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THE DUTCH DELTA MODEL FOR POLICY ANALYSIS ON FLOOD RISK MANAGEMENT IN THE NETHERLANDS

R.M. Slomp[1], J.P. de Waal[2], E.F.W. Ruijgh[2], T. Kroon[1], E. Snippen[2], J.S.L.J. van Alphen[3]
1. *Ministry of Infrastructure and Environment / Rijkswaterstaat*
2. *Deltares*
3. *Staff Delta Programme Commissioner*

ABSTRACT
The Netherlands is located in a delta where the rivers Rhine, Meuse, Scheldt and Eems drain into the North Sea. Over the centuries floods have been caused by high river discharges, storms, and ice dams. In view of the changing climate the probability of flooding is expected to increase. Moreover, as the socio-economic developments in the Netherlands lead to further growth of private and public property, the possible damage as a result of flooding is likely to increase even more. The increasing flood risk has led the government to act, even though the Netherlands has not had a major flood since 1953.

An integrated policy analysis study has been launched by the government called the Dutch Delta Programme. The Delta model is the integrated and consistent set of models to support long-term analyses of the various decisions in the Delta Programme. The programme covers the Netherlands, and includes flood risk analysis and water supply studies. This means the Delta model includes models for flood risk management as well as fresh water supply. In this paper we will discuss the models for flood risk management.

The issues tackled were: consistent climate change scenarios for all water systems, consistent measures over the water systems, choice of the same proxies to evaluate flood probabilities and the reduction of computation and analysis time.

Key words: Flood Risk, Policy Analysis, Public Participation, Probability, Model Integration, Delta Programme, Delta model

1. INTRODUCTION

1.1 Situation

The Netherlands is located in a delta where the rivers Rhine, Meuse, Scheldt and Eems drain into the North Sea. Floods over the centuries were caused by high river discharges (sometimes in combination with ice dams) and storms. In view of the changing climate the probability of flooding is expected to increase. Moreover, as the socio-economic developments in the Netherlands leads to further growth of private and public property, the possible damage as a result of flooding is likely to increase too. On the other hand, the Netherlands has not had a major flood since 1953, which means that flood risk awareness by the general public is relatively low (OECD, 2014).

Therefore an integrated policy analysis study on flood risk management and fresh water supply has been launched by the government, as a part of the Dutch Delta Programme. Prinsen et al. (2013) presented the models for fresh water supply; in this paper we will discuss the models for flood risk management and how they are used. The information from the Delta model and other studies for the general public and specialists is provided on the Delta Portal: http://www.deltaportaal.nl/.

1.2 Delta Programme

The Delta Programme (Van Alphen, 2014) is a national programme in which the Dutch government, provinces, municipalities and water authorities work together in collaboration with civil society organisations, the business community and research institutes under the direction of the appointed commissioner for the Delta Programme (the Delta Commissioner). The Delta Programme is aimed at maintaining the Netherlands as a safe and attractive country.

The current Delta Programme has three national programmes (fresh water supply, new safety standards for flood risk and reconstruction and development) and six regional programmes (the Coastal zone (mainly dunes), the Wadden Sea Area, the South Western Delta (Scheldt Delta), the Rhine and Meuse Delta, the lake IJsselmeer Area and the two major rivers Rhine and Meuse). The programme aims at supporting the Delta Decisions on five major issues related to water management in the Netherlands, by providing long-term analyses that cover the period from 2015 to 2100. In performing the analyses, three main phases are identified: the problem analysis, the selection of favourable (sets of) measures and the selection a preferential (set of) measures (preferential strategies). For the analysis several computation tools were required; these will be described in this paper.

1.3 The Delta model as the computation tool within the Delta Programme

The Delta model is the integrated and consistent set of models to support long-term analyses of the various decisions in the Delta Programme (Kroon and Ruijgh, 2012).

Large parts of the water systems which cause the flood risk are also used for water management (drainage and water supply) and for transport purposes (navigation). For a national policy analysis a common set of climate change scenario's, physical models and description of measures have to be used. This is because the water systems overlap, even though problems drought and flood do not overlap in time. This has been a major achievement of Delta Programme and the Delta model: a set of common references and common tools for analysis on a national scale.

A policy analysis also has to be performed within a certain time frame and be reasonably precise or correct in its analysis. In the Delta model both aims have been balanced. The precise tools for the assessment of flood defences have been used; at the same time, time needed to make new calculations of water levels and waves for each scenario has been reduced, by reducing the number of calculations and by speeding up calculations. Uncertainty analysis (Haasnoot et al, 2012) and (Nicolai et al, 2011) was done parallel to the main analysis and prepared with prototypes of the tools used in the Delta Programme. The (Nicolai et al, 2011) study shows that flood defences should be about 0.4 to 1 meter higher in the Netherlands if all known uncertainties are accounted for in probabilistic models.

1.4 History of policy analysis in the Netherlands

The Netherlands has a long history in policy analysis especially in programmes which reduce flood risk. Large programmes like the enclosure of the Zuiderzee (1891, first plan - 1975 completion) which consisted of the Afsluitdijk (great barrier dam) and the Flevo polders and the Delta Works (1953 start - 1997 completion) have always been preceded by a cost benefit analysis and have also been evaluated using cost benefit analysis methodology after they were finished (Bos et al, 2013).

In 1978 with help from the Rand corporation new policy analysis techniques were introduced with the Policy Analysis Water Management Netherlands (PAWN study) (van Veen and G. Baarse, 1982). The concept of using scenarios was introduced in policy analysis.

In the year 2000, with the work of the Committee Water Management in the 21st century (in Dutch: 'Water Beheer 21e eeuw') the concept of climate change scenarios was introduced in policy analysis in the Netherlands (Ministerie van Verkeer en Waterstaat, 2000). These scenarios were provided in 2001 by the Dutch Meteorological institute (KNMI) and were based on research carried out in collaboration with the IPCC (Können, 2001).

1.5 Legal, Organisational and Financial setting

To understand policy analysis in the Netherlands it is essential to understand the legal, financial and institutional context. This is described in detail in (Slomp, 2012). Since the flood of 1953 and near floods of 1993 and 1995 the Netherlands has drastically changed the way flood defences are built, financed and managed. Funding for measures to reduce flood risk is based on flood risk standards, which are set by law. The current standards are being re-evaluated (van der Most et al, 2014). Flood risk varies over time, economic development, policy choices and climate change influence flood risk. Acceptable standards for flood risk depend on more than only cost benefit analysis. Societal risk and individual risk is now also being considered.

2. FLOOD RISK ANALYSIS WITHIN THE DELTA PROGRAMME

2.1 Reference situation

The reference situation for the Delta Programme is the year 2015. This is when three large ongoing programmes will have delivered: a programme for strengthening flood defences 'HWBP2', and two programmes which have to lower design water levels by increasing the discharge capacity: 'Room for the River' and 'Meuse works'. These programmes include a set of measures such as: side channels, lowering the flood plain, bypasses, lowering groins in the river, laying back dikes or removing dikes altogether.

2.2 Climate (change) scenarios

Climate change has its effect on the rate of sea level rise and higher precipitation (KNMI, 2006). There is no indication the wind climate is also changing, which may be due to the fact that describing the present wind climate for extreme wind speed events (e.g. a 0.0001 probability) is a major challenge in itself (Caires et al, 2009).

In the Delta Programme both sea level rise, lake level rise and river discharge changes have been taken into account (Table 1 and 2). The climate scenarios of 2006 (KNMI, 2006) are implemented (together with scenarios on socio-economic changes) in the Delta scenarios (Deltares, 2011). The reference dates for sea level rise and river discharge are the year 1990 and 2001 respectively. The maximum scenario ("Warm") for 2100 includes a 20% increase in precipitation and a sea level rise of 0.85 m. During the WB21 study in 2001 Rijkswaterstaat elaborated a national method for translating climate scenarios into discharge and sea level scenarios. An important issue for determining discharge scenarios is the fact that flooding may occur in Germany (Lammersen, 2004), delaying the arrival of most of the extra precipitation and thus reducing the extreme discharges in the Netherlands. Therefore Rijkswaterstaat has chosen to use an extreme discharge for the Rhine River up to 18 000 m^3/s in 2100 in the calculations with the Delta model for the Delta scenarios. Values mentioned in Deltares (2011) can be used for additional sensitivity analysis in flood risk modelling.

Table 1: Delta scenarios for sea level rise and effect on lake level in large lakes (lake IJsselmeer and Markermeer.) * = sea level rise of 0,01 m in between 1985 -1990 has been neglected.

Scenario	Sea level rise in reference to the year 1985 (m)	Lake level rise due to sea level rise	
		basis (including effect of planned new sluices / pumps) (m)	in case of extra pumps (m)
Reference 2015	0,07*	0,00	0,00
2050 Moderate	0,15	0,00	0,00
2050 Warm	0,35	0,20	0,00
2100 Moderate	0,35	0,20	0,00
2100 Warm	0,85	0,45	0,00

Table 2: Delta scenarios for river discharges.

Scenario	Rhine	Meuse	Vecht
	Design (m^3/s)	Design (m^3/s)	Design (m^3/s)
Reference 2015	16000	2601	550
2050 Moderate	16000	2665	564
2050 Warm	17000	2755	583
2100 Moderate	17000	2755	583
2100 Warm	18000	2974	629

Storms produce both storm surges and waves, for the North Sea coast these often coincide. For the estuaries, the Wadden sea, major lakes, and rivers, storm surges and waves usually do not coincide. Another important issue is that river discharges and storm surges are not correlated (van der Made, 1968) and (Geerse, 2013).

Multiple combinations of storms and discharges which can each lead to failure of flood defences is the reason probabilistic models were developed in the 1990's (CUR, 1990). Since 1990 much progress has been achieved in the field of probabilistic modelling. We have introduced a single concept for probabilistic modelling for Hydraulic loads in the Netherlands, the model Hydra-Zoet (Geerse, 2013). This concept has been used to provide the probability of flooding for the Delta Programme. This model Hydra-Zoet provides the results that are being used as input for the policy analysis.

2.3 Safety issues and measures considered

The focus of the Delta Decision on Water Safety is on new water-safety standards. These new standards will be drawn up using a risk-based approach in which the risk of flooding and the possible consequences together determine the level of the standard. The type and level of these standards differ from the current standards and the level may change in future due to socio economic developments (varying over the Delta Scenarios).

The Delta Decision on the lake IJsselmeer Area involves three strategic choices: discharge into the Wadden Sea, the water levels of the lakes IJsselmeer, Markermeer and the Randmeren (border lakes in the Veluwe region), and the freshwater supply. The statistics of the (freshwater) water volume in these lakes may change due to sea level rise, changing river discharges, changing water management (target volumes) and changing infrastructure (sluices, pumps). These changes will have impact on the safety of dikes in the region.

The Rhine-Meuse Delta is the transitional area in which the rivers and the sea converge. It comprises the area of the large rivers, Rhine Estuary-Drechtsteden and the South-western Delta. The Delta Decision on the Rhine-Meuse Delta involves four elements: the application of new flood defences, the distribution of the discharge from the Rhine across the branches of the Rhine (the Waal, Lower Rhine and IJssel), emergency flood water retention in the Volkerak and Grevelingen, and an adequate freshwater supply.

2.4 Choice of proxies for flood risk assessment

Choice of the proper proxies to evaluate flood risk is essential. In the compulsory assessment every 6 years of flood defences we use more than 40 different analysis techniques. In policy analysis we have evolved from one proxy for evaluating flood risk / the probability of flooding to nine. We started by only using differences in design water levels e.g. with the Delta Committee of 1960 (van Dantzig, D. 1956) and the Cost Benefit Analysis of Room for the River (Eijgenraam, 2002). In time we evolved to using dike height in the RBSO (Kok et al, 2005), WV21st century/ DP Safety studies (Kind, 2011) and to using dike strength, dunes erosion and structures in the national Flood Risk Project VNK-2 (Jongejan et al, 2011). The more indicators for flood defences you use, the more information has to be collected and processed and the more computation time increases. The VNK-2 project has evaluated one single scenario, the year 2010). This took more than seven years. The Delta model has made it possible to evaluate multiple climate change scenarios and multiple strategies in a relatively short period of time.

The Delta model focuses on computing (changes in) the 'safety task': the difference between the local hydraulic load level (which is exceeded at the normative frequency) and the local reference strength level (see Figure 1 and Figure 2). The problem analysis (impact of Delta Scenarios) and assessment of the effectiveness of measures can easily be performed by comparing safety tasks.

Two hydraulic load level types are identified: the water level and the required crest level. The required crest level is the crest level which is needed to exactly meet a critical wave overtopping discharge (like 1 l/s/m) standard. The water level is compared with two (geotechnical) reference strength values: the critical water level for piping and the critical water level with respect to inward sliding (macro stability). The required crest level is simply compared with the actual crest level (the reference strength with respect to wave overtopping).

The easiest to evaluate is the water level, since it requires no information about the dike. This parameter is traditionally used in the upper river areas of the Rhine and Meuse for flood risk analysis, where the river discharge is much more important for flood risk than wind.

In the estuaries, lakes and along the coast we traditionally use the required crest level as an indicator. The wind action increases the water level (and depth) and the waves. So the change in hydraulic load level (Δ H) for both waves and water levels has been chosen as a national indicator (Kind, 2011). This is described as the decimate height, the change in required crest level if you increase the probability by a factor 10. This factor is independent of climate change but changes due to projects which increase the discharge capacity on rivers.

The Delta programme has to evaluate changes in flood risk due to climate change, economic development and propose strategies to cope with increased flood risk. The most important indicator is changes in required dike heights (Kind, 2011). Large changes in flood risk due to piping and slope stability have been accounted for in the costing of measures using the programmes DAM and KOSWAT. So some ideas from the VNK-2 project have been incorporated in the Delta programme. The DAM programme uses the hydraulic loads to calculate necessary dike profiles (height en width). The KOSWAT programme then subsequently calculates the change in costs (see also Figure 4).

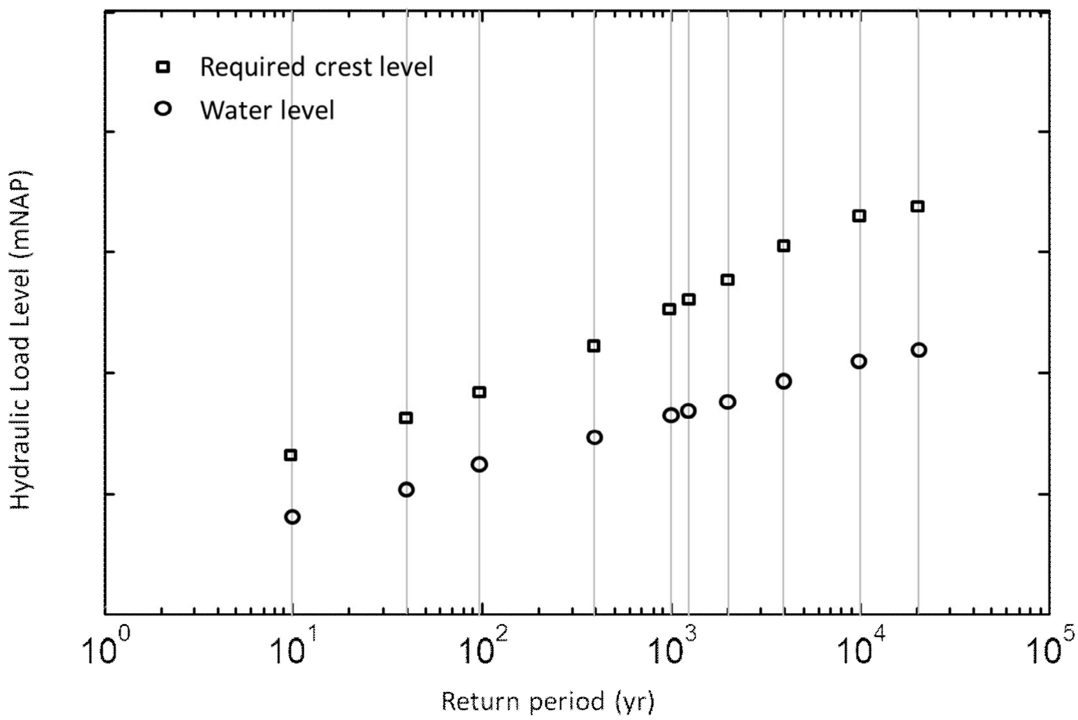

Figure 1: Typical results: the hydraulic load level (water level and required crest level) at a fixed set of return period values.

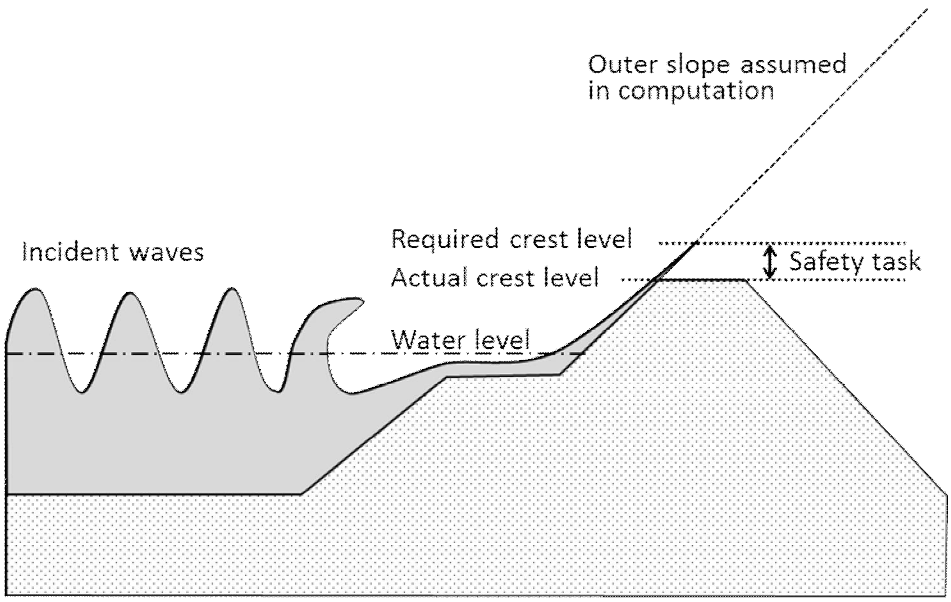

Figure 2: Definitions of hydraulic load (required crest level at actual normative return period), strength (actual crest level) and safety task in case of the wave overtopping safety requirement.

3. INTERCONNECTED MODELS AND THE CALCULATION PROCESS

3.1 Consistent reference and data

Flood risk studies need consistent sets of data. The probability of flooding has to be consistent with flooding scenarios and with the cost of measures (e.g. dike reinforcement to counter them). The Delta model provides a computational facility based on Delft-FEWS (Werner et al 2013) which automates the workflow of running sets of the interconnected models. The Delta Model enables analyses of the present reference situation (2015) and future 2050 and 2100 scenarios, as well as strategies to cope with the effects of climate change. Figure 3 shows how this input remains consistent.

3.2 Type of input needed

Cost benefit analysis studies (Eijgenraam, 2002, Kind, 2011) need three types of input: changes in probability of flooding (ΔH), changes in potential damage and costs to reduce the probability of flooding. The hydrodynamic models in combination with probabilistic models provide the probability of flooding. These models also provide the input for 2D flood scenarios (in case of a dike breach) using the Delft FLS or SOBEK 1D-2D model (this determines water depth and speed) and subsequently the damage function determines the total cost per flood scenario. The cost of improved flood defences is determined by using the waves and water levels determine for a certain probability of flooding to design new flood defences.

We use two indicators to determine current flood risk: Societal Risk and Individual Risk. These studies need the probability of flooding, the flooding scenario (water depth and speed) and the damage function. These figures also have to be consistent.

3.3 Detailed description of the work flow

The hydrodynamic models in the Delta model form the basis for the flood risk management calculations. These models have been developed over many years by the national water authority (Rijkswaterstaat) for different water systems in the Netherlands, and include applications of 1D-Sobek as well as 2D-Waqua. As it was a key objective of the development of the Delta model to enhance consistency, specific attention was paid to harmonise the various hydrodynamic models. The hydrodynamic models are applied in the Delta model in a probabilistic setting, this is to take into account various possible conditions related to upstream river discharge, wind force and direction, and downstream water levels (sea or lake levels). Depending on the specific water system, 9 to 1025 different combinations of these conditions for water levels are taken into account. 5 wind speeds and 16 wind directions are added using a 1 dimensional wave model Bretschneider (Slomp et al 2002). Based on the results of the hydrodynamic calculations the design water level is calculated for the dikes along the rivers with the Hydra-Zoet software package (Geerse, 2011).

With formal flood risk assessment tools we have evolved from 1D models (SOBEK for water levels) and Bretschneider (for waves) to 2D models (WAQUA for water levels) and SWAN (for waves) (Chbab, 2012). However calculation time for WAQUA (weeks) is significantly higher than for SOBEK (days), when one has to evaluate multiple scenarios and strategies to cope with them this becomes a constraint. We have therefore chosen to use WAQUA for the upper river areas (Meuse and Rhine). SOBEK is being used in combination with the Bretschneider formula for waves for the Rhine and Meuse Estuary. For the IJssel and Vecht estuaries we have chosen to use WAQUA in combination with Bretschneider). The available SOBEK model is not considered reliable for storm surges. The modelling skills for the Rhine, Meuse river and estuaries are very high. We are using the fifth generation of hydrodynamic models and validation is compulsory each year.

The calculation results of the hydrodynamic models and the probabilistic model can be exported to be used in other (effect) models. At present exports are available to the KOSWAT module to evaluate the costs for dike strengthening. In future this might be extended to exports to software to calculate the possible damage and risks in flooded areas.

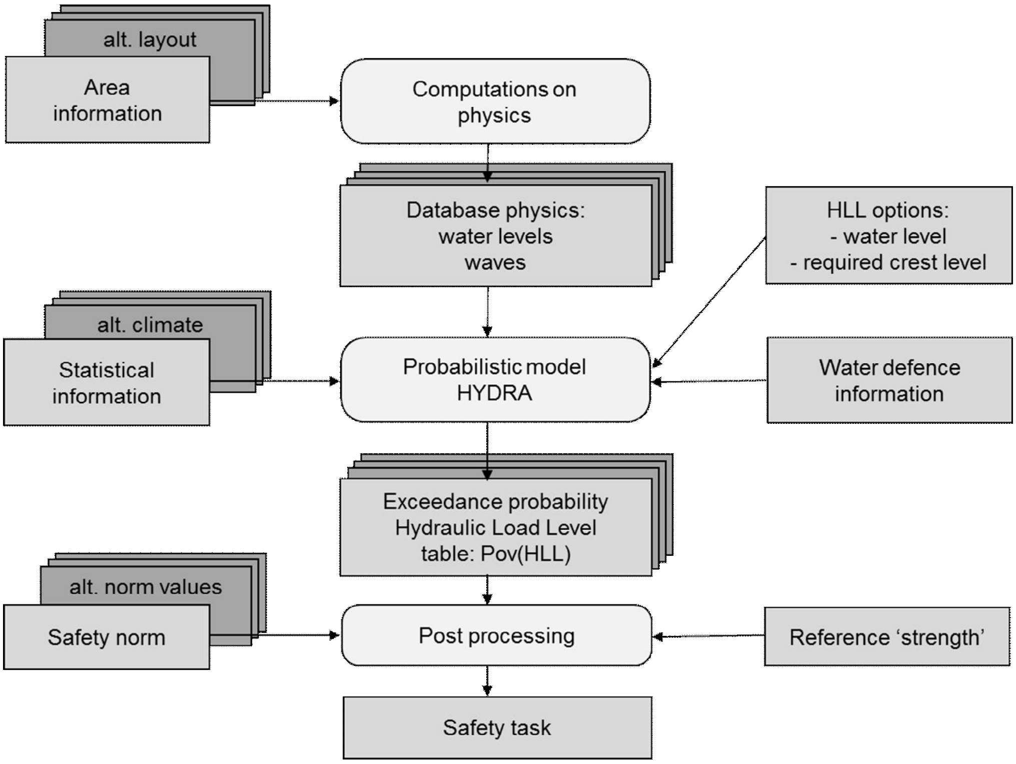

Figure 3: Data flow in calculating (changes in) hydraulic load level statistics, translated into safety tasks.

Statistical data also changes with climate change. For river discharges and sea level rise this has been shown in tables 1 and 2. For lake levels of the Markermeer and IJsselmeer it is more complicated. Lake levels change due to the possibility to drain to the North Sea and the input from rivers and pumping stations. How much can be drained depends on the number of sluice gates, tidal action, sea level rise, the target water levels for the lake and the exact water levels during the drainage process which depend on the wind speed and direction. Since the extra sluice gates decided on in 2000 will be replaced with a large pumps in a number of the existing sluice gates (in 2014/2015) calculating the effect on statistics for lake levels is rather complicated. A new process to calculate statistics for lake levels was determined using the SOBEK model for the lake IJsselmeer area and 30 years of data (Hoonhout, 2011).

3.4 Delta instruments / Other models / workflows

The Delta model was introduced during an ongoing programme. The main issue was introducing a common practice and common references. In the river and lake area water quantity and flood risk issues overlap. The focus for accelerating data flow in the Delta model was therefore in the river and lake areas. The Delta Programme uses whole set of models some have been included into the Delta model and some still remain outside. These models have been called the Delta Instruments, see Figure 4.

Hydra-Zoet has been included in the Delta model for certain work flows. Other workflows are carried out outside of the Delta model. The immediate need for a certain work flow usually determines if it is carried out within or outside of the Delta model.

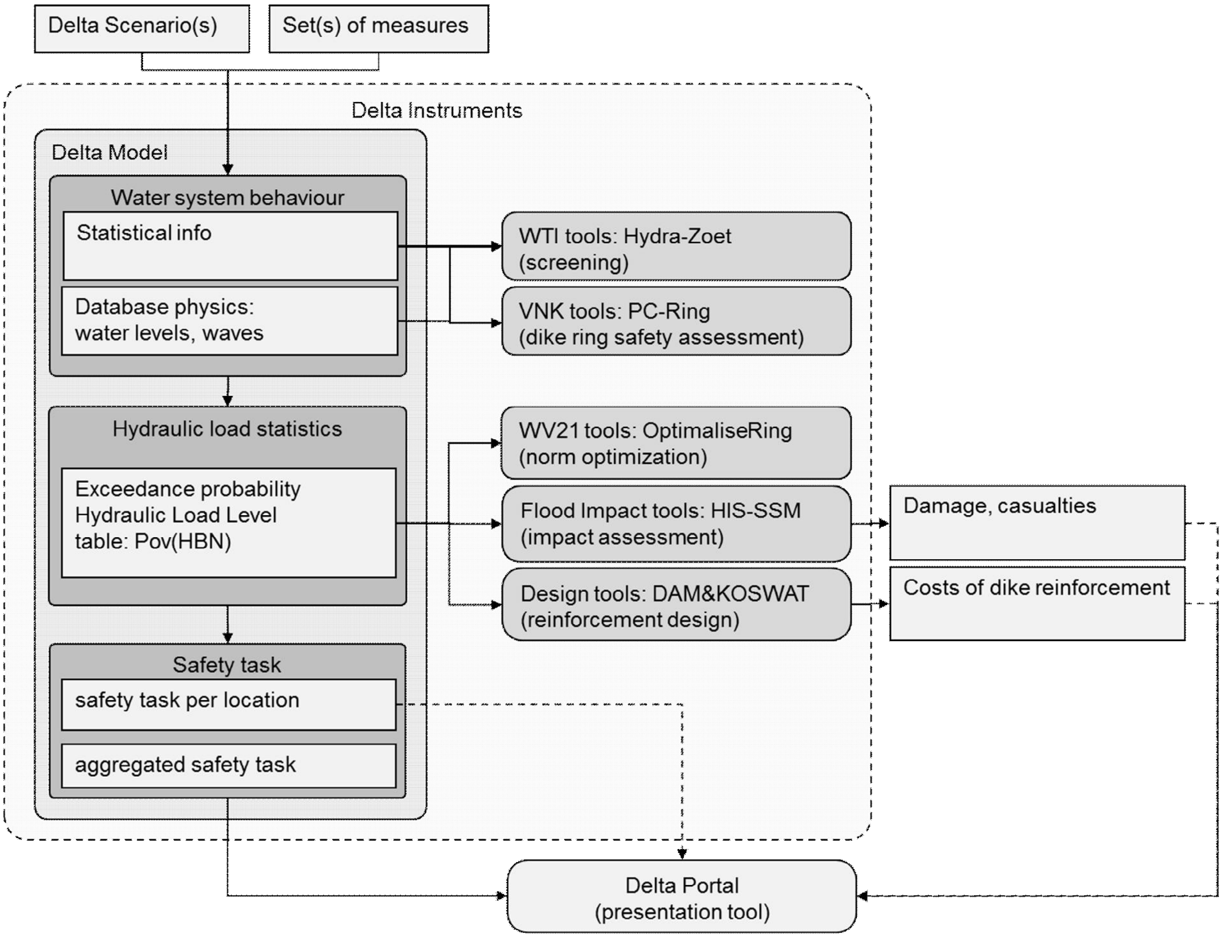

Figure 4: Position of Delta model in the (less striclty defined) Delta Instruments in the data flow from scenarios and sets of measures to the presentation of results for public participation

4. SUPPORTING THE POLICY DECISION PROCESS

4.1 Differentiating between national and regional interests

National and Regional interests are not always the same. In the Delta Programme it is important to follow the national interests while incorporating regional interests if they do not conflict. Rijkswaterstaat has enumerated the national interests (Koeman, et al. 2013). Regional interests are often focussed on other issues than Flood Risk, e.g. local ecological issues, Waal Weelde or more on regional economical issues as tourist development e.g. “doorsteek Grevelingendam” or housing development in flood prone areas.
Regional issues should not be accepted only because there is a local consensus among the institutional organisations. The most important issue is that the regional idea delivers a solution for the national problems. This is the main reason the Delta model is:

- Transparent and self explanatory
- Consistent in the water systems and between flood risk and water supply issues
- Discriminatory – trends and issues are explained

4.2 Public participation often oversimplifies problem analysis

Public participation is an important issue in the Delta programme. Public participation also has a down side. To make complex problems understandable for a general public, they have to be simplified. This was a similar problem in the Room for the River project. The room for the river project focussed on changes in design water levels. These changes are easy to explain. The planning kit (Kors, A.G., 2002) was developed to communicate with the general public, experts and politicians. The purpose of the planning kit is to find optimal strategy per river branch for measure to lower the design water levels. The planning kit shows the target water level "red line" which has to be lowered over the whole branch of the river, on average 30 cm. This means measures to increase discharge capacity are easily evaluated. However flood risk as mentioned above is determined by about 40 indicators. In the estuaries and deltas where wind setup of water levels and wave action are important the focus on design water levels sometimes erroneous. A drop in design water levels of 30 cm by increasing the width of the river can cause an increase in required crest levels of more than 1 meter. Uncertainty in design water levels introduced by new side channels was also not covered. Side channels can react differently to other discharge waves than the standardized design discharge or cause morphological changes in the river, which distort the conveyance capacity.

This oversimplification is also an issue in the Delta programme. The policy of focussing on dike heights since 1953 and 1995 meant that other issues have emerged as critical. Important issues are often difficult to understand. The VNK-2 study (Jongejan et al, 2011) showed that piping and slope stability are important issues for flood risk analysis in the Netherlands. Especially the uncertainty of the consistence the subsoil is an important factor in determining failure probabilities. The Delta model has included piping and slope stability in sensitivity analysis (Knoeff et al, 2011) and in the cost estimates (Grave and Baarse 2011). The Delta model is still mainly focussed on differential dike height, this is acceptable for a policy analysis. For the implementation of the programme from 2015 to 2050, the new assessment and design tools will be used. These tools incorporate the insights and techniques from the VNK-2 study and the Delta model.

4.3 Conclusion

The development of the Delta model has strongly supported consistency between the national analyses and regional analyses in the Delta Programme. This is essential for decision making process of the national policy and for acceptance of difficult choices in the regions, the different water systems. This is the only way to determine if a local solution also fits in with the national solutions.

By using the Delft-FEWS platform it was possible to make the immense number of computations on time needed for the national analysis, in a transparent and consistent way.

The results of the calculations with the Delta model have been used in the various regional sub-programmes of the Delta Programme. Results for the regional programme the Rhine and Meuse Estuary are covered by (Kind et al, 2014) and for the Rhine and Meuse rivers by (Schielen, 2014). Results for the national programme, are covered by (van Alphen, 2014) and New Flood risk standards (van der Most 2014). For the lake IJsselmeer area the results have been published on the website of the Central Planning Bureau (Zwaneveld, 2014).

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