Inspection methods of water retaining dikes inspected -

Enhancement and implementation of dike monitoring techniques within dike inspection and examination practices

Master thesis Water Science and Management

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MSc Water Science and Management, Environmental track
Environmental sciences

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Abstract

The aim of this research is to provide insight in how dike monitoring techniques can enhance dike inspection and examination and how it could be implemented in those practices. Dike inspection is conducted by the water authorities and offers continuous practice based control of irregularities at the dike. Examinations are approached separately to dike inspection and contain model based calculations of the probability for failure mechanisms to occur referenced to the statutory safety standards. Many dike monitoring techniques are developed, offered and pending for implementation to contribute enhancement towards the traditional concept of water retaining dike management. The lack of implementation compared to the large investments in dike monitoring techniques and the expensive traditional dike (re)construction programs, urges the importance for this research.

To gain insight in dike inspection, examination and dike monitoring techniques, data were collected by means of literature and qualitative interviews. Literature is distinguished in policy documents, scientific reports, consultancy reports and the internet. The interviews were conducted with the three main stakeholders: water authorities, research agencies and product developers.

Within the available literature it became clear that: 1. Overviews of techniques and applicability thereof are available, 2. Dike monitoring techniques are not taken into account in legal policy documents, 3. Dike monitoring techniques are not developed in relation to current dike inspection and examination practices, 4. Dike inspection can mainly face enhancement with dike monitoring techniques by identification of irregularities through objective dike process pictures and 5. Examination can mainly face enhancement with dike monitoring techniques by parameter persuasion in models through more accurate parameter values. Most important notifications from the interviews were: 1. Cooperation within and between the stakeholders addressing mutual demands has too little attention. 2. Water authorities do not see the urgency to implement dike monitoring techniques on a regular basis, 3. Water authorities do not have a clear idea about the costs and benefits of dike monitoring techniques, 4. Water authorities do not have a clear insight about the status of dike monitoring techniques. 5. Product developers believe in the validity of their product, which is largely substantiated by the research agencies.

The notifications should be addressed as recommendations towards the corresponding stakeholders, which will increase the awareness of enhancement possibilities and thus the level of implementation. Cooperation towards mutual demands is considered as most important. The application of dike monitoring techniques can be implemented in five scenarios' by which interaction towards current water retaining dike management practices is sought. 1. Preventive monitoring, 2. Monitoring in addition to dike inspection due to irregularity notifications, 3. Monitoring in addition to uncertainties of examination, 4. Monitoring during (re)construction of dike structures and 5. Monitoring to validate dike monitoring techniques and parameters. Meanwhile dike monitoring techniques are validated during these practical applications. By eliminating current thresholds, dike monitoring techniques will have the chance to prove what they claim.

Preface

This master research thesis was established after discussions with dr. Maurits van Dijk from Tauw. The research originated from concerns arisen in the field of dike monitoring and thereby it was thought that enhancing dike inspection and examination practices by means of dike monitoring techniques could have potential. The company of Tauw was therein especially interested in the current interactions and characteristics of dike monitoring techniques. This research was conducted according to the course guide of the Master's Thesis Internship Water Science and Management 2015. Tauw is a consultancy agency at which the research is conducted in combination with an internship.

Supervision was given by dr. Paul Schot from Utrecht University who provided constructive feedback and interesting insights. Dr. Carel Dieperink from Utrecht University was involved as second reader of this thesis. The mentor at Tauw, dr. Maurits van Dijk, gave me the opportunity to conduct my thesis at their company and offered interesting insights towards this topic. For this I kindly thank all of them.

Gijs Woldring

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Table of contents

List of abbreviations

HIW	Handreiking Inspectie Waterkeringen
HR	Hydraulische Randvoorwaarden primaire waterkeringen
ILT	Inspectie Leefomgeving en Transport
PIW	Professionaliseren Inspectie Waterkeringen
PIW2.0	Professionaliseren Inspectie Waterkeringen 2.0
VIW	Verbetering Inspectie Waterkeringen
VTV	Voorsrift Toetsen op Veiligheid primaire waterkeringen
WTI2011	Wettelijk Toets Instrumentarium 2011
WTI2017	Wettelijk Toets Instrumentarium 2017

List of Tables and Figures

List of Tables

List of Figures

1. Introduction

1.1 Background

The Dutch government organizes water management in order to prevent the water damaging the hinterland. A multi-layered dike system is constructed to regulate the water flows. Dike constructions follow the constraints of set regulation towards the probability of inundation, dependent on the consequences for the hinterland (Rijksoverheid, 2015b). Due to ongoing natural forces deterioration of the dike construction is inevitable. These forces are taken into account within the durability of the design (VTV, 2007). Still, it remains a sensitive system as the weakest spot of the dike determines the strength of an entire dike trajectory. Natural forces and human interactions could cause unexpected hazards to the dike, which could lead to a so called dike failure occurrence, by which a dike loses its water retaining function. Recently, this led to unforeseen dike breaches in Wilnis (2003) and Stijn (2004) (Rijksoverheid, 2006). In this thesis water retaining dike management is defined as the management to retain the regulatory inundation probability of the dike. It is practiced to provide insight in the actual status of the dike (effective safety level of the dike).

Dikes are partitioned in dike trajectories to provide closed systems to manage safety and easier maintenance of the dike. The water authorities (the water boards and Rijkswaterstaat) are due to article 5.1 in the 'Waterwet' (Rijksoverheid, 2015b), required to show that the dike trajectories within the area comply with the regulatory probability of inundation. The maintenance and management of dikes is thus a governmental task, executed by 24 water boards (regional water authorities) and Rijkswaterstaat (state water authority). Together they control 3.200 kilometers of primary dikes and 14.000 kilometers of regional dikes (STOWA, 2008). Primary dikes are the main defense structures against sea, large rivers and lakes and the required probability of inundation is appointed by the Minister of Infrastructure and Environment. Probabilities of inundation of regional dikes are appointed by the provinces and generally give protection from water bodies with a lower degree of risk (STOWA, 2008).

In current practice of the water authorities, dike inspection and examination are separated methods to fulfill their obligations to practice water retaining dike management (Moser et al, 2005). Traditional dike inspection is conducted in daily practice by 'operators', which are local water board representatives who check for irregularities at the dike that can affect the actual status of the dike (STOWA, 2014). The execution of dike inspection is rather basic and conducted by visual inspection (Annex 4). It contains personal observations by eye with subsequent expert judgement as most important tool, walking as most important transportation method and an app as most important processing tool (Swart, 2007). 'Specialists' at the office of water authorities provide political boundary conditions and technical guidelines for operators in the field. Regular procedure currently used for dike inspection is by means of identifying, diagnosis, prognoses and operationalize (STOWA, 2012). This procedure is originated to standardize the concept of dike inspection in different phases of processing.

Examination is approached separately to dike inspection and aims to provide a mathematical foundation through calculation to determine the actual status the dike once in every six years (VTV, 2007). Examination contains model based calculations of the probability of failure mechanisms (Annex 5) to occur, referenced to the statutory inundation probability. It is decided in a maximum of three stages whether or not the current safety levels of the dike trajectories comply with the set regulation (Inspectie Verkeer en Waterstaat (2011). After each stage that the dike does not comply, (local) parameter research will be intensified to eliminate uncertainties. If the actual safety level does not comply with the regulations after the third stage, then (re)construction programs address forthcoming requirements (HWBP, 2014). The outcome is dependent on the input of parameters, which differ per calculated failure mechanism. Availability of new parameter values due to research, developing calculation methods and the natural degradation of the dike cause the recurrence of calculations (Rijkswaterstaat, 2013).

Dike monitoring techniques determine, in addition to dike inspection and examination, the status of the regulatory inundation probabilities of the dike by means of technological equipment. Product developers offer a range of dike monitoring techniques which show technical characteristics of processes at the inside and outside the dike. There is no standardized procedure within the water authorities as seen for dike inspection and examination. Specified information is no common knowledge and has to be gained throughout the research.

The development of dike monitoring techniques is consistent to the professionalization in the dike inspection program. 'Verbetering Inspecties Waterkeringen' (VIW, 2004-2008), 'Professionaliseren Inspectie Waterkeringen' (PIW 2009-2012) and 'Professionaliseren Inspectie Waterkeringen 2.0' (PIW2.0 2013-2015) are the most comprehensive research programs in which dike monitoring techniques are investigated. VIW focused on research towards improvements within the dike inspection process and exposure of possibilities by dike monitoring techniques. PIW structured the application of dike inspection in the 'Handreiking Inspectie Waterkeringen' (HIW) (STOWA, 2012), developed an app on a mobile device for data processing (Digispectie) with a cohesive overview of possible dike damages (Digigids) and contributed to the validation of dike monitoring techniques within the 'IJkdijk experiments' (STOWA, 2012). PIW2.0 has two pillars of which the first is continual examination with integration of dike inspection. The second is professional maintenance and innovation by 'efficient' and 'transparent' dike management based on asset management. Dike monitoring techniques are despite the sustained developments not specifically mentioned (STOWA, 2013).

The research programs increased the amount of documentation concerning dike inspection and dike monitoring techniques, but research towards the more theoretical principle of examination is noticeable more. Multiple guidelines give attention to the hydraulic boundaries in 'Hydraulische Randvoorwaarden Primaire Waterkeringen' (HR, 2007), calculation procedures 'Voorschrift Toetsen op Veiligheid Primaire Waterkeringen' (VTV, 2007) and methods and rules are set in the 'Wettelijke ToetsInstrumentarium2011' (WTI2011) (Inspectie Verkeer en Waterstaat, 2011). HR, VTV and WTI will be shortly revised in the 'Wettelijke Toetsinstrumentarium 2017' (WTI2017) (Rijkswaterstaat, 2013). The calculation method to determine if the statutory inundation probability is met will be based on calculating failure mechanisms probabilities on cross section level (WTI2017) instead of high river water level probabilities (WTI2011) (Rijkswaterstaat, 2013). The determination of the statutory inundation probability becomes a risk based approach, which is a combination of the outcome of social costs and benefits analysis, chance of evacuation and the 'desired' local individual risk (Rijkswaterstaat, 2013). It has most attention within current water retaining dike management due to the large associated investments in dike (re)construction of dikes that were determined unsafe after WTI2011 calculations. These need to meet the new regulatory safety demands of WTI2017. The current array of 31 projects shows the large scale of financial and social belongings within the ongoing debate (HWBP, 2014).

Changes in the Dutch legal policy documents 'Bestuursakkoord Water' (Rijksoverheid, 2011) and the 'Waterwet' (Rijksoverheid, 2015) noted an increased emphasis on the duty of care ('Zorgplicht'). The water authorities need to improve the continuous source of documentation to prove that the regulatory inundation probability is met (ILT, 2015). Data substantiation in documentation about the quantity and quality of dike inspection, examination, data standardization and monitoring methods is emphasized. The new ‘Zorgplicht’ asks for continuous and objective insights, above periodic inspection and calculation, with sufficient substantiation about the actual status of the dike. The current dike inspection and examination methods seem not to be able to fulfill the demands in its entirety and thus give rise to the necessity of new methods. Meanwhile budget and personnel cuts are seen at water boards, which ask for a higher efficiency of the working process (van Dijk, 2015). Dike monitoring techniques are therefore interesting and relevant.

1.2 Problem description

In order to gain increased insight in the actual status of the dike as urged in the new ‘Zorgplicht’, the current water retaining dike management practices are not comprehensive. Dike inspection is mostly limited to personal observations at the outside of the dike (Swart, 2007) and also examinations are mainly prone to a high level of uncertainty due to the range of parameter assumptions (van den Berg and Koelewijn, 2014). Dike inspection and examination are rather unconnected processes: one merely determines the actual status of the dike by observing irregularities through daily visual inspection, while the other process merely determines the actual status of the dike by self-provided calculations (Moser et al., 2009). Research programs towards dike monitoring techniques thereby provide theoretical enhancement towards the demand for additional and objective observations, but face unclear problems with implementation.

A. Dike inspection as introduced in chapter 1.1 faces by vision a variety of uncertainties in order to determine the actual status of the regulatory inundation probability of the dike:

1. Subjectivity, human errors and limitations in knowledge by operators and specialists;
2. Visibility limitations of irregularities at the dike. Not everything is visible by eye at the outside of the dike and many important processes initiate within the dike;
3. Temporary insights over time due to human limitations of presence;
4. Data management. A lack of analysis opportunities due to lacking quantitative data by means of manual processing and storage;
5. Lack of attention due to multiple topics of attention for operators and specialists. Besides the level of attention is sensitive to changing policies.

B. Examination as introduced in chapter 1.1 faces by vision a variety of uncertainties in order to determine the actual status of the regulatory inundation probability of the dike:

1. Uncertainty within the accuracy of parameters that determine the outcome of models;
2. Overprotection due to rounding of uncertain parameters;
3. The preferred level of assumptions and research;
4. Subjectivity of the specialist in making subjective estimations along the calculation process;
5. Low frequency of examination calculations makes it a snapshot in time;
6. Border between ‘safe’ and ‘unsafe’ determination is fragile. Outcome difference can be small, but financial and environmental consequences large.

C. Dike monitoring techniques as introduced in chapter 1.1 faces by vision two uncertainties in order of enhancement and implementation the current practice of dike inspection and examination:

1. The potential of how they can offer enhancement towards the current practice;
2. They are not yet structurally implemented unless the research programs and investments.

Dike monitoring techniques identify irregularities to the dike body by means of specified measured data through diverse products (Swart, 2007). The anomalies shown as output vary from specific parameters to damage pictures of a dike process (de Vries et al., 2014). This offers the occasion of unique additional insights for research, but also during dike inspection and examination. Further advantages could be earlier detection and thus earlier prevention (safety), earlier detection with solutions at lower costs (cheaper) and increase of knowledge.

D. Dike monitoring techniques by vision may potentially provide enhancement to dike inspection and examination uncertainties by providing:

1. Objective technological insight of outer dike processes and in dike processes;
2. Insight in various parameters that influence the actual status of the dike;
3. Detection of failure processes in an early stage;
4. A continuous source of objective data;
5. Comparison to outcomes of current dike inspection and examination;
6. A different solution next to (re)construction.

The potential enhancement of dike monitoring techniques does not offer clear insight in the enhancement within the current method of dike inspection and examination practices. Despite the potential enhancements implementation of dike monitoring techniques is little seen. Dike inspection and examination are the dominant features in water retaining dike management (van Dijk, 2015). Thus dike monitoring techniques potentially should be able to provide enhancement to dike inspection and examination, but are actually only very limited implemented. This research focusses on this mismatch.

1.3 Aim

The aim is to provide insight in how dike monitoring techniques can enhance dike inspection and examination. Moreover this report aims to describe how it can be implemented in those practices.

1.4 Research question

This leads to the following main research question shown below.

The main research question is:
How can dike monitoring techniques (potentially) enhance, and be implemented in, water retaining dike management of dike inspection and examination?

The main research question is separated in two research questions:

1. How can dike monitoring techniques enhance existing dike inspection and examination practices?
2. How can dike monitoring techniques be implemented in existing dike inspection and examination practices?

1.5 Reading guide

This report is structured as follows.
This introduction offers background information with a subsequent problem description, from which the aim and research questions are determined. It offers the base throughout the research. The methodology is described in chapter 2 and explains the methods that are used to answer the research questions within the results chapter 3. Chapter 3 contains the results and is divided in two sub chapters, subsequent to the two research questions. Each sub chapter has multiple paragraphs. Chapter 4 offers the uncertainties within the research and recommendations for the related stakeholders and further research. In chapter 5 the conclusion is given. Chapter 6 contains the reference list of all literature used and interviews conducted.

2. Methodology

2.1 General approach

The approach of information gathering in dike inspection, examination and dike monitoring techniques started with literature research to gain insight in the available knowledge in writing on paper and the internet. With this information and the discussions with the supervisors at Tauw and Utrecht University the findings were gained to set the background at first, then the problem description and finally the aim and main research question with subsequent research questions. As shown in the methodological framework (Figure 1) research question 1 was approached first and then research question 2. To obtain results and answer research questions 1 and 2, the output from literature and interviews were required.

The interviews were constructed by information from the literature study and subject to the determined research questions (Figure 1). The interviews were conducted to gain specified information and perceptions of the three main stakeholder categories: water authorities, research agencies and product developers. The sources for literature study were divided in four categories: governmental documents, scientific reports, consultancy reports and internet. Due to a combination of existing literature and interviews new information and insights were gained in current (dike inspection and examination) and future water retaining dike management practices (including dike monitoring techniques). The results are discussed per research question in chapter 3.

Throughout this report literature and interviews are discussed separately in different paragraphs, but information can be intertwining and therefore mentioned within the same paragraph. The sub chapters and paragraphs are designed to provide the maximum amount of input to answer the research questions and subsequently the main research question.

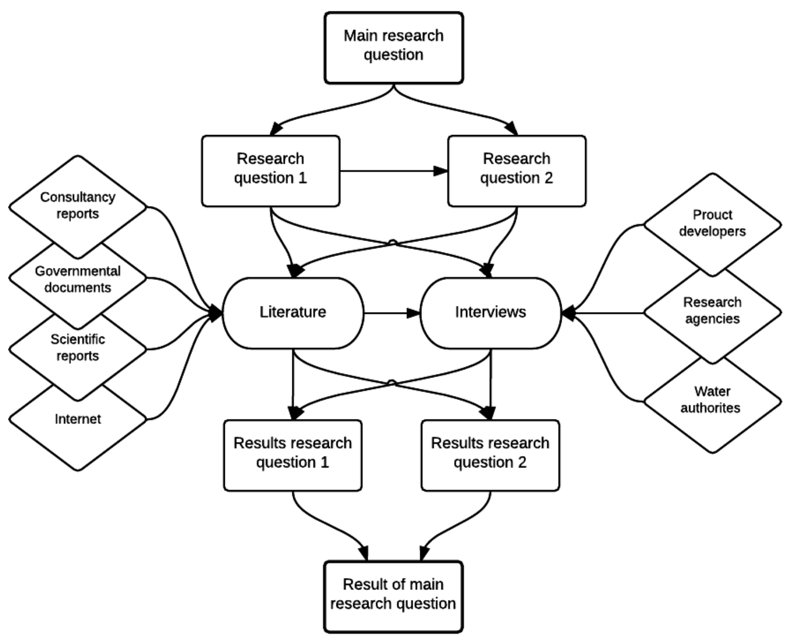


Figure 1. Methodological framework of the research method

Literature

The literature study was conducted continuously during this research in order to gain overview of relevant insights, status and developments. Water retaining dike management literature was gathered, containing the following information: policies, guidelines, examination principles, dike properties, methods of dike inspection and dike monitoring techniques. Governmental policies and guidelines provide visions, aims and technical research for topics within the concern of the water authorities. Consultancy reports are written by product developers and research agencies to provide input, required by the commercial market. Scientific reports are written by scientists with often specialized information. Internet provided general information and access in the before mentioned. The literature used is structured in chapter 6: References.

Interviews

Interviews were held to create new insights in the main research question and offers information that cannot be found in the literature. It creates the asset of visions, aims, sensitivities and knowledge of specialized and related stakeholders. The interviews mainly aimed to answer the research questions, but also offered background information for a better understanding of the concept and context. With interviews, literature was challenged or confirmed. The interview questions are shown in Annex 1 per category. The three stakeholder categories with a total of 20 interviewees (Table 1), provided an indicative overview. The interviewees were divided in the following stakeholder categories:

- Water authorities (water boards, Rijkswaterstaat and Rijksoverheid)

The water boards show most influence within the practice of this research and therefore have more attention than Rijkswaterstaat and Rijksoverheid. The interviewed water boards (Table 1) are spread over the country for a representative national overview. Different water boards can use varying instruments and methods. Additionally water safety characteristics are different per type of landscape and soil composition. Four water boards were chosen and per water board two persons were interviewed: the operator and the specialist. Both were addressed separately giving a total of four interviewed operators and four specialists. Insights by the operators and specialists show the different perceptions and knowledge within a water board. Operators are the local water board representatives in the field and are continuously involved in management and maintenance of the dike (Rijksoverheid, 2006). Specialists are office employees that supervise and/or advice in the process of dike inspection and conduct examination by research and documentation (Rijksoverheid, 2006). One specialist of Rijkswaterstaat was interviewed and one inspector of Inspectie Leefomgeving and Transport (Rijksoverheid), because they are also relevant specialists and could therefore offer interesting conceptual input. All water authorities and preferred employees contacted were willing to be questioned.

- Research agencies (Consultancies and Universities)

Research agencies are the front line of innovative investigation towards dike monitoring techniques, inspection and examination methods. They offer important information to the latest insights. Four researchers were interviewed at the consultancies of Deltares, TNO, BZ Innovatiemanagement and Fugro (Table 1). University employees were not interviewed due to a lack of time and direct interest, although the researcher from TNO is also professor at the University of Amsterdam. Two professors and two consultancies did not apply to interview requests.

- Product developers

The product developers create their own dike monitoring technique(s) in order to contribute innovation to the market of water retaining dike management. Their aim is to take profit from a niche in the market. There is a large variety of product developers; mainly small initiatives and some large commercial companies. Six product developers were interviewed (Table 1). They were contacted due to the relevance of their dike monitoring technique and differences between the techniques. Two product developers out of eight denied participation.

Table 1. Overview of interviewees

Category	Function	Company	Referred to as	Date interview
Water boards	Specialist	Seconded at water board Groot Salland, Tauw	Specialist 1, 2015	30-04-2015
	Advisor water safety, operation manager	Water board Noorderzijlvest and Livedijk XL	Specialist 2, 2015	13-05-2015
	Senior advisor	Water board Rijnland	Specialist 3, 2015	01-07-2015
	Senior specialist	Water board Brabantse Delta	Specialist 4, 2015	09-07-2015
	Operator	Water board Groot Salland	Operator 1, 2015	09-06-2015
	Operator	Noorderzijlvest	Operator 2, 2015	11-06-2015
	Operator	Water board Rijnland	Operator 3, 2015	30-06-2015
	Operator	Water board Brabantse Delta	Operator 4, 2015	09-07-2015
Rijksoverheid	Inspector water safety	Inspectie Leefomgeving en Transport	Inspector ILT 1, 2015	09-06-2015
Rijkswaterstaat	Senior advisor flood safety	Rijkswaterstaat	Advisor RWS 1, 2015	25-06-2015
Product developers	Owner	Miramap	Product developer 1, 2015	11-05-2015
	Managing director and inventor	InTech	Product developer 2, 2015	11-05-2015
	Owner	StabiAlert	Product developer 3, 2015	13-05-2015
	Contract director	Inventec	Product developer 4, 2015	18-05-2015
	Director professional services	SkyGeo	Product developer 5, 2015	27-05-2015
	Owner	DMC system	Product developer 6, 2015	15-07-2015
Research agencies	Senior strategist	TNO	Researcher 1, 2015	13-05-2015
	Specialist research and development	Deltares	Researcher 2, 2015	19-05-2015
	Owner and chairman	BZInnovatiemanagement, Stichting IJkdijk,	Researcher 3, 2015	16-06-2015
	Head GeoServices	Fugro	Researcher 4, 2015	23-06-2015

2.3 Research question 1

In this chapter, relevant literature towards research question 1 is summarized. Thereafter the method of interviewing and the relevant interviews to research question 1 are discussed.

Literature

The literature research started with exploring the current role of dike monitoring techniques, dike inspection and examination in relation to determining the actual status of the dike. The relevant literature was mostly found in governmental documents and the internet. When the topic and research focus became clearer, the first insights towards possible enhancement came through.
Relevant literature solely related to the topic of research question 1 was mostly found in governmental documents and consultancy reports and to a lesser extent in scientific reports and the internet.

The first paragraph (3.1.1) was determined by literature about existing dike monitoring techniques and its characteristics (governmental documents, consultancy reports, scientific reports and internet) and how it could relate to existing dike inspection and examination (governmental documents). A conclusion is drawn from synthesis related to research question 1.
The second paragraph (3.1.2) was elaborated in the same manner as paragraph 3.1.1.
The third paragraph (3.1.3) was determined by interviews.

During the literature study the topic and research focus became clearer and preliminary interviews were sketched. During the set-up and execution of interviews literature research continued.

Interview

Three standardized question lists per stakeholder category were set-up by the literature study and problem description during the analysis of research question 1. Questions have small differences per stakeholder category, because of specific knowhow per category (Annex 1). The interviews were structured, validated and tested in collaboration with the internship company Tauw. At first interviewees were chosen by Maurits van Dijk, but interviewees were mainly found in relevant literature and an expanding personal network. The conditions that determined a suitable interviewee were:

1. A specialist in one of the three stakeholder categories;
2. Thorough specialized knowledge of one aspect of water retaining dike management;
3. Working at different organizations (except specialists and operators within water boards).

Interviewees were contacted by phone and alternatively mail, to clarify the need and agree on a face to face appointment. Before a face to face interview was conducted the standardized question list was sent towards the interviewee. Due to this the interview was less confronting and the interviewee better prepared, which leads to a higher quality of the outcome (EURIB, 2010). After an interview was conducted all answers were elaborated, returned to the interviewee for validation and formed to 20 definitive interview reports. To structure and replicate the outcome a recorder was used. The entire reports of the interviews are not included in the annexes due to the large quantity, but available if asked for. Partial reports have been formed to analyze the results per research question and stakeholder category. The most relevant information and relations is described in chapter 3: Results.

Questioning was based on qualitative interviews, as this research needs more profound information and professional visions towards the research questions than can be found in existing literature. Qualitative interviews require a relatively low number of interviewees and have open and flexible results (EURIB, 2011). The qualitative approach offers open questions and thus mutual communication with one on one interaction at location. This urges for a clear target group of interviewees due to the time consuming method of interviewing and reporting (Malterud, 2001). Mutual communication during an interview has three benefits (Zwieten van and Willems, 2004):

1. The occurrence of unexpected information during a conversation with the opportunity to discuss that information further;
2. It gives insight in the perception and interpretation of the interviewee;
3. Qualitative interviews, which took on average approximately one hour, offer thorough time with and thus information from the correspondent.

A point of attention is that the replicability is endangered because of mutual communication, but trough the standardized questions per stakeholder category it is still the aim that the interviews are replicable and do have the same outcome with a different interviewer (AmCOGG, 2002). Qualitative interviews are an iterative process. The same open questions are repeated with different interviewees, but the outcome is different due to the respondents' perception and area of knowledge (AmCOGG, 2002).

Each interview addressed and thus offered input to both research questions within one interview. The interviews started with general information about the interviewee and then addressed five topics in five chapters:

1. General aspects of dike inspection and/or examination;
2. Detailed aspects of dike inspection;
3. Dike monitoring techniques;
4. Policy;
5. Future vision.

Paragraph 3.1.3 was determined to answer research question 1 by means of perception found in the interviews. Concerning the interview structure the following topics questioned offered input: 1. General aspects of inspection and/or examination, 2. Detailed aspects of dike inspection and 3. Dike monitoring techniques. The figures were a result from the interviews and the conclusion is a synthesis.

During the entire interview process development of knowledge was seen because of literature and interviews. Research question 1 was elaborated first and the input gained served research question 2 also.

2.3 Research question 2

The approach of gaining insight in research question 2 started during elaborating research question 1. It continued by further literature study and conducting and analyzing interviews in the meantime. Therefore relevant literature is addressed per paragraph, followed by explanation of the related interview questions.

Literature

Relevant literature within the topic of research question 2 was mostly found in governmental documents as it offers reference to the current implementation level and future aims and goals. To a lesser extent consultancy reports, scientific reports and the internet gave input.

The first paragraph (3.2.1) was formed by literature and personal analysis. The heading literature implementation was formed by governmental documents and scientific and consultancy reports. The policy heading was a review of governmental documents. For practical implementation within dike inspection, examination and research every source of literature was consulted.
The second paragraph (3.2.2) was determined by interviews.
The third paragraph (3.2.3) is mostly a literature study of consultancy reports and the internet. A synthesis was created from the literature. The figures are drawn from personal analysis.
The fourth paragraph (3.2.4) was determined by interviews mostly and partially by governmental documents and personal analysis.

The fifth paragraph (3.2.5) is a synthesis drawn from personal analysis of which the foundation is found in all relevant literature, but also interviews. The figures are drawn from personal analysis.

Since both literature and interviews did not provide direct answers to the research question, a synthesis often had to be conducted as most solid base for conclusions. The interviews conducted during the elaboration of research question 1 caused preliminary insights. The combination of research gaps in literature and interviews offered the base to analysis.

Interviews
Most interviews were conducted during the first analysis of research question 1, but some interviews were conducted within research question 2. This immediately urges the necessity of awareness about feedback, while the interview analysis in research question 1 changed due to new interview outcomes.

Two paragraphs were drawn from the interviews to answer research question 2.
The first paragraph (3.2.2) was made from interview chapters: 3. Dike monitoring techniques and 5. Future vision. Conclusions have been made from the interviews and personal analysis.
The second paragraph (3.2.4) had consideration within all set interview questions. Literature by means of governmental documents and personal analysis also contributed within the conclusions.

When the interviews for research question 2 were finished, results of research question 1 were reviewed with the new knowledge and insights of additional literature and interviews gained. This connection is seen throughout the research. Answering is therefore cohesive to the main research question.

3. Results

3.1 How can dike monitoring techniques enhance dike inspection and examination practices?

Remote sensing, in situ and standardization techniques are found to be the existing dike monitoring techniques (Bakkenist and Zomer., 2010; Swart, 2007; de Vries et al., 2014). Remote sensing techniques observe phenomena at and from the outside of the dike produced by product developers (de Vries et al., 2014). In situ techniques observe phenomena from and about the inside of the dike produced by product developers (de Vries et al., 2014). Standardization techniques offer practical tools towards data processing produced by water authorities to enhance procedures (STOWA, 2012c).
A general overview of the most common remote sensing and in situ techniques in relation with the most common failure mechanisms are shown in Annex 6. The results from the annex is analyzed and elaborated with the associated literature to determine the remote sensing, in situ and standardization techniques that can enhance dike inspection (3.1.1) and examination (3.1.2).
The general concept of dike inspection and examination to which the dike monitoring techniques relate for enhancement is shown in Annex 4 and 5.
The perceptions by all involved stakeholders towards dike monitoring techniques in general and in relation to dike inspection and examination (3.1.3) are gained by interviews.

3.1.1 Enhancement of dike inspection with dike monitoring techniques

In this paragraph it is clarified how dike monitoring techniques can enhance the current practice of dike inspection.

Overview of dike monitoring techniques that could enhance dike inspection

Remote sensing, in situ and standardization techniques are found to be the dike monitoring techniques appropriate to enhance dike inspection and are elaborated further (Bakkenist and Flos., 2015; Bakkenist and Zomer., 2010; van den Berg and Koelewijn., 2014; Thijs, 2007; Kolk et al., 2011; Moser et al., 2005; Moser et al., 2009; Moser and Zomer., 2006; STOWA, 2004; Swart et al., 2007; Swart, 2007; de Vries et al., 2014).

1) <u>Remote sensing</u>

Table 2 shows the characteristics of the remote sensing techniques that can offer enhancement to dike inspection. The techniques shown are overarching concepts and all have different fields of application of which for some multiple product developers exist. Most important characteristics towards dike inspection enhancement that show are:

- There are five effective types of remote sensing techniques.
- The useful observation is by identifying irregularity. Irregularities could be notified before notification in dike inspection and thus offer enhancement. When overlap is shown in observations, outcomes strengthen each other. All techniques observe different irregularities.
- Output of all effective techniques is by means of a picture that shows the status of a parameter. Output appears when an anomaly is seen. The output offers immediate diagnosis at the office, which is an enhancement. Mostly output substantially differs per technique.
- The variety of failure mechanism notifications per technique could be predictions. A technique shows specified, but limited parameters. During analysis of the output, continued monitoring and dike inspection the actual status of the failure mechanism has to be determined.
- The scope is varying from local, dike trajectory to national. Satellite shows the largest reach and thus fastest insights, sonar and infra-red show the smallest reach and thus most detail.

- The five effective techniques can contribute to the entire inspection cycle. A picture brings identification during the phases of identifying and operationalize and further diagnosis/prognoses possibilities.
- Pictures do not offer direct parameter values, but show parameter processes.
- Not all influences of the dike could be captured by remote sensing techniques.
- Ground radar does not enhance dike inspection because it does not identify threats.

Table 2. Overview of characteristics remote sensing techniques that could enhance dike inspection

Technique	Observation	Output	Parameter(s)	Failure mechanisms	Scope (frequency)	Inspection cycle
A) Infra-red	Surface water excess	Heat picture	Temperature	Piping	Dike trajectory, local (Continuous and temporarily)	Identifying, diagnosis, prognoses, operationalize
B) Micro wave	Inner dike water	Soil moisture picture	Revetment quality and moisture content	Macro stability, micro stability, heave, overtopping	Dike trajectory (Temporarily)	Identifying, diagnosis, prognoses, operationalize
C) Satellite/ In SAR/Lidar /Laser altimetry	Deformation and detailed location insights	(Deformation) picture	Deformation	Overflow and overtopping	National, dike trajectory (Continuous and temporarily)	Identifying, diagnosis, prognoses, operationalize
D) Sonar	Irregularities under water	Deformation, picture under water	Deformation Cracks Non regularities	Erosion foreland, piping, macro stability	Dike trajectory, local (Temporarily)	Identifying, diagnosis, prognoses, operationalize
E) Drones	Irregularities at the outside of the dike	Live view, picture	- (weak spots)	Overtopping, overflow and piping	Dike trajectory (Temporarily)	Identifying, diagnosis, prognoses, operationalize
F) Ground radar	-	-	-	-	-	-

2) <u>In situ</u>

Table 3 shows the outcome of the in situ techniques that could offer enhancement to dike inspection. The techniques shown are overarching concepts and all have different fields of application of which for some multiple product developers exist. Most important characteristics towards dike inspection enhancement that show are:

- There are five effective in situ techniques.
- Observations are about inner dike processes that could not be gained within traditional dike inspection and is thus a clear enhancement. Observations differ per technique.
- The output delivered is by means of irregularity data. The data mostly needs analysis before it is correctly interpreted. All techniques obtain different types of data.
- The parameters offered are way more sensitive and detailed than with visual observations. Small anomalies are shown and offer enhancement. The level of enhancement dependents on the actual occurrence of notifications. Parameters gained differ per technique.

- Failure mechanisms during dike inspection are predictions. The techniques notifies a parameter that could lead to a failure mechanism. Actual occurrence is dependent on analysis of the observation with continuous output and could be referenced by visual inspection.
- The scope is local and the objects stationary. Enhancement is customization and possible after reoccurring uncertainties within dike inspection and/or remote sensing techniques.
- All techniques contribute to the operationalize phase within the inspection cycle. All techniques could theoretically also attribute within the other phases, but implementation due to scale is less likely for more 'random' identifying processes than during (re)construction.
- Not all influences of the dike can be captured by in situ techniques.

Table 3. Overview of characteristics in situ techniques that could enhance dike inspection

Technique	Observation	Output	Parameter(s)	Failure mechanisms	Scope (frequency)	Inspection cycle
A) Stability sensor	Deformation inside the dike	Data (irregularity)	Deformation	Macro stability, micro stability, (overtopping, overflow)	Local (Continuous) /stationary)	Operationalize, (identifying, diagnosis, prognoses)
B) Glass fiber	Deformation and water flow inside the dike	Data (irregularity)	Temperera-ture, permeability	Piping, macro stability, micro stability	Local (Continuous) /stationary)	Operationalize, (identifying, diagnosis, prognoses)
C) Water tension meter	Water tension in soil layers	Data (irregularity)	Water tension, ground water flow	Piping, macro stability, micro stability	Local (Continuous /stationary)	Operationalize, (identifying, diagnosis, prognoses)
D) Density recorder	Density of the surface layer	Data (irregularity)	Erosion	Overflow, overtopping, piping, micro stability	Local (Continuous /stationary)	Operationalize, (identifying, diagnosis, prognoses)
E) Pressure recorder	Ground water movement	Data (irregularity)	Ground water pressure, ground water level	Piping, macro stability, micro stability	Local (Continuous /stationary)	Operationalize, (identifying, diagnosis, prognoses)

3) <u>Standardization techniques</u>

With 'Digispectie' a photograph with possible damage signs of the dikes are made by the operator on a mobile device. It is processed through an app in the database where the photo is elaborated by the specialist at the office. The photos taken from irregularities, for both failure mechanisms and maintenance procedures, are compared towards a guide where general example pictures of irregularities are shown (STOWA, 2011). It causes cooperation and understanding between the operators and specialists, easier data access as paper free method and replicable results and proof (STOWA, 2012a). This is an enhancement compared to paper based processing and data management and is still in development with structural improvements.

Conclusion

Dike monitoring techniques offer in a range of dike inspection topics (Annex 4) enhancement opportunities. They are designed to enhance the identification of irregularities at the inside (in situ) or outside (remote sensing) of the dike by offering objective data. This shows that a dike could not meet the statutory probability of inundation (Moser et al., 2005). Irregularity identification also offers enhancement to the diagnosis and prognoses phases due to the existence of the objective data (Thijs, 2007). During the operationalize phase in which measures (STOWA, 2012) takes place possible enhancement is seen by notifying risk (irregularities) during (re)construction. This again leads to identification.

Remote sensing techniques are the most appropriate because it is closely related towards the identifying method of dike inspection by offering a picture of a preferred process outside the dike. Furthermore it offers surveys at large scale. This is useful for first separation of sensitive areas. The parameter and thus remote sensing technique of preference is dependent on the sensitivities shown in dike inspection. The local and stationary in situ techniques could be appropriate when remote sensing techniques and/or dike inspection show locations with returning irregularities and ask for more detailed knowhow of inner dike processes. During the operationalize phase risks always show and in situ techniques offer enhancement through detailed notifications. It is important to note that parameters gained by remote sensing do not completely overlap with in situ techniques. The preferred insights give importance to relations and choosing the correct technical application.

Traditional dike inspection cannot be completely substituted. Even when a technique offers continuous output (mostly in situ) with set alarm values if anomalies are seen, only specified output is gained and does not address all phenomena that affect the regulatory inundation probability of the dike. Temporarily output (mostly remote sensing) could offer enhancement during critical circumstances. The set alarm values can notify irregularities when it would not have been known during regular dike inspection. An office specialist could than notify the operator, which is opposite to current practice. Dike monitoring techniques can also offer a categorization of the risk level of irregularities, which enhances the diagnosis and prognosis phases. Clusters of irregularities can show locally, per dike trajectory or nationally.

The standardization technique of 'Disispectie' currently offers most enhancements towards dike inspection. It is designed with complete notion of the current dike inspection method and thereby standardizes the process of data management. It is a direct enhancement to a former weakness. The relation of remote sensing and in situ techniques to current practice is more difficult and thus less capable.

3.1.2 Enhancement of examination with dike monitoring techniques

In this paragraph it is clarified how dike monitoring techniques with subsequent characteristics can enhance the current practice of examination. The role and sensitivities of parameter persuasion therein needs special attention.

Overview of dike monitoring techniques that could enhance examination

Mainly in situ techniques and in lesser extent remote sensing and standardization techniques are found to be the dike monitoring techniques appropriate to enhance examination (Bakkenist and Flos., 2015; Bakkenist and Zomer., 2010; van den Berg and Koelewijn., 2014; Kolk et al., 2011; Moser and Zomer., 2006; Rijkswaterstaat, 2013; STOWA, 2004; Swart, 2007; Swart et al., 2007; de Vries et al., 2014; VTV, 2007).

1) <u>Remote sensing</u>

Table 4 shows the outcome of the remote sensing techniques that could offer enhancement to examination. The techniques shown are overarching concepts and all have different fields of application of which for some multiple product developers exist. Most important enhancements towards examination that show are:

- There are six effective remote sensing techniques.
- The input from parameters that could offer enhancement to examination is limited to soil composition values. The parameters soil moisture content, deformation ratios and.

- There is a variety of failure mechanism that can be notified. Limitations are that a technique shows specified, but limited parameters. During analysis of the output compared to the specification within the examination procedure, the actual threat can be determined.
- The scope varies from local to national, but is mostly per dike trajectory. It therefore could give continuous and temporarily insights of irregularities at dike trajectories as reference to calculation outcomes. This is a different method and therefore also be addressed as addition instead of input.
- One technique, ground radar, could enhance directly to all phases of the examination cycle, because it offers clear parameter values for model calculation. Two other techniques (B and C) also offer parameter values, but have less importance towards calculations.
- All techniques are appropriate during the (re)construction phase. It could act as a reference for actual irregularities by means of actual damage pictures.
- Not many influences of the dike could be captured by remote sensing techniques for examination.

Table 4. Overview of characteristics remote sensing techniques that could enhance examination

Technique	Observation	Output	Model input parameter(s)	Failure mechanisms	Scope (frequency)	Examination cycle
A) Infra-red	Reference for actual irregularities	Heat picture	-	Piping	Dike trajectory, local (Continuous and temporarily)	(Re)construction
B) Micro wave	Reference for actual irregularities	Soil moisture picture	Soil moisture content	Overtopping, macro stability, micro stability	Dike trajectory (Temporarily)	(Re)construction Parameter research (round 2, 3)
C) Satellite/ In SAR/Lidar /Laser altimetry	Reference for actual irregularities	(Deformatio n) picture	Deformation rate	Overflow and overtopping	National, dike trajectory (Continuous and temporarily)	(Re)construction Parameter research (round 2, 3)
D) Sonar	Reference for actual irregularities	Deformation , picture under water	-	Piping, macro stability, Erosion foreland	Dike trajectory, local (Temporarily)	(Re)construction
E) Drones	Reference for actual irregularities	Live view, picture	-	Overtopping, overflow, piping	Dike trajectory (Temporarily)	(Re)construction
F) Ground radar	Soil characteristic	Data of soil structure in radar gram	Soil composition	-	Local (Temporarily)	Parameter research (round 1, 2, 3), (re)construction

2) <u>In situ</u>

Table 5 shows the outcome of the in situ techniques that could offer enhancement to dike inspection. The techniques shown are overarching concepts and all have different fields of application of which for some multiple product developers exist. Most important enhancements towards examination that show are:

- There are five effective in situ techniques.
- Observations that offer information differ from parameter information in the normal state towards sensitivity observations during hydrological and/or natural differences.
- The output offers a large enhancement, seen because in situ techniques offer clear output of data from which parameters can be analyzed that serve as and enhance input to the models. It does

show most use during the second and third research phase, because detailed local data is needed on locations that are determined as unsafe.

- There is a variety of failure mechanism that can be notified. Limitations are that a technique shows specified, but limited parameters. During analysis of the output compared to the specification within the examination procedure, the actual threat can be determined.
- The scope is local and the objects stationary. Implementation is customization in correspondence towards the needs.
- All techniques contribute to all research phases and the construction phase within the examination cycle.
- Irregularities observed can be a reference to the outcomes of examination calculations about the actual status of the dike. This offers additional insight and thus enhancement.
- Phenomena about the inside of the dike give detailed insights that would not be known within regular examination procedure.

Table 5. Overview of characteristics in situ techniques that could enhance examination

Technique	Observation	Output	Model input parameter(s)	Failure mechanisms	Scope (frequency)	Examination cycle
A) Stability sensor	Deformation inside the dike	Data (model)	Deformation	Macro stability, micro stability, (overtopping, overflow)	Local (Continuous /stationary)	Parameter research (round 1, 2, 3), (re)construction
B) Glass fiber	Deformation and water flow inside the dike	Data (model)	Temperera-ture, permeability	Piping, macro stability, micro stability	Local (Continuous /stationary)	Parameter research (round 1, 2, 3) (re)construction
C) Water tension meter	Water tension in soil layers	Data (model)	Water tension, ground water flow	Piping, macro stability, micro stability	Local (Continuous /stationary)	Parameter research (round 1, 2, 3), (re)construction
D) Density recorder	Density of the surface layer	Data (model)	Erosion	Overflow, overtopping, piping, micro stability	Local (Continuous /stationary)	Parameter research (round 1, 2, 3), (re)construction
E) Pressure recorder	Ground water movement	Data (model)	Ground water pressure, ground water level	Piping, macro stability, micro stability	Local (Continuous /stationary)	Parameter research (round 1, 2, 3), (re)construction

3) Standardization techniques

The DDSC is the main standardization technique which enhances examination. It offers objective validation of the parameters over large data sets (FloodControl IJkdijk, 2015). All data that is ever gained of all measurements by all inscribed dike monitoring technique developers is stored. As most of the information is no primary need for the water authorities, it will not immediately be used. Still these data are useful in examinations over time. The platform receives raw data, which is structured and analyzed to monitor the preferred project related outcomes (de Vries et al., 2014). It also facilitates interpretation of actual alarm values, the clutch to databases and reports of water authorities and accessibility through apps and software on computer, tablet or mobile phone. Combination of real-time and historical data offers a connection between the data of multiple water boards and offers structural enhancement possibilities in parameter validity (FloodControl IJkdijk, 2015).

Parameter persuasion to enhance examination

Parameters are of major importance to determine the actual status of the dike. Dike monitoring techniques do address them sometimes directly and sometimes indirectly (table 2, 3, 4 and 5). Dike monitoring techniques could also measure a different set of parameters compared to dike inspection and examination. A failure mechanism being calculated in examination is the result from the occurrence of parameters and the array of parameters is different per failure mechanism (Swart, 2007).

Parameters can be seen in different manners. Construction parameters are used for the construction of the dike structure, hydraulic parameters address the hydraulic condition and occurrence parameters are defined as irregularities. It is important to make these distinctions, while they all are important properties to water retaining dike management, but used in other contexts (Swart, 2007). Overflow is for example mostly dependent on height (construction parameter, Table 6), but meanwhile height undergoes change as a consequence of subsidence (failure parameter, Table 7) and the subsidence is dependent on the soil composition and ground water level (occurrence parameter, Table 8).

Within examination, construction and hydraulic parameters have most attention (Table 6, 7 and 8), but is thus influenced by other parameters. Dike monitoring techniques sometimes offer direct input towards the parameter used in examination, but also focuses on different sensitivities. Observations by dike monitoring techniques are most holistic, although it requires customization as the observations are separated in many types. Also dike inspection gives attention to many parameters, but the observations do not offer direct parameter values that can be used during examination practices. Examination parameters that cannot be addressed by dike monitoring techniques are mostly dependent on standard assumptions and conditions set during the design.

Table 6. Construction parameters related to failure mechanisms

Nr.	Failure mechanism	Dike height	Slope	Type revetment	Quality revetment	Dike core	Soil composition	Permea-bility	Ground strength
1	Overflow	XXX	X	X					
2	Overtopping	XXX	XXX	XX	XXX	X	XX		
3	Macro instability	XXX	XXX			X	XX	XX	XX
4	Micro instability			XX	XXX	X			
5	Piping / heave						XX	XX	
6	Erosion foreland								
7	Softening						XX	XX	

Xye = Examination, Xbr = Dike monitoring techniques, Xbl = Dike inspection

Table 7. Hydraulic parameters related to failure mechanisms

Nr	Failure mechanism	Water height	Wave height	Water pressure	Subsi-dence	Rain impact	Infil-tration	Traffic	Rough-ness	Ice	Animals	Drought
1	Overflow	XXX	XXX		XX			X	XX		X	
2	Overtopping	XXX	XXX		XX	X	X	X	XX		X	
3	Macro instability	XXX	XXX	XX				X	XX	XX		X
4	Micro instability	X		XX		X	X	X			X	X
5	Piping / heave	X	XXX	XX					XX	XX		
6	Erosion foreland	X										
7	Softening			XX	XX				XX	XX		

Xye = Examination, Xbr = Dike monitoring techniques, Xbl = Dike inspection,

Table 8. Irregularity parameters related to failure mechanisms

		Revetment					Dike core				
Nr.	Failure mechanism	Cracks	Bald	Color	Wet	Lower-ing	Tempe-rature	Water tension	Material flow	Ground water level	Vibrations
1	Overflow	X	X			X				X	X
2	Overtopping	X	X	X	XX	X					X
3	Macro instability	X	X				X	X	X	X	X
4	Micro instability	X	X	X	XX		X	X	X	X	
5	Piping / heave						X	X	XX	X	
6	Erosion foreland										
7	Softening							X		X	

Xye = Examination, Xbr = Dike monitoring techniques, Xbl = Dike inspection

In former examination programs a lack of budget was an important cause of non-extensive parameter research (Rijkswaterstaat, 2013). This now triggered the demand for cost efficiency to which the objectivity of dike monitoring techniques can contribute. The interaction between research investments and preferred knowledge is thereby of importance.
The main parameter uncertainties in current examination programs are described in van den Berg and Koelewijn (2014): the normative water levels, soil composition, soil characteristics, water tension sensitivities, top load and overall strength. As seen in Table 6, 7 and 8 most uncertainties can be researched and thus enhanced by applying dike monitoring techniques. The uncertainties occurred because dike inspection and examination offer limited observations. Profound insights in these parameters were not possible before the development of dike monitoring techniques.

Conclusion
For enhancement in examination it is most important that dike processes are increasingly known. This gives a higher quality of input (parameters) and determines the accountability of the mathematical models (Rijkswaterstaat, 2013). The three phases of parameter research after a dike is determined unsafe face offers most enhancement opportunities through dike monitoring techniques. In situ techniques are most appropriate as they give usable parameter values to which the standard assumptions can be referenced. Especially on locations where the specialist and the operator agree that uncertainties are large it could offer direct enhancement. Preliminary research, available knowledge and historical context can determine to what parameters further knowhow is needed or not (Swart, 2007). A large risk by applying dike monitoring techniques is monitoring the wrong parameters, due to which actual degradation of the dike is not seen, but occurring (van den Berg and Koelewijn, 2014).

Remote sensing techniques are mostly a possible enhancement in order to serve as reference to gain insight in the actual status of the dike by means of irregularity notifications. Within examination this could be useful when a dike is determined as unsafe, but that the difference between safe and unsafe is small. When the concerned failure mechanism or parameter shows overlap with the technical characteristics of a remote sensing and/or in situ technique this can be applied to reference the outcome. Ground radar as remote sensing technique does offer direct enhancement by providing parameter values.

The accountability of models is important while they are the most important reasoning for (re)construction processes water retaining water management. Currently one third of the dikes are being regarded as 'unsafe', meaning that (re)constructions have to take place, which costs approximately €5-10 million per km (VNK, 2012). Due to the range of assumptions it is possible that dikes with the status safe are actually in need of (re)construction and vice versa. On the long term the application of dike monitoring techniques leads to structural verification of parameter values. Moreover it offers reference of examination outcomes over time compared to actual occuring damage pictures. The application and intensity of dike monitoring techniques can be adjusted to forthcoming results. Towards this concept the standardization techniqe and concept of DDSC can offer enhancemenent. This relates towards the operators' judgement. The operator also verifies examination outcomes when it is determined that the dike is unsafe with his personal experiences (Rijskwaterstaat, 2013).

3.1.3 Perception stakeholders towards the enhancement by dike monitoring techniques
The perception of the enhancement by dike monitoring techniques is in this paragraph shown through the general perception of the sufficiency and enhancement within dike inspection and examination practices.

Perception sufficiency of dike monitoring techniques
The interviews conducted have offered information about the perception of the sufficiency of dike monitoring techniques (Table 9). The most important results that can be drawn are that:

- Specialists and operators at the water boards do not see the current knowhow about dike monitoring techniques as sufficient, while research agencies and product developers do so.
- Specialists at the water boards believe that the level of current implementation of dike monitoring techniques is sufficient, but research agencies and product developers disagree.
- There is a common believe in the possibilities of dike monitoring techniques by all stakeholders, although there is a varied level of skepticism at the water boards.
- Research agencies and product developers believe that the current sense of urgency is not enough, the operators and specialists at water boards however do think the opposite.

Table 9. Perception towards the sufficiency of characteristics dike monitoring techniques

Dike monitoring	Stakeholders							
Characteristics	Operator water board		Specialist water board		Research agency		Product developer	
Sufficient?	Yes	No	Yes	No	Yes	No	Yes	No
Knowhow	0	4	1	3	3	1	6	0
Implementation	-	-	4	0	0	4	0	6
Possibilities	3	1	2	2	4	0	5	1
Urgency	4	0	4	0	1	3	1	5

Further elaboration is shown below to clarify the line of thinking more thoroughly.

Operator water board

It becomes clear that not only the use of dike monitoring techniques is not practiced by operators, but that they also have little to no knowledge about the concept of dike monitoring techniques. 'Research towards dike monitoring techniques is the working field of our specialists' (operator 1, 3, 2015). All operators are positive about the progression in standardization that is gained by Digispectie, which they do all apply, and do think that this is the most important technological feature. 'Although the app also has its drawbacks because it causes more cooperation and therefore bureaucracy' (operator 2, 3, 2015).

Specialist water board

Specialists at water boards have no clear image about the costs and benefits, validity and available techniques. Symbolic statements about dike monitoring techniques are: 'it has to be a limited effort to first find the possibilities and then to implement it' (specialist 1, 2015), 'visions and insights of us are all based on personal initiatives and this is therefore an ad hoc process' (specialist 1, 2015), 'the most important benefits are hard to tell because we do not know what the exact added value or the preferred accuracy of the techniques is' (specialist 2, 2015) and 'the products need to prove themselves as I do not have clear what their direct added value is' (specialist 3, 2015).

Research agencies

All research agencies agree that the current status of dike monitoring techniques offers theoretical enhancement by offering a more objective insight towards current water retaining dike management practices. They also believe that the dike monitoring techniques have proven themselves the previous years and that implementation should follow (researcher 1, 2, 3, 4, 2015), but also that techniques should focus more on demand (researcher 3, 2015). More financial budget is needed for research to enlarge the small group of current specialists (researcher 2, 2015).

Product developer

All product developers are convinced that their product has additions to the concept of dike monitoring techniques. Their most important references are unique expertise and objectivity. The product developers claim that the water boards are not aware of the possibilities and not willing to adapt. They believe that marketing gets increasingly important, but mostly that water authorities should change their attitudes (product developer 1, 2, 3, 4, 5, 6, 2015).

Conclusion

In general the operators and specialists at the water boards have the same perception tendency and research agencies and product developers also. Researchers and product developers investigate the technical feasibility of dike monitoring techniques, but they only assume that it additions to the demands of the water authorities. It seems that water authorities do not have clear what the status and concrete added value of dike monitoring techniques are, while product developers think that it is obvious. The research agencies endorse the necessity and enhancement that the product developers claim, but it seems that structural change is needed to persuade the water boards. The lack of urgency at the water boards stresses the need for a new approach, because urgency is seen at the research agencies and product developers. The fact that operators and specialists do believe in the possibilities offers opportunities.

Perception enhancement dike inspection with dike monitoring techniques
The interviews conducted offer the perception about the sufficiency of dike inspection and potential enhancement through dike monitoring techniques (Table 10). The most important results that can be drawn are that:

- Operators and specialists of water boards believe that the knowhow that dike inspection gives (without monitoring) is sufficient. Research agencies do agree that it gives knowhow, but think that it could by enhanced more objectivity. Product developers claim that it is not a sufficient procedure to determine the actual status of the dike.
- The water boards and research agencies think that the current level of dike inspection implementation is sufficient, because even with dike monitoring techniques it remains necessary. Product developers believe that it provides too little knowhow and that it thus should not be conducted in this order of scale.
- All stakeholders think that possibilities to further improvements of dike inspection are possible and that applying dike monitoring techniques is the most appropriate and thus inevitable over time.
- The water boards believe that possibilities do not mean urgency. The current sufficiency of dike inspection does not urge change. This is an opinion to which research agencies and product developers disagree, because they believe water safety depends on seldom seen critical circumstances and that enhancement by dike monitoring techniques have to take place.

Table 10. Perception towards sufficiency of characteristics dike inspection and potential with dike monitoring techniques

Dike inspection	Stakeholders							
Characteristics	**Operator water board**		**Specialist water board**		**Research agency**		**Product developer**	
Sufficient	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
Knowhow	4	0	4	0	2	2	6	0
Implementation	4	0	4	0	3	1	0	6
Possibilities	4	0	4	0	3	1	5	1
Urgency	1	3	0	4	3	1	6	0

Further elaboration is shown below to clarify the line of thinking more thoroughly.

<u>Operator water board</u>
The operators are the executors of dike inspection and believe in the use and necessity of this concept, although they are mostly aware that their method of practice is to a certain extents not comprehensive. Still a common conception of current practices is that ‘750 years of knowledge does not need sudden changes now’ (operator 1, 2015). The recent change seen in dike inspection is the focus on processes and does feel like ‘putting old wine in new bags’ (operator 1, 2015). Operators are not aware of the possibilities that dike monitoring techniques offer. Also the operators think, more than the specialists, that when techniques improve it is the way to more efficiency (operator 2, 3, 4, 2015).

Specialist water board

The specialists of the water boards believe in the current method of dike inspection and do think that the dike monitoring techniques available first need to prove themselves. All specialists emphasize with the 'Inspectieplan' (STOWA, 2012) and believe that it offers a clear and sufficient guideline for the identifying, diagnosis, prognoses and operationalize steps as leading method. They all agree that current focus is on dike inspection, 'because it offers the desired insights' (specialist 3, 2015). Dike inspection also need enhancement of data management, processing of that data and the general approach (risk based) and not just objectivity of the outcome by means of dike monitoring techniques (specialist 1, 2015). It is seen that the corresponding focus next to monitoring techniques draws all attention of enhancement and implementation within their field of practice and less by 'vague' techniques.

Research agency

Most research agencies think that dike inspection is necessary, but that it should be structurally complemented by dike monitoring techniques as additional tool. The research agencies agree that the current focus of the water boards is at dike inspection, while the focus of the commercial market is on dike monitoring techniques. Mainly because the water boards do the same trick for a long time this works quite well and emergency situations are rare. This together with their large responsibilities to the inhabitants causes that they cannot follow every trend. Now that developments go so fast and it could possibly provide cost reductions the awareness starts to grow (researcher 2, 2015). All interviewees of the research agencies believe that 'the most important point of attention for dike inspection is that they should have more attention for monitoring techniques' (researcher 1, 2015). An operator conducting inspection has many inaccuracies, due to his relative little experience compared to the dikes history, change in forces circumstances and the large exceeding norms, which he probably will never experience. Furthermore does the operator have insights about the outside, while the most important processes initiate at the inside of the dike.

Product developer

The product developers think that the techniques are fully developed and that it is time that the required implementations in water retaining dike management takes place. All the product developers are very unanimous and experience that the current focus is on dike inspection. Despite all efforts dike monitoring techniques still do not have a substantive contribution to the traditional dike inspection methods. This causes dissatisfaction that sometimes leads to reproaches towards 'the conservative water authorities' (product developer 1, 4, 2015). Like the research agencies they believe that the most important enhancement of dike inspection should be the implementation of dike monitoring techniques. All product developers believe that 'the current approach is too subjective and that a more advanced overview of the processes in the dikes is necessary to increase the knowledge about the system' (product developer 1, 2, 3, 4, 5, 6 2015). Failure mechanisms are hard to detect with visual observations, but damage pictures are more feasible. These enhancements are only possible, and already developed, by means of dike monitoring techniques' (product developer 1, 3, 4, 5, 2015). It is seen that they do know little about dike inspection methods themselves and rather focused on the development of their own product.

Conclusion

In general the operators and specialists have the same perception tendency and research agencies and product developers also. The current method of dike inspection through visual observations of operators is considered as a reliable source of daily regulation by the operators and specialists. However research agencies and product developers believe that the current method could be enhanced by means of more objective observation in which dike monitoring techniques are validated as useful addition. The water boards do endorse the possibilities of improvements in dike inspection by dike monitoring techniques, but do not feel the urgency. It is case for the product developers to prove the urgency they state is needed within dike inspection to be valid. Hereby they can use the perception of the research agencies.

Perception enhancement examination with dike monitoring techniques
The interviews conducted offer the perception about the sufficiency of examination and potential enhancement through dike monitoring techniques (Table 11). The most important results that can be drawn are that:

- The operators at the water boards and the product developers do not have sufficient knowhow to give well founded answers to the questions asked about examination and are therefore not included.
- It is thought by the specialists of water boards that the current knowhow about examination is sufficient. Researchers within research agencies mostly disagree and believe that large enhancements could be shown, mainly by reducing the uncertainties. Dike monitoring techniques could contribute.
- Both the specialists and the research agencies believe that examination is properly implemented. Meaning that they accord on the importance and future need.
- The possibilities of improvement that examination could face cause different opinions among the specialists and research agencies. Research agencies mostly believe in better parameterization through technology.
- The research agencies do think that the current level of urgency towards enhancements is not sufficient. They believe large investments are at stake with the lacking objectivity in current practice, the specialists do not see this.

Table 11. Perception towards sufficiency of characteristics examination and potential with dike monitoring techniques

Examination	Stakeholders							
Characteristics	Operator water board		Specialist water board		Research agency		Product developer	
Sufficient	Yes	No	Yes	No	Yes	No	Yes	No
Knowhow	-	-	4	0	1	3	-	-
Implementation	-	-	4	0	4	0	-	-
Possibilities	-	-	2	2	3	1	-	-
Urgency	-	-	4	0	1	3	-	-

Further elaboration is shown below to clarify the line of thinking more thoroughly.

Operator water board
The operators do not have a clear image by examination. They state that their focus is on dike inspection and that such operations are addressed by the office specialists (operator 1, 2, 3, 4, 2015).

Specialist water board
The specialists at the water authorities believe that examination gives a clear image about the status of the dike and that it is therefore legitimate to determine and execute construction programs (specialist 2, 3, 2015). The actual relevance towards examination is limited as it addressed as separated processes, although 'a more risk based manner of examination could offer enhancement' (specialist 1, 2015). Dike monitoring techniques could bring more objectivity towards the concept of examination, but should first prove their use. They see enhancement of dike monitoring techniques separated to examination.

Research agency

The research agencies are very aware of examination principles. Research agency 2 and 3 conducted multiple researches themselves towards the uncertainties in calculation. They found that the uncertainties are very high and that the consequences are large also. They urge for an improved parameterization. In this they emphasize on dike monitoring techniques, while it has the potential to offer the insight required within parameter validation and irregularities notification. in offering Hereby it is of most importance that techniques are also suitable to give substantial output to the current field of application (dike inspection and examination) (research agency 2, 3, 4, 2015).

Product developer

It is noticeable that the product developers do not have a clear opinion about examination. It clarifies that their focus is on the application of dike inspection (product developers 1, 4, 5, 2015). It thus also clarifies that their products are designed more towards dike inspection than examination, which shows the lack of direct parameter output. They believe that dike monitoring techniques offer a more thorough manner of information output than examination and examination is thus inferior.

Conclusion

The specialists of the water board and research agencies have different opinions. By specialists of the water authorities the current method of examination is considered as a reliable source of thorough foundation to determine the statutory inundation probability. Some endorse the possibilities towards enhancement, but urgency is again not felt. The research agencies believe that the current method should be improved by more accurate parameter input. In their opinion dike monitoring techniques are the most promising possibility to face structural enhancement. The current amount of investments clarifies urgency. Operators and product developers have limited knowledge in the concept of examination. This is noticeable because product developers try to contribute within the concept of water retaining water management. It is seen that they thus try to develop a new concept instead of an additional concept towards current practices. Special ignorance is seen towards the concept of examination.

3.2 How can dike monitoring techniques be implemented in dike inspection and examination practices?

This sub chapter shows how the potential enhancements of sub chapter 3.1 can be implemented within the current practice of dike inspection and examination. The first paragraph elaborates the current level of implementation of dike monitoring techniques within dike inspection and examination (3.2.1). This relates to the perception towards current and future developments by the stakeholders (3.2.2). Costs and benefits (3.2.3) and cooperation (3.2.4) show processes that influences the level of implementation. All elaborated information leads to five possible implementation scenarios (3.2.5).

3.2.1 Current implementation of dike monitoring techniques

Implementation of monitoring techniques exists. It is researched to what extent the dike monitoring techniques are implemented in literature, policies and in practice of dike inspection, examination and validation research to understand the context towards future implementation.

Literature implementation of dike monitoring techniques

The implementation of literature towards dike monitoring techniques is subsequent to the unforeseen dike breaches in Wilnis (2003) and Stijn (2004) (Rijksoverheid, 2006). The first report by Swart et al. (2003) provided stocktaking and also the last substantive questionnaires in which it was shown that remote sensing techniques could offer additional insights towards the practice of the operator. There was a lack of financial decisiveness and the subsequent reports in the program were not created. The first substantive subsequent report came forth from the VIW program. The report of STOWA (2004) offered an overview of dike inspection and dike monitoring techniques for dry peat slopes (case in Wilnis and Stijn). The report of Moser et al. 2005 mainly concerned the practice of dike inspection, but recommended further research to remote sensing techniques. This led to an overview of substantive background information in all known measurement techniques by Moser et al. (2006) to improve mutual insights. A more practical approach was provided by Swart (2007) in which the application of remote sensing is related to dike inspection processes. The dike monitoring techniques showcased did not face implementation as it has not been taken account in governmental guidelines.

The main feature in dike monitoring literature during the PIW program was IJkdijk. IJkdijk aims for practical validation tests of existing techniques and to create awareness by water authorities (3.2.1 validation research p. 35). The report of Bakkenist and Zomer (2010) en de Vries et al., (2014) provided updated overviews the specifications of all dike monitoring techniques. Van den Berg and Koelewijn (2014) gave notion towards sensor techniques with the link towards examinations and practical field tests. The first implementation of these descriptive researches in a practical policy guideline was the HIW, which provided 'Inspectiewijzers' (3.2.1 policy p. 34).

Besides the 'Inspectiewijzers' towards dike inspection and van den Berg and Koelewijn (2014) towards examination the literature does not seem to cope with an approach of dike monitoring techniques towards current practice. STOWA (2004), Moser et al. (2006), Swart (2007) and de Vries et al., (2014) all contributed to technique validation with a substantive variety of frameworks, but a lack of attention in literature over time is towards the needs of the client (water authorities) and their practices. Reports of the product developing companies are not insightful; however they develop the technique and thus have the technical knowhow and insights. The interviews in this research therefore seem to fill a research gap.

Policy implementation of dike monitoring techniques

Dike monitoring techniques can be an enhancement for dike inspection and examination practices as it provides related, additional and objective data (chapter 3.1). Policy (Annex 3), determines the legal boundary conditions towards possible implementation of innovations as dike monitoring techniques. It is seen that it still has little attention in current policy documents that of dike monitoring techniques. The policy documents that have most influence towards dike inspection and examination are analyzed: the ‘Waterbeheerplannen’, the ‘Onderhoudsplannen’, the ‘Inspectieplannen’ and WTI2017.

It is seen that the traditional ‘Waterbeheerplannen’ are not focused on substantive information, but on general processes and aims (Delfland, 2014). The current process based focus of water retaining dike management is on dike inspection only in which dike monitoring techniques and examination are not mentioned. All responsibilities and tasks of the water boards are mentioned. Innovation in general is not mentioned too, which shows the limited attention and implementation in practice.

The ‘Onderhoudsplannen’ are very much focused on maintenance procedures that address the general upkeep of designed water bodies, dike structures and water structures. No attention is given to further management aspects that could undermine the actual statutory probability of inundation in which dike processes next to upkeep are discussed (Noorderzijlvest, 2014).

The new ‘Zorgplicht’ is in developing policy reports of water boards addressed and interpreted in many ways (STOWA, 2015a). Mostly current concept reports are called ‘Inspectieplannen’ in which current procedures are rewritten towards the wishes of ILT, who provide supervision (ILT, 2015). The change in policy does not change the approach of addressing water retaining dike management thoroughly. It is limited to increased attention in conceptualizing and framing the process of dike inspection. As this in itself is already ‘new’ to the water boards most attention goes to following the new rules. Not towards critical reviewing the water retaining dike management concept with subsequent designations and enhancements with for example dike monitoring techniques. The existence is only mentioned (briefly) in one of the five analyzed concept reports of the water boards (Noorderzijlvest, 2014). The annotation of remote sensing and in situ techniques is not seen. Table 12 shows the large variety and different levels of concern among the water boards that the five water boards addressed within their ‘Inspectieplannen’. The broader concept term of innovation is mentioned more often, but this thus does not face actual concrete qualifications.

Table 12. Water retaining dike management elements considered in concept ‘Inspectieplannen’

‘Inspectieplan’ water board	Dike inspection	Examination	Innovation	Monitoring	Standardization technique	Remote sensing	In situ
Rivierenland	X	X	-	-	-	-	-
Groot Salland	X	X	X	-	-	-	-
Brabantse Delta	X	-	X	-	-	-	-
Noorderzijlvest	X	X	-	-	X	-	-
Rijnland	-	-	X	X	-	-	-

The different and inconstant contents of policies influence the possibilities of implementation for dike monitoring techniques. The lack of attention by policy makers affects the attention by specialists and operators, whom are the client for product developers. Currently dike monitoring techniques are taken very little in account without reasoning. It would be well-founded when all relevant topics (dike monitoring techniques proved validity de Vries et al., 2014) are concerned in policies with substantial foundation about the choices made of applying a relevant method and/or development or not. This is a shortcoming, while the only real structural progression seen in the last decade is with ‘Digispectie’ an enhancement by a standardization technique (STOWA, 2011). Policy was made in VIW and has thus proved its effect.

Dike inspection implementation of dike monitoring techniques
Identifying irregularities is the aspect that has most overlap and potential enhancement with dike inspection and dike monitoring techniques (3.2.2). The HIW (STOWA, 2012) is the only guideline that gives input to the practical applications of the identification process with both dike inspection and dike monitoring techniques. It contains 61 'Inspectiewijzers', which gives insight in 61 practical possibilities of dike irregularities and a corresponding array of identification, prognoses, diagnosis and operationalize methods (STOWA, 2012c). These 'Inspectiewijzers' cover traditional methods rather thoroughly and gives sideways attention to additional dike monitoring techniques (STOWA, 2012c). This amalgamation seems to be the only way towards implementation, but despite the mentioning in the 'Inspectiewijzers' structural implementation is still not seen. This could be the case because the lacking knowledge of product developers towards this mentioning in policy and policies in general. The interviews showed that they are not aware of the 'Inspectiewijzers' and new 'Zorgplicht'. An increasing attention could be of importance. No attention is given to the relation of examination within dike inspection. Some water boards stated (specialist 3, 4, 2015) that they have conducted some research with dike monitoring techniques, but none water board told about structural implementation. Waterschap Rijnland for example conducted height measurements through satellite three years ago to identify irregularities, but this was not continued. It is limited to research validation programs (3.2.1 p. 35).

Examination implementation of dike monitoring techniques
Research towards parameters is the aspect that has potential overlap and possible enhancement between examination and dike monitoring techniques (3.2.3). This research is in practice seen in lab and field measurements (Berg and Koelewijn, 2014). Lab research is small scaled with simplified methods that mimic specified field appearances. Field research though contains real life measurements dependent on dike monitoring techniques to observe anomalies (Rijkswaterstaat, 2013). Not all techniques are sufficient for implementation in parameter research though as most remote sensing techniques focus solely on a damage image (chapter 3.1.2), which gives insight in irregularities. The dike monitoring techniques already offer substantive input towards current parameter uncertainties and thus examination in all ongoing research validation programs. Research depends on finance though. And finance is only gained if all stakeholders see the added value. Currently this added value is seen partly.
Dike monitoring techniques function by disparities over time and the quality of data will only improve. Within WTI2017 program new data will therefore already be taken into account thoroughly (Rijkswaterstaat, 2013). To make the new information flow common custom organizational efforts have to show as already seen in DDSC. The organizational structure should aim for knowledge transparency and cooperation within and between stakeholders.

Research validation implementation of dike monitoring techniques
Research validation projects are the only practice where implementation is structurally seen. Dike monitoring techniques get validated and it creates awareness. IJkdijk had a lot of the first real time simulation of dike inundation circumstances. Five tests gave the most important contribution towards the validation of dike monitoring techniques. The five experimental IJkdijk failure tests are: 'Macro stability test' (Weijers et al., 2009), 'Piping test' (Koelewijn et al. 2010), 'All-in-one Sensor Validation test' (de Vries et al., 2014) and 'Subsidence flow test' (FloodControl IJkdijk, 2015). Within the experiments it is essential at what stage each technique observes change, if any. The contribution towards practical implementation is seen in the 'Livedijken' component. These are smaller scaled tests within existing dikes, set up for real time dike monitoring to gain objective insights in expected practice based problems. Anomalies seen during long term monitoring are compared to the expected calculations by which assumptions of the technique and calculations change (Berg and Koelewijn, 2014). The scale and application of the 'Livedijken' depends on

the assigned aim and location. A further density of implementation will also be the focus of future IJkdijk projects (research agency 3, 2015).

Next to the 'Livedijken' some water boards also conduct their own researches. The scope is specified to specific failure mechanisms and/or parameters and applications are rare, but they offer the opportunity for techniques to prove their abilities. 22 researches have been conducted in total and are thoroughly described and analyzed in van den Berg and Koelewijn (2014) on grounds of measurements, results and particularities. All Livedijk experiments show diverse characteristics and satisfactions of the outcome. During most experiments problems were seen in the material of the technique, which is striking because it shows that dike monitoring techniques are not finished developing yet. Furthermore it shows that unsatisfying results occur in which data interpretation is the main problem. Positive feedbacks also show. The problems faced prove that dike monitoring techniques are no common practice. It is thereby hard to state whether consistency will improve fast when more intensive implementation is seen.
Theory does not always correspond with practice. During the experiment of LivedijkXL it was told that eight identical sensors were put in an apparently homogenous sand layer (researcher 2, 2015). During application it seemed though that the sensors responded substantively different during high water events. After increased soil property research it seemed that the sand layer was not as homogenous as expected and that it had a very large influence on the result. This raises questions about the validity of actual enhancement of small sensor amounts and underestimates the importance of the implementation of the correct set of dike monitoring techniques.

Next to the IJkdijk program other research programs exist. 'Flood control 2015' was a research program executed by nine Dutch consortiums (FloodControl 2015, 2015). The goal was to improve operational flood protection and finished in 2012. The program was mostly focused on actual floods and partially on dike inspection methods (Urban flood, 2012). Weather forecasting, decision making and use of dike monitoring techniques were the key findings to improve flood control. They state that for implementation it is important to determine what kind of threats dike faces in order to implement the correct set of techniques. 'The added value of dike monitoring techniques has to be insightful and rather be a tool of enhancement than investigation' (Urban flood, 2012).

Current practice shows the trend in which investigation has most importance, but with research programs as the 'Livedijken' it goes hand in hand with its contribution towards examination. Dike inspection only faces small enhancements by the research projects as it only covers a small quantity of dikes.

3.2.2 Perception of stakeholders on implementation of dike monitoring techniques

This paragraph elaborates the perception of the stakeholders about the perception towards the current level of implementation and vision towards the future. Within a general, dike inspection, examination and research context as shown in paragraph 3.2.1.

Operator water board

The operators know little about the status of dike monitoring techniques and therefore also do not have a clear perception about current and future implementation. Due to their practical approach they do not meet dike monitoring techniques often, while it is not structurally implemented. They all state that other persons (policy makers and office specialists) are responsible for implementation decision making. Most do like the thought of the implementation of techniques (operator 1, 2, 3, 2015), but due to the lack of basic knowledge their interpretation towards the future differs substantially.
As the operators execute dike inspection this suggests that dike monitoring techniques are not implemented in the dike inspection procedure.

The operators are not directly involved within the examination procedure.
The lack of practical orientated research shows with the ignorance of operators.

Specialist water board

All specialists do agree that implementation of dike monitoring techniques is little seen. The specialists agree that the implementation of dike monitoring techniques will be inevitable over time, but that it is currently little seen because they are skeptical towards the status and usefulness of the dike monitoring techniques (specialist 2, 3, 2015). They believe that prove is the most important aspect towards future implementation and 'do not expect that in the close future this will change thoroughly' (specialist 1, 2015). It is believed that 'within 15 years monitoring will be increasingly important, while it has proved itself in the form of experiments, pilots and explorations' (specialist 4, 2015). And that 'in 50 years all products will be proven and standard implemented along the visual dike inspection and examination practices' (specialist 2, 2015).
Implementation in dike inspection will only show if it relates towards the current practice, because dike inspection will always remain (specialist 4, 2015). Skepticism exists because of the quantity of dike structures. 'It is impossible to implement dike monitoring techniques within all dike structures' (specialist 3, 2015). To face implementation costs have to be low.
Before structural implementation within the examination procedure dike monitoring techniques should focus on gaining parameter values of failure mechanisms, which cannot be conducted with visual dike inspection, but also on cost reductions (specialist 2, 2015).
Research projects are necessary to validate techniques and meanwhile the current efforts of dike inspection and examination are continued (specialist 1, 2015). They believe that their role should be more active when their demands are met and that the added value is irrefutably.

Research agency

The research agencies believe in the future implementation of dike monitoring techniques. Subjectivity within dike inspection and examination irrevocable leads to the call of research in objective observations. Demands are very specialized now, but when more knowledge is gained information is more broadly supported. 'The current phase is a matter of trial and error that requires enough trials' (researcher 1, 2015). 'We have to wait on thorough financial attention to conduct focused and cooperative science' (researcher 1, 2015). 'Physical validations with response functions are required, which has to be matched to scenarios' (researcher 1, 2015). They in generally state that in five years little is changed but that the matter will be more proven, in 15 years monitoring will keep developing and standardized and in about 50 years everything is smart with critical dike trajectories under continue surveillance of dike monitoring techniques (researcher 1, 2, 3, 2015).
All researchers state that integration towards daily processes of dike management with dike inspection, examination and dike monitoring techniques is needed. A critical note is that dike monitoring techniques are not a tool per se, but have to show its advantage. This is somewhat too vague now. Some products are more suitable for dike inspection and some for examination. 'A clearer overview of appropriate techniques per scenario is needed' (researcher 2, 2015).
Current pilot projects have to be up scaled from a regional to a national level. It is very important that efforts are intensified, because after a certain amount of time of little implementation attention research knowledge will be lost (researcher 1, 2, 3, 4, 2015).

Product developer

All product developers believe that techniques are fully developed and will be structurally implemented if the perception of the water authorities is correct. Little projects are seen, but they all aim 'to become a substantial player in the field of water retaining dike management' (product developer 3, 2015). To

improve the implementation of their products it is found necessary to convince the water authorities of the added value and the possibilities of their product (product developer 4, 2015). Most aim to create more technical consistency and to make a change from research to implementation through brand awareness, but the exact method toward structural implementation is still somewhat vague for them. Mostly it is thought that in five years dike monitoring techniques will be more applied, in 15 years it will be more or less standardized and in 50 years the processes will be fully computerized with continuous monitoring for the most critique dike bodies.
'To breach the traditional system clearer documentation of the monitoring possibilities are necessary' (product developer 1, 2015). By some developers it seen that 'satisfying the demands of the ordering parties' (product developer 5, 6, 2015) is crucial with 'combining initiatives to provide holistic advices of the entire content of monitoring to water authorities' (product developer 2, 2015). The perspective between product developers therein differs noticeably as some believe that their product is a self-selling product (product developer 1, 3, 2015). The necessity of contributing to current practices of dike inspection and examination or provide a total new concept also differs. This causes indistinct implementation possibilities. 'Recent research projects showed validity and now it is time for structural implementation' (product developer 1, 2, 4, 6, 2015).

Conclusion
In general the interviewed stakeholders do not expect that monitoring will take place structurally in practice on short notice. Different perceptions exist between the expected moments of implementation. At one side everybody endorses the potential of dike monitoring techniques, but meanwhile only product developers feel (and research agencies see) urgency (3.1.3). This influences the level of implementation. It is seen that water authorities are not in a hurry to make a transition, because they have the responsibility of care towards the inhabitants in their region. They want to make sure that dike monitoring techniques prove their use rather than implementation with the possibility of negative consequences. Furthermore the water boards do think that is should relate to dike inspection and examination practices, which is something the product developers are not aware of. The water authorities thus do think that standardized implementation is 'future thinking', while product developers are 'waiting' for years for the tide to change. Due to previously mentioned constraints it is mostly limited to research programs, but when accepted to be proven subsequent structured implementation will be seen step by step. Product developers thereby need to focus on the need and practices of water authorities.

3.2.3 Costs and benefits of dike monitoring techniques implementation
During interviews it seemed hard to get insight in the costs and benefits of dike monitoring techniques compared to traditional water retaining dike management. However costs and benefits are an important aspect that contributes towards the success or failure of implementation.
The research of Knoef et al (2013) shows that innovation has various stages before it faces structural implementation. The idea phase, development phase, design phase, realization phase and implementation phase exist. Dike monitoring techniques can be scaled in the implementation phase. Physical innovations are applied, but still require adjustments to satisfy demand. Ideally when a technique is sufficiently proven this leads to standardization (Knoef et al., 2013). For full standardization it is required to be achievable, effective (does it wat it has to) and efficient (does it bring advantages). Dike monitoring techniques are 'fully' developed and therefore achievable. The methods are also effective as it fully validates the wishes of the producers. The efficiency is a field that is underexposed. Probably because recent efforts has been put in achieving results within the techniques effectiveness. Efficiency is a field of major importance though, without clear advantages to current practices no standardization will be seen. Therefore most important differences between traditional methods and innovation need to be refuted by the product developers.

In the Netherlands a system is sought that satisfies the statutory level of water safety with the lowest costs (Rijksoverheid, 2015). The traditional option is to meet the statutory inundation probability traditionally with dike inspection and examination with subsequent large (re)constructions and without dike monitoring techniques. It offers direct safety with large initial costs and low maintenance costs. Initial and maintenance costs are clear and benefits also.
Recent reorganizations, increasing knowledge and changing dike inspection and examination policies have led to asset management. This brings a variety of possibilities to implement dike monitoring techniques. The detailed costs and benefit differs per project and dependents on the age and type of the dike, but the overarching principle is the same (van den Berg and Koelewijn, 2015).
The statutory inundation probability could be met by implementing intensive dike monitoring techniques within any phase of dike inspection and examination. It gives insight in the local depletion of the dike and could give information during (re)construction activities. This means relative low investment costs and relative high maintenance costs. Within this concept initial costs are clear, but maintenance costs and long-term benefits are not. This differs per project, but the concept offers difference in the dike safety cycle.

Figures 2 and 3 do show the effect of dike monitoring implementation on costs and benefits in the dike safety cycle. Dikes are always designed with a duration expectancy in which the dike is over dimensioned in the beginning of the cycle. The decrease of the safety level of the dike on the long term, due to natural and human forces, causes increasing uncertainties about the actual depletion. The blue line with the expected safety level shows the designed depletion time of the dike, which is calculated as a constant. The green lines show that monitoring can be profitable in case of a higher safety level determination of the dike after monitoring than designed. In this case reconstruction investments are needed later than predicted. Earlier investments are required in case of the red line scenario in which the dike is less safe than expected. Still the benefit is large because the safety level is maintained and of first concern where the lack of statutory safety would be otherwise unknown. Therefore it could also been seen as profit that a potential dike breach is prevented. In all cases of monitoring knowledge is added. Figure 3 shows that safety levels do not come in straight lines, but that natural varieties cause variance over time.

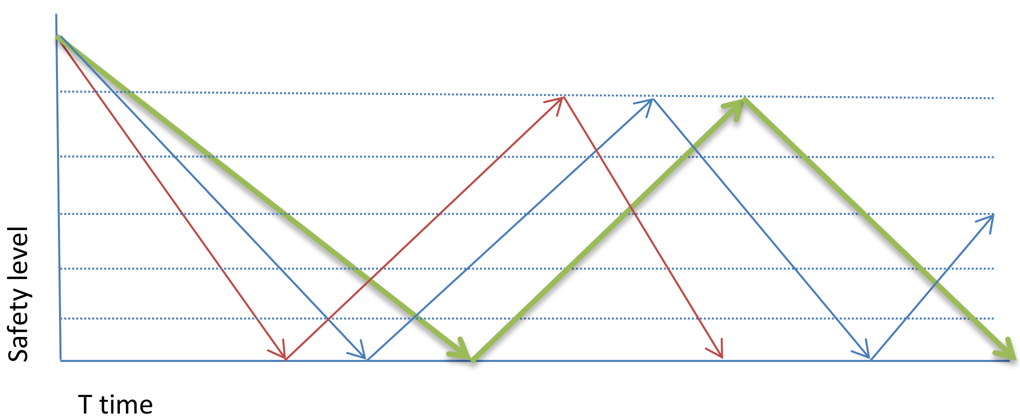
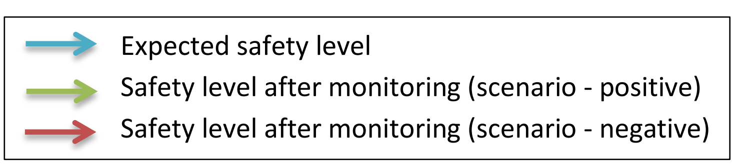


Figure 2. Constant safety level of the dike over time in three scenarios



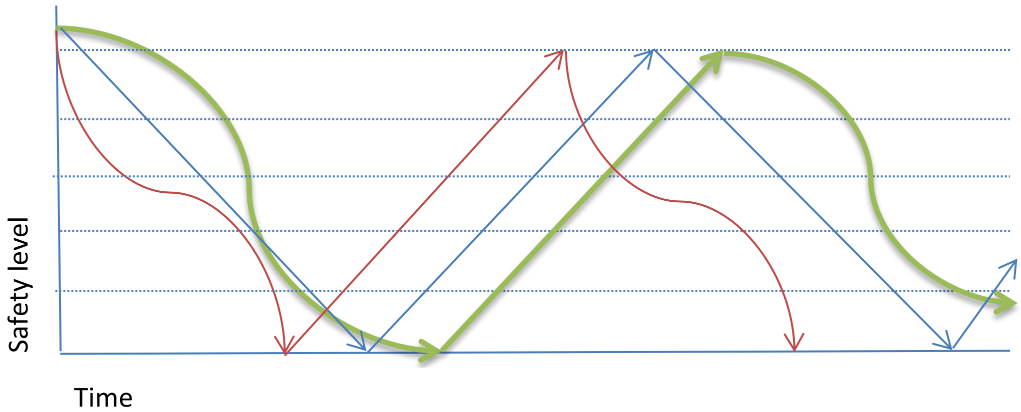


Figure 3. Dynamic safety level of the dike over time in three scenarios

Further research of costs and benefits is necessary. Per dike monitoring technique it should become accessible what the general costs and benefits are per type of application. Detailed insight should be custom made per case.

3.2.4 Implementation of dike monitoring techniques through cooperation

During the interviews it was found that the level of cooperation within and between the stakeholders towards the concept of dike monitoring techniques differs greatly. This makes it an important aspect, because it influences the level of implementation. Interview and also literature outcomes are explained to connect implications.

Perception of cooperation within stakeholder categories

Within the water boards consistency is seen in their opinions and therefore, but the opinions per stakeholder on cooperation differ. The relations are elaborated.

Operator water board

The operators state that cooperation between operators or between operators and specialists within the water boards is not seen on approaching dike monitoring techniques. The specialists address this phenomenon and operators are not asked for contribution (operator 1, 2, 3, 4, 2015). Within dike inspection an increasing level of cooperation is seen (operator 2, 2015) and examination not.

Specialist water board

Dike inspection and examination are conducted rather individualistic per water board. This is motivated with the local characteristics of their area that cannot be directly compared to others (specialist 4, 2015). This is also the reason that different water boards exist and subsequently show different practices (specialist 1, 2015). The PIW program stimulates cooperation, but it is still not generally applied. Within the implementation of dike monitoring techniques cooperation is found to be more useful. The data gathered can be overlapping and be of use at several water authorities (specialist 4, 2015). Some cooperation shows to give input to the ‘Zorgplicht’. The cooperation’s are not fully structured, but occurred due to overlapping difficulties (specialist 2, 3, 2015).

Research agency

The cooperation within research agencies is somewhat less important as they are not fully dependent from the demand of the water authorities. Research agencies conduct research when they are asked to do so (researcher 3, 2015). Within research it is always important to investigate existing theories in the subjected subject. Therefore cooperation is more frequently seen. If other research agencies are highly specialized in the subject it makes sense to cooperate and mostly the demand is thus already set up in cooperation. More research means more knowledge and more cooperation (researcher 1, 2, 3, 4, 2015).

Product developer

The cooperation within product developers is marginal. Most product developers are small innovative initiatives founded and developed from applications in the infrastructure. They believe that their product is sufficient and that it gives the desired results and thus not in need of cooperation (product developer 1, 2, 5, 6, 2015). In this they seem to forget the complexity of their field of practice and the advantage they can give to each other. All product developers complain about the conservative attitude of the water authorities (product developer 1, 2, 5, 2015) instead of seeking mutual controversies with each other. Some product developers (product developer 3, 4, 2015) were open towards cooperation, but did not find others who shared their interest. Noticeably they do think that water authorities operate too individualistic and are in need of cooperation and uniformity.

Conclusion

Cooperation within the organizations of water boards and product developers is scarce and therefore continuous emphasis should be given. In order of uniformity towards the implementation of dike monitoring techniques all stakeholders need to cooperate optimally within their own organization before an optimal level of cooperation within stakeholders is seen. It increases the general insights towards dike monitoring techniques within water authorities and strengthens the position and transparency of product developers.

The fact that most product developers are specialists is not a problem on itself, but therefore numerous companies try to contribute in the same market, offering slightly different applications. This causes a large unclear maze of available techniques, which makes it hard for the water authorities to determine what technique(s) could be useful for them. It is case for the product developers, as their techniques are ‘fully’ developed, to come together and satisfy the demands of the water authorities. Then water authorities would increasingly know the variety of options and what suits their interest in a specific problem.

Cooperation within can be sought during researches instead of competing. Within these researches they could learn from each other and stand stronger to water authorities. For the water boards as client consistent functional requirements to the market fit best to enhance implementation. However cooperation within the water boards does not immediately mean that dike monitoring techniques will gain attention. As little notice is given towards dike monitoring techniques it is more likely that enhancements in the current application of dike inspection and examination are implemented. This thus also asks for an increased level of cooperation between stakeholders.

Perception of cooperation between stakeholder categories

Within the water authorities consistency is seen in their opinions, but the opinions per stakeholder on cooperation differ. This causes non similarities in demands. The relations are elaborated.

Operator water board

The operators do not have a clear perception about the cooperation between stakeholders regarding dike monitoring techniques. Their field of work is within their own management area (operator 1, 2, 3, 4 2015).

Specialist water board

As discussed in chapter 3.1.3 the specialists believe that the product developers and research agencies should prove the use of the dike monitoring techniques and do think that current implementation is sufficient. In their perception it is not their role to link the different stakeholders in this field until implementation becomes structural (specialist 4, 2015). The cooperation in their believe shows in research projects (specialist 2, 2015).

<u>Research agency</u>
The research agencies do contribute in cooperation between stakeholders. They are dependent on the demand of the market and therefore in need of good relations. In their opinion the water authorities should take a leading role in cooperation is they have the constitutional power (research agency 1, 3, 2015). The fact that the water authorities do not cope to their expectations is according to the research agencies because of the lack of urgency sense at water authorities. This is on their turn the responsibility of the product developers and in lesser extent of research agencies (research agency 2, 2015).

<u>Product developer</u>
The opinion of the role of the other stakeholders differs between the product developers. Some believe actual implementation is not the clients (water authority) aim, which is not what the product developers were expecting (product developer 1, 2015). Most state that the water authorities are too conservative and not willing to adapt (product developer 3, 4, 6, 2015).Their own contribution to cooperation is less critical reviewed as they believe that they have proven validity to the water authorities, but they are just not willing. In this they believe that their main point of attention is towards marketing and thus cooperation. 'More attention at the water authorities with structural research and implementation budgets towards dike monitoring techniques is very important' (product developer 5, 2015).

An important obstacle in the current implementation of dike monitoring techniques with cooperation characteristics is the method of tender (product developer 6, 2015). To prevent unreferenced techniques for application during dike improvements a minimum amount of turnover from a company is asked for as prove that their technique is valid. Currently many product developers are small independent companies that only offer one specified dike monitoring. This means that they cannot even compete to a tender, because they do not fulfil the requirements (product developer 6, 2015). Problem is that if it is not possible to compete the required turnover will never be created, however most techniques proved to be valid in small researches.

<u>Conclusion</u>
Tension is seen due to a difference in scope between profit based product developers whom provide supply and the service orientated water authorities whom offer demand. Meanwhile little constructive communication towards structural implementation shows. The product developers located a niche in the market which had the interest of the government, but during development of their product they focused too much on developing the effectiveness of their own technical design and too little on the characteristics of demand. The water authorities follow the statutory inundation probability demands and innovations will only be implemented if it fulfils requirements. They have a wide field of interests and are therefore in the position to be critical against innovations. Ignorance has to be reduced and motivation and resistance of the utilities should become clear through cooperation between all stakeholders to gain uniformity towards the concept of implementing dike monitoring techniques. Where overlapping demands are seen actual implementation is most likely. Now that the techniques are fully developed it is crucial to focus on each other needs in which the product developers need to be flexible towards their clients' preferences.

Investments in innovations are conducted to gain benefits in the long term. The economic responsibilities are during development with both stakeholders (offer and demand) and most financial risk should carried by the stakeholder that has the most influence on the outcome (van den Berg and Koelewijn, 2015). This is the product developer in the first phase of research of proving enhancement, but the techniques currently are validated. Therefore the water authorities now have most influence towards implementation and should also dare to take financial risks with structural implementation investments. The lower the financial risks of techniques the more likely the water authorities will implement it. A transition is necessary by which the water authorities take more initiative due to which developments and insights are also faster gained as a result from the increased involvement.

3.2.5 Scenarios for the implementation of dike monitoring techniques

In this chapter the possible scenarios towards implementation are created. The outcomes come forward from the previous chapters and additional literature of which interpretation lead to personal analysis.

General description

It is stated in van den Berg and Koelewijn (2014) that dike monitoring techniques are believed to be valid from 2011 onwards. The existence of techniques proven to be valid in theory does not mean instant implementation in practice. In the interviews it is found that especially the method to gain the correct and necessary information out of the dike monitoring techniques needs enhancement in order to practical contribution. Dike monitoring techniques are found useful when uncertainties about the status of the dike can be clarified to meet the set regulatory inundation probability

As shown in chapter 3.1.1 and 3.1.2 dike monitoring techniques could enhance the field of dike inspection and examination and intertwine with the field of water retaining dike management. To implement dike monitoring techniques and provide insight how preliminary to overcome the constraints five scenarios are found applicable:

1. Monitoring to gain preliminary insight about changes of the status of the dike;
2. Monitoring the sensitive areas determined during dike inspection;
3. Monitoring parameter values and/or unsafe areas determined during examination;
4. Monitoring to gain critical insights during (re)construction activities;
5. Monitoring to validate dike monitoring techniques and/or determine dike parameters.

The scenarios offer the opportunity of implementation in different phases of water retaining dike management. Scenario 1 is a scenario which will form a new area of implementation, scenario 2 is in relation with dike inspection, scenario 3 is in relation with examination, scenario 4 is in relation to dike inspection and examination in terms of (re)construction and scenario 5 is the area that currently faces most implementation. The scenarios are chosen with the idea in mind that it is rarely required and no achievable due to costs to put all forms of dike monitoring techniques in one area of the dike. One location appropriate technique gives more information than multiple more randomly picked techniques (Moser and Zomer, 2006). Therefore it is important to determine and analyze the situation first and then choose the associate scenario.

Scenario 1: Monitoring for preliminary insights

The first scenario shows the possibility of dike monitoring techniques to give insight about the actual status of the dike before problems are noticed by traditional water retaining dike management practices. Figure 4 shows this concept in a schematic overview.

Within this concept it is key to start with a large scope. Remote sensing (applied within the office) thereby offers the best opportunity due to the detection of anomalies over large surfaces in a chosen return period by means of satellite, airborne and/or stationary techniques (3.1.1). If discrepancy is shown during the application of remote sensing monitoring will continue, if not the section is known as safe and the traditional dike inspection is used. A return period can be chosen to see irregularities evolve over time.

Some sections as a whole can thereby show to face faster depletion than others. It also gives quantification to applying the regular water retaining dike management procedure.

At the locations where discrepancy shows dike inspection is needed to rectify the thread. This together with the analysis of the remote sensing technique(s) gives reasoning towards the subsequent steps. The level of zoom gets more detailed and in situ techniques are implemented if ought necessary. In situ techniques give more locally detailed information. The increased level of detail could notice no major threats towards the regulatory status of the dike and thus the label safe.

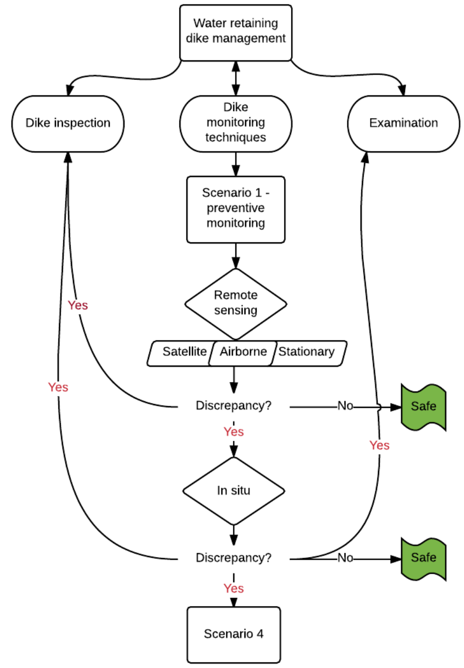


Figure 4. Schematic overview scenario 1

After shown discrepancy the site is again visited through dike inspection and also calculated by means of examination. Dike inspection and examination are thus risk based in this scenario. It is practice with dike monitoring techniques is decision maker. In case the regulatory inundation probability of the dike is not met (re)construction or continuous monitoring has to follow. Construction is of use when major unsafety issues are shown and continuous monitoring when the risks are small or uncertainties large. See scenario 4 for more detail of this phase.

Scenario 2: Monitoring during dike inspection

Scenario 2 is forthcoming from dike inspection (3.1.1). During dike inspection lots of information is gained, but determination of the actual status of the dike is often subjective and the existent occurrence of irregularity is not always straight forwards.

Knowledge and documentation of the operator and specialist offers insight in reoccurring irregularities. This gives insight in the sensitive locations where dike monitoring techniques could offer enhancement by implementation (Figure 5). To be sure that dike monitoring techniques will answer the problem and that the correct dike monitoring technique is chosen thorough preliminary research is required. The appropriate technique is thus totally dependent per case on scale and local characteristics. Commercial companies could add by offering a thorough costs and benefits analysis of the appropriate technique at the specified location(s). Therein water authorities could take the lead by open a public tender of the problems face during dike inspection. The tender needs a clear set of requirements to offer boundary conditions of application, which is not seen currently. Product developers could also take the initiative and focus on the outcomes of dike inspection and offer possible solution. This is also not seen towards the practice of dike inspection. Once the research and/or tender is finished, a dike monitoring technique is chosen and implementation can be seen.

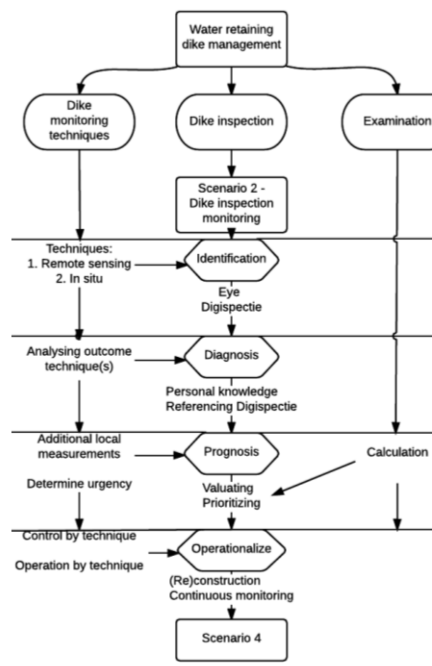


Figure 5. Schematic overview scenario 2

The first phase of identification is an ongoing process and offers ongoing opportunities to apply dike monitoring techniques. Remote sensing and in situ techniques could both be appropriate. When the preliminary researched stressed the need of knowledge about processes within the dike in situ is most feasible. If outer dike processes are unclear one of the remote sensing techniques is most useful. It also has to be determined whether the observation is required to be continuous or temporary. It offers an additional and more objective method of identification. During the second phase of diagnosis the outcome of techniques can be analyzed and/or additional research can be conducted to help the traditional diagnose. During the prognoses dike monitoring techniques again contribute by providing objective data and determine the level of urgency. When it becomes clear during the diagnose phase that (re)construction could be required, examination also have to be taken into account. The necessity is than referenced and for actual (re)constructions calculation is required. When it is determined in this phase that statutory inundation probability of the dike is not met construction or continuous monitoring has to follow (scenario 4).

Scenario 3: Monitoring during examination

The third scenario addresses the implementation possibilities of dike monitoring techniques during examination (Figure 6). The various calculation rounds within examination offers enhancement opportunities for dike monitoring techniques, as mentioned in paragraph 3.1.2. Implementation has to focus on the process when the dike is determined unsafe after a calculation round. It could thereby offer additional research. The technique that should be applied differs per failure mechanism on which the dike structure is disapproved. In Annex 7 it is shown which techniques are applicable for what failure mechanism and in paragraph 3.1.2 it is shown what parameters can be addressed by dike monitoring techniques. In general in situ techniques have the most direct relation during the research phases of examination by offering parameter values.

If dike monitoring techniques are applied after the first phase it will give continuous insight throughout the other stages. Inspection can give additional information after the second round of disapproval by means of physical and visual verification.

After examination has taken place there will always be dike trajectories that are determined as unsafe. The difference between safe and unsafe can be very small (Rijksoverheid, 2006). Additional monitoring could provide actual damage images that relate the outcome of the examinations and more detailed information about parameters that can be used as new input for the calculation of the models. Again the type of implementation is scale dependent and allocated on the existing problem. Remote sensing and in situ techniques could both be applied, although in situ techniques show relatively more relevance towards model parameters.

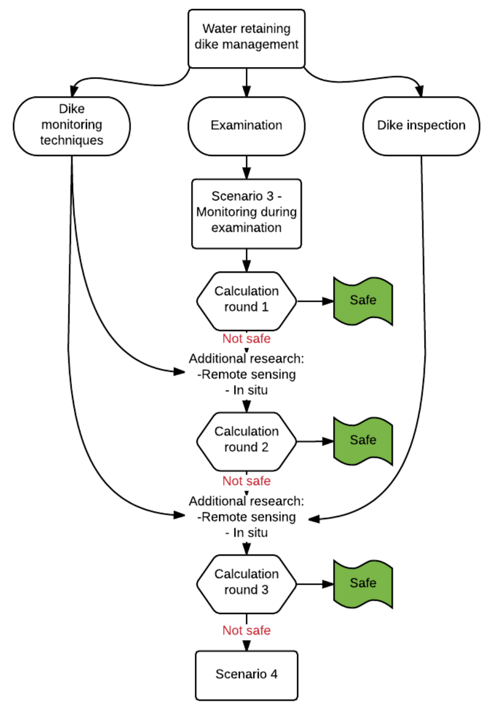


Figure 6. Schematic overview scenario 3

Scenario 4: Monitoring when a dike is determined unsafe

After dike inspection, examination and/or dike monitoring techniques a dike can be determined as, not satisfying regulatory safety probabilities, unsafe. This urges for scenario 4 (Figure 7). Three possibilities arise when a dike is determined unsafe: (re)construction of the dike, continuous dike monitoring and hydraulic improvements of the water system.

Hydraulic improvements could not face implementation by dike monitoring techniques. Implementation could for example show through water retention areas, room for the river and water level reductions.

(Re)construction is a processes during which the status of the dike is critical due to external forces and changing dike structure. To determine wheter a critical situation arises monitoring is very useful. Mostly a dike is determined unsafe due to examination, which serves as input during the design of the (re)construction. During this phase it could already be thought of which dike monitoring technique(s) could be applicable. Fast input can be given to the design if the preliminary unsafe label was also formed by dike monitoring techniques. Execution follows after the design has been determined and approved within all other spatial and stakeholder belongings. During the supervision of construction most value can be gained by dike monitoring techniques instead of dike inspection. This would be additional. After the (re)construction is completed with the help of dike monitoring techniques the choice has to be made whether the techniques are remained or removed for regular monitoring (scenario 1, 2 and 5). Another option is to remove the dike monitoring techniques, but maintain the excavation site so that it can be easily implemented during critical circumstances. Monitoring during (re)construction is not only useful to detect anomalies during construction, but also to verify the robustness of the construction compared to the design. Design assumptions can be tested and verified.

Figure 7: Schematic overview scenario 4

Continuous monitoring is urged when differences between safe and unsafe are small. During the monitoring it gets insightful how a dike reacts on critical circumstances. This gives notion towards effectively choosing the correct set of measures to react on the occurring threat. Also data is than gathered about the response of the parameters and/or failure mechanism towards the threat. This can be related towards the outcome of the examination and thereby verifies the result. It could be the case that the examination was inaccurate and the actual threat in practice does not correspond with the calculated safety. Much information is than gained for the given and future calculations and (re)construction can be postponed. This saves substantial amounts of investment money. Furthermore can the large amount of dike (re)constructions that are determined not all be executed immediately. For those dike trajectories dike monitoring techniques could always be an opportunity. Insight is gained about the actual necessity of the dike enhancement and the desired level of safety is provided. The longer the measurements are conducted the more information is gained. Also do critical events offer the most important insights due to the external forces and that is more likely in a longer time frame.

In both cases remote sensing and in situ techniques can be applied, but in situ techniques are more likely to be used. Implementing in situ techniques during (re)construction is relatively cheap, because the dike is already under construction. During continuous monitoring investments are always lower than (re)construction. Also very detailed, continuous and local information is preferred in both cases, which are all specialties of in situ techniques. As benefits are high and costs low product developers should strive for implementation in this phase. Remain the dike monitoring techniques afterwards is seen less, but very good possible as the initial costs are already highest and already made. Especially during critical circumstances dike monitoring techniques could give very much information on the long term.

Scenario 5: Research validation monitoring

Research is the field of implementation that is currently most seen. In practice most research focuses on validation of the techniques. During this validation the results also offer interesting insights towards the practical meaning of the outcome. Results mostly give different outcomes than values assumed during examination or irregularities seen during dike inspection. Monitoring techniques do and could contribute within this concept (Figure 8).

It is shown in paragraphs 3.1.3 and 3.2.2 that dike monitoring techniques need more awareness at the water authorities. Research validation monitoring can contribute more to this area. It is now mostly limited to few 'Livedijk' locations, but implementation for research can be scaled up when investments increase. It is a beneficial concept, while product developers validate their own product and create awareness of their product. Meanwhile water authorities gain better insights about the possibilities and gather useful data for model uncertainty and important insights in irregularity detection. Remote sensing and in situ techniques are available for both, but implementation is dependent on the preferred outcome. Researching a peat dike requires different parameters and thus techniques are required then when researching the effects of erosion.

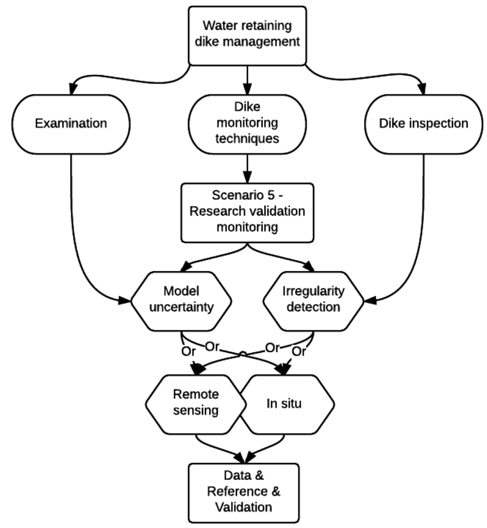


Figure 8. Schematic overview scenario 5

Model uncertainty (scenario 3) is the area that faces most enhancements during research as parameters show after the implementation of dike monitoring techniques. The technical input that is delivered by the dike monitoring techniques is referenced to the existing parameters. Differences can be observed and analyzed and thereby deliver a contribution to a better understanding of the sensitivities and actual values in practice.

Uncertain outcome of inspection (scenario 2) could face enhancements by a better observation through dike monitoring techniques. The technical input that is delivered by a dike monitoring technique gives attention to irregularity that would otherwise not been shown. Mostly the research programs do not address this uncertainty. For future implementation it therefore offers interesting opportunities when given attention to.

4. Discussion and recommendation

4.1 Uncertainties in results

The topic of water retaining dike management is in this research limited to dikes. Clear boundaries have been set for applying the correct scope. Other processes also influence the statutory inundation probability. Water structures as barriers, sluices and pumping stations are therein not taken into account. Hydraulic circumstances influence parameter quantification, but mentioning is limited to appointing. Maintenance is important for the upkeep of the dike and thus the actual status of the dike, but is only briefly mentioned. Non water retaining dikes are not considered.

This research focused on the three major stakeholder groups (water authorities, research agencies and product developers) that have different belongings, because it was found in literature as most important. In practice multiple other stakeholders as inhabitants and contractors also show influence, but with less substantive relevance towards dike inspection and examination and enhancement and implementation by dike monitoring techniques.

The literature and interviews are both prone to uncertainties. An overview is shown below.

Interviews

1. Interaction with the interviewee causes influence of the interviewer on the outcome. The qualitative approach causes room for interpretation and therefore a decrease of replicability.
2. The interviewees willing to conduct interviews are the persons with interest and belonging to this topic. At one hand this causes qualitative input, but it also causes a more affected response towards the topic. Less affected persons could offer interesting insights also.
3. The quantity of interviewees is limited and therefore not sufficient for applying statistics. More interviews mean more insights and more reliable results.
4. Questions could be interpreted differently by interviewees. This means that personal knowledge, field of work and interests are important towards a person's perception and do influence the result. A different set of interviewees and/or questions would influence the outcome.
5. Limited time of the interview. Difference in time between interviewees and therefore difference in the thoroughness of the answers.

Conducting interviews always brings uncertainties. Despite the uncertainties results found are thought to be useful. Outcomes are clearly documented and ascertainable. The three stakeholder groups thereby subjected show strong overlap within each group yet the repeating differences between the groups emphasizes reliability. This gives the opportunity to comparisons and shows the importance of perspective and belongings. Furthermore in the report of Swart et al. (2003) interviews are also conducted towards this topic in which an overlap of outcomes is seen with coherent perceptions within, but different perceptions between stakeholders.

Literature

1. The literature used contains a lot of governmental documents, because it finances most research in this practical topic. Governmental documents are written and based on a certain preliminary perspective.
2. Profound findings and recommendations in literature could be different than enhancement and implementation in practice.

3. The literature and policy documents undergo continuous change and developments. Findings in this research are therefore subject to time, although important future policy changes known are mentioned. Most insights could be relevant for a longer time span.
4. There is a lack of scientific documentation towards the practice of dike inspection. Processes that relate to examination are scientifically substantively more researched.
5. Scientific documents about dike monitoring techniques have a restricted for students. Insights in technical specifications and costs of dike monitoring techniques are not always given by product developers. Therefore not all existing literature could be taking into account. Relevance shown is mostly in other scientific topics (e.g. geo engineering and infrastructure).
6. Technical specifications of dike monitoring techniques are not researched thoroughly due to the high level of detail per technique and quantitative appearances of techniques.

The limitations during the literature research are small and inherent to conducting research. It therefore does not affect the results of this research thoroughly. The main research question is based on practical enhancement and implementation of dike monitoring techniques and therefore the availability in relevant literature of mostly guidelines is acceptable. With the available literature profound results are obtained. Results found in literature thereby are rather constant.

4.2 Recommendations for main stakeholders

The main implications with forthcoming recommendations for the three most important stakeholders on enhancing and implementing dike monitoring techniques within dike inspection and examination practices are mentioned below. In general it is shown that the cooperation within and between the stakeholders should be improved to eliminate ambiguities and clarify mutual demands. Dike monitoring techniques should develop to the current practice of water retaining dike management.

Water authorities

1. Clarify personal demands (costs and benefits, added value to current practice and validity) towards product developers to increase the probability of implementation of dike monitoring techniques. Currently indistinctness reigns.
2. Do not focus solely on dike inspection and examination, but also on dike monitoring techniques. Processes are practiced separately, but the overlaps are substantial. Increased unity offers a risk based approach by which vulnerabilities are enhanced by another.
3. Create an open market. The current situation limits tenders to specific constraints by which small product developers cannot participate freely. Everyone should have the opportunity to compete by which the best tenders will prove themselves.
4. Make national policy towards the subject of dike monitoring. The existence of dike monitoring techniques is not mentioned in legal policy documents, but in research only. Justification of choices towards aims and/or implementation or not should be the minimum.
5. Cooperation within and between the water boards. Despite recent improvements locally within and between departments, cooperation on national scale is seen less, but cannot be urged enough. Then decisiveness, uniformity, knowledge, economies of scale and awareness can increase.

Besides these main recommendations it is also important for water authorities to stay critical, but open for innovation, focus on asset management for lowering costs, involve the operators' knowledge more within the specialists' field of work and show initiative as consequence of the role as client.

Research agencies

Appoint opportunities more clearly. The research agencies conduct lots of useful researches, but the effects are mostly limited towards the direct client, while all clients could benefit, but are not aware of the findings. By stressing the opportunities universally awareness increases.

1. Demand increased level of research. Researchers involved observe the capabilities of dike monitoring techniques, but are restricted to a level of investment. Urgency should be stressed for more finance.
2. Put emphasis on the constraints of implementation and the increased level of efficiency dike monitoring techniques could offer. Too little documentation is seen towards the direct increase of efficiency per technique in terms of costs and benefits. Current limitations towards quantification and characteristics are not reaching enough.
3. Conduct more holistic research of dike monitoring techniques with emphasis towards dike inspection and examination. Address water retaining dike management as a coherent subject.
4. Offer the foundation of decision making due to independent, objective and scientific point of view.

Besides these main recommendations it is also important for research agencies to increasingly cooperate within the research agencies for a uniform approach, increase the group of experts and give notion of the importance to continue research. The water authority as client seems to have more areas of attention and it is possible that research will be conducted less due to which acquisition and other methods should be taken into account to stress emphasis.

Product developers

1. Develop the products towards the demand of the water authorities. Investigate requirements and alter the necessities. Understanding of the client's skepticism is important
2. Emphasis on marketing. Fame of the products and its added value creates increasing interest by the client. This will lead to an increase of implementation.
3. Quantify the application of dike monitoring technique(s). The functions of the techniques should be more insightful and especially related towards the costs and benefits within current overlapping processes of the water authority.
4. Cooperate with other product developers. The product developers act too individually. Cooperation increases the uniformity, clarity and thus impact of the dike monitoring techniques by the water authorities. Thereby it increases mutual overview and insights for themselves.
5. Gain insight in policy of the water authorities and react proactive on future developments. Product developers do not seem interested in policy developments of water authorities, while these determine the opportunities for implementation and thus the correct product adjustment.

Besides these main recommendations it also important for product developers to keep improving (as side emphasis) the technical specifications of the dike monitoring techniques, to gain expertise and references in other markets than water retaining dike management that need accurate monitoring, provide explanation of the results by mean of reports rather than supply raw data only and focus more on parameters that are used in examination. Implementing the dike monitoring techniques in the mentioned scenarios with continuous emphasize of the benefits, utilities and achievements.

4. 3 Recommendations for further research

The dike monitoring techniques available offer a range of enhancements and implementation possibilities that needs to be customized per case. Due to the wide array of specifications this asks for thorough decision making in which using the appropriate technique is of major importance. The frameworks, overviews and analysis provided give insight in the variety and sensitivities of this customization. Improvements towards offering more detailed technical insights in the specifications and costs and benefits of the techniques per case are required. Ideally through an intensive collaboration of water authorities, research agencies and product developers in which the case specific demand are clear for and agreed upon all stakeholders. Gaining profound insight in this manner required a scope too specialized and detailed for this research and is therefore explicitly recommended for future research, where with the insights gained in this research a more thorough base is offered to rely on. The dike monitoring techniques technical specifications towards the mentioned scenarios would be a useful addition. Detailed research is asked for to clarify the potential of dike monitoring techniques in every process that the client offers.

5. Conclusion

The aim of this research was to provide insight in how dike monitoring techniques can be implemented in water retaining dike management to enhance dike inspection and examination practices. The product developers aim to enhance the current methodology with an entire new approach of varied and highly specified set of dike monitoring techniques. It is separated in remote sensing, in situ and standardization techniques and provides enhancement with detailed information about process(es) affecting the inside and outside of the dike. Currently this only partly overlaps with dike inspection and examination practices and is subsequently not taken into account in policies and daily operation. Therefore enhancement and implementation is limited to research programs validating accuracy and to prove use.

It is believed by water authorities that the current approach of dike inspection and examination is satisfactory. It is stated by operators and specialists that both methods are proven over a long period of time, have a lot of knowledge available and offer sufficient insights to the current concept of water retaining dike management. The water authorities believe that enhancements by dike monitoring techniques are possible over time, but also known and taken into account properly through research programs. Research agencies and product developers agree with each other that dike inspection is a rather subjective approach and that examination results suffer from a high level of uncertainty, but do think that dike monitoring techniques are not sufficiently taken into account.

Within this context the water authorities state that there is a need for an overview of the dike monitoring techniques with special attention to costs and benefits and validity. Product developers opine that overviews are already available and that techniques are obviously needed due to the objective outcomes that are not accessible in current procedures. Arguments from both sides are comprehensible, but in state of mutual controversy. Water authorities have more areas of attention, research agencies only conduct research when asked for and product developers are over convinced of their own products. A break through can most likely be reached by means of an increased level of cooperation, not limited to validation only, but towards mutual demands. The most important mutual demand that needs to be collaborated continuously is project specific efficiency and costs and benefits of dike monitoring techniques. The relation of dike monitoring techniques towards dike inspection and examination is in this research elaborated.

Dike inspection is practiced in four phases (identifying, diagnosis, prognoses and operationalize) in which dike monitoring techniques could all contribute. Current developments in dike inspection are process orientated towards uniformity and standardization. Little attention is given to additional dike monitoring techniques that enhance insight about the status of the dike. It is shown that the product developers are rather focused on the technical specifications of their technique instead of researching the characteristics of dike inspection. Enhancement in dike inspection by dike monitoring techniques can be seen by offering insight in identifying irregularities. Mainly by use of remote sensing techniques that could offer preliminary insights on large scale of outer dike irregularities. If diagnosed necessary enhancement with stationary and more specified local in situ techniques about inner dike irregularities is possible. Standardization techniques can enhance the process of data processing. Identification can take place during the identifying, diagnosis, prognoses and operationalize phase. Actual enhancement is dependent on location specific irregularities and strongly relies on choosing the correct set of dike monitoring techniques. This can be ensured by preliminary research, define clear requirements and/or place a project specific tender.

It is seen that examination can be influenced and enhanced by dike monitoring techniques during the three phases of local parameter research and when a dike is determined unsafe. Operators and product developers are not aware of examination processes. For product developers this awareness is of importance as it is shown that it is a field to which dike monitoring techniques offer enhancements. This is endorsed by research agencies. Most attention at the water boards within examination is currently given towards the outcome instead of profound parameter research, while correct parameters determine the real necessity of dike (re)construction. Many remote sensing techniques do not comply towards immediate output of parameter values that can contribute to model calculations and thereby offer little enhancement and thus undergo limited implementation. In situ techniques can offer direct parameter values and thereby offer clear enhancements. Both remote sensing and in situ techniques can offer a reference through continuous monitoring on the location that is determined unsafe. Standardization techniques that address data storage and review can bring benefit to parameter values over time.

Five scenarios are distinguished that show how the enhancement by dike monitoring techniques can face implementation within, but also additional to, the current practices of dike inspection and examination:

1. By applying a large scope with remote sensing techniques that gain preliminary insights of occurring anomalies. Reoccurring anomaly locations can be inspected by operators, modeled with examination or researched with in situ.
2. Monitoring sensitive areas of reoccurring irregularities locations that are located by dike inspection.
3. Monitoring during the phases of additional parameter research within examinations and critical areas of safe and unsafe after examinations.
4. Additional insight during dike (re)construction as solution and/or by providing insight in the actual status of the dike after dike inspection and examination.
5. Validation of dike monitoring techniques to prove use and parameter values to gain continuous input in all of the above mentioned arrays of implementation.

Dike inspection and examination can both face implementations of dike monitoring techniques when profound enhancement shows.

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B. Interviews

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Specialist 2 (2015), Advisor water safety and operation manager, waterschap Noorderzijlvest and LivedijkXL, conducted at Stedumermaar 1, 9735 AC Groningen, 13-05-2015

Specialist 3 (2015), Senior advisor, Hoogheemraadschap van Rijnland, conducted at Archimedesweg 1, 2333 CM Leiden, 01-07-2015

Specialist 4 (2015), Senior specialist, Waterschap Brabantse Delta, conducted at Bouvignelaan 5 4836, AA Breda, 09-07-2015

Operator 1 (2015), Operator, waterschap Groot Salland, conducted at Handelskade 37, 7400 AC Deventer, 30-04-2015

Operator 2 (2015), Operator, waterschap Noorderzijlvest, conducted at Stedumermaar 1, 9735 AC Groningen, 11-06-2015

Operator 3 (2015), Operator, Hoogheemraadschap van Rijnland, conducted at gemaal De Leeghwater, Buitenkaag, 30-06-2015

Operator 4 (2015), Operator, Waterschap Brabantse Delta, conducted at Bouvignelaan 5, 4836 AA Breda, 09-07-2015

Rijkswaterstaat and Rijksoverheid
Advisor RWS (2015), Advisor, Rijkswaterstaat, conducted at Zuiderwagenplein 2, 8224 AD Lelystad, 25-06-2015

Inspector ILT (2015), Inspector water safety, Inspectie Leefomgeving en Transport, Rijksoverheid, Conducted at Europalaan 40, 3526 KS Utrecht, 09-06-2015

Research agencies
Researcher 1 (2015), Senior strategist, TNO, Conducted at Eemsgolaan 3, 9727 DW Groningen, 13-05-2015

Researcher 2 (2015), Specialist Research and Development, Deltares, conducted at Rotterdamseweg 185, 2629 HD Delft, 19-05-2015

Researcher 3 (2015), Owner BZ innovatiemanagement and Chairman Stichting IJkdijk, conducted at Zutphenseweg 51, 7400 AK Deventer, 16-06-2015

Researcher 4 (2015), Head GeoServices, Fugro, conducted at Archimedesbaan 13, 3439 ME Nieuwegein, 23-06-2015

Product developers

Product developer 1 (2015), Owner, Miramap, conducted at Kokermolen 11, 3994 DG Houten, 11-05-2015

Product developer 2 (2015), Managing director and inventor, InTech, conducted at Waarderweg 50-P 2031, BP Haarlem, 11-05-2015

Product developer 3 (2015), Owner, StabiAlert, conducted at Wasaweg 18-1, 9723 JD, 13-05-2015

Product developer 4 (2015), Contract director, Inventec, conducted at Galvaniweg 11, 8071 SC Nunspeet, 18-05-2015

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Product developer 6 (2015), Owner, DMC system, conducted at Handelskade 37, 7400 AC Deventer, 15-07-2015

Annex 1. Interviews

All interviews were held in Dutch and therefore the interview questions are also in Dutch. Three different set of interview questions were formed to conduct the interviews. The interview questions for the 'water authority' is shown completely and the 'research agency' and 'product developer' questions that have additions and/or differences are also shown.

Water authority (waterschap)

0. Algemene kenmerken

    1) Wat is uw functie?

    2) Wat is uw betrokkenheid in dijkinspectie?

    3) Hoe zijn de werknemers betrokken en georganiseerd in uw organisatie ten behoeve van dijkinspectie?

    4) Wat voegt uw instelling toe aan de ontwikkeling van dijkinspectie?

1. *Algemene kenmerken van dijkinspectie en toetsing*

    1) Welke veranderingen heeft dijkinspectie in de laatste jaren ondervonden?

    2) Waarom (of waarom niet) is de focus meer op visuele of technologische dijkinspectie?

    3) Waarom (of waarom niet) moet de focus meer op visuele of technologische inspectie zijn?

    4) Waarom (of waarom niet) kan er in visuele of technologische inspectie meer vooruitgang geboekt worden?

    5) Welke producten ten behoeve van dijkinspectie zijn er?

6) Hoe verloopt de samenwerking tussen waterbeheerders, onderzoeksbureaus en initiatieven?

7) Hoe is het beheersgebied bepaald voor toezichthouders en toepassingsgebied voor bureau medewerkers?

8) Hoe is het proces tussen bureau medewerkers en toezichthouders gepraktiseerd?

9) Welke faalmechanismen en schadebeelden zijn het belangrijkst in uw beheersgebied, en waarom?

10) Welke grondsoorten komen het meeste voor, en welke invloed heeft dit op de faalmechanismen en schadebeelden?

11) Welke rol heeft toetsing in dijkinspectie?

12) Welke rol heeft toetsing naast dijkinspectie?

13) Welke maatregelen en methoden worden tijdens calamiteiten gehanteerd?

14) Welk type calamiteiten onderscheiden jullie?

2. Visuele dijkinspectie

1) Wat zijn de belangrijkste aandachtspunten voor visuele dijkinspectie?

2) Welke tools worden momenteel gebruikt voor visuele dijkinspectie?

3) Hoe onderzoeken jullie nieuwe visuele methodologieën?

4) Welke faalmechanismen of schadebeelden zijn het makkelijkst en moeilijkst te detecteren met visuele dijkinspectie, en waarom?

5) Met welke stappen wordt visuele dijkinspectie uitgevoerd door de toezichthouder?

6) Hoe draagt de bureau medewerker bij tot visuele dijkinspectie?

7) In hoeverre worden kosten meegewogen?

3. Monitorings technologieën

1) Wat zijn de belangrijkste punten van aandacht voor nieuwe monitorings technologieën?

2) Hoe onderzoeken jullie monitorings technologieën?

3) Wat is de meest veelbelovende technologie binnen dijkinspectie, en waarom?

4) Welke monitorings technologieën worden door jullie gebruikt?

5) Wat zijn de belangrijkste voordelen om nieuwe technologieën te implementeren?

6) Wat zijn de belangrijkste nadelen om nieuwe technologieën te implementeren?

7) Welke verbeteringen voor implementatie zijn er mogelijk m.b.t. nieuwe monitorings technologieën?

8) Waarom is technologische inspectie meer geschikt voor tijdelijke inspectie of monitoring?

9) Welke faalmechanismen of schadebeelden zijn het makkelijkst en moeilijkst te detecteren met monitoring, en waarom?

10) Welk verband hebben theoretische parameters met monitoring?

11) Hoe worden medewerkers opgeleid in nieuwe monitorings technologieën?

12) In hoeverre worden kosten meegewogen?

4. Beleid

1) Welke externe beleidsdocumenten hebben het meest invloed in de praktijk, en waarom?

2) Welke veranderingen zijn er in de laatste jaren door externe beleidsdocumenten?

3) Hoe ziet u de verhoogde nadruk op de zorgplicht?

4) Zijn externe beleidsdocumenten nodig om elektronische inspecties te stimuleren, en waarom wel of niet?

5) Wat is de invloed van externe beleidsdocumenten op de samenwerking tussen verschillende waterbeheerders?

6) Wat is de invloed van externe beleidsdocumenten op de samenwerking tussen toezichthouders en bureau medewerkers?

7) Welke beleidsverbeteringen zijn er nodig na PIW en PIW2.0?

8) In hoeverre zijn jullie bereid om nieuwe technologieën toe te passen?

9) In hoeverre zijn andere waterbeheerders bereid om nieuwe technologieën toe te passen?

5. Toekomst

1) Waar moeten ontwikkelingen in monitorings technologieën zich op focussen?

2) Wat is de ambitie van het waterschap voor de toekomst?

3) Hoe kunnen nieuwe monitorings technologieën zich inpassen?

4) Wat zijn mogelijke verbetering in de markt?

5) Hoe ziet u de toekomst van dijkinspectie voor de komende 5 jaar?

6) Hoe ziet u de toekomst van dijkinspectie voor de komende 15 jaar?

7) Hoe ziet u de toekomst van dijkinspectie voor de komende 50 jaar?

Research agency (onderzoeksbureaus)

0. Algemene informatie

No differences compared to water authority questions.

1. Algemene kenmerken dijkinspectie en toetsingen

Question 8 within the water authority questions is not taken into account for research agencies.

No further differences.

2. Visuele dijkinspectie

Question 6 and 7 from the water authority questions are not taken into account for research agencies.

No further differences.

3. Nieuwe monitorings technologieen

Question 11 within the water authority questions is not taken into account for research agencies.

No further differences.

4. Beleid

Questions 8, 9 and 10 are different compared to the water authority questions

8) In hoeverre zijn waterbeheerders bereid om nieuwe technologieën toe te passen?

9) In hoeverre geeft de overheid subsidies?

10) Hoe verloopt de interactie met de waterbeheerder?

No further differences.

5. *Toekomst*

There are no structural differences compared to the water authority questions in this topic.

Product developer (Productontwikkelaars)

0. Algemene informatie

5) Hoe kwam uw product tot stand?

6) Wat voor veranderingen ondervond uw product in het verleden?

1. Algemene kenmerken dijkinspectie en toetsingen

Question 8 is additional in the water authority questions.

The following questions are different in the product developer question:

5) Welke producten ten behoeve van dijkinspectie hebben jullie?

No further differences.

2. Visuele dijkinspectie

Question 5 and 6 from the water authority questions are additional to the product developer questions.

3. Nieuwe monitorings technologieen

The following questions are different to the water authority questions

4) Welke dijkinspectie technologieën worden door het waterschap toegepast?

The following questions are additional tot the water authority questions

11) Hoe legt uw product de link met faalmechanismen en bodemtypen?

12) Welke type metingen onderscheid uw product?

13) Hoe verwerkt uw product de data, hoe kan het de gegevens vastleggen en hoe sluit dat aan bij de processen en systemen van beheerders?

14) Op welke schaal is uw product inpasbaar?

15) Wat is de kracht van uw product?

16) Wat is de zwakte van uw product?

17) Wat zijn de kosten voor korte termijn implementatie (inspectie)

18) Wat zijn de kosten voor lange termijn implementatie (monitoring)

Question 11 from the water authority questions is not taken into account and question 12 elaborated.

No further differences.

4. *Beleid*

The following question is different to the water authority questions

9) In hoeverre zijn waterbeheerders bereid om nieuwe technologieën toe te passen?

The following questions are additional tot the water authority questions

10) Hoe verloopt de interactie met de waterbeheerder?

11) In hoeverre geeft de overheid subsidies?

5. *Toekomst*

There are no structural differences compared to the water authority questions in this topic.

Annex 2. Failure mechanisms

Failure mechanisms are technical principles, due to which a dike loses its function of maintaining safety (Helpdesk water, 2006). They may be caused by numerous reasons. The most important is natural variability as high water levels, droughts and infiltration due to heavy rainfalls. An important point of influence on these variances is soil composition that has a different sensitivity per type of soil and failure mechanism. Failure mechanisms may cause instability of the dike which in the worst case leads to a dike breach (Figure 1). Eight failure mechanisms of dikes are generally known (TAW,2001):

1. Overflow. The water level is higher than the top of the dike. This causes direct inundation and erosion of the surface of the dike. Sensitive for subsidence.
2. Overtopping. Overflow due to wave action. Not the water level, but the waves are higher than the top of the dike. This causes direct inundation and primarily erosion of the surface of the dike. Sensitive for subsidence.
3. Macro instability at the inner slope. The land side of the dike is unstable due to drought or wetness and the soil composition then subsides. This occurs mainly due to high pressure in the groundwater underneath and behind the dike. Infiltration also causes instability.
4. Macro instability at the outer slope. During low water level at the river side the levee could subside due to instability. The cause is a high water pressure within the dike after a fast drop of outer water level after high water levels or rain intensity.
5. Piping/heave. The water moves underneath the dike due to a high water level at the outside and a low water level at the inside. This causes channels underneath the dike that transport sediments and create erosion and instability behind the dike.
6. Micro instability. The construction of the protection layer is affected by wave motion. This erosion causes washes at these locations.
7. Erosion foreland. The foreland has influence on the stability of the dike. When erosion takes place this stability decreases and causes instability of the dike structure.
8. Softening. The mass within the dike gets saturated. Thereby the ground gets soft and prone to movement. This occurs due to a steep slope, upper load, wave frequencies and wave action that creates a critical water tension.

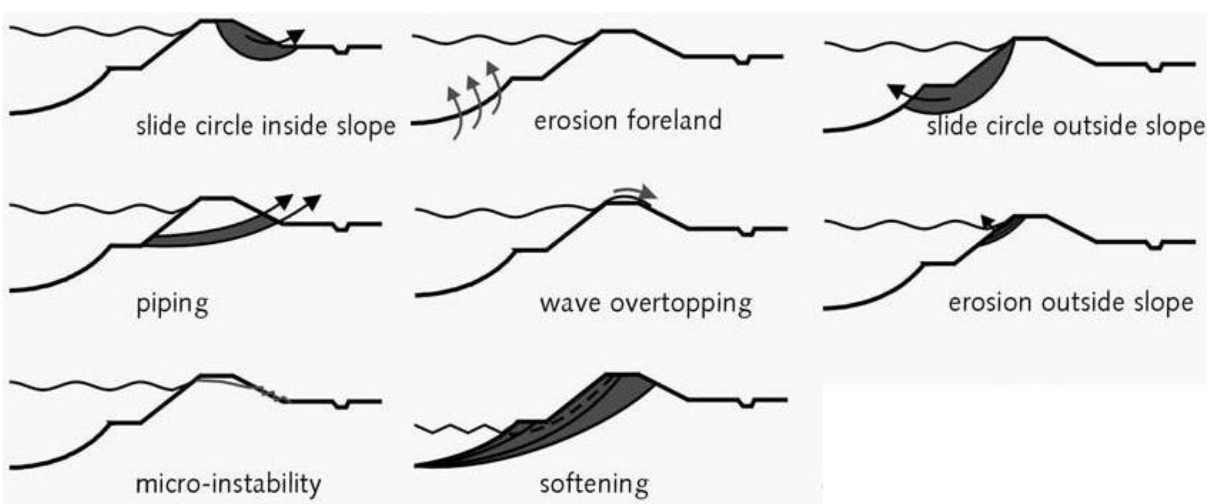

Figure 1. Failure mechanisms of a dike (www.deltares.nl)

Annex 3. Policy

This annex describes the policy that is involved with water safety of dikes and thus water retaining dike management. The state, province and water boards determine the legal boundary conditions. Table 1 gives a short overview of current legal policy documents with the legislation, norms and implementation that influence water retaining dike management.

Table 1. Overview of legal policy documents with respect to water safety

Institute	Legislations	Norms	Implementation
The state	Waterwet	Primary water defense Inundation probability	Wettelijke toetsinstrumentarium
The province	Provinciale verordening	Secondary water defense inundation probability	-
Water board	Zorgplicht 'duty of care'	Maintenance and management	Waterbeheerplan / Inspectieplan / Legger / Keur

The state
The state is the leading authority towards legislation. They determine the input of the most important legislations being the 'Waterwet', 'Waterschapswet' and 'Nationaal Waterplan' (Rijksoverheid, 2015). This is relatively consistent and of direct influence on the legal responsibilities towards dike inspection. The state also provides 'guidelines and handbooks' by STOWA and Rijkswaterstaat, which function as a knowledge platform towards dike inspection subjects. Also is the state an important financer of large constructions (dike improvements) and researches (FloodControl IJkdijk, 2015). Conclusively the state has an execution branch (Rijkswaterstaat) that has the direct responsibility of the water safety next to water boards.

The province
The province implements the policies of the state with more specified applications. They have two important policy implications for the water boards. The first are the 'Regionale waterplannen', which contain the aims and targets on a provincial level and offer a bridge between policy documents of the state and local water policy documents. The second policy implication is the 'Waterverordeningen', which gives notion towards the exact implementation towards the duty of the water boards. It states that the water board is obligated to draw a 'Waterbeheerplan' and appoint the norms of regional water defenses. Provinces have no direct responsibility towards dike inspection itself.

Water boards
Water boards are an executive governmental organization. In this they are responsible of providing safe dikes, the water system, purification of waste water and nature. The water boards are the main authorization in the Netherlands in managing the water systems. Since 2010 all policy documents of the water boards are merged in a maintenance plan 'Waterbeheerplan'. This describes the desired process and aims with a 6 year return period, from 2010-2015. It is the first integrated water maintenance plan based on all principles within a water board: safety, water quantity, water quality, waste water and cooperation with other water authorities. The 'Waterbeheerplannen' are very process orientated and focuses mainly about the strategy and aims and less on the actual implementation. Currently a transition is seen towards 'inspectieplannen' that gives more urge towards inspection processes.

Table 2 elaborates the policy that influence water retaining dike management with an explanation of the policies by aim, effect and influence on the implementation of dike monitoring techniques. The influence of the legislation and policy on dike monitoring techniques is determined by the signs --, -, -/+, + and ++. The signs mean the following: -- no effect, - small, -/+ moderate, + substantial and ++ large effect. It is an indication based on synthesis.

Table 2. Policy towards water retaining dike management

Policy water retaining dike management	**Aim**	**Effect**	**Influence policy on dike monitoring techniques**
European legislation			
'Richtlijn Overstromingsrisico's' (ROR)	Principals for all EU-members towards mapping safety flood risks.		--
State legislation			
Waterwet	Integral legal document towards all activities in water management with an approach for decentralization and uniformity. Long term based.	Legal basis for water boards in water safety, water quantity, water quality and permits.	+
Waterschapswet	Contains the general rules and the legal base of the water boards.	The legal basis of composition, rights and finance of the water boards.	-
Nota Ruimte	National spatial policy until 2020.	Legal spatial restrictions.	--
Wet op de veiligheidsrisico´s, 2004	Operational help during a calamity by means of cooperation between fire brigade, police, hospitals and water authorities.	Proactive, preventive and operation program against possible calamities within the area of safety.	-/+
Nationaal Bestuursakkoord Water (NWB), 2003 → 2008	Legal agreements on terms on water safety and disturbance and processed based agreements about water quality and water quantity to get the water system in order.	Water policy has to be based on the river basin, the 'Watertoets' is obligated in spatial planning and the 'retain – store –discharge' principle is central.	+
Nationaal Waterplan	Contains the policy of the state, aims and measurements in	For water safety: multi layered security, new	+

(NW)	water management. Frequently updated together with the regional water plans.	norms towards examinations, robust 'delta dikes', weak spots in outer dike areas and natural processes.	
Guidelines and handbooks	Give technical knowledge about water safety phenomena	'Voorschrift Toetsen op Veiligheid', Handreiking Constructief Ontwerpen', 'Technisch rapport Waterkerende Grondconstructies' and 'Handreiking inspectie Water'.	++

Province legislation

Regionale waterplannen	Aims and targets for the water policy for the long and short term. Guidance towards the provincial implementation of the water regulations of the state.	Implementation is together with 'Waterbeheerplan' of water boards. Secure the safety regulations (NW), water quantity (NWB) and water quality (KRW).	+
Structuurvisie/Bestemmingsplan	The law spatial planning gives clarity towards the function of an object.	It determines the function of an object and can give spatial defense in critical parts of water structures.	-
Waterverordening	The legal regulations that state the boundaries of the water boards.	Regulations are: water levels, 'Waterbeheerplan', norms of dikes and distribution secondary dikes.	++

Water board legislation

Waterbeheerplan	Describes the general aims and future visions of the water board towards their entire set	The guideline towards the rules to which the employees should	-/+

	of responsibilities.	comply.	
Inspectieplan	The practical policy towards the entire inspection process of the water board.	Description that is used during application and feedback of inspection.	++
Legger	The 'Legger' is the normative condition of the dike in geographic, morphological and hydrological context.	This is the standard from which the water defenses are inspected. Water defenses has to comply to the 'Legger'.	++
Keur	The 'Keur' is the regulation with the rules to maintain the water defenses.	During construction there is a need of permission from the water board to retain the function of the dike. Continuous supervision.	++

Annex 4. Dike inspection in practice

The method of conducting and processing dike inspection is by identifying, diagnosis, prognosis and operationalize and shown in Table 1. This process is operated by the operator in the field and the specialist at the office offers the legal boundaries, guidelines and conducts additional research.

Table 13. Application of current dike inspection in the field

	Daily inspection	Annual inspection 'Schouw'	Special circumstances	Calamities
Execution	Foot and car	Foot	Foot and car	Foot and car
Methods	Inspectieplan	Inspectieplan	Calamity plan	Calamity plan
Dikes	Varies daily	All dikes	Facing risk	Facing risk
Return period	Daily	Annual	Droughts, High water levels, Intensive rainfall, Ice	Extreme droughts, Extreme high water levels
Stipulation	Signals, Notifications/Alerts	Maintenance plan ('Onderhoudsplan)'	Signals, Notifications/Alerts	Signals, Notifications/Alerts
Observation	Eye, touch and listening	Eye, touch and listening	Eye, touch and listening	Eye, touch and listening
Techniques	App	App	App	App, Dike monitoring technique

Visual inspection is the core of dike inspection and this could for a large extent also be addressed by dike monitoring techniques. They have the same principle by getting insight in irregularities occurring in the dike. Regular procedure currently used for dike inspection is by means of identifying, diagnosis, prognoses and operationalize (STOWA, 2012). Dike monitoring techniques can enhance these phases by offering objective data. Figure 1 shows all processes of the current dike inspection procedure. The signs colored green are the processes that could be enhanced by dike monitoring techniques.

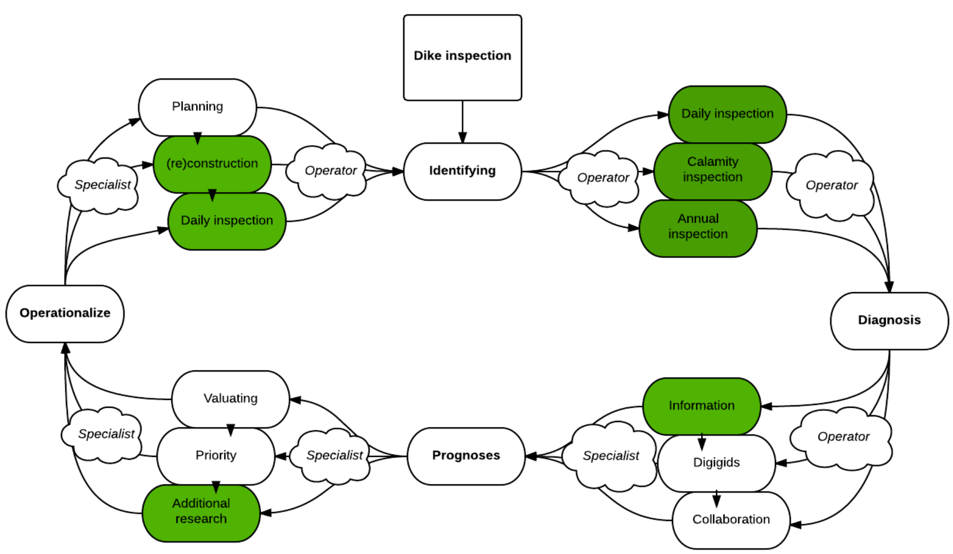

Figure 1. Process of dike inspection to which dike monitoring techniques (in green) relates

Identifying
Identifying is the core business of the operator and the start of the visual dike inspection cycle. The aim is to identify the occurrence of aspects that have influence on the state of the dike. Inspection is by means of physical inspection at sight. There are various identification moments, varying from daily inspection, annual inspection, special circumstances and calamity inspection (Moser et al, 2009). Currently the local knowledge about the dike is gained by three senses: sight (eye), touch (feet and hands) and hearing (natural sounds). Additional tools are the utility probe, conversation and historical knowledge. Identifying is a continuous process of the operator who is aware of the local system and occasions of potential risk (Moser et al, 2005).

Diagnosis
The notice of identification requires a diagnosis after it is processed. The standard input to diagnosis is at the office, although minor detections are mostly immediately dealt with by the operator. This leads to a procedure in which it is determined what further actions should follow and gives insight in the consequences of the damage towards the state of the dike. Recent developments of the app 'Digigids' provided immediate insight of the identification at the desktop in the office (STOWA, 2011). It therefore seems to be a useful tool for the link between the operator and the office employees (Swart, 2007). The actual diagnosis is based on the knowledge and interpretation of the specialist at the office. The 'Handreiking Inspectie Waterkeringen' provides a reference among his former experiences. In case of doubt collaboration with other specialists or operators is done (Moser et al., 2009). For certain parameters standards are set to which identification can easily be referenced.

Prognosis
In the former two steps data is gathered and processed. After these steps it is crucial to assess and judge the actual danger level of the located damage sign(s). The level of urgency is determined via the diagnosis. The specialist (or the operator) can predict further needs for the given damage sign and therefore make a prognosis about the seriousness of the threat (Swart, 2007). A value is given to the water retaining ability of the dike and estimations are made that corresponds with the core of the thread. Prognoses with low priority (minor damages) are often easy to assess and operationalized regularly. Larger damages have higher priority, but are also harder to finance and repair. Mostly, dependent on the level of urgency, a more intensive procedure of identification and further research is conducted (Swart, 2007). Immediate threats towards the water safety ask for immediate action. If it is uncertain what the influence is on the safety additional research or examinations will be conducted (Bakkenist and Zomer., 2010). More irregularities within the same area also mean a higher priority as these increases the insecurity (STOWA, 2012).

Operationalize
If a priority is given after which operation seems necessary there is need of actual construction with subsequent maintenance procedures. The measures are defined, planned, prepared and executed. During execution there is continuous visual inspection by the operator during which he again identifies dissatisfactions and is in contact with the contractor. After the measures are completed it will be administratively processed and the result checked by visual inspection. Especially unknown risk potentials are noticeable as unknown risks mostly will contain further research after which a new consideration is made towards reinforcements (STOWA, 2012b).

Annex 5. Examination in practice

The method of conducting examination is by means of calculation through models and formulas. Table 1 with forthcoming parameters, judgement methods, mathematical methods and calculation is provided by van der Plicht (2015) and shows most important characteristics of current examination practices.

Table 14. Current practice of examination

Failure mechanism	Parameters	Judgement method	Mathemetic model	Calculation
Overflow	Type revetment, height dike, talud inner slope, water level	WTI2011 (/OI2014v3 for HWBP)	Excel, GIS	-
Overtopping	Type revetment, height dike, wave height, talud inner and outer slope, water level	WTI2011(/OI2014v3 for HWBP)	Excel, GIS	-
Piping	Soil composition, sea page length, erosion, dike width, thickness layers	WTI2011(/OI2014v3 for HWBP)	Excel	Sellmeijer formula
Macro stability	Soil composition, water height, strength, slope	VTV2006(/OI2014v3 for HWBP)	D-Geo Stability, PLAXIS	Bishop (Spencer-Van der Meij from WTI2017/OI2014v3)
Micro stability	Water level inside and outside dike, phreatic line, thickness clay revetment, drained yes/no	VTV2006(/OI2014v3 for HWBP)	Excel	-
Erosion foreland	Gully depth, material foreland, height foreland	WTI2011(/OI2014v3 for HWBP)	D-Geo stability	-

Figure 1 shows the processes of the examination method. Examination has three phases of research during simplified judgment, detailed judgment and advanced judgment (Rijkswaterstaat, 2013). It is judged by means of calculation (defined by parameters and models) what the probability is for a failure mechanism (Annex 2) to occur. If one failure mechanism is determined as not safe further (parameter) research is conducted. In the end there is necessity of (re)construction and/or location specific dike monitoring after which the examination procedure is finished and later on repeated in the multiannual cycle (VTV, 2007). The possible enhancement of monitoring techniques is shown in the green colored signs.

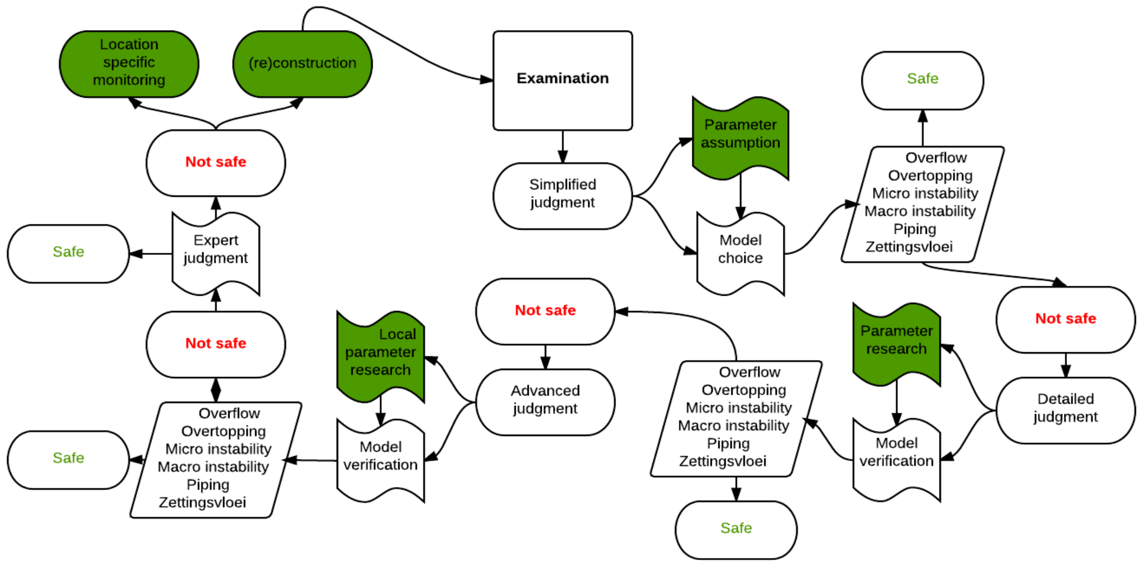

Figure 1. Process of examination to which dike monitoring techniques (in green) could offer enhancement

Simplified judgement

Examination first contains a simplified judgement with general parameter assumptions, which is implemented in a model that differs per calculated failure mechanism. If the outcome is safe for all failure mechanisms no further actions will follow beside regular management and maintenance. If one or more failure mechanisms are determined not to be safe detailed judgement takes place for those failure mechanisms only (Thijs, 2007).

Detailed judgement

Detailed judgement is in fact the same as simplified judgement, but with an intensified parameter research. This research contains mostly a higher intensity of parameter values. Measures of the strength and forces lead to an interpretation model for the research failure mechanisms (Swart, 2007).

Advanced judgement

Again after an outcome is determined to be unsafe parameter research will take place for the second and last time. Specific locally measured parameters will be lifted that contribute to the failure mechanism(s) that cause an unsafe situation (Swart, 2007). Customization must be provided to determine in what way optimal knowledge could be gained.

If the calculations show that the dike is again not safe then (re)construction is necessary (Moser et al, 2009). (Re)construction are structural improvements towards the dike body to counter the given failure mechanism(s). A large variety of reinforcement opportunities' exist for each failure mechanism, but the similarity is that the execution is critical. Therefore monitoring can take place during reinforcements to take notice of unwanted situations. In this phase dike inspection also contributes (Rijkswaterstaat, 2013). The second solution is location specific dike monitoring (3.2.5).

Expert judgement

The expert judgement contains the judgement of the operator. When he did not face irregularities further parameter research and/or further model verification can ought to be necessary.

Annex 6. Dike monitoring techniques and failure mechanisms

The most common remote sensing and in situ techniques are presented in relation with the most common failure mechanisms. The tables show the relevance towards applicability (level of implementation), inspection (opportunity to maintain), monitoring (long term supervision) and costs (related costs). The signs mean the following: - - is very bad, - bad, -/+ moderate, + good and ++ very good and determined by personal observations from literature (Bakkenist and Flos., 2015; Bakkenist and Zomer., 2010; van den Berg and Koelewijn., 2014; Deltares, 2011; Koelewijn et al., 2010; Kolk et al., 2011; Moser et al., 2005; Moser et al., 2009; Moser and Zomer., 2006; STOWA, 2004; Swart et al., 2007; Swart, 2007; de Vries et al., 2014; Weijers et al., 2009). The failure mechanisms noted are the most important failure mechanisms in practice (Annex 2) (van de Berg and Koelewijn, 2014)

i. Remote sensing

A. Moisture content of the surface - Infra-red

Main characteristics:

- Detection of piping and micro stability;
- Does not detect macro stability, overflow and instability foreland;
- Pictures of heat dike surface by camera;
- Partly maneuverable;
- Difficult transformation to failure occurrence.

Table 1. Characteristics infra-red vs. failure mechanisms

Infra-red technique	**Failure mechanism**				
Characteristics	**Overflow**	**Macro stability**	**Micro stability**	**Piping**	**Erosion foreland**
Applicability	--	+	-/+	++	--
Inspection	--	+	+	+	--
Monitoring	--	-	-	-	--
Costs	--	--	--	--	--

B. Moisture content inside the dike - Microwave

Main characteristics:

- Detection of piping, micro stability and macro stability;
- Does not detect overflow and instability foreland;
- Pictures of water content in the dike;
- Maneuverable (from helicopter to ATV);
- Difficult transformation to failure occurrence.

Table 2. Application vs. failure mechanisms - microwave

Microwave	**Failure mechanism**				
Characteristics	**Overflow**	**Macro stability**	**Micro stability**	**Piping**	**Erosion foreland**

Applicability	--	+	-+	+	--
Inspection	--	+	+	+	--
Monitoring	--	-	-	-	--
Costs	--	-/+	-/+	-/+	--

C. Height measurement – Satellite/In SAR/ Laser altimetry / Lidar

Main characteristics:

- Detection of the height differences of the dike over time;
- Detects the failure mechanism of overflow indirectly.
- Does not detect macro stability, micro stability and instability foreland;
- Large reach and focused zoom;
- Return period of images is 5-20 days;
- Difficult transformation to failure occurrence.

Table 3. Application vs. failure mechanisms - satellite

Satellite	**Failure mechanism**				
Characteristics	**Overflow**	**Macro stability**	**Micro stability**	**Piping**	**Erosion foreland**
Applicability	++	--	--	--	--
Inspection	-	--	--	--	--
Monitoring	++	--	--	--	--
Costs	+	--	--	--	--

D. Surface underneath the water body - Sonar

Main characteristics:

- Detection of piping and soil properties;
- Does not detect macro stability, micro stability, overflow and instability foreland;
- Echo towards the bottom of the soil;
- Maneuverable over water;
- Difficult transformation to failure occurrence.

Table 4. Application vs. failure mechanisms - sonar

Sonar	**Failure mechanism**				
Characteristics	**Overflow**	**Macro stability**	**Micro stability**	**Piping**	**Erosion foreland**
Applicability	--	+	-+	+	-
Inspection	--	+	+	++	+
Monitoring	--	-	-	-	--
Costs	--	--	--	--	--

E. Live data – Drones

Main characteristics:

- Detection of damages and irregularities;
- Does not detect overflow, micro stability, macro stability, overflow and instability foreland;
- Live coverage of the status of dikes;
- Can be supplemented with high resolution cameras, infra-red etc.
- Highly maneuverable, but not applicable during storm;
- Very difficult transformation to failure occurrence.

Table 5. Application vs. failure mechanisms - drones

Drones	Failure mechanism				
Characteristics	Overflow	Macro stability	Micro stability	Piping	Erosion foreland
Applicability	+	+	+	+	--
Inspection	++	++	++	++	+
Monitoring	-	-	--	-	-
Costs	-/+	-/+	-/+	-/+	-/+

F. Soil properties - Ground radar

Main characteristics:

- Detection soil properties;
- Does not detect overflow piping, micro stability, macro stability and instability foreland;\
- Useful to understand the system and unknown parameters;
- Radiographs of the soil by pulsing waves into the soil from 16 MHz until 1500 MHz;
- Maneuverable (Car to men);
- No possible transformation to failure occurrence, only indirect;

Table 6. Application vs. failure mechanisms - ground radar

Drones	Failure mechanism				
Characteristics	Overflow	Macro stability	Micro stability	Piping	Erosion foreland
Applicability	-	-	-	-	-
Inspection	-	-	-	-	-
Monitoring	-	-	-	-	-
Costs	-	-	-	-	-

ii. In situ

A. Deformation – Stability sensor

Main characteristics:

- Detection of overflow, macro stability and micro stability;
- Does not detect piping;
- Measures change in the dike structure;
- Not maneuverable;

- Difficult transformation to failure occurrence.

Table 7. Application vs. failure mechanisms - stability sensor

Stability sensor	**Failure mechanism**				
Characteristics	**Overflow**	**Macro stability**	**Micro stability**	**Piping**	**Erosion foreland**
Applicability	-	-	-	--	-
Inspection	+	+	+	--	+
Monitoring	++	++	++	--	++
Costs	-	-	-	--	-

B. Deformation – Glass fiber

Main characteristics:

- Detection of piping, instability foreland, macro stability and micro stability;
- Does not detect overflow;
- Pictures of temperature differences and info of deformation at installation location;
- Not maneuverable;
- Difficult transformation to failure occurrence.

Table 8. Application vs. failure mechanisms - glass fiber

Stability sensor	**Failure mechanism**				
Characteristics	**Overflow**	**Macro stability**	**Micro stability**	**Piping**	**Erosion foreland**
Applicability	--/+	--/+	--/+	--/+	--/+
Inspection	+	+	+	++	+
Monitoring	+	++	+	++	+
Costs	+	--/+	--/+	--/+	--/+

C. Ground water level – Water tension meter

Main characteristics:

- Detection of macro stability and micro stability;
- Does not detect piping, overflow and erosion foreland;
- Measures change of the water level and pressure in the dike;
- Not maneuverable;
- Difficult transformation to failure occurrence.

Table 9. Application vs. failure mechanisms - water tension meter

Water tension meter	**Failure mechanism**				
Characteristics	**Overflow**	**Macro stability**	**Micro stability**	**Piping**	**Erosion foreland**
Applicability	--	-/+	-/+	--	-
Inspection	--	+	+	--	-
Monitoring	--	++	++	--	-

Costs	--	-	-	--	-

D. Erosion – Density recorder

Main characteristics:

- Gives insight in erosion foreland and micro stability.
- Slightly appropriate for piping and macro stability, but not for overflow;
- Measures the density of the soil and thus erosion;
- Difficult data interpretation;
- Expensive for large implementation.

Table 10. Application vs. failure mechanisms – density recorder

Density recorder	**Failure mechanism**				
Characteristics	**Overflow**	**Macro stability**	**Micro stability**	**Piping**	**Erosion foreland**
Applicability	--	-	-/+	-	-/+
Inspection	--	-	+	-	+
Monitoring	--	-	++	-	++
Costs	--	-	-/+	-	-/+

E. Ground water pressure – Pressure recorder

Main characteristics:

- Detection of piping and macro stability.
- Slightly appropriate for overflow, could not detect micro stability and erosion foreland phenomena;
- Measures the pressure within the soil and varying water levels;
- Difficult data interpretation;
- Expensive for large implementation.

Table 11. Application vs. failure mechanisms – pressure recorder

Pressure recorder	**Failure mechanism**				
Characteristics	**Overflow**	**Macro stability**	**Micro stability**	**Piping**	**Erosion foreland**
Applicability	-	-/+	--	-/+	--
Inspection	-	+	--	+	--
Monitoring	-	++	--	++	--
Costs	-/+	-/+	--	-/+	--