Robust monitoring

- 2009.02.02.2: Scaling perspective for a dike monitoring system

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Document Management

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Management summary

This document is the final deliverable of the “2009.02.02.2 Scaling perspectieve for a dike monitoring system” (2009.02.02.2 Opschalings perspectief voor dijkmonitoring system) activity within the Robust Monitoring project in the Flood Control 2015 tranch 2009 project plan.

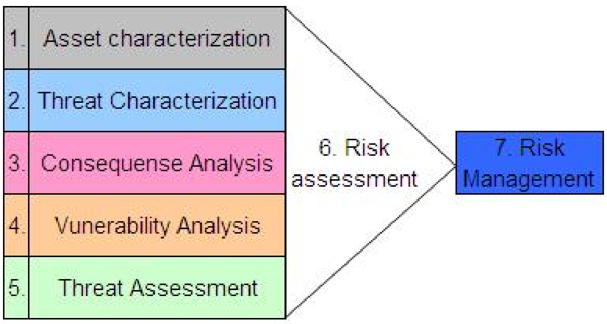
Where the other documents from this project describe what a Flood Control System (FCS) can do, what it measures and what is would look like, this document elaborates on the research that is done to investigate the scaling perspective for a dike monitoring system from a financial perspective.

This documents deals with the different stakeholders and their involvement with a FCS, the parameters influencing the severity of a flood and the consequences a flood has on the economy in first order and second order effects. This is done by making an inventory of the Risk of flooding by means of the RAMCAP framework.

The RAMCAP framework was originally developed in dealing with the risk from terroristic threats, but proved very useful in structuring the threat of a flood as well.

Investing in a FCS is meaningful if it lowers the risk of flooding and/or minimizes the consequences once a flood is actually occurring to a level that outweighs the initial expenses. Therefore, the business case for FCS is centered around risk, and the RAMCAP framework is a valuable tool for understanding the effects of FCS on risk.

The RAMCAP framework addresses the risk in seven steps.



RAMCAP framework for Risk Management

Step one deals with the assets that are under threat (from flooding). Assets include animate ´assets´ such as humans, and animals who can be injured or die and inanimate assets such as real estate, inventory and data which can be lost or damaged.

Step two concentrates on the characterization of the threat of flooding which is influenced by parameters such as the height, duration and speed of the flood water and the robustness and resilience of the assets flooded and lastly also the prediction term and the resources available to mitigate flood damage.

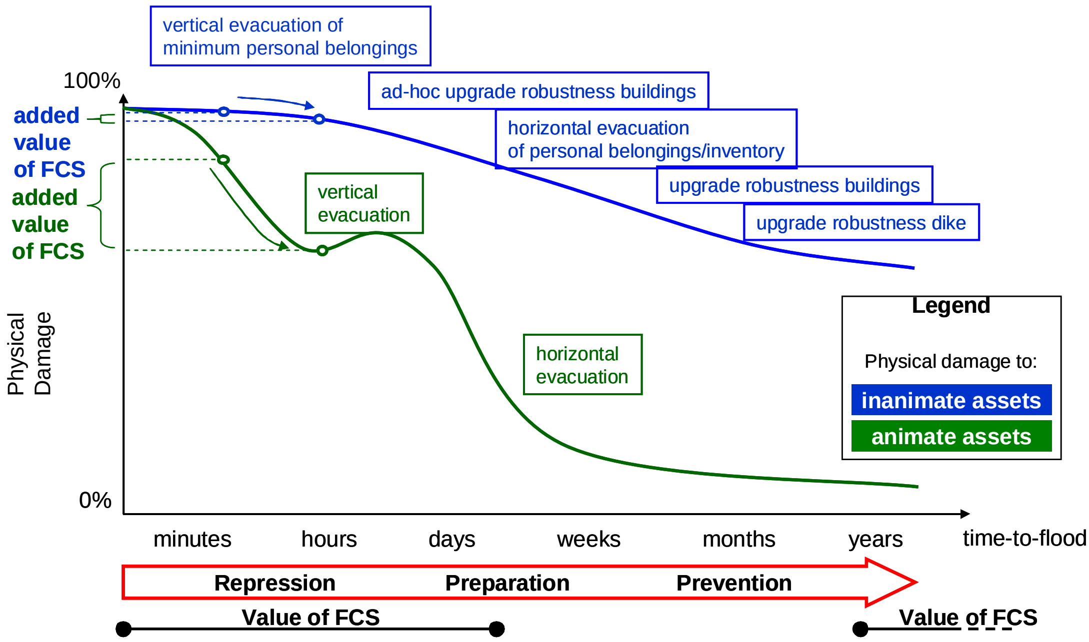
Step three inventories the consequences of flooding by qualifying and quantifying different types of costs for flooded areas.

The analysis of the vulnerability in step four concludes that in the current situation in the Netherlands the best chance of decreasing the vulnerability is for the FCS to decrease the chance of a dike failure by allowing resources to be used to upgrade weak spots before they lead to failure, or to decrease the effects of failure by allowing assets to be better prepared because of an early warning of imminent dike failure.

The threat assessment in step five shows that a dike system surrounding vulnerable assets is a single point of failure which is subject to forces by nature that will exploit any and every weak spot in the defenses. This allows for even less errors in these defenses.

Step six demonstrates that the risk as a function of consequence multiplied by likelihood can be calculated. This allows for a quantification of the benefit of using a FCS if the parameters of the increased prediction time and decreased likelihood for dike failure are known.

Although the risk assessment cannot yet be quantified, some sensible risk management observations can be noted.



When looking at the damage that can be prevented by a FCS in the prevention phase compared to the preparation/repression phase, it evident that preventing a dike failure is better than limiting the damage when flooding is imminent. Further experiments will determine what value a FCS can bring in either phase.

In the next phase of developing a FCS, the team working on the business case needs to find out more details and should try to quantify the influencing factors described in this report. If possible, the research should concentrate on a particular dike ring, so the use of the RAMCAP model can be made specific, the choices for certain uses of technology can be made and the benefits will become clearer as it will be known what damage can occur in that dike ring in case of a failing dike.

The conclusions of the analysis are reported in this document and will fuel further discussions with experts and potential users in the next phase. This is therefore not an end-product, but an intermediate step in a process of developing a business case for Dike Monitoring Systems and Flood Control Systems.

1 Introduction

1.1 Introduction

This document is the final deliverable of the “2009.02.02.2 Scaling perspectieve for a dike monitoring system” (2009.02.02.2 Opschalings perspectief voor dijkmonitoring system) activity within the Robust Monitoring project in the Flood Control 2015 tranch 2009 project plan.

This deliverable describes the research that is done to investigate the scaling perspective for a dike monitoring system if it would be rolled out on lager scale; taking it from the current ´laboratory conditions´ of the IJkdijk facility to the real world application of hundreds, perhaps thousands or ten thousands of sensors throughout a country. What factors determine if the benefits of such a system outweigh the costs? from a financial perspective. Or in other words: the business case for a smart levee.

Although the concept robust dike monitoring is still under development (the other three deliverables within this project cope with this subject) this document takes a in place robust dike monitoring system as a starting point.

The context of this study, the goal, the intended audience of this document and the approach taken to come to this document and the structure of the rest of the document are described in this chapter.

1.2 Background and introduction to FC2015

The Flood Control 2015 foundation was founded to make innovations possible in dealing with (potential) flooding. The participating members of FC2015 are listed in Figure 1-1 below.

Figure 1-1 Members of the Flood Control 2015 foundation

The focus of the program is on the preparation and repression phase of flood control. In 2009, the following 12 projects were initiated, focusing on different topics in the flood control domain:

2009.01 Serious Gaming
2009.02 Robuust Monitoren
2009.03 IJkdijk experiment piping
2009.04 Snelle satellietkartering van overstromingen
2009.05 Operationele dijksterkte voorspelling
2009.06 Kwantificeren en reduceren van onzekerheden
2009.07 Mogelijke maatregelen en risico-gestuurd beslissen bij hoogwater

2009.08	Multi-party besluitvorming
2009.09	SUCCESS Groot Salland – fase 2
2009.10	Menselijk gedrag in crisissituaties II: zelfredzaamheid
2009.11	Demonstrator Flood Control Room
2009.12	Remote Sensing voor dijksterkte

The project Robust Monitoring has logical relations with those projects that result in measures that have an impact on the organization, the processes, the information, applications and infrastructure used. These relationships are for the current PoC phase less important, as there is no training environment yet. In the future, when such a training environment is operational, changes in the organization, processes, information, applications and infrastructure can be safely tested in the virtual environment, before introducing them in the real world.

1.3 Goal of document

The goal of this document is to define the playing field of a Flood Control System (FCS) from a financial perspective. In this document both sides of costs and benefits are elaborated on. Although this study into the financial side of a FCS is by far not exhaustive, it provides a first draft of a document which can be discussed with various experts in the field, such as government officials, insurance companies, crisis managers, representatives from industry, etc.

This is therefore not an end-product, but an intermediate step in a process of developing a business case for Dike Monitoring Systems and Flood Control Systems. The Monster Case project (the follow up of the robust monitoring project in 2010) will continue with the findings of this document and put more detail to the business case.

1.4 Audience

This document is initially intended for representatives from water boards and national governments who want more than a technical view of Flood Control Systems. Other interested people can be other FC2015 projects and the FC2015 board as this financial view may also be a basis for similar discussions in other projects.

A third group of people to share this document with is the people needed to give more detail to the business case in the next project (Monster Case 2010). For them this document will explain the way of thinking in the project and be a starting point for further discussion to validate and enhance the content and allow for a more detailed business case in the next project. Stakeholders are (influencers of) decision makers interested in RM solutions, technology developers with solutions for Dike Monitoring Systems and flood control experts.

1.5 What is a business case

A business case is a description of Service, Technological, Organisational and Financial arrangements on which the viability of an innovative service concept can be determined.

The components used in the business case will come from using the RAMCAP framework which is discussed in chapter 2.
In the business case track we will determine the linkages between the technological, service and organisational components (from tracks 0.1 – 0.7), add to these components when necessary, and using this input complete a financial analysis of the business viability of robust monitoring and flood control systems.

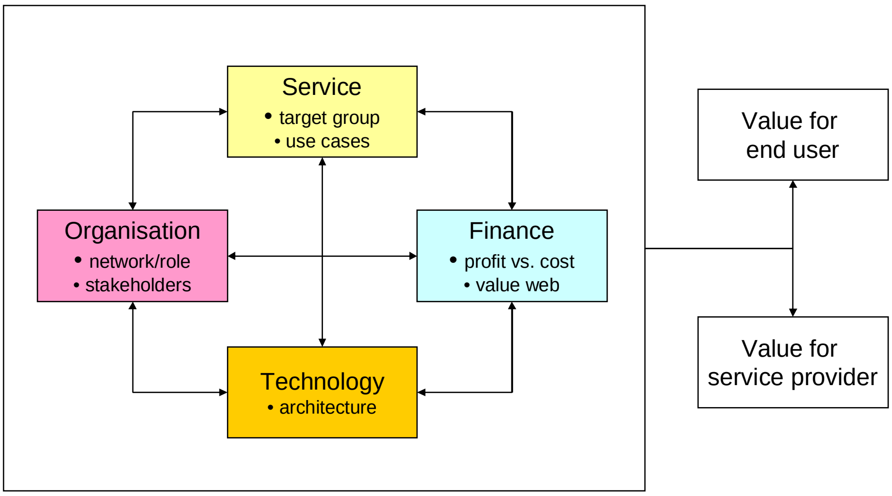


Figure 1-2, Used model for describing a business case

1.6 Why investigate the business case for FCS?

Even though flood control systems serve a public interest, decision makers will want to weigh several alternatives, and judge on both qualitative and quantitative aspects whether they will invest in flood control systems. Analysing the rational of a FCS will also give insights into the question whether the technical possibilities of employing a FCS are sensible from a societal point of view.

A business case also serves as a measure to determine the value of the flood control current line of thinking. A business case can help steer technology into the right direction, and facilitate decision making on project-decisions.

1.7 Approach

The approach towards this study was to answer the question: “demonstrate the insights of the ´business viability´ of the application of Robust Monitoring and Flood Control Systems”. This was done by executing the following steps: hypothesising possible benefits and associated costs and discussing these insights with experts and potential users of a FCS. The validated insights were further developed by desk research and analysis of the material found.

The conclusions of the analysis are reported in this document and will fuel further discussions with experts and potential users in the next phase.

1.8 System Context

The System Context identifies the main stakeholders, the parameters that influence the severity of the consequences of a flood. The system context provides the relevant aspects of the system that are dealt with in the RAMCAP framework.

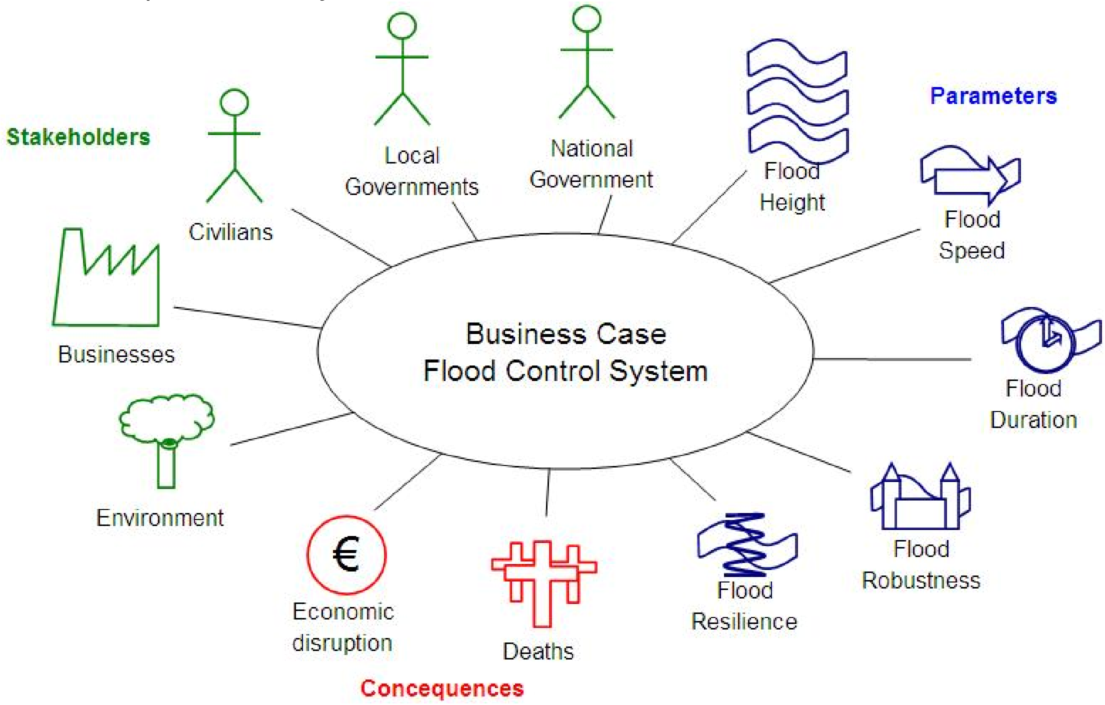


Figure 1-3 gives an idea of the playing field that is used in this document.

Figure 1-3, System Context for the business case

1.9 Document structure

This document is built up of four chapters. Chapter one provides the readers with an overview and sets the scene for the rest of the document. Chapter two introduces the RAMCAP framework. This framework is used to structure the elements that lead to the calculation of the risk of flooding. Chapter three describes the elements that make up the business case. The final chapter, chapter four, gives the main conclusions of this phase of the research into the business case of a Flood Control System-

2 RAMCAP Framework for the economics of flooding

The RAMCAP[1] framework was created to increase awareness of security threats to critical infrastructure in the United States. Although this framework is geared towards terrorist attacks, the basic framework provides a sound approach towards understanding the impact of a flood on the critical infrastructure of a country. By using the RAMCAP[tm] framework a logical link can be made between the impact of a Robust Monitoring system and the value such a system has for a society as a whole.

First the framework will be elaborated on. This is followed by seven sections giving more details on each of the process steps of the framework. These steps are used to structure and scope the elements for the business case in the rest of the document.

2.1 The framework

The framework consists of seven steps from the characterization of assets in step one, to the management of risk in step seven. An overview of the steps and the essential considerations for each step is shown in Figure 2-1.

Process Step	Essential Considerations
Step 1: Asset characterization	Asset identification Assessment of potential severity of consequences Consequence based screening
Step 2: Threat Characterization	Target determination Adversary characterization:Capabilities; Tactics; Weapons
Step 3: Consequense Analysis	Potenatial damage for each threat Worst reasonable case consequences
Step 4: Vunerability Analysis	Identify vulnerabilities leading to worst case reasonable consequences Assessment of likelyhood of adversary success in achieving worst reasonable consequences evaluate existing countermeasures & mitigation capability
Step 5: Threat Assessment	Assess attractiveness and deterrence (asset owner) Adversary capability and intent determination Threat (likelyhood of attack) as function of attractiveness and adversary capability and intent
Step 6: Risk assessment	Consequence from step 3; Vulnerability from step 4; Threat from step 5 Risk = C * V * T
Step 7: Risk Management	Consider risk goals and determine need for recommendations Determine recommendations Evaluate options and decide on enhancements

Figure 2-1, RAMCAP framework

[1] Source: https://www.navi-online.nl/services/Proxy/kennisbank/id/56

2.2 Step 1: Asset Characterization

The RAMCAP frameworks first step is to analyze the assets within the designated area. In the case of a Flood Control System (FCS), this area is the area that can potentially be equipped with a Robust Monitoring Solution (RMS). This area of scrutiny can be a single dike ring, a set of dike rings with a high degree of interconnectedness (i.e. several rings on the same river or sea coast), an area defined by national borders (i.e. the Netherlands) or an area extended beyond national borders (for instance an entire river delta or sea coast).

A RMS affects all assets present within the dike ring in which it is installed. In the RAMCAP methodology, assets are people, buildings, equipment, systems and information. Taking the model away from its military-focused domain, certain types of assets can be added, such as environmental concerns.

For this report, we define assets as “the total of animate and inanimate entities that present value in some way to stakeholders.”

Animate entities are:
- Humans
- Pets
- Livestock
- All other animals living within the area

Inanimate assets are:
- Buildings (houses, offices, hospitals, factories, etc.)
- Land (private or public)
- Infrastructure (roads, railways, power lines, telecommunication networks, sewage systems, etc.)
- Moving property (*roerende goederen*) (personal belongings, cars, food, etc.)
- Economic supplies (mineral reserves, inventory, finished products, manufacturing equipment)
- Information, knowledge (stored in people or in books/devices)

Getting a detailed overview of all assets actually present within a certain area in the Netherlands at a certain time is too complex to actually perform for the scope of this project. However, detailed information on most assets is available within different stakeholders and can be obtained in following projects if desirable and permitted by those stakeholders. Interesting information would amongst others be:
- Number of inhabitants, age distribution etc.
- Number and type of livestock
- Number and economic value of buildings
- Wild animal count
- Etc.

Combining these sources of information, an estimate of the total assets in a certain geographical area at a certain time can be made. With this knowledge it is known what economic value a dike ring is actually protecting. Also, using trend analysis and forecasting methods, an estimate over the future availability of assets within an area can be made.

The second step is to analyse the potential severity of consequences for these assets in case of a flood. Table 2-1 shows some of these consequences for the assets summed up above.

Asset	Potential severity of consequences
Animate	
Humans	Death, injuries
Pets	Death, injuries
Live-stock	Death, injuries, permanent loss of breeding line (live-stock is generally considered to be more than just an economic supply, given its animate nature)
Other animals	Death. Injuries. In case of endangered species permanent loss of biodiversity
Inanimate	
Buildings	Become unusable, reconstruction necessary, occupants must find alternative to fulfil function of building (shelter, production, healthcare, coordination)
Land	Becomes temporary or permanently damaged. Flooding of city or farmland with (non-polluted) river water will result in temporary damage, while flooding of a precious nature reserve with salt or polluted water can permanently destroy a unique ecosystem.
Roads and railroads	Become unusable, reconstruction necessary, cars or trains must use alternative routes or get stranded, goods (including emergency supplies) cannot be delivered.
Infrastructure	Becomes unusable, reconstruction necessary, large areas can be without power, telephony or internet for weeks, alternatives must be placed (e.g. generators, satellite telephony). Even when not struck directly by a flood, communication networks tend to block up due to congestion by heavy traffic in the first hours of a disaster.
Moving property	Become unusable, damaged or temporary non-available. Loss of personal belongings, loss of means of transportation, loss of food supplies
Economic supplies	Become unusable, damaged or temporary non-available. Non-availability of the Groningen Gas supply at Slochteren will have consequences for an area much larger than the area directly affected by the flooding.
Knowledge, information or data	Becomes unusable or temporary non-available (depending on physical damage to either people, physical or digital storages, and the reduncancy of the knowledge, information or data).

Table 2-1, Examples of assets in a protected area, and potential severity of consequences of flooding

From this overview of assets, a ranking can be made with the most important assets to protect. From an ethical viewpoint, loss of human live or injuries is ranked as the highest importance. Prioritizing all assets and consequences is not done, because it is not within the mandate of this research.

2.3 Step 2: Threat Characterization

The second step in the RAMCAP model is an analysis of the threat. From the military context this framework stems from this is usually done in a detailed description of the enemy and his tactics, for use in this report we focus on any event that can lower the integrity of a dike and can be characterized as a threat to the assets protected.

This report mainly focuses on the breach of a levee and consequences thereof. The most common mechanisms for a breach of dike integrity are overtopping, macrostability, micro-stability, instability of levee cover, instability of foreland, piping and heave. Besides these natural mechanisms, the integrity of a dike can also be undermined by acts of man, such as a deliberate attempt to damage a dike (terrorism) or an accident (plane crash).

When the integrity of a dike is breached, and water starts to poor into the area behind the dike ring, several attributes of the flood affect the amount of damage occurred by the assets within the dike ring, such as (but not limited to):

Flood Water Height:	Height of the water in the flooded areas. A 10 cm flood will be very inconvenient; a 6 meter flood will be catastrophic. The flood water height largely depends on the difference between the land height and the height of the surrounding water.
Duration of flood:	The time span between two non flooded moments. A flood of a few hours does less damage to the infrastructure and economy than two months of submerged area.
Speed of water level:	The speed at which water rises around assets. A slow increase in water levels allows for more preparation. A fast rise is dangerous in itself (fast current).

These factors are all dependent on river or sea water levels, weather conditions and so forth, and therefore hardly influenced by human intervention. Factors related to the (both inanimate as well as animate) assets themselves can be influenced by human behaviour. Some of these factors are:

Flood robustness:	The ability of assets to keep its function and withstand flooding. A concrete structure is better able to withstand water in comparison to a TV set. People who know how to swim will have a higher chance of survival.
Flood resilience:	The ability of assets to become operational again after failing. Mechanical equipment can be dried and cleaned and used again, while electric kitchen appliances will probably be damaged beyond repair. People who have stored food and medical supplies will have a higher chance of surviving a long period of flooding than people who haven't.

These factors are on their term influenced by two variables, the time available to take action and the resources available to perform these actions.

Prediction term:	The time span between a warning of an imminent failure of a levee and the moment the water reaches assets. Long prediction terms give time to prepare or remove assets to minimize damage.
Available resources:	The availability of skilled people and adequate materials to perform rescue or mitigation actions affects the outcome of a flood, as well as the availability of financial resources.

All these attributes are interrelated in determining the amount of damage. For example, assets can be made more flood-robust (e.g. by placing sandbags in the door opening of a building). This method works best for a flood with low flood water height, short duration, a long prediction term, low water speed and the availability of sufficient sandbags.

This non exhaustive list of factors determines the severity of a flooding catastrophe. Most of these parameters can be modelled in computer simulations (Flood height, duration, speed of water level increase). Others can be inventoried (flood robustness, flood resilience, availability of resources). Prediction Term is a factor that is heavily dependable on the quality of observations (both from people as from systems) and the forecasting-quality of the used experts and/or mathematical models.

2.4 Step 3: Consequence analysis

In terms of the RAMCAP framework, the direct consequence of a flood is physical damage to animate and inanimate assets. The amount of physical damage these assets sustain is related on the factors determined in step 2, threat analysis. In step 3, the direct or indirect consequence of the physical damage is assessed. Also, a reasonable worst case scenario is determined.

In the Dutch legal system, consequential damage is classified as either material (*vermogensschade*) or psychological (*immateriële schade*). Table 2-2 gives an overview of the type of damage that can occur after a disaster such as a flooding. The table shows the large number of consequential damages related to the initial physical damage to the asset. From this table can be concluded that physical damage has many consequences, both on the material and psychological level, and that these effects can occur long after the initial damage has occurred. This long lasting effect is also visible in the New Orleans flooding disaster, where this area in 2009 is still recovering from the 2005 Katrina hurricane, and in the Zeeland floods of 1954, from which certain people today still suffer the emotional consequences.

	Physical damage to animate asset	Physical damage to inanimate asset
Material damage	Funeral cost Medical cost Rescue cost Expert cost Transport cost Temporary housing cost (also for relatives) Cost of adaptations (prosthetics, housing) Loss of productivity Loss of income (also for relatives)	Repair cost Taxation cost Replacement cost Loss of productivity Loss of income
Psychological damage	Loss of “joy” (*gederfde levensvreugd*) Trauma (*shockschade / affectieschade*)	

Table 2-2, Possible consequential damages relating to physical damage of flooding[2]

Estimations of material damage of a flooding can be made in monetary terms. The physical damage to inanimate assets in dike ring 14 (Zuid-Holland) has been calculated in some detail.[3] The Zuid-Holland dike ring is one of the largest in the Netherlands and has the most economic value behind its dikes. Table 2-3 shows a

2 *Adapted from: CTRC (2004) Solidariteit met beleid, Aanbevelingen over financiële tegemoetkomingen bij rampen en calamiteiten*

3 MNP (2007) *Overstromingsschade in Dijkring 14, Een koppeling van het Hoogwater Informatie Systeem aan de Ruimtescanner*

breakdown of these costs. It can be concluded that the majority of economic cost are related to damage to houses (60%), and damage to businesses (30% for both real estate as well as loss of production). Maximum material damage of a massive flood (modelled at a theoretical 99 meters above sea level) is estimated at a staggering 568 billion euro's. The consequential cost of the physical damage to people or movable assets other than means of transportation is not taken into account, and neither the societal cost of the psychological damage. This figure gives an idea of the massive value of the assets within a region, and hence the enormity of the potential damage of a flood.

Economic damage to	amount (M€)	percentage
houses	342.816	60,3%
companies (real estate)	141.848	24,9%
companies (loss of production)	27.289	4,8%
infrastructure	24.630	4,3%
urban area	18.636	3,3%
agriculture	5.584	1,0%
farms	3.151	0,6%
recreational area	1.901	0,3%
means of transport	1.615	0,3%
waterways	1.128	0,2%
total	568.598	100%

Table 2-3, Economic damage due to severe flooding in dike ring 14 (Zuid-Holland) [4]

This being a theoretical worst case scenario (99 meters of flood level), the next step is to determine a reasonable worst case scenario given an expected threat level and the current state of the Dutch dike system. For this, flood maps and models can be used. Figure 2-2 shows examples of flooding scenarios for dike ring 14.

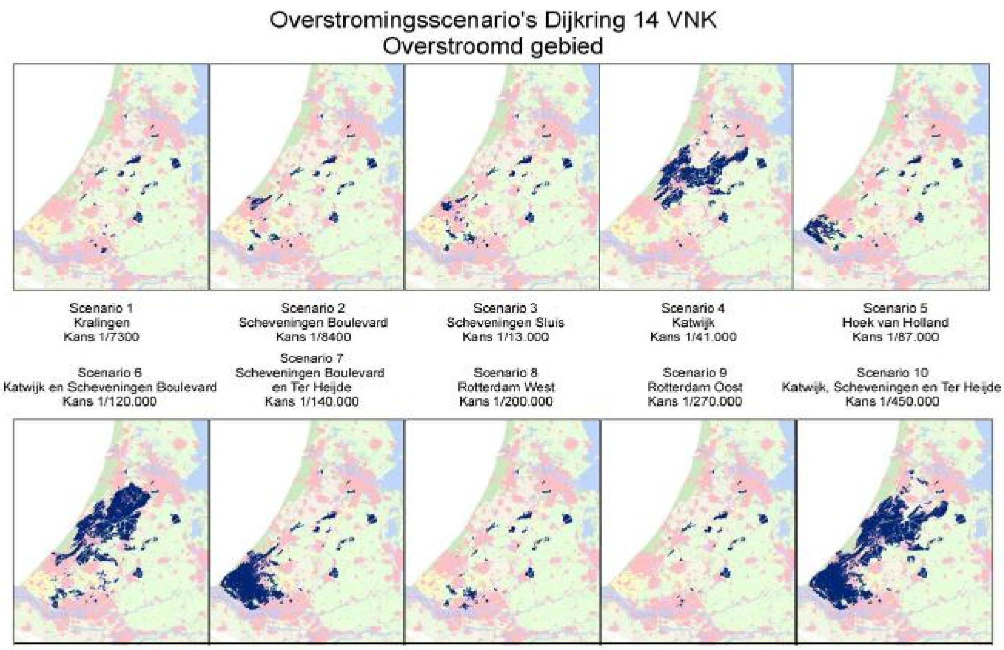


Figure 2-2, example of flooding scenario's for dike ring 14 [5]

[4] Adapted from: CTRC (2004) *Solidariteit met beleid, Aanbevelingen over financiële tegemoetkomingen bij rampen en calamiteiten*
[5] DWW (2005) *VNK: Overstromingsrisico Dijkring 14 Zuid-Holland*

These scenarios show a variation in the flood water depth (one of the major factors influencing the occurrence of physical damage) related to different scenarios of dike integrity failures. Each scenario has a different damage and casualty count, as well as a different likelihood. Using these scenarios an average damage and casualty count per incident can be established, as well as the consequential damage related to this physical damage. These costs and casualties can be averaged and calculated on a yearly basis (given the likelihood of each scenario)

For dike ring 14 in its current state of maintenance, the average yearly physical damage to inanimate assets (only real estate, land and infrastructure) due to flooding is estimated at 2,3 million Euros a year, and the death toll is estimated at 0,012 to 2,44 casualties per year.[6] Consequential damages, such as evacuation costs, medical costs, or (societal) costs due to shock or loss of relatives are not taken into account in this calculation.

2.5 Step 4: Vulnerability Analysis

The next step is to determine the vulnerability of the assets to physical damage, given the threat analysis from step 3, and determine in which way these vulnerabilities can be countered.

The situation that is being maintained is that vulnerable assets are located in areas normally covered with water (river or sea). To keep the assets from being damaged, a few basic options can be thought of. These are shown in Figure 2-3.

This figure shows that the safest, yet unrealistic option is to remove the water from the vicinity of the assets all together. A second option is to increase the height of the land on which assets are placed. This option was used in history with the creation of the so-called ´terpen´. This option works if assets are concentrated in a small area, but is not possible anymore with the current population.

The third option is to contain the rivers with dikes. This option is the current situation in most of the low lying areas in the Netherlands. The advantage is that the costs of creating this situation is relatively low, however any failure in the dike is a systemic failure that will endanger every asset behind this dike.

A forth option is to contain the individual assets so they are protected from the water. The advantage of this option is that any breach of an individually protected asset has little consequence for other protected assets and level of protection can be varied depending on the importance of the asset.

The last basic option is to increase the robustness and resilience of the assets so the variance in water height is coped with without losing the function of the asset.

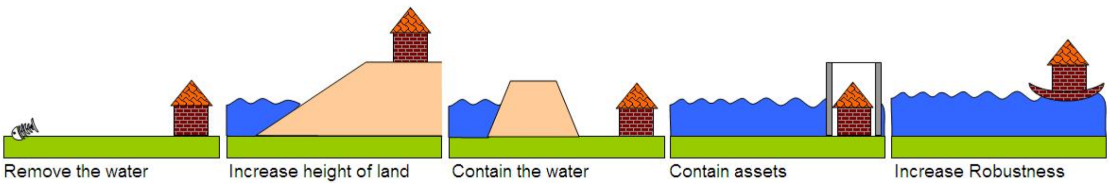


Figure 2-3, Basic options to keep valuable assets from being damaged by water

[6] Ibid.

As said, containing bodies of water with dikes creates a single point of failure. Once water passes the dike, damage occurs. To limit the amount of damage sustained over a long period, two solution directions are simultaneously further developed in which FCS play a role:

1. Decreasing the chance of dike failure through further increasing the robustness of dikes (height, strength, level of maintenance)
2. Decreasing the effect dike failure, once it has occurred through timely vertical or horizontal evacuation, or increasing the robustness and resilience of assets present in the area.

As described in the other Flood Control 2015 documents, dike monitoring systems are not restrained to systems with sensors buried within dikes, but can also use satellite or airplane readings or data gathered by visual inspection. Flood Control Systems combine both raw data from different DMSs as well as models for performance calculation and forecasting, presenting this information as virtual sensors to its operators.

Having Dike Monitoring Systems in place and combining outcomes from different Dike Monitoring Systems as well as data from “virtual sensors” into a Flood Control System affects both vulnerability-factors mentioned before.

Decrease the chance of dike failure
First, real-time views of the structural integrity of dikes through (virtual) sensors provide more insight into maintenance requirements. This allows for an optimal application of resources (time, personnel) to first mend the dike that needs the most attention.

Decrease the effect of dike failure
The combination of real time data streams from the dike sensors, combined with advanced forecasting models for both dike behaviour as well as environmental predictions (future water levels, wind speed, wind direction, weather, precipitation in the upstream river area, river flow, saturation of the dike etc) allows for more precise forecasting.

2.6 Step 5: Threat Assessment

Step 5 in the RAMCAP framework deals with the threat assessment and in the original intension covers the attractiveness and deterrence, adversary capability and intent determination and threat (likelihood of attack) as function of attractiveness and adversary capability and intent.

Since the ´adversary´ in case of flooding is not a sentient being with a plan, this stage will have to be adapted towards the nature of the forces that can do damage to the assets under protection. In a way the forces that can cause a failure of dikes are more sinister than human adversaries as any and all weak spot in the dike will be exploited, whereas a human adversary might not know of or act on a certain weakness in the defences.

The forces that can cause damage adhere to known rules of physics and can to a degree be predicted. On small scales and in controlled environments scientists are more or less able to calculate and predict the behaviour of the environment. However the total ecosystem of a dike is a very complex one and there are still a lot of uncertainties in understanding the whole system. On the other hand there is a lot of experience in withstanding bodies of water with dikes with a relatively low amount of incidents. The threat comes from certain combinations of weather (wind, precipitation, waves, etc.), with soil conditions (saturation, soil type, etc.) that lead to failure mechanisms of dikes.

The FCS is aiming precisely at gaining a better understanding of the total ecosystem, probing the black box that is a dike and understanding more of what conditions lead to what failure mechanisms so they can be acted on.

2.7 Step 6: Risk Assessment

When assessing the risk, the simple formula for this is:

Risk = Consequence * Likelihood = Consequence * (Threat * Vulnerability)

Imagine for a situation without a FCS the risk being:

€x * 1/y years

than the formula for the risk in a situation with FCS is

€(x-a) * 1/(y+b) years

where “a” is the de decrease in damage due to earlier warning, and “b” is the increase in years without a flood due to a better application of scarce resources on maintenance and upgrades of dikes, which lowers the vulnerability with an equal threat.

This section will be further elaborated on in section 3.4.

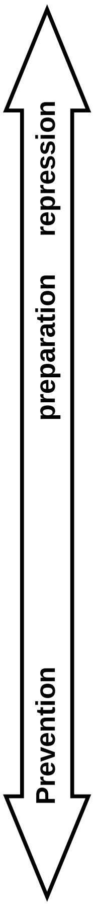
2.8 Step 7: Risk Management

To manage the risk from step 6 of the framework, the options for intervention in the status quo need to be considered to make recommendations as to the area in which the FCS can add most value. This is done from a financial point of view for the relevant phases of the safety chain[7].

Repression and preparation phase

One of the two ways a FCS adds value is by increasing the accuracy by which can be predicted when a certain dike will fail. Increasing the time in which to take action saves both human lives and injuries as well as prevents damage to inanimate assets.

Table 2-4 shows possible effects of the timeliness of a warning on the actions people can take to prevent damage to themselves or others, as well as to their property.



Time-to-flood	Options for animate assets	Options for inanimate assets
t=0	Dike failure occurs	
Minutes before t=0	Ad hoc vertical evacuation	none
Hours before t=0	Ad hoc vertical evacuation	vertical evacuation of very valuable portable assets
Days before t=0	Ad hoc horizontal evacuation	Horizontal evacuation of valuable portable assets Vertical evacuation of assets Ad hoc upgrade robustness buildings Ad hoc upgrade robustness dikes
Weeks before t=0	Organised horizontal evacuation	Horizontal evacuation Ad hoc upgrade robustness buildings Ad hoc upgrade robustness dikes (possible decrease of damage)
Months before t=0	Organised and prepared horizontal evacuation in case upgrade dikes proves unsuccessful	Horizontal evacuation Upgrade robustness buildings Upgrade robustness dikes (possible prevention of damage)
Years before t=0	Organised and prepared horizontal evacuation in case upgrade dikes proves unsuccessful Natural migration	Horizontal evacuation Upgrade robustness buildings Upgrade robustness dikes (possible prevention of damage) Abandonment

Table 2-4, effect of time-to-flood on actions taken to prevent damage

An indication of the amount of damage (as a percentage of the maximum damage a flood would do without a warning) versus time-to-flood is plotted as a graph in Figure 2-4.

[7] See appendix for explanation of the phases of the safety chain

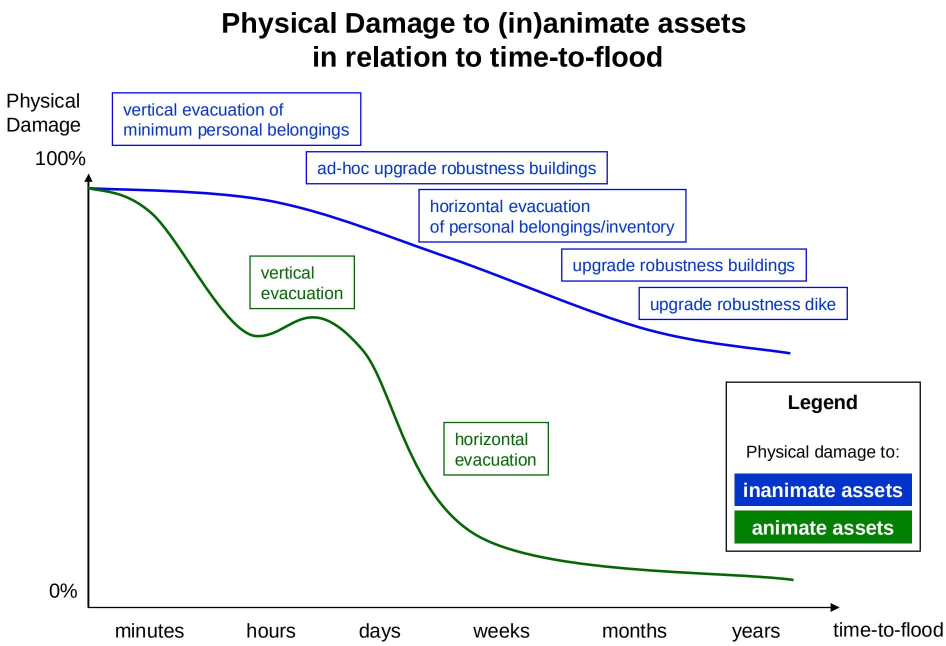


Figure 2-4, Graph showing the amount of physical damage related to time-to-flood

With no warning (t=0), a flood does its maximum damage. When people receive warning only minutes before a flood, some will be able to bring themselves into safety. This could be observed in the Thailand, Sri Lanka and Indonesia Tsunami of 2004, where people were able to run into their hotels or seek shelter in a two-story building and survive the flooding. This is called vertical evacuation. Given a little bit more time, people will be able to bring some most valuable personal objects with them. Given more time, people will start to bring more and more personal belongings with them onto higher grounds. People will also start to reinforce their shelter place in order to be more safe against the water, for instance by closing all doors and windows.

The amount of damage to people drops fairly quickly in the first couple of hours of time-to-flood gained, but then arguably increases again. This is because a fair number of people will try to evacuate horizontally if they *think* they have enough time to do so. People leave the relative safety of their high shelter and the flood will arrive as they are stuck on the low-lying roads.

It is only a warning several days ahead that allows for a safe horizontal evacuation, again lowering the damage to people. Pets and livestock will also be more and more evacuated during this phase.

When warning time reaches weeks, people will be able to have a relatively well-organised evacuation, being able to take a lot of personal belongings with them, storing other belongings in high places, and making their buildings extra robust. Large efforts will be taken to upgrade the strength of the dike, with chances of success.

Even earlier warnings (months, years ahead) though e.g. climate models will not reduce the damage to animate assets to zero, because wild animals will still be stuck, and some people might not be willing to leave, or wander into the area unknowingly. There is time to permanently upgrade the strength of the dikes to prevent the forecasted disaster in the first place. In some cases, abandoning the area might be a better (more economical) alternative than upgrading the dikes. For some island groups such as the Maldives, this is becoming a realistic option when faced with predictions of future sea levels due to climate change.

The graph of the inanimate objects shows a different picture. The minimum damage is much higher in comparison with the animate assets. This is because of the nature of most inanimate objects: hard or even impossible to move quickly and not very adapted to submersion. If a flood warning arrives at a site minutes before the arrival of the water, the first priority of the people will be to get themselves into safety and not saving the value of the inanimate assets. This explains the flat start of the line.

Only if people know that they can be safe once the flood arrives will they spend time to protect the inanimate objects from flood damage as best they can. What can be done depends on the robustness of the inanimate assets.

The effect of a FCS on this graph is that an effective FCS will warn of an imminent flood sooner, thus increasing the time between the warning and the actual flood. This makes it possible for more people to get to safety and more inanimate assets to be prepared for the flood.

Figure 2-5 shows the effects of a FCS on the amount of damage (under the assumption that FCS actually are able to provide better forecasting due to the combination of data from DMS with forecasting models). From this graph, it becomes clear that the added value of a FCS as an early warning device will have a larger effect on lowering damage to animate assets (people, livestock etc) than on inanimate assets (buildings, infrastructure)

The main value of the FCS as a forecasting tool will lie in the repression and preparation phase before a flooding. The value of RMS on longer term predictions diminishes, as long term factors such as climate become more and more important in the forecasts. The value of RMS in that period lies more in the ability to identify weak spots in a dike, and perform maintenance more efficiently than without an RMS.

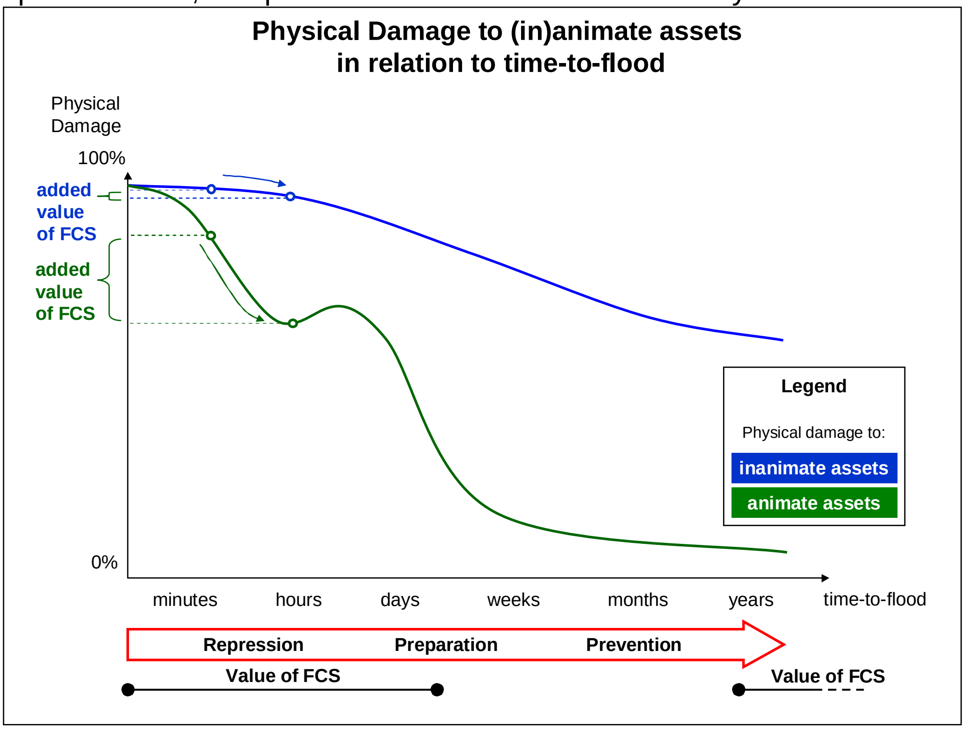


Figure 2-5, Graph showing added value of increasing forecasting period

Prevention phase
A Dike Monitoring Solution would allow the water boards to give a more accurate overview of the safety levels of the dike sections under their control. A FCS would allow the civil servants on a national level to see where investments would be needed most. In theory this would allow funds to be invested in the weakest links of all dikes in a country, optimizing the safety of all assets in a country. This is demonstrated with a hypothetical case as described below.

In this case, illustrated by Figure 2-6, three water boards are responsible for a dike ring. The levels to which the dike sections adhere to the regulations (the norm) are indicated as a percentage of that norm.

If funds for increasing the safety of dikes (regular maintenance & small upgrades) are spent per water board, water board 1 will probably increase the safety level of dike section B until it is up to par with the rest of their dike sections. Waterboard 2 will spend their funds equally over their three sections to try to reach at least 100% of the norm. Although waterboard 3 already adheres to the norm, perhaps they will try to make all three sections equally safe by increasing the levels of sections G and H; or alternatively waterboard 3 decides to postpone investments because all sections adhere to the norm already.

The case described above shows water boards investing funds in their weakest link. This is not necessarily in the best interest of the assets protected in the dike ring, as the dike ring is only as strong as the weakest link. For the good of the assets protected, the funds from water board 3 have to be invested in all sections that score below the norm to raise the safety level of the weakest dike sections and increase the safety of the entire dike ring. This can only happen if a complete picture of the safety levels of all dike sections is available, which is what a FCS is able to facilitate.

Of course the ability to compare the safety of dike sections is only a technical feature and does not take away the political obstructions there might be when an optimization of investment money is needed over the artificial borders of water boards!

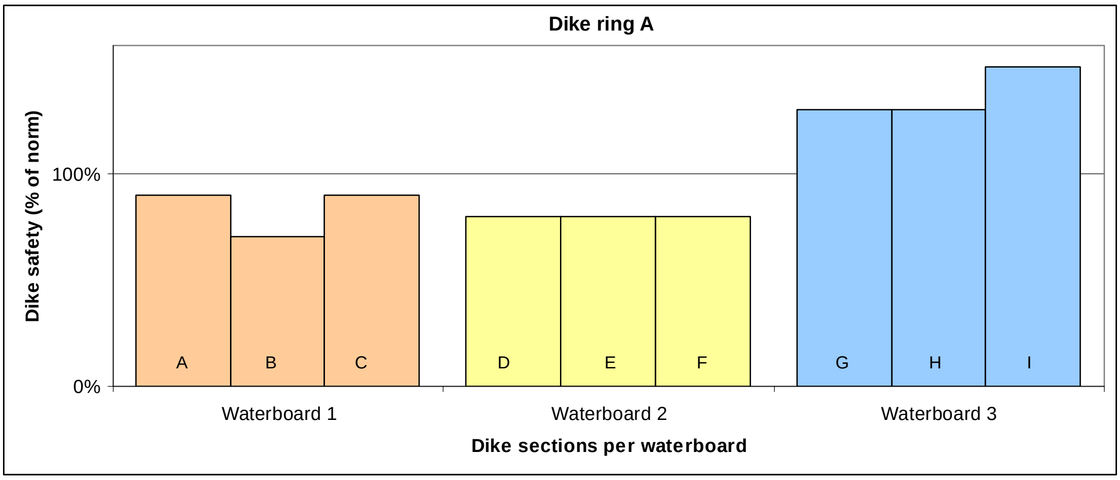


Figure 2-6, hypothetical investments made in a dike ring

In conclusion it can be said that obviously the biggest gain in for a FCS would be to help prevent floods by identifying weak spots in dikes to allow (permanent) upgrading of that weak spot. For this ´feature´ of a FCS to work, the system must be able to measure the parameters of the dike that would indicate these weak spots in the absence of immediate threats such as high loads on the levee because of high water.

But even if all dikes are up to par, a situation can arise that a dike is not sufficient to contain a body of water and a flood will occur. A FCS can still add significant value if the system is able to increase the time between a warning of a flood and the actual flood.

The ability of a FCS aid in the two situations described above will determine the value of a FCS to its users and the assets protected. As the extend of these features of the FCS are still unknown, no more details can be made on risk management at this time.

3 Business Case

A traditional business case involves a detailed overview of the costs of a solution in different phases and deducts this from the benefits of the solution giving a return on the invested Euros. In this chapter an overview is given of the factors that will influence the business case that will be worked out in later stages of the innovation program of FC2105 as not enough details are known to complete a full business case.

3.1 Stakeholders of a FCS

The development of the FCS is still in a research phase. This phase will be followed by the phases in which the FCS will be 2) implemented, 3) operational and 4) taken out of commission. The stakeholders involved in the full lifecycle of a FCS with their main involvement are mentioned in Figure 3-1.

	Phase			
	1. R&D	2. Implementation	3. Ex. & Maint.	4. Decomm.
Consortium partners TNO Deltares IBM	Main Research parties			
Suppliers/Partners Contracters Sensor suppliers Other suppliers		Contractors	Contractors	
Government (local) Dike inspector Dyke manager Director of Water Board		Contract party	Co-owner	Decommissioner of solution
Government (national) National Water Manager State secretary for Water Minister	Subsidizer	Main contract party	Main owner	Decommissioner of solution
Beneficiaries Civilian population Businesses Environment			Beneficiaries	

Figure 3-1, main stakeholders and their involvement in the lifecycle of FCS

3.2 Cost of a FCS

The costs of a FCS are spread out over the four phases. The different lifecycle phases with their main cost components are mentioned below:

1. Research & Development cost
   - Technology to gather relevant data (small scale)
   - Technology and techniques to process data to information
   - Technology to disseminate information to the relevant stakeholders
2. Implementation cost
   - Installing and commissioning sensors and networks (large scale)
   - Connecting data streams and FCS information to existing systems
   - Implementing new protocols and procedures to use FCS information
3. Exploitation & Maintenance cost
   - Gather and process information from FCS
   - Replace malfunctioning parts of the system
4. Decommission cost
   - Taking down the network and sensors
   - Updating processes and procedures accordingly

To determine the stakeholder who pays for the costs, an option is to look at the main beneficiaries of a FCS and see whether these parties are willing to invest in a solution like a FCS. This would mean that the civilian population and the businesses in flood prone areas would directly pay for such a system. This is not likely as water safety is typically an issue for the greater good of society and thus a government concern.

Even if the benefits outweigh the cost the question for a FCS is still what governmental body has to pay for it? As the FCS has a wide scope in functionality, the ownership is not clear cut. Yet this is an important part to make a convincing business case.

An earlier cost calculation made by TNO[8] pointed out that equipping all primary and secondary dikes with sensors would involve operational expenses of over 100 million Euro per year. It further showed that the calculations are very sensitive towards the parameters of the costs per measuring unit, the distance between each measuring unit and the technical life span of a measuring unit. These costs are for the part of the FCS that covers the dike monitoring solution and not the other functionalities that will be part of the FCS.

3.3 Damage matrix

A flood has far reaching consequences for the short and long term. Some of the impacts are direct, such as the loss of lives, injuries, damage to assets, etc. Other impacts are second or even third order effects, such as the perception of safety or the loss of reputation. Combining the impact parameters to the stakeholders gives an overview of possible cost factors playing a role in the business case.

		Impact parameters			
		Financial Damage	Injuries/ deaths	Safety Perception	Reputation
stakeholders	Citizens	Damage to real estate & assets,	Loss of life/injuries	Post Traumatic Stress	
	Companies	Damage to real estate & assets, cost of lost sales	loss of employees	Less attractive to workforce, partners and clients	Risk of loosing partners and clients
	Local Governments		(temporary) loss of employees	Less reliable image	Less businesses and citizens settling in NL
	National government	Compensation of citizens and businesses		Less reliable image	Less businesses settling in NL
	Environment				

The first order effects are already difficult to calculate and certainly valuing the second order effects will cause a lot of debate amongst experts. Nonetheless they do

8 Financiën van generieke dijkbewaking kostenmodel 0.2 (version 1).xls

play a role in the business case as they influence the decision whether investments in FCS are justifiable.

3.4 Benefits

As stated in step 6 of the RAMCAP framework (sectiont 2.7). The benefits of a FCS lie in decreasing the risk of flooding. When assessing the risk, the simple formula for this is:

Risk = Consequence * Likelihood = Consequence * (Threat * Vulnerability)

With the consequences being damage to assets which can be projected in Euros lost. The consequences can be lowered with the functionality of the FCS to warn for dangerous conditions that may lead to dike failures, giving time for repairs, or more time to lessen the consequences of an eventual flood.

The ´threat´ in the equation is represented by the weather parameters which lead to specific dangerous conditions for dikes, such as high water levels and droughts. These parameters are unaffected by the FCS and are thus equal in the situation with and without a FCS.

The vulnerability is influenced by a FCS as it is able to predict weak spots and dangerous combinations of circumstances. Imagine for a situation without a FCS the risk being:

Risk = Consequences valued at €X * the likelihood of a flood 1/Y years

than the formula for the risk in a situation with FCS is

Risk = €(x-a) * 1/(y+b) years

Where “a” is the de decrease in damage due to earlier warning, and “b” is the increase in years without a flood due to a better application of scarce resources on maintenance and upgrades of dikes, which lowers the vulnerability with an equal threat.

The actual calculations of both “a” and “b” are not yet possible to give, because three main questions are still unanswered:

- What is the average gained prediction time by a FCS over time? As science advances, and through field testing such as IJkdijk and Livedijk, knowledge is gained that eventually leads to better and more precise models, which can be constantly run with real-time data for any dikes in an area.

- What is the achievable extra efficiency in distributing scarce resources when a FCS is used to determine which dikes should be maintained or upgraded first?

- Will policy makers choose to use the added efficiency to reach higher safety levels for the same amount of money, or will they aim to reach similar safety levels for lower costs?

The answers to these questions will allow the reduction of the risk to be calculated. Lowering the risk of flooding will prove to be an important factor for investment decisions in FCS. With these three questions answered, a case study can be made of an actual dike ring going through all the stages of the RAMCAP model calculating the added value both in the repression/preparation phase as well as in the prevention phase.

3.5 Financing a FCS

A possible method to pay for the necessary investments for a FCS is to delay investments in dike maintenance for those dike sections that the FCS proves to be above specifications.

Of course in a similar train of thought, implemented FCSs might find that more investments are needed to get dike sections to adhere to the specifications. At this time it cannot be estimated if less investments or more investments are necessary.

3.6 Uncertainty

Another issue which should be addressed is the occurrences of false negatives and false positives as these have a big impact on the perceived reliability of a FCS.

False positives are those instances where a FCS gives a warning of a weak spot in a dike and after studying the situation it turns out that this warning should not have occurred. The consequence of false positives is that people will be less and less alarmed of warnings, thinking more and more that it is another glitch in the system.

False negatives are those instances where something is wrong with the dike, but the system indicates nothing unusual. Possibly this leads to a dike failing with no warning, leading to maximum damage. Faith in the system will be instantly diminished to around zero.

An overview of the possible situations is given in Table 3-1.

		Weak spot in dike	
		Yes	No
Alarm given	Yes	system works investments justified limited damage increased perceived value of FCS	system mal function more tuning necessary unnecessary spending of resources decreased faith in system **False Positive**
	No	system mal function more research necessary possibly large damage Significant decrease in faith in system **False Negative**	system works investments justified no damage increased perceived value of FCS

Table 3-1, concequences of false positives and false negatives

4 Conclusion

The value of a FCS lies in the ability to determine weak spots in dikes through measurements, forecasting/prediction and dissemination of this data to all relevant stakeholders so resources can be assigned to mitigate risks in the prevention phase as well as preparation and repression phases. In these phases the value of a FCS will be to help the stakeholders invest their limited resources in those dike sections that will increase the weakest link in the flood control defences on a local, river system and national level.

At this point in the development of a FCS, there is no clear cut answer possible as to the question whether investments in Flood Control Systems are justifiable. This field of research is still in its infancy, given the very limited amount of actual sensor data collected from permanent dike monitoring systems until now.

The IJkdijk and LiveDijk experiments are first steps in gaining more understanding of how to interpret data from permanent sensors in dikes, as well as combining this information into prediction modules that will help to prevent dikes from failing. When the different modules that make up a FCS begin to give reliable results, that is when more will become clear as to what investments are necessary to make such systems operational and what their contribution to the lowering of flood risk will be.

When looking at the damage that can be prevented by a FCS in the prevention phase compared to the preparation/repression phase, it is evident that preventing a dike failure is better than limiting the damage when flooding is imminent. Further experiments will determine what value a FCS can bring in either phase.

In case of the use of a FCS in the preparation/repression phases, the value of a FCS lies in the increase of the time between flood water reaching assets and the warning people get to the arrival of the water. Any minute that a FCS can warn the people earlier to an imminent flood compared to a situation without a FCS will decrease the death toll of a severe flood significantly as people have more time to seek higher ground. This does mean that a FCS should have the functionality to warn the people of a threatened area or it must have a connection to an existing warning system.

Implications of FCS can be that either a higher level of safety can be accomplished by using the same amount of resources, or a similar level of safety can be accomplished by using a lower amount of resources. It is expected that in practice, policy makers will choose a mix of both options. Determining which will be the dominant direction (higher safety or lower costs) is of eminent importance to understanding the business case of Flood Control Systems, but this direction is unfortunately not clear right now.

In the next phase of developing a FCS, the team working on the business case needs to find out more details and should try to quantify the influencing factors described in this report. If possible, the research should concentrate on a particular dike ring, so the use of the RAMCAP model can be made specific, the choices for certain uses of technology can be made and the benefits will become clearer as it will be known what damage can occur in that dike ring in case of a failing dike.

Appendix

Safety chain

The Flood Control System is not only useful during times of crisis, also in normal times. To distinguish the different applications of the FCS solution, the safety chain is explained below.

Link	Definition
Pro-action	Eliminating structural causes of accidents and disasters to prevent them from happening in the first place (e.g. prohibit building in flood prone areas)
Prevention	Taking measures beforehand aimed at preventing accident and disasters, and limiting consequences in case such events do occur (e.g. building levees)
Preparation	Taking measures to ensure sufficient preparation to deal with accident and disasters in case they happen (e.g. contingency planning, training, early warning, initiating flood fighting efforts)
Response	Actually dealing with accidents and disasters (e.g. response teams)
Recovery	All activities that lead to rapid recovery from consequences of accidents and disasters and ensuring that all affected can return to “normal” and recover their equilibrium.