# HOW TO PROTECT EAST JAKARTA AGAINST FLOODING

WHICH INTERVENTIONS ARE REQUIRED TO COPE WITH THE DIFFERENT SCENARIOS OF LAND SUBSIDENCE

*January 2018*

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|---|---|---|
| Project | How to protect East Jakarta against flooding? | |
| Document | Which interventions are required to cope with the different scenarios of land subsidence. | |
| Status | Final report | |
| Date | 17 January 2017 | |
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# PREFACE

This report has been written to fulfil the requirements of a multi-disciplinary project as part of the Master program at the TU Delft. In this multi-disciplinary project, our project team went to Jakarta for a period of ten weeks to assist in finding a solution to project East Jakarta against flooding.

Our project was undertaken at the request of Deltares, Witteveen + Bos and Royal Haskoning DHV, who introduced us to the other companies involved in the project. Our work activities are part of the National Capital Integrated Coastal Development (NCICD) project, a consortium consisting of several Dutch, Korean and Indonesian parties. Our supervisor at location, P. Letitre, M. van de Watering and V. Coenen , gave us the opportunity to assist in finding solutions to the problems in East Jakarta. The supervisors at the TU Delft are A. van der Horst and J. Timmermans. Both our supervisors at the TU Delft and in Jakarta were willing to answer our questions and were always supportive.

We would like to thank our supervisors for the support during the project. Also, the respondents from Deltares, Witteveeen+Bos, Royal Haskoning DHV and PMU (Ministry of Public Works). Without their cooperation and their data our result would not be that structured and complete as it is now.

It was a wonderful experience for us.

The Authors,
Jakarta, January 2018

# ABSTRACT


Jakarta is heavily subjected to land subsidence. Due to this subsidence, the city is sinking further to under sea level. This has influence on the flood safety, both from an extreme sea event as an extreme rainfall event. The major cause of the subsidence is assumed to be the groundwater extraction, which takes place due to a lack of piped water. To reduce subsidence, the groundwater extraction must stop. It is concluded that this would not be feasible in the short term and scenarios are made on how subsidence will continue in the next years.

To ensure flood safety, measurements have to be taken. Research has already been carried out for West Jakarta, but this report focuses on solutions for East Jakarta. Four different solutions are developed to ensure flood safety. The first is to heighten the coastal dike and the flood defences along the river with the same level as the relative subsidence. To accomplish this, high flood defences should be constructed in the densely populated areas along the rivers. A spatial analysis is performed to come to a cost estimation model for the necessary land acquisition for three types of flood defences. These designs are combined to come to a cost efficient design. Another way to ensure flood safety is too close off the rivers and to pump the water into sea. In this case heightening of the flood defences along the rivers is not necessary. To reduce the peak discharges and thus the needed pumping capacity, a retention lake should be built. This can be done inland, but it is concluded that this will not be a cost efficient solution. A more cost efficient solution is to construct an offshore retention lake. This can be done by building an outer sea dike. In this case, the rivers will flow into the retention lake, which is maintained at a given water level. The pumping capacity needed to ensure flood safety depends on the size of the lake. An optimum has to be found to come to the most cost efficient design. In this study it was concluded that the most cost efficient solution is to not make a retention lake at all, but install pumps with sufficient capacity instead to handle the peak discharge. To reduce the pumping capacity, tidal gates can be constructed at the river mouths. A great advantage of this solution is that an amount of pumps can be constructed to deal with mild subsidence rates and more pumps can be built when concluded that subsidence rates turn out to be larger. In this way an adaptive solution is created.


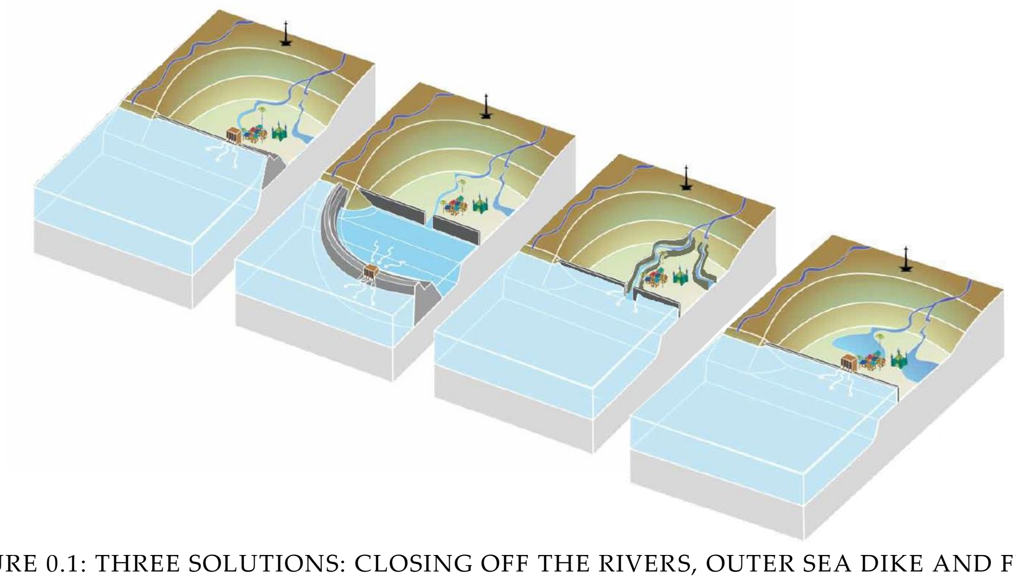

FIGURE 0.1: THREE SOLUTIONS: CLOSING OFF THE RIVERS, OUTER SEA DIKE AND FLOOD DEFENCES ALONG RIVERS (MODIFIED FIGURE FROM NCICD MASTERPLAN 2014)

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# 1. INTRODUCTION

## 1.1. Problem definition

In the past North Jakarta was hit by major floods from the sea and rivers, resulted in a significant amount of damages. In the last ten years there were more than one hundred casualties and thousands of displaced refugees [Warren, 2017].

The problems in Jakarta are mainly caused by the phenomena of land subsidence. Next to this, also climate change has a negative effect on the existing problem. However, the influence of climate change is insignificant compared to the problem of land-subsidence. The land subsidence is caused by natural phenomena such as consolidations of the soil and tectonic activities. But especially human based activities will induce the subsidence: excessive groundwater extraction and loads of the constructions. The excessive groundwater extraction is the dominant factor of the subsidence and the tectonic activities are the least dominant factor. [Abidin, 2015]

In this chapter, the different causative factors of flooding will be explained. In Figure 1.1 an overview is given.

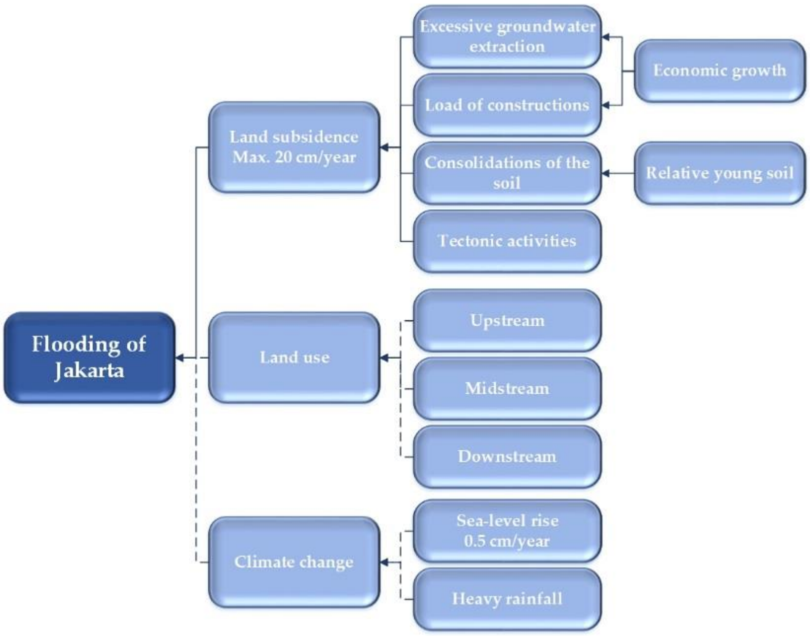



FIGURE 1.1: CAUSATIVE FACTORS FLOODING JAKARTA

### 1.1.1. Land subsidence

In Figure 1.1 there are four causative factors (in which tectonic activities are the least dominant), which cause mean land subsidence rates in West Jakarta of 7.5 cm/year. In East Jakarta this is significantly lower, namely 2.5 cm/year. This is mainly due to the differences between east and west. Flooding risk in West Jakarta is considered to be more urgent and the emphasis until now has been on land subsidence research in West Jakarta. Only little is known about the effect of the continuing land subsidence in East Jakarta and the potential flood risk.

As a result, rivers that end up at the coast of Jakarta can eventually no longer debouch sufficiently into the sea via gravity as the city continues to subside. The water levels at the outflow of the channels are dependent on the sea levels. This will result in the generation of backwater effects far upstream of those channels. During peak precipitation events, peak flood waves generated in the upstream catchment will not be able to debouch, leading to an increase of river flooding impact [Warren, 2017]. Existing river walls are no longer sufficient and dikes along the channels have to be constructed if no additional measures are taken which is further discussed in section 0. This, however, is considered as a difficult challenge as there is little space (see chapter 4) to build dikes along the channels due to a highly populated area. The required dikes should be that high, that it may not be safe.

#### 1.1.1.1. *Economic growth*

Indonesia has the largest economy in Southeast Asia and is one of the emerging market economies of the world. Indonesia is a member of the G-20 major economies and is classified as a newly industrialized country. Indonesia has the 16th largest economy in the world. The economics of Jakarta as the capital of Indonesia is expected to grow in the upcoming years [Post, 2017].

There is a growth in built-up-areas, population, economics and industrial activities [Abidin, 2015]. The growth is related to the expected land subsidence. Due to economic growth, the water extraction will increase and land subsidence rates are likely to increase. Also, due to the construction of extra buildings the weight on the soil will increase, which will also increase the land subsidence rates.

#### 1.1.1.2. *Consolidation of the ground*

The soil of Jakarta is relatively young and soft, so this will increase the risk of land subsidence [Abidin, 2015].

### 1.1.2. Land use

The use of land upstream has a major impact on the river discharges and river levels. Forest areas are replaced by relatively smooth (agricultural) areas, which lead to bigger run-offs to the rivers. At the midstream and downstream part the sides of the rivers are used for residential areas, which lead to a narrowing of the river width and therefore increasing in water depth.

### 1.1.3. Climate change

In the past, a lot of people linked the flooding of Jakarta completely to climate change. It is true that climate change has a negative effect on the safety against flooding, but since the sea level rise is 0.8 cm/year and the land subsidence rates are much higher (max. 20 cm/ year) this was not the main reason of the flooding of Jakarta. The sea level rise in combination with land subsidence is considered as relative subsidence in the following chapters.

Next to sea level rise, climate change will also increase the extreme rainfall events and this could also lead to flooding. All of this is little compared to the subsidence rates (see dashed line in Figure 1.1.)

## 1.2. Scope

To determine the safety of North-East Jakarta against flooding, the topographical boundary conditions have to be known. The catchment areas of the debouching rivers and canals are used to determine the investigation field. As can be seen in Figure 1.2 there are three big debouching channels in North-East Jakarta, these are the Cakung Drain, Banjir Kanal Timur (East Flooding Canal or BKT) and the Sunter. The scope is enclosed by the catchment area of the Sunter and the BKT, including all the debouching channels upstream from the BKT. This area includes:

<u>Rivers downstream:</u>
- Sunter
- Old Cakung

<u>Rivers upstream:</u>
- Buaran
- Jatikramat
- Cakung
- Higher Sunter
- Kali Capinang

<u>Flood canal/drains:</u>
- Banjir Kanal Timur
- Cakung drain

<u>Other:</u>
- Tanjung Priok (port)
- OPQ islands
- Fishing ponds
- Polders

The project scope for the hydraulic boundaries may change when eq. a retention basin, which contains more debouching rivers is necessary. Throughout the report the term East Jakarta is used to refer the scope (North-East Jakarta). When a distinction is made between the upstream and downstream area, the terms North and South Jakarta are used. North Jakarta refers to North-West and North-East Jakarta together.

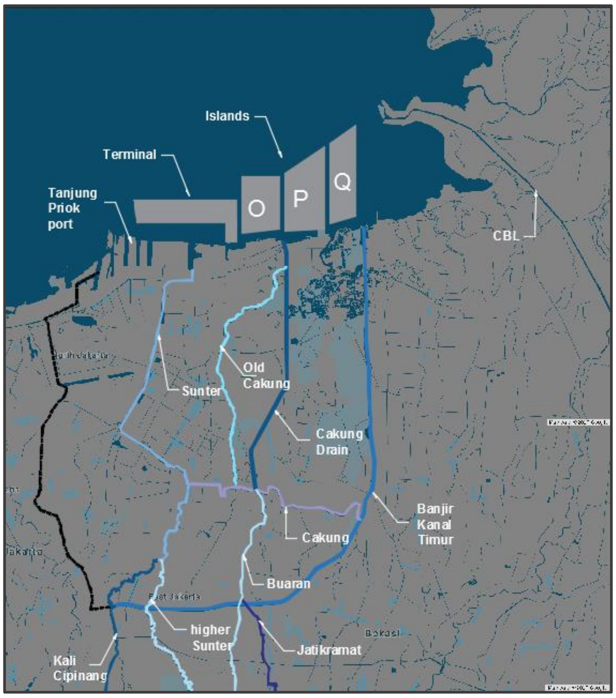



FIGURE 1.2: PROJECT SCOPE

## 1.3. Purpose

The purpose of this report is to come with interventions to cope with the different scenarios of land subsidence to protect East Jakarta against flooding. The research is based on the research done for West Jakarta by the NCICD project. With the new subsidence data of Henk Kooi (2017), 3D- subsidence scenarios are made with the help of an extrapolation model. Depending on the subsidence scenarios, four solutions are investigated: flood defences along the river, inland retention lakes, outer sea dike and closing off the rivers. For the 'flood defence along the river' solution a spatial analysis is done. In Google Earth the areas along the rivers are divided in six different social classes. With the help of this analysis land acquisition costs are calculated for three different flood defences along the river with an extensive Excel model. Based on a flood risk analysis a safety level of the dike is chosen. From this model follows the optimum costs of the solution. Models are also made in Excel to calculate the total costs of the other three solutions.

The pros and cons for each concept will be discussed. Eventually, the most attractive design follows and will be further discussed. For this design, it is estimated when to start with the solution with a Dynamic Adaptive Policy Pathway approach (DAPP). After that, a time schedule is given.

## 1.4. Structure

The emphasis in this report is finding conceptual solutions against flooding in the Eastern part of Jakarta. In the first chapter the problem is described. Chapter 2 is about all the boundary conditions relevant for this project. Chapter 3 explains to which land subsidence scenarios the growth may lead, giving ranges of subsidence rates. The ranges are used to formulate 3D-subsidence scenarios. In Chapter 4 a spatial analysis is done, which will be used at a later time in the report. In Chapter 5, four alternatives for flood safety are formulated. For each alternative the total costs are calculated depending on a chosen subsidence scenario. In Chapter 6, the pros and cons for each alternative are discussed and new combinations are defined. Finally, one optimum concept is chosen. This concept is being worked out in chapter 7. This considers the elaboration of the design checks, the construction method and a time schedule. The time schedule is based on the pathway analysis and the derived construction time. In Jakarta, companies deal with accuracy in a completely different way than European companies. The last chapter is dedicated to a discussion about the accuracy level.

# 2. BOUNDARY CONDITIONS

In defining the boundary conditions, most of the data generated for West Jakarta is used. This data is needed to be interpreted and translated to boundary conditions for East Jakarta. Some boundary conditions are only used qualitatively in the following chapters of this report. As well as the hydraulic conditions, also the hydrologic and other boundary conditions are determined.

## 2.1. Hydraulic conditions

### 2.1.1. Benchmark and reference levels

The benchmark to express the relative sea level in Jakarta expressed in PP*, which stands for Peil Priok* (2002). PP* is defined by fixing a long pole in the sub soil of Tanjung Priok [van de Watering, 2017].

Many benchmarks have been used in the past (MSL, NWP, PP, PKN, and PPK). Because MSL is used worldwide the difference between the different benchmarks relative to MSL is shown in Figure 2.1.

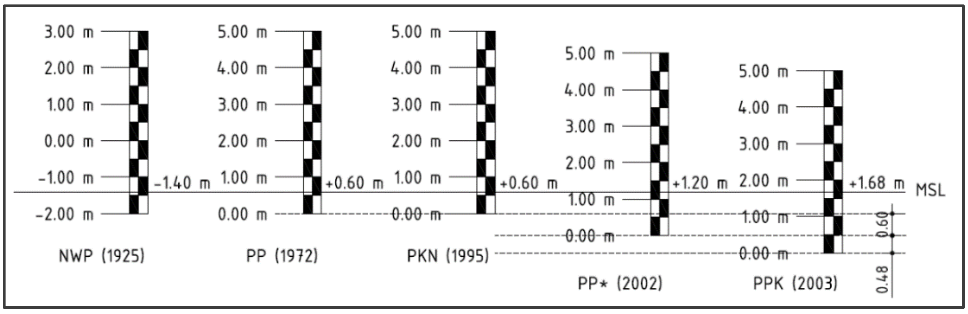



FIGURE 2.1: OVERVIEW DIFFERENT BENCHMARKS (NCICD- FLOOD SAFETY AND BASIC DESIGN)

The tidal data measurements at Sunda Kelapa (Figure 2.2) is used as reference. This reference was also used for West Jakarta. To analyse the tidal prediction measurement data, tidal constants of August 2012 are used. It is stated that for land reclamation projects in Jakarta the World Geodetic System coordinate system (WGS-84) and the vertical reference level of LWS (Lowest Water Spring) are used.

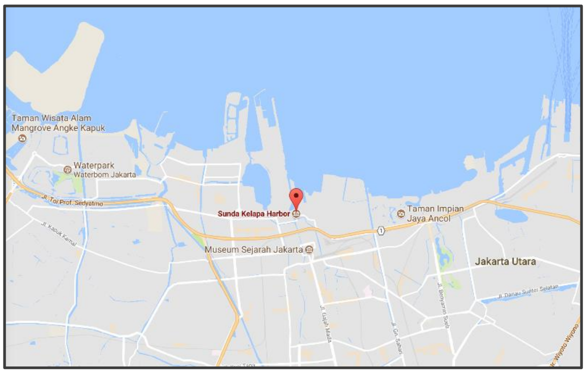



FIGURE 2.2: SUNDA KELAPA (GOOGLE MAPS)

Because water levels are subjected to sea level rise, the benchmark used is the $LWS_{2012}$. $LWS_{2012}$. will be used throughout the report.

### 2.1.2. Tidal data

The tidal ranges in Jakarta bay change during the year approximately 20 cm. Measurements were done by Deltares in 2007 in the FHM1 report. A graph of the change in tidal range for Tanjung Priok and Pelabuan Ratu is shown in Figure 2.3. [van Veen, 2013]

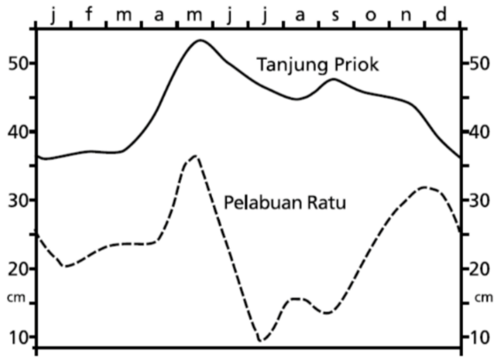



FIGURE 2.3: TIDAL RANGE IN JAKARTA OVER A DURATION OF 12 MOTHS (DELTARES 2007 FHM1 REPORT)

By measuring the tidal data at Sunda Kelapa for a period of 18.6 years the tidal predictions were defined by NCICD. In combination with the $LWS_{2012}$ this resulted in the specific tidal levels shown in Table 2.1. Note that seasonal water level influence is not included.

TABLE 2.1: TIDAL LEVELS (NCICD)

| tidal characteristics | abbreviation | April 2013 |
|---|---|---|
| | | [LWS + m] |
| Highest High Water Spring | HWS | 1.19 |
| Mean High Water Spring | MHWS | 1.00 |
| Mean High Water Neap | MHWN | 0.82 |
| Mean Sea Level | MSL | 0.55 |
| Mean Low Water Neap | MLWN | 0.31 |
| Mean Low Water Spring | MLWS | 0.11 |
| Lowest Low Water Spring | LWS | 0.00 |

The tidal data can be schematized in a more understanding way (Figure 2.4). In this figure, the tidal data for 7 days in Jakarta bay is shown. From Figure 2.4 it can be seen that every day there are 2 peaks.

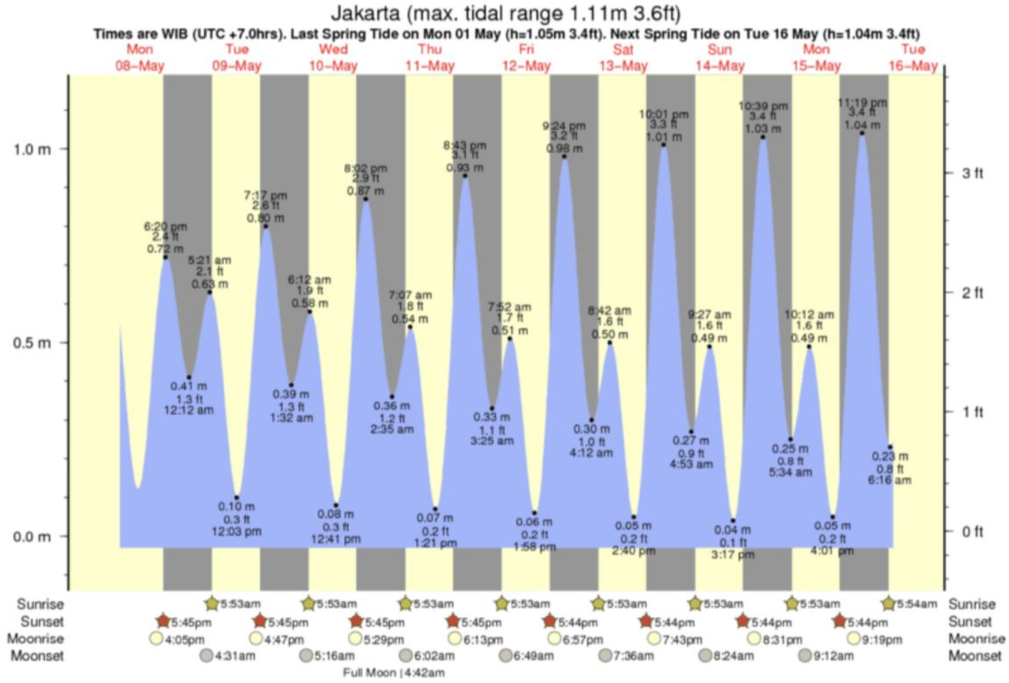



FIGURE 2.4: TIDAL RANGE JAKARTA BAY (NCICD FLOOD SAFETY AND BASIC DESIGN)

### 2.1.3. Design water level

The design water level (DWL) is the still water level that has to be taken into account to successfully design a sea defence. The design water level is the maximum water elevation, which includes flood surcharge. To determine the DWL of East Jakarta a statistical analysis of long period measurements is required. The former boundary conditions were based on old data, since a statistical analysis is done for a period of 6 years (2007-2013) this data will be used to define the most up-to-date boundary conditions.

#### *2.1.3.1. Water level anomalies*

Based on statistical analysis, the water level anomalies are calculated (Table 2.2) [van de Watering, 2017]. Water level anomalies represent the regional extent of anomalous water levels of the sea. HWS is not taken because the difference between the tides is already included in the water level anomalies.

TABLE 2.2: WATER LEVEL ANOMALIES [VAN DE WATERING, 2017]

| Return Period | 1000 year | 10000 year |
|---|---|---|
| Existing coastline [m + MHWS] | 0.69 | 0.79 |
| Depth -15 m [m + MHWS] | 0.48 | 0.53 |

#### 2.1.3.2. *Seasonal influence and oceanic current*

To consider seasonal influences by large wind driven oceanic current patterns and weather phenomena, 0.27 m is added to the water level, which is included in the design water level calculation. This value is based on the research done by NCICD on the probability of exceedance of seasonal water level influences in combination with oceanic currents. [Veen, 2013]

#### 2.1.3.3. *Effect of wind set-up/storm surge*

Different stages can be considered, for this report stage I is used. Stage I describes the project without land reclamation, which is most similar to the situation considered in this report. The effect of wind set-up and storm surge is dependent on the water depth. Since the water depth is different for each stage this must be taken into account [Veen, 2013]. In Table 2.3 it can be seen that the wind set-up for stage III is half of the wind set-up for stage I and II. Considering the project scope for East Jakarta a wind set-up of stage I is used.

TABLE 2.3: WIND SET-UP RELATED TO THE RETURN PERIOD

| **return period** | **[yr]** | **1** | **10** | **100** | **1,000** | **10,000** |
|---|---|---|---|---|---|---|
| stage I/II | [m] | 0.07 | 0.12 | 0.17 | 0.27 | 0.37 |
| stage III | [m] | 0.03 | 0.06 | 0.08 | 0.13 | 0.18 |

#### 2.1.3.4. *Wave set-up and shoaling*

A wave set-up of 0.15 m and 0.075 m (stage I and II) are considered for West Jakarta. For East Jakarta, a wave set-up of 0.15 m is taken into account.

#### 2.1.3.5. *Sea level rise*

According to the most up-to-date information about sea level rise near Jakarta a sea level rise of 8 mm/year is considered [Veen, 2013].

#### 2.1.3.6. *The design water level*

The change in water depth is not taken into account for the water level anomalies shown in Table 2.4 and Table 2.5. By taking this effect and the other hydraulic conditions into account the design water level for 1/1000 year and 1/10000 year are calculated [Veen, 2013].

TABLE 2.4: DESIGN WATER LEVELS FOR A 1/1000 YEAR RETURN PERIOD [VEEN, 2013]

| year of expiry | 2022 | 2030 | 2040 | 2050 |
|---|---|---|---|---|
| mean high water spring (MHWS) | 1.00 | 1.00 | 1.00 | 1.00 |
| water level anomaly | 0.69 | 0.69 | 0.69 | 0.69 |
| sea level rise | 0.08 | 0.14 | 0.22 | 0.30 |
| design water level | 1.77 | 1.83 | 1.91 | 1.99 |

TABLE 2.5: DESIGN WATER LEVELS FOR A 1/10000 YEAR RETURN PERIOD [VEEN, 2013]

| year of expiry | 2030 | 2040 | 2050 | 2080 |
|---|---|---|---|---|
| mean high water spring (MHWS) | 1.00 | 1.00 | 1.00 | 1.00 |
| water level anomaly | 0.53 | 0.53 | 0.53 | 0.53 |
| sea level rise | 0.14 | 0.22 | 0.30 | 0.54 |
| **design water level** | **1.67** | **1.75** | **1.83** | **2.07** |

### 2.1.4. Wave conditions

To analyse wave conditions in Jakarta Bay the Swan wave model is used [Veen, 2013]. This analysis was done for the entire bay of Jakarta (73 locations from West to East). Every 500 m of the West and East coast of Jakarta the waves are measured. Because of model inaccuracies a design factor of 1.1 (10%) is taken into account. From the analysis, it became clear that the design values of the waves vary along the coast [van der Watering 2017]. Figure 2.5 shows the output from Swan wave model for phase I, which will be used for East Jakarta in this report.

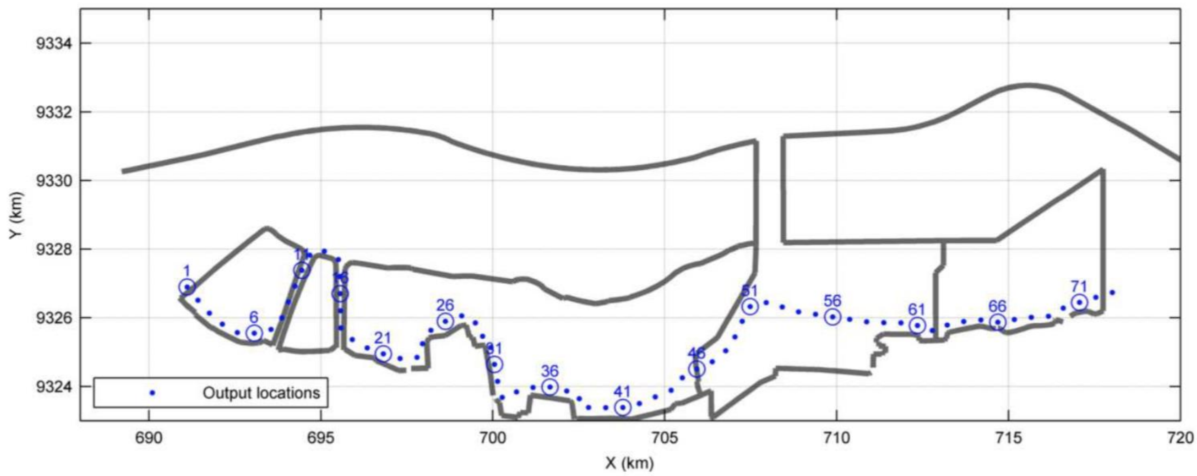



FIGURE 2.5: SWAN WAVE MODEL OUTPUT [VAN VEEN, 2013]

From the measurements at the different locations the governing (maximum) wave conditions are shown. In the exact numbers from the analysis are given. The segments F and G Table 2.6 and Table 2.7 are applicable to East Jakarta since these segments are in East Jakarta.

TABLE 2.6: MAXIMUM WAVE CONDITIONS LOCATION A-H [VEEN, 2013]

| **Segment** | | | **RP 1 year** | | | **RP 10 year** | | | **RP 100 year** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| name | first point | last point | $H_{m0}$ [m] | $T_{m-1,0}$ [s] | $T_p$ [s] | $H_{m0}$ [m] | $T_{m-1,0}$ [s] | $T_p$ [s] | $H_{m0}$ [m] | $T_{m-1,0}$ [s] | $T_p$ [s] |
| A | 1 | 7 | 1.0 | 4.5 | 6.9 | 1.3 | 5.4 | 7.6 | 1.6 | 6.0 | 8.6 |
| B | 8 | 11 | 1.1 | 4.5 | 6.1 | 1.5 | 5.2 | 7.1 | 2.1 | 6.3 | 8.4 |
| C | 12 | 15 | 1.2 | 4.5 | 6.2 | 1.7 | 5.4 | 7.1 | 2.4 | 6.5 | 8.4 |
| D | 16 | 18 | 1.0 | 4.9 | 6.4 | 1.5 | 5.9 | 7.3 | 2.2 | 6.9 | 8.4 |
| E | 19 | 50 | 1.4 | 5.1 | 7.4 | 1.8 | 5.7 | 7.8 | 2.1 | 6.6 | 8.5 |
| F | 51 | 61 | 1.6 | 5.3 | 6.3 | 2.1 | 5.9 | 7.2 | 2.4 | 6.6 | 8.6 |
| G | 62 | 73 | 1.2 | 5.1 | 6.5 | 1.3 | 5.7 | 7.6 | 1.4 | 6.3 | 9.0 |

TABLE 2.7: MAXIMUM WAVE CONDITIONS LOCATION A-H [VEEN, 2013]

| Segment | | | RP 1,000 year | | | RP 10,000 year | | |
|---|---|---|---|---|---|---|---|---|
| name | first point | last point | $H_{m0}$ [m] | $T_{m-1,0}$ [s] | $T_p$ [s] | $H_{m0}$ [m] | $T_{m-1,0}$ [s] | $T_p$ [s] |
| A | 1 | 7 | 1.7 | 6.5 | 10.0 | 1.8 | 6.9 | 11.3 |
| B | 8 | 11 | 2.7 | 7.2 | 9.4 | 3.3 | 7.8 | 10.5 |
| C | 12 | 15 | 3.0 | 7.3 | 9.4 | 3.7 | 8.0 | 10.6 |
| D | 16 | 18 | 2.9 | 7.6 | 9.5 | 3.2 | 8.1 | 10.8 |
| E | 19 | 50 | 2.3 | 7.1 | 9.9 | 2.4 | 7.6 | 12.5 |
| F | 51 | 61 | 2.5 | 7.1 | 10.3 | 2.7 | 7.4 | 12.4 |
| G | 62 | 73 | 1.6 | 6.9 | 10.5 | 1.7 | 7.3 | 12.4 |

### 2.1.5. Earthquakes and potential tsunami

Exact tsunami parameters are hard to determine, because it depends on the epicentre of the earthquake and local conditions. Because of this, the design in the West is not designed for a tsunami. But the design has to withstand a tsunami and this will be evaluated in the detailed engineering phase [Veen, 2013].

NCICD (2014) has evaluated the highest possible tsunami for East Jakarta. The tsunami height at a depth of 10 meter is 0.9 m and the wave period is equal to 120 min. Horizontal movements and slope stability for the possible solution in East Jakarta have to be checked.

In Indonesia, there is an earthquake design code (SNI, 2002) in which the Region is divided in six earthquake zones. Jakarta lies in zone 4, so this gives an PGA (Peak Ground Acceleration) of 0.9g for a return period of 500 years. The structures in Jakarta have to be designed for a PGA of 0.36g [Coenen, 2014]. The corresponding seismic coefficients for this earthquake acceleration can be calculated in the following way [Liang, 2011]. In this formula a soil factor is used of 2.0 (soft soil) [Emergency Preparedness Canada, 1999] and r depends of the type of structure and is given in Table 2.8.

$$k_h = \frac{a_{pga}}{g}\frac{S}{r} \quad (2.1)$$

$$k_v = 0.33\ k_h \quad (2.2)$$

TABLE 2.8: COEFFICIENT RELATING THE SEISMIC COEFFICIENT TO THE AMOUNT OF ACCEPTED WALL DISPLACEMENT [EUROCODE 8]

| Type of retaining structure | r |
|---|---|
| Free gravity walls that can accept a displacement $d_r$ < 300 (mm) $a_g \gamma_i g S$ | 2 |
| As above with $d_r$<200 $a_g \gamma_i g S$ (mm) | 1.5 |
| Flexural reinforced concrete walls, anchored or braced walls reinforced concrete walls founded on vertical piles, restrained basement walls and bridge abutments | 1 |

## 2.1.6. River system

In this section, the rivers and drains are inventoried together with their important characteristics.

Rivers and drains may cause flooding in two ways. First, some of the rivers and drains are directly connected to the sea and therefore will partly follow the height of the sea during high water levels due to the backwater effects. Secondly, the rivers and drains need to discharge the rain, which has fallen in the city but some of them also have to deal with the flood waves evolving by rainfall in the upstream catchment areas.

The main channels in East Jakarta are the Banjir Kanal Timur, the Cakung Drain and the Sunter. These channels are discussed in the next subsections. The river system for East Jakarta is illustrated in Figure 2.6**.**

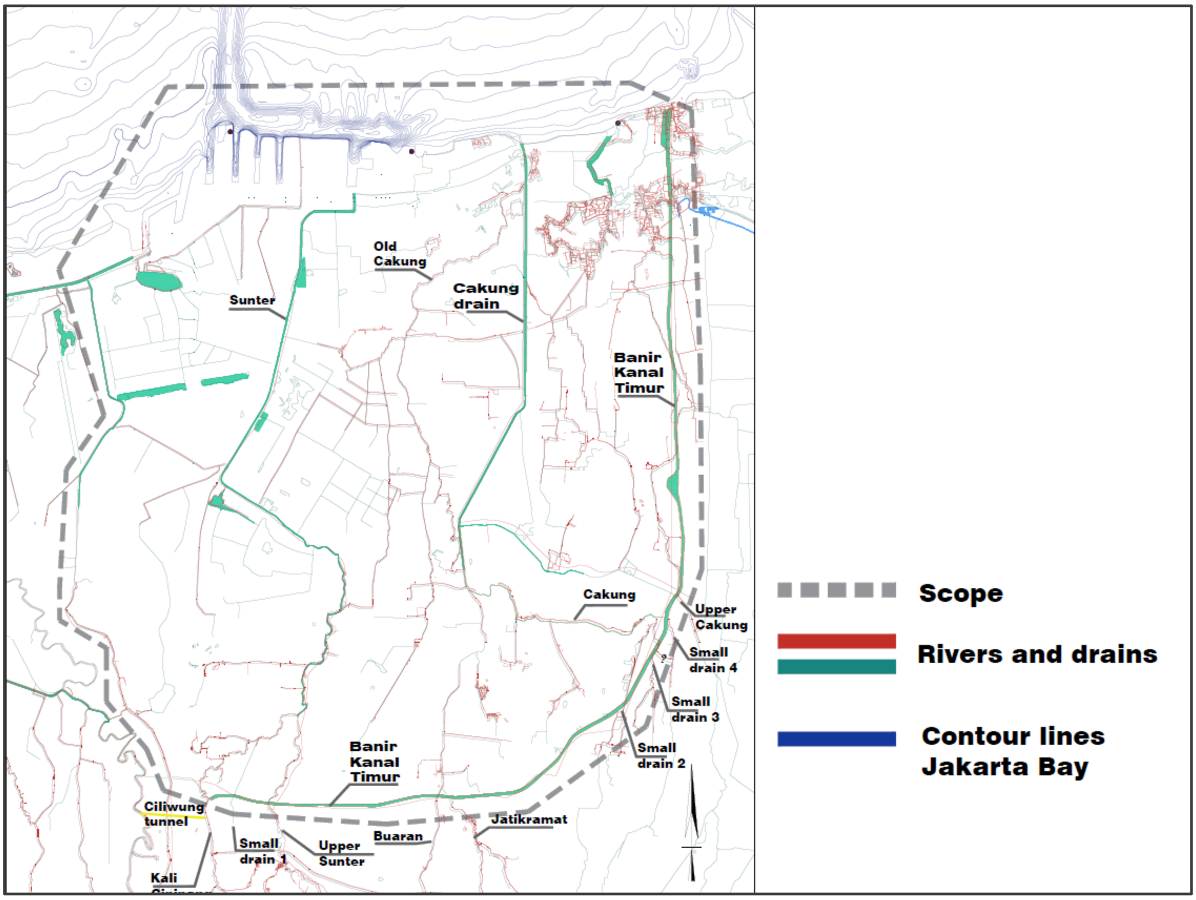



FIGURE 2.6: RIVERS AND DRAINS EAST JAKARTA

### 2.1.6.1. *Banjir Kanal Timur*

The river with highest discharge in the east is the Banjir Kanal Timur (BKT). Due to the construction of the BKT in 2008 the risk of flooding in the eastern part of Jakarta is already reduced. By interrupting the big rivers coming from upstream, the BKT is discharging all the water from the upstream region. Because of this, the rivers north and west of the BKT only need to discharge the local rainfall.

The rivers, which are interrupted are the Cipinang, Upper Sunter, Buaran, Jatikramat and the Upper Cakung. Also some small drains flow into the BKT but due to low discharges they are not been taking into account in the model.

The BKT is build up by three components, which can be separated by gates. During low discharge conditions these gates will be closed to make it possible to open the gates to the rivers downstream of the BKT and flush them. During high discharge conditions the gates to the downstream rivers are closed and they will discharge all the water from the upstream catchment areas.

Probably in the future also the Marunda Polder needs to discharge in the BKT. It is planned to build a pumping station, but it is uncertain when this will be done.

Also, a bypass has been built from the Cilliwung to the BKT to reduce discharge in the Banjir Kanal Barat (BKB), designed for a maximum discharge of 60 $m^3/s$. At this moment, the tunnel is finished but the entrances are not yet completed due to a lawsuit.

#### *2.1.6.2. Sunter*

During high flow conditions the Sunter only needs to discharge the rain from the local rainfall, because of the interruption of the BKT. The total area of the Sunter catchment is 39.44 $km^2$ of which 15.5 $km^2$ can still discharge under gravity. In Figure 2.7 the catchment area of the Sunter is given. It could be seen that there is an area of 10.25 $km^2$, which could be drained to the Cakung drain or to the Sunter drain, this should be regulated. At the Kali Item at 7.1 km from the coast there is a gate, which can divert the Cempaka Putih into the Sunter or into the Marina Sentiong polder. The Cempaka Putih has a catchment area of 8.02 $km^2$.

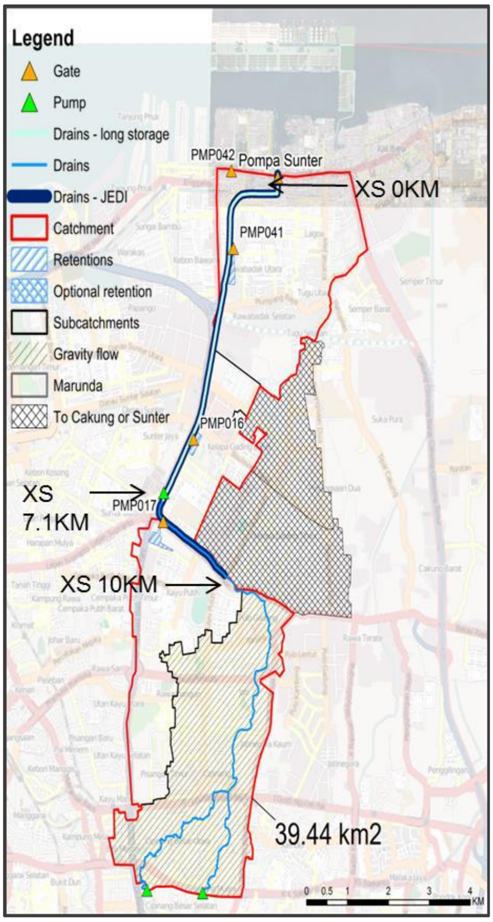



FIGURE 2.7: SUNTER CATCHMENT [DELTARES, 2014]

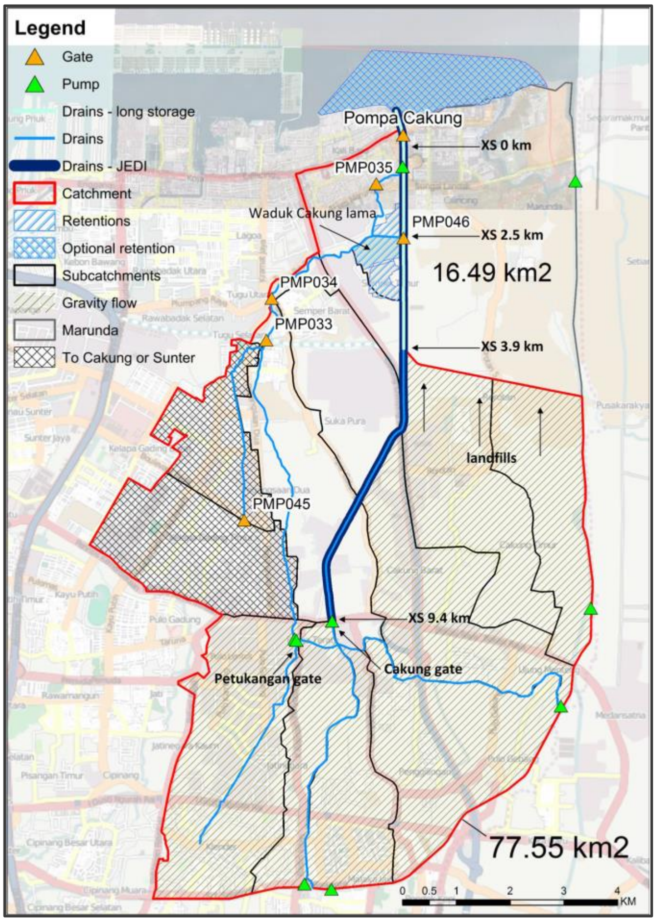



FIGURE 2.8: CAKUNG CATCHMENT [DELTARES 2014]

### *2.1.6.3. Cakung area*

The Cakung area has two main waterways, the Old Cakung and the Cakung Drain. At 1 km from the sea the Old Cakung flows into the Cakung Drain.

In Figure 2.8 the catchment area of the Cakung Drain is given. At this moment the total area of the Cakung catchment is 67.35 km². As said in section 2.1.6.2, the area of 10.25 km² should be divided into the Sunter or the Cakung polder, this depends on which is most favourable.

## 2.1.7. Polders and pumping system

In this section, the polders and catchment areas are described along with the pumping stations in East Jakarta. In Figure 2.9 the polder areas in East and West Jakarta are illustrated [DKI Jakarta]. As already explained in previous section, the polders discharge water to the Sunter and Cakung Drain. All the pumping stations related to the polders are inventoried. NCICD has already proposed new locations for pumping stations. In Figure 2.10 the existing and proposed pumping stations are illustrated for East Jakarta, including the relevant water gates.


| No | Nama | Daerah Layanan (Ha) |
|---|---|---|
| 1 | Rawa Buaya | 50.00 |
| 2 | Cengkareng Timur | 450.00 |
| 3 | Kapuk Poglar | 650.00 |
| 4 | Pantai Indah Kapuk Utara | 250.00 |
| 5 | Pantai Indah Kapuk Selatan | 150.00 |
| 6 | Muara Angke | 50.00 |
| 7 | Muara Karang | 75.00 |
| 8 | Pluit Industri | 50.00 |
| 9 | Teluk Gong | 90.00 |
| 10 | Jelambar Barat (Wijaya Kusum | 100.00 |
| 11 | Jelambar Timur | 100.00 |
| 12 | Tomang Barat | 170.00 |
| 13 | Grogol | 80.00 |
| 14 | Rawa Kepa | 229.00 |
| 15 | Jati Pulo | 45.00 |
| 16 | Pluit | 2.083.00 |
| 17 | Siantar Melati | 860.00 |
| 18 | Setiabudi Barat | 216.00 |
| 19 | Setiabudi Timur | 132.00 |
| 20 | Mangga Dua | 160.00 |
| 21 | Pademangan | 635.00 |
| 22 | Kemayoran | 850.00 |
| 23 | Sumur Batu | 278.00 |
| 24 | Sunter Selatan | 340.00 |
| 25 | Sunter Barat | 1,250.00 |
| 26 | Sunter Timur I Kodamar | 200.00 |
| 27 | Sunter Timur 1B (Utara) | 600.00 |
| 28 | Sunter Timur III Rawa Badak | 570.00 |
| 29 | Sunter Timur II Kebantenan | 528.00 |
| 30 | Sunter Timur II KBN | 600.00 |
| 31 | Sunter Timur II Petukangan Ck | 253.00 |
| 32 | Perum Walikota (Don Bosco) | 90.00 |
| 33 | Marunda | 2,240.00 |
| 34 | Penggilingan | 103.00 |
| 35 | Istana Merdeka | 15.00 |
| 36 | Hankam Slipi | 4.00 |
| 37 | Komplek TVRI Cengkareng | 7.00 |
| 38 | Pulomas | 460.00 |
| 39 | Tanjungan/Tegal Alur | 390.00 |
| 40 | Kapuk Muara 1,2 & 3 | 220.00 |
| 41 | Industri / Gn. Sahari | 60.00 |
| 42 | Penjaringan Junction | 200.00 |
| 43 | Kedoya Green Garden | 260.00 |
| 44 | Kedoya Taman Ratu Greenvile | 155.00 |
| 45 | Kali Deres | 950.00 |
| 46 | Komplek Dewa Ruci | 16.00 |
| 47 | Komplek Dewa Kembar | 140.00 |

FIGURE 2.9: POLDER AREAS NORTH JAKARTA [DKI JAKARTA]

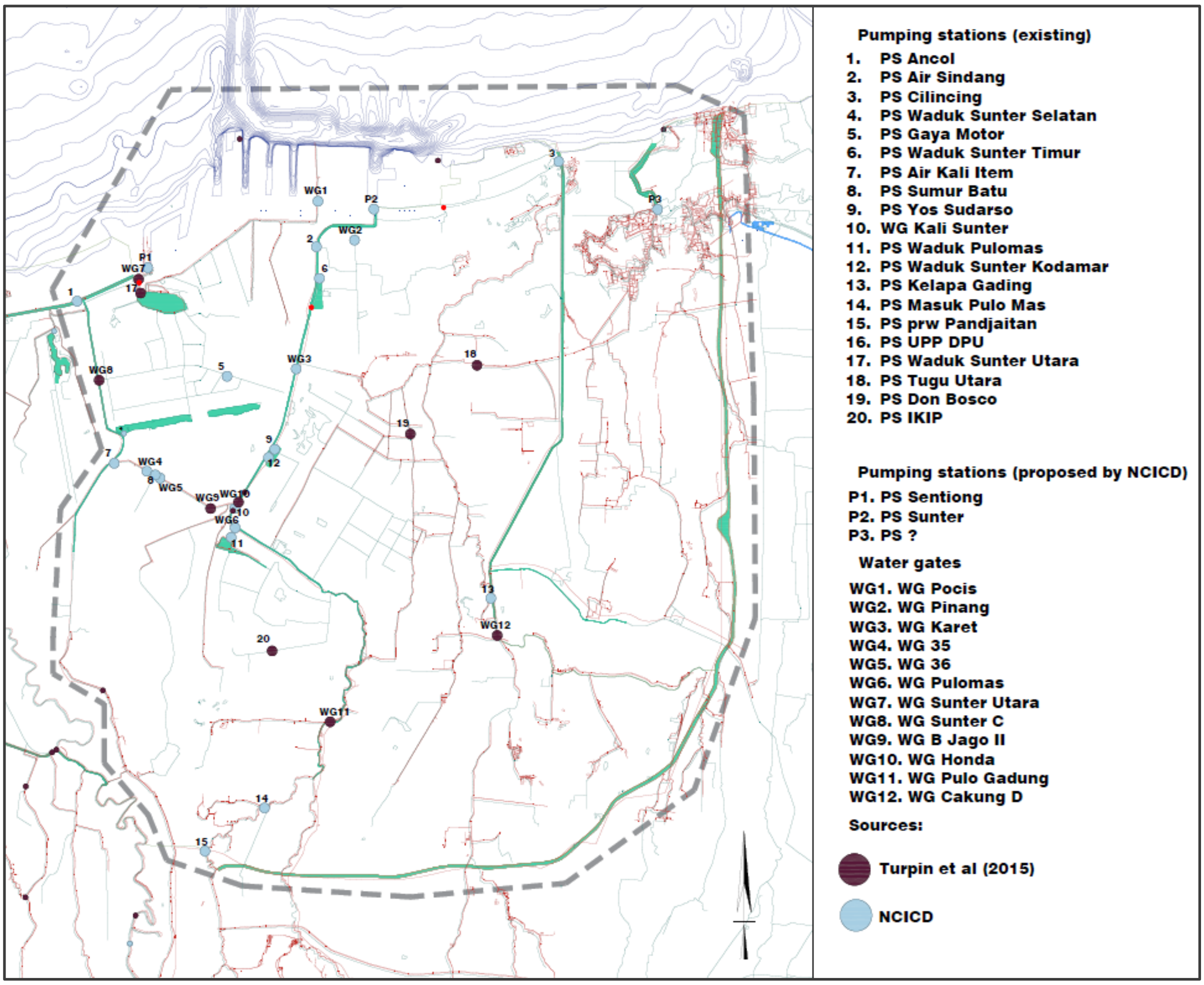



FIGURE 2.10: PUMPS AND WATER GATES

## 2.2. Hydrologic conditions

There are a lot of uncertainties in defining the hydrologic conditions. Due to a lack of data about river discharge and rainfall, often scenarios are made based on the 2007 extreme rainfall event. Some important data, which is also used for the original Master plan of 2014 is described and translated into design values for extreme wet events.

### 2.2.1. Water balance of the East

The water balance in East Jakarta will be subjected to changes when designing solutions. Therefore an overview of the existing in- and outflow is given in Figure 2.11. Inside the polders there are several drainage canals leading to the lowest point where it is pumped to the rivers outside the polder. Deep groundwater can be seen as an input, because the used water origins from underground layers, which has no influence on the surface water. When there will be a switch from groundwater to treated raw water, the used water is an input in the water balance, which needs to be pumped away if it is not evaporated. In case of a gravity based catchment area, there is no need for pumping. This flow is called Runoff. [Van Steijn, 2014]

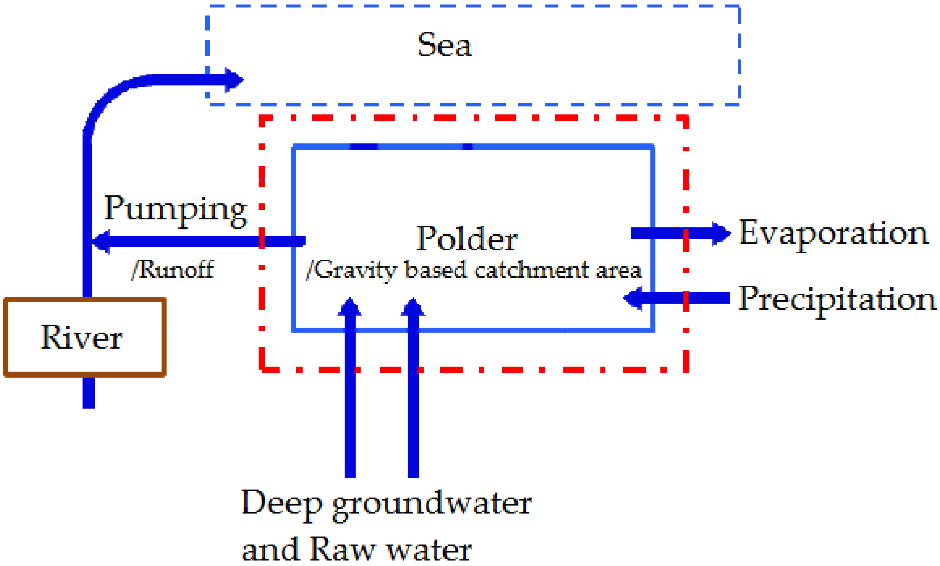



FIGURE 2.11: WATER BALANCE COMPONENTS

### 2.2.2. Rainfall

The past 15 years rainfall is not monitored very well. So, the amount of rainfall is based on the 2007 extreme rainfall event and the derived design rainfall in NEDECO [1973] and JICA[1996].

#### *2.2.2.1. Daily rainfall event*

In this report, it is assumed that the daily rainfall in West Jakarta is equal to the daily rainfall in East Jakarta. During rainy seasons, rainfall is moving from West to East, so there is an overestimation in East Jakarta [Deltares, 2016].

The daily maximum amount of rainfall with a return period of 2 years is equal to 98 – 108 mm/day. For a return period of 100 years, it is equal to 231 - 238 mm/day. To transform the maximum daily rainfall to the maximum 24-hour rainfall a correction factor of 1.13 is needed [Brinkman, 2013]. After applying this, the design rainfall is respectively equal to 111 – 122 mm/day and 261 - 269 mm/day. Average values of 117 and 265 mm/day are used.

Due to climate change rainfall patterns will change, this will lead to more extreme rainfall intensities. The rainfall in the southern part will decrease (less rainfall in the dry season), while the rainfall in the northern part will increase (more rainfall in the wet season). The increase in rainfall in 2080 is equal to 10% and the decrease is equal to 5% to 15%. So, the design rainfall becomes 122 – 134 mm/day for a return period of 2 years and for the 100 years return period it becomes 287 – 296 mm/day in 2080. With average values of 128 and 292 mm/day. [van de Watering, 2017].

#### 2.2.2.2. *Multi-day event*

For West Jakarta different multi-day events (3, 6, 16 days) are used to describe the 2007 extreme rainfall event. In this report a three-day event will be used. The first two days are described with a 1:2 event and the last day is described with a 1:100 event, see Table 2.9. The rainfall is equally distributed per hour.

TABLE 2.9: THREE- DAY RAINFALL EVENT

| Day | Rainfall [mm/day] | Rainfall per hour [mm] | Return period [years] |
|---|---|---|---|
| **Day 1** | 128 | 5.3 | 2 |
| **Day 2** | 128 | 5.3 | 2 |
| **Day 3** | 292 | 12.2 | 100 |

#### 2.2.2.3. *Areal reduction factor*

An areal reduction factor (ARF) is used to transform the design rainfall to catchment rainfall. This factor depends on the duration and catchment size. The ARF's can be calculated with formula 2.3 [Deltares, 2014]. The area has to be filled in in km².

$$ARF = 1 - \alpha A^{\beta} \qquad 2.3$$

TABLE 2.10: FITTING PARAMETERS FOR EQAUATION 2.3, DEPENDING ON DURATION [DELTARES, 2014]

| Duration | α | β |
|---|---|---|
| **1h** | 0.025 | 0.57 |
| **2-5h** | 0.015 | 0.61 |
| **12h** | 0.01 | 0.61 |
| **24h** | 0.004 | 0.69 |

### 2.2.3. Runoff

The runoff will be calculated using a soil conservations surface (SCS) method in combination with ARF's. This SCS method does not take into account groundwater storage, but for single high intensity rainfall events it can be used.

The method takes as input parameter the curve number (CN), which is for catchments like Jakarta (strongly urbanized) assumed to be 95. [Deltares, 2014]

The initial abstractions are all losses before runoff begins. These losses are due to water retained in surface depressions, water interception by vegetation and evaporation and infiltration. These losses are assumed to be 20% of the potential maximum retention after runoff begins. [Deltares, 2016]

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \qquad P > I_a \tag{2.4}$$

$$Q = 0 \qquad P \leq I_a \tag{2.5}$$

$$S = 254\left(\frac{100}{CN} - 1\right) \tag{2.6}$$

$$I_a = 0.2S \tag{2.7}$$

Where:

- $Q$ = Catchment runoff [mm]
- $P$ = Rainfall [mm]
- $S$ = Potential maximum retention after runoff begins [mm]
- $I_a$ = Initial abstraction [mm]

From this follows that $S$ is equal to 13 mm, $I_a$ to 3 mm and $P$ is dependent of the rainfall event. The influence of the ARF is larger than the influence of the SCS method for multi-day events.

The time lag at which the first run-off reaches the sea is calculated with the formula below.

$$t_L(\text{min}) = 60\frac{L^{0.8}(2{,}540 - 22.86CN)^{0.7}}{14{,}104CN^{0.7}Y^{0.5}} \tag{2.8}$$

Where:

- $t_l$ = time lag [minutes]
- $L$ = flow path [m]
- $CN$ = SCS Curve Number
- Y = average sub-basin slope [m/m]

### 2.2.4. River scenarios

In this section the maximum discharges and water levels are calculated.

#### *2.2.4.1. Water level rivers*

The water levels for the rivers are modelled in SOBEK by Deltares (2014). These models are based on a 1/100 rainfall event and uses a catchment area and runoff which are also modelled in SOBEK.

#### 2.2.4.2. *Discharge rivers*

Because Deltares is currently working on the SOBEK model, in this report the discharges needed to be calculated in a simplified way. This may be less accurate, but for the moment this will give a good indication.

To determine the discharge in the river, a multi-day rainfall event is used of three days, 1/2 year event, 1/2 year event and a 1/100 year event. By using the runoff model from section 2.2.3 the discharges are calculated, The catchment areas of the Sunter, Cakung Drain and the Old Cakung are based on the report of Deltares (2014). The catchment areas of the BKT are described in the ATLAS (2011) and include the Cipinang, Upper Sunter, Buaran, Jatikramat and the upper Cakung. This will lead to a discharge event per river as is given in the graph below.

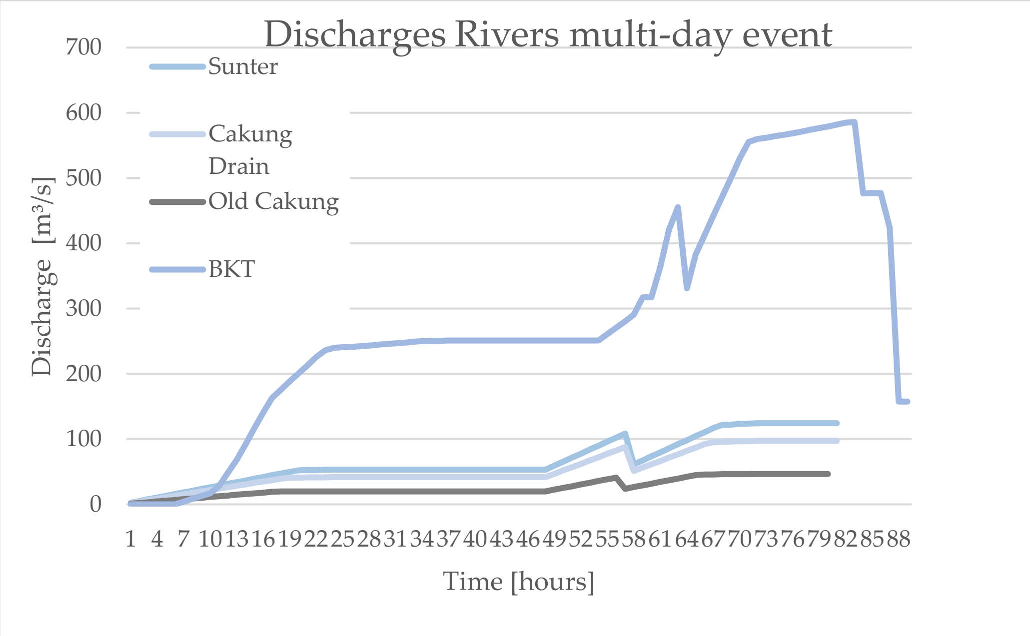



FIGURE 2.12: DISCHARGE PER RIVER BASED ON A MULTI-DAY EVENT

### 2.2.5. Evaporation

Open water evaporation in Jakarta varies between 5 to 10 mm/day. In West Jakarta an evaporation of 5 mm is assumed by Deltares [Watering, 2017]. The same value is used for East Jakarta.

### 2.2.6. Raw water demand and supply

At this moment the largest part of the water demand is supplied by deep water extraction. A smaller part by raw water via pipelines. Raw water is untreated and directly taken from a water reservoir. For designing the water balance the raw water supply can be dominant. When there is a shift from groundwater extraction to treated raw water use (no groundwater extraction in 2030), like stated in the spatial planning of DKI Jakarta, the raw water demand will rise. However, at this moment there is a limited capacity of raw water sources and pipelines.

The largest raw water source is from the Jatiluhur dam (PDAM). From this source a supply of 9.0 m3/s is planned until 2050. In the research done, a conservative approach is used, considering no water supply after 2050 from the Jatilhur dam. [Waryono, 2013]

#### *2.2.6.1. Water demand*

The situation in 2010 is used as reference, when total population of Jakarta consisted of 9.6 million domestic and 2.5 million commuters. Domestic water demand is estimated to be 160 L/d/p and commuter water demand is estimated to be 50 L/d/p. [Waryono, 2013]

The estimated total population of Jakarta is growing fast and in 2017 estimated to be about 10 million domestic and about 3.0 million commuters. The eastern part is still less densely populated than the western part of Jakarta (after analysis of aerial photographs assumed to be ¼ of total), but it will become as densely populated as west in the future (assumed ½ of total). In 2017 it is estimated that about 2.500 million people (assumed ¼ of total) are living in East Jakarta and 0.750 million commuters (assumed ¼ of total). Like done in West Jakarta, it is expected that in the future, 2030 and onward, the domestic water demand is expected to be lower due to a change in mindset. From 2040 and onward, it is assumed that east and west will growth at the same rate (½ of total). The population growth is 1.4 % in 2010-2030 and expected to decrease proportionally to 0.4 % in 2070-2080. In Table 2.11 the estimated water demand in East Jakarta is shown. [Jakarta Population 2017]

TABLE 2.11: WATER DEMAND IN EAST JAKARTA

| PARAMETER | UNIT | 2010 | 2017 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 |
|---|---|---|---|---|---|---|---|---|---|
| POPULATION DOMESTIC (×MILJ.) | pop | 2.40 | 2.50 | 3.17 | 7.14 | 7.89 | 8.54 | 9.07 | 9.44 |
| POPULATION COMMUTER (×MILJ.) | pop | 0.625 | 0.750 | 0.825 | 1.86 | 2.05 | 2.23 | 2.36 | 2.46 |
| DOMESTIC WATER DEMAND | L/d/p | 160 | 150 | 150 | 150 | 150 | 150 | 150 | 150 |
| COMMUTER WATER DEMAND | L/d/p | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| TOTAL DOMESTIC WATER DEMAND (XMILJ.) | L/d | 384 | 375 | 475 | 1070 | 1180 | 1280 | 1360 | 1420 |
| TOTAL NON-DOMESTIC WATER DEMAND (×MILJ.) | L/d | 31.3 | 37.5 | 41.3 | 93.0 | 103 | 111 | 118 | 123 |
| LOSSES | % of total | 40 | 30 | 20 | 10 | 10 | 10 | 10 | 10 |
| TOTAL WATER DEMAND (×MILJ.) | L/d | 581 | 536 | 620 | 1280 | 1410 | 1530 | 1630 | 1690 |

#### 2.2.6.2. *Water supply*

As explained earlier, there will be a shift from groundwater extraction to piped water. Now, it is assumed that more than 55% of the water in Jakarta is extracted from deep groundwater by drilling a well and pumping it up. This is done at depths of sometimes two or three hundred meters. It depends on the length of the filter of the well, which ground layer(s) are influenced by the well.

This piped water can originate from dams outside the city (Jatiluhur dam) or from retention lakes inside the city. The latter will be difficult because of the water quality and the lack of capacity. In the east of Jakarta even a smaller part (about 20%) of the water supply is done by pipes. In Table 2.12 the expected production capacity of Jatiluhur dam (¼ to East until 2040, ½ after 2040) is shown, resulting in a deficit.

TABLE 2.12: WATER SUPPLY IN EAST JAKARTA BY JATILUHUR DAM RESULTING IN DEFICIT

| PARAMETER | UNIT | 2010 | 2017 | 2030 | 2040 | 2050 | 2060 | 2070 | 2080 |
|---|---|---|---|---|---|---|---|---|---|
| TOTAL PRODUCTION CAPACITY OF JATILUHUR DAM (XMILJ.) | L/d | 389 | 233 | 584 | 1170 | 1170 | 779 | 779 | 779 |
| DEFICIT (×MILJ.) | L/d | 192 | 303 | 36.2 | 113 | 247 | 753 | 848 | 914 |

It can be concluded that there is not enough capacity to realise a complete shift from groundwater extraction to piped water. Extra water plants have to be realised. At the moment a new water plant is under construction in West Jakarta.

## 2.3. Other boundary conditions

Besides the hydraulic and hydrologic boundary conditions, there are also other boundary conditions that need to be considered. First, the topography and bathymetry conditions are elaborated. Also wind data from measurements and models is described, leading to design wind speeds and directions. Furthermore the geotechnical data is elaborated, which give a good insight between the differences in soil composition between East and West Jakarta.

### 2.3.1. Topography and bathymetry

The coastal area is relatively flat in comparison with the upstream regions. The ground level is MSL + 70 approximately 10 km from the bay in landward direction. Near the coastal area, the ground level in West Jakarta fluctuates more in contrast to East Jakarta (see Figure 2.13 and Figure 3.1). The colours indicate the ground level, where the red colour represents a low ground level and the blue colour represents a high ground level [Witteveen+Bos].

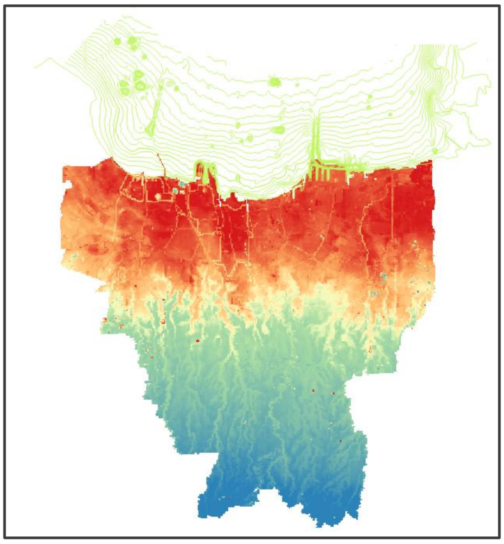


FIGURE 2.13: RELATIVE GROUND LEVELS JAKARTA (WITTEVEEN+BOS)

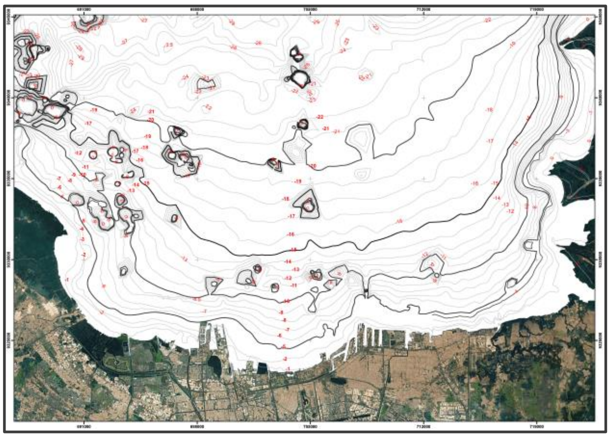


FIGURE 2.14: BATHYMETRY JAKARTA BAY (WITTEVEEN+BOS)

The Jakarta bay consists of shallow waters up to a water depth of 20 m below LWS, as can been seen in Figure 2.14 The elevation between the contour lines is 1 m down towards the north. In West Jakarta there are variations in the bathymetry, which can be seen in the concentrated contour lines (small islands). The east of Jakarta Bay is, however, relatively flat [Witteveen+Bos]. At the coast near the port Tanjung Priok an approach channel is dredged.

### 2.3.2. Wind

Wind data is obtained from the ECMWF (European Centre for Medium-Range Weather Forecasts) model. This is an atmospheric model that provides time series of wind speed and direction at 6-hour intervals for the period 1979 till 2012. Wind speeds $U_{10}$ are determined at a height of 10 meter above MSL and comprise of the 6-hourly average value. The offshore hourly wind speeds and directions from this model can be found in Figure 2.15 [Zoon et al, 2014]. There are also wind measurements available at Jakarta Airport and there is data available from offshore measurement device. These three are combined and the following graph (Figure 2.16) is obtained, with wind speed in the vertical axes and the return period in the horizontal axis [van Veen, 2013]. There are no big spatial differences expected, therefore this data is used for East Jakarta.

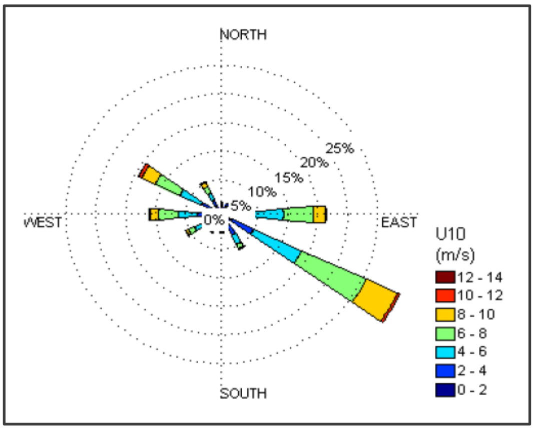



FIGURE 2.15: OFFSHORE HOURLY WIND SPEEDS AND DIRECTIONS FROM ECMWF (30° BINS) [ZOON AND VAN DEN BOOMEN, 2014]

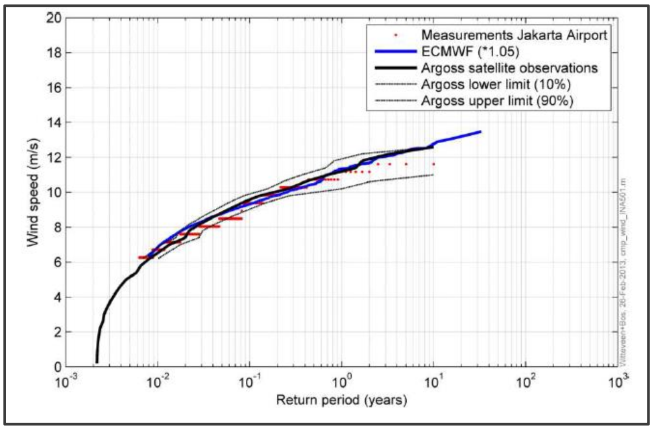



FIGURE 2.16: WIND SPEEDS AGAINST RETURN PERIODS [VAN VEEN, 2013].

The offshore wind speeds are shown in Table 2.13 These wind speeds are extreme hourly ECMWF wind speeds in m/s. The highest wind speed is 22 m/s from NNW direction for a return period of 10,000 years.

TABLE 2.13: OFFSHORE WIND SPEED

| | | 1 year | 10 years | 100 years | 1000 years | 10000 years |
|---|---|---|---|---|---|---|
| omni-directional | | 12.3 | 14.0 | 15.8 | 17.4 | 19.0 |
| N | 0 | 3.0 | 5.6 | 8.7 | 12.8 | 18.7 |
| NNE | 22.5 | 3.2 | 5.1 | 6.4 | 7.6 | 8.9 |
| NE | 45 | 3.3 | 6.0 | 8.5 | 11.2 | 14.4 |
| ENE | 67.5 | 6.3 | 8.2 | 9.7 | 11.2 | 12.8 |
| E | 90 | 10.1 | 12.0 | 13.6 | 15.1 | 16.6 |
| ESE | 112.5 | 10.8 | 11.9 | 12.9 | 13.8 | 14.8 |
| SE | 135 | 9.5 | 10.5 | 11.4 | 12.2 | 13.0 |
| SSE | 157.5 | 6.3 | 8.5 | 10.1 | 11.6 | 12.9 |
| S | 180 | 4.3 | 6.4 | 8.1 | 9.6 | 11.1 |
| SSW | 202.5 | 4.7 | 7.0 | 9.0 | 11.0 | 12.9 |
| SW | 225 | 7.2 | 10.7 | 13.7 | 16.5 | 19.3 |
| WSW | 247.5 | 9.8 | 12.1 | 13.9 | 15.5 | 16.9 |
| W | 270 | 10.6 | 13.3 | 15.7 | 18.1 | 20.4 |
| WNW | 292.5 | 11.3 | 13.8 | 16.1 | 18.2 | 20.3 |
| NW | 315 | 11.0 | 13.1 | 14.8 | 16.4 | 17.9 |
| NNW | 337.5 | 8.6 | 12.5 | 15.6 | 18.7 | 22.0 |

### 2.3.3. Geotechnical data

The geotechnical data of Jakarta can be found in the ATLAS [Edisi, 2011]. This is shown in Figure 2.17.

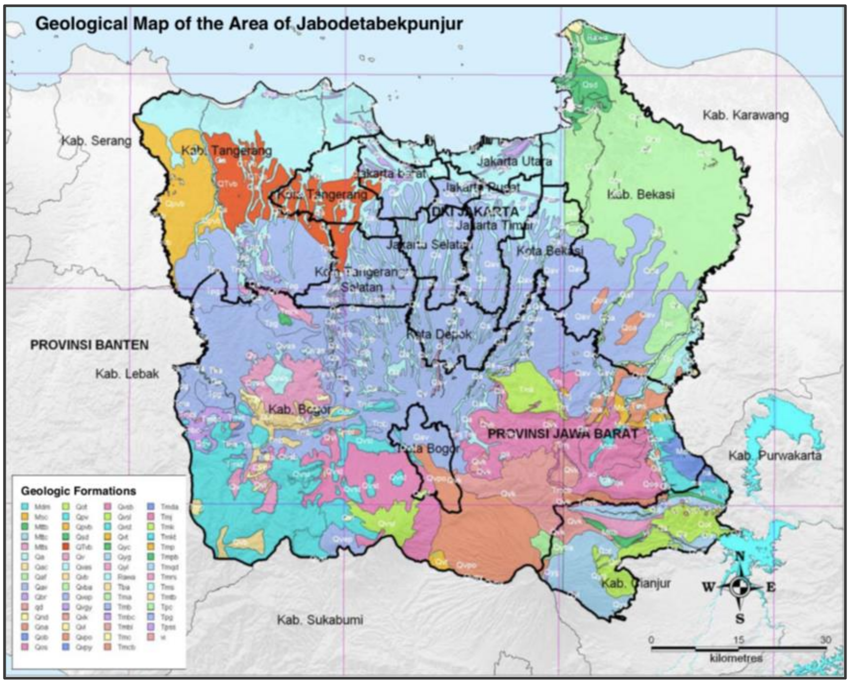



FIGURE 2.17 :GEOLOGICAL MAP OF JAKARTA REGION [EDISI, 2011]

The oldest rock can be found in the core of an anticline, which is covered by younger rocks covering the anticline in the north and south wings. The sheets of Jakarta and Karawang can be grouped into four rock units, which can be found in appendix II.

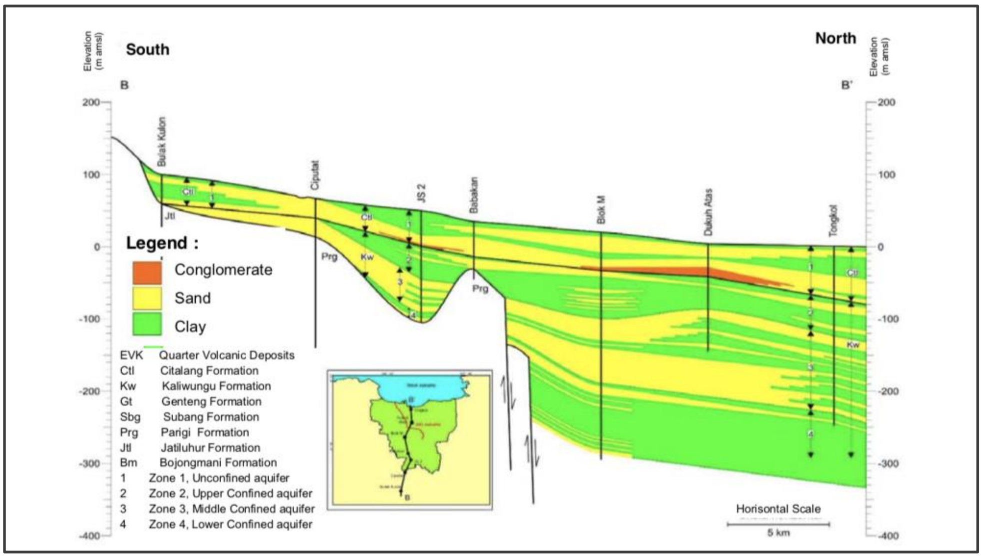



FIGURE 2.18 SOUTH-NORTH JAKARTA CROSS SECTION [EDISI, 2011]

In Figure 2.18 the cross section of the soil of Jakarta (South-North) is shown. It can be seen that the soil in South Jakarta mainly consists of sand and some clay layers. More towards the sea (North Jakarta) the soil layers show a fluctuating behaviour. The soil mainly consists of clay layers, some conglomerate and some deep clay layers. This data will be used for East Jakarta where the layers are thicker. This data will be used for analysing the land subsidence in section 3.

#### 2.3.3.1. *Soil types*

In Figure 2.19 the different soil types are shown, only Jakarta Utara Jakarta Pusat, Jakarta Timur, Bekasi, East are taken into account. For the South area of the project scope the Red Latosol, Reddish brown Latosol (light-blue) are considered. In the North part of the project scope (near the coast) the dark grey alluvial and brown-grey alluvial and brown alluvial are present. These soils are present in East Jakarta and will be used to check the quality and accuracy of the calculated land subsidence in section 3.


FIGURE 2.19 SOIL TYPE IN AREA OF JABODETABEKPUNJUR [EDISI, 2011]

### 2.3.4. Impact along the main rivers and drains

The population in East Jakarta is growing and the number of people living along the rivers is increasing. Space for designing walls and dikes is limited. This section gives insight in the impact when increasing the protection along the rivers.

The impact along the coast is not considered in this section, because there is almost no constraint when looking at the available space. Besides, the enforcement of the existing sea wall has already started (current master plan, phase EA+). Along the coast, the main social/spatial problems have already been encountered. When enlarging this sea wall, some bamboo jetties of fisherman might be replaced. [NCICD PMU + Consultants, 2017]. For more information about the phases, see appendix III.

#### 2.3.4.1. *Social and spatial aspects*

There are a lot of slum areas located in East Jakarta (Tanjung Priok, Koja and Cilincing) as can be seen in Table 2.14 and Figure 2.20 [Dewi, 2014]. Most of them are concentrated along the riverbanks of the Sunter and the Cakung.

The rivers are used for various purposes like a source of raw water for drinking water, fishing, but the main function of the river and canal network is as a means of drainage. While waste water disposal facilities are practically non-existent, the people throw their garbage into the river. The people living next to the rivers are mostly immigrants with a level of income equal to the lower middle class in Jakarta. Their houses are often a sleeping place and business place combined, so they are not willing to move to flats further away from the river.

At some locations along the rivers, people are already moved away to flats. Along the KBT people have already made small gardens in the summer bed. Somewhere even small sheds are present. This development can have a negative effect on the drainage function of the canal during peak discharges.

TABLE 2.14: SLUM AREA IN JAKARTA BAY ACCORDING TO SUB-DISTRICT, 2011 YEAR [DEWI, 2014]

| Sub-district | Population | House Hold (HH) | Number of slum area location (location) | Number of building house in Slum Area (unit) | Number of HH in Slum Area |
|---|---|---|---|---|---|
| PENJARINGAN | 306,108 | 66,526 | 9 | 1,619 | 1,826 |
| PADEMANGAN | 143,811 | 39,904 | 10 | 2,592 | 2,586 |
| TANJUNG PRIOK | 374,585 | 97,173 | 39 | 7,963 | 9,252 |
| KOJA | 293,425 | 74,680 | 24 | 4,645 | 5,099 |
| CILINCING | 369,782 | 85,007 | 22 | 4,483 | 5,720 |
| TOTAL | 1,487,711 | 363,290 | 104 | 21,302 | 24,483 |

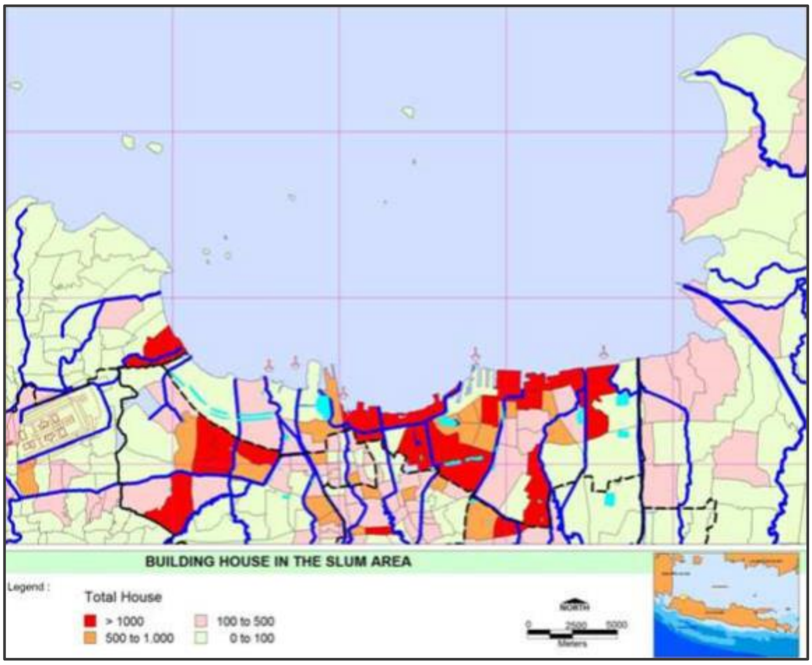



FIGURE 2.20:NUMBER OF BUILDING HOUSE (UNIT) ON THE SLUM AREA IN NORTH JAKARTA, 2011 YEAR [DEWI, 2014]

FIGURE 2.21: SLUM ALONG THE RIVER [DEWI, 2014]

FIGURE 2.22: SLUM ALONG THE RIVER [DEWI, 2014]

#### 2.3.4.2. *Economical aspects*

Costs for land acquisition, water quality deterioration, environmental impact, impact on fish ports and communities, loss of natural habitat and loss of resources are not included in the direct cost estimates [Beumer, 2014]. These aspects are important to take into account for the project costs.

Land acquisition stimulates the economic, social, and environmental risks. The loss of production systems and loss of income due to land acquisition will enhance this risk. Land acquisition will result in loss of communities and social networks in these communities.

The deterioration of water quality will enhance the environmental and economic risks. This will result in water quality becoming more expensive, which is less attractive. The construction of river embankments, dikes may influence the environment in a negative way. The construction of dikes could result in fishers not being able to fish in certain areas. Fishers might experience a reduction in productivity or be unable to produce at all. The construction of flood defences can negatively influence the natural habitat, which could result in loss of natural resources.

These costs cannot be prevented, but the impact can be reduced by cash compensation. These costs have a large impact on the project Net Present Value and Internal Rate of Return. These costs influence the economic viability and performance of the project. Therefore, these costs will be considered when the concept designs will be evaluated.

The method used for quantifying land acquisition costs for retail + office, industrial and non-built area is based on land prices and invested capital [Beumer, 2014]. For residential land use a 30% increase in costs for resettling is taken into account.Table 2.15 shows the land acquisition unit prices.

TABLE 2.15: LAND ACQUISITION UNIT PRICES [BEUMER, 2014]

| Unit prices land acquisition | Residential | Office + retail | Industrial | Non-built |
|---|---|---|---|---|
| Unit price | USD 1,575 /m$^2$ | USD 1,630 /m$^2$ | USD 880 /m$^2$ | USD 760 /m$^2$ |

The distribution presence of the different type of land use will be calculated in section 4.The resettlement cost per capital with a population density of 122 people/ha (Jakarta) is 122 $/m2.

# 3. SUBSIDENCE

Techniques to measure subsidence have changed in the years. In the first part these techniques will be explained. Because there are several factors causing land subsidence in Jakarta (section 1.1.1) predictions are uncertain. In this section is explained how to deal with these uncertainties. Finally, the most recent scenarios from Henk Kooi (2017) are mentioned and a 3D- model is made with the use of stations that monitors the subsidence.

## 3.1. Subsidence measurements

Data on land subsidence is mainly based on studies of Jabotabek Water Resources Management Study (JWRMS) and with GPS measurements. Data from 1974 till 1990 is determined with conventional techniques within an extensive network. From 1990 till 2000 a measurement network using GPS is used and from 2000 till 2010 GPS and INSAR technologies are used. Current methods to calculate the land subsidence have improved over the years, so old future predictions have been changed and are outdated. Current land subsidence predictions (2010-2080) are based on groundwater extraction in combination with GPS and INSAR technology. [Edisi, 2011]

## 3.2. Level of knowledge of factors controlling future subsidence in Jakarta

Subsidence cannot be predicted on a high level of accuracy, because the influence of the factors is not known completely. In a qualitative assessment, the importance of all factors is given and how well known they are. The expectations are depending on groundwater use. The development of the groundwater use is uncertain, due to which the subsidence developments are also uncertain.

But there is dealt with this uncertainty in a realistic way. Deltares makes prognoses with the help of 1D-models where hydraulic head and geological data are available and where past subsidence is known by local observations. Due to the great variability of the ground, subsidence can change over a small distance. So, with this method interpolation/extrapolation cannot be used. But with these models a range of possibilities is calculated, from which scenarios could be defined. [van den Berg, 2017]

TABLE 3.1: SUBSIDENCE DEVELOPMENT FACTORS [VAN DEN BERG, 2017]

| **Factors that influence subsidence development** | **Sensitivity** | **Knowledge** |
|---|---|---|
| Groundwater extraction | | |
| Future of groundwater extractions (where, when, depth, how much) | Very high | Speculative |
| History of groundwater extraction (where, when, depth, how much) | High | Poorly (after 1940) |
| Lateral extent and thickness of aquifer(s)/lenses that are pumped | Very high | No/poorly |
| Thicknesses of clay(ey) layers above, below and between pumped aquifers | Very high | At deep boreholes |
| Permeability of clay(ey) layers above, below and between pumped aquifers | Very high | Poorly |
| Other | | |
| Compressions properties of clay(ey) layers (natural consolidation) | High | Poorly |
| Other subsidence processes (e.g. tectonics, load of constructions) | Low | Partly |

## 3.3. Subsidence reduction

Despite the many factors involved to subsidence, groundwater extraction is the only factor, which could be changed. So, future scenarios will be based on the level of groundwater extraction. When extraction stops, the head in the aquifer will quickly recover, but in the clay layers the decrease in head will continue for a few years. Also, subsidence will still continue. It takes many years to decades for subsidence to stop completely. The thicker the clay layers, the longer it takes to stop. [van den Berg, 2017]

## 3.4. Difference subsidence east and west

In Figure 3.1 land elevation along Jakarta coast is showed based on measurements and predictions (note the predictions in this figure are out-dated) [Steijn, 2014]. From the figure, it can be seen that subsidence in the past is lower in the East than in the West. In the west, the mean subsidence is equal to 7.5 cm/year while this is in the east 2.5 cm/year. The groundwater extraction in the East started developing later compared to the West. The current rate in the east will not give large flooding risks or problems for debouching of the rivers at the moment, but with the current rate it could give problems in the future. Besides that, the water demand is expected to increase (see section 2.2.6), also attention has to be paid to East-Jakarta.

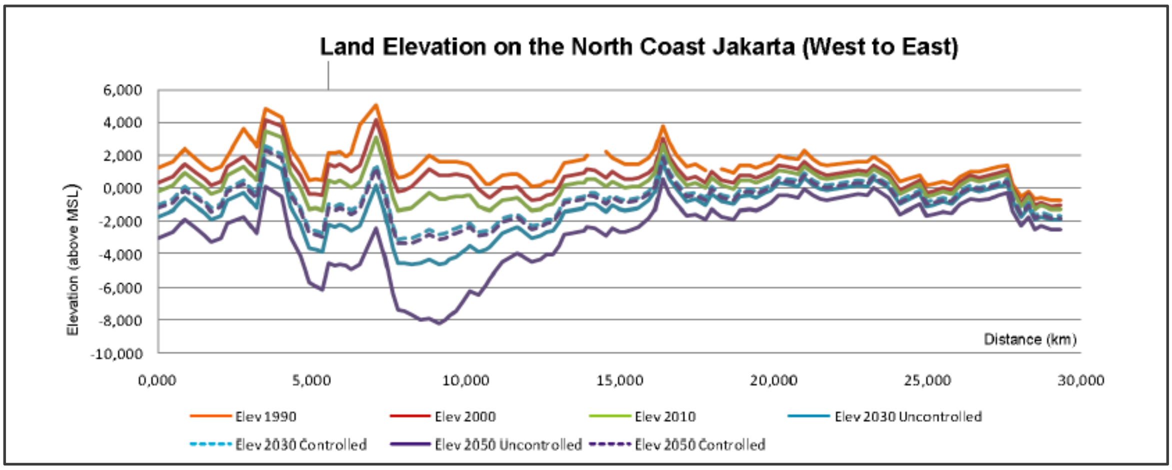



FIGURE 3.1: LAND ELEVATION ALONG JAKARTA COAST FROM MEASUREMENTS AND PREDICTIONS [STEIJN, 2014]

## 3.5. Subsidence scenarios

There are three land subsidence scenarios defined by Andrew Warren. Henk Kooi (2017) has added an extreme scenario called -business as usual 'plus'- and has adjusted the previous scenarios.

1. **Business as usual 'plus':**
   Without new regulations, groundwater extraction from deeper aquifers is likely to occur. To illustrate this scenario, it is assumed that lowering of groundwater heads continued with 1 m per year to 2025. After that, drawdown increases to 1.5 m per year till 2100. Lowering until 2100 with these rates seems unrealistic because of the 'natural' limit of drawdown, but it gives a good ultimate limit expression.

2. **Business as usual:**
   Continued lowering of groundwater heads with 1 m per year until 2100. This is a scenario in which groundwater abstractions and subsidence continue at present rates. In previous calculation by NCICD (2017) it was assumed that groundwater heads are lowered until 2050. Also for this scenario, it is not completely realistic due to the 'natural' limit of drawdown.
3. **Reduced/controlled deep groundwater use**:
   In this scenario groundwater heads are stabilized from 2025. In this scenario groundwater extractions are reduced to slowdown subsidence. From this year, more piped water is available.
4. **Stopped deep groundwater use:**
   In this scenario groundwater extraction is completely stopped in 2025, to halt subsidence as quickly as possible. An exponential recovery character of hydraulic heads is used instead of the linear recovery character of 1 m per year used in previous calculation done by NCICD (2017). This exponential recovery character describes more realistic the recovery behaviour of groundwater systems. A slow recovery model and a fast recovery model is used. Due to the elastic rebound of the ground, a mild uplift could be seen.

### 3.5.1. Results

Two locations are considered for the East by Henk Kooi (2017): Sunter and Marunda. At these locations, data about the subsidence, geology and groundwater head is available to make a 1D-model to predict the future subsidence [Kooi, 2017]. The distances between the three data sources vary up to more than 2 km. The data is used by Henk Kooi (2017) to make some indications. The actual condition will vary to some unknown degree. With the use of GPS data at different locations in the east, a 3D-model will be made. The model gives indications of the subsidence per location.

#### *3.5.1.1. Sunter*

The results of Sunter are presented in Table 3.2 Minimum and maximum values provide a rough indication of the uncertainty range of the prognoses [Kooi, 2017]. Scenario 1 (business as usual 'plus' for Sunter) is not known and has to be determined in the future. The subsidence graphs can be found in Appendix IV: Subsidence graphs.

TABLE 3.2: SUMMARY OF SUBSIDENCE AND SUBSIDENCE RATES FOR RELEVANT MOMENTS AND PERIODS IN SUNTER (MIN./ MAX.) [KOOI, 2017]

| | Subsidence rate 2018 (cm/yr) | Subsidence rate 2028 (cm/yr) | Subsidence rate 2050 (cm/yr) | Subsidence 2018 - 2028 (cm) | Subsidence 2018 – 2050 (cm) | Subsidence 2018 – 2080 (cm) |
|---|---|---|---|---|---|---|
| **Scenario 1: business a.u. 'plus'** | TBD | TBD | TBD | TBD | TBD | TBD |
| **Scenario 2: business a.u.** | 1.3 / 2.7 | 2.7 / 4.7 | 5.0 / 9.5 | 16 / 29 | 109 / 196 | 317 / 468 |
| **Scenario 3: reduced abstraction** | 1.3 / 2.7 | 0.7 / 2.1 | 0.1 / 1.1 | 10/ 24 | 17 / 58 | 28 / 79 |
| **Scenario 4a: stopped deep abstraction (slow recovery)** | 1.3 / 2.7 | -0.5 / 1.3 | -0.8 / -0.2 | 8 / 32 | -11 / 28 | -20/ 7 |
| **Scenario 4b: stopped deep abstraction (fast recovery)** | 1.3 / 2.7 | -2.3 / 0.3 | -1.1 / -0.7 | 4/ 20 | -40/ 20 | -44 / -22 |

#### *3.5.1.2. Marunda*

The results of Marunda are presented in Table 3.3. Minimum and maximum values provide a rough indication of the uncertainty range of the prognoses [Kooi, 2017].

TABLE 3.3: SUMMARY OF SUBSIDENCE AND SUBSIDENCE RATES FOR RELEVANT MOMENTS AND PERIODS IN MARUNDA (MIN./ MAX.) [KOOI, 2017]

| | Subsidence rate 2018 (cm/yr) | Subsidence rate 2028 (cm/yr) | Subsidence rate 2050 (cm/yr) | Subsidence 2018 - 2028 (cm) | Subsidence 2018 – 2050 (cm) | Subsidence 2018 – 2080 (cm) |
|---|---|---|---|---|---|---|
| **Scenario 1: business a.u. 'plus'** | 2.8 / 4.4 | 3.3 / 6.4 | 5.5 / 10.1 | 45 / 59 | 151 / 255 | 327 / 600 |
| **Scenario 2: business a.u.** | 2.8 / 4.4 | 3.0 / 5.9 | 3.7 / 7.6 | 28 / 49 | 104 / 202 | 227 / 436 |
| **Scenario 3: reduced abstraction** | 2.8 / 4.4 | 2.3 / 3.4 | 0.8 / 1.5 | 27/ 44 | 61 / 85 | 83 / 109 |
| **Scenario 4a: stopped deep abstraction (slow recovery)** | 2.8 / 4.4 | 1.0 / 2.3 | -0.7 / -0.2 | 26 / 41 | 23 / 48 | 9 / 38 |
| **Scenario 4b: stopped deep abstraction (fast recovery)** | 2.8 / 4.4 | -1.6 / 0.5 | -1.1 / -0.7 | 23/ 36 | -17/ 18 | -30 / 4 |

#### *3.5.1.3. 3D-model*

The GPS points in Figure 3.2 show the locations of the levelling stations for monitoring subsidence in East Jakarta for recent years. The exact coordinates of the data points located in East Jakarta can be found in Appendix V: GPS coordinates with the corresponding subsidence rates.

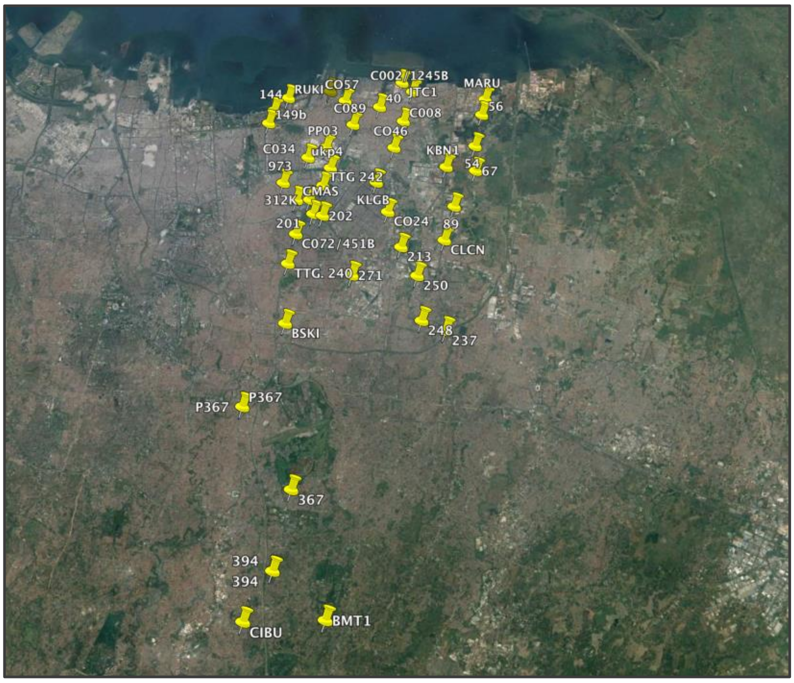



FIGURE 3.2: GPS COORDINATES EAST-JAKARTA (GOOGLE EARTH PRO)

The subsidence rates are linked to the subsidence rates of Henk Kooi (2017) by comparing the subsidence rates at Marunda. Only maximum values of the subsidence prediction of Henk Kooi (2017) are used in the 3D-model. A subsidence prediction at each location can be made by assuming that the ground and groundwater head in a GPS point are the same as for the Sunter or Marunda. A point close to Marunda follows more the characteristics of Marunda and a point close to Sunter follows more the characteristics of the Sunter. The calculation can be found in Appendix VI: Subsidence prediction per GPS location.

In QGIS the subsidence per location is extrapolated with an inverse distance weighting method. Now the subsidence at all locations for each scenario is known. The output is given in Appendix VII: 3D-subsidence model. Subsidence rates above 10 meters are assumed to be unrealistic and are adjusted to 10 meters, because ground cannot consolidate that much. [Kooi, 2017].

The model is inaccurate, because the soil and water head differ per location. This model is only used to give an indication of the subsidence per location. For a more accurate solution, further research is required.

## 3.6. The backwater effect

Because of the subsidence, the influence of the sea on the water levels in the river system rises. For the solutions in West Jakarta it is mentioned that additional heightening of the walls is needed to compensate for the "backwater effect" and a freeboard of 1 meter is added. In the recommendations of "2.B2b NCICD technical survey" of the Masterplan 2014 is stated that the backwater effects for the main rivers and canals still need to be determined. In this section, some interpretations of this backwater effect are discussed and finally one interpretation is used for the solutions in East Jakarta.

### 3.6.1. Theoretical backwater effect

In theory, a backwater effect is described as a curve from the point of impact to a point further upstream where the impact is zero. This depth, where the influence is zero, is called the equilibrium depth $d_e$. The equilibrium depth can be determined with the following formula:

$$d_e = \left(\frac{c_f\, q_w{}^2}{g\, i_b}\right)^{1/3} \qquad 3.1$$

Where:

| | |
|---|---|
| $c_f$ | = Friction coefficient |
| $q_w$ | = Specific discharge |
| $g$ | = Gravitational forcing |
| $i_b$ | = Bottom slope |

This is also called the normal flow depth because steady and uniform flow (Chézy) is assumed. There are several backwater curves as can be seen in Figure 3.3. For the case of Jakarta where the river is sinking and the sea level is rising, the M1 curve should be applicable. The critical depth $d_g$ (Froude is 1) is for the case in Jakarta always smaller than $d_e$. In Figure 3.4 this theoretical backwater curve in Jakarta is shown.

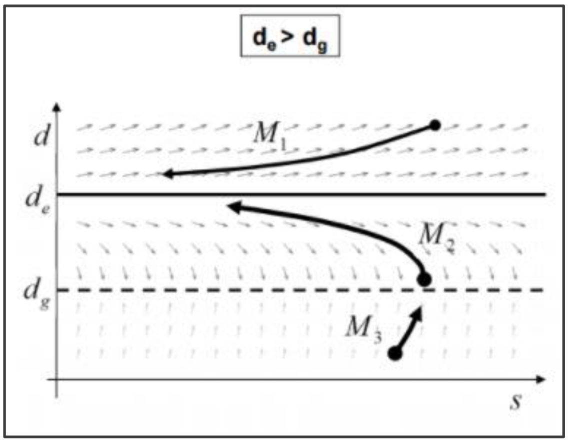



FIGURE 3.3: TYPE OF BACKWATER CURVES – MILD BED SLOPE SUBCRITICAL [BLOM, 2017]

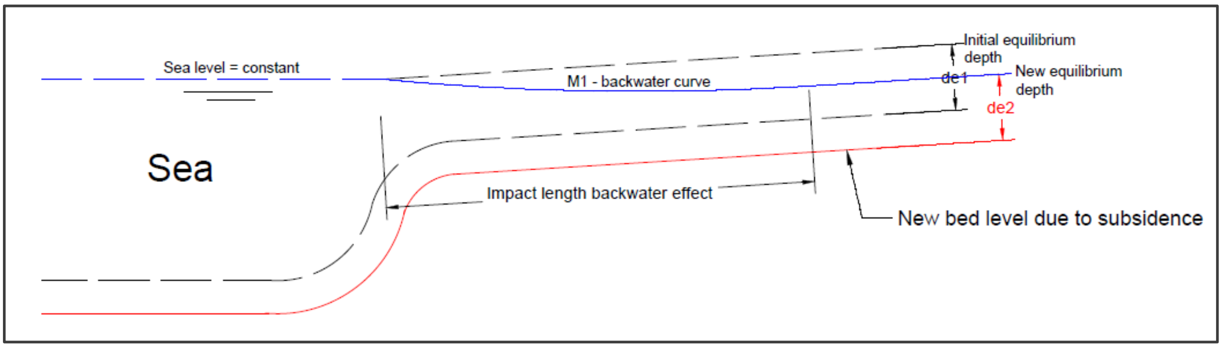



FIGURE 3.4: THEORETICAL BACKWATER CURVE

### 3.6.2. Constant water level

In this interpretation the effect on the river is fully determined by the sea. The river bottom and walls along the river subside but the water level in the river close to sea remains the same. The walls along the part of the river, which subsided need to be heightened with the same amount as subsided. When at a certain location a subsidence of 1 meter occurred, the wall at this location need to be heightened with 1 meter to cover the backwater effect. This way of thinking is rather conservative because in theory the length of impact of the backwater curve is limited. Next to this, the outflow of the river will also counteract the effect of the sea.

The bottom slope is assumed to stay constant in time. Another argument in favour of this interpretation is linked to the sedimentation. One says that due to the subsidence, aggregation along the subsided river will occur while the walls are sinking. This aggregation leads to the same conclusion: water level stays constant while walls are subsiding, see Figure 3.5.

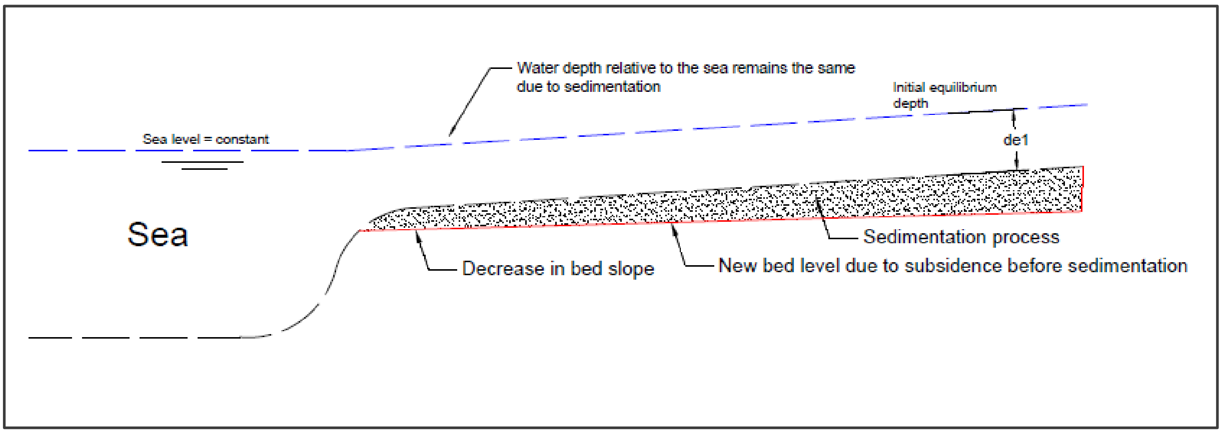



FIGURE 3.5: CONSTANT WATER LEVEL ALONG THE RIVER

### 3.6.3. Decreasing slope

Because of the land subsidence, the slope of the river bottom near the sea decreases, resulting in an increasing water depth. In this interpretation, there is a full effect of the sea as described above plus the increasing water depth. This approach is more conservative than the constant water level interpretation. As can be seen in Figure 3.6, the subsidence result in a sort of bathtub where the river flows through. Because of the combination of the decreasing slope and subsidence this interpretation of the backwater effect is unlikely to occur.

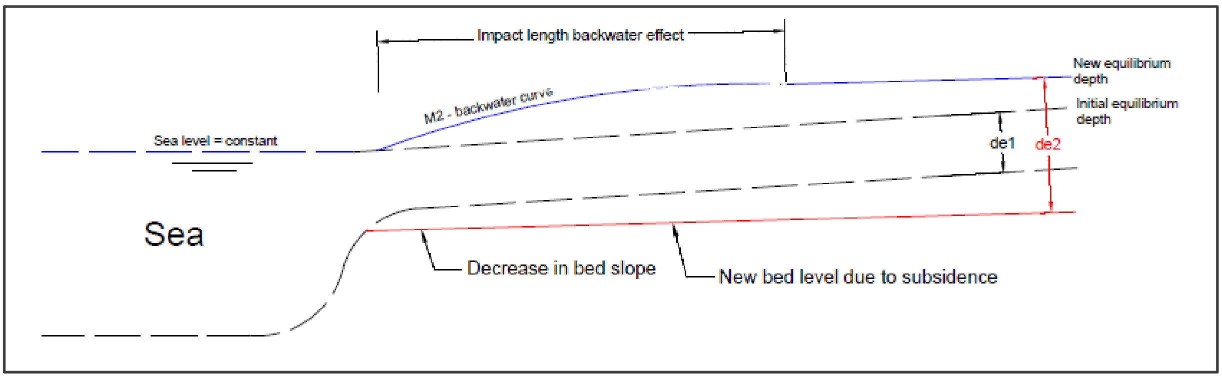



FIGURE 3.6: ADDITIONAL BACKWATER EFFECT

### 3.6.4. Conclusion

The theoretical backwater curve is hard to apply for the case of Jakarta. Too little is known about the input parameters for the equilibrium depth. Next to this, the rivers vary in width and there are also spatial variations in slope and friction. Therefore, there is no use in quantifying the theoretical backwater curve.

Actually, several short backwater curves will develop for every part of the river with about the same characteristics. Defining these backwater curves for every part is a study on its own. Looking at the scope of this report, the fully sea dependent backwater effect is taken as the definition of the so-called backwater effect.

# 4. SPATIAL ANALYSIS

In this chapter, a spatial analysis is done along the Sunter, Cakung Drain, Old Cakung and the Banjir Kanal Timur. The analysis will be used later on to determine optimal solutions for flood defence structures along the rivers and canals.

## 4.1. Social impact classes

To do the spatial analysis, a land use map is generated within a certain radius (50 to 150 m) from both sides of the rivers. The areas are subdivided according to in total six social impact classes: non-built, industrial, residential, office + retail, roads and large bridges + gates. The areas that are linked to the social impact classes are determined with Google Earth Pro images from July-September 2017 and the most recent Google Street view images. The fieldtrips helped to interpret these images.

**1. Non-built (orange)**
This class consists of all the rural non-built areas. Along the BKT the major part is non-built, but in some cases, it could be observed that some area has already been prepared to build on. These kinds of areas are considered as build (Residential or office + retail).
**2. Industrial (purple)**
In this 'industrial' class is included: fishing ponds, small industry and storage (parking lots). When looking at the large industry as can be found in the Tanjung Priok area, the area will be considered as the more expensive class "office + retail".
**3. Residential (green)**
This class is more expensive than the previous ones because the population living in this area need to be resettled to buildings further away from the river. Next to slum (in the riverbanks), also normal neighbourhoods are included in this class.
**4. Office + retail (yellow)**
This class is characterized by large buildings and industry. Also malls, silos and mosques are included. When a part of a building is situated in the 100-meter boundary along the rivers, the whole building is taken into account as an area to be demolished in case of a dike.
**5. Roads (no colour)**
The roads are not indicated with a colour but considered in the calculations. In case a dike will be build, the roads need to be rebuilt on top of the flood defence or replaced.
**6. Bridge + gates (red)**
Bridges and gates have to be removed and rebuilt. Small pedestrian bridges are not included.

Examples of the output of the spatial analysis are shown in Figure 4.1, Figure 4.2 and Figure 4.3, the highlighted areas are represented in the legend.

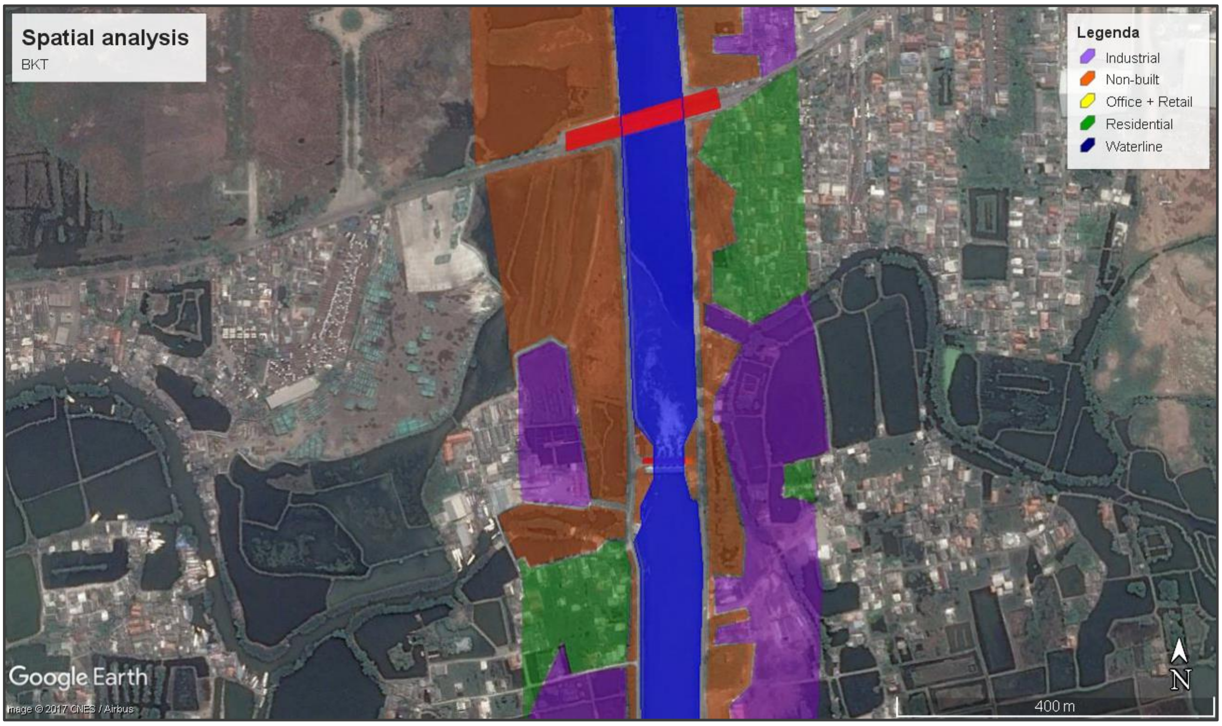



FIGURE 4.1: SPATIAL ANALYSIS OF THE BKT


FIGURE 4.2: SPATIAL ANALYSES OF OLD CAKUNG AND CAKUNG DRAIN

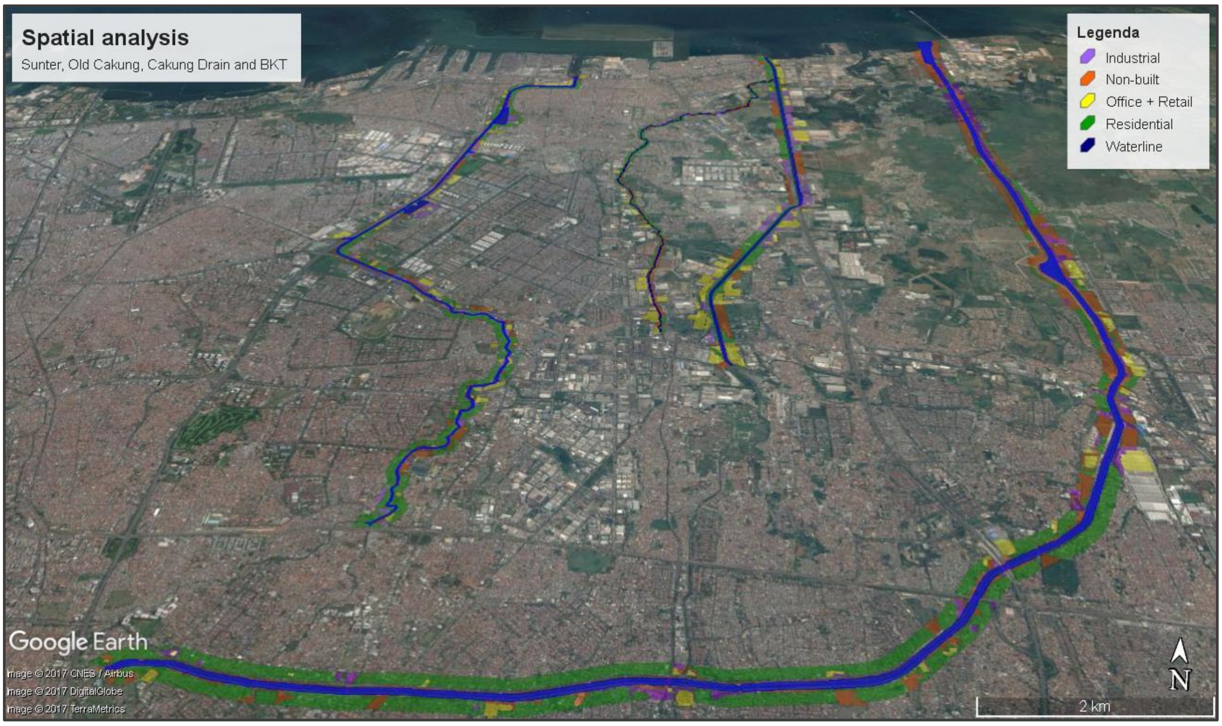


FIGURE 4.3: SPATIAL ANALYSES OF ALL RIVERS CONSIERED

## 4.2. Parts

After linking the areas to the social impact classes, they are divided into parts (see Figure 4.4). These parts are used to approximate the surface area per social impact class along the rivers. The strategic way to determine a part, is to take a part along the river where there is only one type of area in river length direction. As can be seen in the figure below the example part (left lower corner) consists of 25 m residential (green area), 5 m road (no colour) and 120 m non-built (red area). Each river has its own amount of parts, depending on the spatial characteristics. In chapter 6 all the parts are considered individually to come to the best (cheapest) flood defence structure per part.

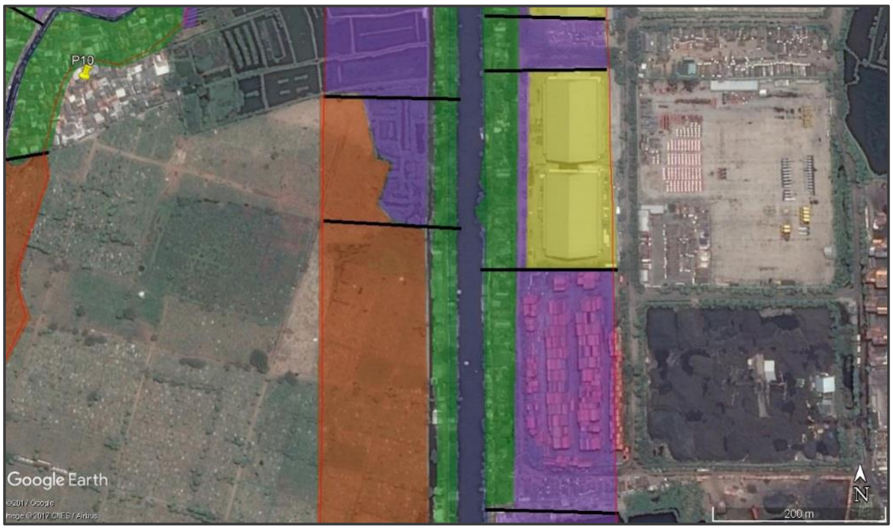


FIGURE 4.4: PARTS CAKUNG DRAIN INDICATED WITH BLACK LINES

## 4.3. Bridge categories

Bridges across the rivers can be divided into three categories:

1. Small bridges: Only motorcycle.
2. Medium bridges: One or two lanes for cars.
3. Large bridges: Three or more lanes (including rail bridges and toll roads**).**

In Appendix VIII: Examples bridge classes, examples can be found.

# 5. ALTERNATIVES FOR FLOOD SAFETY

In this chapter, four alternatives for flood safety will be discussed: the outer sea dike, on shore retention, closing rivers and flood defences along the river. For every solution social and construction costs are calculated. In section 6, alternatives will be combined to give an optimum solution to cope with the different land subsidence scenarios. The costs considered in all alternatives are shown in Table 5.1. The costs of the unit prices are shown in Table 5.2. In section 4 Spatial analysis, the classes are explained. Costs of bridges are based on reference projects.

TABLE 5.1: COSTS CALCULATION [WARYONO, 2017]

| Costs | |
|---|---|
| **Total construction costs** | **(10) = (8) + (9)** |
| Known direct costs | (1) |
| Unknown direct costs | (2) = 20% × (1) |
| Direct costs | (3) = (1) + (2) |
| Site expenses | (4) = 15% × (3) |
| Overheads and profit | (5) = 10% × ((3) + (4)) |
| Preparatory works | (6) = 5% × ((3) + (4) + (5)) |
| Indirect costs | (7) = (4) + (5) + (6) |
| Known construction costs | (8) = (3) + (7) |
| Contingency | (9) = 10% × (8) |
| | |
| **Total design costs** | **(11) = 2.5% × (10)** |
| **Total supervision costs** | **(12) = 3% × (10)** |
| **Total social costs** | **(15) = (13) + (14)** |
| Social costs | (13) |
| Contingency | (14) = 10% × (13) |

TABLE 5.2: UNIT PRICES [WARYONA, 2017]

| Cost component | Price |
|---|---|
| **Sand onshore / offshore** | 7.4 / 11.1 USD/m³ |
| **Rock < 1 ton / offshore** | 37 / 55.6 USD/m³ |
| **Rock 1-3 ton / offshore** | 51.9 / 74.1 USD/m³ |
| **Rock > 3 ton / offshore** | 74.1 / 96.3 USD/m³ |
| **Clay** | 4.4 USD/m³ |
| **Concrete sheet piles** | 163 USD/m |
| **Asphalt** | 292 USD/m² |
| **Excavation onshore** | 7 USD/m³ |
| **Dredging offshore** | 10 USD /m³ |
| **Onshore Land acquisition, resettlement, demolition of existing structures** | 880 USD/m² |
| **CAPEX pumps** | 829461 USD/m³ |
| **OPEX pumps** | 424999 USD /m³ |
| **Demolish bridge and construction new bridge** | |
| - Category 1 | 1 million USD |
| - Category 2 | 7 million USD |
| - Category 3 | 12 million USD |

| Land acquisition, resettlement, demolition of existing structures along the river | |
|---|---|
| - Class 1: Non-built | 760 USD/m² |
| - Class 2: Industrial | 880 USD/m² |
| - Class 3: Residential | 1575 USD/m² |
| - Class 4: Office + retail | 1630 USD/m² |
| - Class 5 : Roads | 55 USD/m² |

## 5.1. Alternative 1 – Outer Sea Dike

To ensure flood safety it is an option to close off the rivers and maintain a water level in the system, which is lower than the sea level. This can be done by installing pumps downstream. However, to handle peak discharges the pump capacity should be very high. To reduce the pump capacity, retention lakes should be made. They temporary store the water to delay the peak discharge. Retention lakes can be built offshore when there is no room available on land.

### 5.1.1. Pump capacity

The size of the retention lake determines the needed pumping capacity which is needed. An iterative process is used to find an optimal between the lake size and the pumping capacity. Besides the size of the lake some other factors influence the pumping capacity.

#### *5.1.1.1. Design water level*

The maximum water level in the retention lake depends on the coastal dikes, which are constructed for stage A and on the maximum water level, which can be managed in the rivers. It is calculated that the coastal dike level will be at $LWS_{2012}$ + 4.8 m [Sawarendro, 2017]. The maximum water level in the rivers under 1/100 flood conditions are based on $LWS_{2012}$ +2 m, assumed is that there will be no flooding at this condition. In NCICD 1 is decided that the maximum water level variation cannot be more than 2.5 m. Since the river conditions dominate $LWS_{2012}$ +2 m is taken. So, the water levels will vary between $LWS_{2012}$ -0.5 m and $LWS_{2012}$ +2 m.

##### 5.1.1.1.1. Wind-setup

Since the water height at the coastal dikes is the limiting factor of the design water level the wind-setup is calculated. Table 2.13 gives a maximum Northern windspeed of 12.8 m/s for a 1/1000 year event. It is assumed the retention lakes are rectangular.

The total wind-setup is given by:

$$\frac{dS}{dx} = C_2 \times \frac{u^2}{g\,d} \qquad 5.1.$$

Where:

$S$ = Wind-setup [m]
$x$ = Fetch [m]
$C_2$ = Constant $\approx 3.5 * 10^6$
$u$ = Windspeed [m/s]
$d$ = Depth [m]

#### 5.1.1.2. *Hydraulic head*

Since the range in hydraulic head is varying due to the water level in the lake, the pumping capacity is dependent on the hydraulic head at that moment. The water level at the sea site is assumed constant at mean sea level since the operation time of the pumps are larger than a tidal period. A pumping curve is used take care of the pumping capacity due to the different levels in the retention lake. [NCICD, 2014]

#### 5.1.1.3. *Subsidence and sea level rise*

For subsidence an average is taken for the subsidence near the coast and is than taken constant for the whole offshore area, since there is no subsidence data available for the offshore area. Subsidence will lead to lowering of the coast, the lake and the dikes. Since the water level in the lake is kept constant compared to the river level, subsidence only influences the hydraulic head of the pumps and the heightening of the dikes.

#### 5.1.1.4. *Maximum emptying time*

It is important that the retention lake can be emptied in a specific time to handle a second flood event. In NCICD 1 it was decided that the emptying time is maximum 72 hours. Further research has to be carried out on this 72 hours since it is not likely that another extreme multi-day event will occur within this timeframe. If the emptying time is to large, additional pumps are needed.

#### 5.1.1.5. *Pumping costs*

The total costs of the pumps depend on the amount of pump units. It exists of:

- Investment cost (3 million USD/unit)
- Maintenance costs (1% of investment costs)
- Construction costs (9 times the investment costs)
- Energy costs (0.268 million USD/year with a power supply of 4500 kW/unit)

A total life cycle of 40 years is taken. [NCICD 2014]

### 5.1.2. Design

The offshore retention lake will be designed to be cost efficient. To accomplish this, several layouts of the lake have been taken into account. All with different dimensions and taken into account different rivers.

#### 5.1.2.1. *Design Outer Sea Dike*

The outer Sea Dike is designed as proposed in 'Cost comparison of construction NCICD Stage A, E, M, and O' see Figure 5.1 [Dedi Waryono, 2017]. The costs depend on the length of the dike and the water depths at the location of the parts. It is assumed that, when the depth is zero no dike is needed. In a more detailed design, also the connections between the outer sea dike and coastal dike need to be investigated.

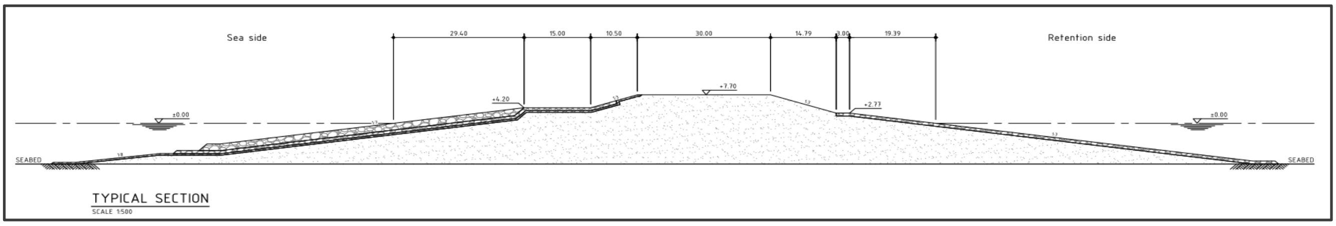



FIGURE 5.1: DESIGN OUTER SEA DIKE

### 5.1.2.2. *Outflow Sunter*

Since the downstream part of the Sunter drains into the Tanjung Priok port area, a bypass has to be made to guide the water into the retention lake. The mouth of the river now has a width of 45 m excluding embankments. Taking into account subsidence, which will lead to larger embankments, the subsidence of scenario 2 is used. The average depth of the river is 4.0 m [Deltares, 2014]. In Figure 5.2 a layout of the bypass is shown, which has a length over land of 1800 m.


FIGURE 5.2: POSSIBLE BYPASS SUNTER

### 5.1.2.3. *Dredging*

To maintain a certain minimum water level in an offshore retention lake the areas near the coast should be dredged. The internationally used costs for offshore dredging are $ 10 per $m^3$. Depending on the shape and size of the lake, these costs will vary. Also, the sediment transported by the river should be dredged since it will settle in the retention lake.

## 5.1.3. Costs

To come to an overall costs efficient solution, a design is made for different combination of rivers which flow into the retention lake. In Table 5.3 an overview of the costs of the most efficient designs are given for each subsidence scenario, it is concluded that the smallest retention lakes are the most efficient since it happens that the pumps are less expensive than a large offshore dike. After some iterations, it was concluded that no retention lake will be the most feasible solution, this will be further discussed in chapter 5.3. The designs can be found in Appendix IX: Outer sea dike examples. Also the less efficient designs are given.

TABLE 5.3: COSTS OUTER SEA DIKE [×MILLION]

| | Scenario | Only Sunter | Only Cakung | Only BKT | Sunter + Cakung | Cakung + BKT | All Rivers |
|---|---|---|---|---|---|---|---|
| **Surface[ha]** | 1, 2, 3, 4a, 4b | 82.1 | 312.7 | 1262.8 | 312.7 | 1785.1 | 2750.7 |
| **Number of pumps [-]** | 1 | 2.66 | 3.12 | 7.57 | 6.23 | 11.44 | 8.36 |
| | 2 | 2.64 | 3.09 | 7.49 | 6.17 | 11.35 | 8.27 |
| | 3 | 1.76 | 2.07 | 4.86 | 4.13 | 7.95 | 5.45 |
| | 4a | 1.67 | 1.96 | 4.61 | 3.92 | 7.54 | 5.18 |
| | 4b | 1.64 | 1.92 | 4.51 | 3.83 | 7.35 | 5.06 |
| **Pump Costs [× million]** | 1 | $111 | $130 | $315 | $259 | $476 | $348 |
| | 2 | $110 | $129 | $312 | $257 | $473 | $344 |
| | 3 | $73 | $86 | $202 | $172 | $331 | $227 |
| | 4a | $70 | $82 | $192 | $163 | $314 | $216 |
| | 4b | $68 | $80 | $188 | $160 | $306 | $211 |
| **Dike Costs [× million]** | 1 | $536 | $1000 | $900 | $1000 | $1402 | $2049 |
| | 2 | $533 | $993 | $894 | $993 | $1393 | $2037 |
| | 3 | $265 | $513 | $467 | $513 | $749 | $1150 |
| | 4a | $219 | $428 | $291 | $428 | $634 | $990 |
| | 4b | $200 | $394 | $361 | $394 | $588 | $925 |
| **Bypass Sunter [× million]** | 1 , 2, 3 ,4a, 4b | $185 | - | - | $185 | - | $185 |
| **Total costs [× million]** | 1 | $832 | $1129 | $1216 | $1444 | $1878 | $2582 |
| | 2 | $827 | $1121 | $1206 | $1435 | $1865 | $2566 |
| | 3 | $523 | $599 | $669 | $869 | $1080 | $1561 |
| | 4a | $472 | $510 | $583 | $776 | $948 | $1390 |
| | 4b | $453 | $474 | $549 | $739 | $894 | $1321 |

## 5.2. Alternative 2 – On shore retention

Where space is available, an onshore retention lake could be build. The most feasible option is to build retention lake per river. Looking at the available space and the need of land acquisition, a retention lake for the Sunter, the Old Cakung and the BKT will be discussed. To create storage the lake should be dredged to a certain level, which is used as the minimum water level, this determines the total storage height. The lake should be connected to the rivers by gates to remain a minimum water level in the rivers.

### 5.2.1. Factor retention lakes

#### *5.2.1.1. Storage*

The storage of the retention lakes depends on the depth at which they are dredged. As reverence the Waduk Sunter Timur III is used. The banks will have a 1:2 slope. The dredging will costs approximately $ 7 per m$^3$, depending on the pumping costs, an optimal depth is chosen. [Sinotech Engineering Consultants LTD, 2011]

#### 5.2.1.2. *Land acquisition*

The major part of the costs consist of the land acquisition costs. In this case class 1 is used. However it is doubtful that the land prices at the east boarder of Jakarta will be the same as used in Table 5.2. Since these prices dominate the costs, more research is needed on this topic.

### 5.2.2. Sunter

The Sunter already got some retention lakes: Waduk Sunter Timur III, Waduk Kodamar and Waduk Pulomas. These retention lakes are already modelled in SOBEK. There is potential space in between Waduk Sunter Timur III and Waduk Kodamar for an extra retention lake, see Figure 5.3. The area and the approximate elevation at this point is shown in Table 5.4.

TABLE 5.4: ONLAND RETENTION LAKES

| Retention | Surface area [ha] | Elevation 2012 [m +LWS] |
|---|---|---|
| **Waduk Sunter** | 20.2 | 1.5 |
| **Waduk Cemetery** | 59.3 | 0.5 |
| **Waduk Old Cakung 1** | 33.1 | 0.1 |
| **Waduk Old Cakung 2** | 8.9 | 0.3 |
| **Waduk BKT 1** | 762 | (0.4) |
| **Waduk BKT 2** | 306 | 0.4 |


FIGURE 5.3:POTENTIAL RETENTION LAKE SUNTER

### 5.2.3. Old Cakung

The Old Cakung is flowing into the Cakung drain. An option is to block the connection to the Cakung Drain and to make use of a retention lake which can be pumped into the Cakung Drain. There are three sections, which could function as a retention lake, see Figure 5.4. Waduk Cemetery is, as the name already said, a cemetery and should be dredged.

Waduk Old Cakung 1 and Waduk Old Cakung 2 are fishing ponds. It is possible to use all the areas or to use them separately. In Table 5.4 the surface areas and the approximate elevations of the areas are given. When the areas are coupled the water level of the lowest area is used so no wall has to be build.

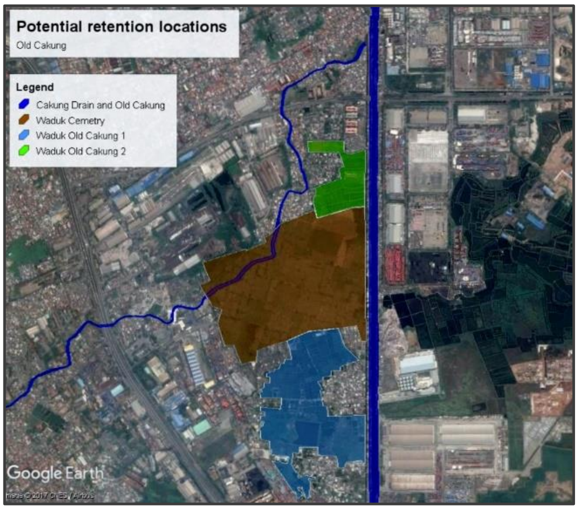


FIGURE 5.4 POTENTIAL RETENTION LAKES OLD CAKUNG

### 5.2.4. BKT

Also for the BKT it could be possible to make an onshore retention lake. However, these should be large to deal with the high discharges. Some potential locations are given in Figure 5.5. The surface areas of Waduk BKT 1 and Waduk BKT 2 are given in Table 5.4 just as the approximate elevation of Waduk BKT 2. For the elevation of Waduk BKT 1 no data is available, so the same elevation of Waduk BKT 2 is assumed since they are close to each other.

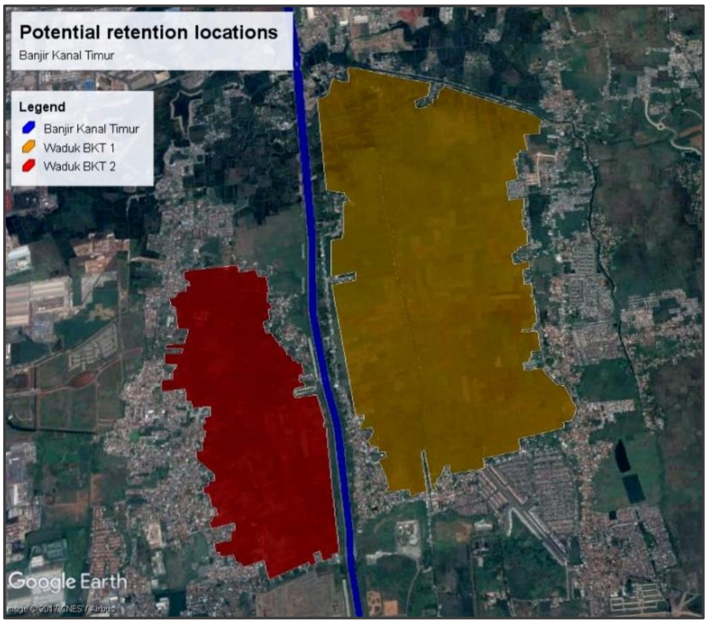


FIGURE 5.5: POTENTIAL RETENTION LAKES BKT

### 5.2.5. Costs

The costs of the Sunter retention lake is not taken into account since the retention is to small and in the middle of the river. The costs of the Old Cakung and the BKT retention lakes are given in Table 5.5.

TABLE 5.5: COSTS INLAND RETENTION LAKES

| | Scenario | Old Cakung | BKT |
|---|---|---|---|
| **Surface [ha]** | 1, 2, 3, 4a, 4b | 101.3 | 1068.4 |
| **Land acquisition [× million]** | 1, 2, 3, 4a, 4b | $770 | $8120 |
| **Dredging [× million]** | 1, 2, 3, 4a, 4b | $6 | $51 |
| **Pumps [× million]** | 1 | $39 | $591 |
| | 2 | $38 | $579 |
| | 3 | $18 | $250 |
| | 4a | $17 | $237 |
| | 4b | $17 | $229 |
| **Total cost [× million]** | 1 | $815 | $8763 |
| | 2 | $814 | $8750 |
| | 3 | $794 | $8421 |
| | 4a | $793 | $8409 |
| | 4b | $792 | $8400 |

## 5.3. Alternative 3 – Closing off the rivers

From section 5.1 it is concluded that enlarging the retention lake is more expensive than increasing the pumping capacity. The extreme scenario of this conclusion is not building a retention lake at all. In this case the rivers are closed off and pumps must be installed in the river mouth. These pumps need to be designed to deal with the maximal discharge of the river. This alternative will only protect the land from a river flood event. To ensure safety from the sea, also a coastal dike has to be build which will be discussed in section 5.4.4. The costs per river are given in Table 5.6.

TABLE 5.6: COSTS DIRECT PUMPING OF RIVER

| | Scenario | Sunter | Cakung | BKT |
|---|---|---|---|---|
| **Number of Pumps [-]** | 1 | 4.3 | 5.0 | 20.2 |
| | 2 | 4.3 | 4.9 | 20.0 |
| | 3 | 2.6 | 3.0 | 11.9 |
| | 4a | 2.4 | 2.8 | 11.3 |
| | 4b | 2.4 | 2.8 | 11.1 |
| **Costs [× million]** | 1 | $179 | $208 | $841 |
| | 2 | $179 | $204 | $833 |
| | 3 | $108 | $125 | $496 |
| | 4a | $100 | $117 | $471 |
| | 4b | $100 | $117 | $462 |

## 5.4. Alternative 4 – Flood defence along river

This section is about the flood defence structures, which may be implemented along the four rivers (Sunter, Cakung Drain, Old Cakung, BKT). First, the flood risk will be considered to choose a rainfall event for which the flood defences along the rivers are designed for. After that, the flood defence along the river is designed. Also, the use of extra pumps and the increase in height of the coastal dikes are taken into consideration in determining the costs.

### 5.4.1. Flood risk

To protect the land from flooding it is essential that the flood defences meet the current level of safety. In this part, the sensibility of overflow will be analysed. Overflow of the flood defence will happen if there is a rainfall event larger than 1/100 year. A 1/100 year rain event is calculated at 292 mm/day. Every mm/year more will result in inundation of the hinterland. Minor flooding due to overflow of the defences is not seen as a problem. A tipping point is defined by NCICD, which stated that inundation of more than 2 meters is unacceptable [NCICD, 2014]. This is due to vertical evacuation possibilities. Also, a tipping point of 3 meters is investigated.

#### *5.4.1.1. River capacity*

The capacity of the BKT is based on the amount of rainfall for a 1/100 event because it is assumed that the flood defence is designed for this event (an event of 292 mm/day). The BKT has a catchment area of 187 $km^2$ over a length of 23.5 km. In case the rainfall is more than 292 mm/day, the river will overflow at the locations of the pouring rivers and the catchment areas will flood. These pouring rivers and their catchment are: Cipinang (50.5 $km^2$), Upper Sunter (73.1 $km^2$), Buaran (13 $km^2$), Jatikramat (16.5 $km^2$) and the Cakung (34.5 $km^2$).

The discharge of the rivers Sunter, Cakung Drain and the Old Cakung is fully dependent on the catchment areas alongside the rivers, since the entire upstream catchment is taken by the BKT. As the river system is designed for a 1/100 event, the pumping stations are designed for a 1/100 event as well. In theory these rivers will not flood, but the water in the catchment will simply fill up. The total catchment area is approximated at 120 $km^2$.

#### *5.4.1.2. Critical rainfall events*

The goal is to find out for which rainfall event the (lower parts of) land will flood more than 2 or 3 meters in the downstream catchment of the BKT. This is done by making a model. First, the two catchment areas are considered; upstream and downstream the BKT. When there is a flood that exceeds the 1/100 rainfall event, it is assumed that 100% of the catchment downstream the BKT will contribute to the flood and 50% of the upstream catchment. Since the water wants to find its way to the lower areas in the catchment, it is not possible to distribute the discharge over the entire area. Therefore, one takes the lowest point in the downstream catchment and determines how much rain have to fall to fill up the catchment area to reach the 2 or 3 meters flooding in the lowest point, which is the tipping point. The parts are divided into 100x200m slices. A model is made where the total volume of storage is calculated. For a 2 meters tipping point, the rainfall event which caused this flooding height is equal to 349 mm/day. For a tipping point of 3 meters this event is equal to 505 mm/day.

#### 5.4.1.3. *Conclusion*

A 1/1000 year flooding height of 2 or 3 meter of the hinterland (depending on the chosen tipping point) is considered acceptable. The rainfall event which caused a flooding height of 2 m is equal to 349 mm/day. This rainfall event has a return period of 380 years, which is more frequent than the acceptable return period of 1000 years. To meet the criteria of the 1/1000 year flood, the dike has to be designed for a 1/260 rainfall event instead of the now chosen 1/100 rainfall event. If a tipping point of 3 meter is chosen, the rainfall event is 505 mm/day with a return period of 15920 years. The flood defences along the river meet the requirement to have at least 1/1000 year flooding of 3 meter of the hinterland. See Table 5.7 for the results.

TABLE 5.7: OVERVIEW RESULTS FLOOD RISK

| **Flooding height hinterland (tipping point)** | 2 m | 3 m |
|---|---|---|
| **Rainfall event** | 349 mm/day | 505 mm/day |
| **Return period rainfall event** | 380 years | 15920 years |
| **Safety level dike based on 1/1000 year flooding** | 260 years | - |

### 5.4.2. Flood defences along river

The structures which are considered are dikes, sheet piles, L-shaped concrete walls and a combined optimum solution.

The dike which consists of a sandy core and a clay layer will provide a natural protection against flooding in case there is enough space available and land acquisition is not too costly. The sheet piles will be used if there is minor space available or land acquisition is not profitable. The L-shaped concrete walls are an alternative solution for sheet pile walls since this solution requires less space than the sheet pile wall.

All three alternatives are analysed and put into a model, to compute the final costs for each alternative. Based on the spatial analysis of each river, the costs of implementation of flood defence structures are calculated. It is taken into consideration that in class 4: office + retail, it is not possible to remove a part of the construction. If the flood defence crosses a part of class 4, the whole area of class 4 is taken into account for the costs calculation.

In each model, the input for sea level rise is constant and the land-subsidence varies per part.

#### 5.4.2.1. *River dike*

The height of the dike determines the required land acquisition. A higher crest level requires more space for the dike. It is assumed that the maximum current water level in the rivers is equal to the crest height of the current flood defence along the river for a 1:100 rainfall event. So, the increase in height is equal to subsidence plus sea-level rise.

For the top width of the dike, a value of 10 m is chosen. Since the dikes mostly have a grass revetment an outer slope of 1:3 is required. The thickness of the clay layer on top of the sandy core layer is chosen to be 1 m. This thickness is sufficient to grow grass and to have sufficient stability. The inner slope of the dike is the same as the outer slope because it is decided not to use additional protection and the dike has to be safe against overflow. The ground level on the land site is chosen for each to be 1 meter lower than the current flood defence. This is a rough estimate, so further investigation is required.

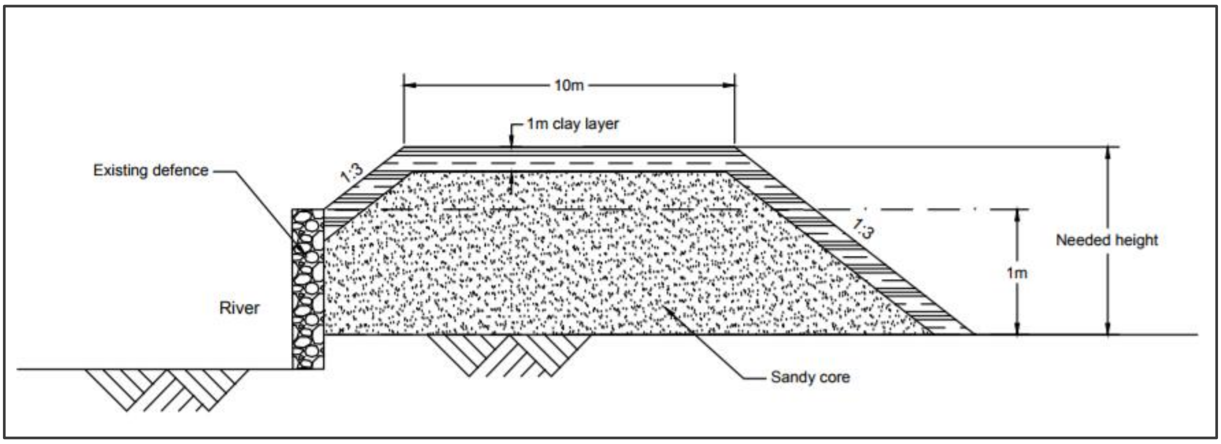



FIGURE 5.6 RIVER DIKE FLOOD DEFENCE STRUCTURE (NTS)

### 5.4.2.2. *Concrete sheet pile*

The concrete sheet pile defence structure requires less space. This defence structure is well known in Jakarta and can easily be constructed. In case an existing defence is present the sheet pile will be placed directly behind the flood defence. To provide sufficient stability the length below ground level is equal to two times the length above ground level. Clay with a slope of 1:2 is used to guarantee sufficient stability and resistance to overflow.

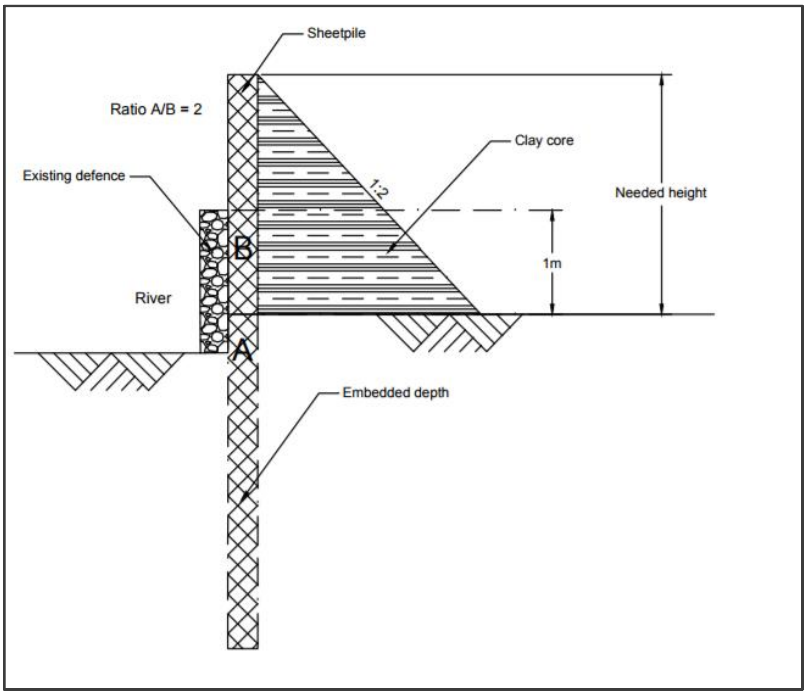



FIGURE 5.7: SHEET PILE WALL (NTS)

### 5.4.2.3. *L-shaped concrete wall*

The L-shaped wall defence structure requires less space. This defence structure is more expensive than a sheet pile wall. In case an existing defence wall is present the L-shaped wall will be placed directly behind the old wall.

The wall has a thickness of 0.5 m and the slab a thickness of 1m, which follows from the experience of civil-engineers (but this dimension could change in an optimum design) [Molenaar, 2017]. Clay with a slope of 1:1 is used to guarantee sufficient stability and resistance to overflow. The length of the horizontal part is 2/3 of the vertical wall.

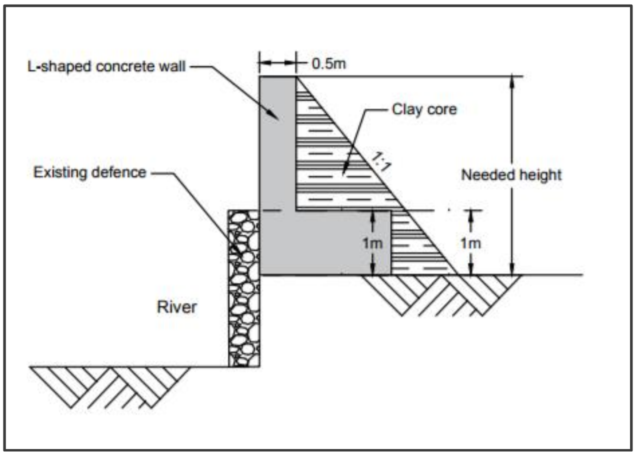



FIGURE 5.8: L-SHAPED WALL (NTS)

#### 5.4.2.4. *Optimum flood defence*

For each part, the above mentioned solutions are considered and the most cost effective is chosen.  for an optimum cheapest solution. The construction costs for a dike are lower than for a sheet pile or concrete wall, but the social costs are higher. If an area along the river is non-built, the optimum solution will be a dike because the social costs are not that high. But in parts where big shopping malls are close to the river, it is better to use a more expensive sheet pile wall to reduce the social costs.

### 5.4.3. Pumps

Next to the costs for construction of the dikes along the river and coastline, also costs for extra pumps need to be considered in this solution. Some catchment areas, depending on the subsidence scenario's, instead of runoff under gravity need to be pumped into the rivers. The pump capacity of the already existing polders may need to be improved when heightening the walls. For every polder/catchment area the elevation is determined by taking the average elevation near the rivers of the earlier mentioned parts (section 4.2) that are enclosed by the catchment areas. Also, the average water level is taken into account per catchment area. The required hydraulic head per catchment area follows from average elevation minus the average water level, the total subsidence in 2080 per scenario and the sea level rise in 2080. Pumps are required if this value becomes negative, which differs per subsidence scenario. The needed capacity is calculated using the Runoff formula and the Aerial Reduction Factor, as described in section 2.2.3. The existing pump capacity (for most catchment areas there are no pumps) and the capacity of the existing retention lakes are also considered in determining the needed pump capacity. Several assumptions for this model need to be highlighted. These are:

1. The effect of evaporation and input via deep groundwater extraction is significantly small compared to rainfall, so neglected.
2. Day 3 of the 3-day rainfall event is used.
3. In defining the catchment areas, the shape-file of Witteveen + Bos is used. When the catchment belongs to two rivers, the area is divided by two. Figure 2.7 and Figure 2.8 are used for determining the catchment areas.
4. For areas which are not directly connected to one of the main rivers and canals, this area is added to the river where small canals flow to.
5. Only the areas along the rivers in this scope are taken into account in this calculation.
6. The surface areas of the retention lakes (waduks) are according to source: "Pengendalian Banjir-Jakarta Dinas PU DKI Jakarta" and assumed is an average capacity of 3 meters water level increase.
7. The BKT is not considered because no extra costs for pumps are expected. The majority of the area along the BKT will always have the possibility to flow under gravity and the other part downstream can flow to sea via other canals.

The costs for the pumps are calculated according to the cost estimation model for the pumps needed for a retention lake, see section 5.1. The only difference is that for the off-shore retention lake pumps of 42 $m^3/s$ discharge are used and in this section unit prices are defined based on the price of the 42 $m^3/s$ discharge. Thus, the number of pumps is not evaluated, only the total pumping discharge per catchment area. Furthermore, extra cost for increase in hydraulic head is integrated in the model. These extra costs are assumed to be 5 percent of the OPEX cost per meter head. The CAPEX and OPEX are given in Table 5.2. These costs are used for the total pump costs calculation.

### 5.4.4. Coastal dike

Many different types of coastal dikes are possible. For stage A, six dike concepts were already developed. In this report the base case, port concept and green concept are further looked into. The base concept design is also considered for stage A, this design can be seen as a dike in front of the existing coastline (Figure 5.9).

The second design of a coastal dike is the reduced base case. The reduced base case is a dike concept which is used in case there is less space available (Figure 5.10). This design is not capable of carrying roads. This design will be used for places where a road is already present or no road is needed.

The third design of a coastal dike is the port concept, see Figure 5.11. Since there is a large port area at Tanjung Priok where small industry is present, this alternative has to be considered. The dimensions of this design are slightly different from the dimensions of the base case.

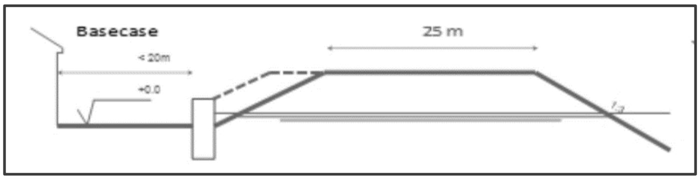



FIGURE 5.9: BASE CONCEPT AS A COASTAL DIKE [SAWARENDO, 2017]

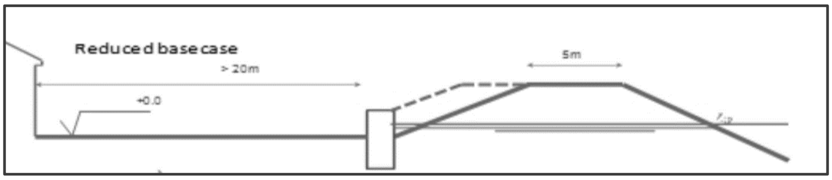



FIGURE 5.10: REDUCED BASE CASE DESIGN CONCEPT AS A COASTAL DIKE [SAWARENDO, 2017]

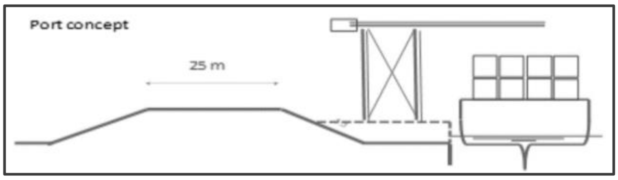



FIGURE 5.11: PORT CONCEPT DESIGN AS A COASTAL DIKE [SAWARENDO, 2017]

The alignment of the coastal dike along the coast of East Jakarta is shown in Figure 5.12. The line represents the alignment of the coastal dike, it is decided to also construct dikes in the harbour areas. When it is considered acceptable that the harbour floods in case of a 1/1000 event, an on land dike will be constructed. An analysis of the coastal dike for stage A is done by NCICD [Sawarendo, 2017]. The total length of the coastal dike in the east is divided into 9 parts. Table 5.8 shows lengths and the names of the different parts.

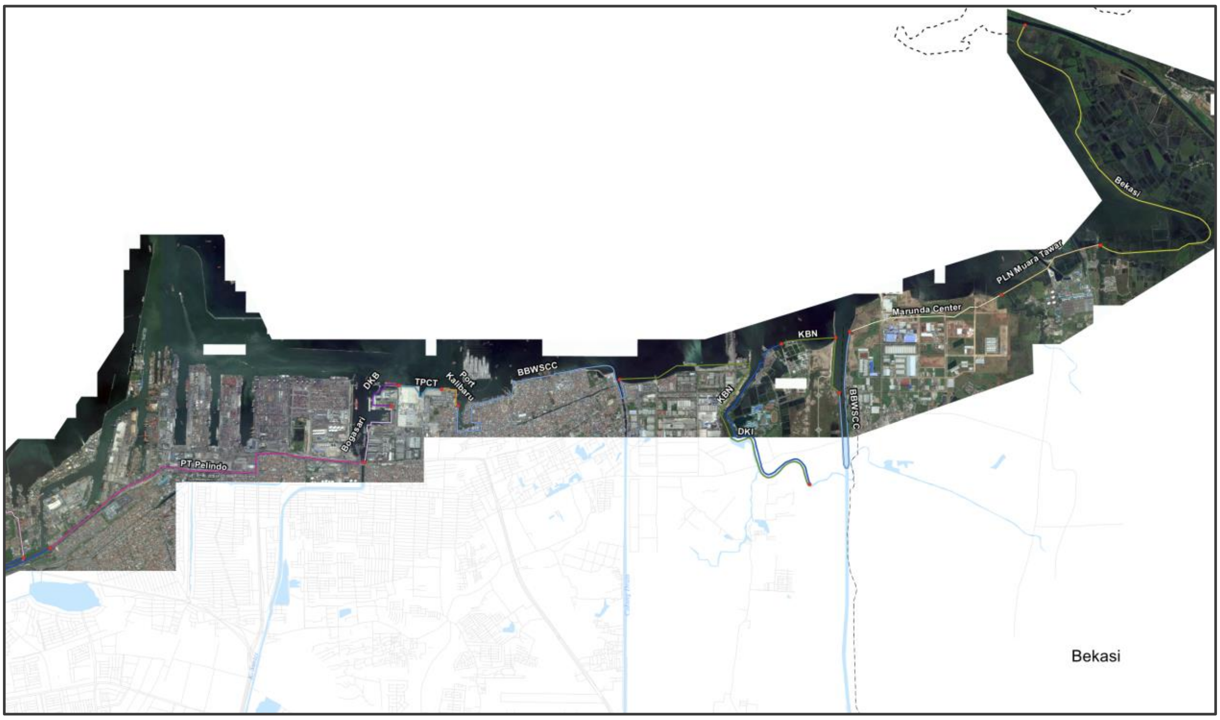



FIGURE 5.12: ALIGNMENT OF THE COASTAL DIKE [GOOGLE EARTH PRO 2017]

TABLE 5.8: DIKE CONCEPTS ALONG EAST COAST

| Part | Name | Dike concept | Length [m] |
|---|---|---|---|
| 1 | PT Pelindo | Port Concept | 6.640 |
| 2 | PT Bogasari | Port Concept | 513 |
| 3 | PT DKB | Port Concept | 481 |

| | | | |
|---|---|---|---|
| 4 | TPCT | Port Concept | 224 |
| 5 | Port Kalibaru | Port Concept | 22 |
| 6 | BBWSCC | Base Concept | 2.225 |
| 7 | KBN 1(reduced) | Base Concept | 1.968 |
| 8 | KBN 2 (extended) | Base Concept | 1.473 |
| 9 | Marunda Center | Reduced concept | 2.386 |

For each part, the costs for the dike can be calculated according to Table 5.1 and Table 5.2. Only PT Pelindo, PT Bogasari and PT DKB require land acquisition, the other parts will be built in the sea for which no land acquisition costs are used. The river parts which can be seen in Figure 5.12 are already analysed in the spatial analysis and are therefore not taken into account for this cost estimation.

#### 5.4.4.1. *Design of the dike*

The design of the coastal dike is based on the dike designs for West Jakarta [Sawarendo, 2017]. The parameters used in the excel model are shown in Appendix X.

### 5.4.5. Bridges

When heightening the walls and dikes along the river, the costs of replacing the bridges need to be determined. The number of bridges are counted and added to the total costs. The Sunter, Old Cakung, Cakung Drain and BKT counts respectively 36, 23, 5 and 32 bridges in different categories. It is assumed that all bridges for all scenarios have to be replaced, because the current situation is already not sufficient in most cases.

### 5.4.6. Conclusion

The total costs in million per scenario are shown in Table 5.9.

TABLE 5.9: COSTS IN MILLION USD DOLLAR PER SCENARIO. S= SUNTER, OC= OLD CAKUNG,CD= CAKUNG DRAIN

| | **Construction + Social costs** | | | | | | | | | | | | | | | | | **Demolish bridge and construction new bridge** | | | | **Total costs installing pumps** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Dike | | | | Concrete Sheetpile | | | | Concrete L-wall | | | | Optimum flood defence | | | | Coastal dike | Bridges | | | | Pumps | | | | **Total** |
| | S | OC | CD | BKT | S | OC | CD | BKT | S | OC | CD | BKT | S | OC | CD | BKT | | S | OC | CD | BKT | S | OC | CD | BKT | |
| **Scenario 1** | 2878 | 1651 | 2767 | 3180 | 1390 | 881 | 1054 | 968 | 1047 | 629 | 849 | 831 | 995 | 623 | 837 | 815 | 544 | 220 | 93 | 50 | 236 | 104 | 45 | 82 | 0 | **4646** |
| **Scenario 2** | 2940 | 1661 | 2752 | 3262 | 1410 | 906 | 1048 | 991 | 1067 | 654 | 843 | 851 | 1014 | 647 | 832 | 834 | 534 | 220 | 93 | 50 | 236 | 105 | 69 | 124 | 0 | **4757** |
| **Scenario 3** | 1256 | 886 | 1262 | 834 | 510 | 250 | 423 | 196 | 469 | 186 | 358 | 241 | 439 | 183 | 345 | 185 | 184 | 220 | 93 | 50 | 236 | 46 | 62 | 110 | 0 | **2155** |
| **Scenario 4a** | 769 | 592 | 713 | 470 | 361 | 142 | 308 | 121 | 332 | 104 | 260 | 134 | 321 | 101 | 225 | 112 | 123 | 220 | 93 | 50 | 236 | 30 | 60 | 107 | 0 | **1709** |
| **Scenario 4b** | 541 | 410 | 588 | 324 | 307 | 103 | 258 | 90 | 277 | 69 | 218 | 88 | 275 | 69 | 217 | 82 | 97 | 220 | 93 | 50 | 236 | 27 | 59 | 106 | 0 | **1530** |

## 5.5. Additional costs

In every solution, there are some additional costs caused by the dike located at Tanjung Priok. Independent of the chosen solution a dike has to be built at this location. So, on top of the calculated costs of a solution the costs in Table 5.10 have to be added.

TABLE 5.10: COSTS DIKE TANGJUNG PRIOK IN MILLION USD DOLLAR

| | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4a | Scenario 4b |
|---|---|---|---|---|---|
| **Costs [$]** | 1074 | 1077 | 502 | 376 | 324 |

## 5.6. OPQ islands

It is still not known if the OPQ islands will be constructed. In the previous sections the OPQ island where not taken into account. In this section, the consequences of building the OPQ islands in the different designs will be explained.

### 5.6.1. Flood defences along the rivers

In this case the main rivers will drain in between and next to the islands as given in Figure 5.13. This will lead to approximately 13 km of extra sea dike. It could also be plausible to increase the elevation of the OPQ islands with the level of subsidence to ensure they stay above sea level.

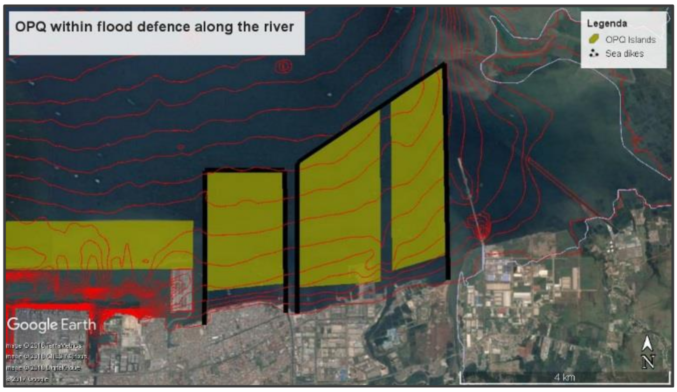


FIGURE 5.13: OPQ WITHIN FLOOD DEFENCES ALONG THE RIVER

### 5.6.2. Offshore retention lake

For the offshore retention lake, it depends on which lake is chosen and which rivers will flow into it. It is most efficient if all the rivers will flow in the lake and the lake has the layout as given in Figure 5.14. In this case the islands can be made on the current land level and subsidence would not play a role. Since the outer sea dike is already in place, only some small lake dikes along the islands have to be built. Another positive aspect is that parts of the islands are connected to open sea and can be used as a port.

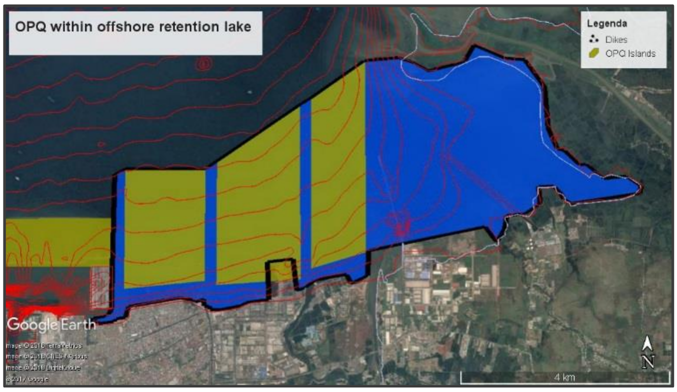


FIGURE 5.14: OPQ WITHIN OFFSHORE RETENTION LAKE

### 5.6.3. Onshore retention lake

This will be same as with flood defences along the rivers. A large extra length of sea dike has to be build. The same designs as for flood defences along the rivers are applicable to deal with the subsidence.

### 5.6.4. Closing of the rivers

In this case also some extra dikes have to be built along the islands. However, the pumping station of the Cakung Drain could be built at the seaside of the islands, which means that 5.6 km of sea dike can be built as river dike, as can be seen in Figure 5.15.

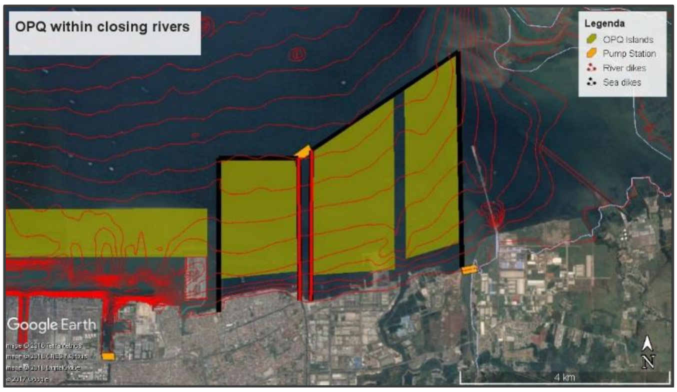


FIGURE 5.15: OPQ WITHIN CLOSING OF THE RIVERS

# 6. CONCEPTUAL DESIGN

In the previous chapter several solutions are described and their costs are determined. Solutions are an outer sea dike, inland retention lakes, closing off the rivers and heightening of the flood defences along the rivers. In this chapter combinations of the different solutions will be considered to come to a conceptual design. This will be done for scenario 2 where subsidence will continue "Business as Usual" and for scenario 3 where the groundwater abstraction is reduced "Reduced Abstraction". Considering the current political situation these two scenarios are the most likely to occur.

## 6.1. Inland retention lake

For the Old Cakung there is the possibility to create an inland retention lake downstream and to block the connection with the Cakung Drain. In this case the catchment area of the Old Cakung will turn into a large polder where the water can be pumped into the Cakung Drain. As a result, no flood defences along the Old Cakung , which could result in a reduction in costs. (Figure 6.1).

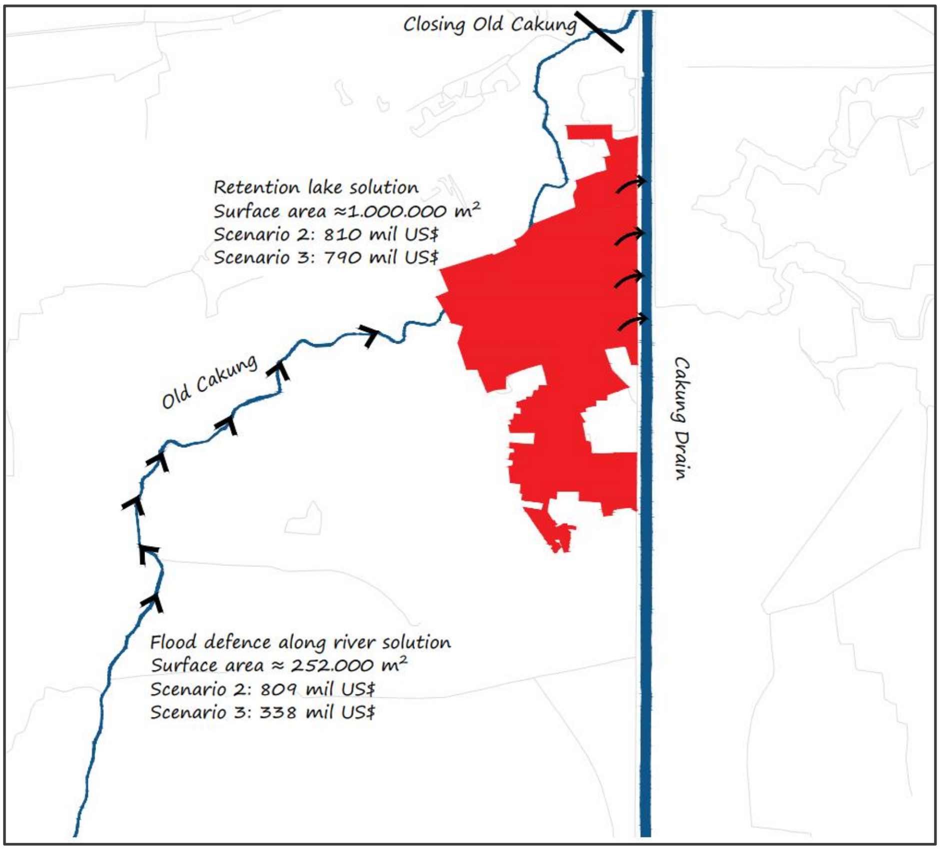



FIGURE 6.1: INLAND RETENTION LAKE VERSUS FLOOD DEFENCE ALONG RIVER

The costs of this inland retention lake are estimated to be 810 million USD for scenario 2 and 790 million USD for scenario 3. The costs of the dikes along the Old Cakung are 809 million USD for scenario 2 and 338 million USD for scenario 3. For scenario 2 it is certainly worth considering the inland retention lake, but for scenario 3 it would be cheaper to heighten the flood defences along the Old Cakung.

Along the Sunter there is not enough space for a retention lake to be sufficient. Next to the BKT there is enough space, but the lake would become too large and therefore too expensive to consider (8.4 -8.8 billion USD).

## 6.2. Outer Sea dike in combination with flood defences along the rivers

When creating an offshore retention lake by placing an outer sea dike in the entire bay of East Jakarta, there is no need for heightening the flood defences along the rivers. It is also possible to look at a combination of the offshore and inland solution. The combinations are called after the rivers, which flow into the offshore lake. Combination G is a fully inland solution and combination H can be seen as an infinite small offshore retention lake. In Figure 6.2, Figure 6.3 and Figure 6.4 an overview of the combinations is given.

**A**: Outer sea dike Sunter
**B:** Outer sea dike Cakung Drain/Old Cakung
**C:** Outer sea dike BKT
**D:** Outer sea dike Sunter/Cakung Drain/Old Cakung
**E:** Outer sea dike Cakung Drain/Old Cakung/BKT
**F:** Outer sea dike all rivers
**G:** No outer sea dike, flood defences rivers
**H:** No outer sea dike, closing off the rivers

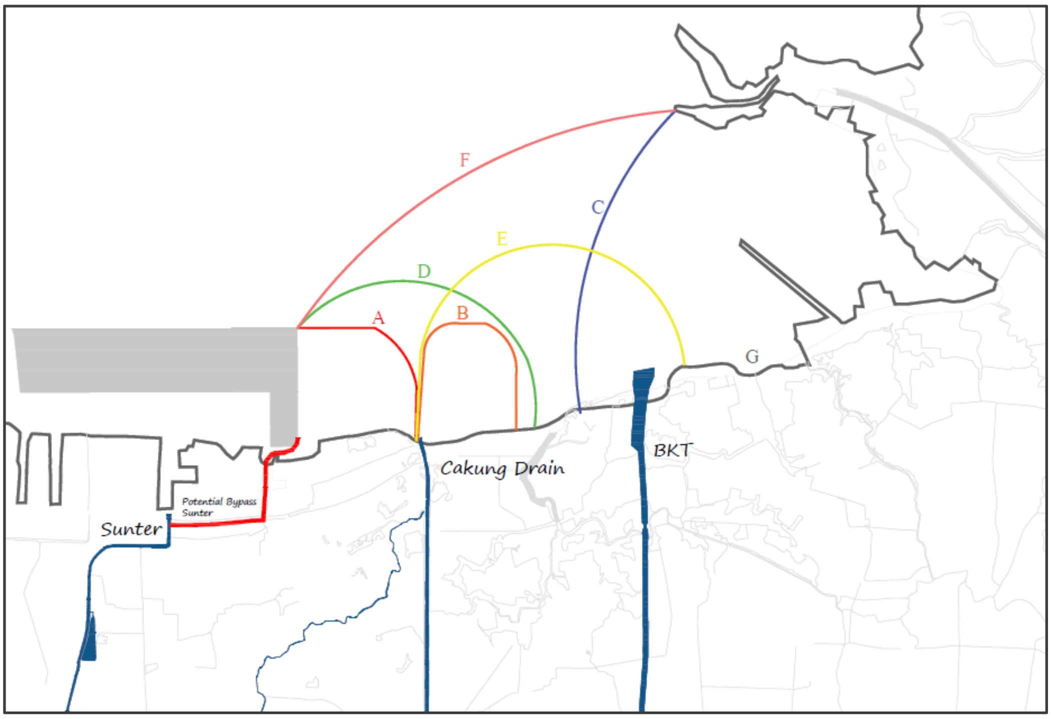


FIGURE 6.2: OVERVIEW POSSIBLE COMBINATIONS OUTER SEA DIKE AND HEIGHTENING OF THE FLOOD DEFENCE ALONG THE RIVERS

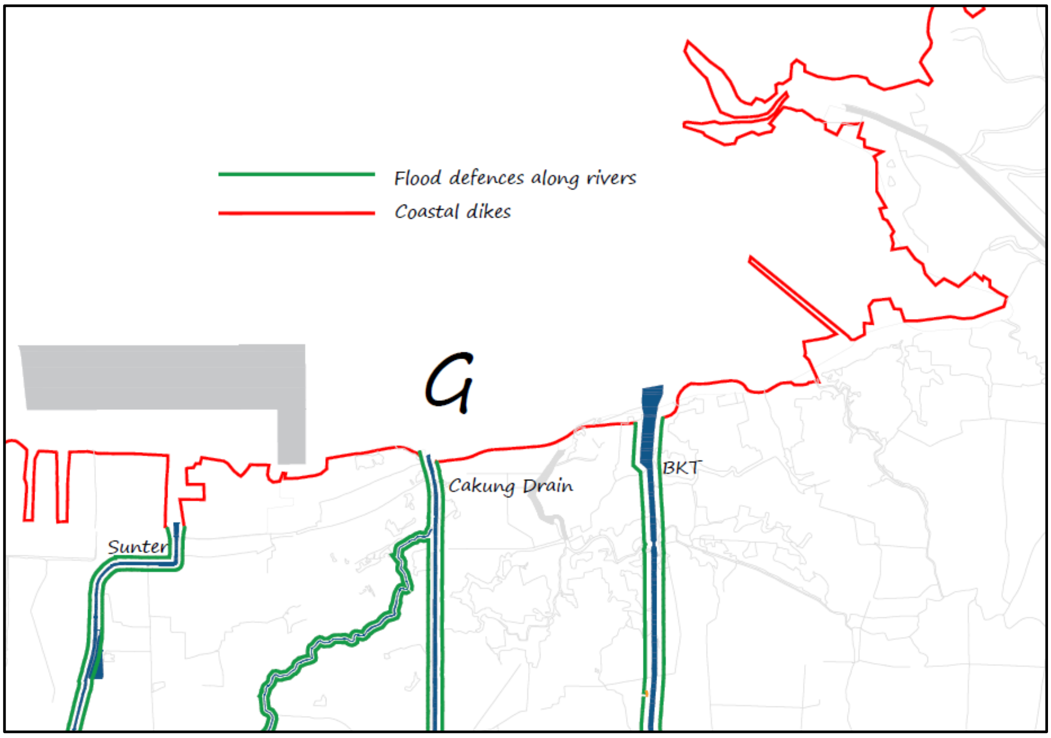



FIGURE 6.3: COMBINATION G NO OUTER SEA DIKE, FLOOD DEFENCES ALONG THE RIVERS

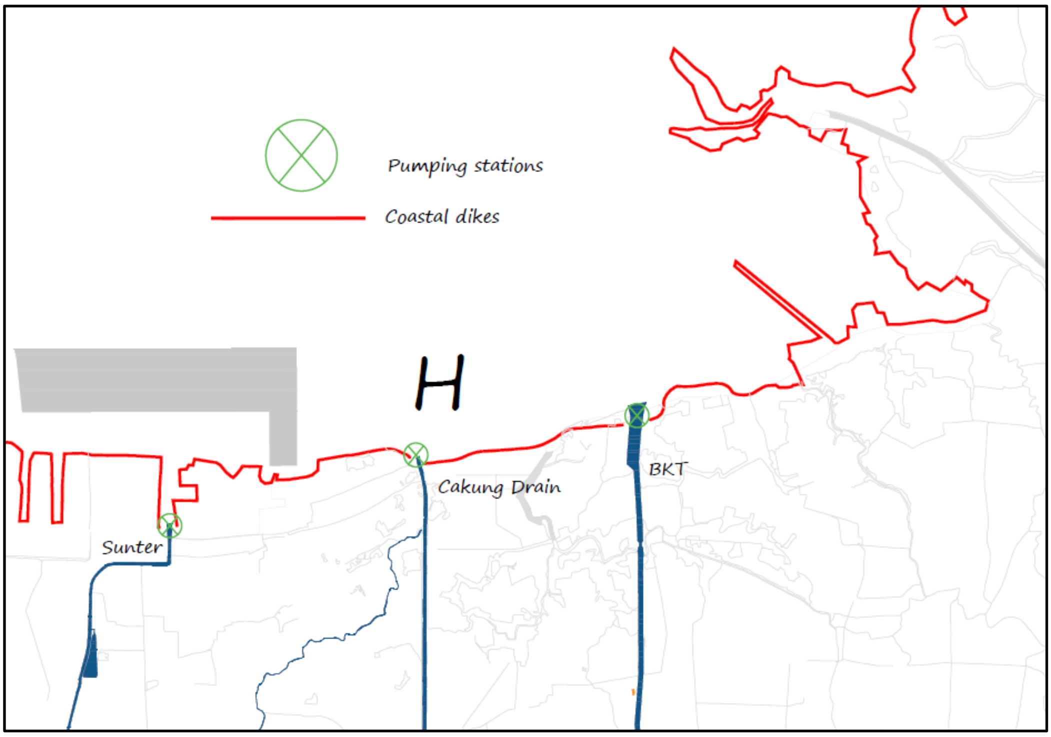



FIGURE 6.4: COMBINATION H NO OUTER SEA DIKE, CLOSING OFF THE RIVERS

## 6.3. Scenario 2 - Business as usual

For this scenario the costs of the described combinations are calculated and summarized in Table 6.1. As can be concluded from this table, combination H is the cheapest. The costs under 'outer sea dike' only consist of pump cost. The coastal dike costs are maximum compared to the other combinations and there are no costs for flood defence along the rivers.

The rivers can continue to flow out normally without the effect of the sea, because the water level at the end of the rivers is kept constant by pumping. The needed number of pumps can be adjusted every couple of years. The showed number provides enough capacity for the 1/100 discharge event in 2080.

When it turns out that an outer sea dike becomes a must (e.g. extensive risk analysis), combination D and F are the cheapest.

In this case there is no need for a heightening of the flood defences along the Cakung Drain and Old Cakung, so the idea of an inland retention lake as described in section 6.1 becomes unnecessary and is therefore not shown in this table.

TABLE 6.1: SCENARIO 2 BUSINESS AS USUAL COSTS OF THE COMBINATIONS IN BILLIONS USD

| Combination | Outer sea dike (incl. pumps) | Coastal dike | Flood defences rivers | Total costs | Number of pumps outer seadike |
|---|---|---|---|---|---|
| **A: Outer sea dike Sunter** | $0,85 | $0,38 | $2,88 | $4,11 | 2,6 |
| **B: Outer sea dike Cakung Drain/Old Cakung** | $1,14 | $0,27 | $2,41 | $3,82 | 3,1 |
| **C: Outer sea dike BKT** | $1,23 | $0,36 | $3,15 | $4,74 | 7,5 |
| **D: Outer sea dike Sunter/Cakung Drain/Old Cakung** | $1,45 | $0,27 | $1,07 | **$2,79** | 6,2 |
| **E: Outer sea dike Cakung Drain/Old Cakung/BKT** | $1,89 | $0,15 | $1,34 | $3,38 | 11,4 |
| **F: Outer sea dike all rivers** | $2,59 | $0,00 | $0,00 | **$2,59** | 8,3 |
| **G: No outer sea dike, flood defences rivers** | $0,00 | $0,53 | $4,22 | $4,75 | 0,0 |
| **H: No outer sea dike, closing off the rivers** | $1,22 | $0,53 | $0,00 | **$1,74** | 29,2 |

## 6.4. Scenario 3 - Reduced abstraction

This scenario is more optimistic than the previous one, which can be clearly seen in the numbers of Table 6.2. Again, combination H is the cheapest and he number of pumps can be adjusted every year. The showed number of 17.5 pumps provides enough capacity for the 1/100 discharge event in 2080.

When it turns out that an outer sea dike becomes a must (e.g. extensive risk analysis), combination D and F are again the cheapest. This means that a design can be made for scenario 3 according combination D or F and eventually adapted to scenario 2 if the government is unable to stop the deep-water abstraction.

In this scenario, combination G (no outer sea dike) becomes more attractive compared to the case in scenario 2, where it was not worth considering. The difference in costs between combination F (outer sea dike all rivers) and G (no outer sea dike) becomes smaller as can be seen in Table 6.2.

TABLE 6.2: SCENARIO 3 REDUCED DEEP WATER EXTRACTION COSTS OF THE COMBINATIONS IN BILLIONS USD

| Combination | Outer sea dike (incl. pumps) | Coastal dike | Flood defences rivers | Total costs | Number of pumps outer sea dike |
|---|---|---|---|---|---|
| A: Outer sea dike Sunter | $0,54 | $0,13 | $1,27 | $1,94 | 1,8 |
| B: Outer sea dike Cakung Drain/Old Cakung | $0,62 | $0,09 | $1,13 | $1,84 | 2,1 |
| C: Outer sea dike BKT | $0,69 | $0,13 | $1,55 | $2,37 | 4,9 |
| D: Outer sea dike Sunter/Cakung Drain/Old Cakung | $0,89 | $0,09 | $0,42 | **$1,40** | 4,1 |
| E: Outer sea dike Cakung Drain/Old Cakung/BKT | $1,10 | $0,05 | $0,71 | $1,86 | 8,0 |
| F : Outer sea dike all rivers | $1,58 | $0,00 | $0,00 | **$1,58** | 5,5 |
| G: No outer sea dike, flood defences rivers | $0,00 | $0,18 | $1,97 | $2,15 | 0,0 |
| H: No outer sea dike, closing off the rivers | $0,73 | $0,18 | $0,00 | **$0,90** | 17,5 |

## 6.5. Pros and cons per combination

Looking at the costs of the different combinations, some combinations appear to be favourable. To come to a conceptual design the pros and cons per combination are considered.

**A: Outer sea dike Sunter**

PROS

1. Relatively small part of the existing coast is excluded from connection to sea.
2. No heightening of the inland flood defences along the Sunter.
3. Marunda Center Terminal Port is not interrupted.
4. No outer sea dike for BKT (large discharge) needed.
5. Because of the lowered water level in the retention lake, the consequences when the outer sea dike breaks will be smaller. First, the offshore retention lake will fill up and therefore delay the effect of flooding.
6. Creates retention and therefore less risks at the Sunter in case of an extreme rainfall event.
7. Connection to 'New Priok Container Terminal' possible.

CONS

1. Bypass for Sunter needed.
2. Lots of improvised port activities (fisheries).
3. Along Cakung Drain/Old Cakung and BKT heightening of the flood defences, land acquisition, rebuilding bridges and replacing many people is needed.
4. Expensive construction of outer sea dike.
5. Pollution in offshore retention lake.
6. Difficult to combine with the OPQ islands.

**B: Outer sea dike Cakung Drain/Old Cakung**

PROS

1. No heightening of the inland flood defences along the Cakung Drain and Old Cakung which are situated in a densely populated area.
2. Relatively small part of the existing coast excluded from connection to sea.
3. No outer sea dike for BKT (large discharge) needed.
4. No bypass Sunter needed.
5. Fishery activities close to the Port of Tanjung Priok are not interrupted.
6. Marunda Center Terminal Port is not interrupted.
7. Because of the lowered water level in the retention lake, the consequences when the outer sea dike breaks will be smaller. First, the offshore retention lake will fill up and therefore delay the effect of flooding.
8. Creates retention and therefore less risks in case of an extreme rainfall event.

CONS

1. A lot of port activities up to 1.4 km upstream the Cakung Drain.
2. Along BKT heightening of the flood defences, land acquisition, rebuilding bridges and replacing many people is required.
3. Pollution in offshore retention lake.
4. Expensive construction of outer sea dike.
5. Difficult to combine with the OPQ islands.

**C: Outer sea dike BKT**

PROS

1. Because of the lowered water level in the retention lake, the consequences when the outer sea dike breaks will be smaller. First, the offshore retention lake will fill up and therefore delay the effect of flooding.
2. Creates retention and therefore less risk in case of an extreme rainfall event.
3. No heightening of the inland flood defences along the BKT.
4. No bypass Sunter needed.
5. Fishery activities close to the Port of Tanjung Priok are not interrupted.
6. Possibility to create a large retention lake for relatively short outer sea dike.
7. Possible to combine with the OPQ islands.

CONS

1. Marunda Center Terminal Port situated at the east of the BKT.
2. Pumps need to handle the relatively large discharge of the BKT.
3. Expensive construction of outer sea dike.
4. Pollution in offshore retention lake.
5. Along the Sunter, Cakung Drain/Old Cakung heightening of the flood defences, land acquisition, rebuilding bridges and replacing many people is required.

**D: Outer sea dike Sunter/Cakung Drain/Old Cakung**

PROS

1. No heightening of the inland flood defences along the Cakung Drain/Old Cakung and Sunter which are situated in a densely populated area.
2. Because of the lowered water level in the retention lake, the consequences when the outer sea dike breaks will be smaller. First, the offshore retention lake will fill up and therefore delay the effect of flooding.
3. Creates retention and therefore less risks in case of an extreme rainfall event.
4. No outer sea dike for BKT (large discharge) needed, so less pumps needed.
5. Marunda Center Terminal Port is not interrupted.
6. Connection to 'New Priok Container Terminal' possible.

CONS

1. Lots of port activities along the coast and 1,4 km upstream the Cakung Drain.
2. Along BKT heightening of the flood defences, land acquisition, rebuilding bridges and replacing many people is required.
3. Bypass for Sunter needed.
4. Expensive construction of outer sea dike.
5. Pollution in offshore retention lake.
6. Difficult to combine with the OPQ islands.

**E: Outer sea dike Cakung Drain/Old Cakung/BKT**

PROS

1. Because of the lowered water level in the retention lake, the consequences when the outer sea dike breaks will be smaller. First, the offshore retention lake will fill up and therefore delay the effect of flooding.
2. No heightening of the inland flood defences along the Cakung Drain/Old Cakung and BKT.
3. Creates retention and therefore less risks in case of an extreme rainfall event.
4. Fishery activities close to the Port of Tanjung Priok and activities at Marunda Center Terminal Port are not interrupted.
5. Possible to combine with the OPQ islands.
6. No bypass Sunter needed.

CONS

1. Along Sunter heightening of the flood defences, (land acquisition) and replacing many people.
2. Marunda Center Terminal Port situated at the east of the BKT.
3. Lots of port activities along the coast and 1,4 km upstream the Cakung Drain.
4. Pollution in offshore retention lake.
5. Expensive construction of outer sea dike.
6. Pumps need to handle the relatively large discharge of the BKT.
7. Along the Sunter heightening of the flood defences, land acquisition, rebuilding bridges and replacing many people is required.

**F: Outer sea dike all rivers**

PROS

1. One solution for all the rivers.
2. No heightening of the flood defences along the rivers.
3. Because of the lowered water level in the retention lake, the consequences when the outer sea dike breaks will be smaller. First, the offshore retention lake will fill up and therefore delay the effect of flooding.
4. Creates large retention and therefore less risks in case of an extreme rainfall event.
5. In combination with OPQ islands this forms a robust system
6. No pumps along any river needed.
7. Connection to 'New Priok Container Terminal' possible.
8. Easy to combine with the OPQ islands.

CONS

1. Pollution in offshore retention lake.
2. Marunda Center Terminal Port situated at the east of the BKT.
3. Lots of port activities along the coast and 1.4 km upstream the Cakung Drain.
4. Bypass for Sunter needed.
5. Expensive construction of outer sea dike.

**G: No outer sea dike, flood defences rivers**

PROS

1. No outer sea dike needed.
2. Only one solution for all the rivers.
3. Coastline remains in contact with sea, so fishery activities close to the Port of Tanjung Priok and activities at Marunda Center Terminal Port are not interrupted.
4. No pollution in an offshore retention lake and along the waterfront of the city.
5. Less pumping capacity needed.
6. No bypass Sunter needed.

CONS

1. Large coastal dikes needed.
2. Complicated construction method in densely populated areas.
3. Flood defences along the rivers needed.
4. Land acquisition and replacing many people.
5. A lot of bridges need to be rebuild.
6. In the long term, people are living in increasingly deep polders protected by only one dike, which makes the consequences higher in case of failure.
7. Pumping capacity needed to keep the polders free from flooding.
8. Expensive to combine with OPQ islands.

**H: No outer sea dike, closing off the rivers**

PROS

1. No outer sea dike needed.
2. Relatively cheap solution.
3. Coastline remains in contact with sea, so fishery activities close to the Port of Tanjung Priok and activities at Marunda Center Terminal Port are not interrupted.
4. No pollution in offshore retention lake and along the waterfront of the city.
5. No land acquisition and replacement of bridges along the rivers needed.
6. No pumps along any river needed.
7. Can be easily adapted to future scenarios.
8. BKT already has a tidal gate.
9. Only one solution for all rivers.
10. No need for construction offshore or in densely populated areas.

CONS

1. Large coastal dikes needed.
2. Clogging up of waste at pump inlets, so rivers need to be cleaned.
3. Fishery activities 1.4 km upstream the Cakung Drain need to be replaced.
4. Extreme pumping capacity will be required to keep the polder free from flooding.
5. In the long term, people are living in increasingly deep polders protected by only one dike, which makes the consequences higher in case of failure.
6. Requires a lot of power/electricity in a short time.
7. Expensive to combine with OPQ islands.

## 6.6. The adaptive solution – closing off the rivers

Taking all the pros and cons into account and the various scenarios, one conceptual design will be made for combination H "No Outer Sea Dike, closing off the rivers". In the design process it is not possible to consider continuously all the possible scenarios of subsidence. Therefore, scenario 3 is chosen for the initial building process, which can be adapted if the scenario changes in the future: an adaptive solution.

The design is made, such that it can handle different kind of discharges by adjusting the pump capacity at the mouth of the rivers. An advantage of this adaptive solution is that it spreads the costs over the entire period until 2080 compared to the major capital investments of the other combinations. The question is however, to what extend it is feasible to build pumps that large. And next to this, the risk of flooding when a pump fails, may be larger when there is no retention lake to delay the consequences.

Initially, all the rivers will be equipped with tidal gates instead of a permanent closure as described in section 5.3. The advantage of a tidal gate is that it stimulates the trough flow of the river. So, these gates provide protection against the backwater effect during high water. When the subsidence is not stopped (scenario 2) the tidal gates cannot function anymore. The gates will be closed off and the pumps will be switched on continuously.

Several pumps will be installed directly to handle the subsidence of scenario 3. Other areas are already reserved for extension. From that moment on the subsidence will be monitored to check in which extent scenario 2 is taking place and if additional pumps are needed. This will be further discussed in section 7.3.1.

Currently, as a short term 'no regret' measure, a coastal wall (stage AE+ NCICD 2017) is already under construction in East Jakarta and will be extended in the future with a coastal dike at the seaward side of the EA+ wall. This dike will be constructed to fulfil the safety requirements with subsidence of scenario 2. This will be done because heightening of the dike is much more complicated and expensive than building an extra pump. Therefore, the pumping capacity will be adaptive and the height of the coastal dike is directly designed for scenario 2.

### 6.6.1. Improve water quality

With a sinking city being closed off from the sea, the water quality problem needs to be investigated. This is important, because clogging of waste in the pumps can have major consequences. To prevent clogging of waste, especially attention has to be paid to the solid waste management. As can be seen in Table 6.1 and Table 6.2 , combination H is 500 million to 1 billion cheaper than the cheapest outer sea wall combination. This money can be used for the solid waste management by placing racks and grabs at several places along the rivers.

An integral water quality improvement program should be started. This includes waste water treatment, solid waste management, dredging and non-structural measures. Luckily, the first steps have already been made according to the first Master Plan of NCICD 2014. The work of the Public Facility Maintenance Agency (PPSU), the so-called "Orange Army", is essential and more money need to be invested in this agency.

### 6.6.2. Additional hydraulic measures

Additional upstream measures help alleviate flood risks in the coastal area: diversion of water coming to Jakarta (Ciliwung BKT connection), improving the city drainage system (allowing better through flow) and improving the drainage pumping capacity to the main river and canals.

## 6.7. Impressions – adaptive solution

At the following page some impression drawings are shown of the adaptive solution.

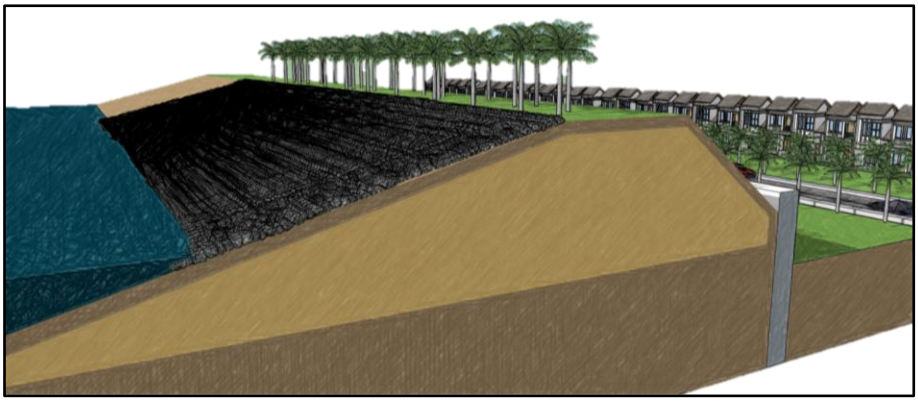


FIGURE 6.5: IMPRESSION DRAWING COASTAL DIKE

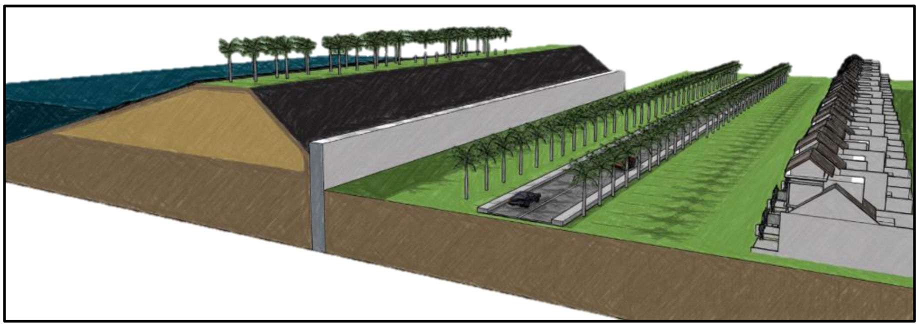


FIGURE 6.6: IMPRESSIONS DRAWING COASTAL DIKE

FIGURE 6.7: IMPRESSION DRAWING GATES + 3 PUMPS AT THE END OF A RIVER

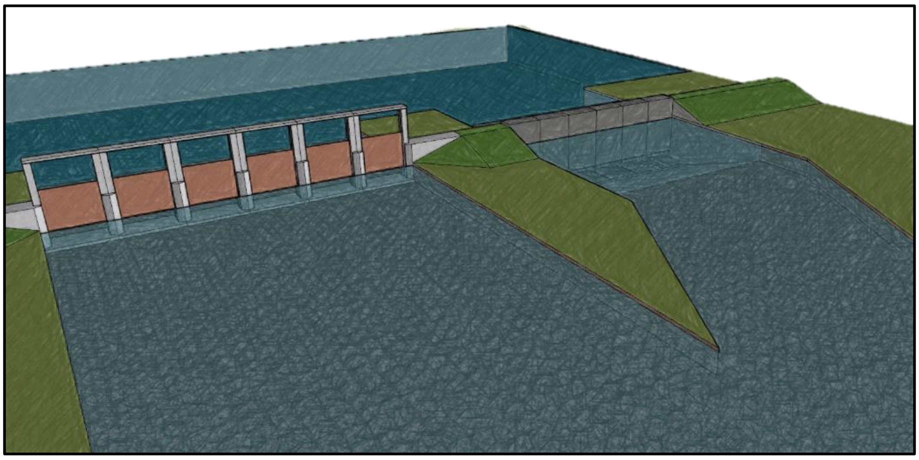


FIGURE 6.8: IMPRESSION DRAWING GATES + 6 PUMPS AT THE END OF A RIVER

# 7. CONSTRUCTION TECHNOLOGY

In this chapter, the construction technology of the coastal dike is described. First the most important design checks are addressed. After this the construction process of the coastal dike will be discussed. For the construction process the method of construction is discussed which is an important aspect of the project. In the last part the time schedule of the project is discussed. In this part the adaptive pathway method for this project will be explained. This part is followed by an explanation of the construction time and a planning for construction.

## 7.1. Design checks

The crucial part of the adaptive solution is the design of the coastal dikes. To protect the land from flooding it is essential that these dikes meet the required level of safety. To assess the feasibility of this solution several design checks are executed. In Figure 7.1 possible failure mechanisms are shown. Also extreme hazards loads are considered.

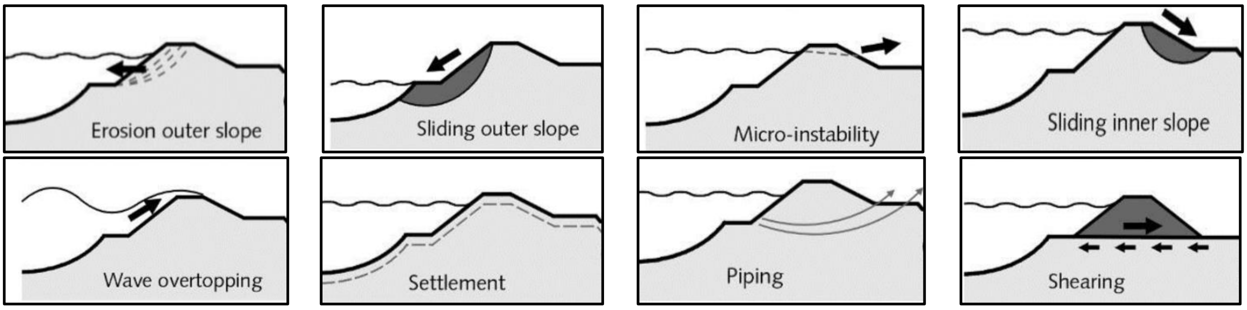



FIGURE 7.1: FAILURE MECHANISMS DIKE

### 7.1.1. Overtopping

To determine the overtopping discharge, the extreme wave conditions for a 1/1000 event are used. Three types of the coastal dike are considered: the base concept, port concept and the reduced concept. For these dikes segments F and G (Table 2.7) are used for determining the wave conditions. The design water level for the dike section is given with respect to $LWS_{2012}$. These values can be found in section 2.1.3.6.

To calculate the overtopping discharge per part the following formulas are used [Hydraulic structures manual, 2017]:

$$\frac{q}{\sqrt{g\, H_{mo}{}^{3}}} = a \times e^{\left(\frac{-b\, R_c}{H_{mo}}\right)} \qquad 7.1.$$

Where:

$\frac{q}{\sqrt{g * H_{mo}{}^{3}}}$ = Dimensionless overtopping discharge [-]

$q$ = Overtopping discharge [m3/s/m]

$\frac{R_c}{H_{mo}}$ = The relative crest freeboard [-]

$R_c$ = Crest height [m]
$H_{mo}$ = Significant wave height [m]
$a = \frac{0{,}067}{\sqrt{\tan\alpha}} \gamma_b \xi_{m-1.0}$ [-]
$b = \frac{4{,}3}{\xi_{m-1.0} \gamma_b \gamma_f \gamma_\beta \gamma_v}$ [-]
$\gamma_b$ = Influence factor of a berm [-]
$\gamma_f$ = Influence factor of roughness of slope [-]
$\gamma_\beta$ = Factor of oblique wave attack [-]
$\gamma_v$ = Influence factor of vertical wall on the dike [-]
$\xi_{m-1.0} = \frac{\tan\alpha}{\sqrt{\frac{H_{mo}}{L_o}}}$ [-]

The height of the highest wave is 2.5 m (Table 7.1). In combination with the design water level and the crest level per part, the crest freeboard for each part can be determined. For these dikes, no berms are used. For both subsidence scenarios, the crest freeboard stays the same, only the dike height below water level increases in case of more subsidence.

TABLE 7.1: CREST HEIGHT AND OVERTOPPING DISCHARGE PER PART OF THE COASTAL DIKE (SCENARIO 2 AND 3)

| **Part** | Name | Dike concept | Length (m) | Crest height 2080 (+LWS m ) | Crest freeboard 2080 (m) | q (l/m/s) |
|---|---|---|---|---|---|---|
| 1 | PT Pelindo (Private) | Port Concept | 6.640 | 8,16 | 3,59 | 14,9 |
| 2 | PT Bogasari (Private) | Port Concept | 513 | 7,41 | 2,84 | 64,3 |
| 3 | PT DKB (Private) | Port Concept | 481 | 7,43 | 2,86 | 62,6 |
| 4 | TPCT (Private) | Port Concept | 224 | 7,50 | 2,93 | 57,1 |
| 5 | Port Kalibaru (Private) | Port Concept | 22 | 7,54 | 2,97 | 54,2 |
| 6 | BBWSCC | Base Concept | 2.225 | 6,77 | 2,2 | 10,2 |
| 7 | KBN 1(reduced) | Base Concept | 1.968 | 6,70 | 2,13 | 11,9 |
| 8 | KBN 2 (extended) | Base Concept | 1.473 | 6,74 | 2,17 | 10,9 |
| 9 | Marunda Center | Reduced concept | 2.386 | 6,87 | 2,3 | 34,2 |

As a reduction factor for the slope roughness a factor $\gamma_f$ of 0.7 is used (rock). The value for $\gamma_b$ is chosen to be 1 (no berm present). Since there is no vertical wall in front of the dike, the factor $\gamma_v$ is chosen to be 1. The slope $\tan\alpha$ is different for the base concept type of dike. From the result above, it becomes clear that the maximum overtopping discharge for the coastal dike is 64.2 l/s/m. Since there is no berm taken into account, the effect of wave overtopping is substantial. The expected damage is depending on the duration of the storm. The design of the dikes should be able to withstand an overtopping rate up to 100 l/m/s [Molenaar, 2017]. The dike is considered safe for overtopping and the design is sufficient, since the dike has an inner slope with an asphalt revetment.

TABLE 7.2: OVERTOPPING DISCHARGE LIMITS [MOLENAAR, 2017]

| **Hazard type and reason** | **mean discharge** $q$ (l/s/m) |
|---|---|
| **Embankment seawalls / sea dikes** | |
| No damage if crest and rear slope are well protected | 50-200 |
| No damage to crest and rear face of grass covered embankment of clay | 1-10 |
| No damage to crest and rear face of embankment if not protected | 0,1 |
| **Promenade or revetment seawalls** | |
| Damage to paved or armoured promenade behind seawall | 200 |
| Damage to grassed or lightly protected promenade or reclamation cover | 50 |

### 7.1.2. Piping

As with micro-instability, piping starts to develop at the land-side of the dike. If the hydraulic gradients in the subsoil towards the land-side are sufficiently high, soil particles will start eroding which leads to the formation of channels in the subsoil (pipes). These pipes can grow and undermine the construction. Piping could have a substantial effect on the stability of the dike. Therefore, a safety assessment of the dike regarding uplift, heave and piping, characteristic value of each variable should be done.

The effects are depending on the soil conditions, which of no data is available. A detailed soil investigation (cone penetration test) should be carried out before starting the detailed engineering of the coastal dike. In a more detailed engineering stage the stability against these failure mechanisms can be verified. In general, the top soil layers along the coast of Jakarta consist of clay [Kops, 2014]. The phenomena of piping and seepage are unlikely to occur with clay layers. It is not expected that piping or seepage is likely to occur. These phenomena are not further considered at this stage of the design.

It is expected that the existing seawall behind will function as a boundary for piping and reduce the effect of piping (if present) substantially. This wall will function as a cut-off wall, which will reduce the flow of water in the cross section of the dike. This is only possible if the piles of the existing wall are installed through the non-permeable layer. In case the sheet piles are penetrated into a non-permeable layer under the dike base, the groundwater flow will be reduced and block seepage in the dike entirely.

### 7.1.3. Geotechnical macro and micro stability

Both macro and micro geotechnical stabilities have to be checked. The micro stability occurs when seepage water causes the phreatic surface to rise and reach the inner slope of the dike. In case of impermeable cover layers (clay) on the inner slope, the increased pressure in the dike body can just push up that cover. If in turn the inner slope consists of permeable, granular material, internal erosion can be initiated. Failure as a result of geotechnical instability of a dike may result in a sudden collapse of the dike. In this report, a global geotechnical stability check is done based on a simplified soil profile for the coastal dike. Taking into account the phase of the project the geotechnical stabilities should be done over again in detail for the detailed design.

#### 7.1.3.1. *Sliding inner slope*

The most common stability problem with dikes is the instability or sliding of the inner slope. As the outside water level rises, the infiltrated water leads to saturation of the dike body and to increasing pore pressures. The effective stress and the shear strength reduces, which can lead to development of sliding planes in the slope. This failure mechanism is checked by using the software D-Geo Stability, which is developed by Deltares. In this case, the simplified Bishop method is used to calculate the stability. This method checks the moment equilibrium of a circular slip plane. The factor of safety (FoS) is determined by the ratio of the driving force $M_r$ and the resisting force $M_s$. A safety factor above 1.15 is considered acceptable.

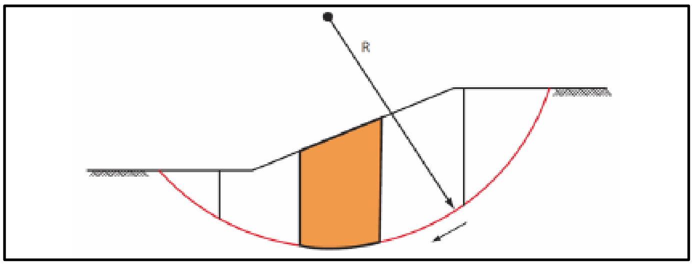



FIGURE 7.2: PRINCIPLE BISHOP METHOD [SOURCE: JONKMAN ET AL,2016]

To perform such a calculation, assumptions have to be made. The following assumptions are made:

- The soil underneath the dike consists of a soft clay layer.
- The revetment on the dike consists of a stiff clay layer.
- The phreatic line goes linear from design water level at sea side to ground level at land side through the dike body.
- The minimum freeboard is 2.13 m.
- The bed level at land side is equal to the top of the existing wall, thus modelling the wall as a continuous soft clay layer.

This check is done for the governing parts (scenario 2) of the coastal dikes for all three dike designs (base, reduced and port). The safety factors are shown in Table 7.3.

TABLE 7.3: SAFETY FACTORS

| **Type design** | **Safety factor [-]** |
|---|---|
| **Port** | 1.28 |
| **Base** | 1.40 |
| **Reduced** | 1.33 |

The results can be found in Figure 7.3 - Figure 7.5 . As can be seen in the table, all types of dike designs are sufficient.

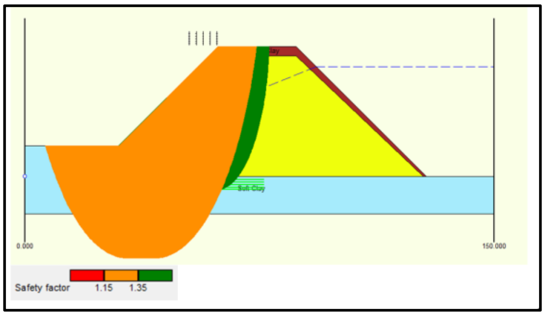



FIGURE 7.3: SAFETY OVERVIEW PORT DESIGN DIKE (D-GEO STABILITY)

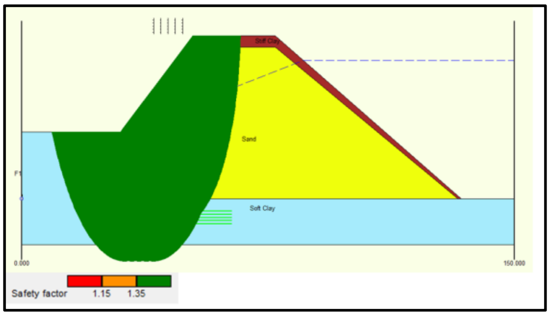



FIGURE 7.4: SAFETY OVERVIEW BASE DESIGN DIKE (D-GEO STABILITY)

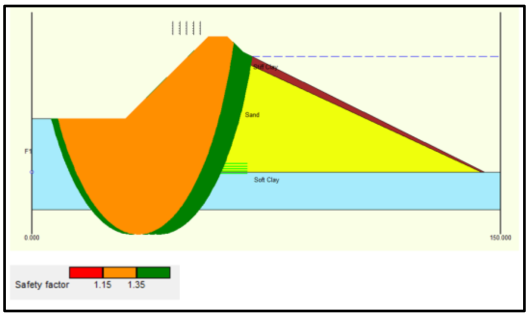



FIGURE 7.5: SAFETY OVERVIEW REDUCED DESIGN DIKE (D-GEO STABILITY)

#### *7.1.3.2. Sliding outer slope*

Sliding of the outer slope can occur, if the outside water level drops very quickly. The pore water in the dike cannot follow at the same pace and the pressure of the water inside the dike. This causes the outer slope to slide towards the water. Since the water level of the sea is not expected to drop very quickly, this failure mechanism is not further considered.

#### *7.1.3.3. Shearing (horizontal sliding)*

Similarly, to sliding of the inner slope, sliding or shearing can also occur along the base of the dike body. The main driving force is the horizontal force of the water exerted on the outer slope. This failure mechanism is an issue for dikes made of light material where the effective stresses at the base are very low. Because the dike mainly consists of heavy sand, this is not seen as an issue.

### 7.1.4. Erosion outer slope

The erosion of the outer slope happens in case of revetment failure. This failure mechanism can eventually result in collapse of a dike. Since the dike is located in the sea, the dike requires protection from currents and waves by revetment. For the coastal dike the wave attack is substantial and strong revetments are required. For this phase of the project a thickness of 1.4 m is used. For the detailed design a detailed calculation for the revetment of the dike should be done. For this phase of the project and for the conceptual design a fixed thickness is used.

### 7.1.5. Settlement

When determining the crest height, one has also to take into account the settlement of the dike after construction, see Figure 7.6. The water in the pores of the soil layers squeeze out, causing a decrease in volume. Depending on the type of soil layer, the settlement process can take months to years.

The settlement is already calculated for the coastal dikes in West Jakarta. Since the same soil properties are assumed, these results apply for East Jakarta as well. After 15 years, a maximum settlement of 1.2 meter is calculated, see Figure 7.7. This settlement is already taken into account for the coastal dike designs (base, port and reduced).

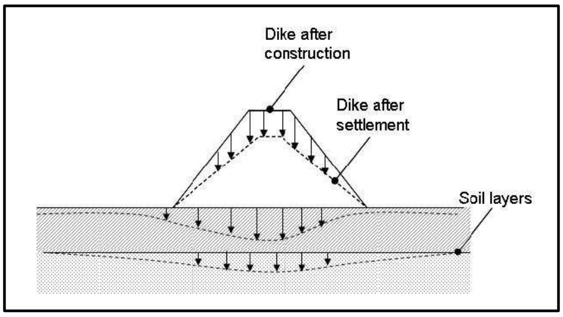



FIGURE 7.6: SETTLEMENT OF A DIKE DUE TO LOADS [SOURCE: NCICD, 2014]

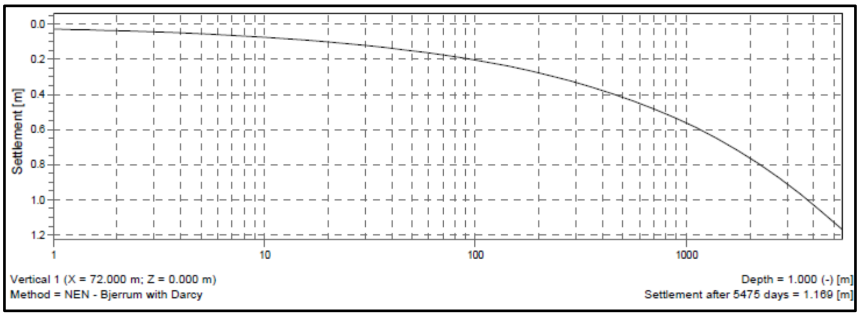



FIGURE 7.7: SETTLEMENT VERSUS TIME [SOURCE: NCICD, 2014]

### 7.1.6. Extreme hazard

The Jakarta region is sensitive to earthquakes. Therefore, all structures should be designed to withstand earthquakes (section 2.1.5). In this conceptual design phase the dikes were not checked against earthquakes. This should be done in a later phase for the detailed design. Tsunamis are not considered for the conceptual design because the Jakarta region is not sensitive to tsunamis, but this should be checked during the detailed design [Veen, 2013].

## 7.2. Construction method

In this chapter, the execution and construction methods of the coastal dike will be explained. An overview of the equipment is given in appendix XI.

### 7.2.1. Stages of constructing the dike

Basically, an entirely new dike will be constructed. The primary objective is to build the dike in a cost and time efficient way and to prevent flooding. The following stages for construction the dike are defined and are discussed further on in this section:

**Stage 1: Site clearance**
Preparing the construction site
**Stage 2: Embankment**
Filling of the dike means the deposition, spreading and compaction of sand and clay.
**Stage 3: Revetment**
Finally, the revetment is placed on the dike, which consists of rocks and asphalt.

### 7.2.2. Site clearance

#### *7.2.2.1. Resettlement*

Before construction, at some places resettlements have to take place. This cannot be done before alternative areas are available. First, a location has to be chosen for the resettlement and the relocation buildings and facilities have to be built. When this is done, the resettlement can take place and the acquisitioned areas can be demolished. Now, the rest of the construction can take place.

#### *7.2.2.2. Preparing the construction area*

Before construction can start, the construction area needs to be ready. Because of the +/- 11 m depth of very soft soil of the seabed surface, dredging works are necessary. This is done by dredging out the soils and replaces it with sand. Dredging is done until it reaches the competent layer. Profiling can be carried out to obtain the trench in its final level; the process is completed by a trailing suction hopper or a grab dredger. The dredged material should be disposed at a disposal area nearby.

The access roads consist of permanent or temporary routes to the coastal dike from outside the construction area. The access routes should be safe and especially wide enough to ensure that construction materials can be delivered on time and labour equipment costs are low. The access roads should fulfil the following requirements:

- Ability to withstand construction equipment high wheel loads
- Provide adequate space for movement because only few space is available.
- Provide a safe working environment and safety for the public because many people will be living in the area.
- Have sufficient clearance between the roadway and the overhead power lines. Since, there are many low hanging overhead powerlines this has to be taken into account.

To prevent delay of construction, it is important that the processes to obtain permits start as early as possible. Land acquisition should be taken into account to make the access roads. A map including the access roads should be available before construction starts. This map includes access points to the construction area and routes to the nearest main roads. Planning and coordination with highway authorities and municipalities are required to avoid disruptions in traffic during the project and to improve time efficiency. The access points should be arranged in such a way that lorries enter and exit the site in a forward direction. Mainly trucks, construction workers, the project team and off-road dump trucks will enter the site from the access roads.

It is important to manage site traffic, since it can cause delays to local traffic and it can affect safety on the construction site. A well organised construction area is likely to provide a positive perspective to the locals. Because the access roads and parts of the project will be constructed in an urban area, a well organised construction area is a must.

## 7.2.3. Building materials

### *7.2.3.1. Sand*

The core of the dike consists of sand, which may originates from the Java Sea. For East Jakarta, the sand will be collected from sand location 1 which is shown in Figure 7.8.

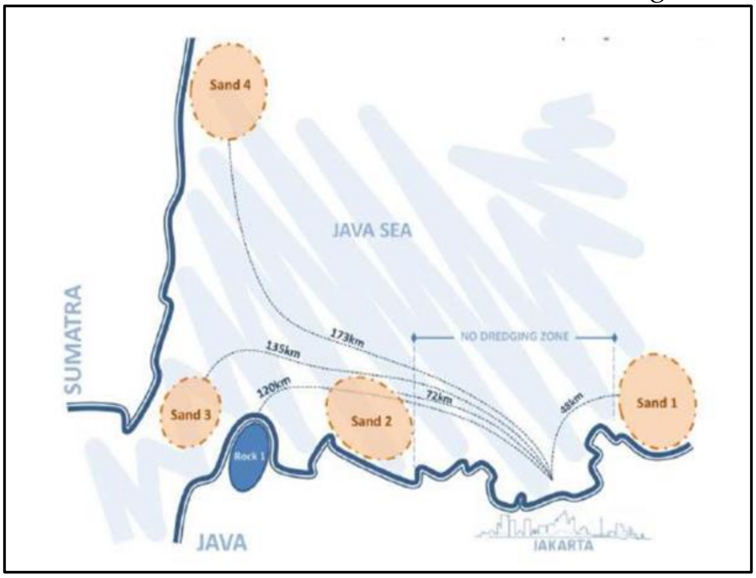



FIGURE 7.8: SAND DEPOTS [SOURCE: NCICD, 2017]

The transport from sand location 1 to the building site will be done by a trailing suction hopper dredger. A large hopper dredger with a capacity of 18,292 $m^3$ will be used for this process. The hopper dredger will be used for the suction, transport and deployment of the sand. The deployment takes place at about 5 kilometres from the coast by connection to a floating pipeline which will transport the sand to the coast as showed in Figure 7.9. Dumping or rainbowing the sand is not possible because of the limited depth on the location of the coastal dike. Before the transport phase can start, the route should be checked for obstacles. To limit the risks during transport and limit the transport time, a short distance for transport is preferred. Another restriction is the draught in combination with the tide. The draught of the hopper dredger is 10.5 m, so the location where the hopper dredger connects to the pipeline must be in sufficiently deep water (about 5 kilometres from the coast).

FIGURE 7.9: HOPPER DREDGER [SOURCE: VAN OORD

Other important factors are side currents, flow velocities, constrained areas, weather conditions and other ships using the transport route. Transport should take place during good weather conditions. High wind velocities can cause problems in terms of navigability of the dredger. Wave heights should be considered as well, since the dredger is not able to come close to shore if the waves are too high. The side currents and flow velocities should not be a problem for these types of dredgers, since these ships are built to operate in these circumstances. For the larger part of the coast of East Jakarta the pipeline will not hinder the port activities, but for the Tanjung Priok area it could be challenging.

The distribution and compaction of the sand should be done carefully. The reclamation material will be placed in uniform layers using the trailer hopper dredger. The first layer should be thin (approx. 0.5 m) to avoid instability of the seabed and followed by subsequent layers of 1 m until it reaches approximately 1.5 m below water level. Filling usually continues up to +2 m above the water level. [Maris, 2017] Prefabricated vertical drains will then be installed in a triangular pattern from the toe of the dike, extending to the fill area. Afterwards, sand filling continues up to the design fill level (includes surcharge). The sand fill process can be done in series or parallel, depending on the number of hopper dredgers. The compaction of the sand will be done using vibro-compaction. For the vibro-compaction a vibrator is used which is hanged from a crane and lowered vertically into the soil under its own weight and vibrations (see figure below). The induced vibration will result in consolidation of the ground.

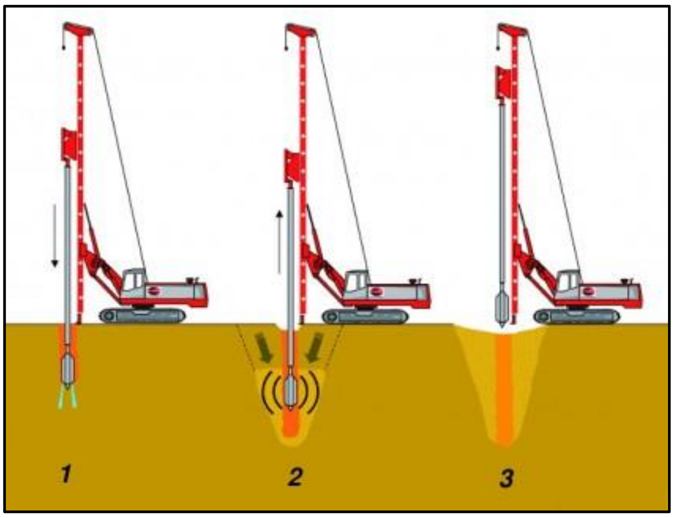


FIGURE 7.10: VIBRO-COMPACTION (HAYWARD BAKER.COM)

*7.2.3.2. Clay*

The coastal dike requires clay to stop the infiltration into the dike. The clay layer is chosen to be 1 m thick. After the sand layer is placed the clay layer can be placed on top of the sand layer. The clay will be collected and dumped on the construction site by the use of cranes with draglines. After that, a bulldozer will spread the clay over the dike in the dry part of the dike. The clay for the wet part of the dike will be placed by the use of a crane on a barge. A description of the bulldozer and crane can be found in appendix XI: Equipment.

#### 7.2.3.3. *Asphalt*

The inner slope of the coastal dike will be covered with an asphalt layer. The asphalt is sufficiently watertight if the voids are smaller than 8%. To obtain sufficient durability, the void ratio of the asphalt on the slopes will be 6%. The asphalt is used as an impermeable revetment on the inner slope of the coastal dike. Because the asphalt has to be compacted mechanically, it cannot be placed in the tidal zone or underwater. This is not a problem, since asphalt will only be placed on the inner slope, which is in dry conditions. The asphalt will be placed with the help of earth moving equipment. A crane will put the material on the slope and spreads it. If necessary, additional finishing by hand has to be carried out. The length of the coastal dike is long and the slope is relatively steep. Therefore, it is possible to make use of special designed asphalt finishers. Compaction of the asphalt is done by tandem vibratory rollers. Due to the relatively steep slope, the compaction equipment may be attached by cables to winches at the top of the slope to neutralize the weight. Once the construction is finished, a seal coat of bitumen emulsion blinded with chipping is provided.

#### 7.2.3.4. *Armour layers*

The armour layers on the outer slope consist of large amount of rocks. A relatively large share of the rock material needs to be of the grade 60-300 kg. Since this grade of rock material is assumed to be available in Jakarta, this is not seen as a drawback. The rocks will be transported to the construction site by barges via the sea. A grab dredger or crane barge can be used to place the stones on the dike from the seaside. To ensure accuracy, it is important to pay attention to the tidal and wave conditions during the process. To ensure stability, the placement of the rocks on the dike should be done from the toe to the top of the dike.

### 7.2.4. Tidal gates

To prevent the seawater from flowing into the rivers the first thing which has to be done is the construction of the tidal gates. The tidal gates have to be built in parts to ensure that the river can still discharge during construction. Since the conveyance area of the river will reduce during construction, the construction has to take place in the dry season, which reaches from March till October.

#### 7.2.4.1. *Construction*

First the construction site should be ready to accommodate transport, storage and space for a crane. After this, a temporary sheet pile has to be constructed at the place of the first part to guarantee a dry construction site (Figure 7.11). When the site is dry, the ground should be improved with an excavator and the formwork for the foundation and the sill should be placed to cast the concrete. When this is done, the bed protection on the top structure could be placed. Finally, the prefab gate can be placed. When the first gate is ready the sheet piles will be removed and the gate will be in function to guarantee conveyance area. After that, the next gate can be constructed in the same way and so on.


FIGURE 7.11: DRY CONSTRUCTION SITE

## 7.2.5. Pumps

### *7.2.5.1. Construction site*

At the river mouth of each river a pumping station has to be build. During construction the river still has to discharge. Because of this, the following building locations are chosen, see Figure 7.12, Figure 7.13 and Figure 7.14. When the pumping station is finished, a connection to the river has to be dredged.


FIGURE 7.12: CONSTRUCTION SITE BKT


FIGURE 7.13: CONSTRUCTION SITE CAKUNG DRAIN


FIGURE 7.14: CONSTRUCTION SITE SUNTER

#### *7.2.5.2. Construction*

The pumps will be constructed in a dry construction site. Because of this, the supply of the materials and equipment will be land based. First, the construction sites have to be made ready, some buildings and settlements have to be broken down and a road connection has to be made. After this, soil improvements have to be carried out where needed, this will be done with excavators and the useless soil will be carried away. When the ground is improved, the foundation of the pumping station can be made in situ. After this, the rest of the pumping station can be built in situ. Thereafter, the pumps can be placed. The pumps will be brought in parts to the construction site and will be placed by a crane in the pumping station. The pumps need to have a proper connection with the dikes. At the suction side of the pumps, the river connection can be made. First in the dry and at the end the old dike will be broken, so the connection is made. The same applies at the discharge side with the sea connection.

## 7.3. Time schedule

In this section, it is determined till what time a solution is effective. This is done with an adaptive pathway. After that, the construction time of the adaptive solution is calculated. Combining the tipping point followed from the adaptive pathway and the calculated construction time, a planning is made.

### 7.3.1. Adaptive pathway

Adaptive pathway analyses are done for the Sunter, Cakung Drain, BKT and the coastal dike. In section 6 it is explained how the adaptive solution can be adjusted by adding pumps in the rivers when required. For each pathway, all subsidence scenarios of Henk Kooi (2017) are added. With the help of these pathways, the tipping points of a solution can be determined. The tipping points are defined till 2080, after that no subsidence predictions are available. So, in all pathways, tipping points are time and condition based. If a subsidence scenario will change, the pathways can still be used.

#### *7.3.1.1. Sunter*

The current situation in the Sunter does not longer meet the requirements. So, the first tipping point is now. To handle the current head difference, three or more pumps have to be build. When choosing three pumps, a new tipping point is reached for 5.5 m subsidence. At that moment, a new pump has to put into operation. This makes the solution an 'adaptive solution', because not all pumps have to be built immediately. Pumps can be added when needed, depending on the subsidence scenario.

To decrease the pump intensity, tidal gates can be used. A tidal gate at the Sunter is effective till 1.7 m subsidence. In scenario 2, the gate can be used till 2035. All tipping points per scenario can be found in Table 7.4.

TABLE 7.4: TIPPING POINTS SUNTER

| | Subsidence [m] | Scenario 1 [years] | Scenario 2 [years] | Scenario 3 [years] | Scenario 4a [years] | Scenario 4b [years] |
|---|---|---|---|---|---|---|
| **Current situation** | 0 | 2018 | 2018 | 2018 | 2018 | 2018 |
| **3 Pumps in use** | 5.5 | 2061 | 2061 | 2080 | 2080 | 2080 |
| **4 Pumps in use** | 8.5 | 2080 | 2080 | 2080 | 2080 | 2080 |
| **5 Pumps in use** | 9.5 | 2080 | 2080 | 2080 | 2080 | 2080 |
| **6 Pumps in use** | 10 | 2080 | 2080 | 2080 | 2080 | 2080 |
| ***Tidal gate*** | *1.7* | *2035* | *2035* | *2078* | *2080* | *2080* |

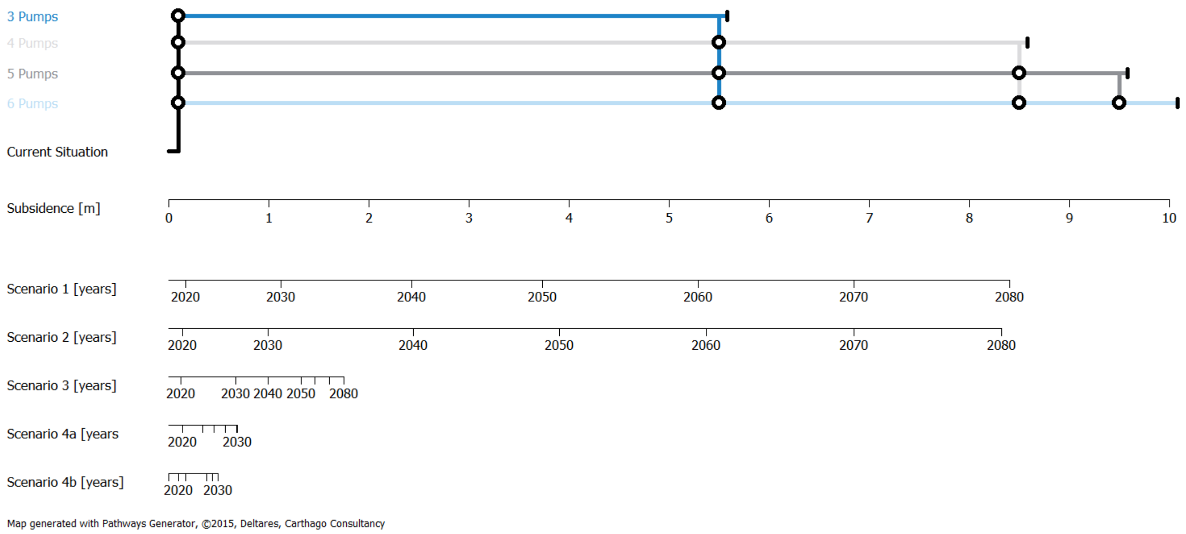



FIGURE 7.15: ADAPTIVE PATHWAY SUNTER

### *7.3.1.2. Cakung Drain*

Also, the current situation in the Cakung Drain does not meet the requirements. In this case, 4 pumps have to be built immediately. To deal with scenario 2 till 2080, a total of 7 pumps must be built. The pump discharge can be decreased till a total subsidence of 1.6 m, because then the gates are still effective. The tipping points can be found in Table 7.5.

TABLE 7.5: TIPPING POINTS CAKUNG DRAIN

| | Subsidence [m] | Scenario 1 [years] | Scenario 2 [years] | Scenario 3 [years] | Scenario 4a [years] | Scenario 4b [years] |
|---|---|---|---|---|---|---|
| **Current situation** | 0 | 2018 | 2018 | 2018 | 2018 | 2018 |
| **4 Pumps in use** | 2.50 | 2033 | 2034 | 2067 | 2080 | 2080 |
| **5 Pumps in use** | 6.50 | 2068 | 2068 | 2080 | 2080 | 2080 |
| **6 Pumps in use** | 8.00 | 2077 | 2078 | 2080 | 2080 | 2080 |
| **7 Pumps in use** | 9.00 | 2080 | 2080 | 2080 | 2080 | 2080 |
| **8 Pumps in use** | 9.50 | 2080 | 2080 | 2080 | 2080 | 2080 |
| **9 Pumps in use** | 10.00 | 2080 | 2080 | 2080 | 2080 | 2080 |
| **Tidal gate** | 1.6 | 2033 | 2034 | 2067 | 2080 | 2080 |

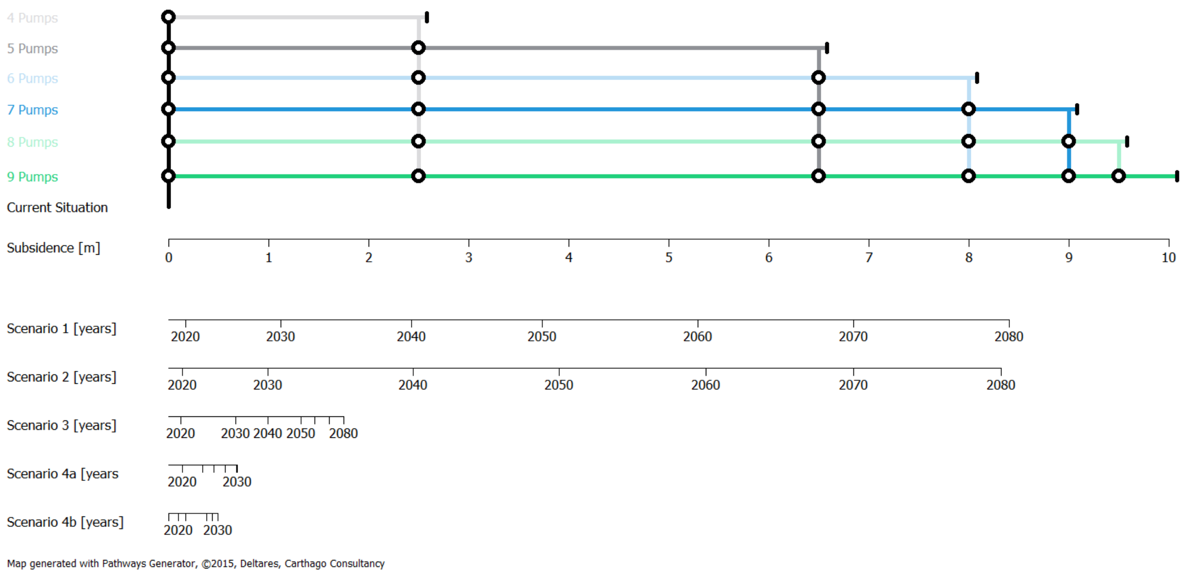



FIGURE 7.16: ADAPTIVE PATHWAY CAKUNG DRAIN

#### 7.3.1.3. *BKT*

The BKT has the largest discharge, due to which more pumps are required to deal with the situation. Now, 12 pumps are needed and in 2080 a total of 19 pumps will be need for scenario 2. The tidal gate at the BKT can decrease the needed pump intensity till a total subsidence of 1.7 m. After this tipping point the tidal gate becomes useless. The tipping points of the BKT are shown in Table 7.6.

TABLE 7.6: TIPPING POINTS BKT

| | **Subsidence [m]** | **Scenario 1 [years]** | **Scenario 2 [years]** | **Scenario 3 [years]** | **Scenario 4a [years]** | **Scenario 4b [years]** |
|---|---|---|---|---|---|---|
| **Current situation** | 0 | 2018 | 2018 | 2018 | 2018 | 2018 |
| **12 Pumps in use** | 2.50 | 2041 | 2040 | 2080 | 2080 | 2080 |
| **13 Pumps in use** | 4.50 | 2055 | 2054 | 2080 | 2080 | 2080 |
| **14 Pumps in use** | 5.50 | 2061 | 2061 | 2080 | 2080 | 2080 |
| **15 Pumps in use** | 6.50 | 2068 | 2068 | 2080 | 2080 | 2080 |
| **16 Pumps in use** | 7.00 | 2071 | 2071 | 2080 | 2080 | 2080 |
| **17 Pumps in use** | 7.50 | 2074 | 2074 | 2080 | 2080 | 2080 |
| **18 Pumps in use** | 8.00 | 2077 | 2078 | 2080 | 2080 | 2080 |
| **19 Pumps in use** | 8.50 | 2080 | 2080 | 2080 | 2080 | 2080 |
| **21 Pumps in use** | 9.00 | 2080 | 2080 | 2080 | 2080 | 2080 |
| **23 Pumps in use** | 0.50 | 2080 | 2080 | 2080 | 2080 | 2080 |
| **26 Pumps in use** | 10 | 2080 | 2080 | 2080 | 2080 | 2080 |
| **Tidal gate** | 1.7 | 2034 | 2035 | 2076 | 2080 | 2080 |

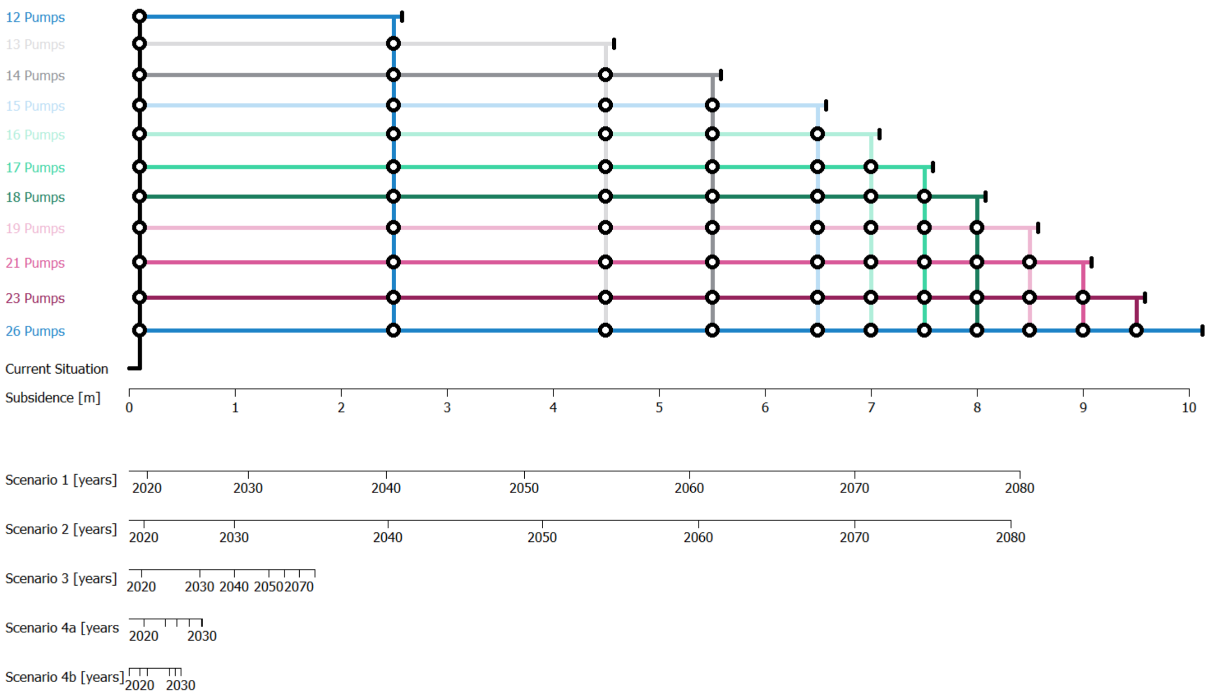



FIGURE 7.17: ADAPTIVE PATHWAY BKT

#### *7.3.1.4. Coastal dike*

It is hard to adapt the coastal dike per meter subsidence, because heightening of the coastal dike will lead to construction of a new clay-, asphalt- and armour layers. Construction of these layers is very expensive. In Figure 7.18 it can be seen that the current sea defence is safe enough for scenario 4b. In the case of scenario 4a, it could be cheaper to increase the height of the current sea defence instead of building a whole new dike behind the current sea defence, because the difference in height is not that much.

Because subsidence scenario 2 and 3 are the most likely scenarios, it is recommended to build a dike which is height enough for subsidence scenario 3 till 2080. If it turns out that subsidence scenario is not the right scenario, the dike height can be increased to a scenario 2 height. In this case two times the costs of the expensive layers have to be taken into account. Another option is to build immediately a dike with a scenario 2 height. The dike height has not to be adjusted anymore, but if scenario 2 is not the right scenario the dike could be over dimensioned. In this report, a dike for scenario 2 is made immediately.

From the adaptive pathways follows that both scenario 2 and scenario 3 the AE+ wall does not satisfy the predicted conditions. The wall is designed to guarantee safety till 2030, but from subsidence scenarios of Henk Kooi (2017) follows that the tipping point of the wall is equal to 2027 for scenario 2 and equal to 2029 in scenario 3. Concluded from this, a new coastal dike has to be finished before this time. The tipping points are shown in Table 7.7.

TABLE 7.7: TIPPING POINTS COASTAL DIKE

| | Subsidence [m] | Scenario 1 [years] | Scenario 2 [years] | Scenario 3 [years] | Scenario 4a [years] | Scenario 4b [years] |
|---|---|---|---|---|---|---|
| **Current situation (AE+)** | 0.63 | 2025 | 2027 | 2029 | 2080 | 2080 |
| **Dike scenario 4b (mean height: 5.7 m)** | 0.50 | 2024 | 2025 | 2026 | 2080 | 2080 |
| **Dike scenario 4a (mean height: 5.9 m)** | 0.69 | 2026 | 2028 | 2031 | 2080 | 2080 |
| **Dike scenario 3 (mean height: 7.0 m)** | 1.75 | 2035 | 2035 | 2080 | 2080 | 2080 |
| **Dike scenario 2 (mean height: 13.6 m)** | 8.32 | 2079 | 2080 | 2080 | 2080 | 2080 |
| **Dike scenario 1 (mean height: 13.7 m)** | 8.40 | 2080 | 2080 | 2080 | 2080 | 2080 |

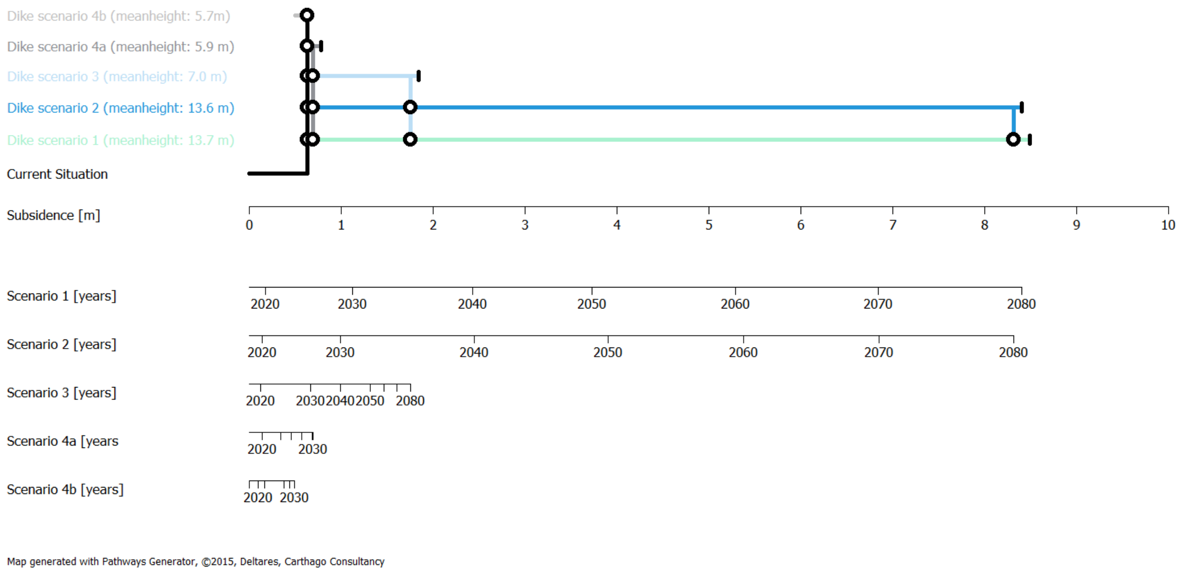


FIGURE 7.18: ADAPTIVE PATHWAY COASTAL DIKE

## 7.3.2. Construction time

In this section the construction time of each element of the coastal dike is explained.

### *7.3.2.1. Land acquisition and land clearance*

In West- Jakarta the expected time for land acquisition and land clearance is 1 year (365 days) for 2670900 m² [Maris, 2017]. At the moment it is not known which influence the political activities and decisions making have on the duration of these activities. So, in this report it is assumed that 500 days is enough for the land acquisition and land clearance taking the decision making process into account. In this case, this process is not a time limiting factor.

### *7.3.2.2. Preparation of the construction area*

The dredging works of the trailing suction hopper dredger including the disposal will take one hour for 6250 m³ [Van der Horst, 2016]. The total time to remove all slurry is equal to 259 days using 1 ship. After that the sand key has to be constructed. The total mixed capacity of the used suction hopper dredger is equal to 18292 m³.

The capacity of only sand is equal to 15404 $m^3$ [Van Oord, 2015]. The suction speed of sand is 1.56 $m^3/s$. From this follows a total loading time of 2.7 hours [Vlasblom, 2007]. As a rule of thumb, the discharge time is equal to the suction time and become also 2.7 hours. The loaded speed is equal to 15.5 knots and the unloaded speed is assumed to be 20 knots [Van Oord, 2015]. From this follows a total cycle time of 8.5 hours, because the distance between the construction area and the sand source is 48 km. So, the total construction of the sand key will take 1221 days using 1 ship.

#### 7.3.2.3. *Sand*

Also for the sandy core one trailing suction hopper dredger with a cycle time of 8.5 hours will be used. So the total time becomes 980 days.

#### 7.3.2.4. *Clay*

Marine placing and dry placing is used for construction the clay layer. Marine placing takes 25 $m^3$/hour and dry placing take 62.5 $m^3/h$. Half of the clay is constructed dry and the other half wet. Five units are used, which will lead to a total construction time of 456 days.

#### 7.3.2.5. *Asphalt*

It is assumed that the construction of an asphalt layer will take 25 $m^3$/hour. Using five units this will lead to a total construction time of 464 days.

#### 7.3.2.6. *Armour layers*

The armour layers are placed with one barge, which will take 25 $m^3$/hour [van der Horst, 2016]. The total construction time of armour layer S1 is equal to 704 days and S2 is equal to 18 days.

#### 7.3.2.7. *Pumps*

The construction time of the pumps is based on a reference project in New Orleans, which is at the moment the largest pumping station of the world. The total construction period of this pumping station is equal to 56 months [Maris, 2017]. The pumping station that will be used in the East of Jakarta are somewhat larger, pumps of 4500 kW instead of 4083 kW are used. Because of this, a construction period of 62 months (1364 days) is expected. The pumps will be built simultaneously. So, the construction period remains the same.

#### 7.3.2.8. *Tidal gate*

The construction time of a tidal gate is assumed to be equal to 200 days, since it has be done in the dry season.

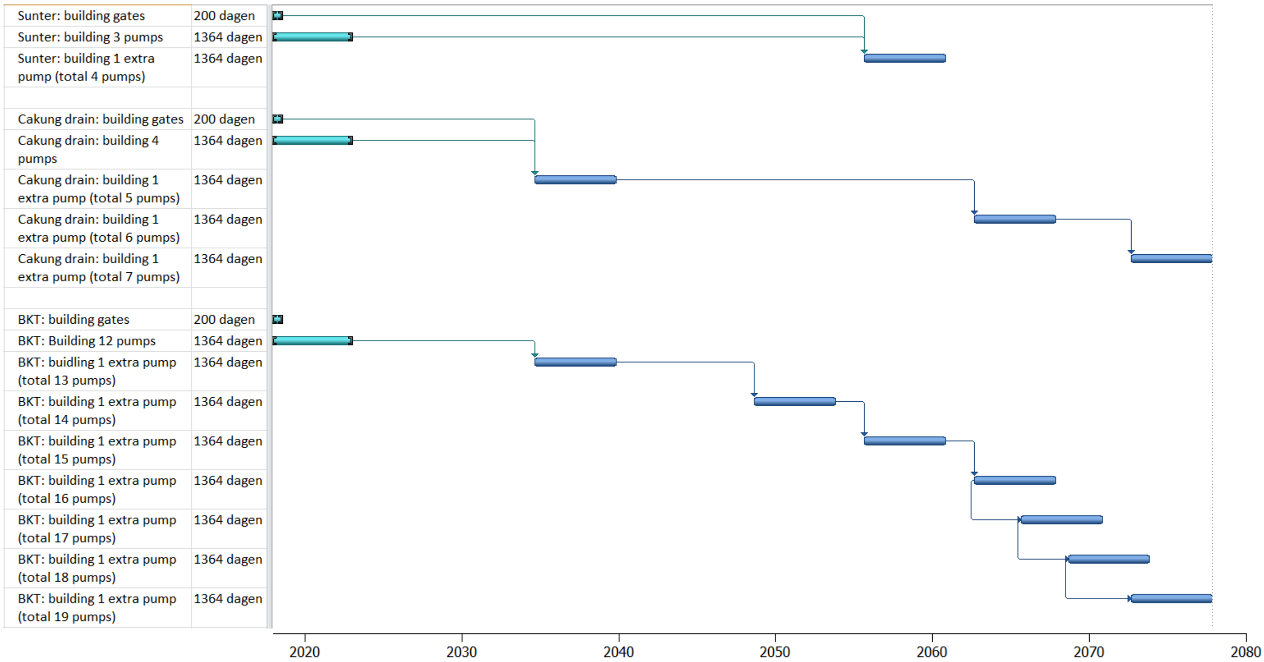
### 7.3.3. Time planning

By combining the adaptive pathways with the construction time a planning can be made for the rivers (building of the gates + pumps) and a planning can be made for the coastal dike. Both schedules are based on subsidence scenario 2.

#### 7.3.3.1. *Rivers*

IN

Figure 7.19 the construction time of the gates and pumps in the rivers is shown. The start of the project is in 2018 to handle the current situation. Pumps are added 5 years before a tipping point is reached (building time of a pump is 5 years). If only pumps are added when required,




the project is finished in 2078.

FIGURE 7.19: TIME SCHEDULE RIVERS

#### 7.3.3.2. *Coastal dike*

The tipping point of the coastal dike is in 2027. So, the dike has to be finished before 2027. The total construction time is 7 years. So, the project has to be started in 2020.

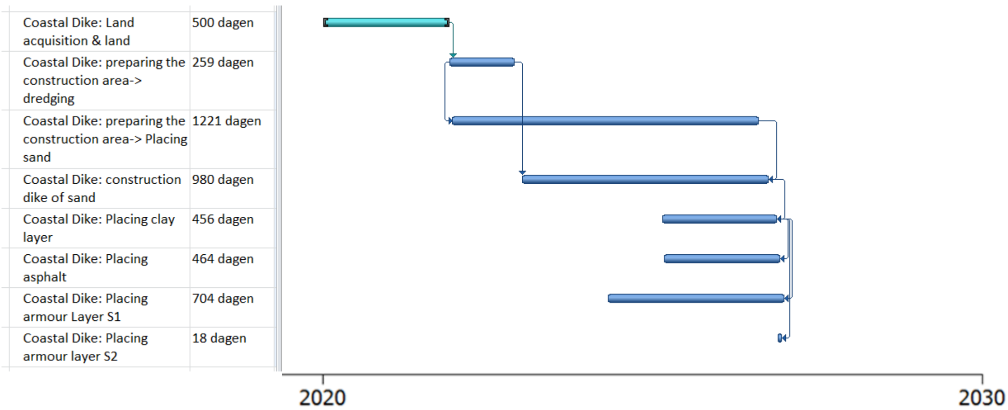



FIGURE 7.20: TIME SCHEDULE COASTAL DIKE

# 8. DISCUSSION

This report is made in Jakarta at the office of Public Works. Throughout the process it became clear that the used sources must be looked at critically. A lot of used data originates from researches that are already done for East and West Jakarta. The difficulty relies on how to translate these data to our case in an accurate way. This is considered as a challenge, since in this working environment the presentation of the results is key, rather that the results itself. Most of the information is known by hearsay or mentioned in presentation sheets and reports, where the data is often presented in beautiful tables and graphs. However, when one tries to dig deeper to find the original source, the data often deviates or there is no original source at all. Also, in this working environment assumptions are far more accepted than in the Netherlands, simply because there is no other option. In our research, extra attention is payed to the reliability of the sources and the level of accuracy of the report.

To deal with the uncertainties in this project, all assumptions, where the results of this project are based on, are analysed. They are examined to their accuracy level and sensitivity level. The level of accuracy depends on the reliability of the source. The level of sensitivity depends on the expected impact on the results. Per assumption, their consequences and mitigation options are described qualitatively, see Appendix XII: Assumptions. The assumptions with a low accuracy level and a high sensitivity level are considered as critical assumptions. For these assumptions it is highly recommended to do further research to obtain a higher level of accuracy and this will improve the reliability of the results. The five most critical assumptions are listed below:

- The current river system is designed for a 1/100 flood event.
- The unit prices of Beumer are used for land acquisition costs.
- Land subsidence between Marunda and Sunter is determined with linear extrapolation.
- The backwater effect: during the relative subsidence of the riverbed, the water level remains constant.
- Ground level at land side is 1 m below current flood defences.

The question is: how reliable are the results from this report, considering all uncertainties? It can be concluded that the recommended solutions are safe. When one has to deal with an uncertainty, there is chosen for a conservative approach. A good example is dealing with the land subsidence scenarios of Henk Kooij. Per scenario, he gave ranges for the expected subsidence rates. For the designs, the most pessimistic values of his results are used. In this way, there is a risk in overdesigning the solutions, but it does ensure a robust, reliable system.

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# 10. APPENDIX

## Appendix I: Stakeholder analysis

Many stakeholders are involved in the project (governmental and non-governmental). Stakeholders have to be involved in different phases during the project considering the planning and decision-making. Stakeholder involvement is important to create coherence between the stakeholders during the project. Poor stakeholder involvement could undermine the potential positive effects of government-supported projects like NCICD. In this chapter, a stakeholder analysis is done to have a clear overview of the stakeholders involved during the project.

**Stakeholder definition**

According to the IFC's handbook on stakeholder engagement (2007) stakeholders are defined as 'persons or groups who are indirectly affected by a project, as well as those who may have interest in a project and/or the ability to influence its outcome'.

**Stakeholder map**

There has been a research on stakeholders in the pre-feasibility study for the OPQ islands. These islands are part of East Jakarta and therefore this study is useful in defining all the stakeholders. Like is done in the study for the OPQ islands, the stakeholders can be divided in 3 main categories i.e., government, civil society and private sectors [Rijksdienst voor Ondernement Nederland, 2017]..

Goverment

**National Government**

-Ministry of transport
-Ministry of public Works and Housing
-Ministry of Environment and Forestry
-Ministry of Marine Affairs and Fisheries
-Coordinating ministry of Maritime Affairs
-Coordinating ministry on Economic Affairs
-National Development Planning Agency (Bappenas)
-Ministry of Foreign Affairs
-National Navy

**Provincial Government**

-Jakarta Provincial Government
-West Java Provincial Government
-Jakarta Provincial of Transport Agency
-Jakarta Provincial of Marine and fisheries agency
-Jakarta Provincial of Environmental Agency
-Jakarta Provincial of Development Planning Agency (Bappeda)

**Local Government**

-Administrative City of North Jakarta
-Sub District Clincing
-Marunda Village
-Cilincing Village
-Kali Baru Village
-Government of Bekasi City

**Dutch Government Embassy**

**-International Government**

FIGURE 10.1: STAKEHOLDERS SECTOR 1 [SOURCE: PRE-FEASIBILITY STUDY OPQ INDUSTRIAL ISLANDS]

**Civil Society**

**Affected Communities**

-Community industries
-Fisherman community
-Supplier/vendors of port industries
-Other population/Settler

**Non-Governmen and Community Organization**

-WALHI
-KIARA
-KRuHA
-SNI-Fisherman union
-Forum Komunikasi Nelayan Jakarta
-Indonesian Center for Environment Law
-Urban Poor Consortium
-Rujak Community
-KNTI
-LBH Jakarta

**Universities**

-ITB
-IPB
-UI

**Non-Governmen and Community Organization**

-LIPI-LON
-DISHIDROS
-BPPT
-PUSAIR

FIGURE 10.2: STAKEHOLDERS SECTOR 2[SOURCE: PRE-FEASIBILITY STUDY OPQ INDUSTRIAL ISLANDS]

**Private Sector**

**Developer/Investor**

-Jakarta Propertindo (Jakpro)
-Pelindo/IPC
-PT Pembangunan Jaya (DKI)
-Port of Rotterdam

**Affiliated Parties**

-Kawasan Berikat Nusantara (Marunda)
-Marunda Center
-PLN Muara Tawar
-PGN/Nusantara Regas
-Pertamina
-Directorate General of Post and Telecommunication

FIGURE 10.3: STAKEHOLDERS SECTOR 3 [SOURCE: PRE-FEASIBILITY STUDY OPQ INDUSTRIAL ISLANDS]

Each stakeholder of the sector has own interest and influence. Therefore, the stakeholders will now be categorized based on interest and influence. This is done to understand the potential support or opposition for the project. The stakeholders from all sectors are divided into 4 different type of stakeholders. Each stakeholder is coded by colour. Green represents supporters, red stakeholders are opponents and orange represents neutral stakeholders.

**Type 1: The blue block** resembles stakeholders for which meeting their needs is important. Engage and consult is done on interest area. It is important that the level of interest of these stakeholders should be increased. Eventually these stakeholders should become part of the stakeholders in the orange block.

**Type 2: The orange block** resembles stakeholders, which are considered as key players. High focus on this group is important and these stakeholders should be involved in governance/decision making bodies. These stakeholders engage and consult regularly and are involved in high risk areas.

**Type 3: The green block** resembles stakeholders not considered as key players and are the least important stakeholders in the project. These stakeholders are informed via general communications, newsletters and websites. Eventually these stakeholders should become part of the stakeholders in the yellow block.

**Type 4: The yellow block** resembles stakeholders, which show consideration in the project. These stakeholders make use of interest through involvement in low risk areas. These stakeholders should be informed and consulted on interest area.


FIGURE 10.4: STAKEHOLDER MAP

## Attitude of the stakeholders

There are many stakeholders defined in the stakeholder map (Figure 10.4). All stakeholders are coded by a colour. In this report, it is assumed that a supporting stakeholder (green) of the OPQ islands is also supporting the idea of the sea wall. The specific ideas and opinions of the different stakeholders can be found in a document produced by the NCICD project. In this report three stakeholder attitudes are applied; supporting, opponents and neutral.

# Appendix II: Soil information

Sedimentary rocks
-Rengganis Formation (Tmrs): fine and coarse sandstone, conglomerate and clay stone.
-Kelapanunggal Formation (TMK): coral rock, limestone layer, marl, glauconitic sandstone
-Jatiluhur Formation (TMJ): marl, clay stones and standstone layers
-Bojongmanik Formation (TMB): sandstone, clay, stone layers with plant remains
-Genteng Formation (TPG): tuff, pumice, sandstone, andesite breccia, conglomerate, claystone layers
-Serpong Formation (Tpss): conglomerate layer, sandstone, clay, stone with plant remains
-Coral rock units (QL): colonies of coral, crushed coral, mollusk shells ( in Jakarta Bay)

Surface sediment
-Old alluvial unit (Qoa): conglomerate, siltstone
- Bogor alluvial unit (Qav): fine tuff layer, sand-tuff, conglomerate layers, volcanic units of Mount Salak and Mount Pangrango.
-Beach ridge sediment unit (Qbr): fine and coarse sand with mollusk shells. Rocks are scattered along the northern coast (from Bekasi to Tangerang)
-Alluvial unit (Qa): clay, sand, small gravel, big gravel, boulders of coarse (in bedding river in South of Jakarta) and fine fractions (in plain area).

Volcano rocks
-Banten Tuff unit (Qtvb): tuff, pumice tuff, sandstone
-Unknown volcanic unit (Qvu/b): breccia lava
-Volcanic unit of Mount Salak (Qvsb): lava breccias, pumice tuffs, general andesite, basalt boulders.
-Volcanic unit of Mount Pangrango (Qvpo/y): andesite, lava boulders

Intrusive rocks
-The intrusive rock of Dago Mount is basalt in nature and forfiritik andesite is found in Mount Pandar

## Appendix III: Stages of the project

This section will explain in short, the different stages of the project. The source is the NCICD presentation (10-7-2017) about the final implementation strategy. The project consists of different stages, which are shown in Figure 10.5. In Figure 10.6 the stage definition of the outdated masterplan 2014 is shown. In the 2014 masterplan two stages are considered namely stage A and stage B.

Stage A: short term requirements providing flood safety until 2025 and finished by 2018. Stage B: the western retention lake to be constructed before 2025 and based on a disastrous event in 2025.


FIGURE 10.5: PHASES OF THE NCICD PROJECT JAKARTA (MASTERPLAN 2014) [PRSENTATION 10-7-2017 FINAL IMPLEMENTATION STRATEGY]

Once the 2014 masterplan was finished the legitimacy of the project, emphasis on disaster risk management & reduction, social integrating, environmental benefits and improving the livelihoods of the people of North Jakarta had to be improved. This leaded to the 2016 updated masterplan in which new phases were considered.

Stage E (Emergency): this stage is part of stage A. The flood safety should increase to 1:1000 lasting to 2025-2030, this stage is seen as NO REGRET. This stage (A+E) has some important objectives to take into account:

- Strengthen the current sea wall
- Develop E components to be constructed/finalized by end of 2018
- Additional measures(E+ A) start of construction by 2018, finalized by 2022 (latest 2025)
- flood safety until 2030
- On shore retention of 150 ha finalized by 2019
- Pump capacity to be optimized & constructed
- Develop lateral channel to interconnect existing polders
- Ensure full inclusion of Social and Environmental aspects
- Flood safety >> 1:1000 to 2028-2030 (average LWS + 4.8 now to last until 2030 with - 1:1000 considering land subsidence)
- Ensure proper budgeting and finance by 2017-2019
- Consider combining stage A and stage M to use benefits

Stage O: this stage considered as the new stage B (West and East part of stage B). Start in 2017 and finished by 2030 (Figure 10.6).

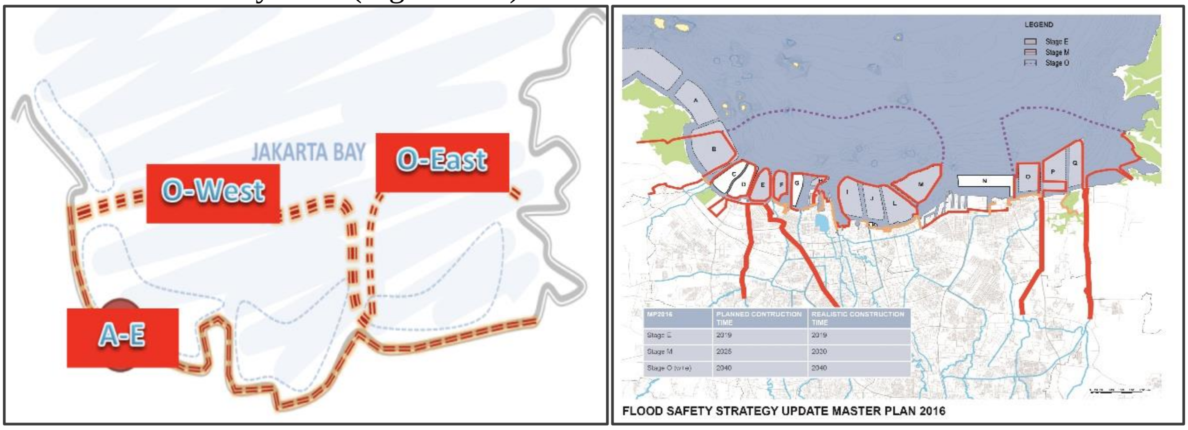


FIGURE 10.6: STAGE O WEST AND O EAST (UPDATEDMASTERPLAN 2016) [PRSENTATION 10-7-2017 FINAL IMPLEMENTATION STRATEGY]

This stage (O) has some important objectives to take into account:

- Pre-design & develop outer sea wall until 2018 + FID
- DED + procurement and financing by 2020
- Develop pumping capacity & pumping strategy
- Gates and locks and weirs
- Develop road links
- Add compartments for water quality control, building with nature
- Adaptive design
- Flood safety outer sea wall >> 1:10.000 to 2080 Add social, livelihood and environmental aspects
- Loan Agreement and financing to be in place

Stage M: in this stage, the river dikes are considered, the outer sea wall is not present but dikes around land reclamations are constructed. There are no retention lakes present for this stage. It is decided by NCICD that stage M is not feasible considering phasing, economic assessment, constructability and overall flood safety considerations.

Figure 10.7 shows the timeline of the stages of the updated masterplan 2016.


FIGURE 10.7: TIMELINE OF PHASES OF THE NCICD PROJECT JAKARTA (UPDATEDMASTERPLAN 2016) [PRSENTATION 10-7-2017 FINAL IMPLEMENTATION STRATEGY]

# Appendix IV: Subsidence graphs

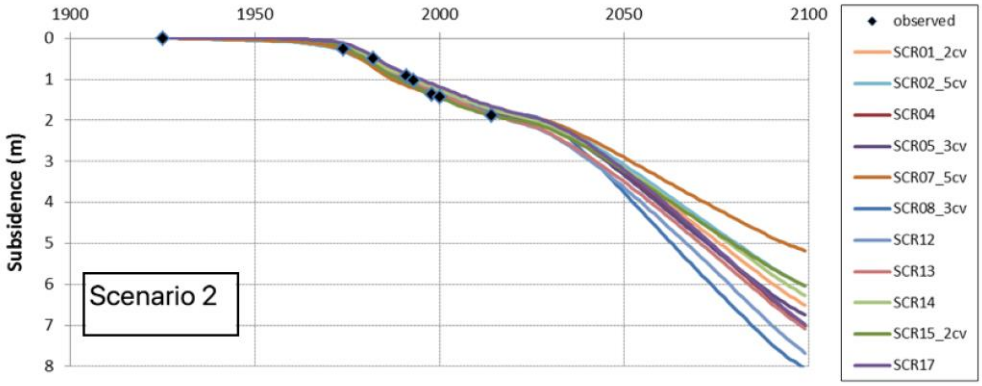


FIGURE 10.8: SUBSIDENCE GRAPHS SUNTER –SCENARIO 2 [KOOI, 2017]

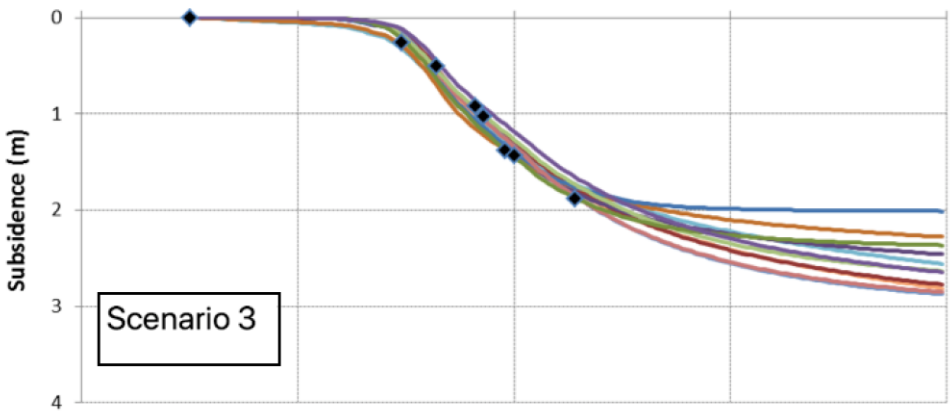


FIGURE 10.9: SUBSIDENCE GRAPHS SUNTER –SCENARIO 3 [KOOI, 2017]

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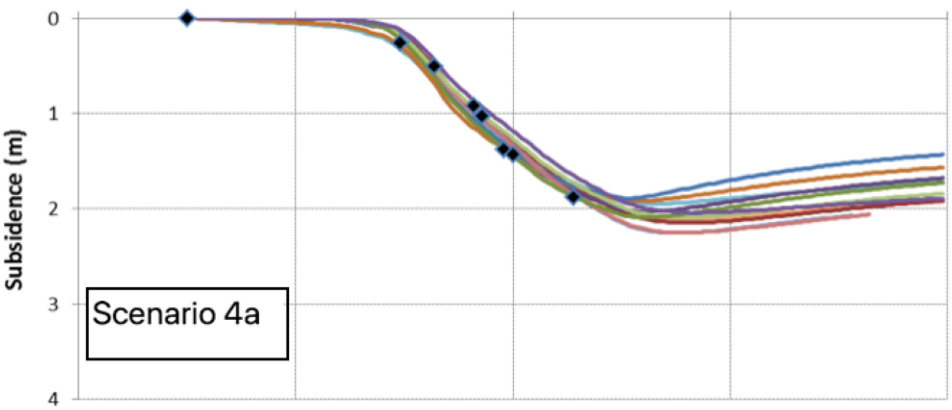



FIGURE 10.10: SUBSIDENCE GRAPHS SUNTER –SCENARIO 4A [KOOI, 2017]

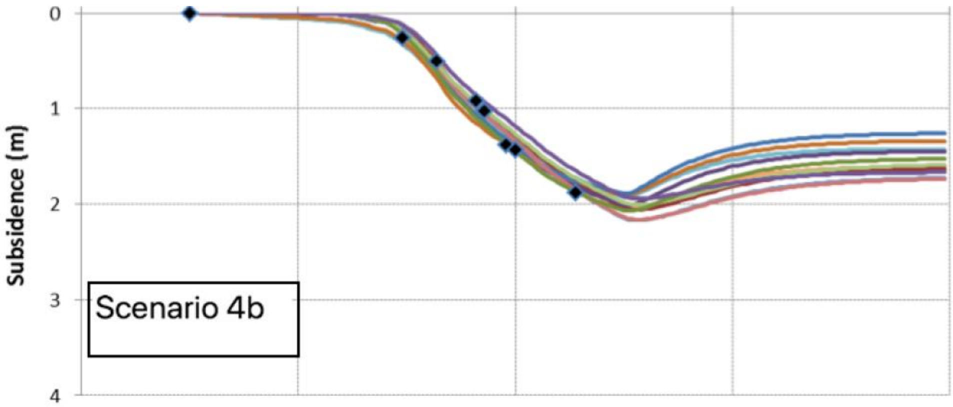



FIGURE 10.11: SUBSIDENCE GRAPHS SUNTER –SCENARIO 4B  [KOOI, 2017]

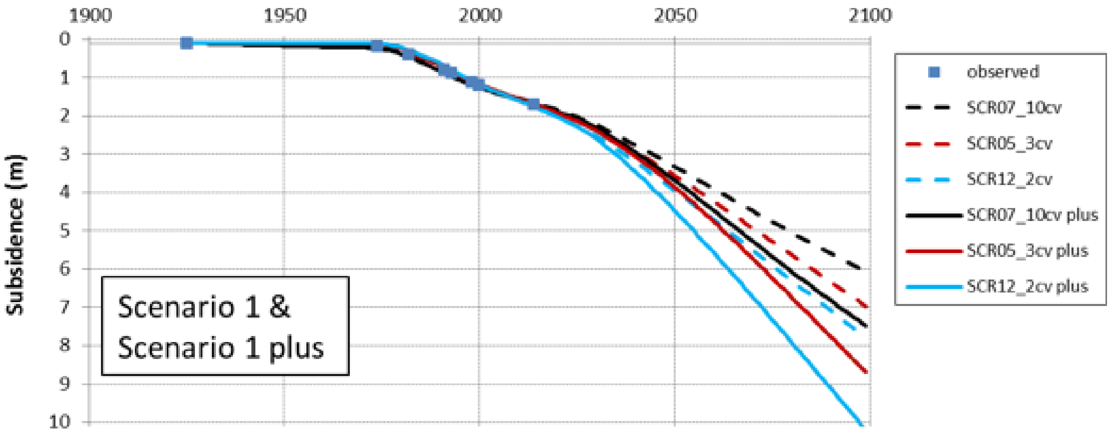



TABLE 10.3: SUBSIDENCE GRAPHS MARUNDA- SCENARIO 1 PLUS [KOOI, 2017]

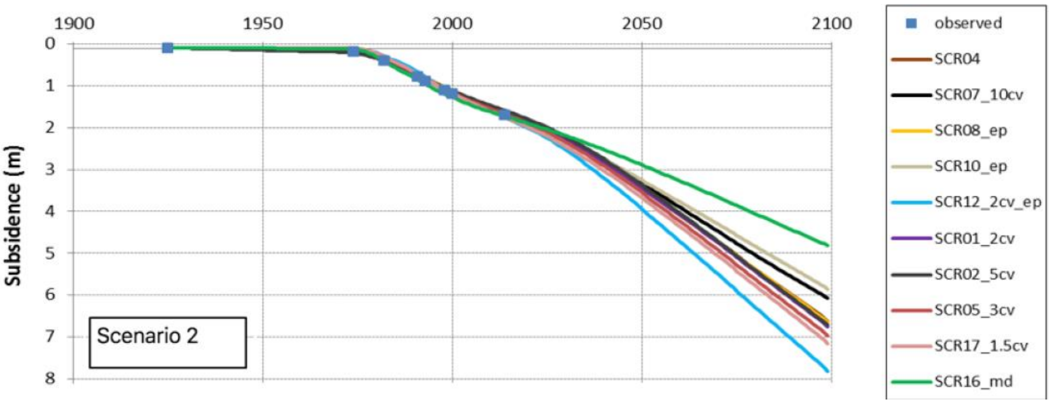



FIGURE 10.12: SUBSIDENCE GRAPHS MARUNDA- SCENARIO 2 [KOOI, 2017]

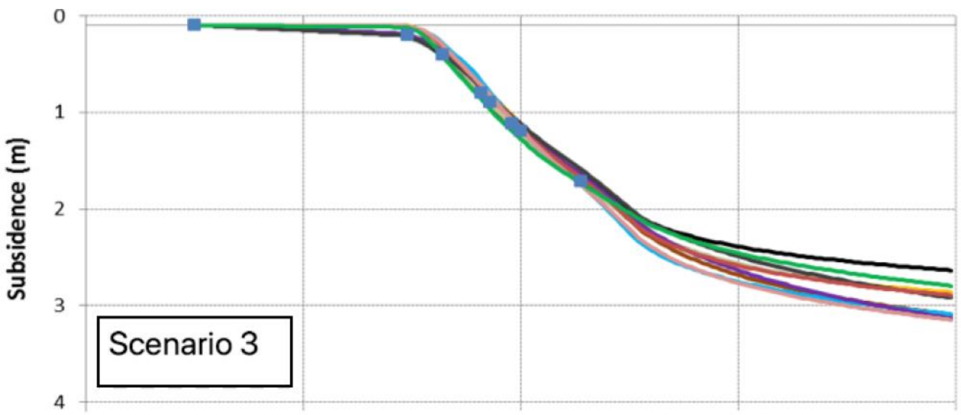



FIGURE 10.13: SUBSIDENCE GRAPHS MARUNDA- SCENARIO 3[KOOI, 2017]

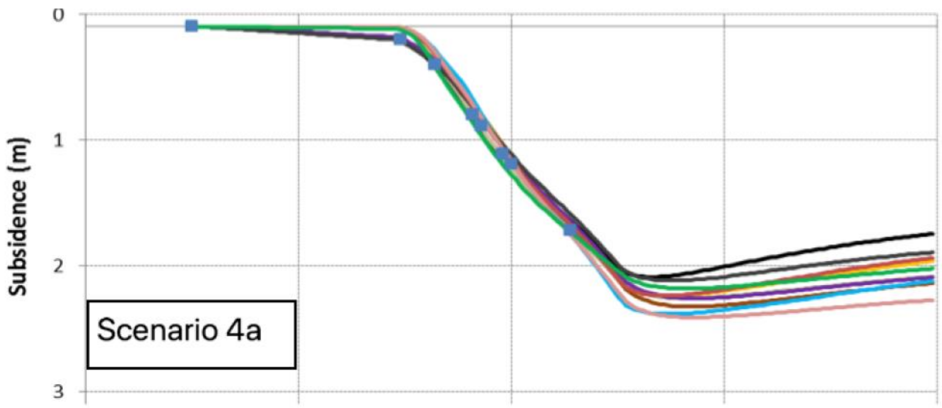



FIGURE 10.14: SUBSIDENCE GRAPHS MARUNDA- SCENARIO 4A [KOOI, 2017]

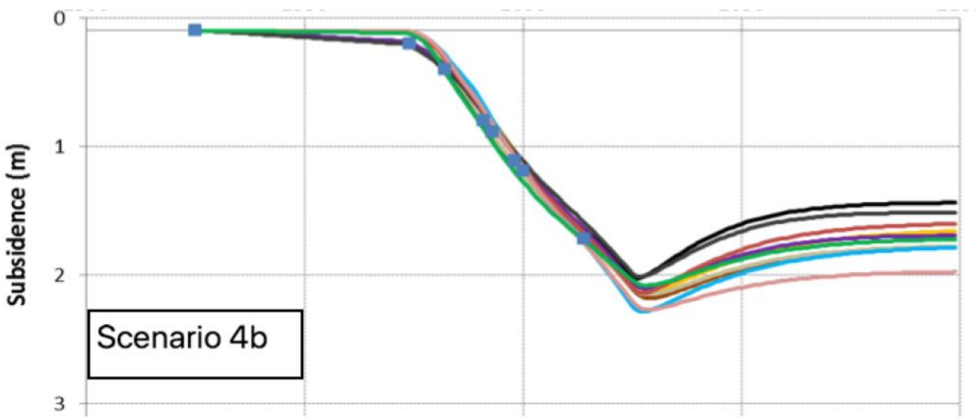



FIGURE 10.15: SUBSIDENCE GRAPHS MARUNDA- SCENARIO 4B [KOOI, 2017

## Appendix V: GPS coordinates

| Point ID | Latitude | Longitude | Subsidence recent years [m] |
|---|---|---|---|
| 144 | -6,1237300 | 106,8564000 | -0,0953 |
| RUKI | -6,1166495 | 106,8620687 | -0,0368 |
| P367 | -6,2633307 | 106,8654658 | -0,0028 |
| 973 | -6,1591600 | 106,8665000 | -0,0450 |
| CMAS | -6,1669285 | 106,8737865 | -0,0315 |
| TTG. 240 | -6,1975000 | 106,8747250 | -0,0325 |
| C034 | -6,1457263 | 106,8758029 | -0,0321 |
| C072/451B | -6,1832375 | 106,8760347 | -0,0028 |
| BSKI | -6,2249887 | 106,8779258 | -0,0286 |
| 312K | -6,1662792 | 106,8798204 | -0,0216 |
| CIBU | -6,3515333 | 106,8808333 | -0,0177 |
| 17 | -6,1114900 | 106,8810000 | -0,0529 |
| 201 | -6,1729500 | 106,8823000 | -0,0700 |
| PP03 | -6,1400225 | 106,8833667 | -0,0280 |
| PP03 | -6,1400225 | 106,8833667 | -0,0280 |
| TTG. 242 | -6,1588890 | 106,8847200 | -0,0856 |
| 202 | -6,1733800 | 106,8867000 | -0,0568 |
| UKP4 | -6,1499409 | 106,8868138 | -0,0304 |
| C057 | -6,1157736 | 106,8886129 | -0,0489 |
| 394 | -6,3304200 | 106,8896000 | -0,0065 |
| 367 | -6,2966300 | 106,8920000 | -0,0050 |
| C089 | -6,1275256 | 106,8940219 | -0,0423 |
| 271 | -6,2002700 | 106,9039000 | -0,0569 |
| 40 | -6,1174400 | 106,9050000 | -0,0646 |
| KLGD | -6,1552377 | 106,9086497 | -0,0455 |
| JTC1 | -6,1040737 | 106,9138073 | -0,0168 |
| BMT1 | -6,3478523 | 106,9141959 | -0,0144 |
| C046 | -6,1373155 | 106,9143558 | -0,0332 |
| C024 | -6,1689171 | 106,9157371 | -0,0036 |
| C008 | -6,1237342 | 106,9169738 | -0,0427 |
| C002/1245B | -6,1083609 | 106,9192509 | -0,0275 |
| 213 | -6,1851000 | 106,9239000 | -0,0649 |
| 250 | -6,1978600 | 106,9328000 | -0,0225 |
| 248 | -6,2182800 | 106,9373000 | -0,0246 |
| KBN1 | -6,1446748 | 106,9394101 | -0,0671 |
| CLCN | -6,1801318 | 106,9428199 | -0,0239 |
| 89 | -6,1636400 | 106,9453000 | -0,0783 |
| 237 | -6,2219000 | 106,9484000 | -0,0194 |
| 54 | -6,1332100 | 106,9514000 | -0,0244 |
| 56 | -6,1171000 | 106,9527000 | -0,0258 |
| 67 | -6,1453700 | 106,9530000 | -0,0340 |
| MARU | -6,1091585 | 106,9534207 | -0,0252 |

# Appendix VI: Subsidence prediction per GPS location

```
import numpy as np
import matplotlib.pyplot as plt
import gmplot
from pandas import read_csv
import matplotlib.mlab as mlab
import matplotlib.image as mpimg
from mpl_toolkits.mplot3d import Axes3D
%matplotlib inline
```

## Loading data

```
* GPS data / current subsidence rates [2018]
* Subsidence data Sunter
* Subsidence data Marunda
```

```
data=read_csv('subsidence_data.txt',delimiter=' ',index_col=0)
coordinates_marunda=np.array([-6.1091821,106.95342125833334])  #Maru,used by Henk Kooi
coordinates_sunter=np.array([-6.141647110323912,106.89225196838379])#unknown point now assumption used by Henk Kooi
data.Yearly_recent_years=data.Yearly_recent_years*-100 # translated to cm/y
```

```
sunter=read_csv('subsidence_sunter.txt',delimiter=' ',index_col=[0])
```

```
marunda=read_csv('subsidence_Marunda.txt',delimiter=' ',index_col=0)
```

## Factor calculation to transform GPS data to Henk Kooi to make future scenario's

- Translate to subsidence rates henk kooi: Sub_GPS/ Sub_GPS_Maru*Maru_Henk Kooi
- Factor marunda: GPS translated to Henk Kooi / sub_rate Marunda
- Factor Sunter: GPS translated to Henk Kooi/ sub_rate Sunter
- Calculate distance to Sunter and Marunda
- Use inverse distance weighting method

Subsidence rate 2080 Henk Kooi --> max 4.4 cm/yr measured order 2.5 cm/yr. This is transformed to the fits of Henk Kooi to make some indications for the future. Factor is based on distance to Marunda and Sunter, the closer a GPS point lies to for example Sunter, the more the Sunter model will be used.

```
Henk_Kooi_sub_rates=data.Yearly_recent_years/data.Yearly_recent_years.MARU*marunda.Subsidence_rate_2018[0]
Factor_Marunda=Henk_Kooi_sub_rates/marunda.Subsidence_rate_2018[0]
Factor_Sunter=Henk_Kooi_sub_rates/sunter.Subsidence_rate_2018[0]

distance_sunter=np.sqrt((data.Latitude-coordinates_sunter[0])**2+(data.Longitude-coordinates_sunter[1])**2)
distance_marunda=np.sqrt((data.Latitude-coordinates_marunda[0])**2+(data.Longitude-coordinates_marunda[1])**2)
```

## Function that plots on google maps

```
gmap = gmplot.GoogleMapPlotter.from_geocode("Jakarta")
gmap.scatter([coordinates_marunda[0],coordinates_sunter[0]],[coordinates_marunda[1],coordinates_sunter[1]], 'red',size=150,marker
gmap.scatter(data.Latitude, data.Longitude, 'k', size=150, marker=False)
gmap.draw("Map.html")
```

## Calculation per year and scenario

### 2028

```
sub_Scenario1=Factor_Marunda*marunda.Subsidence_2018_2028[0]
sub_Scenario2=(Factor_Marunda*marunda.Subsidence_2018_2028[1]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2028[0]*distanc
sub_Scenario3=(Factor_Marunda*marunda.Subsidence_2018_2028[2]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2028[1]*distanc
sub_Scenario4a=(Factor_Marunda*marunda.Subsidence_2018_2028[3]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2028[2]*dista
sub_Scenario4b=(Factor_Marunda*marunda.Subsidence_2018_2028[4]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2028[3]*dista
```

### 2050

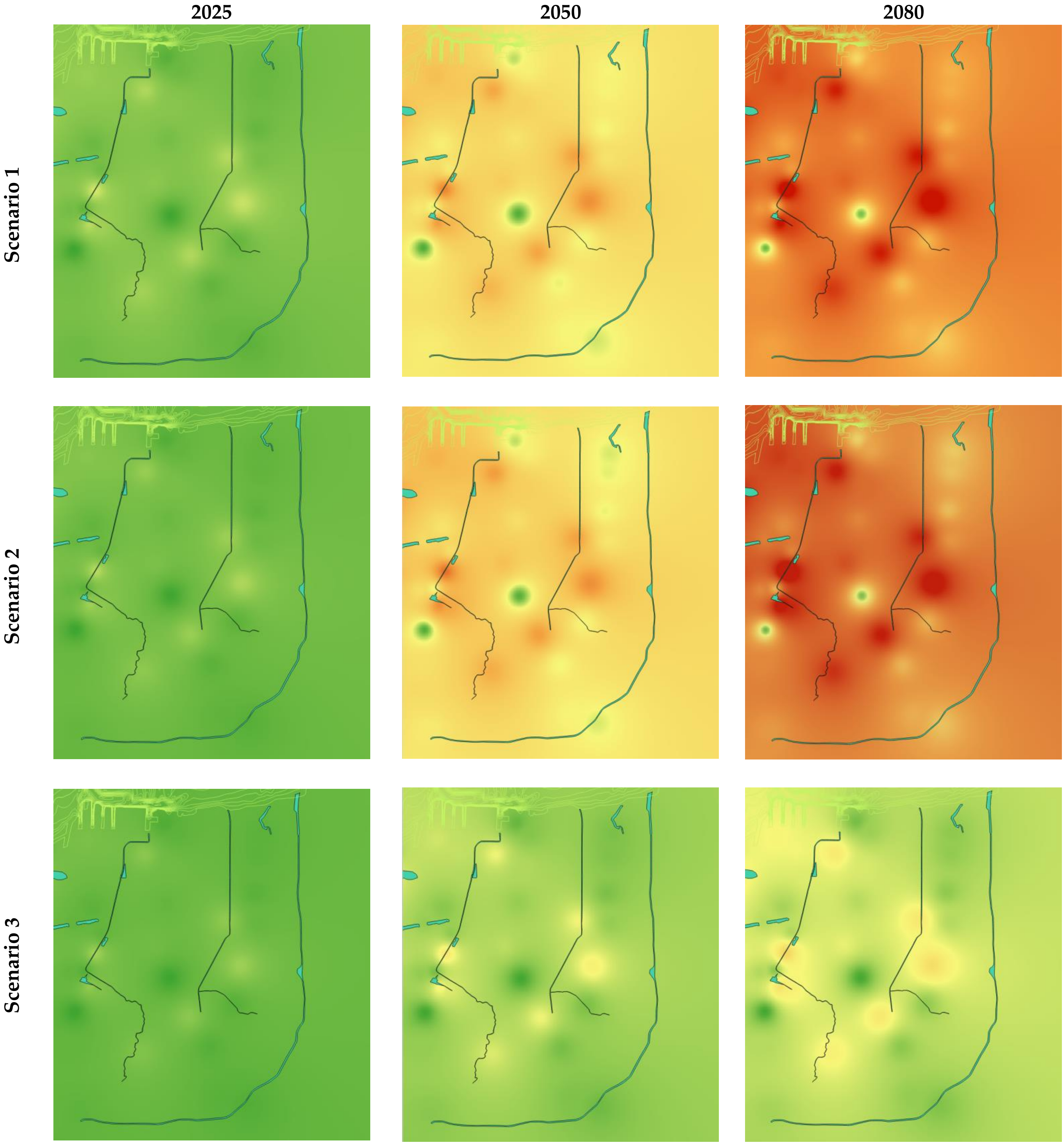
```
sub_Scenario1=Factor_Marunda*marunda.Subsidence_2018_2050[0]
sub_Scenario2=(Factor_Marunda*marunda.Subsidence_2018_2050[1]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2050[0]*distan
sub_Scenario3=(Factor_Marunda*marunda.Subsidence_2018_2050[2]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2050[1]*distan
sub_Scenario4a=(Factor_Marunda*marunda.Subsidence_2018_2050[3]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2050[2]*dista
sub_Scenario4b=(Factor_Marunda*marunda.Subsidence_2018_2050[4]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2050[3]*dista
```

## 2080

```
sub_Scenario1=Factor_Marunda*marunda.Subsidence_2018_2080[0]
sub_Scenario2=(Factor_Marunda*marunda.Subsidence_2018_2080[1]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2080[0]*distan
sub_Scenario3=(Factor_Marunda*marunda.Subsidence_2018_2080[2]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2080[1]*distan
sub_Scenario4a=(Factor_Marunda*marunda.Subsidence_2018_2080[3]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2080[2]*dista
sub_Scenario4b=(Factor_Marunda*marunda.Subsidence_2018_2080[4]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2080[3]*dista
```

```
sub_Scenario1_2028=Factor_Marunda*marunda.Subsidence_2018_2028[0]
sub_Scenario2_2028=(Factor_Marunda*marunda.Subsidence_2018_2028[1]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2028[0]*d
sub_Scenario3_2028=(Factor_Marunda*marunda.Subsidence_2018_2028[2]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2028[1]*d
sub_Scenario4a_2028=(Factor_Marunda*marunda.Subsidence_2018_2028[3]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2028[2]*
sub_Scenario4b_2028=(Factor_Marunda*marunda.Subsidence_2018_2028[4]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2028[3]*

sub_Scenario1_2050=Factor_Marunda*marunda.Subsidence_2018_2050[0]
sub_Scenario2_2050=(Factor_Marunda*marunda.Subsidence_2018_2050[1]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2050[0]*d
sub_Scenario3_2050=(Factor_Marunda*marunda.Subsidence_2018_2050[2]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2050[1]*d
sub_Scenario4a_2050=(Factor_Marunda*marunda.Subsidence_2018_2050[3]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2050[2]*
sub_Scenario4b_2050=(Factor_Marunda*marunda.Subsidence_2018_2050[4]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2050[3]*

sub_Scenario1_2080=Factor_Marunda*marunda.Subsidence_2018_2080[0]
sub_Scenario2_2080=(Factor_Marunda*marunda.Subsidence_2018_2080[1]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2080[0]*d
sub_Scenario3_2080=(Factor_Marunda*marunda.Subsidence_2018_2080[2]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2080[1]*d
sub_Scenario4a_2080=(Factor_Marunda*marunda.Subsidence_2018_2080[3]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2080[2]*
sub_Scenario4b_2080=(Factor_Marunda*marunda.Subsidence_2018_2080[4]*distance_sunter+Factor_Sunter*sunter.Subsidence_2018_2080[3]*

data['Henk Kooi Subrates']=Henk_Kooi_sub_rates

data['Secnario1_2028']=sub_Scenario1_2028
data['Secnario2_2028']=sub_Scenario2_2028
data['Secnario3_2028']=sub_Scenario3_2028
data['Secnario4a_2028']=sub_Scenario4a_2028
data['Secnario4b_2028']=sub_Scenario4b_2028

data['Secnario1_2050']=sub_Scenario1_2050
data['Secnario2_2050']=sub_Scenario2_2050
data['Secnario3_2050']=sub_Scenario3_2050
data['Secnario4a_2050']=sub_Scenario4a_2050
data['Secnario4b_2050']=sub_Scenario4b_2050

data['Secnario1_2080']=sub_Scenario1_2080
data['Secnario2_2080']=sub_Scenario2_2080
data['Secnario3_2080']=sub_Scenario3_2080
data['Secnario4a_2080']=sub_Scenario4a_2080
data['Secnario4b_2080']=sub_Scenario4b_2080

data.to_csv("subsidence_scenario.txt", sep='\t')
```

# Appendix VII: 3D-subsidence model



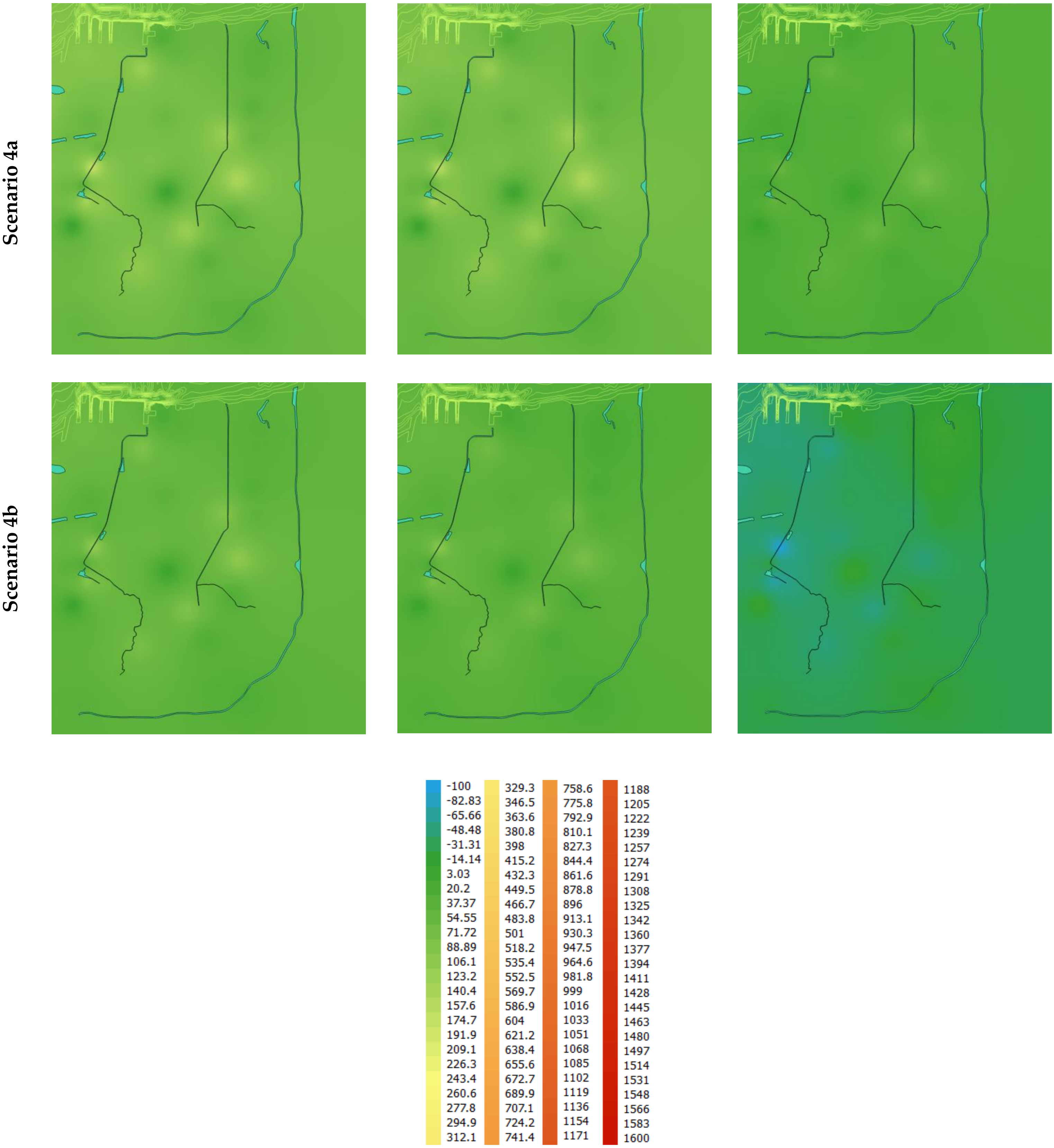
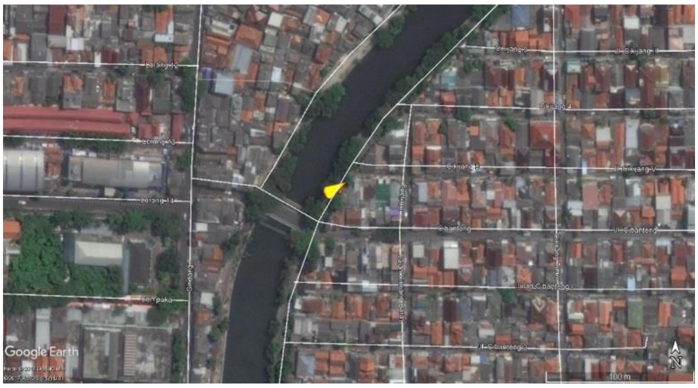


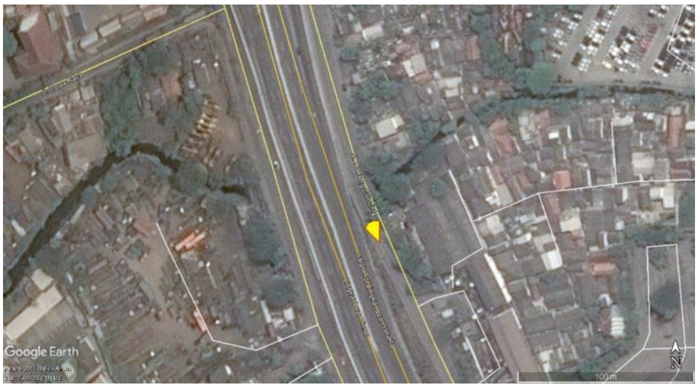

FIGURE 10.16: SUBSIDENCE 3D-MODEL WITH AN INVERSE DISTANCE WEIGHTING METHOD

# Appendix VIII: Examples bridge classes

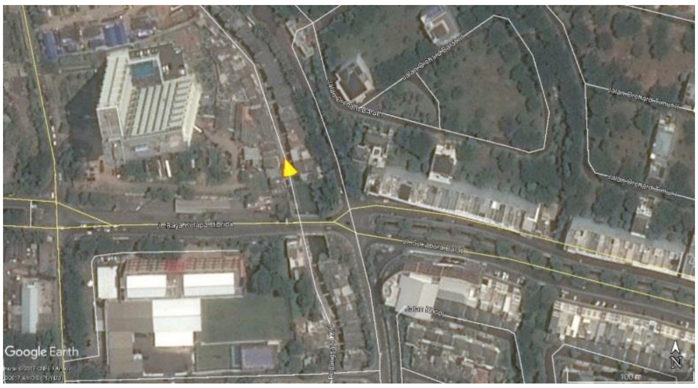



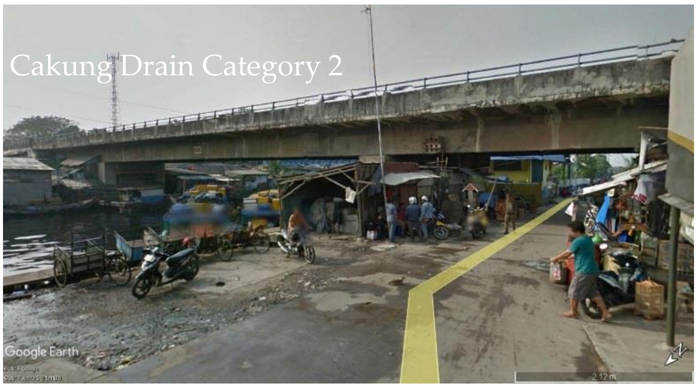




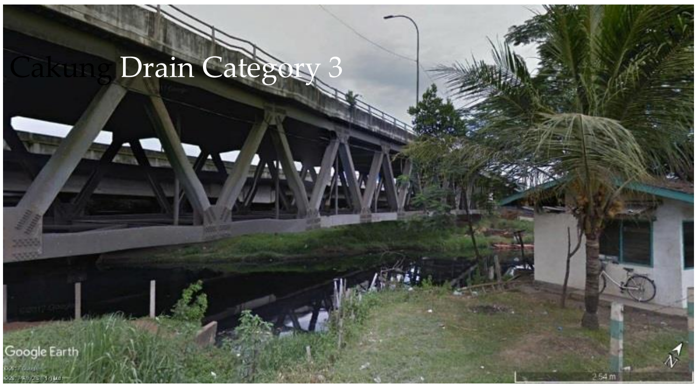




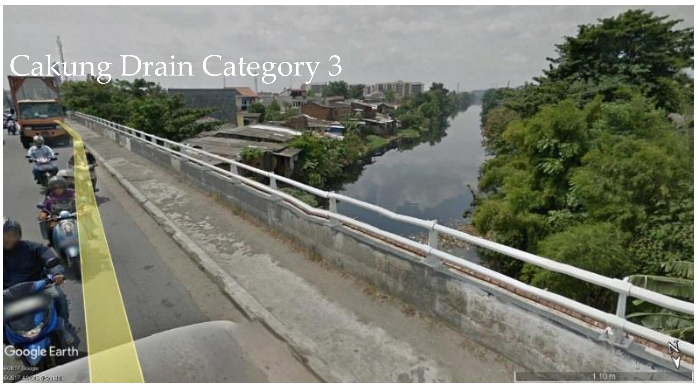


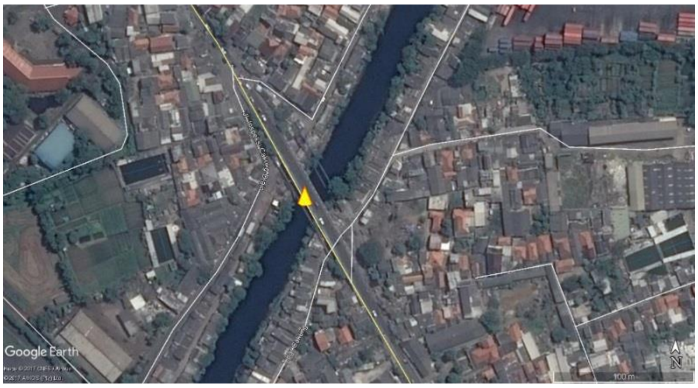

Cakung Drain Category 2
Google Earth


Google Earth


Cakung Drain Category 3
Google Earth


Google Earth


Cakung Drain Category 3
Google Earth

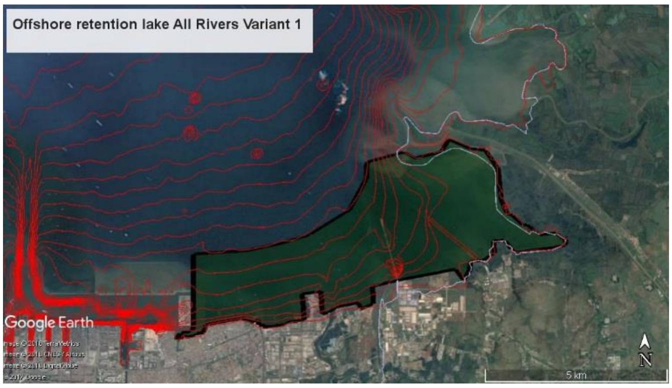

Google Earth

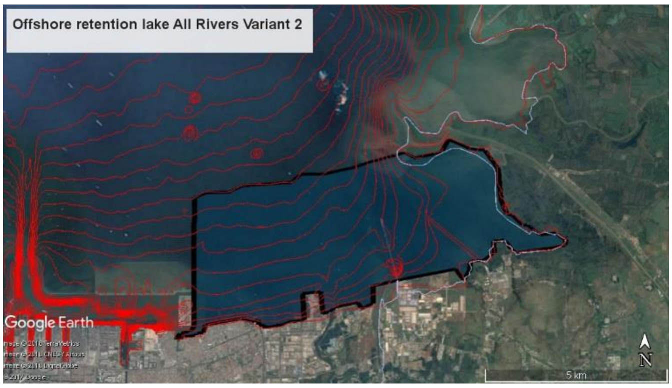

BKT Category 2
Google Earth

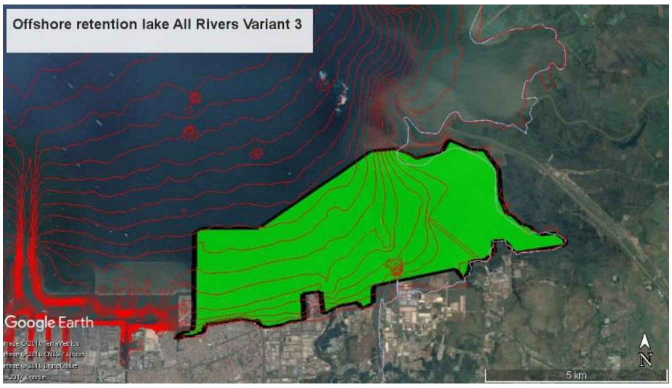

Google Earth

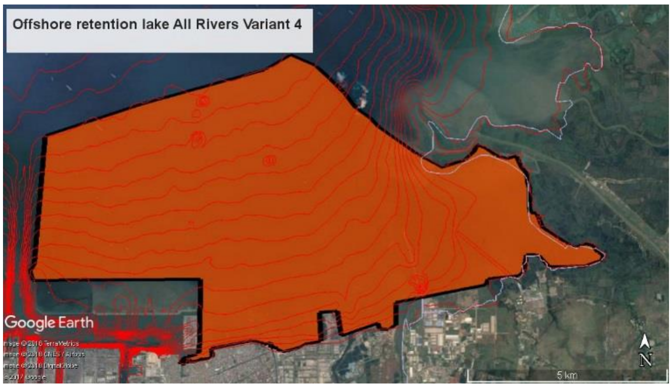

FIGURE 10.17: BRIDGES IN DIFFERENT CATEGORIES

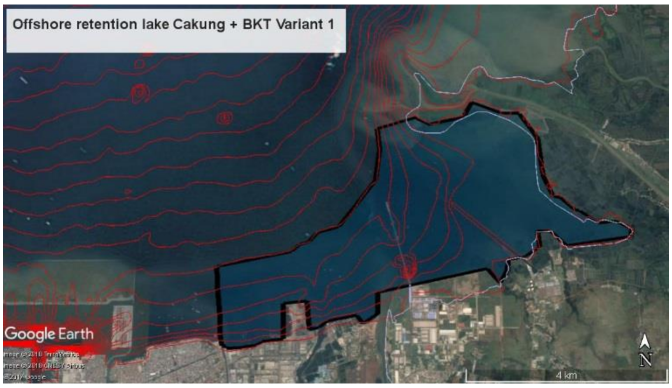
# Appendix IX: Outer sea dike examples

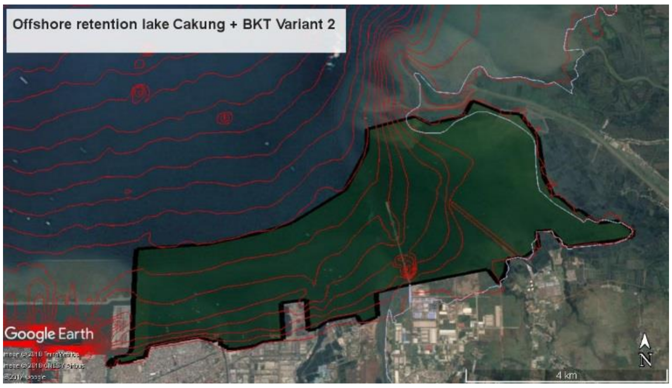


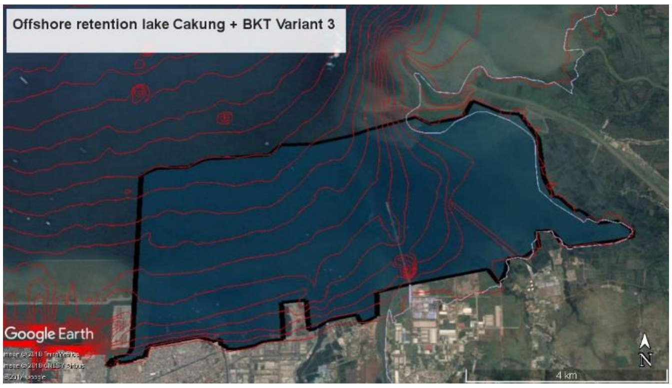



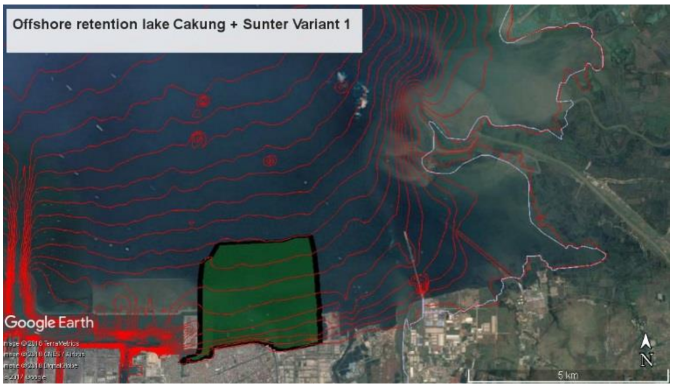



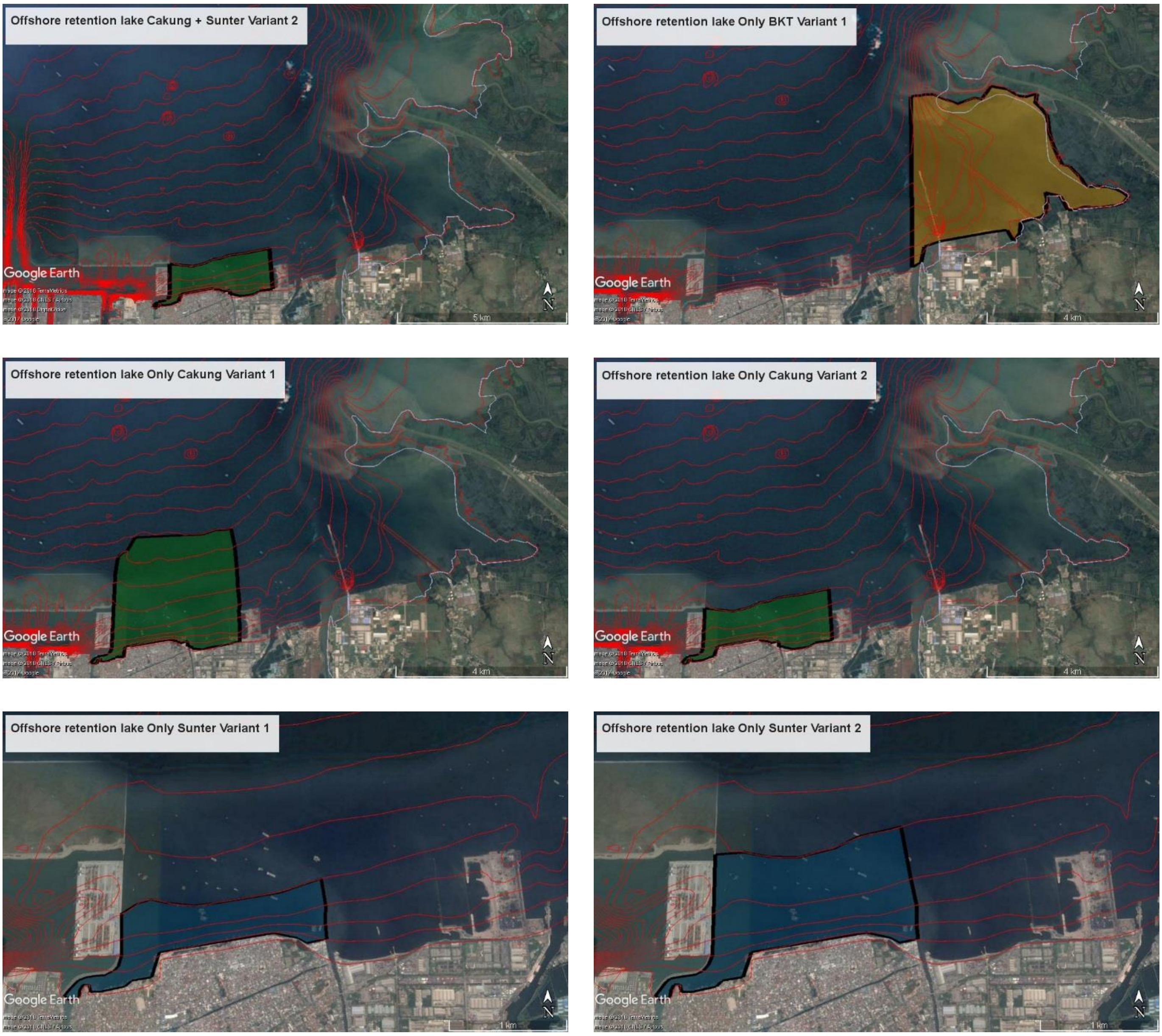



FIGURE 10.18: EXAMPLES OUTER SEA DIKE

# Appendix X: Input parameters coastal dike

The model is built based on the following criteria:

1. Level of the existing sea wall for each part
2. The bed level of the sea by looking at the bathymetry of along the coast
3. The effect of the sea level rise in 2080 (8mm/year)
4. The average land subsidence per part per scenario for 2080
5. The crest height of the dike and the height of the berm

In the table below, the input parameters are shown, these values are depending on the design, which is considered. The height of the existing sea wall (H4) has a constant value for each part. The slopes S1, S2, S3 are also chosen as constants depending on the design. L2, which is the crest width is reduced in case the reduces design is considered. The armour layer of rock on the upper- and lower outer slopes is constant and is not considered for the port concept. Note that for all designs no berm in taken into account. The thickness of the clay layer, which surrounds the sand core of the dike is chosen to have a constant value of 1 m. The initial height is with respect to $LWS_{2012}$.

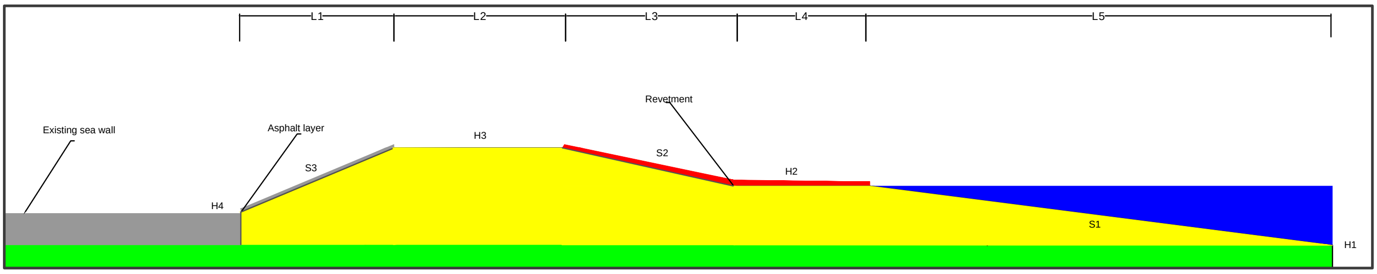



FIGURE 10.19: COASTAL DIKE

TABLE 10.1: INPUT PARAMETERS COASTAL DIKE

| | Symbol | Unit | Base concept | Reduced concept | Port concept |
|---|---|---|---|---|---|
| **Sea level rise 2030-2080 (m)** | | m | 0,4 | 0,4 | 0,4 |
| **-initial crest height in 2030** | H4 | LWS + m | 4,8 | 4,8 | 4,8 |
| **Outer lower berm** | S1 | hor/vert | 4 | 6 | 3 |
| **Outer upper berm** | S2 | hor/vert | 4 | 3 | 3 |
| **Inner slope** | S3 | hor/vert | 3 | 3 | 3 |
| **Crest width** | L2 | m | 25 | 5 | 25 |
| **Outer berm width** | L4 | m | 0 | 0 | 0 |
| **Armour layer lower outer slope (L5)** | | | | | |
| **60-300 kg** | | m | 0,9 | 0,9 | 0 |
| **10-60 kg** | | m | 0,5 | 0,5 | 0 |
| **Thickness** | | m | 1,4 | 1,4 | 0 |
| **Armour layer upper outer slope (L3)** | | | | | |
| **60-300 kg** | | m | 0,9 | 0,9 | 0 |
| **10-60 kg** | | m | 0,5 | 0,5 | 0 |
| **Thickness** | | m | 1,4 | 1,4 | 0 |
| **Thickness clay** | | m | 1 | 1 | 1 |

# Appendix XI: Equipment

| Type | Photo | Uses in levee construction | Advantages | Disadvantages | Remarks | Rating |
|---|---|---|---|---|---|---|
| Bulldozer (tracked)<br>*courtesy Stephanie Terry* |  | *Primary:*<br>• excavating soil<br>• ripping rock.<br>*Secondary:*<br>• compacting soils<br>• moving/spreading materials<br>• towing compactors<br>• towing discs and ploughs. | Wide ranges of sizes and power available. | Must be transported over public roads by low loader. | Wide array of attachments (rippers, blades, etc) available. | Rated by flywheel power.<br>Typically 50–600 kW. |
| Crane with dragline or clamshell bucket<br>*courtesy Stephanie Terry* |  | *Primary:*<br>• excavating soils, especially below water level or in very soft terrain.<br>*Secondary:*<br>• lifting and placing pipe and associated items<br>• loading materials<br>• placing revetment. | Can be used to reach a wide radius of work area, including underwater. | Transport and erection are expensive and difficult. | Losing favour to hydraulic excavators with extended boom operations. | Rated by bucket size.<br>Typically 1–2 $m^3$, but can be much larger for major dredging. |
| Truck/lorry<br>*courtesy USACE* |  | *Primary:*<br>• transport materials over public and haul roads.<br>*Secondary:*<br>• none. | • can travel public roadways<br>• readily available in a wide variety of sizes and axle configurations. | Difficult access in rugged terrain or poorly maintained haul roads. | Most versatile and readily available method for material transport. | Rated by flywheel power, number of axles, and hauling capacity (weight or volume).<br>Typically 50–500 kW, 1–3 axles, 1–25 $m^3$ or 1–70 tons. |
| Off-road dump truck<br>*courtesy USACE* |  | *Primary:*<br>• transport materials on site.<br>*Secondary:*<br>• none. | • can traverse rugged terrain and steep grades<br>• high volume and speed capability. | Cannot be used on public roads. | Available in articulated (cab/driver vs. load) configurations for added manoeuvrability and safety. | Rated by capacity.<br>Typically less than 1 $m^3$. |
| Tracked equipment<br>*courtesy Pierre Hingle* |  | ***Primary:***<br>• compact soils which are amenable to static compaction.<br>***Secondary:***<br>• seal embankments against water intrusion<br>• Provide 'grouser' surface texture on embankment slopes to retard erosion. | These activities (compacting, sealing, grousing) can be incidental to excavation, stripping, and spreading. | Compactive effort limited by ground pressure and static weight of equipment. | Many homogeneous levees composed of high plasticity clay require only bulldozer compaction. | Rated by flywheel power (bulldozers and tracked loaders above). Ground pressure exerted may also be calculated using operating weight (5000–100 000 kg) and track contact area (1–6 $m^2$). |
| Self-propelled compactors<br>*courtesy Michael Siu* |  | ***Primary:***<br>• compact a wide range of soils.<br>***Secondary:***<br>• spread materials. | Dual use machines. | • care must be exercised to limit activity to either spreading or compaction to ensure uniform embankment density<br>• easily misapplied to wrong soil types. | These are available in a wide variety of drum types, configurations, weights, and sizes. | Rated by flywheel power, weight, number/type of drums/wheels, and presence or absence of vibratory capability.<br>Typically 150–400 kW, 15–40 tons, one to three tamping or smooth drums/feet or tyres. Some models also offer vibratory compaction. |
| Hand-operated compaction equipment<br>*courtesy USACE* |  | ***Primary:***<br>• compact embankment soils where the use of larger equipment might overload or otherwise damage nearby structures and pipes. | Can be more closely controlled than larger wheeled and tracked equipment. | • limited compactive effort and area of coverage<br>• thinner embankment lift thicknesses are required. | Photo depicts what are commonly called 'jumping jack' impact compactors (on the right) and a small remotely controlled roller (on the left). | Varies. Rated by compactive force, typically 9–35 kN. |

FIGURE 10.20: EQUIPMENT INFORMATION [SOURCE: PILARCZYK (1998)]

## Appendix XII: Assumptions

| Nr. | Subject | Assumption | Reliability [accurate - neutral - inaccurate] | Sensitivity [high - medium - low] | Risk/Consequence | Mitigation option |
|---|---|---|---|---|---|---|
| **1** | Stakeholders | Supporters of OPQ Islands are also supporting sea wall solutions. | Neutral | Low | It might turn out there is less support for the sea wall solution. | Survey/lobbying/communication with stakeholders. |
| **2** | River system | The current river system is designed for a 1/100 flood event. | Inaccurate | High | Risk of under- or over dimensioning of the designs. | Further research in current river system. |
| **3** | River system | Catchment areas between rivers are equally divided when no information is given. | Neutral | Medium | Risk of unjustified distribution of discharge to the rivers, resulting in different pump capacities per river. | Further research in polder/catchment areas. |
| **4** | Rainfall event | The daily rainfall of West Jakarta is equal to East Jakarta. | Neutral | High | Risk of unjustified use of rainfall event, resulting in under- or over dimensioning of designs. | Further research in weather data. |
| **5** | Run-off | The curve number is 95. | Neutral | Medium | Risk of unjustified run-off discharge. East actually less densely populated than west where number originates from. | Define a curve number for East Jakarta. |
| **6** | Run-off | Losses are 20% of the potential maximum retention. | Neutral | Low | Risk of unjustified run-off discharge. | Further research into losses. |
| **7** | Evaporation | The same evaporation of West Jakarta is used for East Jakarta. | Accurate | Low | Risk of unjustified distribution of discharge to the rivers, resulting in different pump capacities per river. | - |
| **8** | Population | The future population density in East Jakarta is equal to West Jakarta. | Neutral | Low | No risk on design, since land subsidence scenarios of Henk Kooij are used. | - |

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| **9** | **Population** | **From 2040, East and West Jakarta will grow in population with the same rates.** | **Neutral** | **Low** | **No risk on design, since land subsidence scenarios of Henk Kooij are used.** | **-** |
| **10** | Water demand | >55% of water demand is from deep water extraction. | Neutral | Low | No risk on design, since land subsidence scenarios of Henk Kooij are used. | - |
| **11** | Wind | Wind data used for West Jakarta is used for East Jakarta. | Accurate | Low | Set-up and waves may be under- or overestimated. | - |
| **12** | Land acquisition | The unit prices of Beumer are used for land acquisition. | Inaccurate | High | Incorrect cost estimation of the on land solution. | Further research into land acquisition costs by for example looking at reference projects. |
| **13** | Retention lakes | The elevation of Waduk BKT 1 is the same as for Waduk BKT 2. | Neutral | Low | Dredging costs can be different. | |
| **14** | Land subsidence | Land subsidence scenarios of Henk Kooij are leading. | Accurate | High | Risk of over-dimensioning of the designs in case Henk Kooij is too pessimistic and under-dimensioning on the other hand. | Improvement of subsidence measurements in Jakarta. |
| **15** | Land subsidence | Maximum subsidence values of Henk Kooij are leading. | Neutral | High | Risk of under- or over dimensioning of the designs. | Improvement of subsidence measurements in Jakarta. |
| **16** | Land subsidence | Land subsidence between Marunda and Sunter is determined with linear interpolation. | Inaccurate | High | Risk of an underestimation of local high subsidence rates where soil conditions are bad and the other way around. | Improvement of subsidence measurements in Jakarta. |
| **17** | Land subsidence | Subsidence >10m is unrealistic. | Accurate | High | Wrong subsidence is used for design. | |

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| **18** | The backwater effect | During the relative subsidence of the riverbed, the water level remains constant. | Inaccurate | High | The real water level related to backwater theory can differ. The flood defences along the rivers can therefore be over or under designed. | Further research in river characteristics to perform an accurate backwater analysis. |
| **19** | Spatial analysis | Google maps data is up-to-date. | Accurate | High | Risk of spatial deviations, resulting in unjustified land use map. | |
| **20** | Wind set-up | Retention lakes are rectangular. | Neutral | Low | Relatively small wind set-up is calculated wrong. | - |
| **21** | Outer sea dike | No dikes are needed when the water depth is zero. | Inaccurate | Medium | Risk of higher cost. | More information on land/sea connection is needed. |
| **22** | Inland retention lakes | Same prices of Beumer are leading. | Neutral | High | Costs will differ. | Further research is required. |
| **23** | Flood risk | 100% of the downstream catchment (North of BKT) will contribute to flooding, | Accurate | Medium | Wrong definition of tipping point about flooding depth. | Further research is required. |
| **24** | Flood risk | 50% of the upstream catchment (of BKT) will contribute to flooding. | Neutral | Medium | Wrong definition of tipping point about flooding depth. | Further research is required. |
| **25** | River dike | Ground level at land side is 1 m below current flood defences. | Inaccurate | High | Unjustified estimation of the costs of the flood defences along the river. | Improvement of elevation measurements along the rivers in Jakarta |
| **26** | Pumps | The effect of evaporation and input via deep groundwater extraction is significantly small compared to rainfall, so neglected. | Accurate | Low | Rainfall may be over- or underestimated. | - |
| **27** | Pumps | Day 3 of the 3-day rainfall event is leading. | Accurate | High | Rainfall may be over- or underestimated. | - |
| **28** | Pumps | For areas which are not directly connected to one of the main rivers and canals, this area | Neutral | Low | Rainfall may be linked to the wrong river. | Further research into catchment areas is required. |

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| | | is added to the river where small canals flow to. | | | | |
| **29** | Pumps | Existing retention lakes have a capacity of 3 m water level increase. | Neutral | Low | Pumps may not handle the rainfall. | Better determination of the capacity of the existing retention lakes. |
| **30** | Pumps | The catchment areas of the BKT flow entirely under gravity for all scenarios. | Neutral | High | Additional pumps need to be installed. | More detailed information about elevation level along the BKT is needed. |
| **31** | Pumps | Hydraulic head is taken into account by adding 5% of the OPEX costs per meter. | Neutral | Low | Additional pumps need to be installed. | Further research into the effect of the hydraulic head on the OPEX costs. |
| **32** | Coastal dike design | Coastal dike designs for West Jakarta are leading for East Jakarta. | Accurate | Medium | - | - |
| **33** | Bridges | Bridges have to be replaced for all scenarios. | Neutral | Medium | Overestimation of the costs of the inland solution. | Further research into the type and height of the bridges along the rivers. |
| **34** | Land subsidence scenarios | Scenario 2 and 3 are considered most likely to occur. | Accurate | High | Over- or underestimation of the land subsidence. | |
| **35** | Piping and seepage | No piping will occur. | Accurate | Medium | Dike can be subjected to micro instability and can fail. | Further research into soil layers required. |
| **36** | Sliding inner slope | The soil underneath the dike consists of a soft clay layer. | Neutral | Low | Risk of inner slope failure. | This will not affect the results of the report, since this will be further investigated in a final design. |
| **37** | Sliding inner slope | Phreatic line goes linear in dike body. | Neutral | Low | Risk of inner slope failure. | This will not affect the results of the report, since this will be further investigated in a final design. |
| **38** | Sliding inner slope | Bed level is equal to top existing wall. | inaccurate | Low | Risk of inner slope failure. | This will not affect the results of the report, since this will be further investigated in a final design. |
| **39** | Sliding outer slope | Sliding of the outer slope will not occur. | Accurate | Low | Risk of outer slope failure. | This will not affect the results of the report, since this will be further investigated in a final design. |
| **40** | Shearing | Shearing of the dike body will not occur. | Accurate | Low | Risk of shearing of the dike body. | This will not affect the results of the report, since this will be further investigated in a final design. |
| **41** | Erosion outer slope | Existing revetment on | Accurate | Low | Risk of revetment failure of the dike. | This will not affect the results of the report, since this will be further investigated in a final design. |

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| | | dikes is sufficient. | | | | |
| **42** | Settlement | Settlement conditions are the same for East as for West Jakarta. | Neutral | Low | Risk of under design of crest height. | This will not affect the results of the report, since this will be further investigated in a final design. |
| **43** | Construction | The grade of rock material is not scarce in Jakarta. | Neutral | Low | Risk of project delay. | - |
| **44** | Construction | It takes 500 days maximal for land acquisition and land clearance. | Inaccurate | Low | Risk of project delay. | - |
| **45** | Construction | The construction time of a tidal gate is 200 days. | Neutral | Low | Risk of project delay. | - |