Rijkswaterstaat
Ministerie van Infrastructuur en Milieu

Uncertainty in climate predictions:

How to take this into account for dike design?

13 October 2016

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1. Uncertainties in Climate Change

At present fixed increments on water level for Sea Level Rise from the KNMI’06 scenario’s for dike design:

- W-scenario is 85cm SLR in 2100; exceedance prob. ~ 80%
- G-scenario is 35 cm SLR in 2100; exceedance prob. ~20%

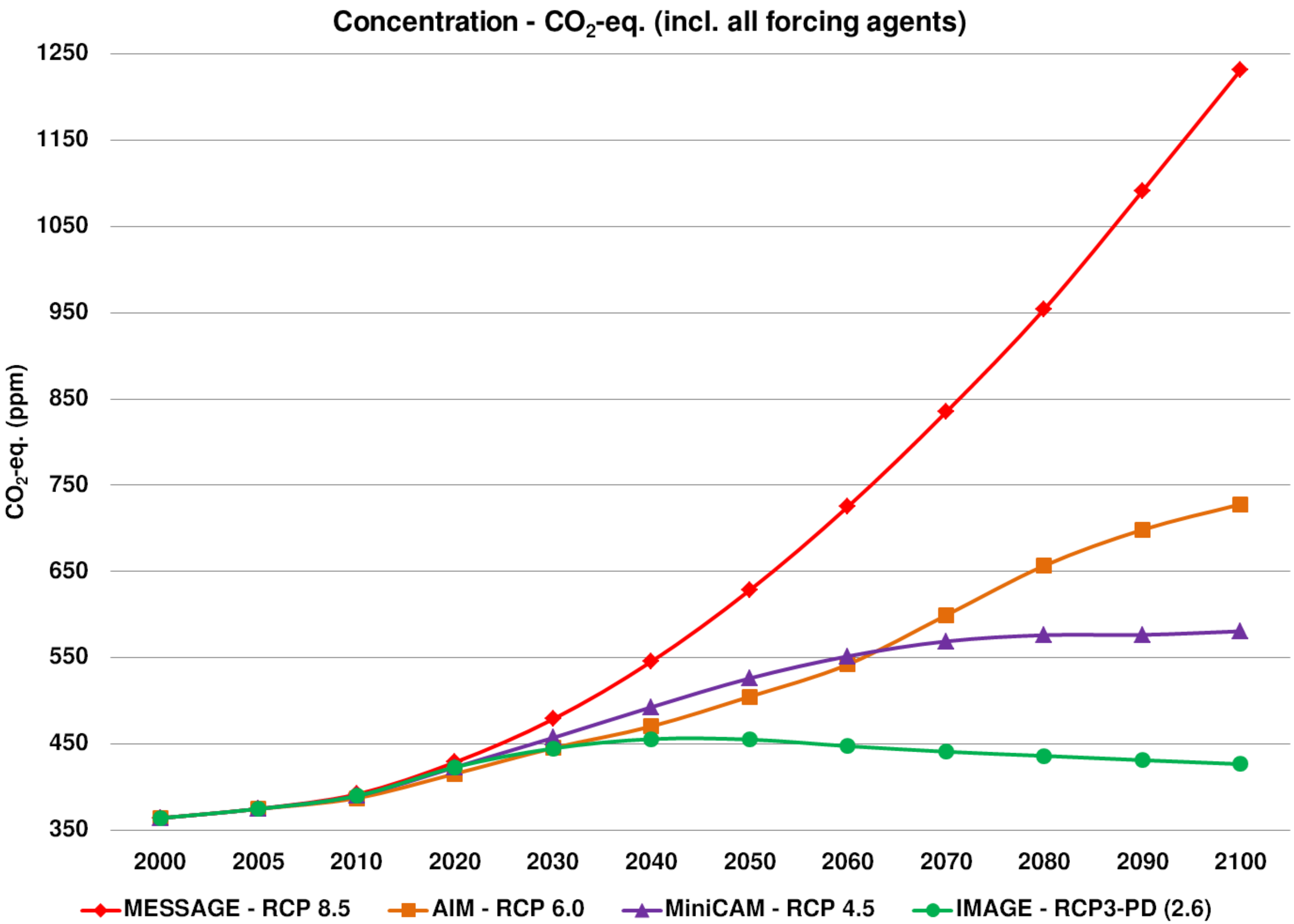
However: **uncertainties in climate change are not taken into account**. These are:

1. Uncertainties in CO2 emissions (scenario’s):

- IPCC uses RCP scenario’s (Representative Concentration Pathways): global CO2 emission scenario’s;
- RCP scenario’s are transferred by KNMI into global temperature scenario’s: KNMI’06/KNMI’14 scenario’s.

2. Conditional uncertainties in Climate models given the emission scenario’s

RCP's: CO2 scenario's



Ambition of the Ministry and Water Boards

- To deal with climate scenario's and climate uncertainty in a practical, understandable, but economically efficient way in dike design (using LCC);

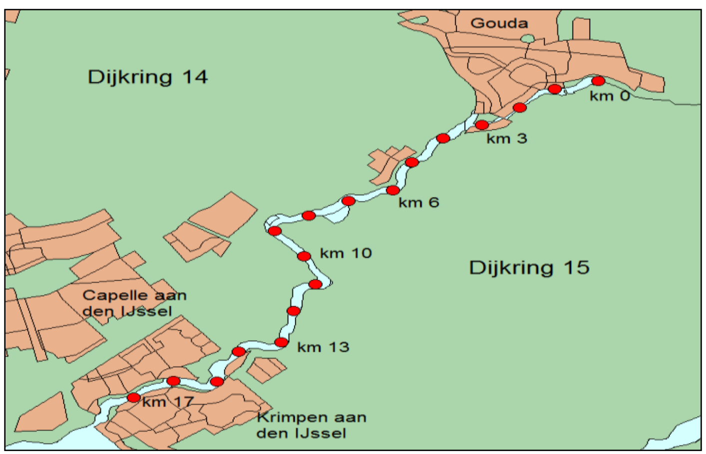
- To prevent overestimation of dike height due to double counting of uncertainties and too much risk aversion

- To anticipate on large climate uncertainties for the next century (relevant for hard constructions like storm surge barriers, sluices etc.)

- How to take into account other tipping points as well that are not related to climate change?

Hollandsche IJssel: a system with extra tipping points for dike design

- Until when can demolishment of housed be prevented?
- When must the storm surge barrier be replaced wit a new one?



2. Dike design in the Netherlands

- The Netherlands have thousands of kilometers of river- and coastal levees that need to be maintained, tested and (re)designed. Consequences of flooding can be dramatic;

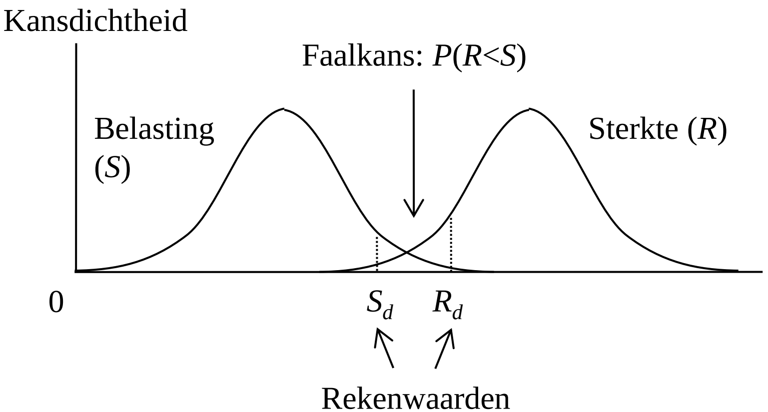
- Testing of dikes, dams and barriers is done with the WTI and a set of legal norms. WTI is a software instrument;
- Design or improvement of dikes that did not withstand the test is done with the OI, the design instrument.
- OI is based on the WTI but has extensions for the projection into the future: the design is based on the end of the life span

What is the Design Instrument OI?

- Design is the task of the water boards. The OI is build by the Ministry IenM (commissioner is DGRW, execution by RWS)
- OI is based on assessment of the probability of flooding of legalized trajectories.
- For design in OI the trajectory must satisfy with the norm at the end of the life span.

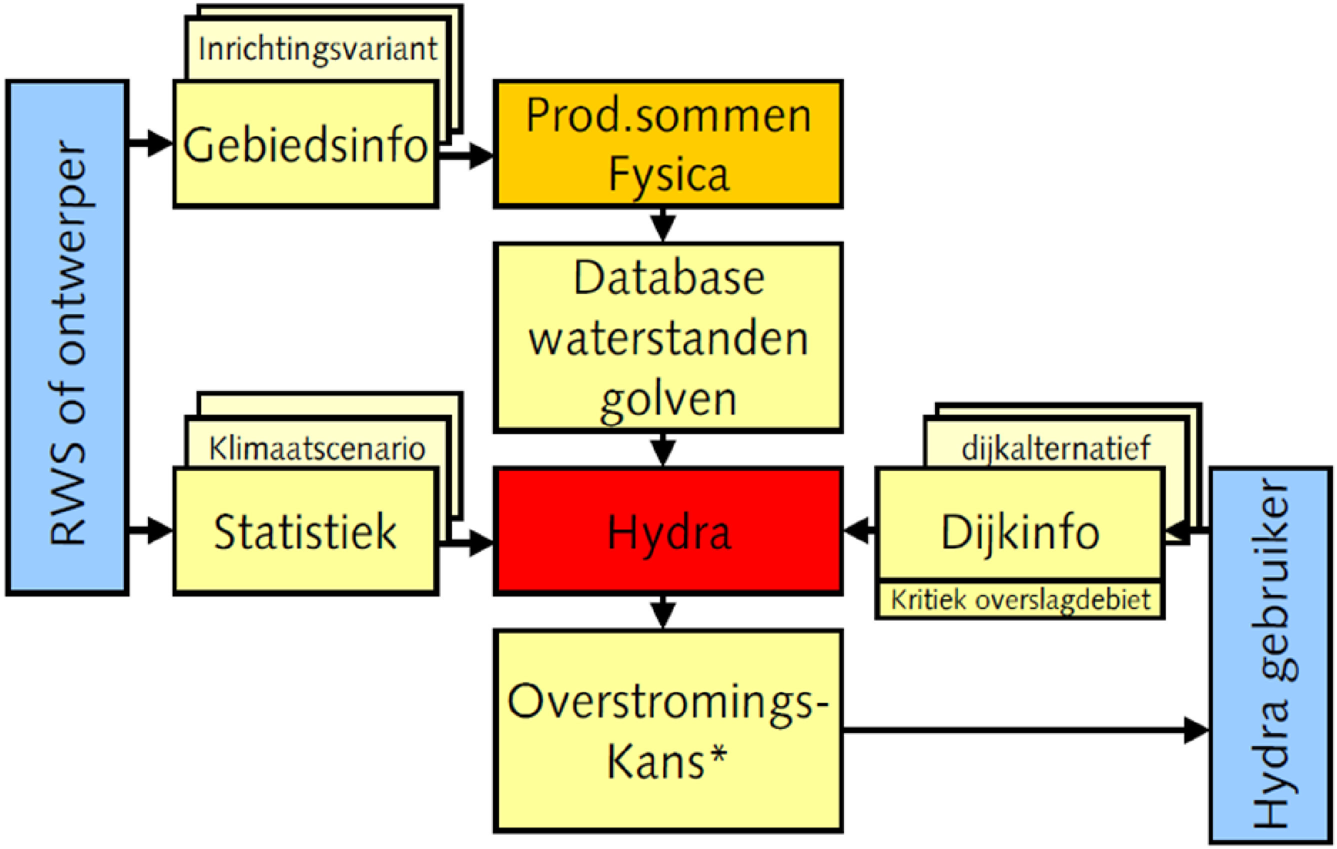
Testing and Design → Resistance (R) vs. Hydraulic Loads (S)

- Hydraulic loads (S) are due to waterlevel and waves influenced by wind (eg S is an overtopping discharge Q in l/m/s);
- Resistance (R) is to piping, macrostability, revetments etc (eg R is a critical overtopping dicharge).
- Failure occurs for a failure mechanism when S > R (prob. approach given the norm).
- In a semi-probabilistic approach use is made of (calibrated) “calculation values” S_d and R_d . Failure is for $S_d > R_d$

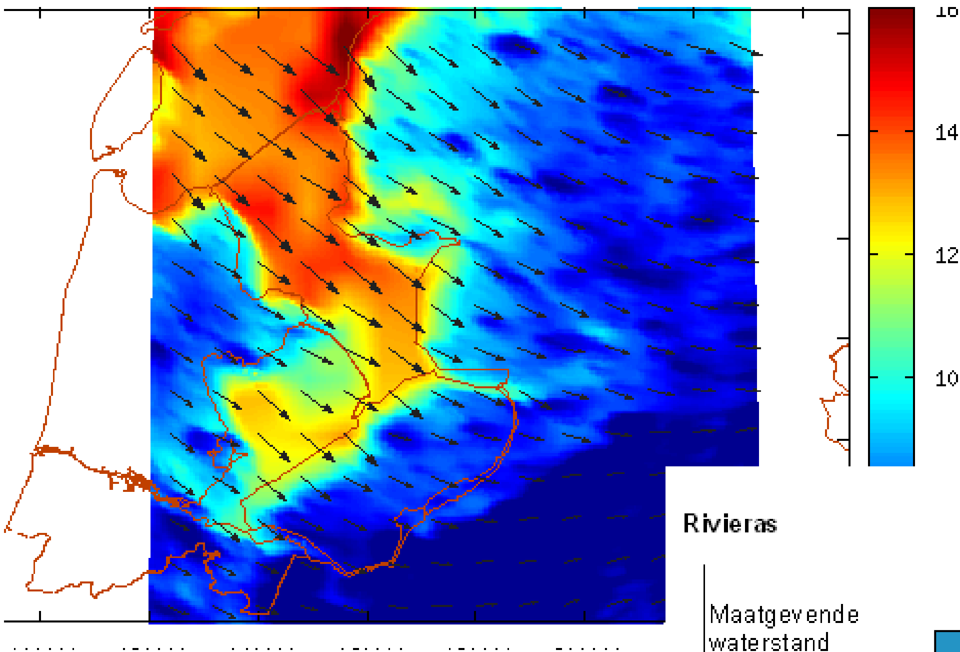


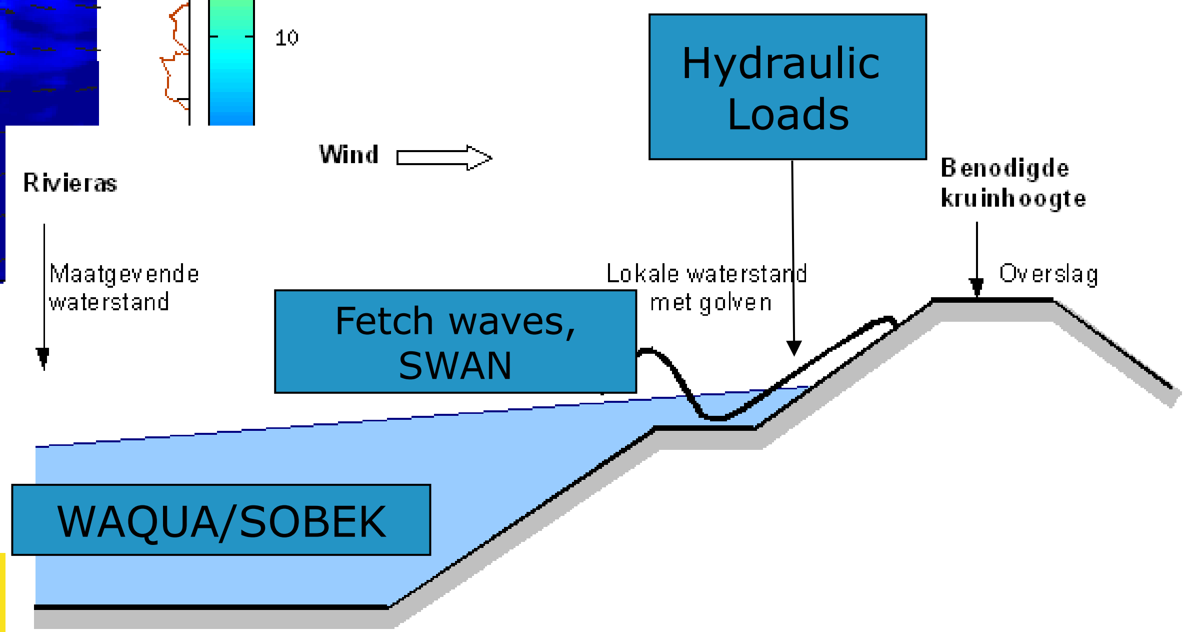
Probabilistic calculation of Hydraulic Loads with the Hydra software

- Combination of physics, statistics and dike profiles in a probabilistic tool



Physics: highest water levels (tide/lake level/river peak and wind setup), waves





3. Uncertainty supplements for loads

- Statistical- and modelling uncertainties in water levels;
- Statistical- and modelling uncertainties in wave parameters.

These uncertainties are <u>time-independent</u>;

- "S_d" for loads has a supplement for uncertainties in the loads;

- Example: Coast +20-40cm on water level and +10% on wave parameters (H_{m0}, $T_{m-1,0}$)

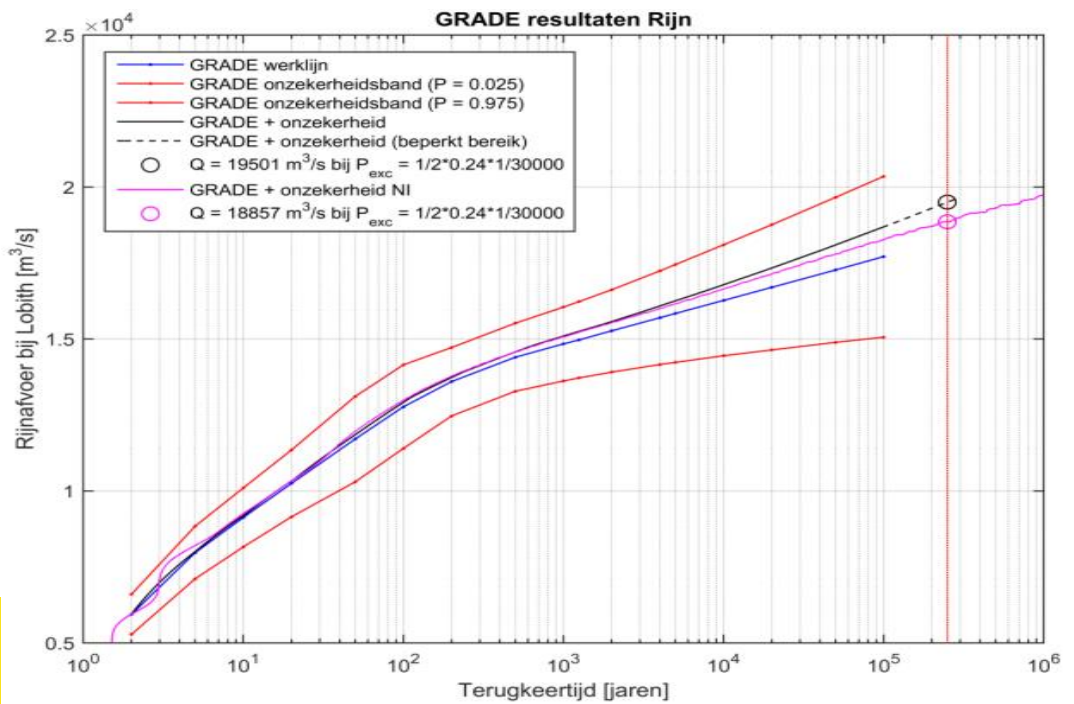
- This gives a dike supplement of approx. 1 m to retain the critical overtopping rate Q_{kr} (depending on dike profile etc.).

Uncertainty supplement follows from integration of uncertainty distributions

- Example for river discharges Rhine River:

blue upper line is the integrated expectation value of the river discharge with the supplement

- Supplement ~ 0,5σ
- Depends on return period or norm



Time dependent components of hydraulic loads

1. Climate change: increase of river discharges (eg Rhine and Meuse) and Sea Level Rise **without any uncertainty**.
2. Soil subsidence of dikes (especially due to peat > climate change): little uncertainty, is monitored;
3. Anthropogenic measures like Room for Rivers project, regulation of river flows with barriers etc. Large uncertainty on a longer time scale.

- These factors are dealt with in the OI
- However, their uncertainties are not addressed in OI

4. Can climate uncertainties be used in dike design?

Social uncertainties

Design solutions

Climate Uncertainties
(KNMI, Deltares)

?

LCC, social impact, policy making

MinIenM commissioned a Pilot to study climate uncertainties for Sea Level Rise (2016-2017)

1. KNMI makes probability density functions (PDF) for SLR;
2. Deltares studies influence of PDF on dike design;
3. Deltares and Waterboard perform LCC

2017: Rijnen from TU Delft has recently finished his Thesis on step 1+2+3

Notice

- For rivers this is different and more complicated (2017-?)

Uncertainties in hydraulics loads for dike design

- Statistical and modelling uncertainties that do not change during the life-span :

These uncertainties are accounted for in dike testing WBI and dike design Tool OI (by integration)

- Uncertainties that change during the life-span:

Uncertainties in climate change (SLR or 10-dat periods of rainfall) **change during the life-span**.

These uncertainties are not incorporated in OI.

- Note: these uncertainties may interact! (rivers)

Climate uncertainties Sea Level Rise (SLR)

P(SLR,t) = P(RCP)*P(SLR,t|RCP)

1) P(RCP): Uncertainty in scenario's: complex and complicated since it contains a political component (eg Paris convention??).
2) P(SLR,t|RCP): Uncertainty in SLR given the RCP => recent analysis by KNMI (Le Bars et al. 15/9/16), including the dynamics of melting of the Antartic Ice Sheet given RCP4.5 (average CO_2 emission) and RCP8.5 (high CO_2 emission)

- RWS is interested in uncertainty ranges

1) P(RCP): probability of CO2 scenario

- Avoid political choices now!
- Perform a sensitivity analysis for P(RCP4.5) =1.0; P(RCP8.5) =1.0; and a combined P(RCP)
- (*Example Koen Rijnen, TU Delft*)

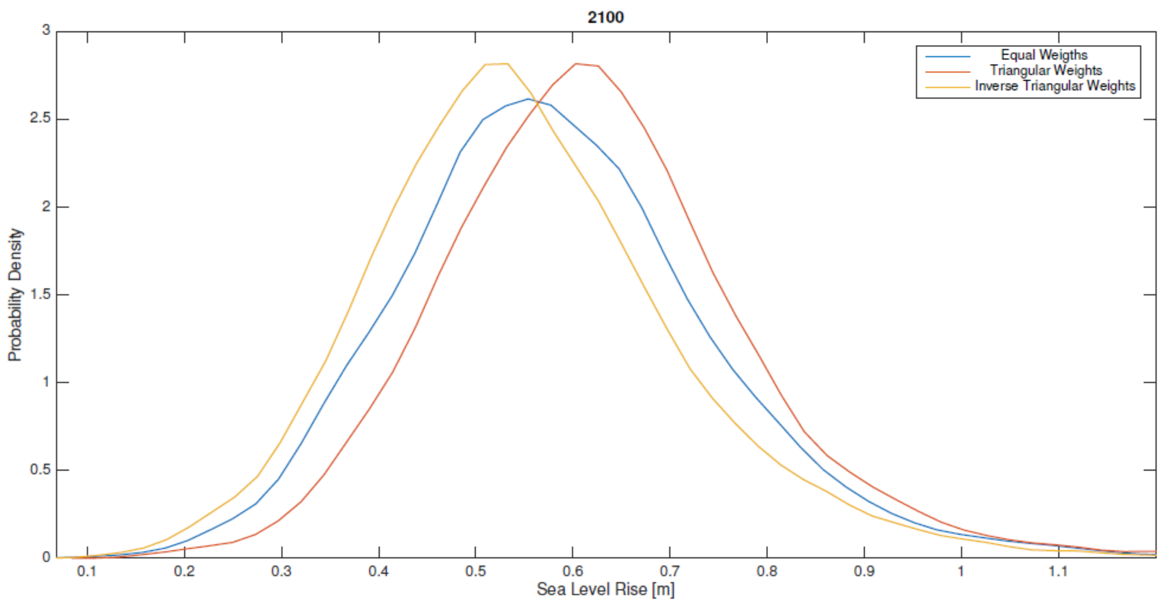


Figure 3.15: The probability density function of SLR for each combined scenario in the year 2100.

2) P(SLR,t|RCP): Input from KNMI (dr. D. LeBars, prof. S. Drijfhout, prof.B. van den Hurk)

- Uncertainties in modelling SLR are influenced by dynamics of melting of the Antartic Ice Sheet (How fast does it melt?).
- IPCC does not take this into account (AR5)
- RWS: What does it imply for design of large storm surge barriers, dams and constructions on the long term?

KNMI The Netherlands; Le Bars et al.: Climate uncertainty (PDF) conditional on a CO2 emission scenario (RCP): P(ZSS,t|RCP)

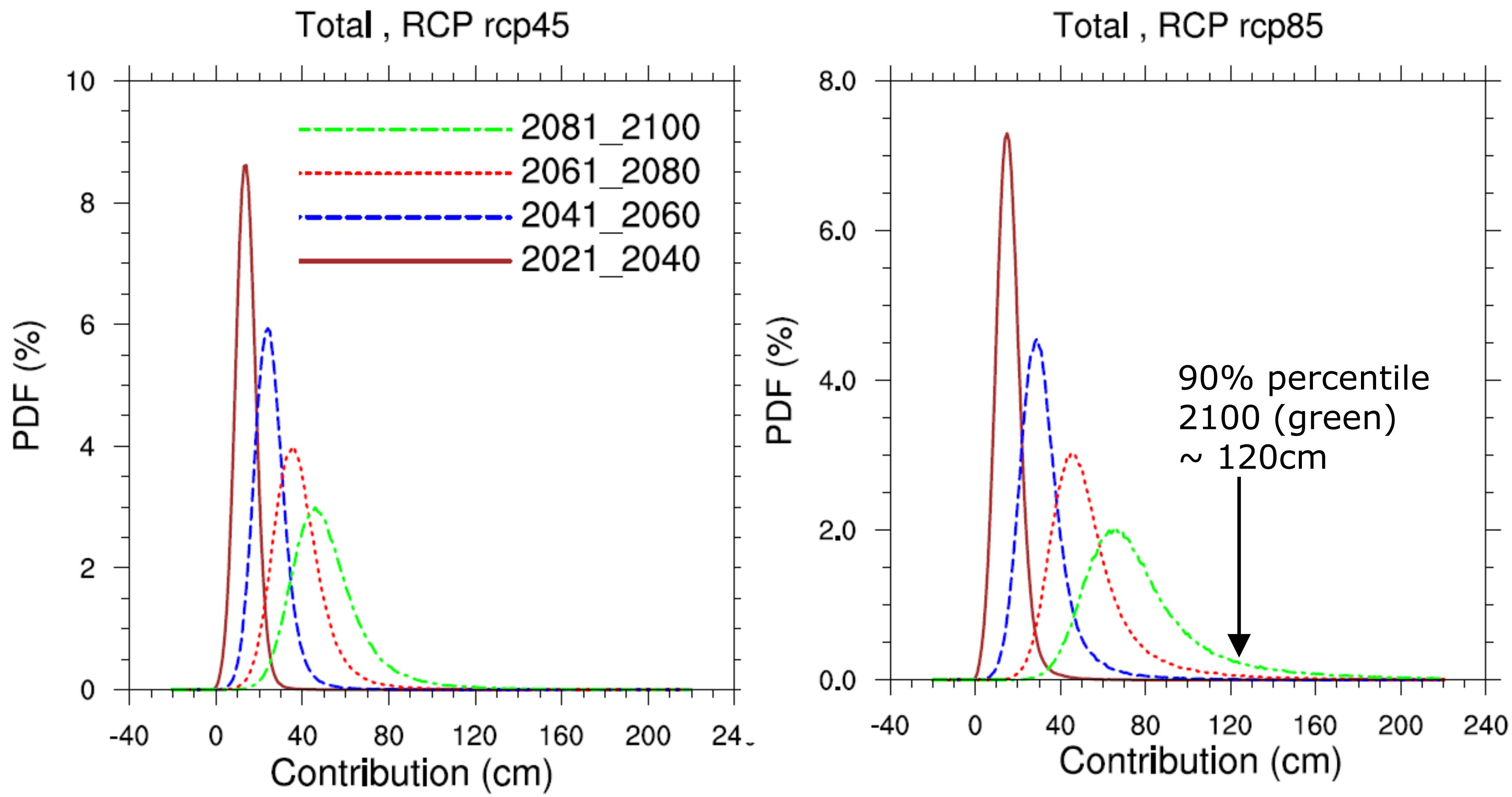
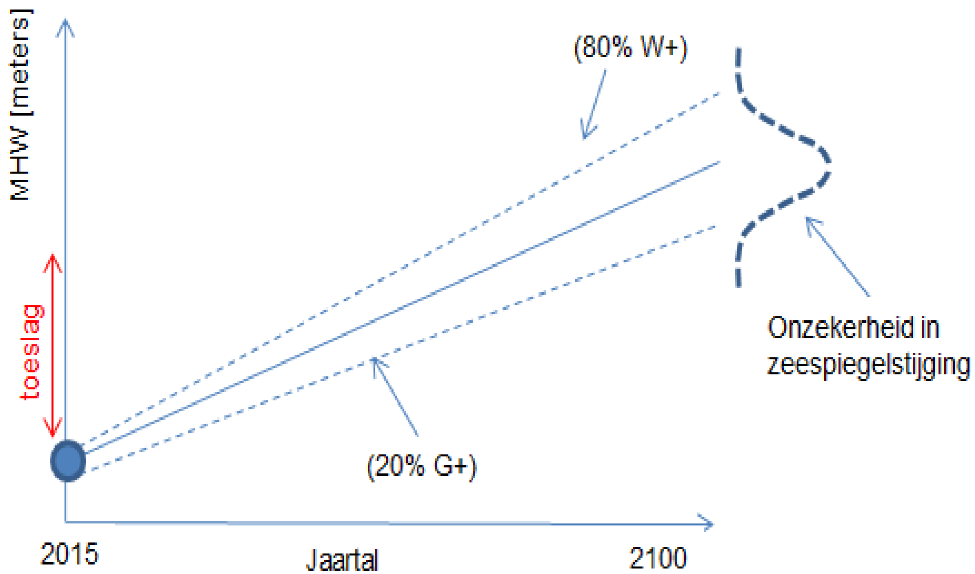


Figure 1: Comparison of total sea level along the Dutch coast for RCP4.5 (left) and RCP8.5 (right) scenarios. **D. Le Bars et al. KNMI The Netherlands. 15 /9/ 2016**

Termijn

Time characteristics Sea Level Rise Coast

- Zero uncertainty for next year
- Increasing uncertainty for higher life spans of dike design
- 30 years of data required for new insights: then we can establish new SLR-scenario's



Figuur 3.1 Ontwikkeling MHW gedurende de levensduur als gevolg van zeespiegelstijging en onzekerheid in deze zeespiegelstijging.

Time characteristics River discharges

- Different from coast since uncertainty can not be discriminated from statistical uncertainty (extreme discharges occur 1:300-100.000 years);
- New climate observations probably add little information;
- Uncertainty might be “nearly” constant in time.

Options to take climate uncertainty into account

A. Integration of expectation value over the PDF (rivers?);
B. Define a confidence level (eg 10%) that must be met during the life span. Confidence level and PDF together determine the life span (seas?)

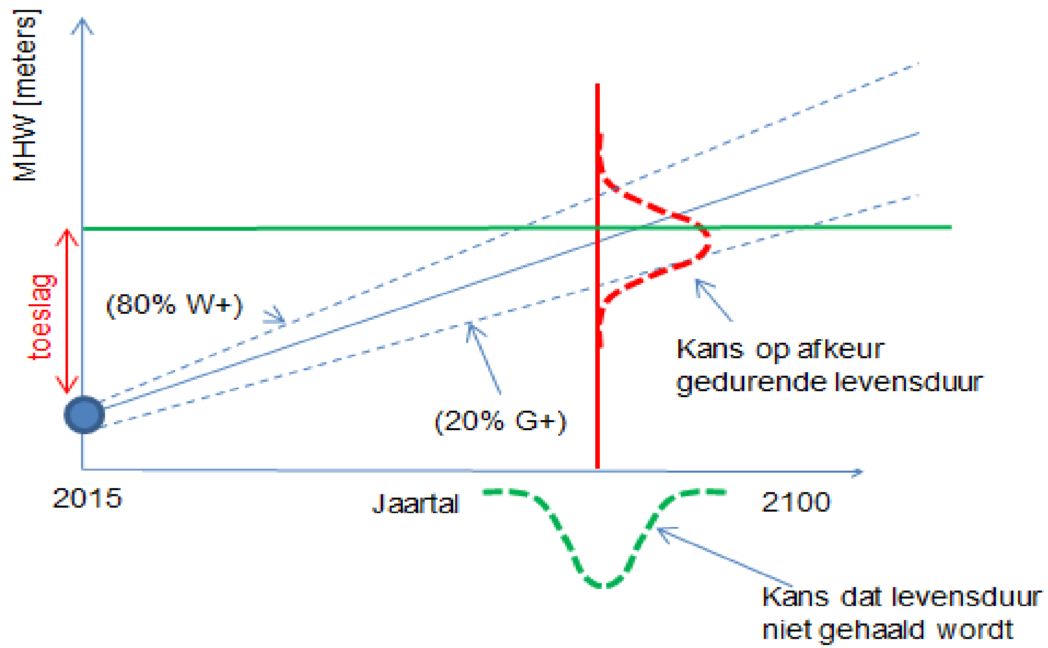
- Both options can be combined with LCC or MKBA approach, and with adaptive pathways (smaller steps in order to incorporate important social tipping points like demolishment of houses).

Option A: Integration of climate uncertainties (rivers)

- Integration will most likely lower the river discharge increments due to climate change that we apply today;

- This is because it is unlikely that the standard increment due to modelling uncertainty and statistical noise and the increment due to climate uncertainty will all coincide (this is assumed now in the present approach for climate and other uncertainties)

Option B: A demand on life span and percentage of not surviving the life span (Seas)



Figuur 3.2 *Ontwikkeling MHW gedurende de levensduur als gevolg van zeespiegelstijging en onzekerheid in deze zeespiegelstijging, nu inclusief kansverdeling van deel levensduur*

Option B: MKBA results by Koen Rijnen (Master Thesis, TU Delft) for KNMI’06 scenario’s

- MKBA leads to much lower Dike height for W-scenario and stable results for G-scenario.

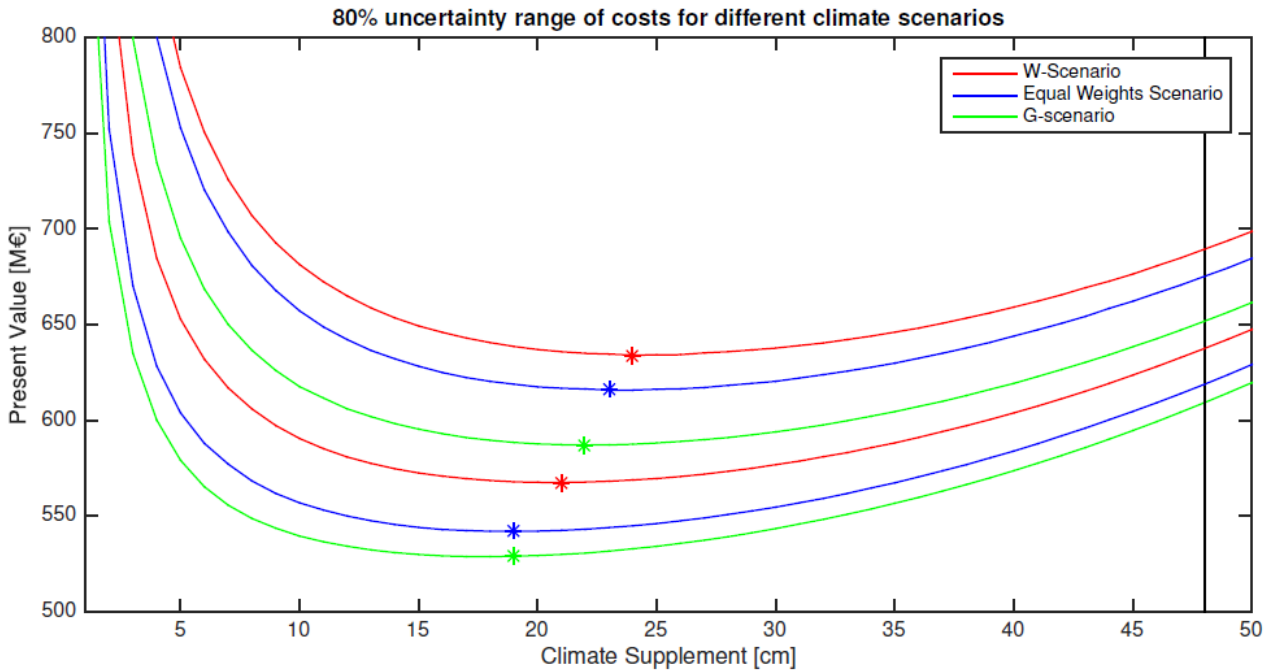


Figure 8.2: 80% uncertainty ranges of total costs for multiple climate supplements for the G-scenario (green lines), Equal Weights Scenario (blue lines) and the uncertainty given the W-scenario (red lines). The vertical black line indicates the current design practice, which proposes a 48 cm climate supplement. The economically optimal climate supplements are much smaller than the current design practice. The 80% lifetime uncertainty range related to these climate supplements can be found in figure 8.1

However

- Figure shows 2 problems:

- Optimized life span in MKBA is much shorter than default choice of 50 years
- Climate scenario W might be to conservative;

Most probably the figure shows problem 1 and not 2 (to be investigated)

5. Follow up

- Look at methodology for Sea Level Rise in more detail (Deltares)
- Think about a pilot with a water board to test the LCC and practical difficulties (tipping points)
- Synthesis for a simple approach, preferably a rule of thumb
- Future: analysis for riverdischarges

6. Thesis

- It is useful to develop a rational basis for climate uncertainties, even when it is uncertain what our future will be with respect to CO_2 emissions.