage of urban development.

Such vision also offers space for integration with other needs in the urban space, such as parks and recreation areas. In The Netherlands, the need for correcting earlier mistakes in planning, a costly Room for Rivers concept was developed to deal with the expected increase in River Rhine peak flows, partly caused by climate change impacts. Handling future urban flooding problems require equivalent creative solutions based upon integrated water management concepts. In this way, many coastal cities can avoid flooding problems for at least the coming century.

2. 5TH IPCC REPORTS

In 2013 the 5th IPCC reports were finalized and approved in 2014. In this Section we will limit ourselves to a discussion on the latest insights into sea level rise. The question is not if sea level rise will happen. It is “when and how much”. Figure 1 shows recorded mean sea levels along the Dutch coast. Over the last century this level has risen nearly 20 cm.

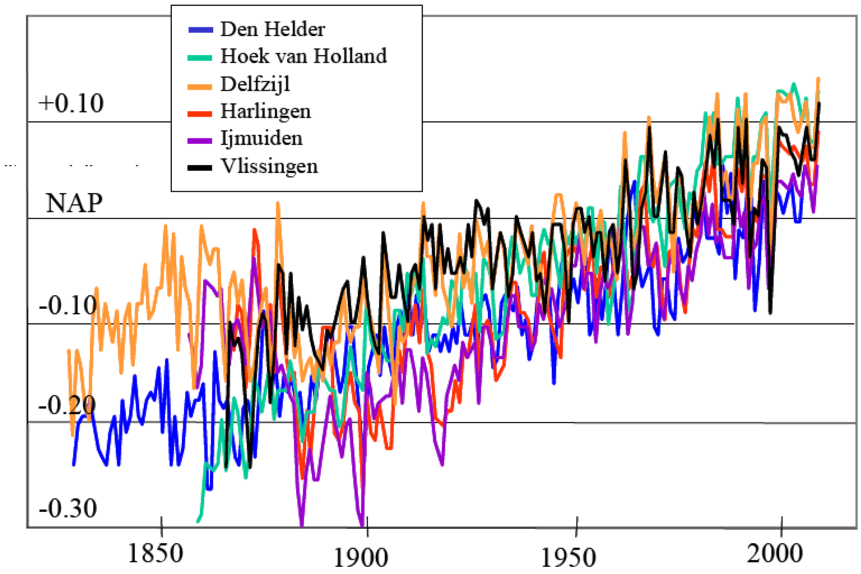

Figure 1 Sea level rise as measured along the Dutch coast

Projections in the 4th IPCC Report gave an expected range of sea level rise of 18 – 59 cm up to the year 2100. The 5th IPCC report, approved in 2014, comes with higher values, depending on the emission scenario considered. Table 1 shows the expected range of these higher values. The lowest range in this table represents an extemely unlikely scenario, as it assumes that carbon emissions come to a complete end by the year 2070, with drastic reductions starting shortly. Moreover, it assumes active carbon removal from the atmosphere as well. These achievements cannot be expected realistically. Even this low range is on average nearly three times larger than the globally observed 17 cm change over the 20th century. In conclusion, it may be expected that sea level will rise somewhere between 40 – 100 cm during the 21st century.

Table 1 IPCC-5 expected ranges for sea level rise as a function of emission scenarios

Emission Scenario	**Mean cm**	**Range cm**
RCP2.6	44	28-61
RCP4.5	53	36-71
RCP6.0	55	38-73
RCP8.5	74	52-98

3. CLIMATE CHANGE IN NORTH AND YUEN LONG DMP REVIEWS

In 2010, updates of the drainage master plans (DMPs) for the districts Yuen Long and North in Hong Kong were completed. The studies were performed by the global consulting firm Mott

MacDonald, supported by Deltares of The Netherlands. Extensive analysis was made of sea level and rainfall data to be taken as representative for the update of the master plans. Various conclusions were drawn:

- Regional frequency analyses on local rainfall data showed values below those based upon rainfall records at HKO (Hong Kong Observatory) headquarter at Kowloon district. So far, in all drainage studies in Hong Kong, HKO headquarter data were used for the design of required drainage capacities;
- Analyses of expected climate change impacts on rainfall in Hong Kong, based on HKO records, showed values of the same order of magnitude as the differences between local rainfall parameters and those of HKO headquarters;
- Historic sea level records along Hong Kong coasts did not provide a solid basis for quantifying probable future sea level changes in the northern part of Hong Kong. However, for Tsim Bei Tsui Gauge at Deep Bay, sufficient data was available to estimate design extreme sea levels for different return period used in the study, representative for the 2010 situation.

The updated master plans were completed on the basis of land use scenarios for the year 2030. For the reasons given above, it was decided to continue using the updated HKO headquarter rainfall data series, as being representative for the 2030 rainfall conditions in the north of Hong Kong. Moreover, the designs have been based upon the currently observed global sea level rise, estimated at 3 mm/year on average, or a 6 cm sea level rise between 2010 and 2030.

In order to test the robustness of the existing drainage system, sensitivity analyses have been made of various climate change scenarios. Rainfall trends were derived from HKO, based upon trend considerations using the time-dependent Generalized Extreme Value (GEV) method, showing increased rainfall intensities of about 0.9% to 1.9% per decade for intense, short duration storms (Wong and Mok, 2009). For a period of 20 years and various return periods, the resulting changes are shown in Table 1.

Table 1 Percentage increase of rainfall depth for Standard Scenario (time horizon 2030)

	% increase of rainfall depth in climate change scenario for various return periods						
	T2	***T5***	***T10***	***T20***	***T50***	***T100***	***T200***
-4.0	**1.5**	**1.1**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**
-3.5							
-3.0	**1.9**	**1.4**	**1.2**	**1.0**	**0.9**	**0.8**	**0.7**
-2.5							
-2.0	**2.5**	**1.9**	**1.6**	**1.4**	**1.2**	**1.1**	**1.0**
-1.5	**3.4**	**2.6**	**2.3**	**2.0**	**1.8**	**1.6**	**1.5**
-1.0	**3.7**	**2.9**	**2.6**	**2.3**	**2.1**	**1.9**	**1.8**
-0.5							
0.0							
0.5							
1.0							
1.5	**3.4**	**2.6**	**2.3**	**2.0**	**1.8**	**1.6**	**1.5**
2.0	**2.5**	**1.9**	**1.6**	**1.4**	**1.2**	**1.1**	**1.0**
2.5	**1.9**	**1.4**	**1.2**	**1.0**	**0.9**	**0.8**	**0.7**
3.0							
3.5	**1.5**	**1.1**	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**
4.0							

For the sensitivity analyses the following four scenarios were defined:

1. **Baseline Scenario**: based upon the 2010 existing drainage system, with rainfall design profiles in accordance with the updated rainfall analysis results for HKO headquarter;
2. **Standard Scenario**: % rainfall increase based on Table 1, combined with a 6 cm sea level rise (SLR), representing driving forces conditions in the year 2030;

3. **High Scenario**: double the % rainfall increase of the Standard Scenario, combined with a 12 cm SLR, also representing year 2030 conditions. This can also be considered to be an approximation of an extrapolation of the Standard Scenario to the year 2050; and
4. **Extreme Scenario**: double the % rainfall increase of the Standard Scenario over a period of 40 years, combined with a 40 cm SLR, representing an extreme extrapolation to the year 2050.

Simulations were based upon a calibrated SOBEK integrated rainfall-runoff and 1D/2D hydrodynamic model for return periods of 2, 5, 10, 20, 50, 100 and 200 years. For each simulation, a combination of different return periods for rainfall and sea levels was made. An extensive investigation led to the best combinations of these return periods. For each scenario and selected combinations of return periods, representing in total 52 simulations, the number of kilometres where the water levels exceeded the existing channel bank levels have been tabulated.

4. CLIMATE CHANGE PERCEPTIONS

When floods occur, there are frequently comments that the event is the result of climate change. It proves that concern about climate change is well established in society. Although this usually relates to layman chat, there are many factors concerning climate change that even confuse scientists. Let us, therefore, consider some truths and myths about climate change.

In The Netherlands, extreme Rhine discharges with a return period of nearly 100 years occurred in two successive winter periods of 1993-1995. In the 1920's, equivalent peak discharges entered the country twice within one decade, as shown in Figure 2. The figure also presents 5-year averages, showing an oscillation. Apparently there are periods with successions of dryer and wetter years, which may point fingers at climate change. Although there is also a distinguishable upward trend in the yearly peak discharges, this is certainly partly caused by all kinds of drainage improvements in the river basin. In the last century many interventions were made to boost agricultural production in Europe. Another important factor may have been the construction of embankments along Rhine River and its tributaries. It is well known that such interventions increase the speed of flood wave runoff and increase peak values. In principle, such interventions have to be accompanied by the construction of retention in the form of reservoirs or dry polders.

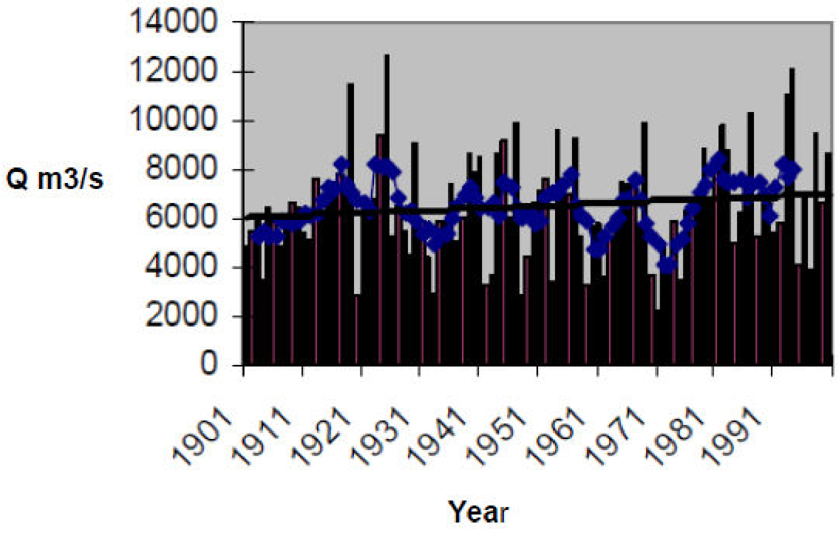

Figure 2 Yearly peak Rhine discharges entering The Netherlands

Rapid conclusions are also often drawn in relation to the intensity of rainfall. Figure 3 shows the 25-year averaged yearly rainfall depths observed at HKO headquarters in Kowloon District.

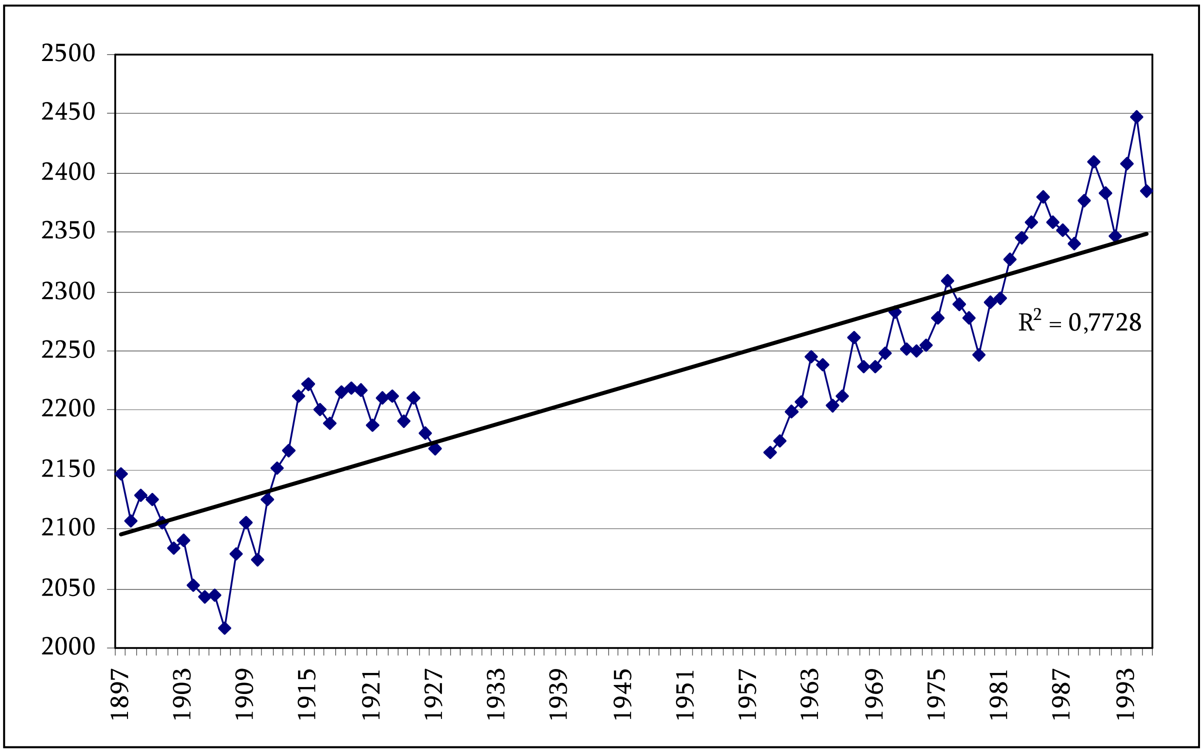

Figure 3 Trend in yearly rainfall depths observed at HKO headquarters, Kowloon, Hong Kong

Due to the data gap between 1940 and 1946, the graph shows a gap of 30 years, due to the 25-year averaging process. Most likely, climate change plays a role. However, there is certainly also an important effect of urban heat increase. Over the years, the city has been more intensely urbanized. Even more important is the effect of increased energy consumption by transport and air conditioning. The increased heat production leads to more frequent and increased intensity of convective storms. In urban areas it is virtually impossible to isolate the effect of climate change on rainfall. If the trend is explained as climate change, it is only justified if it is defined as “micro-climate change”. In any case, such trend would not be applicable to the rural areas. This is most likely the reason why the recent statistical analyses for the districts North and Yuen Long showed lower rainfall intensities than HKO headquarters.

Also subsidence of soils plays a role in the perception of impacts of climate changes. Figure 4 shows the composite effects of sea level rise and subsidence. Examples of areas where subsidence is or has been a much greater threat than clime change are: The Netherlands, with currently its deepest ground level at nearly 7 meters below mean sea level, Bangkok and Jakarta. Most important reasons are excessive ground-water extraction or maintaining the ground-water table too low in soft soils.

Finally, climate change impacts are sometimes used as an excuse for neglected maintenance. Figure 5 shows a drainage canal in Khulna, Bangladesh, which has been heavily silted up. The rehabilitation study in this case was combined with a study on the impacts of climate change. In this project it was demonstrated that the climate change impacts on salt intrusion were the most damaging in this region.

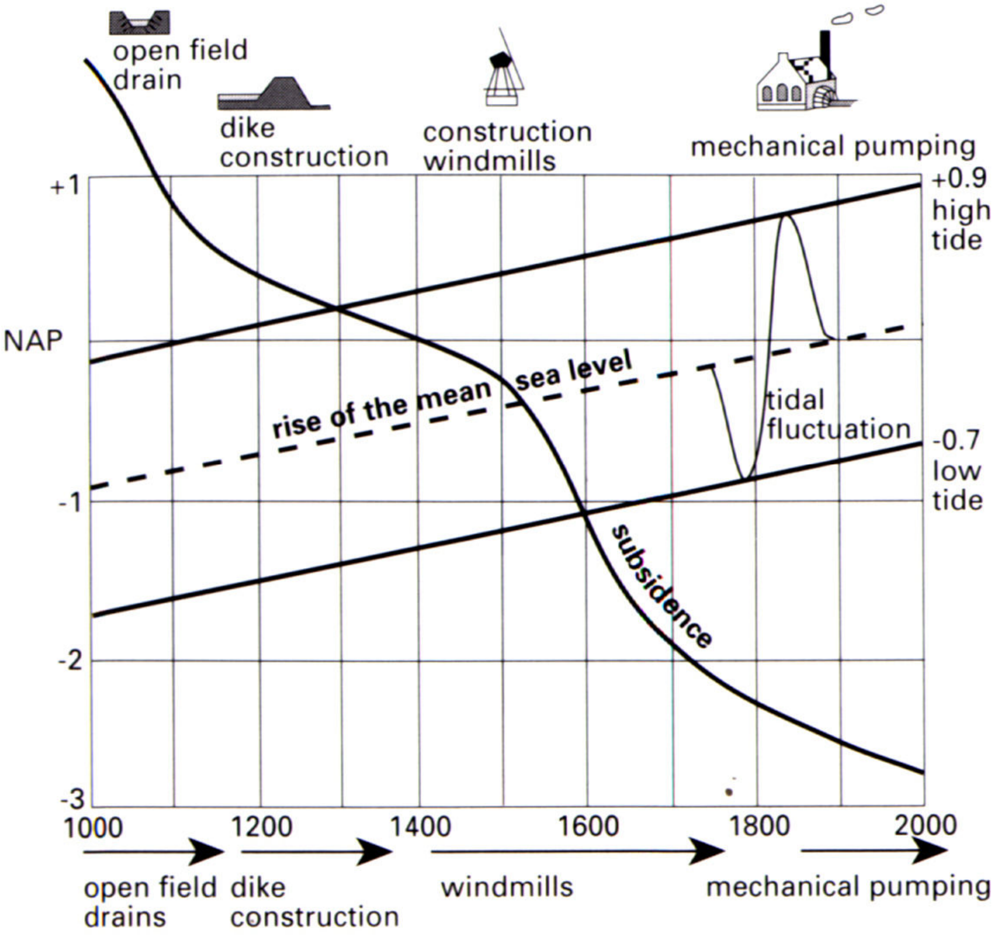

Figure 4 Comparison of the effects of climate change and soil subsidence in The Netherlands

Figure 5 Reduction in discharge capacity due to lack of maintenance in Khulna, Bangladesh

5. ADAPTATION STRATEGIES

Historically, flood risk management is based primarily on defence against high water levels. Structural methods such as dikes or levees were the answer to the threats of flooding. This passive way of defence has gradually been replaced by an active way, reducing the source of problems. Reservoirs were constructed to lower river or drainage channel water levels, so that dikes would not have to be heightened above reasonable levels or drainage channels would have to be rehabilitated by increasing their width in densely urbanized areas. In urban areas, in particular, the concept of sustainable urban drainage systems (SUDS) was borne, reducing the need for large drainage infrastructure rehabilitation works.

Due to continuing urbanization, many cities face the problem of drainage congestion. This is often explained to the public as a result of the decreased infiltration capacity of soils, where vegetation is replaced by asphalt. However, this is a misconception. The primary reason for the increased peak discharges is the increased speed of runoff from the urban catchments. Reduced infiltration plays a secondary role. This is even more the case when dealing with extreme rain events, where the fraction of rainfall infiltrating into the subsoil is limited due to saturation of the top soil layers. The replacement of rough terrain covered with vegetation by smooth surfaces such as asphalt, however, leads to discharge of the volume of water represented by the storm rain depth that comes to runoff in a much shorter time. Hence, the peak value of discharge turns out to become much higher than before the urbanization took place.

As a partial answer to these problems, SUDS represent a collection of measures reducing peak runoff in urban areas. The basic notion is to spread the runoff in time, so that local runoff peaks, causing flooding of roads and buildings, are reduced. There is a wide variety of measures slowing down runoff, such as green roofs, green walls, infiltration devices, local retention, such as the use of parking places and sport terrains, artificial wetlands, etc. It should be realized that such measures are not always effective. The measures should focus on reducing problems at problematic spots. In general, flood management should focus on speeding up runoff in downstream parts of urban catchments and slowing it down in the upstream parts, In general, SUDS measures are most effective in the upstream parts of catchments and may turn out to be counterproductive in the downstream parts.

If a bottleneck in the drainage system appears to be located relatively close to the catchment outlet it may be more interesting to increase the discharge capacity locally. This was the adopted solution in Singapore, when Orchard Road, one of the main shopping streets, faced too frequent flooding problems. Various measures were taken, prior to the construction of retention facilities upstream and the construction of a diversion channel. At the problematic location, as a first step, the street level was increased by up to 60 cm. As a second step, the discharge capacity of the culvert underneath Orchard Road was increased in three ways, by: (1) removing a pipeline following the channel and culvert sections in longitudinal direction; (2) removing service lines crossing the drainage channel; and (3) covering the drainage channel culvert with a polymer lining. Together, these measures increased the drainage capacity at the flooding hotspot by around 50%. These measures also avoided the interruption of traffic, if the culvert widths would have to be increased.

All options discussed play a role when the impacts of climate change have to be reduced in urbanized areas. There is no single solution to the problems to come as a result of climate change impacts. Solutions will have to be based upon the knowledge of the system and the understanding of the causes of the problems. This understanding is much supported by the use of mathematical models which have been calibrated well on past events. In the case of Singapore, the SOBEK modelling system was used. Such calibration also needs the collection of discharges from the catchments, rather than water levels alone. In general, it is strongly recommended to expand the network of discharge measuring stations in urban environments.

An important new development is the notion that a city is designed to cope with rising flood problems. Where SUDS is already a measure to reduce flooding problems by going to the source, a newer way of thinking is the acceptance of floods and arrange the urban environment to “live with floods”. An example in a very different context is the city of Minneapolis in the USA and likely other cities in that part of the world. To reduce the problems of extreme cold, the various apartment blocks are connected by galleries, which enable people to move around without facing extreme cold temperatures outside. Similarly, in flood prone cities connections between buildings could be designed to move around during periods of flooded streets. This would have to go hand in hand with the protection of the buildings on the ground floors.

One interesting new development is the use of a temporary flood barrier. This newly developed system can be rolled out around a building or on top of a dike and fills itself with flood water once arriving at it. It provides flood protection up to slightly more than 1 meter of depth on top of its base (Figure 6).

Figure 6 Tube Barrier, an innovative concept to fight floods with water (courtesy.tubebarrier.com)

The Dutch way of thinking these days is to allow for some flooding in extreme events. In other words, getting adapted to living with floods. The answer to this is a dike resistant to breaching at a selected frequency of overflow. Once exceeded, water may flow over the dike which has been constructed to resist damages during overflow. As an alternative, dikes may be built to the legally defined flood level with enough strength to allow for topping up with sand bags or a tube barrier. Given the fact that protection is provided up to, usually, 1/100 year frequencies, these concepts provide the additional means to reduce extreme losses, such as experienced, for example, in New Orleans in 2005.

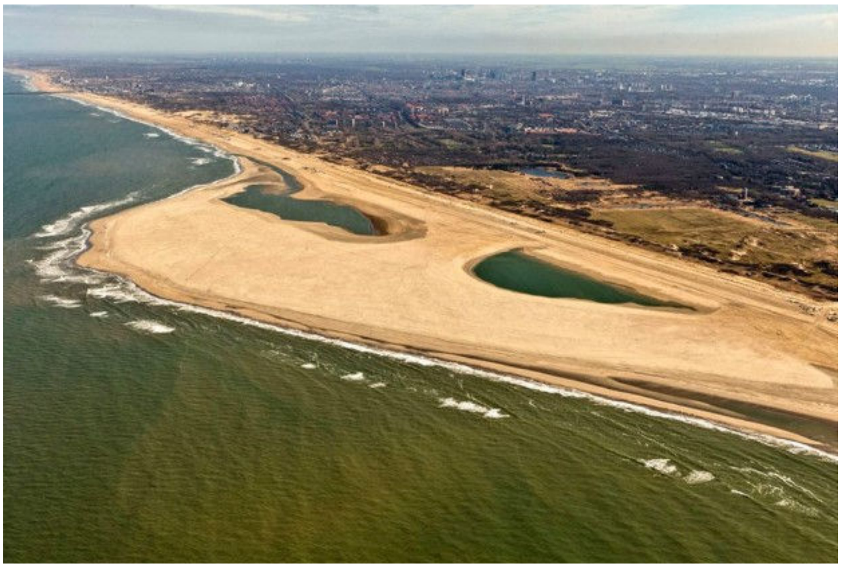

Figure 7 Formation of a sand supplied barrier in front of the Dutch coast

Living with floods goes hand in hand with a good functioning flood forecasting system and emergency support in case of exceedance of the flood protection standards. This also requires a good information system that is readily accessible at a flood emergency centre. Examples are information on possible evacuation routes, impacts of possible floods caused by the overtopping of dikes or dike breaches, critical assets such as hospitals, etc.

Another Dutch innovation is the concept of “Building with Nature”. This opens up possibilities to resist flooding problems for at least the coming century. Figure 7 shows the suppletion of large volumes of sand along the Dutch coast near Hook of Holland. In this way a sand barrier is formed which creates a lagoon in front of the coast. Natural processes will create entrances to this lagoon which will dampen tidal waves and storm surges directly in front of the current coast. In this way the Dutch and many other coasts in the world will be able to stand at least one century of sea level rise. In Hong Kong, this concept may work very well at Tai O at Lantau Island, where flooding of this interesting historical place, also flooded by tourists from mainland China, is caused by a combination of storm surges and river floods. Creating a sand barrier out in the bay will provide a dampening of the storm surges and tides, while also creating storage for the river extreme discharges.

CONCLUSIONS

Climate change impacts on urban drainage systems have become a fact that has to be taken into account during the planning, design and adaptation of such systems. Early planning of principal drainage canals and the required future capacity is a need to avoid future costly adaptations.

As for various reasons, including climate changes, required capacities of flood management assets require adaptation, new visions are being developed on flood management that drift away from hard structural engineering measures. This goes beyond the recent introduction of sustainable urban drainage systems and includes concepts such as “living with floods” and “building with nature”.

ACKNOWLEDGEMENTS

The author has greatly appreciated the support given by staff of Deltares in The Netherlands and Mott MacDonald in Hong Kong by providing useful material for and comments on this presentation.

REFERENCES

Fourth IPCC Report, 2007

Fifth IPCC Report, 2014

Wong, M.C. and H.Y. Mok, “Trends in Hong Kong Climate Parameters Relevant to Engineering Design”, HKIE Civil Engineering Conference 2009, Hong Kong