DEVELOPMENT OF FLOOD RISK REDUCTION INVESTMENT STRATEGIES THROUGH GLOBAL FLOOD RISK TOOL AND APPLICATION OF ADAPTATION PATHWAYS

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INTRODUCTION

Flooding is an issue of growing concern worldwide. Cities around the world are threatened by sea level rise, land subsidence as well as extreme river discharges and intensified precipitation during short periods of time. The interaction of these phenomena potentially causes severe flood problems. In addition, cities are often densely populated centres with high socio-economic development and sophisticated networks of water-related infrastructure. Hence, the impact and damage of flooding can be significant and very costly. In addition to climate change and socio-economic growth, many cities are sinking as a result of land subsidence.

In response to these issues, Royal HaskoningDHV has been developing the Global Flood Risk Tool (GFRT). The GRFT is Royal HaskoningDHV's cloud-based platform that delivers accurate and comprehensible flood risk analysis and recommends strategic investment proposals to reduce risk on losing lives and economic damages to the society, infrastructure, industries and businesses.
The Global Flood Risk Tool has been thoroughly tested and successfully applied in project all over the world. Clients who are currently using the tool are port authorities (Port of Rotterdam), government agencies (Invest NL and Dutch Governmental Real Estate Agency), private industries, insurers, and international financial institutes (World Bank, ADB).

FLOOD RISK ASSESSMENT

GFRT conducts a thorough flood risk assessment and greatly contributes to subsequent adaptation planning through pathways development by delivering a set of customized adaptation solutions if the identified flood risk is considered significant. These adaptation pathways are being tested on effectiveness and evaluated using certain selection criteria (MCDA) to arrive at the preferred adaptation pathways for implementation The tool can be applied on either coastal, fluvial or pluvial flood risk assessments. The output is generated instantly, for multiple scenarios, with large extent of upto160 million grid cells e.g.: 20x20km at 5m resolution or 40x40km at 10m resolution. GFRT is currently being applied on the Southeast coast Climate change adaptation project in Singapore for the Public Utilities Board (PUB). Through a fictive case, GFRT's application is explained and demonstrated to show its performance and functionality.

USP'S OF GFRT

- Interactive, visually attractive, geospatially distributed flood risk, and understandable user interface for non-experts;
- Enables informed decision-making for increasing flood resilience and business case modelling;
- A cloud-based platform with supercomputer power and parallel computing performance;
- Output is generated instantly: has been used to stimulate stakeholder dialogue during real life sessions.

5-STEP APPROACH OF GFRT

With the GFRT, a thorough flood risk analysis can be conducted through a 5-step approach providing a set of customized flood risk reduction strategies formulated in close consultation with the stakeholders. The five steps are as follows:

- Calculation and visualization flood hazard, providing flood maps for multiple return periods based on existing hydraulic models, or series of water levels;
- Calculation and visualization of geospatial distributed economic damage, providing economic damage maps per return period and damage graph based on land uses in a given area;
- Calculation and visualization of flood risk: risk maps and risk graphs with present value of the risk;
- Developing conceptual flood measures, information on investment costs for various safety levels and averted damages they deliver;
- Adaptation pathway modelling to arrive at preferred alternative supported by qualitative multi-criteria analysis (MCA), cost-benefit analysis (CBA) and sensitivity tests.

TECHNICAL BACKGROUND GFRT

The online tool is being developed by a team comprising experts with geospatial, software development and flood risk expertise. The tool is written in the Kotlin language, utilizes open-source tools like GeoTools, GeoServer and Leaflet, and calculates its computations on a scalable Kubernetes cluster running in the cloud on Microsoft Azure. Mapbox is being used to visualize the calculated data on online maps for interactive usage. The GFRT is used as an online digital shell with a visually attractive and user-friendly user interface in which the hazard assessments, damage curves, exposure data, vulnerability data and costs for interventions are being combined, see Figure 1.

Figure 1 - GFRT's online user interface demonstrating the Europoort case, a flood risk assessment that was conducted for the Port of Rotterdam

APLICATION OF GFRT

The GFRT assesses the potential adverse consequences through calculation of economic damages for multiple probabilities of flood events and number of climate scenarios results. Economic damage can be calculated by projecting the inundation depth on the exposure (land use with economic land values of the area of interest) with its vulnerabilities (through vulnerability/damage functions). Flood risk is then, the combination of the probability of flood events and of the potential adverse consequences for land uses and its economic activity associated with a flood event in an urban environment. Thus, Risk = hazard x exposure x vulnerability. An example of a hazard map, land use map and damage map developed for the Port of Rotterdam in the Netherlands is shown in Figure 2.

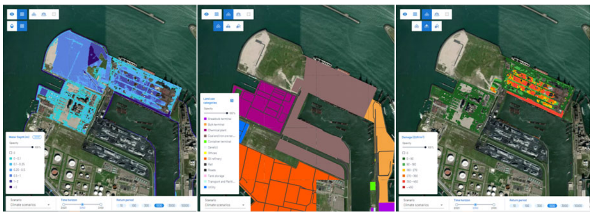

Figure 2 - Example of the Global Flood Risk Tool applied in the Port of Rotterdam

When applying preventive measures, the risk reduction per year can be calculated. This risk reduction can be translated into benefits which are discounted for the lifetime of the measure. The life cycle costs are determined based on unit rates for reference projects multiplied with the length or volume of its application. The offset between the present value benefits and life cycle costs is the net present value of a measures. By comparing multiple options for measures the most effective measures can be found through MCA and CBA.

ADAPTATION PATHWAY MODELLING

Besides looking into the most effective measure for the present day, an assessment needs to be made if this measure is also the most effective measure under future unknown circumstances like different scenarios for sea level rise or subsidence rate. Therefore, it is of great interest what the most effective consecutive measures could be considering these uncertain future effects. The way to do this is by developing adaptation pathways and applying an associated planning method (Haasnoot, et al., 2013), see Figure 3.

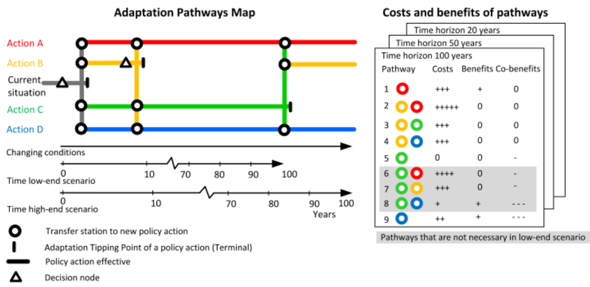

Figure 3 - Adaptation pathway maps (source: Deltares)

A framework has been developed that automatically develops adaptation pathways for a predefined set of measures, i.e.: levee system, flood wall, deployable flood wall, landfill, dryproofing, elevation and storm surge barrier. In total 45 combination of measures are being assessed within the framework with a maximum of three consecutive measures in time. The framework can carry out automated sensitivity tests on predefined parameters and a probabilistic assessment on the uncertainties (Trommelen, 2022). The framework is directly linked to the outputs of the GFRT.

FICTIVE CASE

A fictive case has been developed to demonstrate the application of the framework in combination with the GFRT outputs. It considers a flat area of 100x50m in the coastal zone (Trommelen, 2022). In the current situation flood protection is already required and will be required more because of future sea level rise. Three example pathways that have been generated by the framework are presented in Figure 4. The preferred pathway includes a landfill in 2023 and a consecutive floodwall in 2143. The Net Present Value of this adaptation pathway until 2200 is €3.6 million, B/C ratio of 25.0 and total investment of 150k€ as shown in Table 1 (together with the other two example pathways).

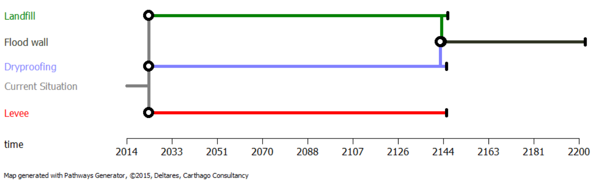

Figure 4 - Schematization of example three different pathways

Table 1. Results of example three different pathways

Adaptation pathway	End date	Investment [k€]	NPV [€]	B/C-ratio [-]
Land fill + Floodwall	2200	150	3.6	25.0
Dryproofing + flood wall	2200	180	3.6	20.7
Levee	2143	1150	1.9	2.7

Figure 5 gives a clear insight when measures need to be implemented to make sure that the required safety level is met. A first incremental build is needed directly that would provide lasting flood safety until 2143. Then a consecutive measure is needed to make sure the area is protected until 2200. Next to that it recommends the most cost-effective safety level (10,000 years) for the implementation.

Figure 5 - Representation of the pathway in time with the objective to stay above the required safety level at all times

Sensitivity tests

Sensitivity tests have been done on the preferred pathway to be able to analysis its behavior under different circumstances. The following tests have been performed:

- change climate change scenario from SSP3-7.0 (max. 0.6m in 2100) to SSP5-8.5 (max. 1.1m in 2100);
- decrease net discount rate by 1%;
- increase the inflation rate increase from 1% to 8%.

By changing the climate change scenario from SSP3-7.0 to SSP5-8.5 the maximum sea level rise in 2100 increases from 0.6 to 1.1m. Figure 6 shows how the pathway changes over time. Because of the higher acceleration of the sea level rise it is advised to have the incremental build at a higher safety level. The increment measure will last less long; therefore, a consecutive measure is already required in 2110 and again at similar, higher safety level.

Figure 6 - Pathway under increased sea level rise

Figure 7 shows that lowering the net discount rate by 1% results in a recommendation for a higher safety standard for the incremental build that therefore will last longer, and as a result a consecutive measure is no longer required.

Figure 7 - Pathway under lower net discount rate

Figure 8 shows the effect on the pathway by applying a higher inflation of 8% instead of 1%. It shows that the recommendation is to implement the incremental build at a lower safety level and therefore there is a need to do a consecutive measure sooner (2080) but this measure then only lasts until 2140.

Figure 8 - Pathway under higher inflation rate

Probabilistic assessment

A probabilistic assessment has been performed to assess the robustness of the preferred adaptation pathway. The Log-normal distribution of the costs has been changed by factor 10 and the Coefficient of Variation of the discount rate, inflation rate and socio-economic growth rate has been changed from 0.1 to 0.2 to represent a low and high uncertainty respectively. With the high uncertainty the most likely NPV decreases, and the spread is greater.

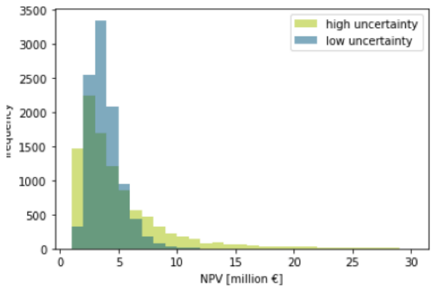

Figure 9 - NPV for 10000 simulations with high and low uncertainty band

CONCLUSIONS

The set-up of GFRT is designed such that it is very user friendly. The approach results in a transparent reasoning towards the proposed climate adaptation measures and pathways, taking into account future uncertainty and provides solid adaptation pathways. The sensitivity test provides good insights in behavior of preferred adaptation under different condition and its robustness is assessed through a probabilistic assessment.

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