BUSINESS GEOMATICS
WIRTSCHAFTSZEITUNG

SENCEIVE – Getting ahead of the event

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Deutsche Bahn is building a heavy rain early warning system. To ensure the safety and reliability of train operations even during extreme weather events, the railway company is using heavy rain simulations and a real-time monitoring system from Senceive.

The grain field near the village of

Kai Herzogenrath explains the area at risk of heavy rainfall in the immediate vicinity of Mertesheim train station. The steep slope results in a high volume of water at the culvert (background) during heavy rain, as well as a strong flow of water down the embankment of the station (location of the photo marked on the map). Photo: OpenTopMap

Mertesheim, population 400, lies bathed in dazzling sunlight before Kai Herzogenrath. The freshly mown field slopes gently; to the left, behind a wooded hilltop, one can hardly imagine that the terrain rises further. To the right, the Eistalbahn railway line winds its way through the northern Palatinate. Herzogenrath, a civil engineering specialist, needs to protect himself from the scorching sun, but his thoughts are more on the cool water. More precisely, on extreme downpours, which are becoming an increasing danger for the railway in general and for the Mertesheim section in particular. When large amounts of rain fall in a short time, the terrain, especially with dry soils that have very low absorption capacity, becomes a dangerous funnel. Further down, at the lowest point directly adjacent to the railway line, is a culvert designed to channel the water further down into the Eisbach valley. This culvert must be able to handle more than 2,700 liters of water per second, as Herzogenrath calculated using simulations. If it cannot, the water threatens to cause major damage, even endangering life and limb.

The danger can be devastating – as Deutsche Bahn painfully experienced in the summer of 2025. On a branch line in Riedlingen, Upper Swabia, a gravitational mass movement triggered by heavy rain – the geological term for a landslide – flooded the track bed, even though, according to the recently published investigation report, it hadn't even rained exceptionally heavily and the line was classified in a low hazard category for heavy rain. The train, without warning, entered the muddy section of track at normal speed and derailed, even though the landslide comprised less than 10 cubic meters of earth. The tragic accident claimed three lives.

The problem immediately reached the executive boards of Deutsche Bahn, and in September Kai Herzogenrath, a specialist in drainage and monitoring systems, was tasked with developing a heavy rain warning system for DB. A major and vital task that has kept Herzogenrath extremely busy ever since.

And consequently, a fruitful one. The railway infrastructure operator has gained momentum on the issue of heavy rainfall risk. On the section of track in Mertesheim, which has long been known as a high-risk area for heavy rainfall and has already experienced closures due to such events, a solution was implemented within just one week. This solution, along with two other measuring stations (Backnang/Erdmannshausen), serves as a foundation, learning platform, and experience-based learning environment for the large corporation.

Decision for nationwide deployment in September 2027

Heavy rainfall and rail infrastructure – this is a known risk relationship since the beginning of the railway age. However, it is increasing dramatically in the age of climate change: heavy rainfall events are becoming ever more intense, unpredictable, and far more frequent than previously assumed, as a 2021 study by the Potsdam Institute for Climate Impact Research (PIK), commissioned by Deutsche Bahn, confirmed. The consequences range from mudslides on embankments to massive landslides or undermining of the track bed. "We have to consider all these hazards and determine which extreme events on which routes necessitate either a reduction in train speed or a complete line closure," explains Herzogenrath. The heavy rainfall early warning system is being evaluated as part of a DB strategy program, with the involvement of external experts. "The aim is to pilot the concept in depth," says Herzogenrath. In September of next year, following an in-depth evaluation as part of a large-scale innovation program by the railway ("certainly excellent"), it will be determined whether the approach pursued there for a heavy rain warning system is ready for nationwide use.

A weather station installed by the railway company in the danger zone, which, in combination with radar-based heavy rainfall forecasting, serves to assess the risk. These stations are to be set up in all danger zones, supplemented by radar-based systems that measure the intensity of heavy rainfall in the sub-areas more accurately than is offered by commercial weather data providers or the German Weather Service (DWD). Photo: sig Media GmbH

Three-part risk concept

Deutsche Bahn (DB) has long been aware of the dangers posed by heavy rain, but it has taken the recent events as an opportunity to develop a heavy rain early warning system. Similar to the long-established early warning system for fallen trees after storms, the system will provide train control with precise information so that speed limits and track closures can be implemented in a targeted manner. The guiding principle is: maximum safety on the one hand, and as few closures and restrictions as possible on the other. Proactive action is crucial. "We have to anticipate the event!" is how Herzogenrath describes the approach.

A three-stage concept is currently being developed for this purpose. The first stage focuses on forecasting heavy rainfall. For this, Deutsche Bahn (DB) is not only using commercially available weather data but is also building its own measurement network in areas at risk of heavy rainfall. In Mertesheim, both traditional measuring stations and radar-based systems are being installed to record the development of heavy rainfall zones. The combination of localized precipitation stations and weather radar is intended to provide spatially and temporally high-resolution quantitative precipitation data for the hazard zones. This will give the railway company data that will deepen its understanding of local hotspots.

The reason for this is that heavy rainfall events are very localized, occur spontaneously, and can develop very high intensities in hotspot zones. Meteorologists unanimously agree that this trend will continue to increase due to climate change. However, the installed measurement network of weather data providers is very sparse; the German Weather Service (DWD), for example, currently operates 18 weather radars, each with a range of approximately 180 kilometers. Local supercells with a risk of heavy rainfall cannot be detected as reliably and accurately as the DWD requires. Therefore, measurements are being intensified to enable more precise forecasts for at-risk areas.

Test project near Eisenberg. The embankment (under the trees) is characterized by sandy soil, which is why sudden landslides are likely during heavy rain. Therefore, no laser sensors are installed. Photo: sig Media GmbH

On the second level, the railway company is installing measuring stations for soil moisture. These provide insights into the soil's storage capacity, which is a crucial parameter for assessing the current hazard situation. "Using this data, we can learn how the risk develops under different weather conditions and soil conditions," says Herzogenrath. This is particularly evident after prolonged dry periods: the soil then loses its absorbency, making heavy rainfall significantly more dangerous.

The third level concerns real-time monitoring. For this, the InfraGuard Senseive technology is used. It is capable of continuously detecting even the slightest movements in the area, whether on embankments or the track bed. "The technology is cost-effective, flexible, reliable, and creates possibilities that simply didn't exist before," says Herzogenrath. DB has gained considerable experience with the technology in recent years, for example, in structural monitoring. In heavy rain preparedness, it is used to monitor landslides, measure water volume during heavy rainfall, and also assess soil moisture. In addition to the corresponding sensors, DB also uses cameras. Overall, the monitoring level also verifies how the parameters calculated through simulation and forecasting behave in reality.

Details on the measurement concept

Several years ago, Deutsche Bahn (DB) defined high-risk areas for heavy rainfall across Germany. The section of track near Mertesheim is classified as a high-risk hotspot and is therefore one of the pilot systems for the development of a heavy rainfall early warning system. Under the direction of Herzogenrath, researchers are investigating how this could be implemented nationwide.

The basic idea is that the danger depends very much on the specific local conditions. This applies particularly to embankments and culverts at points along the route where large amounts of rainwater can accumulate. Embankments are especially dangerous when they are located below slopes or ridges and where drainage channels form.

DB (Deutsche Bahn) primarily needs information on how much rainwater per second can reach the culverts. This will allow them to assess whether the culverts, channels, and inlets are correctly sized. Furthermore, it is important to know where flow paths form during heavy rainfall and whether these can develop on embankments. Besides the risk of mudslides, there is also the danger of tree roots being undermined, which could then lead to trees falling in the vicinity of the railway line.

The simulation and forecasting are provided by Okeanos, a spin-off company from Ruhr University Bochum, which specializes in creating precise predictions for heavy rainfall and flooding. This requires highly accurate terrain models with a height accuracy of one decimeter. Since official agencies do not provide terrain data of this precision, Deutsche Bahn (DB) conducted aerial surveys of surrounding areas prone to heavy rainfall within the test sites.

In Mertesheim, for example, the catchment area of the affected culvert is 27 hectares. A water flow of approximately 7,000 liters per second was calculated for the Mertesheim culvert during a 100-year rainfall event. Furthermore, the water flow paths were calculated, which led to initial measures being taken to prevent water from overflowing the embankment (protective tubes filled with sand).

Monitoring: more than real-time monitoring

Two measuring chains provide data on the movement of the retaining wall (lower chain) and on landslides in the upper section. The left section is steeper, but has a rocky subsoil and is therefore not at risk. Photo: sig Media GmbH

DB is also gaining insights from the pilot projects into which measurement concepts are successful at the respective locations. As always when monitoring earthworks, soil types play a major role. They determine the water retention capacity, which is crucial for absorbency during rainfall and significantly influences water runoff. In the case of the Eisenberg measurement section, for example, sandy loess soils predominate, which is why sudden landslides are to be expected during heavy rainfall, whereas the more clayey embankment in Mertesheim is subject to slow, gradual slope movements. This has implications for sensor selection during monitoring. In Mertesheim, for instance, the absorbency of the clay means that the slope could slowly bulge out. Therefore, laser-based distance sensors measure the horizontal distance to a fixed point. With angle-measuring sensors, there is a risk that they will not detect such a bulging movement of the slope.

The measurement concept in Eisenberg, however, does not use laser sensors. "We have to generate information from the numerous raw measurement data points that ultimately influence the decision of whether a road needs to be closed or the speed limit reduced—that's basically it," explains Herzogenrath. This requires an interpretation of the measured values, incorporating expertise from geology, hydrology, and meteorology.

Against this backdrop, permanently installed cameras within the InfraGuard systems play a crucial role. Their primary function is to verify alarm messages. Senceive has long developed fully autonomous (solar-powered) imaging systems that, for example, operate without flash or illumination, a requirement for rail network operators due to potential disruption to train drivers. In the future, AI-based image analysis will also be utilized. The company is currently developing corresponding systems that Deutsche

Bahn can also use to support its alarm system. The ongoing challenge lies in preventing potential false alarms caused by AI misinterpretations. "However, the hope is that the AI can be trained so effectively with images of track and structures that it can reliably detect high-risk anomalies," explains Herzogenrath.

exchange of experiences

Senceive technology has been used worldwide for many years to monitor railway tracks. The British rail network operator Network Rail is currently Senceive's largest customer and already has around 30,000 gateways—communication points, each connected to a sensor network—in operation. Risk management for heavy rainfall is far more advanced in rainy England than among rail network operators in Central Europe, where the issue of heavy rainfall has only recently risen to the top of the risk agenda. Kai Herzogenrath visited Network Rail in England to exchange experiences and developed a valuable network. "We learned a great deal, and in England, they are also watching our innovative developments with interest," said Herzogenrath.

This includes, for example, connecting the point-like sensors to a kind of barrier fence (see images). Contrary to what one might initially assume, these fences are not used to catch falling stones or soil, but rather to detect earth movements, rockfalls, or falling trees. "The fence then transmits the movement to the sensor, thus transforming a point-like measurement strip into a linear one," explains Herzogenrath, describing the idea, which has not yet been implemented in England but is generating considerable interest there.

Above all, the monitoring system is crucial for verifying and refining the assumptions derived from the simulation. It implements an observational method that integrates theoretical modeling, forecasting, and real-world measurements, continuously improving the system. "This is the only way we can better address the increased risks posed by heavy rainfall in the future," says Herzogenrath.

The goal of the test projects is also to develop standards for configuring the monitoring system. This will need to be adapted depending on the terrain, soil structure, and existing building context. "We need as many sensors as necessary, but as few as possible, to reduce costs and effort," says Herzogenrath. Developing standard configurations should also reduce installation effort and engineering work for each individual case.

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