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Fault Assessment of Flood Protecting Dikes with Remote Sensing

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Abstract

Riparian and extensive industrial areas at rivers and tidal estuaries in many parts of the world have been protected against regular and extreme floods with a system of dikes and dams for centuries. In Germany approx. 32.000 km of river, estuary and coastal dikes have to be maintained and improved against water level rises and increase of flood events by climate changes. Detection of faulty reaches by local inspections is costly and often ineffective. During storm and flood events it is often impossible to approach endangered parts for quick analysis and prevention of dam breaks and bursts.

Airborne remote sensing before and during events of storms and floods with special High Resolution Stereo Space Cameras together with infrared photographing and GPS and GIS supported surveys are used to assess potential positions of risk for dam or dike failures. To identify basic sets of fault imaging, e.g. specific vegetation from certain seepage configurations or construction methods, a laboratory dike has been erected at the University of Hannover. Images from airborne remote sensing are compared with controlled laboratory conditions and specific programs are under development for near real time dike failure and risk assessment.

Introduction

A natural phenomenon in the hydrological cycle is flooding. Flooding is necessary to replenish soil fertility by periodically adding nutrients and fine grained sediment.

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However, it can also cause loss of life, temporary destruction of animal habitat and permanent damage to urban and rural infrastructure. Inland floods can result from disruption to natural or man-made dams, rain, river ice jams and / or excessive runoff. Coastal floods can result from failures of the coastal defence system (especially of dikes) during storm surges.

Remote sensing techniques are used to measure and monitor the aerial extent of flooded areas in order to efficiently target rescue efforts and to provide quantifiable estimates of the amount of land and infrastructure affected. Incorporating remotely sensed data into a GIS allows quick calculations and assessments of water levels, damage, and areas facing potential flood danger.

Moreover 3d stereo cameras, thermal infrared and microwave sensors are used to detect damages in dikes and dams. Therefore vegetation type, soil moisture, soil temperature and spatial surface structure were measured.

Model investigations

In this paper results of basic investigations of the application of different remote sensors for the detection of damages on an open-air laboratory dike at the Franzius-Institut of the University of Hannover, Germany will be shown (Figure 4). Furthermore results of field investigation of costal and river dikes in comparison to the laboratory experiments will be presented.

One of the remote sensors used in the project is the High Resolution Stereo Camera-A. Originally designed by the DLR for international missions to Mars, the small dimensions, low mass, low power consumption and robust design of the High Resolution Stereo Camera (HRSC) made an ideal system to be modified for airborne remote sensing applications (HRSC-A). The HRSC-A is a push broom style, multispectral stereo scanner. HRSC-A data are recorded in a georectified, digital format, allowing for easy access and analysis (Lehmann, F. et al., 1998).

The data produced include a panchromatic nadir channel with a spatial resolution of 0.16 m, four multispectral channels (blue: 395 – 485 nm, green: 484 – 576 nm, red: 729 – 777 nm, near infrared: 920 – 1020 nm) with a spatial resolution of 0.5 m and a Digital Surface Model (DSM) with a spatial resolution of 0.32 m. The multispectral data allows spectral classification of vegetation and land using a high spatial resolution mapping. For the generation of Digital Terrain Models (DTMs) a digital multiple correlation process is performed (Renouard, L. et al., 1999).

The resulting identical image points are converted into object points by ray intersection. Figure 1 show the HRSC-A sensor together with the geodetic reference unit T-AS.

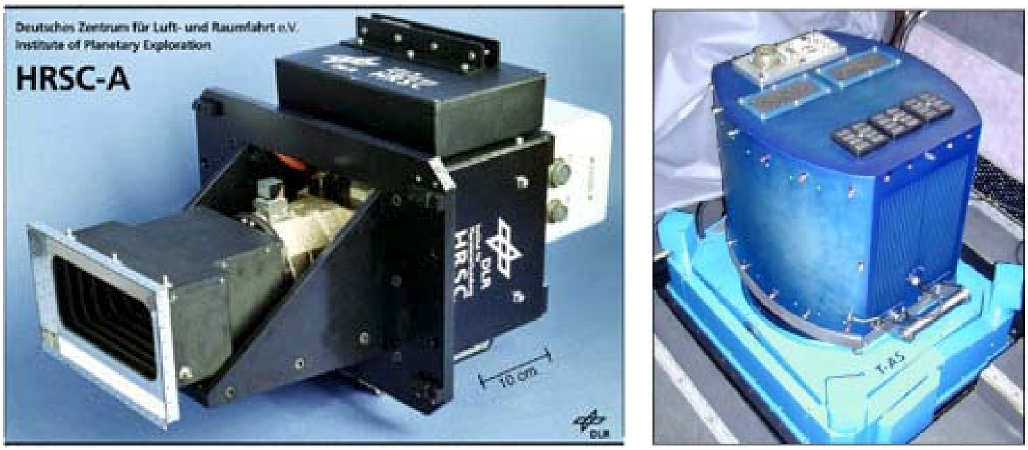

Figure 1. High Resolution Stereo Camera-A (HRSC-A) and geodetic reference unit T-AS.

The second remote sensor used in the project is a Nikon "Thermal Vision Infrared Camera" of the type LAIRD-3AS, sensitive to radiation within the 3-5 µm wavelength range (TIR). All bodies with temperatures greater than ambient emit significant amounts of IR radiation within this wavelength range. This wavelength range is less affected by atmospheric water vapour absorption than the other commonly used long wave IR waveband (8-14 µm), which is important due to the fact that, unlike overhead satellite or aerial views, the ground-based viewing path lies consistently through the peak of atmospheric water vapour concentration. The IR images were output through the camera BNC terminal (analogue video) and the RS422 port as digital data. The original resolution of the camera is 764 x 494 pixels. The left hand side of Figure 2 shows the Nikon LAIRD-3AS camera.

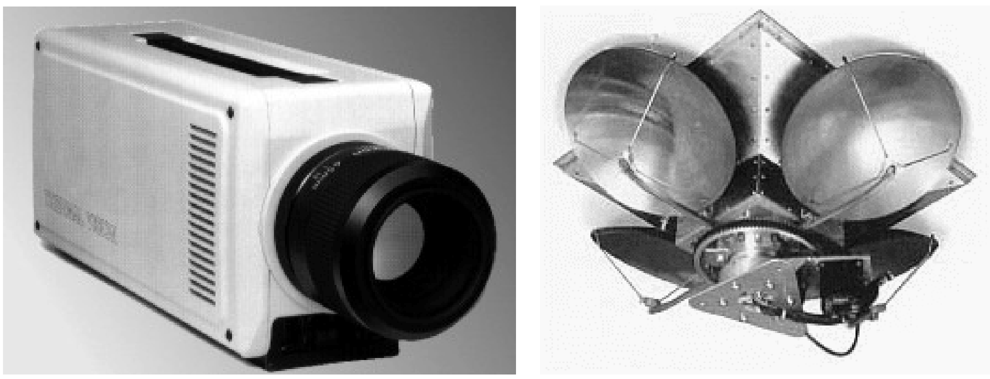

Figure 2. Nikon "Thermal Vision Infrared Camera" of the type LAIRD-3AS and modified microwave radiometer (MWR).

Another used remote sensor is a modified microwave radiometer (MWR) as it shown on the right hand side of Figure 2. The main objective of the MWR is the measurement and determination of surface emissive and soil moisture over land. To avoid interferences with other radiation the MWR use wavebands in the 18 GHz, 36 GHz and 89 GHz spectrum which is reserved for physical experiments. Figure 3 shows the vertical transmission in the microwave band in a cloud free atmosphere.

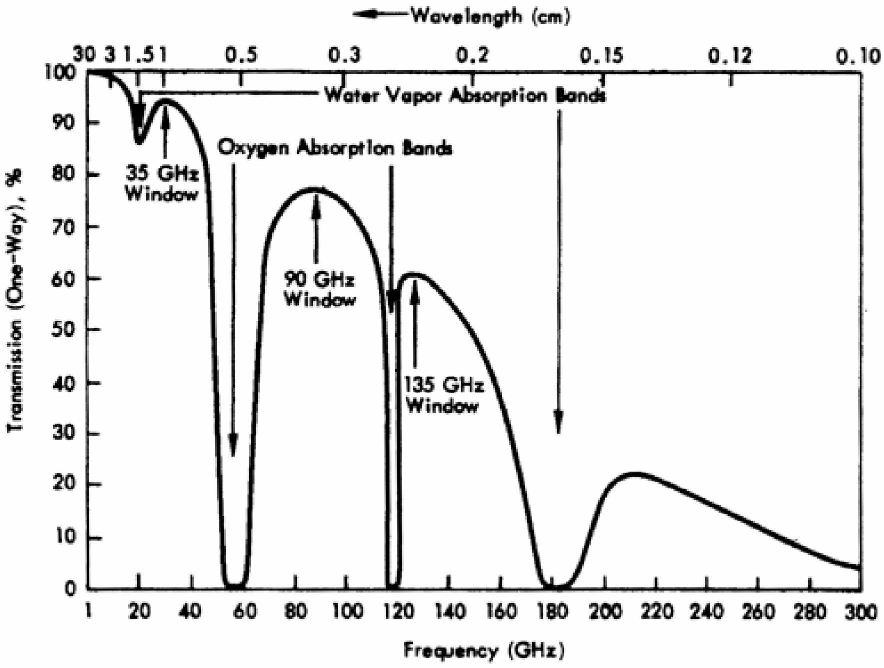

Figure 3. Vertical transmission in the microwave band in a cloud free atmosphere (Ulaby, F.T. et al., 1981).

The main advantage of the MWR is the capacity to measure in different meteorological situations. In opposition to the TIR sensor, measurements with the MWR are also possible in cloudy, foggy and even rainy situations. Moreover the reflection zone and penetration depth of the microwave signal is more significant to detect potential positions of risk for dam or dike failures.

Measurements at a laboratory dike

In order to simulate dam and dike failures and to calibrate the remote sensors, a laboratory dike has been erected at the Franzius-Institut of the University of Hannover. The dike has a crest height of 3 m a landside slope of 1:2 and a waterside slope of 1:3. The maximum water level for infiltration can be up to 3 m. The main purpose of the dike is to investigate the possibilities of recognizing eventual dam and dike breach zones during or even before a high flood under defined boundary and failure conditions. Figure 4 shows an aerial view and the measure equipment of the laboratory dike in Hannover Marienwerder.

Figure 4. Open-air laboratory dike at the Franzius-Institut of the University of Hannover, in Hannover Marienwerder, Germany.

Figure 5 gives an idea of the infiltration and seepage of water into the laboratory dike and the detection of the seepage water in the thermal infrared pictures. The left hand side of the pictures show the situation of the dike directly after the beginning of the infiltration. The right hand side show the situation after 10 days of infiltration.

The upper charts give the water level inside the dike for two cross-sections (dotted lines). The pictures in the centre give an aerial view of the laboratory dike with a visual camera. Inside the boxed area which gives the view field of the thermal infrared picture (bottom of Figure 5) one can see dry areas after the beginning of the infiltration and wet areas after seepage of 10 days.

The same areas can be found in the thermal infrared picture. Here warmer areas and therefore dryer areas are displayed in green colours and cooler areas respectively wetter areas in blue colours. The change of the colours can be detected even before a significant visual change can be found.

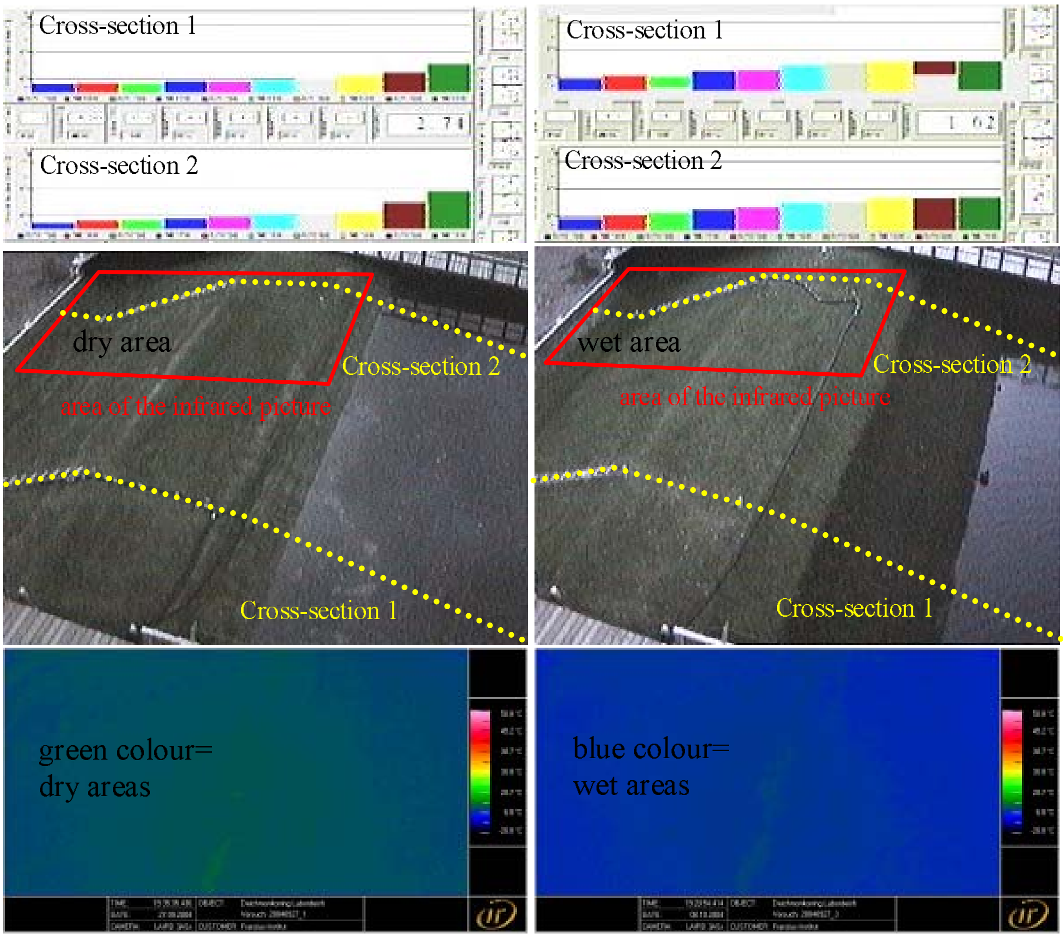

Figure 5. Infiltration data (top), visual data (middle) and thermal data (bottom) directly after infiltration of a dike (left) and after infiltration of 10 days (right).

Therefore the infrared pictures are applicable for the forecast of seepage water level in dikes during high floods and the detection of areas where piping or ground seepage and failures can occur. The disadvantage of the thermal infrared sensor is the above mentioned limited utilizability during special meteorological situations. Therefore the modified microwave radiometer (MWR) will be tested in spring 2005 to avoid theses disadvantages. Due to high costs and a constant operational use there are no investigations planed with the HRSC-A sensor in the hydraulic model.

On-site measurements

Figure 6 shows the location of the project areas and on-site measurements at the dikes of the rivers Ems, Mulde, Elbe and Oder. In contrast to the hydraulic model investigations the HRSC-A and the thermal infrared camera TIR were used as remote sensors during the on-site airborne surveys. In autumn 2005 the modified microwave radiometer MWR shall also be used for the on-site measurements.

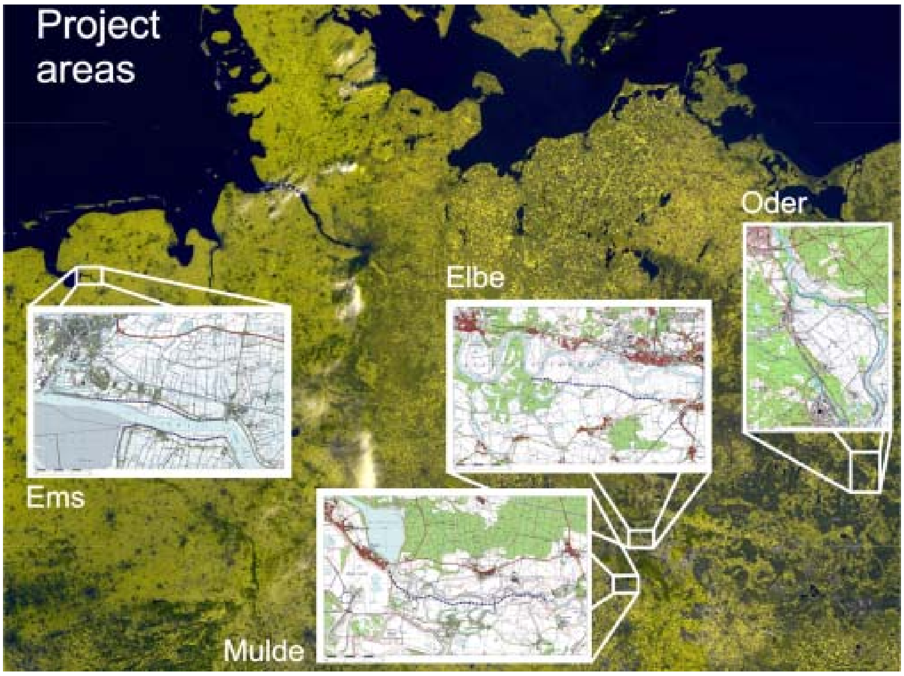

Figure 6. Location of the project areas and on-site measurements.

Parallel to the remote sensing operations and measurements basic on-site ground measurements and investigations taking place. Figure 7 gives an overview about the different measurements and data collections.

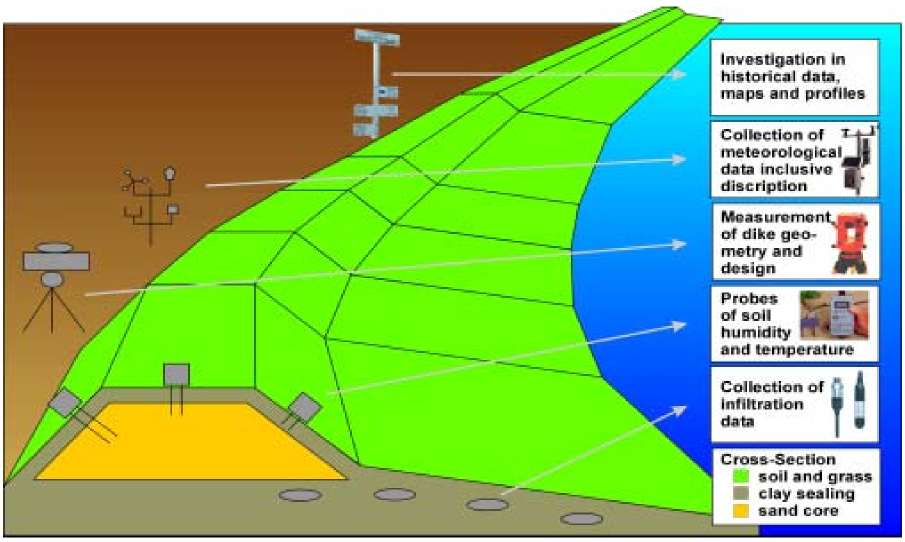

Figure 7. Type of basic on-site ground measurements and data collections.

Integration of the measurements in a GIS

Finally all collected data and measurements were integrated into a Geographic Information System (GIS), so that potential user can work fast end efficient with the data. In the GIS system different data types and information's are collected (e.g. Mai, S. et al., 2003). Due to interpolation, differentiation and mergence of all data it is possible to identify potential positions of risk for dam or dike failures. Criteria for those positions are strong gradients in the thermal infrared radiation, erosions and subsidence in the dike geometries, identification of special vegetation types, molehills and musquash or fox holes (Kühn, F. et al., 1998).

Moreover visual elements like vehicle crossings and trials, buildings and structures like culverts, sluices and water scoops can be identified. The identification of all uncertainties is semi-automated in the GIS and is weighted by an operator e.g. a geologic or geographic specialist. The result will be a zoning of the dike in different hazard areas. Figure 8 gives an example of a visual false RGB (left hand side) and a visual PAN image as aerial view of a dike at the river Mulde and its integration in the GIS.

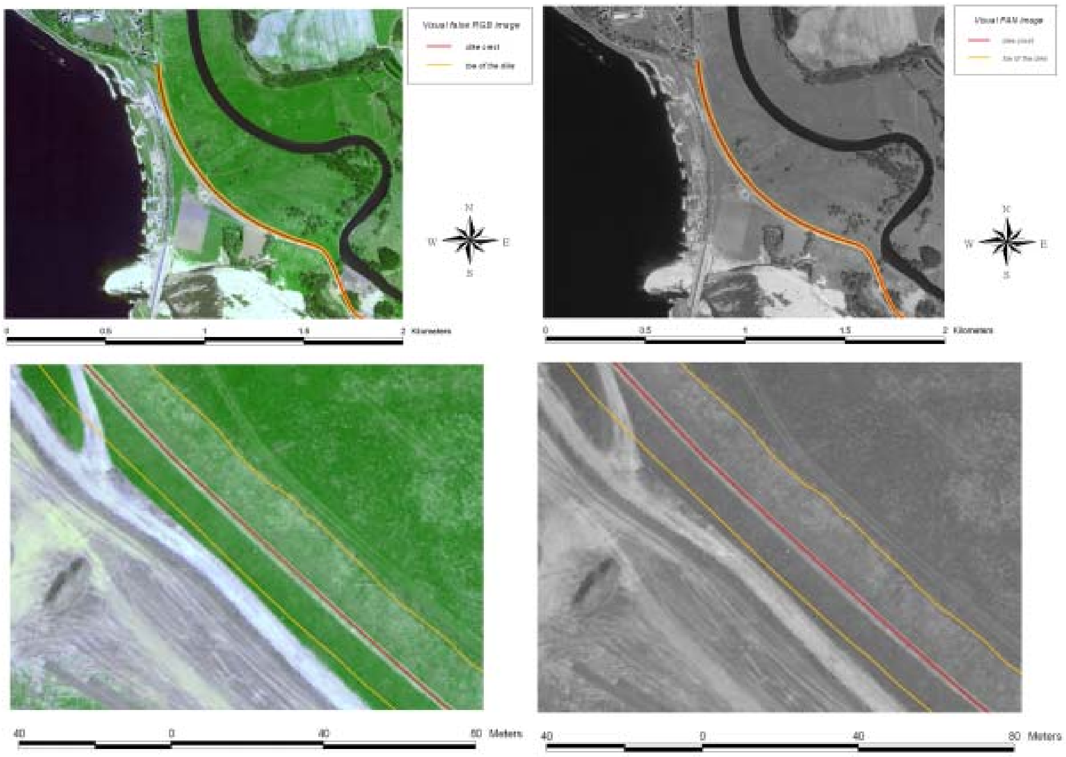

Figure 8. Aerial false RGB (left) and visual PAN (right) images of a dike at the river Mulde.

Figure 9 gives a section of the calculated Digital Terrain Model DTM from measurements of the HRSC-A sensor and their integration in the GIS.

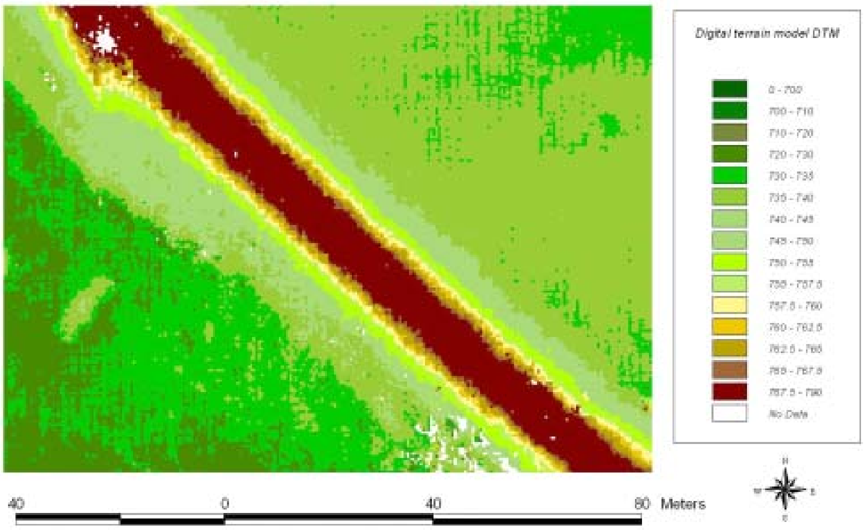

Figure 9. Data of the HRSC-a as Digital Terrain Model DTM in the GIS.

Figure 10 shows the semi-automated zoning of the dike in different hazard areas and the identification of special dike elements.

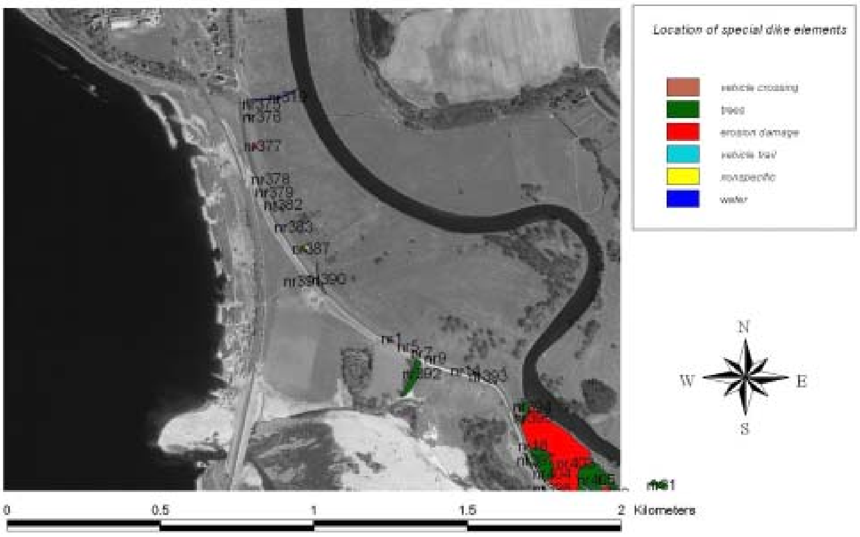

Figure 10. Location of identified special dike elements in the GIS.

Conclusion

By combining GIS techniques with data of multi-spectral sensors, it is possible to extract and identify potential positions of risk for dam or dike failures. Moreover it is possible to create a manipulate thematic mask within the GIS to zone the dike in different hazard areas. The ability to mix and match different classes and data sets between themes in the GIS alleviates the interpretation of all measurements and data for the applied task.

Additional work is required to better automate the masking and zoning processes and to make the analysis more time sensitive. A consideration of the seasonality and the meteorological conditions is especially relevant for the thermal infrared layer, as soil moisture conditions can change rapidly, but can only be measured at the time where the scene was captured. Nevertheless the incorporation of high spatial resolution panchromatic PAN, false RGB and stereo imagery with thermal infrared and passive microwave data provides high classification accuracy for the fault assessment of flood protection.

Acknowledgement

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