Combating floods together – targeted approaches towards countering the risks

Homes destroyed, assets wiped out, existences under threat: it would seem residents in flood-risk regions are increasingly having to stand by and watch water taking away their property. The risk comes not only from swollen rivers that flow over or break their banks; because the groundwater level increases so much during a flood this puts cellars and underground infrastructures under threat too. Professional risk management is essential if the dangers posed to business and residential areas are to be avoided.

Both floods and low waters form part of the natural dynamic of all river landscapes. However, the impact of global climate change has given rise to a trend of extreme meteorological events in Central Europe, such as droughts and extreme rainfall. There has also been an increase in so-called "hundred-year floods". Floods are already the most widespread natural threat in Europe. As the soil is increasingly being sealed off, ever decreasing amounts of precipitation are filtering down. Measures to shore up river flood plains and to channel waters have also led to a loss of natural retention areas. This increases the flow speed during floods, makes flood waves higher, and causes the prospects of damage to rise too. The advanced age of some dykes also presents a risk as breaches can occur.

Transdisciplinary research activities

There is to be an improvement in the options available in future to detect dangerous situations in advance and reduce damage. This requires comprehensive risk management in both the planning and operation stages. Research in this area must develop transdisciplinary examination approaches, obtain results from these and then prove they can be applied by means of example. In order to ensure that results can be transferred into practice, the Federal Ministry of Education and Research (BMBF) is involving representatives from economics and administration in its research projects on flood protection. The participants come from universities, national authorities, state authorities, local authorities, private companies, water boards and insurance firms.

The BMBF was funding flood research projects even before the flood disasters involving the Oder and Elbe, but these events intensified those efforts. Here are some examples of the subject areas receiving BMBF funding: the acute pollution as a result of the August 2002 Elbe flood was the subject of investigation (project 1.4.01) and also served to clarify the consequences of the extremely high groundwater level in Dresden even long after the Elbe flood through the use of models (projects 1.4.02 and 1.4.04). Important findings were also obtained through monitoring and stabilising dykes with drainage elements (project 1.4.05) and using sensor-based geotextiles inside (project 1.4.06). To prevent floodwater from getting through windows and doors in extreme events, scientists from the Saxon Textile Research Institute in Chemnitz have developed self-sealing water barriers that can also be fitted in old buildings with uneven walls and are removed just as easily (project 1.4.07). The MULTISURE ("Development of Multisequential Mitigation Strategies for Urban Areas with Risk of Groundwater Flood") project focuses on how to estimate the potential for damage and risk as a result of rapidly rising groundwater in urban areas (project 1.4.03).

Sustainable protection against flood events

In 2004, the BMBF established flood protection as a focus for its research funding. Since then, the "Risk Management of Extreme Flood Events" measure (RIMAX, see project 1.4.06) has been combining skills and driving forward further development (www.rimax-hochwasser.de). Funding of around EUR 20 million in total has been channelled into 38 projects between 2005 and 2010, the aim being to detect pending flood events at an earlier stage in future and to be quicker and more effective in preventing damage. RIMAX thus made a significant contribution towards the implementation of the government's five-point programme for flood protection and also forms part of its high-tech strategy. Through RIMAX, the BMBF has also formed an early basis for the national implementation of the EU Floods Directive dated 23 October 2007 (Directive 2007/60/EC of the European Parliament and of the Council on the assessment and management of flood risks). (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:288:0027:0034:EN:PDF)

The consequences of a hundred-year flood – pollution following the flooding of the Elbe

When extreme flood events mobilise pollutants as in the Elbe basin◄, large amounts of harmful sludge and wastewater are distributed over the flood plains – and also residential areas and farmland. A team of scientists investigated the pollution left behind and evaluated the ensuing risks. The result: pollution levels within the soil were generally no greater than they were prior to the flood. Nevertheless, the experts recommend a comprehensive water and risk management system for future use.

In August 2002, heavy rainfall caused extreme flooding of the Elbe and its tributaries, leading to significant contamination of the flooded area. The floods released pollutants from old sources, expanded contaminated river sediments and carried along polluted soil and excavated material from industrial areas and mine dumps. Oil flowed from tanks on private property and both communal and industrial wastewater escaped from overcome sewage plants into the rivers. The water infiltrated residential areas, gardens and farmland, where the solids were deposited and formed a layer of sludge contaminated with heavy metals, organic pollutants and harmful germs. As such, the risks posed to health needed to be clarified as soon as possible.

The first stage saw numerous research institutes and authorities independently examining the effects of the flood on the pollution levels in the groundwater and flooded areas. So that these measurements could be combined and an analysis gained of the overall situation, the BMBF initiated a research project called "**Schadstoffuntersuchungen nach dem Hochwasser 2002 – Ermittlung der Gefährdungspotenziale an Elbe und Mulde**" (Pollution investigations after the flood of 2002 – determining the potential risk at the Elbe and Mulde). 28 partners worked under the guidance of the centre for environmental research at Leipzig-Halle to investigate the river basins of the Mulde and Elbe from the Czech Republic to Hamburg.

Chronic pollution of river sediment

The numerous pollutants in the Elbe come from many sources. Elements such as arsenic and heavy metals occur naturally across the entire basin and have always been carried down from the bordering low-mountain regions. Depending on the river dynamics, they are deposited or carried further and cause the "geogenic background contamination◄" in the waterways. Other sources of pollution include mining and other industrial activities within the region.

Oil tank torn off by the Elbe flood (Source: Thomas Egli)

Virtually no changes as a result of the flood

The substantial (in part) concentration of heavy metals and organic pollutants exhibited by the rivers during the flood quickly dropped again as the waters receded according to tests. With just a few exceptions, the flood did not significantly increase the amount of pollution in flood plain soils and sediments. However, this should not take away from the fact that the regularly flooded land beyond the dyke beneath the confluence of the Mulde and Saale is heavily contaminated. As the recommended values for use as pasture were way exceeded in terms of dioxin and mercury in many samples, experts recommend the implementation of consistent use management. This would mean that the heavily contaminated hollows and watering holes

Sediment deposits after the 2002 Elbe flood (Source: Dagmar Haase)

should not be used and that grazing should only commence after cleaning through precipitation.

The great flood of 2002 also affected locations normally protected by dykes. In the researchers' view, no acute risk is posed to the health of the population: the analyses indicated only disparate increases in the concentration of pollution. Nevertheless, the measurements indicated that the basic pollution load of the researched area was already pretty high before the flood occurred. (See UFZ final report: Schadstoffbelastung nach dem Elbe-Hochwasser 2002 (pollution load after the Elbe flood of 2002) at www.ufz.de/data/HWBroschuere2637.pdf).

Introducing risk management

Floods and the associated hazards are not going to go away. However, the intensity of the events and the extent of the damage can be reduced. As such, the researchers propose employing preventive water management and land usage in a far more consistent manner than before and consolidating fragmented areas of responsibility for flood-related issues. The aim is to ensure integrative and interdisciplinary water management in the river basin, which is also to include flood risk management. The researchers view integrated pollution management – particularly for the Mulde and Saale – as a potential basis for long-term remediation within central Germany.

A recently developed pollution distribution model is the first step in this direction. The coupling of a hydraulic model with a land and pollution distribution model for the first time enabled scenarios for moderate to extreme flood events to be determined and then fed into a decision support system◄ – a system already in use within Anhalt Bitterfeld. It is also used for current flood exercises and for resettlement operations in order to assess the risk of pollution ingress during flood events.

In order to reduce the risk posed by toxins and harmful germs during future floods, the experts also advocate the creation of handling instructions for dealing with flood sediments, installing pollution sources such as private oil tanks and heaters and commercial chemical stores in locations secured against flooding and devising measures to enhance protection of industrial facilities, sewage plants and other similar installations. The scientists also recommend compiling research results through a database-supported decision support system (DSS)◄ so that the necessary information is available when making decisions in future.

The legacy of a century of mining: slag heaps in Muldenhütten near Freiberg. Around 9,000 tonnes of high-grade lead and arsenic-loaded material were eroded here during the flood of 2002 (Source: Günther Rank)

Greater efforts should also be made to keep flood zones free from buildings and inappropriate use as a preventive measure (preventive land use). Abandoning farmland and planting greenery is an effective way to counteract erosion of contaminated soil on river flood plains. Undeveloped land also provides natural retention areas◄; this method all but eliminates damage to buildings.

In a second project funded by the BMBF called "Flood risk mitigation based on non-structural land use schemes in runoff generation and flood plains" (MinHorLam), scientists investigated the influence of non-structural land use measures on flood risks. One of the topics covered was the risk potential for producers and consumers when pollution contaminates the plant stocks and soils on land used for agriculture and forestry. The researchers devised damage-limitation measures such as changing land use, introducing special types of plant, accumulating pollution in only small amounts and compensation for leaving land uncultivated. The findings gained are being made available to the general public through an Internet platform.

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3ZM-GRIMEX project – coupled models simulate flood scenarios

When a flood occurs, the danger is not only posed by submerged land but often by rising groundwater as well. This spreads out under the earth and can cause a great deal of damage. Up to now, most water flow simulation systems have treated these processes separately or as two components, and it has not been possible to map surface water, the sewage system and groundwater together. A research project led by the Dresden Groundwater Research Center interlinked computer-aided models to provide a better assessment of how these components interact during flood conditions.

Flooding in Dresden: Water flowing out of the sewage system onto Terrassenufer

Floods in recent years have caused a terrible amount of damage. The amount of damage in Dresden alone amounted to around a billion euro in August 2002 – roughly 10% of the total damage nationwide. Groundwater counts for 16% of the damage to property in Saxony: it has therefore become apparent that floods can affect groundwater even in urban areas. The floodwater generally takes two courses as it spreads beneath the earth:

- Surface water getting into the groundwater and spreading. The groundwater flowing into the receiving waters◄ from the hinterland backs up.
- Surface water spreading via infrastructures such as the wastewater sewage system (technogenous regions◄) to areas outside the region flooded directly.

Researchers at the Dresden Groundwater Research Center used model support to begin mapping the interaction between surface water and groundwater in flood conditions immediately after flooding occurred. The aim was to assist the clean-up in the wake of flooding and to improve prevention measures. At that time however, only individual technical model solutions were available for interactions between surface water and groundwater and between groundwater and the sewage system: they were based on simulation programs relating to a single component – surface water, the sewage system or groundwater.

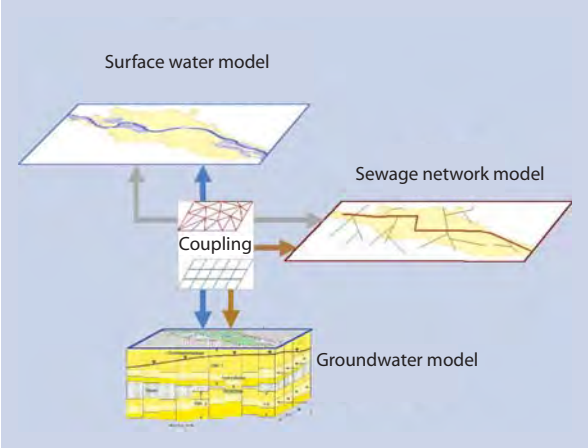
Coupled modelling: three zones – one system

This is where the BMBF project **"Development of a 3-Zone model for groundwater and infrastructure management after extreme flood events in urban areas" (3ZM-GRIMEX) was able to help**. The scientists making up the project team developed an innovative modelling tool for the state capital Dresden that maps the interactions between the following hydraulic components in extreme flooding on the basis of existing models: surface water effluent, effluent in the technogenous zone and groundwater. This coupled modelling system enables the development of solution strategies for designing and safeguarding the underground infrastructure networks, for managing groundwater-related flooding and for supporting town-planning decisions.

The experts used coupling software from the Fraunhofer Institute to link together simulation programs with a proven record in mapping significant flows of water during a flood. In doing so, they had to take into account both the time and spatial differences between the individual model components. To ensure that the coupling was successful, full awareness of the fundamental connections within the system – comprising sewage network, surface water and groundwater – and the time and spatial scales of the flow processes was required. A scale determined how a certain feature of a process was recorded and rendered measurable.

Computer-aided coupling process

Computer-aided coupling is based on the strategy that the individual modules – models for surface water, the sewage network and groundwater – calculate their respective water levels and throughflows as separate instances and then exchange these calculations. Each module then supplies these "coupling variables" to the others. The coupling software ultimately combines the information from the individual modules (blending). If, for example, sewage elements, groundwater levels and flooded surface areas are blended together, it is possible to determine which residents are affected by adverse weather and warn them in good time.



Schematic of the model coupling within the 3ZM-GRIMEX project

The programs used provided the project team with different challenges depending on the field of application. Take the sewage network for example: the hydrodynamic sewage network calculation did not require an especially high level of performance from the computers and the level of data in most areas was also very good. However, the only way to integrate the effect of the sewage system on the dynamic of the groundwater was to use greatly simplified approaches.

Advance calculation of flooded surface areas through realistic modelling (Map background source: city of Dresden)

Practical application in Dresden

The focus of the first processing phase was on the individual models. This depended on harmonising their spatial relationships and recording all relevant water flows that have an effect during flooding and need to be mapped in the modelling system. The researchers created a general water flow schematic for this purpose, which formed the basis for the coupling activities. The main thing was to ensure adequate mapping of temporary components such as flood relief wells, flooded surface areas and overly backed-up sections of sewer. These algorithms were tested in a synthetic test model, which involved the team of experts trialling first the couplings and then all three instances.

The entire system has since been implemented in Dresden. The coupled modelling has enabled the exchange of water between surface water effluent, effluent in the sewage system and groundwater to be calculated for a variety of flood scenarios. Experts also used the new system to identify hotspots with latent flood risks due to emergent sewer water. The transfers from groundwater into the sewage system were able to be localised and quantified. The influence of emergent sewer water on groundwater only has a local effect during flooding, but depending on the intensity can lead to a significant rise in groundwater in the hotspots.

Project website ▶ **www.gwz-dresden.de/dgfz-ev/forschungsbereich/3zm-grimex.html**

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Flood events – the forgotten groundwater

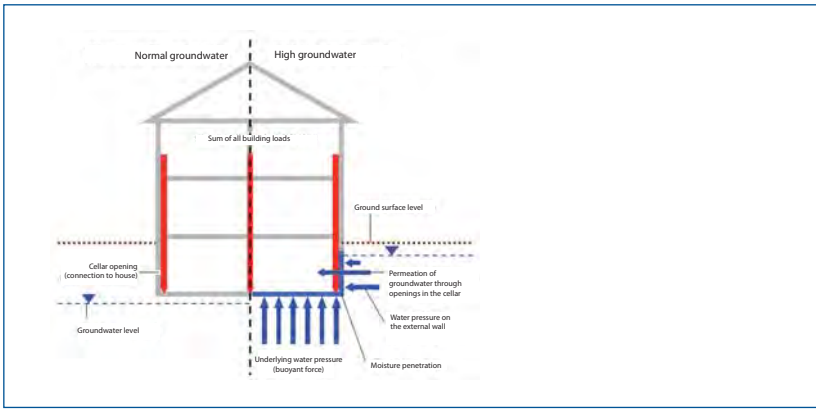
What are the consequences of a groundwater level raised by a flood, particularly for built-up areas near rivers? The MULTISURE project has been seeking answers to this long-neglected question. The scientists involved developed models to enable potential risks and damage to be more accurately pinpointed in future, using Dresden — which is located on the Elbe – as an example.

The specialist community most often perceives a flood as an event involving extreme effluent over the surface of the ground. In addition to flooded surface areas, a rise in groundwater as a result of flooding can also be observed – especially after long periods of flooding in wide valley flood plains. Before now, science rarely factored in the risk to underground structures and infrastructures posed by fast-rising groundwater as a consequence of extreme flooding.

So, how can the risk and damage potential from fast-rising groundwater be estimated? What is the required make-up of models that can predict underground damage due to extreme flooding? These questions were the focus of the project entitled **"Development of Multisequential Mitigation Strategies for Urban Areas with Risk of Groundwater Flood" (MULTISURE)**, led by the Dresden Groundwater Research Center (DGFZ), involving several institutes and running from 2006 to 2009. The aim of the project was to develop tools used to map and assess the hazards, potential damage and risks arising from the interactions between flooding, groundwater and underground infrastructures. The site chosen for investigation was Dresden along with the Elbe valley aquifer and both existing and planned underground building developments.

Two damage models developed

The project partners began by investigating how approaches for estimating damage through flooded rivers can be applied to groundwater-related flooding, and how the two events interact and overlap. The German Research Centre for Geosciences (GFZ) modified the meso-scale damage model developed for river flooding called FLEMOps (top-down approach) in order to estimate the damage caused by rising groundwater. This involved conducting telephone surveys with those affected — specifically regarding damage that occurred outside the flooded surface areas or were caused solely by groundwater. As such, findings could be obtained on handling the groundwater-related flooding individually and on the material and financial damage.



Threat from below: effects on the building structure

A bottom-up approach involved describing damage for types of building and infrastructure in relation to age — and depending on the groundwater dynamic. This enables the remediation measures required to rectify the damage to be determined, and also their costs. Expanding on this, the Leibniz Institute of Ecological Urban and Regional Development (IöR) is developing the new GRUWAD model (damage simulation model for building damage related to groundwater).

Multiple scenarios created

The groundwater risk assessment and depiction used both the above modelling approaches (top-down and bottom-up). FLEMOps and GRUWAD were used for a GIS-based◄ determination of damage caused by groundwater at different spatial resolutions. The basis for this were the scenarios created by the Dresden Groundwater Research Center for the highest groundwater levels under various flood conditions in the Dresden Elbe valley and the implementation of various protective measures (database previously was flood events plus current planning within Dresden).

Threat from below: groundwater escaping to the surface

Interviews conducted

Intensive communication and co-operation among everyone involved is key in ensuring efficient flood risk management: this includes city and state authorities, associations, scientists and residents. MULTISURE has analysed and evaluated these processes.

The basis for co-ordinated public action in flood prevention is meaningful information – and this also increases risk awareness and personal prevention measures among citizens. The interviews conducted during the course of the project and the analysis of existing means of information and communication were co-ordinated by the Institute for Environmental Communication at the Leuphana University of Lüneburg. The resulting brochure – primarily aimed at the general public – deals particularly with the personal responsibility of those affected and is therefore intended to intensify risk prevention.

The project results were fed by Görlitz/Zittau University into the city of Dresden's information system. This enables internal access within authorities to key project results. As such, the results can be used to improve authorities' internal analyses and decisions and to provide the public with information on the risks posed by groundwater-related flooding.

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The underestimated threat posed by groundwater – damage assessment and prevention after the hundred-year flood

In the wake of the flood of August 2002, Dresden had more to tackle than damage to buildings and infrastructure: the groundwater had also risen by up to six metres in places and was taking a long time to recede. A team of local researchers and engineers therefore set about investigating the consequences of the flood beneath ground. The aim was to enable early detection in future of risks to underground facilities and the groundwater so that protective measures can be implemented. To achieve this, the experts modelled the dynamics of the rise in groundwater and analysed the nature of the groundwater as a supply of drinking water and the potential risks due to infiltrating pollution.

During the flood of 2002, groundwater levels underneath the Elbe valley way exceeded anything observed in decades. The triggers for this were the heavy rainfall over 12 and 13 August, the ensuing overflowing of the Elbe tributaries and the flood of the Elbe itself. The groundwater had an impact on building structures both above and beneath ground – their functional capability and stability were significantly affected by the fast-rising levels. As the surface floodwater receded, it was then possible to assess the impact of the underground floodwater on the body of groundwater beneath the city of Dresden. This groundwater is a major source of drinking and process water and plays a major role in the stability of buildings and the urban environment. Scientists and engineers from TU Dresden and the Dresden Groundwater Research Center joined forces with local engineering firms and dedicated themselves to achieving this task through the research project entitled **"Hochwassernachsorge Grundwasser Dresden"** (Dresden groundwater: cleaning up after the flood), which was led by the city's Environment Office. The experts started with short and medium-term consequences, and investigated them in line with the following focus points:

- Further development of the groundwater model to determine the effects of the groundwater dynamic on buildings and potential damage to buildings,
- Investigation of changes to the nature of the groundwater in the wake of significantly risen levels,
- Analysis and evaluation of potential groundwater-related damage ensuing – as a result of flooding – from contaminated areas (abandoned waste), sludge deposits or waste,
- Evaluation of the risks posed by unsealed wastewater channels (contaminant discharge).

The Elbe flood at Kaditz. Groundwater measurement points are engulfed by the flood.

The aim was to use Dresden as an example to evaluate flood-related damage to a body of groundwater underneath a city for the first time and to use this to derive action recommendations for administration, affected companies and citizens.

Model recording the groundwater dynamic

The nature and course of the groundwater flooding differed throughout the city, with wide areas – mainly more than a kilometre away from the receiving waters◄ – displaying a rise in the groundwater level after the flood wave that was then extremely slow to recede and others showing a brief significant rise that then dropped back down rapidly. The experts developed a computer groundwater model to record these different dynamics, which also factored in the basic structure of buildings beneath ground – primarily the historical town centre and the infrastructure. This enabled the project team to simulate the effect of different flood protection measures on the groundwater too.

The investigations of the nature of the groundwater took place on three levels: the working group took samples from a wide area in autumn 2002 and then spring and autumn 2003 to see how the quality had progressed. Investigations also found isolated pollution ingress at abandoned waste sites. The third element took the form of sample site-specific investigations of the natural sediment◄, conducted in the lab. This should enable statements to be made on the discharge and conversion of substances where polluted wastewater reaches the groundwater from the sewage system. The researchers simulated scenarios with different water levels and pressures in the sewers and the aquifer◄.

Protecting the building structure against rising groundwater at a Dresdner school (Source: www.benno-gym.de)

Drinking water unaffected

The experts were able to dispel fears regarding the nature of the groundwater by comparing the readings of specific water characteristics and pollutants values taken prior to the flood. The changes as a result of the flood were then only detectable for three months afterwards; they posed no threat to the drinking water.

The results at the abandoned waste sites investigated varied depending on the substances present and the flow conditions. Increased groundwater levels and flow speed released contaminants from their respective source. The experts detected slight increases in pollutant concentrations in the upper groundwater, plus vertical displacement within certain groups of substances. No significant lateral spread of pollution as a result of the flood was observed.

To enable them to investigate risks posed to the aquifer from unsealed channels, the project team simulated a local unsealed sewer system under pressure and flow conditions akin to a flood. This showed that the ammonium load typical of municipal wastewater only spread a small amount as a result of the flow speed and limited amount of unsealed areas.

Identifying risks, developing protective measures

The experts used the distances between the groundwater table and the surface of the terrain ◄ (depth to groundwater table) from August 2002 to December 2003 to develop a method for detecting risks posed to underground building areas. The parameters used included the intensity and duration of the groundwater flooding, the highest water levels, the speed of the rise in level and the minimum depths to the groundwater table. As a result, it was possible to determine the risk potential for 68 measurement sites within the city.

The assessment of the nature of the groundwater and the flow modelling based on various flood scenarios enabled conclusions to be drawn for use in town planning. According to the project team's findings, town planning should always factor in the threat posed by a rise in groundwater. The investigations also confirmed the effectiveness of the planned protection measures, namely mobile shoring with inner-city Dresden and flood relief wells.

In light of the results of their investigations, the researchers recommend that the processes of groundwater rising be constantly factored into the preparation and execution of measures to tackle flooding, with building precautions forming an essential component. The identification of "danger zones", where increased groundwater levels can be expected, forms the basis for this. As such, prompt measurements of the groundwater dynamic and the identification of the highest groundwater levels using a current groundwater flow model are required.

Project website ►
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Avoiding dyke breaches – monitoring methods and safeguarding concepts for river dykes

Floods in recent years have increasingly led to dyke breaches as these – in part historical – structures have not been able to withstand the hydraulic loads placed upon them. For financial reasons, thorough remediation of all affected dyke areas can only take place in the long term at best. As such, scientists working on two research projects funded by the BMBF have developed a monitoring system for the reliable detection of dykes in critical condition and a procedure for stabilising endangered dykes using drainage elements◄. The efficacy of these developments was confirmed through pilot tests.

A state-of-the-art three-zone dyke comprises a surface seal on the water side and a supporting body in the centre of the cross-section. A drainage body on the land side ensures that drainage water is captured in the dyke and safely diverted away. However – as in other parts of Europe – Germany has old dykes running along stretches of rivers and streams spanning hundreds of kilometres, dykes that do not meet today's safety standards. They have previously been filled, mainly after floods, with materials available locally. Dyke bodies such as these take in water during a flood due to a lack of a sealing layer; this causes progressive moisture penetration that in the worst case can lead to a breach.

Using time domain reflectometry to monitor dykes

The development of moisture penetration over time is crucial to stability, particularly in old dykes such as those mentioned above. A monitoring system is required in order to obtain reliable information on this, and needs to deliver data on the current hydraulic situation of a dyke body along the stretch of a given dyke. Time domain reflectometry (TDR) has proven to be a suitable procedure when used in conjunction with cable sensors. This involves implementing ribbon-cable sensors in the dyke body; a voltage pulse fed in at the sensor start and reflected at the sensor end can be used to determine the distribution of moisture along the cable sensors. This enables sufficiently accurate detection of the drainage line (boundary between moist and dry material) and thus the area penetrated by the moisture. The benefit of this procedure is that the dyke body only needs to be accessed at sensitive spots.

Scientists from the Materialforschungs- und -prüfanstalt (institute of material research and testing, MFPA) at the Bauhaus University Weimar and the Institute of Soil Mechanics and Rock Mechanics (IBF) at the Karlsruhe Institute of Technology (KIT) developed a monitoring system based on the TDR method specifically for flood protection dykes as part of the project entitled **"Bewertung und Prognose der Standsicherheit von Hochwasserschutzdeichen mittels Time Domain Reflectometry"** (evaluation and prognosis of the stability of flood protection dykes using time domain reflectometry).

At the heart of the monitoring system is a forecasting model that uses the moisture distributions measured within a dyke, the predicted course of flooding and the expected precipitation to predict the onward progression of the dyke's moisture penetration. An evaluation model was developed both for the moisture distribution measured during a flood and for the predicted moisture conditions to permit a stability analysis of the outer slope of the backed-up dyke. The developed monitoring system is able to use its own power supply to perform self-sufficient measurements and send data to a central server via remote transmission. The analysed and predicted moisture distributions are made available online along with the stability evaluation. This could then be an effective tool for those responsible for flood management for arranging safeguarding measures or evacuations quickly in the event of a threat. It was not possible to transform the monitoring system into a fully automated monitoring tool during the funding period of this project.

Stabilising dykes with drainage elements

Sections of dyke that are at risk of a breach need to be stabilised in the lower section of the outer slope during flooding; this involves a great deal of labour and materials (e.g. sandbags). The surface of the slope on the river side is to be sealed with films or other materials, but this is only useful if there are weak spots leading to a concentrated throughflow. Otherwise, such measures are not able to reduce the drainage line by any significant amount. If it is not possible to avoid water getting into the dyke, it is then a matter of capturing the drainage water in the dyke body and safely diverting it away. Otherwise, it can emerge from the outer slope; increased flow forces could then lead to a breach.

Standard drilling is to be applied to implement the linear drainage elements in the model dyke (Performed by: Morath GmbH, Albbruck)

The model dyke on a natural scale (height: 3 m) proved the technical feasibility of the stabilisation procedure (viewed from land side)

This is the area that the second BMBF project addressed, entitled **"Stabilisierung bruchgefährdeter Flussdeiche mit Dränelementen zur Sickerwasserfassung und Bewehrung"** (stabilising river dykes at risk of breaching with drainage elements to capture drainage water and for reinforcement) and involving the Institute of Soil Mechanics and Rock Mechanics (IBF) of the Karlsruhe Institute of Technology, the Department of Geotechnics at the University of Kassel and the Saxon Textile Research Institute (STFI) in Chemnitz. During this project, a concept was developed to safeguard backed-up dykes in the event of a flood. An emergency measure like this can also be used as a short or medium-term method for strengthening old dykes.

Effectiveness of the procedure proven

The emergency safeguarding measure specifically intends to apply drainage elements by machine to sodden dykes at risk of breaching, which will then intercept the running drainage water at the foot of the dyke. Standard equipment (e.g. from the construction industry) readily available from multiple locations is to be used for the installation wherever possible. The practicality of the procedure and the tools required for installation were tested on a natural scale using standard drilling equipment. The true-to-life tests confirmed that the stability procedure is indeed effective. A trial on a proper stretch of dyke would also be invaluable in gaining acceptance within standard construction practice; however, this was not possible as part of the research project.

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Integrated warning system – monitoring and stabilising dykes with sensor-based geotextiles

The condition of dykes has almost exclusively been monitored visually up to now. With the appearance of their insides hidden from inspectors, damage is often not noticed until it is in the advanced stages. This means it is generally too late to implement targeted support for sections at risk of breaching in crisis situations. Automated monitoring within the dyke could prove to be helpful here: with funding from the BMBF, the Saxon Textile Research Institute (STFI) has worked together with the Federal Institute for Materials Research and Testing (BAM) and other partners to develop special geotextiles that both secure and monitor dykes at the same time. In the meantime, the research has produced a new spin-off company◄ called fibrisTerre GmbH as well as three marketable patents.

Conventional dyke inspections in Germany monitor the surface and are not always able to detect damage with sufficient speed or reliability. Round-the-clock monitoring would be required during times of flooding, and this is hardly feasible from a manning perspective. There are actually electronic measuring systems already available on the market, but they are expensive and as such are rarely used. Cue the BMBF-funded research project entitled **"Entwicklung von multifunktionalen, sensorbasierten Geotextilien zur Deichertüchtigung, für räumlich ausgedehntes Deich-Monitoring sowie für die Gefahrenerkennung im Hochwasserfall bei der Deichverteidigung"** (development of multifunctional, sensor-based geotextiles for reinforcing dykes, dyke monitoring over greater areas and hazard detection to defend dykes in the event of flooding). Scientists from the Saxon Textile Research Institute in Chemnitz worked together with the Federal Institute for Materials Research and Testing in Berlin and other partners to develop an innovative material with built-in sensor technology as a part of this project.

Geotextiles: a versatile construction material

Geotextiles are heavy-duty fabrics specially designed for outdoor use; they can be made of woven, non-woven or knitted fabrics, and from natural or synthetic materials. They are used within geotechnical and structural engineering – generally to stabilise ground constructions and prevent soil erosion, e.g. in constructing roads and railways or waterways and dykes. Depending on their purpose, geotextiles are either permeable – when installed on steep slopes, berms or embankments – or impermeable, e.g. when used at landfill sites.

Controlled measuring on an area of sensor-based geotextile as part of the application process: field test in Swienna Poremba (Poland)

Automated dyke monitoring

The idea behind the project was to develop a multifunctional geotextile that, as well as being able to secure the dyke slopes, could also be used to monitor dyke stability. Fibre-optic sensors were therefore incorporated into non-woven structures during the manufacturing process itself to serve this precise purpose. These sensors feature the standard, low-cost glass fibres used within telecommunications and use special optical measuring procedures to detect even minimal stretching of the textile structure as well as temperature fluctuations so that dyke deformities can be registered during a flood. The detected changes can then be routed to central measuring and monitoring stations, where they can be called up at any time so that the alarm can be raised promptly in the event of any damage.

A new basis for measuring devices was developed for obtaining and evaluating the readings, work primarily undertaken by the BAM. Based on Brillouin frequency range analysis◄, the new measuring technology developed and patented during the BMBF's **RIMAX** project (Risk Management of Extreme Flood Events) clearly had so much potential that the EXIST research transfer programme approved the application of three young scientists to set up their own company. Founded in January 2010, fibrisTerre GmbH is the first spin-off company from the BAM.

Field test on a full-scale lab dyke at the Franzius Institute of Hydraulics, Waterways and Coastal Engineering in Hanover

Producing the geotextiles

How should textiles be made in order to ensure sufficient protection of the optical fibres? Which materials are most suitable? How can the glass fibres be worked into the textile? To answer these questions, the scientists at the Saxon Textile Research Institute conducted numerous tests on a non-woven Raschel machine. The method used is a conventional production procedure for geotextiles that has been specially modified for this purpose; new test methods have also been developed to determine the sensor and mechanical performance profile of the multifunctional geotextiles. The STFI is obtaining patents both for the production process and for the use of geotextiles with built-in sensors within dykes.

Field test in Solina (Poland)

In the meantime, the functional capability of the geotextiles has been demonstrated in various field tests. Various studies using a trial full-size dyke on the premises of the Franzius Institute of Hydraulics, Waterways and Coastal Engineering at the University of Hanover have shown what the new procedure can achieve. Simulations of different crises and loads were run, proving the functional capability of the sensor-based geotextiles under conditions of practical relevance. BBG-Bauberatung Geokunststoffe GmbH is currently working on marketing the sensor-based geotextiles together with rg-research, which was founded by Rainer Glötzl (http://rg-research.de).

Benefits of the procedure

Comparatively speaking, sensor-based geotextiles are a cost-effective alternative to other dyke monitoring approaches. The optical procedure lowers the costs per measuring point considerably, and provides data for the entire area rather than just isolated spots or along a chain of sensors. This also makes it possible to monitor extremely long sections of dyke with little personnel expenditure and enables precise mapping of damage. Only a monitoring system enables observation of both short-term changes such as cracks and scouring and long-term effects such as dyke subsidence. Finally, the procedure is also financially beneficial when it comes to constructing dykes, as securing the structure and integrating the monitoring system becomes a single-step process.

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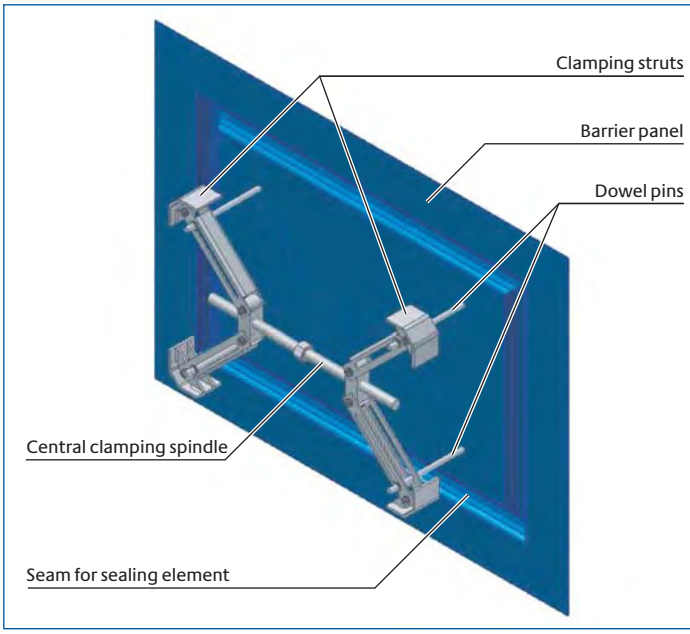
Building security for all – self-sealing water barriers for windows and doors

A large number of towns and communities have been affected by flooding in recent years. The floodwater gets into houses and often destroys all the furnishings inside. Windows and doors must be sealed in good time to prevent water escaping over banks from getting into buildings. There are already various protection systems available on the market, yet experience has shown that old buildings in particular are not sufficiently sealed. Scientists from the Saxon Textile Research Institute in Chemnitz therefore developed self-sealing water barriers for windows and doors for flexible and straightforward installation – even in old buildings with uneven walls – that can also be removed without any problems.

Conventional flood protection systems for windows and doors generally comprise protection panels that are either affixed directly to the masonry with pins and screws prior to a flood or inserted into pre-installed rails. The crucial thing here is that the gap between the panel and the wall is perfectly sealed so that there are no little openings or cracks for the water to access the inside. And yet – as experience from recent floods shows – this prevention is hardly ever implemented, a trait particularly prevalent among a large number of old buildings as the uneven masonry does not enable precise, impermeable sealing to be installed. Even rubber itself is not elastic enough in such cases, and silicone is not easy to remove from plaster, windows and door frames once the barrier system has been taken down.

Mineral sealing material

In light of the above, scientists at the Saxon Textile Research Institute in Chemnitz have been seeking more efficient and effective alternatives as part of the work on the BMBF-funded research project entitled **"Selbstdichtende Wassersperren für Fenster und Türen"** (self-sealing water barriers for windows and doors). And their solution? Mineral sealing materials that can be moulded by adding fluid and can thus flexibly adapt to unevenness. Loam and clay are examples of mineral substances that swell up when moistened and can be moulded into any shape. Used to fill special textile tubes and moistened before use, they can adapt to match the masonry perfectly. Tests have shown that bentonite is an extremely suitable sealant for this purpose. This stone is a mixture of various clay minerals and is particularly effective at absorbing



Barrier system with specially developed clamping struts for increased stability.

water and expanding. The clay granulate used is extremely fine (grain size of 0.1 to 2 mm), making it easy to dispense and helping to prevent the funnel from blocking when filling the textile tubes (bridge-building). This granulate was therefore selected for use in the subsequent tests.

Produced in a single process

The textile tubes are to be filled with bentonite granulate during production so that the complete product is made in a single process. The scientists worked with representatives from Umwelt- und Maschinentechnik GmbH in Pöhl to test special machines used in textile processing that would be suitable for this. These included a circular loom, a circular knitting machine and a "Kemafil" machine. The latter of these can be used to implement a special procedure developed and patented by the Saxon Textile Research Institute, which enables a wide range of materials to be coated with a three-dimensional mesh structure. The sealing system is produced by shaping a non-woven material into a tube and securing with meshed threads, and simultaneously filling this with the mineral substances. The tests showed that a right-left small circular knitting machine was best at producing the seal for the barrier system.

Sealant tube made from a small circular knit with integrated BENTONITE granulate

Modified R-L small circular knitting machine with feed, metering and filling equipment

Additional scouring protection

It has been demonstrated that textile tubes filled with mineral granulate are suitable for balancing out minor and major unevenness in walls and providing perfect sealing. This sealant must be moistened before application between the wall and panel. If a significant flow speed is encountered, additional scouring protection should be applied prior to sealing. A tube made from soft, recycled textile is suitable for this; it does not prevent water gradually seeping through to the seal, but it reduces the flow speed such that the mineral components are not washed away.

Benefits of the self-sealing water barrier

The self-sealing water barrier system is quick, flexible and straightforward to install without any pre-installation work required; it can be applied to all building types and removed again without any problems. As well as the mineral seal and scouring protection, the system includes metallic or non-metallic front panels affixed using a quick-release mechanism. This dispenses with the need to secure directly to the masonry with pins and screws. The perfect seal also means there's no need for laborious resealing once floodwater has come up against the barrier.

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