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# The Use of High Quality Data Sets in Flood Risk Management

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ABSTRACT: Time and time again, flood disasters show us that there are still many lessons to be learned from nature. For many generations, the Dutch, used to living below sea level and behind dikes, have actively shared their expertise and ideas to improve flood prevention and mitigation measures. Being a Dutch company, Fugro gladly participates in the Dutch Flood Control 2015 program, this gives us the opportunity to apply Dutch knowledge to dike and flood problems we encounter all over the world.A key issue is to find new ways to use state-of-the-art high quality area encompassing data and real-time data sets in assessing dike strength and its variations in space and time. In this paper, modern technologies to help manage Flood Risks and other Geo Hazards are presented, and some practical applications are demonstrated.

*Keywords: mapping, laser, geological investigation, risk management, uplift, seepage*

## 1 INTRODUCTION

### 1.1 *Flood Risk Management in the Netherlands*

The Netherlands is situated as a 'delta country' in Northwest Europe situated at the downstream end of the rivers Rhine, Meuse and Scheldt. The Netherlands has 16.4 million habitants, and with an area of 41,528 km$^2$ one of the most dense populated countries in the world (2007). The total length of the dike system is 17,500 km, of which 3600 km are primary dikes and 14,000 km are secondary dikes. The total length of the waterway system is ca. 5000 km. Table 1 shows an overview of some historic floods that have occurred in the Netherlands in the past 1200 years (Jonkman 2007).

Table 1. Historic Floods in the Netherlands

| year | Coastal floods | Victims |
|---|---|---|
| 838 | Frisia coast | ? |
| 1228 | | 100 000 |
| 1287 | Wadden Sea st. Lucia flood | 50 000 |
| 1404 | Zeeland, 1st Elisabeth flood | ? |
| 1421 | Southwest NL, Elisabeth flood | 100 000 |
| 1530 | Zeeland, st. Felix flood | >100 000 |
| 1570 | Coast NL, Allerheiligen flood | 20 000 |
| 1686 | North NL st. Maartens flood | 1558 |
| 1717 | Western coast | 11 000 |
| 1916 | Southern sea | 15 |
| 1953 | Southwest NL watersnood | 1836 |
| | River floods | |
| 1784 | Betuwe area | ? |
| 1809 | | 275 |
| 1855 | Betuwe area, Maas, Waal | 13 |
| 1861 | Bommelerwaard, Maas, Waal | 37 |
| 1880 | Land van Heusden en Altena | 2 |
| 1926 | Meuse | ? |

Inevitably, water management became the core competence of the Dutch. Living in the Netherlands was, is and will also be in the future ‘living with water’:

- Flood Protection is vital for the Netherlands: 60% of the land – including the cities of Amsterdam and Rotterdam -and 70% of our Gross National Product (450 billion €) will be at risk during floods. The large 1953 flood was the ‘wake up call’ for the Dutch initiating their first ‘Delta Plan‘.
- The Dutch know that sea levels have been rising and the land has been subsiding for hundreds of years, and probably will continue to rise and respectively sink for the coming hundreds of years.
- Their river systems are part of bigger catchments (Rhine, Meuse, and Scheldt), so they established long term agreements with neighbouring countries.
- The water system is very fragile, coping with a very high groundwater level, subsidence problems of our very soft soils and oxidation of peat. The Dutch expect to have increasing salinity problems due to sea level rise and subsidence, which will affect fresh water supply and agriculture.

The backbone of the Dutch dike safety approach is the composition of the system to 53 dike-rings with each a safety standard by law (figure 1), controlled by 26 strong water boards responsible for the periodic safety assessments every 5 years. The water boards are responsible for water safety, quantity and quality management (included waste water treatment). The water boards collect their own taxes, ensuring dedicated money to be spent on water issues only. Per water board the maintenance budget is ca. 100 mln euro/year, of which 5% is spent on dike maintenance, ca. 45% on water quantity and ca. 50% on water quality.

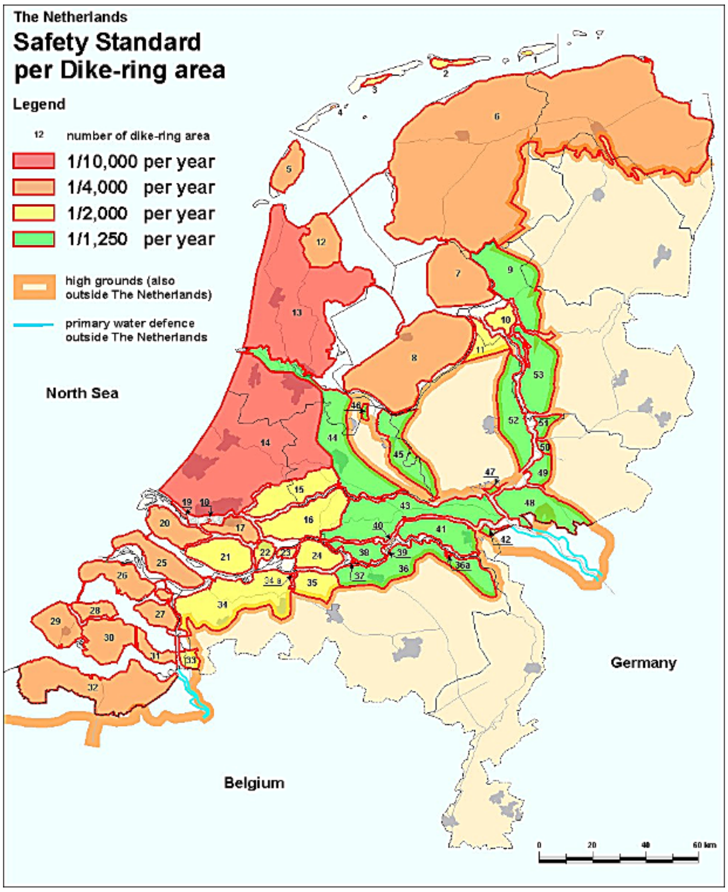


Figure 1. Dike rings and safety standards in the Netherlands

The Netherlands, being a small country at the end of the western European river system, have taken the initiative to set up some important European directives on Water Management: the EU Water Framework Directive (22 December 2000) and the EU Flood Directive (26 November 2007).

The EU Flood Directive 2007/60/EC regarding the assessment and management of flood risks became effective on 26 November 2007. This Directive requires that member countries map their flood plains, determine the potential flood consequences (loss of life and assets) and identify and execute flood risk reduction measures. The goal of this directive is not only to reduce flood risks, but also to manage them with an emphasis on human health, environment, cultural heritage and economy.

The Directive requires Member States to first carry out a preliminary assessment by 2011 to identify the river basins and associated coastal areas at risk of flooding. For such zones they would then need to draw up flood risk maps by 2013 and establish flood risk manage-ment plans focused on prevention, protection and preparedness by 2015. The Directive applies to inland waters as well as all coastal waters across the whole territory of the EU.

The Directive shall be carried out in coordination with the Water Framework Directive, notably by flood risk management plans and river basin management plans being coordinated, and through coordination of the public participation procedures in the preparation of these plans. All assessments, maps and plans prepared shall be made available to the public.

Member States shall furthermore coordinate their flood risk management practices in shared river basins, including with third counties, and shall in solidarity not undertake measures that would increase the flood risk in neighbouring countries. Member States shall take into consideration long term developments, including climate change, as well as sustainable land use practices in the flood risk management cycle addressed in the Flood Directive.

The EU Directives have been incorporated into Dutch legislation. E.g. detailed Flood Risk Maps are made available by internet for the public.

## 1.2 *Trends in Data Acquisition and Data Integration*

Modern airborne mapping technologies, using state-of-the-art remote sensing technology, serve a wide range of natural resources management, urban planning, economic development, emergency response, environmental, and engineering activities. This includes:

- Photogrammetric mapping: High resolution orthoimagery for base mapping and image classification, topographic contours, and planimetric mapping.
- Panoramic mapping: Simultaneous vertical and oblique orthoimagery combined with powerful 3D mapping and visualization software.
- LiDAR mapping: Fast and accurate elevation modeling for engineering-grade corridor mapping (FLI-MAP) and large-area topographic and bathymetric mapping.
- IFSAR and InSAR mapping (GeoSAR): Rapid production of regional and countrywide maps through clouds and dense foliage.

There are several methods for Light Detection And Ranging (LiDAR):

- Fixed wing Wide Area LiDAR, used to measure overall topography with fast aerial surveys, accuracy 10 cm, 4 points per m2. Often combined with area / region wide aerial photography.
- Helicopter LiDAR (FLI-MAP), originally developed for corridor mapping (for powerlines, railroads, pipelines, dikes etc.) but also used for very accurate overall topography mapping, accuracy 3 cm, 40 – 50 points per m2, combined with digital photo and video images.
- Terrestrial LiDAR (DRIVE-MAP), using a car mounted LiDAR data acquisition platform, used for detailed surface mapping (figure 2).

High quality continuous digital terrain models (DTM's) are a very useful tool for asset management, for both authorities and private parties. E.g. they allow detailed condition assessment, such as shallow gully detection by surface inversion, which is very important for dike safety assessments. For this and other reasons, most dike corridors in the Netherlands are mapped with very accurate FLI-MAP measurements, and subsequently the whole of the Netherlands is also flown in with helicopter LiDAR, to improve the height model from 1 point per 16 m2 to 10 points per m2. This enables the assessment of detailed flood risk maps.


Figure 2. High quality terrestrial LiDAR data acquisition with DRIVE-MAP

### 1.3 *Dike strength as the backbone for Flood Risk Management*

In the Netherlands the safety levels of dikes are expressed as the required exceeding frequency of the water surface elevation WSE that the dike can withstand safely. Dutch secondary dikes are evaluated for WSE's having a return period of 10 to 1000 year. As shown in figure 1, Dutch primary dikes are evaluated for the 1,250 to 10,000 year event. In the USA most dike evaluations concern the 100 – 500 year event.

Dike strength analysis is all about first finding the weak(est) spots in the dike system, mostly hidden in the subsoil or the dike core. Knowing these weak(est) spots enables the responsible authorities to take appropriate action; this can be acquiring additional data, the installation of a monitoring system, a dike reinforcement program, the preperation of flood control plans (inspection, preparation of appropriate measures), or the elaboration of likely flood scenarions in calamity plans.

Fugro is partnering in the Dutch flood control research networks to develop and test new ways to tackle these problems. In the Flood Control 2015 program, amongst others the following dike strength topics are being studied:

- continuous dike strength mapping and automated engineering;
- real-time dike strength assessments;
- use of remote sensing in dike strength assessments.

## 2 REAL® CONCEPT

It has been observed that there is a need for a tool to perform dike analyses in long dike reaches, involving dense surface and subsurface data sets, and enabling large numbers of standard dike analyses in a GIS environment (Van der Meer 2007).

To make better use of the FLI-MAP and other state-of-the-art high quality data sets, Fugro developed the Rapid Engineering Assessment of Levees (REAL®) system. This tool allows cost- and time effective assessments of large numbers of dike km's and it enables cost and time effective re-assessments (physical and/or dike safety) if conditions or requirements change in time. The REAL® tool was first demonstrated in California (Van der Meer 2009).

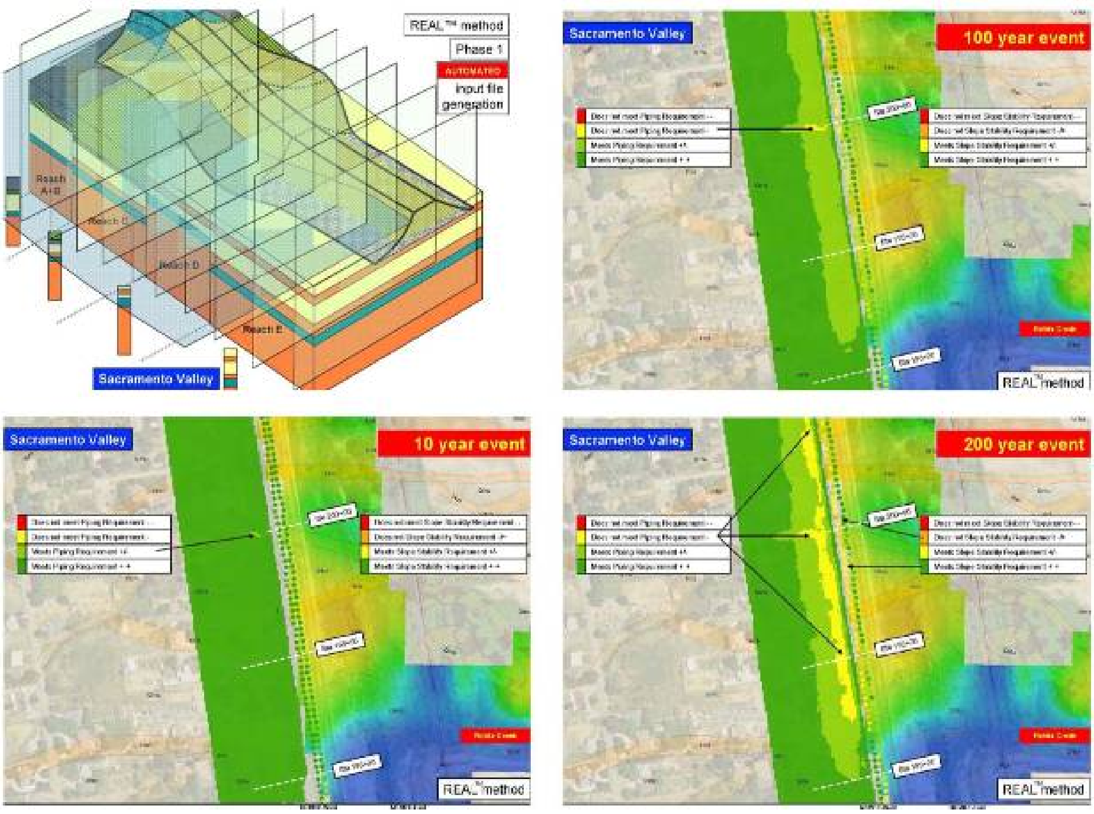

Figure 3. REAL® and multi WSE analyses presented in GIS

The REAL® concept enables us to make full use of the detailed Digital Elevation Model, acquired with the FLI-MAP system, to complete area covering dike strength analysis on all relevant failure mechanisms. E.g. the uplift and piping mechanisms can be checked with grid and vector analyses directly in GIS.

It's also possible to use off the shelve software to do cross section analysis for e.g. piping and/or slope stability analysis. Modules are made to perform automated cross section generation to perform automated engineering using off the shelve software, such as the GeoSlope suite, or the DAM platform and M-series developed by Deltares.

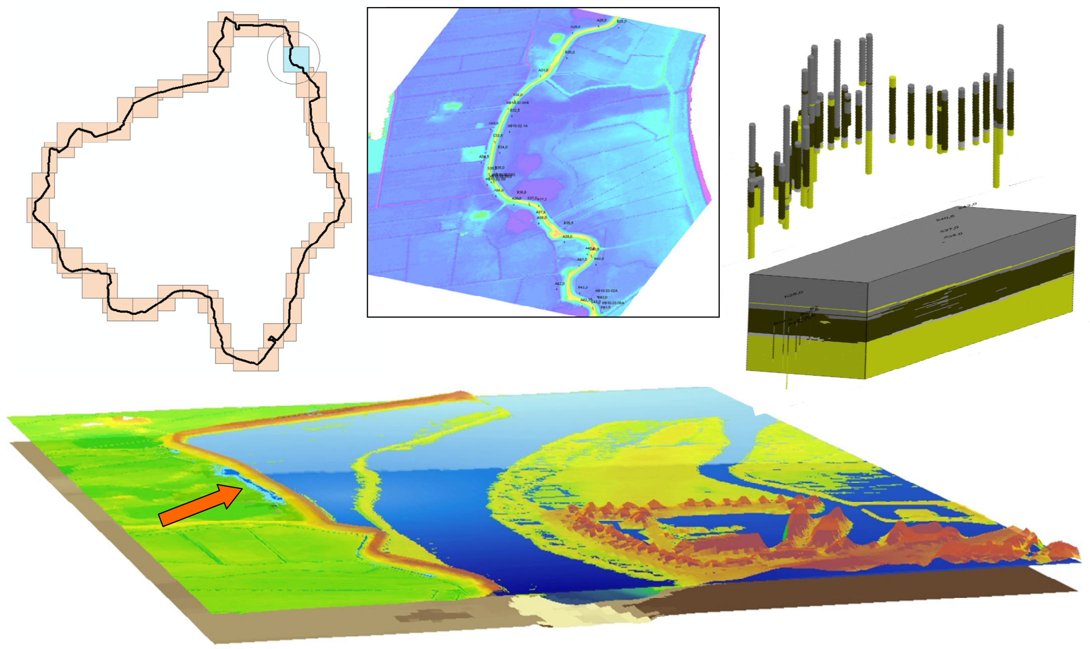
Figure 4. REAL® dike ring analysis, case 'Mastenbroek', the Netherlands

Figure 4 shows the modelling of an entire dike ring, in this case the ring ‘Mastenbroek’ of the water board ‘Groot Salland’, the Netherlands. The key of this project was to demonstrate the near real-time strength calculation of large dike sections in GIS. The figure shows the composition of the dike ring in sections allowing efficient GIS processing, the presentation of subsoil data and the generation of a subsoil model of the toplayers behind the dike, and a helicopter view on calculated uplift and piping safety during high water. The arrow points at a weak spot where the safety is below required standards.

Note that there are similarities between Flood Risk Management and the management of other Geo Hazards. E.g. modern technology developed for Landslide Risk Management or Earthquake Risk Management can be efficiently merged with Flood Risk Management technology and information systems.

## 3 TREE RISK MAPS

Trees can potentially reduce the safety of flood defences. The interaction between geotechnical failure mechanisms and tree physics is a key component in assessing the impact on dike safety. Tree parameters, derived from a database of the physical characteristics of several thousand trees, growing on or near by dikes, are integrated with geotechnical knowledge of embankment structures. The result is a tree risk zoning map, that represents a practical and useful tool to assess the influence of individual trees on dike integrity and safety.

Figure 5 shows an example of a tree risk map, which Fugro created for the Dutch water board Brabantse Delta. Of course this can easily be combined with the REAL® concept, allowing the creation of tree risk maps for any specific water level.

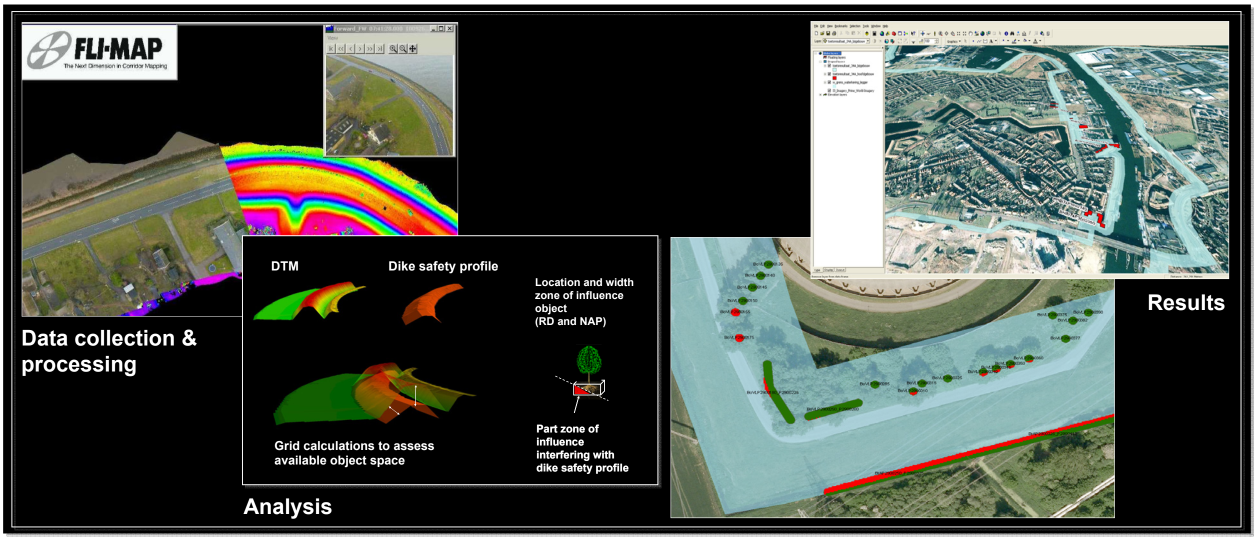


Figure 5. Tree risk map, results dike section Brabantse Delta, the Netherlands

## 4 CONTINUOUS DTMS AND 3D SUBSOIL MODELS

In all cases, the quality of data and the subsoil model is key for accurate failure predictions. So an important topic is the improvement of subsoil models, used for dike strength analyses, using airborne data acquisition techniques.

A known problem for geotechnical praticioneres is that important features are easy to miss when only using conventional ground investigation techniques. Also for the Californian dikes, we combined LiDAR data and Helicopter Electro Magnetics airborne data with more conventional data from cpt’s, borings and geological knowledge (Pearce, 2009). In (Pearce, 2010) a detailed surficial geologic mapping for the northern Sacramento-San Joaquin Delta is presented, thus providing key data to document deposits, past processes, and geomorphic environments. An important first step is combining continuous surface and underwater DTMs to one continuous DTM (see figure 6).

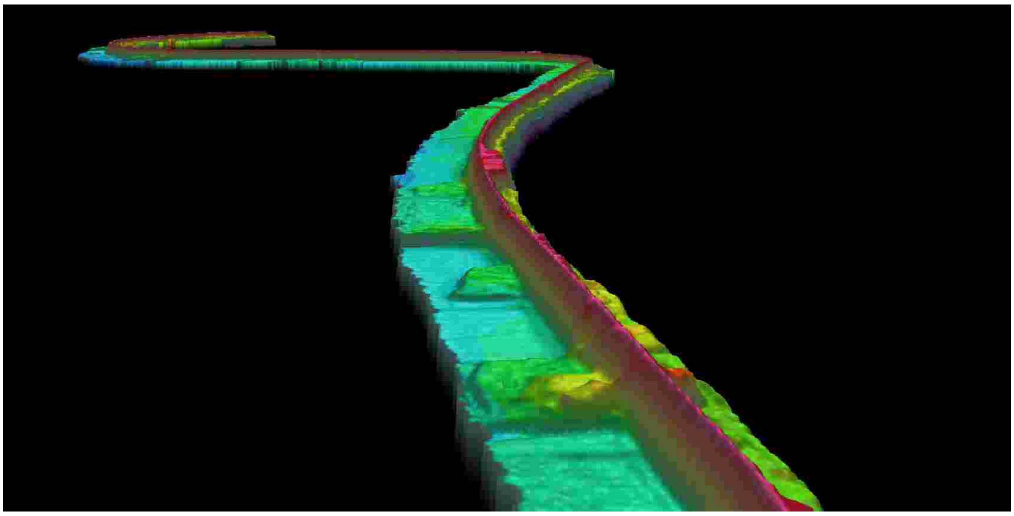

Figure 6. Continuous: bathymetrical and aerial elevation data model of a Californian dike section

## 5 DIGITAL CITY MODELS

Cities are becoming more and more important. Especially cities in delta regions are subjected to increasing flood risks, as a result of growing population and worse conditions due to climate change.

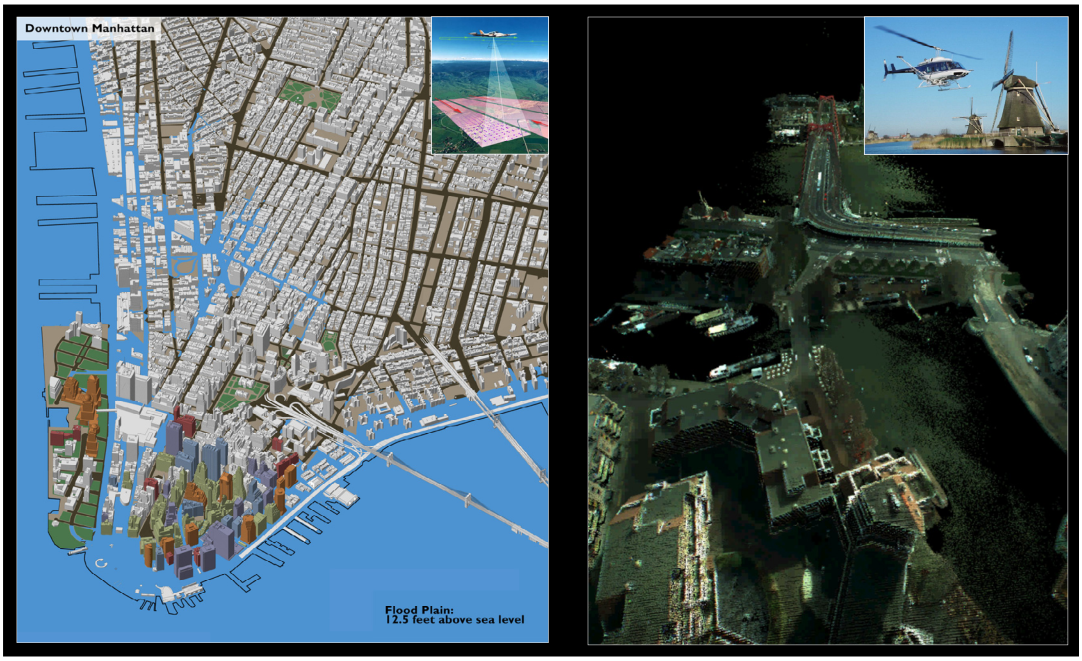


Figure 7. Digital city models, examples New York (Manhattan) and Rotterdam (detail of Willems bridge)

Figure 7 shows examples of digital city models for New York and Rotterdam. These models are used for urban flood risk planning, but also for various other purposes.

Another example is the use of comprehensive GIS-based mapping capabilities for the city of Norfolk (Virginia). This is being used to integrate tidal and other data into a flood prediction model that reacts to various environmental or design criteria input by the user.

These evaluations are being used to prioritise areas for flood defence improvements, to refine engineering design criteria and to analyse alternative flood mitiagion measures and emergency response plans within the city of Norfolk.

## 6 CONCLUSIONS

The following conclusions can be drawn, regarding the use of high quality data sets in flood risk management:

- Integrated Flood Risk Management (prevention, spatial planning and mitigation) needs accessable and visualized information systems, that should be based on solid reliable data.
- High quality data sets provide added 'users value' for both daily and extreme conditions when combined and used for REAL® solutions.
- REAL® accomodates Technology Transfer between several Geo Risk Management compartments (Flood Risks, Landslide Risks, Earthquake Risks etc.).

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