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The Norwegian Water Resources and Energy Directorate
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Date: 29/11/2023
Your ref.: 201206882-19
Our ref.: KRLI/-

Investigation of adverse event at Braskereidfoss Dam, Våler Municipality

With reference to your letters dated 13/09/2023 and 23/10/2023, as well as our reply dated 04/10/2023.

On 09/08/2023, an adverse event occurred at Braskereidfoss Power Station where the embankment dam failed.

Section 7-11 of the Dam Safety Regulation states that if an adverse event occurs, the entity responsible for the watercourse facility must submit a report on what happened, and how the accident or incident was managed, within three months. In your letter dated 23/10/2023, the deadline for submitting the report is set as 30/11/2023.

As we have previously communicated, DNV was engaged to conduct an independent investigation of the incident, and it has, together with Multiconsult, submitted its report to us.

The terms of reference for the investigation were to:

- Document the course of events.
- Identify the immediate (direct) and basic (underlying) causes of relevance to the incident, including human, technical and organisational factors, as well as the interplay between these.
- Identify recommendations for preventing similar incidents happening again

The investigation report prepared by DNV and this letter constitute our report on the incident pursuant to section 7-11 of the Dam Safety Regulation.
The investigation report is appended.

Course of events and causes
The incident and its causes are described in the appended investigation report. A summary of Chapter 1 of the report is provided below:

The immediate cause of the floodgates at Braskereidfoss not being opened when the water level rose was a lack of awareness of the danger from the rising level of surface water. Braskereidfoss Power Station is not manned, and is normally monitored and controlled from the operations centre in Lillehammer. Several alarms were triggered during the night warning that the water level was rising, but the operators at the operations centre were not aware of these alarms.

Nor were there any operational staff present at Braskereidfoss on the night who could have observed the rising water level and activated the floodgates locally.

It has been concluded that the incident was not caused by any faults or failures in technical systems.

There were several basic reasons why the situation was not noticed. These can be attributed to human, technical and organisational factors, and not least the interplay between these.

When the basic causes are viewed in context, it is possible to understand how the incident could occur. In this context, talk about 'human error' or 'mistakes' is not relevant, rather the overall system was not resilient enough to deal with a scenario such as the extreme weather event Storm Hans. The inaction that resulted in the floodgates not being opened must be viewed as a consequence of vulnerabilities in the system, and not as a cause of the incident.

Follow-up after a reassessment was conducted and the nonconformities it listed

A thorough examination and survey of Braskereidfoss Dam was conducted in 2016-2018 in connection with a reassessment of the dam in accordance with section 7-5 of the Dam Safety Regulation. Consequence class 1 dams must be reassessed every 20 years.

The incident at Braskereidfoss revealed no significant new weaknesses or nonconformities at the facility beyond what was described in the reassessment.

The reassessment was conducted using a 1000-year flood as the design factor, although since the dam has been downgraded to class 1, its relevant design factor is a 500-year flood. It is assumed that this change is of little consequence with respect to the conclusions of the reassessment. Meanwhile, in our view the reassessment's assessment of the functional safety of the gates was somewhat inadequate.

Despite the nonconformities in the reassessments, the facility was deemed reasonably resilient. The facility is designed for 3500 m^3/s, and the experience from the flood in 1995 suggests that a rate of flow of this magnitude can be diverted without major problems and that the diversion capacity of the facility is probably somewhat higher than for what it was designed. The gates are operated regularly and the operational experience with the gates has been good. The incident on 09/08/2023 was a scenario that had not been identified and assessed in our risk and vulnerability analyses.

Nonconformities identified in the reassessment had not been closed prior to the incident on 09/08/2023. NVE approved the reassessment, with conditions, on 03/01/2023. Following the approved reassessment, we had started to look at technical solutions that would have closed the nonconformities. Please note that local conditions made finding solutions that satisfied all of the requirements of the Regulation challenging.

The risk analysis from 1992: Report No. 6, Part I

Your letter dated 13/09/2023 requested that the risk analysis from 1992 be assessed, as well as how the findings have been followed up. A specific account of this is provided in the investigation report from DNV, which concludes that:

> *These vulnerabilities did not contribute to the floodgates not being opened as normal as the water level rose on the night of 09/08/2023. However, had these factors been remedied in line with the recommendations, it cannot be ruled out that the extent of the damage might have been limited.*

The measures suggested in this report from the Dam Safety Project have essentially been followed up, and the most important fact is that we have switched to an operations centre that is staffed 24 hours a day. The various topics from the report are discussed in DNV's report, and they are, therefore, not repeated here.

Temporary measures for dam facility

Floodgates 4 and 5 will be raised to the open position and secured, according to the plan, during the year. Floodgate 3 is misaligned and damaged. This will probably be lowered for repair.

We have arrived at estimates using the overflow formula and determined that with the approx. 160 metres of opening (floodgates and breach) we can divert the flooding that can be expected in the period until the dam has been rebuilt with a relatively low rise in flooding.

Third-party safety measures have been implemented. Access to the dam has been blocked on both sides with fences. A risk assessment has also been conducted in relation to the current situation

On the embankment dam, we are planning to bury the edge of the breach. Furthermore, we plan to secure the foot of the edge of the breach with rock fill/pitching to prevent further erosion of the dam. These works will be carried out during the autumn, as soon as we have notified the necessary authorities about the works.

Third-party safety

A risk assessment has been conducted in which the following measures are described:

- The signage plan has been revised.

- Signs, as well as barriers, on the roads into the dam facility on both sides.
- 2-metre high facility fences and access prohibited signs.
- Breach front in the embankment dam.

Implemented and planned measures in the aftermath of the incident

As a company, we are committed to learning from the incident in order to prevent similar situations. In the aftermath of the incident, we have implemented several measures to increase safety at our facilities. We have also drawn up plans for further measures. Below is a list of measures that have been implemented, measures we are planning to implement and measures that will be studied.

We will also share the lessons learned from the incident with the rest of the industry so that nothing similar happens again.

Implemented measures

- Adjusted limit for number of people on duty at Braskereidfoss
- Additional operational monitoring unit in the event of serious flooding and preparedness for levels raised or full
- Increasing staffing levels at the operations centre in emergency situations
- Better overview of vulnerable facilities
- Evaluation of Storm Hans and the incident at Braskereidfoss

Planned measures

- Improve the operations centre's user interface
- Facilitate the sharing of work surfaces in watercourse sections
- Increase the number of dedicated operator jobs at the operations centre
- Clarify the 'high' and 'critically high' water level signals for Braskereidfoss
- Establish an emergency regulator for gates at Braskereidfoss
- Establish/improve emergency raising mechanisms for Braskereidfoss gates
- Protect the power stations, emergency generators and gatehouses from submersion
- Measures for preventing overtopping of buttress dams
- Systematic review of safety and barrier functions at the company's facilities
- Systematic review of signal scope and measurement values for the company's dam and power station facilities
- Ensuring comprehensive risk management for operations

Measures that must be studied

- Review and decide on any changes to the shift plan and staffing at the operations centre – including plans for increasing staffing levels emergency situations

Photos

A number of photos were also taken during the incident that communicate the situation better than just text could. These are appended.

Appendices

This memo has four appendices:

1. DNV's investigation report
2. The investigation report, redacted in accordance with the Emergency Preparedness Regulation
3. Course of events
4. Photos of the incident

The investigation report contains some detailed information about technical solutions, staffing and organisation at the operations centre in Lillehammer that we believe should be redacted in accordance with the Energy Emergency Preparedness Regulation. A redacted version has been appended.

Multiconsult's delivery to DNV, which is appended to the investigation report, is marked as exempt from public disclosure. We do not believe that the contents are sensitive because Braskereidfoss Dam is a consequence class 1 dam.

Yours sincerely,

Hafslund Eco Vannkraft AS

Kristin Lian

CEO

This document has been electronically approved and sent without signatures

Unofficial translation of DNV report 2023-4089, Rev. 01
This is an unofficial translation of DNV report 2023-4089, Rev. 01, originally written in Norwegian (the "Report"). Hafslund has translated the Report for your convenience using Semantix without the involvement of DNV and Muticonsult. If any questions arise related to the accuracy of the information contained in translated report, refer to the original version of the Report.

INVESTIGATION REPORT

Braskereidfoss Incident 09/08/2023

Hafslund Eco Vannkraft AS

Report no.: 2023-4089, Rev. 01
Document no.: 2010341
Date: 17/11/2023

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1 SUMMARY

DNV was engaged by Hafslund Eco Vannkraft to conduct an investigation of the incident that occurred at Braskereidfoss Power Station on Wednesday, 09/08/2023. The extreme weather event Storm Hans in August 2023 was a rare weather phenomenon that produced flooding that rapidly grew in strength and intensity, resulting in a higher rate of flow. Innlandet County saw the greatest amount of precipitation and both the strength and intensity of Storm Hans surpassed a normal flood situation that the organisation is used to handling.

The investigation has uncovered why the dam's floodgates were not opened as normal as the Glomma River's rate of flow rose during the night. The incident resulted in the dam being overflowed, the power station being flooded and ultimately the embankment dam failing.

The investigation's terms of reference were:

- Document the course of events.
- Identify the immediate (direct) and basic (underlying) causes of relevance to the incident, including human, technical and organisational factors, as well as the interplay between these.
- Identify recommendations for preventing similar incidents happening again.

The objective of the investigation was to learn from the incident and improve dam-related safety.

The immediate cause of the floodgates at Braskereidfoss not being opened when the water level rose was a lack of awareness of the danger from the rising level of surface water. Braskereidfoss Power Station is not manned, and is normally monitored and controlled from the operations centre in Lillehammer. Several alarms were triggered during the night warning that the water level was rising, but the operators at the operations centre were not aware of these alarms.

Nor were there any operational staff present at Braskereidfoss on the night who could have observed the rising water level and activated the floodgates locally.

It has been concluded that the incident was not caused by any faults or failures in technical systems.

There were several basic reasons why the situation was not noticed. These can be attributed to human, technical and organisational factors, and not least the interplay between these.

The basic causes that have been identified are (summarised in short form):

- **<u>Vulnerabilities in the barrier function 'open floodgates':</u>** Only one barrier function can prevent Braskereidfoss being overflowed in the event of a high rate of flow: 'open floodgates'. This barrier function in turn relies on a single operational barrier element, which is the 'operator operations centre' who has to activate the gates. No automatic emergency regulation, or other mechanisms, are in place that step in if no action is taken by the operational barrier element for some reason or other.
- **<u>Vulnerabilities at the operations centre:</u>** The operations centre is normally operated by [redacted] 24 hours a day. Increasing the operations centre's staffing [redacted] emergency situations has not been well facilitated in terms of how the work is organised, the physical layout of workstations or the operational control system. No emergency response exercises specifically targeted at the operations centre are conducted where training is carried out based on scenarios involving major incidents at multiple facilities and where operators are challenged by more demanding situations.

  [redacted]
- **<u>Extraordinarily heavy workload at the operations centre:</u>** Storm Hans developed very rapidly over a large geographical area. During the night, a number of critical situations in other areas were managed from the operations centre. The amount of information and the number of alarms were very high, which meant it was difficult to gain an overview of the situation and act on all relevant alarms.

- **<u>Work-related *fatigue* among operators at the operations centre:</u>** [redacted]

  [redacted] Combined with a heavy workload and high stress levels, it is assumed that the operators experienced a degree of physical fatigue and reduced mental capacity, which in turn can increase the risk of miscalculations and mistakes.

- **<u>Weaknesses in the operational control system's user interface at the operations centre:</u>** The system does not provide a good enough situational overview [redacted] for operators to handle events in an emergency situation. Some of Braskereidfoss's alarms are not well enough defined, particularly when it comes to high and critically high water level alarms.

- **<u>Inadequate risk and situational awareness in relation to extreme weather events:</u>** In the emergency preparations, the assessment was that Braskereidfoss did not require permanent staffing during the night, although operational staff were on site and checked the facility at around midnight before they moved on. One assumption on which this assessment was based is that the operations centre was functioning as expected and had the capacity to monitor the situation and would react quickly and call out staff as needed. On the night of 09/08/2023, this did not happen. The overall effects of the extreme weather event were thus underestimated.

- **<u>Technical vulnerabilities in the design of Braskereidfoss:</u>** A number of vulnerabilities have been identified in the design of the Braskereidfoss facility. Several of these were pointed out in the Dam Safety Project in 1992, which included recommendations on risk mitigation measures. Some of these vulnerabilities have been rectified since 1992, others have not. These vulnerabilities did <u>not</u> contribute to the floodgates not being opened as normal as the water level rose on the night of 09/08/2023. However, had these factors been remedied in line with the recommendations from 1992, it cannot be ruled out that the extent of the damage might have been limited. The main vulnerabilities that have been identified are:

  - In situations where none of the three floodgates open, the water level will rise rapidly and overtop the buttress dam in a relatively short period of time. This would in turn result in water penetrating the power station, with the subsequent generator shutdown.

  - The gatehouses are vulnerable to water penetration in the event of flooding, both via the float pipe for measuring water levels and directly through the personnel access hatches. The drainage capacity of the gatehouses is limited. In the event of water penetration, the motors that operate gates can be put out of service, as happened on 09/08/2023.

  - Independent emergency raising mechanisms, that can open the gates independently of the current raising system, have not been installed on the gates.

  - Braskereidfoss Power Station is equipped with its own permanently installed emergency generator. The generator has been installed on the floor, 4 metres below the top of the buttress dam. When the water overflowed the buttress dam and eventually penetrated the power station, the generator room was also partially filled with water and the generator put out of service.

When the basic causes are viewed in context, it is possible to understand how the incident could occur. In this context, talk about 'human error' or 'mistakes' is not relevant, rather the overall system was not resilient enough to deal with a scenario such as Storm Hans. All in all, Hafslund Eco Vannkraft was not prepared for the overall impact of Storm Hans. The investigation identified weaknesses in relation to human, technical and organisational factors that ought to be reviewed and improved in order to prevent similar incidents happening again.

Based on the root cause analysis, the following recommendations have been made (summarised in short form):

- **Ensuring comprehensive risk management for operations:** The recommendation is to strengthen the risk management in order to be better equipped to meet future situations involving extreme weather events. This risk management should be carried out at both an overall level and for specific emergency situations, such that the operations function is viewed as a whole with regard to the resilience of human, technical and organisational factors. The risks associated with potential changes in the nature of extreme weather events should also be included.

- **Make the 'open floodgates' barrier function more resilient at Braskereidfoss:** An automatic emergency regulator should be installed that will step in if the operations centre fails to act and activate the floodgates if the water level exceeds the highest regulated water level (HRWL). Another potential measure that should be considered is that critically high water level warnings should be sent directly to the operational staff on duty to ensure that there are at least two independent barrier elements that can take action and open the floodgates.

- **Make the operations centre more resilient in relation to emergency situations:** The staffing situation should be improved such that the resources required to run the operations centre with a sufficient margin in emergency situations are in place. Better arrangements must be put in place to ensure that [redacted] can work together better in the operations centre. The operations centre should implement relevant emergency response exercises and emergency response training that reflect real flooding situations such as Storm Hans.

- **Review the operations centre's shift arrangements:** The current shift system, which involves two 16-hour shifts with an 8-hour rest period between them, ought to be reassessed with a view to whether it allows operators adequate rest and facilitates the alertness they require for their jobs.

- **Improve the operations control system's user interface at the operations centre:** The recommendation is to carry out an overall assessment of the alarms and signals list with a view to simplifying and improving the ability to prioritise based on criticality and/or response times. Suggestions have also been made concerning some specific alarms that ought to be changed, especially for warnings concerning high and critically high water levels.

- **Staffing at the plant in flood situations:** The current instructions specify that the power station/dam facility at Braskereidfoss must be staffed in the event of a rate of flow of 1800 m^3/s. The recommendation is that the facility should be staffed earlier, i.e. also in the case of smaller floods than this. Staff should be on site on a full-time basis during intense floods, such as Storm Hans, while inspection rounds may be sufficient in the case of seasonal floods (snow melt/spring floods), which normally develop over a longer period of time.

- **Technical recommendations for Braskereidfoss:** In summary, the following technical risk mitigation measures are recommended:
    - Install hydraulically actuated raising mechanisms on the floodgates at Braskereidfoss.
    - Establish a system that opens the floodgates automatically in the event of flooding.
    - Install emergency raising mechanisms on the floodgates.
    - Portable drill connected to existing machinery as a backup solution.
    - Measures for preventing the overtopping of the buttress dam.
    - Measures for better securing the power station and gatehouses from submersion.

Although the recommendations are based on the experiences from the Braskereidfoss incident, the lessons learned will have some transfer value for other dams and other operations centres.

2 INTRODUCTION

During the extreme weather event Storm Hans in August 2023, Innlandet County experienced heavy precipitation. Hafslund Eco Vannkraft had raised its emergency preparedness level. Extra staff had been called in to handle the situation at the facilities. At the operations centre, which operates [redacted] in the Region, staffing had been increased [redacted].

At around midnight on 09/08/2023, staff visited Braskereidfoss to check the situation there. After being in touch with the operations centre by telephone, they moved on to other facilities in the area. The power station was subsequently unmanned.

During the night, the rate of flow in the Glomma River increased rapidly and the water level at Braskereidfoss Power Station rose above the highest regulated water level (HRWL). Normally, the power station's floodgates would be opened as the rate of flow increases, such that the water flows past and does not accumulate above the dam. However, this did not happen. During the night, water thus flowed over the gates and eventually into the power station. Both generators stopped working.

At around 06:20, staff were contacted by the operations centre due to a warning signal from the power station. When they reached Braskereidfoss at around 06:45, the water was overflowing the floodgates, and the water level was still rising. Attempts were made to open the gates locally, but without success. The staff closed the county road that runs across the dam and called the police, who assisted at the scene. The water level eventually rose above the county road that crosses the dam. At 13:00, the police decided to stop all activity on the bridge since it was deemed too risky to carry out further operations on it.

At 16:30, the embankment dam adjacent to the power station failed. The breach in the embankment dam provided sufficient run-off past the power station and the water level receded.

The damage was primarily material in nature. No one was physically injured during the incident.

Photo 1: Braskereidfoss Power Station, 09/08/2023 at 12:16. The water is flowing over the floodgates and the buttress dam and into the two power plants (Photo: Police/Source NVE).

DNV AS was engaged by Hafslund Eco Vannkraft AS to conduct an investigation of the incident. This report describes the results of that investigation.

The investigation covers the factors related to the floodgates and why these were not opened on the night. Therefore, this investigation has not assessed the failure of the embankment dam itself.

DNV has collaborated with Multiconsult AS, which has assisted in the assessment of the technical system associated with the floodgates and represents NVE-approved technical expertise (Discipline area III Shut-off/tapping equipment, pipes and vertical water gates). Multiconsult's work is presented in a separate sub-report. The main findings and recommendations from the sub-report are summarised in the main report.

Although the investigation mainly dealt with the incident and what went wrong, it is nevertheless important to emphasise that a lot worked and was managed well during Storm Hans as well. We assume that everyone involved did their best based on their situational awareness and the given conditions. However, we believe that human error is inevitable and that safety-critical systems need to be established with a sufficient degree of resilience to cope with mistaken actions. This is DNV's approach to incidents.

3 DNV'S INVESTIGATION

3.1 The investigation's purpose and terms of reference

DNV was engaged by Hafslund Eco Vannkraft to conduct an investigation of the incident that occurred at Braskereidfoss Power Station on Wednesday, 09/08/2023 in connection with Storm Hans.

The purpose of the investigation was to find out why the dam's floodgates were not opened as normal as the Glomma River's rate of flow rose during the night.

The investigation's terms of reference were:

- Document the course of events.
- Identify the immediate (direct) and basic (underlying) causes of relevance to the incident, including human, technical and organisational factors, as well as the interplay between these.
- Identify recommendations for preventing similar incidents happening again.

The objective of the investigation is to learn from the event and improve dam-related safety.

3.2 Limitations

The following areas were not part of the investigation and have only been covered in general and to the extent deemed relevant in relation to the investigation's terms of reference:

- The reasons why the embankment dam failed were not investigated since this topic is deemed to have been adequately covered already in the reassessment report for Braskereidfoss 2018 /2/. This report concluded that: "The embankment dam does not satisfy the freeboard requirements necessary to prevent overflow. The embankment dam will be vulnerable to heavy erosion from overtopping in the event of a flood disaster. The assessment is that the dam will not withstand overtopping in a disaster situation."
- Emergency preparedness and incident management, including contact with the emergency services and civilian population, are not addressed in this report beyond what is considered relevant in relation to the investigation's terms of reference. Hafslund Eco Vannkraft is conducting an internal review of the emergency response to, and handling of, Storm Hans. Likewise, assessments of the actual and potential consequences of the incident are not analysed in this report. A brief description of the actual consequences can be found in Chapter 5.1.
- The investigation was time-limited up to the morning of 09/08/2023 at around 08:00 when the overtopping of the dam and water penetration into both power plants had occurred and it was determined that it was not possible to operate the floodgates. Measures and assessments continued to be carried out throughout the day on 09/08/2023 after 08:00. These included delivering materials, responding with an excavator, assessing blowing a hole in the dam with the help of the Norwegian Armed Forces, etc.
- Assessing compliance with Acts, Regulations, rules, etc. was not part of the purpose or terms of reference of the investigation. However, an assessment has been made of whether any technical nonconformities could have affected the incident.
- Braskereidfoss Power Station's ownership and ownership structure have changed since the power station was established in 1978. However, the power station's actual operating organisation has remained relatively stable, and many employees have worked at the power station for many years and under changing ownership. Ownership and the ownership structure were not a topic of the investigation. The company name Hafslund Eco Vannkraft (HEV) is used consistently throughout this report, even though the name was first established in 2020 (press release dated 02/03/2020) and even though some of the activities described took place under a different name.

3.3 Method

DNV uses the Systematic Cause Analysis Technique (SCAT) method for investigating incidents and accidents. The method was originally developed by Bird and Germain (1985) and later modified by DNV in conjunction with the Loss Causation Model. SCAT is designed to help you understand why accidents occur and what you need to do to prevent similar causes of events.

The SCAT method is illustrated in Figure 1 and involves the following four steps:

1. Describe the type of incident and its consequences.
2. Identify immediate causes, such as technical failures or operational failures.
3. Identify basic causes, i.e. the causes that led to the above immediate causes.
4. Identify the management system failures (lack of control) that led to the basic causes.

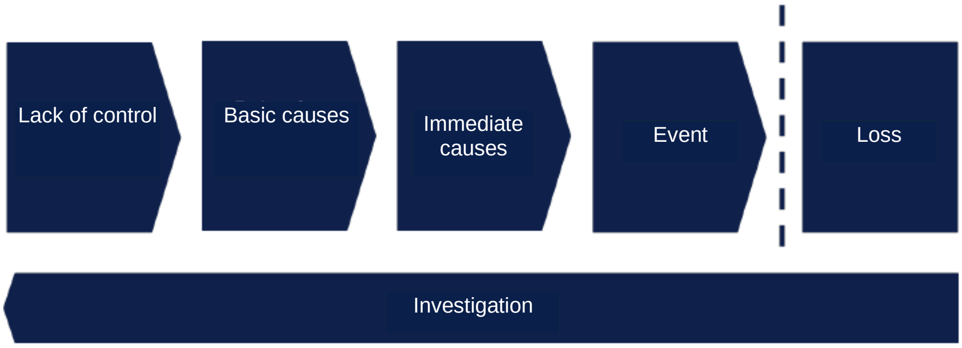


Figure 1: Overview of the SCAT method (Loss Causation Model)

Root cause analysis is a key element of the method and depends on systematic and cyclical processes related to investigating various evidence, formulating hypotheses and testing them against specific criteria, drawing inferences, looking at alternatives, obtaining more information and finally coming to conclusions.

Human, technical and organisational factors must be assessed. The method is based on the premise that human errors are inevitable and that safety-critical systems must be designed and made resilient based on this assumption.

The purpose of SCAT is to move backwards in time based on a timeline running from the incident/accident itself in order to identify where the organisation lacks control over the causes that caused the incident itself. The incident is delineated in time using a timeline and key events are analysed. Finally, structural features related to the management system and improvement measures are pointed out. The control areas in SCAT are primarily organisational and provide a picture of how good the organisation is at risk and safety management.

3.4 Implementation

The investigation was carried out as a combination of interviews/meetings with key personnel, a review of documentation and an analysis of systems and technology.

The investigation of the incident was carried out in four steps:

1. Visiting Braskereidfoss Power Station to view the incident site and interview operational staff.

2. Visiting Hafslund Eco Vannkraft's office in Lillehammer, which included an inspection of the operations centre and interviews of staff with key roles in the general operation of Braskereidfoss, as well as those who were directly involved during the incident.
3. Reviewing the submitted documentation and the information collected during interviews.
4. Further follow-up and interviews with specified people conducted via Microsoft Teams.

Prior to and after visiting the site, DNV had access to relevant governing documentation for Hafslund and Braskereidfoss-specific documentation requested as a basis for the investigation.

The collaboration with Hafslund Eco Vannkraft was characterised by a high degree of transparency and information sharing throughout the investigation. DNV was quickly granted access to all requested documentation, including system logs and similar. Hafslund Eco Vannkraft was helpful with all requests, which were answered quickly, well and thoroughly.

DNV worked continuously with Multiconsult throughout the investigation in order to ensure a common understanding of the elements of the incident.

3.5 Information sources

The information on which the investigation was based consisted mainly of interviews and documentation reviews.

Meetings and interviews were conducted with more than 20 people, including operational, management and technical staff. The following people/positions/roles were interviewed:

- Management and Emergency Management Team (five people)
- Operational staff at Braskereidfoss, including evening and morning shifts
- Manager and operators at the operations centre
- Operational control system system administrators
- Water Resources Technical Manager
- Technical experts

The information received and reviewed included:

- System logs
- System analyses
- System descriptions
- Technical documentation
- Inspection and maintenance documentation
- Telephone logs
- Shift schedules
- Meeting minutes
- Emergency preparedness plans
- Etc.

Please see Chapter 10 for a more detailed overview of the documentation received.

3.6 The investigation team

The investigation team consisted of the following participants:

Table 1 Composition of the investigation team

Name	Role	Company
Christian Stage	Investigation leader	DNV
Tor Stian Hjørungdal	Participant	DNV
Marita Harestad	Participant	DNV
Kurt Benonisen	Participant, Technical Subreport Lead (Appendix A)	Multiconsult
Vegar Tviberg	Participant	Multiconsult
Sverre Gravdahl	Project sponsor	DNV
Dawn Pamphlett	Quality manager	DNV

4 BACKGROUND INFORMATION

This chapter provides a brief description of the facilities, equipment, systems and organisation involved in the incident.

4.1 Operating organisation

Hafslund Eco Vannkraft is part of the Hafslund Group and has around 440 employees in total. Overall, the company wholly or partly owns and operates more than 80 power stations in Southern Norway and is Norway's second largest power producer.

Hafslund Eco Vannkraft (HEV) is divided into four main areas:

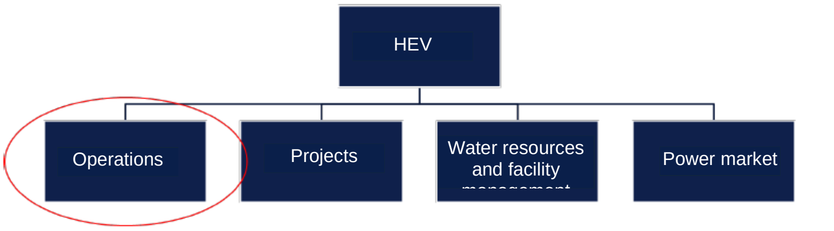
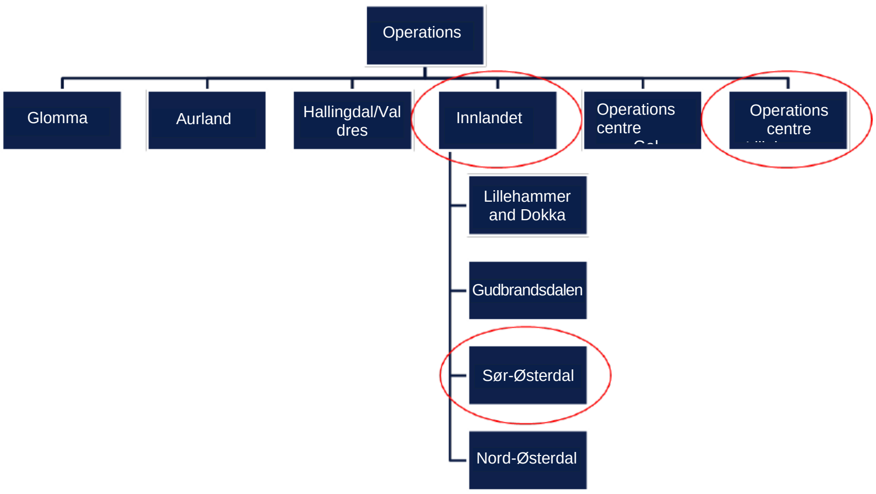


Figure 2: Hafslund Eco Vannkraft's main organisational areas

Operations is the largest of the four areas, with about 220 employees.

Generally, only Operations was directly involved in the incident on 09/08/2023 and, therefore, this is the part of the organisation described here. Employees in other areas also contributed significantly to the investigation.

Operations is divided into four regions and two operations centres.



The most relevant departments under Operations are:

- Lillehammer Operations Centre
- The Innlandet power station area consists of four areas, with Braskereidfoss belonging to Region Sør-Østerdal.
- Sør-Østerdal includes seven power stations, four intake dams on the Glomma River and five smaller regulation dams/intake dams. It has 19 employees (operational staff/maintenance). The three 'Elverum power stations', Strandfossen, Skjefstadfoss and Braskereidfoss, have the same station manager. Thus, Braskereidfoss does not have its own dedicated manager in Operations.

4.2 Emergency Management Team

The Emergency Management Team is divided into three levels: Strategic emergency management team (3rd line), operational emergency management team (2nd line),

Response management team (1st line). This is illustrated in Figure 4.

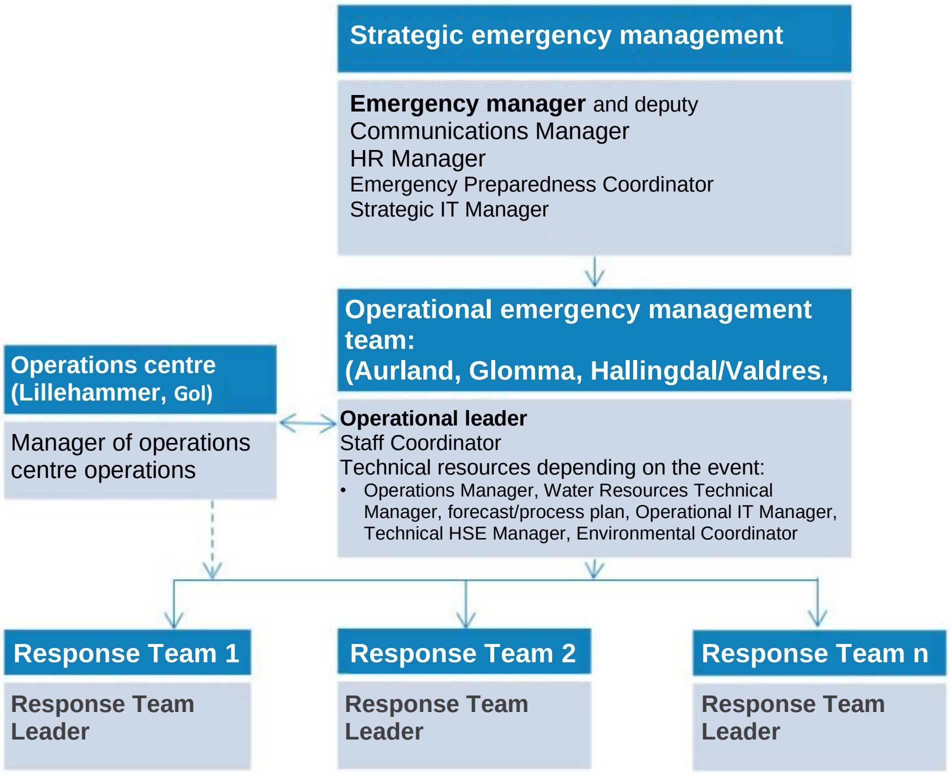


Figure 4: Emergency Management Team

Response teams are responsible for physical crisis management (1st line). The response teams are subordinate to public authorities, i.e. the response team leader/incident site leader (the police, fire service and ambulance service).

The operations centre is part of the operational emergency management team (2nd line). Its duties include making operational decisions and coordinating the response work.

Hafslund Eco Vannkraft has its own Head of Emergency Preparedness/Emergency Preparedness Coordinator, who is responsible for the company's organisation, training and emergency preparedness procedures (3rd line).

It operates with four levels of preparedness: 'basic preparedness', 'moderate preparedness', 'elevated preparedness' and 'full preparedness'.

1) Basic preparedness is day-to-day preparedness. This is the normal situation and is therefore not mentioned in the Emergency Preparedness Plan. Daily events are handled by the line organisation with ordinary shift and on-call arrangements.

Beyond basic preparedness, the other three levels of readiness are defined as follows:

2) Moderate preparedness: The emergency response team is mobilised at one or two levels. Moderate readiness is ordered in the event of abnormal incidents that require resources in excess of basic preparedness and in the event of incidents with moderate loss potential. Emergency meetings are held weekly or more frequently. Examples of moderate preparedness include a moderate flood situation that requires extra emergency staff with coordination at the response level and operational level in a limited part of the organisation, although without the need for mobilisation at the response level.

3) Elevated preparedness: The emergency response team is mobilised at two or three levels. The two levels can be either strategic and operational or operational and response level. Elevated preparedness is ordered in the event of major incidents or great loss potential. Emergency meetings are held daily or more frequently.

4) Full preparedness: The entire emergency preparedness team is mobilised and crisis management is in place round the clock. Full preparedness is ordered in the event of catastrophic incidents and threats with extensive loss potential.

During Storm Hans, the preparedness on 07/08/2023 was set to 'elevated' in the morning, which is the second highest level. Elevated preparedness is ordered in the event of major incidents or great loss potential. Emergency meetings are held daily or more frequently.

A revised version of Hafslund Eco Vannkraft's Emergency Preparedness Plan (rev. 8) was published on 11/07/2023.

4.3 Operations centre

On a day-to-day basis, Braskereidfoss Power Station is operated from the operations centre [redacted]

The operations centre monitors comprehensive information from the facilities [redacted]

Normal staffing levels are [redacted] 24 hours a day.

[redacted]

The three floodgates and the bottom gate are normally operated from the operations centre, although they can also be operated locally at the power station. The timber gate, which is the smallest of the gates, can only be operated locally.

[redacted]

4.4 Braskereidfoss Power Station

Braskereidfoss Power Station is a run-of-the-river hydropower station in Våler Municipality, Innlandet County, Norway from 1978. The power station utilises a 9-metre drop in the Glomma River. Its annual production is about 170 GWh. The dam dates from 1978 and it was built partly as a concrete dam and partly as an embankment dam. It is combined with a road bridge. The power station consists of the following main elements:

- Braskereidfoss 1: Kaplan turbine generator from 1978 with output of 23 MVA and absorption capacity of 270 m^3/s
- Braskereidfoss 2: Kaplan turbine unit from 2016 with output of 18.5 MVA and absorption capacity of 180 m^3/s
- Concrete gated dam with four pillars, foundations standing on rock, three floodgates and two smaller gates: one bottom gate/regulation gate and one timber gate.
- Embankment dam with an impervious core of moraine.
- Concrete buttress dam with buttresses and an abutment. Length approx. 320 m.

The dam was constructed in 1978. County Road 507 crosses over the dam. The road surface is at contour line 166.7.

The highest regulated water level (HRWL) is 163.20.

The contour line for the gated dam and buttress dam is 165.0.

On the east side of the power station's intake (BF1), the top of the buttress dam is also at contour line 165. There is an opening between the bridge and the top of the dam wall with a height of about 30 cm. This gap crosses the entire width of the dam structure. At water levels above contour line 165, the water will flow over the dam wall and onwards into the station. In these circumstances, water will also flow into the access gates in all the pillars, making hand cranking the gates impossible and destroying electrical equipment. (1992)

The facility is not permanently staffed; however, it is regularly inspected by operational staff, who perform maintenance, clear gates, etc.

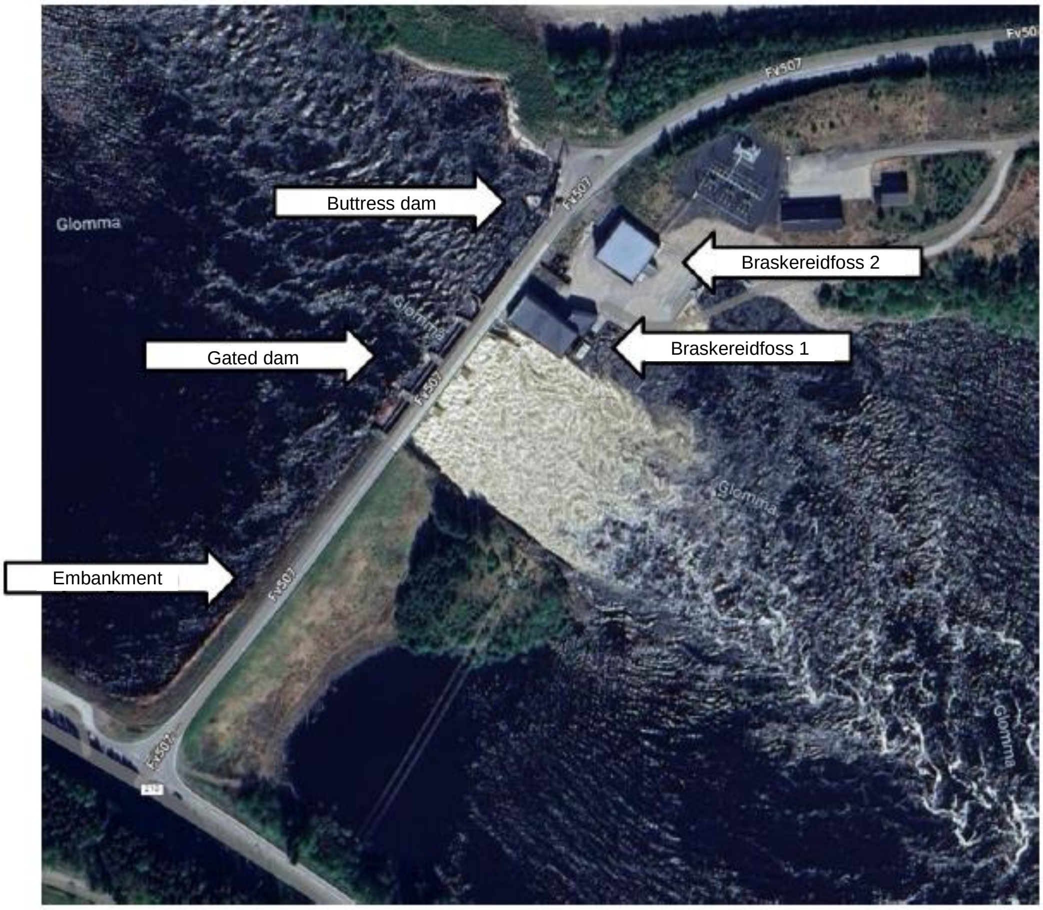


Photo 2: Braskereidfoss seen from the air (Image: Google Maps)

Photo 3: Braskereidfoss Power Station. Generator 1 is in the building on the left, generator 2 is in the building on the right (Photo: HEV)

4.5 Gates

The gates at Braskereidfoss power station consist of: one timber gate, which is a sector gate; one bottom gate, which is a submerged segment gate; and three floodgates, which are segment gates. The timber gate is a radial, surface gate where the opening and closing manoeuvres are achieved by rotating the entire structure around the gate's bearing. When the gate is opened it is lowered into the gate pit and water flows over the gate, making it particularly suitable for diverting objects floating in the water such as timber and ice. The bottom gate and floodgates are radial gates where the opening and closing manoeuvres are achieved by rotating the entire structure around the gate's bearing. Opening is achieved by raising the structure such that water flows under the gate. The power station's five gates are listed in Table 2 and their locations are shown in Photo 4.

Table 2 Gate overview Braskereidfoss

Gate no.	Gate type	Capacity at HRWL (m^3/s)	Width x Height (m)	Comments
1	Timber gate	90	8.0 x 4.0	Can only be regulated locally at the facility
2	Bottom gate	270	8.0 x 2.8	Normally set to automatic, water level regulation
3	Floodgate	750	20.0 x 8.2	Normally set to manual, normally operated from the operations centre
4	Floodgate	750	20.0 x 8.2	Normally set to manual, normally operated from the operations centre
5	Floodgate	750	20.0 x 8.2	Normally set to manual, normally operated from the operations centre

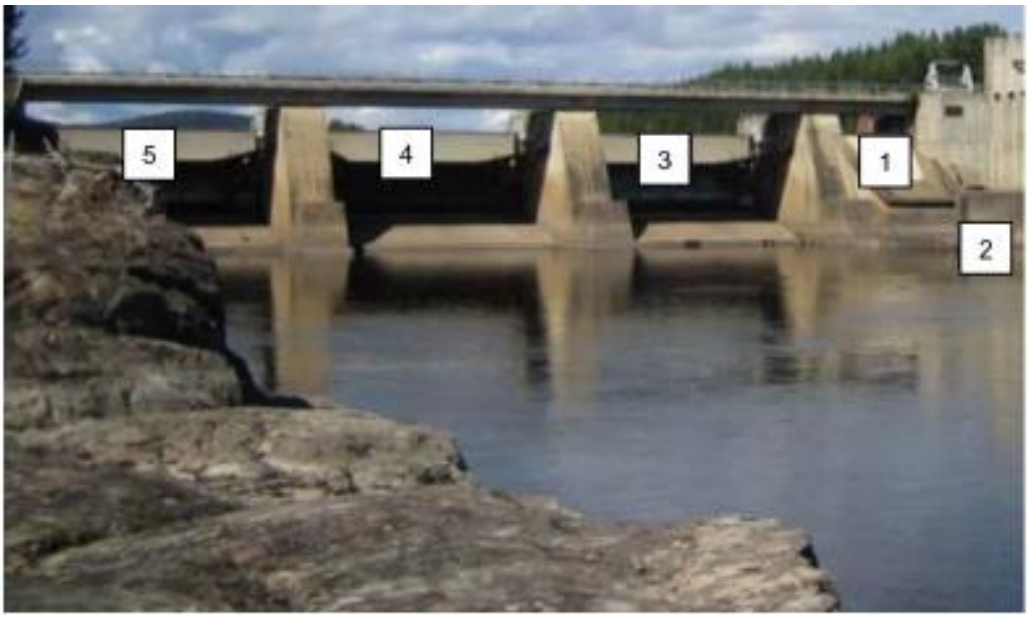


Photo 4: Overview of the gates at Braskereidfoss, as seen from downstream (Photo: Sweco)

Total flood diversion capacity at HRWL is estimated to be 2600 m^3/s, and the maximum flood diversion capacity at the dimensioning flood water level (164.60 metres above sea level) is estimated to be 3500 m^3/s, when all the gates are operational. The bottom gate is normally used for fine-tuning water levels in relation to HRWL and does not have sufficient capacity to divert the full drainage capacity of both Braskereid 1 and 2. Therefore, if the power station shuts down, the floodgates must also be operated manually.

4.5.1 Floodgates

The floodgates are operated by two electromechanical drawworks with chains for raising located in pillars on either side of the gate. The lifting capacity of the gate works is 2 x 40 metric tons. The chain raising mechanism is used to transfer force and movement from the raising machinery to the gate and is partly protected from the flowing water by a cover. Each gatehouse has a hatch at the top that allows access to the drawworks via a staircase. Each of the drawworks is powered by an electric motor and the drawworks are synchronised using an electric shaft. The drawworks must be run synchronously to avoid raising the gate unevenly, which can cause it to get jammed. The gates are primarily opened and closed remotely, although control cabinets are located in the gatehouses for local operation.

Photo 5: Floodgate 4 in closed position (Photo: Sweco)

Photo 6: Floodgate, pillar and gatehouse (Photo: Sweco)

4.5.2 Timber gate

Like the floodgates, the timber gate is operated by two electromechanical drawworks with chains for raising located in pillars on either side of the gate. The drawworks are of the same type but are not controlled remotely and must be operated locally at the power station.

Photo 7: Timber gate (Photo: Sweco)

4.5.3 Bottom gate

The bottom gate has a hydraulic raising mechanism with a centrically placed cylinder. The bottom gate is normally used for water level regulation and lets water past when the power station is at standstill or when the rate of flow exceeds the power station's absorption capacity. In normal operation one of the power station's generators and Gate 2 are set to automatic, i.e. as the water level regulator.

Photo 8: Bottom gate (Photo: Sweco)

4.6 Operational control system

The operational control system at Braskereidfoss is based on an overarching philosophy that divides it into five different levels. Automation has been introduced into the power station over time, so both the power station and gates are mainly controlled remotely.

[redacted]

Braskereidfoss's current operational control system therefore differs from its original design. In normal operation the power station is operated from the operations centre in Lillehammer. This also applies to the timber gate and floodgates. Each gatehouse has a local selector switch that switches between local or remote control. Local control is generally only used for gate maintenance and as a safety barrier for operational staff.

[redacted]

[redacted]

4.6.1 [redacted]

[redacted] Supervisory Control and Data Acquisition (SCADA) is a real-time information system designed to handle all operational activities in a modern control room. The system handles data collection, component and sequence control, events and alarm notifications, graphical station diagrams, power network monitoring, distribution, etc. [redacted]

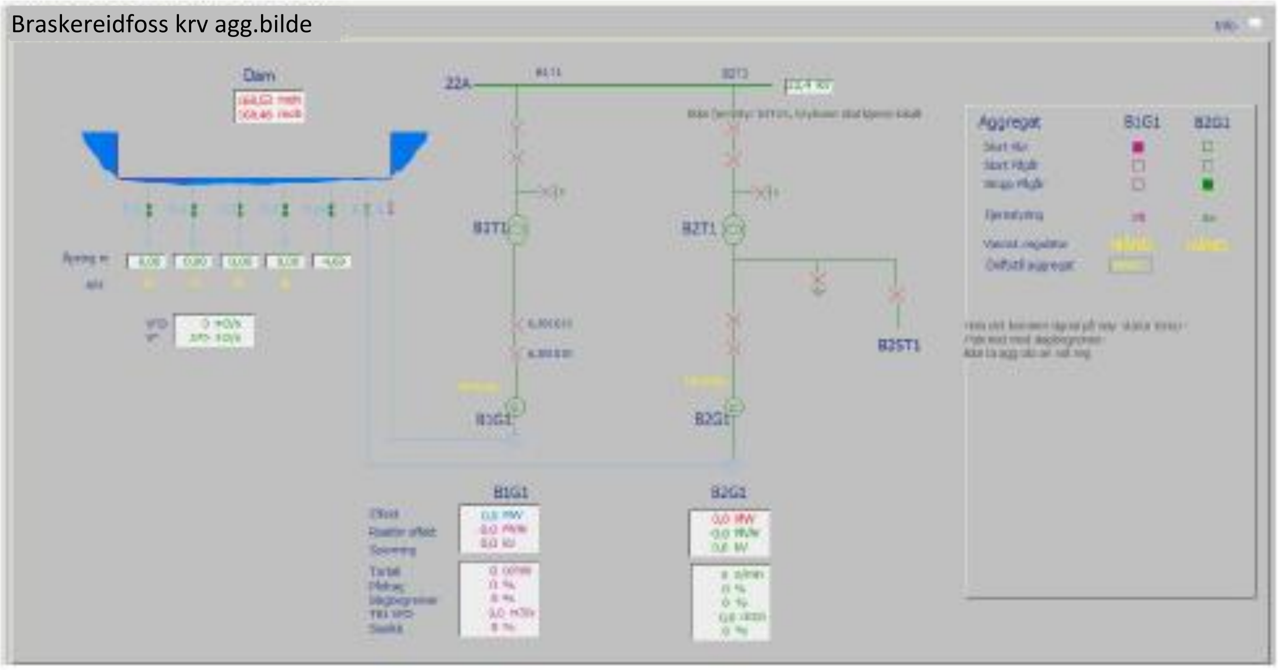


Figure 8: SCADA screenshot (user interface section)

Each power plant has its own SCADA screens, and it is the operator's job to select which screen should be visible in order to acquire relevant information. Alerts and alarms are sent automatically in order to alert the operator to situations that require their immediate attention. A distinction is made between operational notifications (ON) and error notifications (EN). While operational notifications may require the operator to take corrective actions in SCADA, an error notification may require local repairs to be carried out at the power station. These notifications therefore appear on a separate list of alarms at the operations centre. The operations centre always has to take a preventive approach. Signals are categorised to make it easier for the operator to assess the correct measures for each individual alert/alarm.

In addition to alarms and alerts from the power station, the operations centre can set its own limit alerts locally in the control room. Limit alerts can be set at five different levels and provide warnings regarding both high and low measured values. Limit alerts appear in white in SCADA and can be blocked by the operations centre if the reason why the limit alerts are being sent has been clarified. For example, if they are due to a faulty sensor. Blocking alarms is a tool used by the operations centre to separate out important information.

Figure 8 shows the screen used to monitor and operate the gates at Braskereidfoss. It contains measured values and operating data for all of the gates, presented graphically in real time. This provides part of the basis for making decisions at the operations centre and is the tool it has for operating the floodgates and bottom gate. While the floodgates (FL3, FL4 and FL5) are operated manually, the bottom gate (FL2) is usually set to automatic. The gates are operated via pre-programmed signals described as small, medium or high. The actual control of the gates is located in the local joint OBDM B1 facility at Braskereidfoss, as shown in Figure 9.

4.6.2 Local SCADA [redacted]

Local SCADA has been installed at Braskereidfoss as level 2 control, [redacted] This is referred to as station control and enables local operation of the power station should communication with the operations centre be interrupted. Station control provides access to the same information and control options you have at the operations centre and in the SCADA system. There are three different control stations at Braskereidfoss that can be used. Two of these control stations belong to Hafslund Eco, while one of them belongs to the grid company, Elvia.

4.6.3 Aveva PI Vision

Aveva PI is a software system for collecting, analysing and visualising data. It is actively used as a monitoring tool for operational staff to display a situational picture of the power plants in real time. Aveva PI retrieves data from SCADA and displays lists of events. The data has also been through the station computer which results in some lag. Aveva PI is mainly used as a tool for operations and maintenance, and uses data from the ERP system, production plans, operational records, etc. During the investigation, Aveva PI was mainly used to gain an understanding of relevant events and times.

5 THE INCIDENT

5.1 Factual information

Table 3: Facts about the incident at Braskereidfoss

Incident date	09/08/2023
Location	Braskereidfoss Power Station, Nedre Glomma (Sør-Østerdal), Våler Municipality, Innlandet County
Consequence class	Braskereidfoss is classified as being in failure consequence class 1, ref. decision letter from NVE dated 09/10/2019.
Owner	Braskereidfoss Power Station is owned and operated by Hafslund Eco Vannkraft AS
Incident type	Flood, water penetration and flooding of both power plants, dam failure
Involved	Employees at Hafslund Eco Vannkraft Emergency services, Norwegian Armed Forces Employees of the grid company Elvia became indirectly involved
Rate of flow	The rate of flow in the Glomma River measured at Elverum on 09/08/2023: 1617 m^3/s at 00:00, 1905 m^3/s at 06:00. Normal rate of flow in the same period < 500 m^3/s.
Scope of personal injuries	No one was physically injured during the incident.
Scope of damage to the external environment	Little environmental damage. Failure of the embankment dam, where the consequences were that parts of it were washed away by the rate of flow. Otherwise, minor damage to surrounding nature. No signs of oil spillage into the river were found, although this cannot be ruled out.
Scope of damage to assets	Braskereidfoss power plants 1 and 2 both sustained extensive damage due to water penetration. The embankment dam next to the power station was partially washed away by the water. The concrete gated dam appears to be intact, while the gate structures themselves, including motors/driving gear, have sustained damage. County Road 507, which crosses the dam, has been destroyed and closed. Lost electricity production for a prolonged period of time. The costs resulting from the incident have not been estimated as part of this investigation.

5.2 Extreme weather event Storm Hans

Storm Hans affected areas in Southern Norway, as well as parts of Sweden, Finland, the Baltic States and surrounding regions in August 2023. Storm Hans was a special and rare weather event. Never before had such large amounts of precipitation been measured over such large areas in Eastern Norway.

As a result, the Norwegian Meteorological Institute issued a red danger warning for the period from the morning of 07/08/2023 to the evening of 09/08/2023 concerning “extremely heavy rain” that could result in one of the most severe weather events in the affected areas in 25 years. The Norwegian Meteorological Institute issues red danger warnings when they “expect extreme consequences as a result of the weather”, which according to the Norwegian Meteorological Institute means that “there will be a major risk to life, and there may be serious damage to property and infrastructure.” The Norwegian government urged people to “listen to the authorities, avoid unnecessary travel and traffic.” The extreme weather was also forecast in reports and warnings from the Norwegian Water Resources and Energy Directorate (NVE), as well as broad coverage in the Norwegian national and local media.

Innlandet County received the largest amounts of precipitation. On average, more than 100 years pass between each time such large amounts of rain fall in such a short time. It is normal for smaller areas to see a lot of precipitation, but Storm Hans covered a very large area. That is extremely unusual. This led to a great deal of water in the numerous tributaries that eventually flow into a few main rivers.

The consequences of Storm Hans included landslides, floods, overflowing and major damage to infrastructure and property, especially in the Norwegian counties of Innlandet and Viken. This continued for several days after the storm was over, particularly in the form of flooding incidents in the lower reaches of the watercourses belonging to the river drainage basin.

Figure 10 shows a comparison of the annual spring flood in 2023 and Storm Hans in August 2023. Rates of flow are shown in four different locations: Ofossen (Skjåk), Hunderfossen (Lillehammer), Kongsvinger (Glomma River, downstream of Braskereidfoss) and Atna/Rendalen.

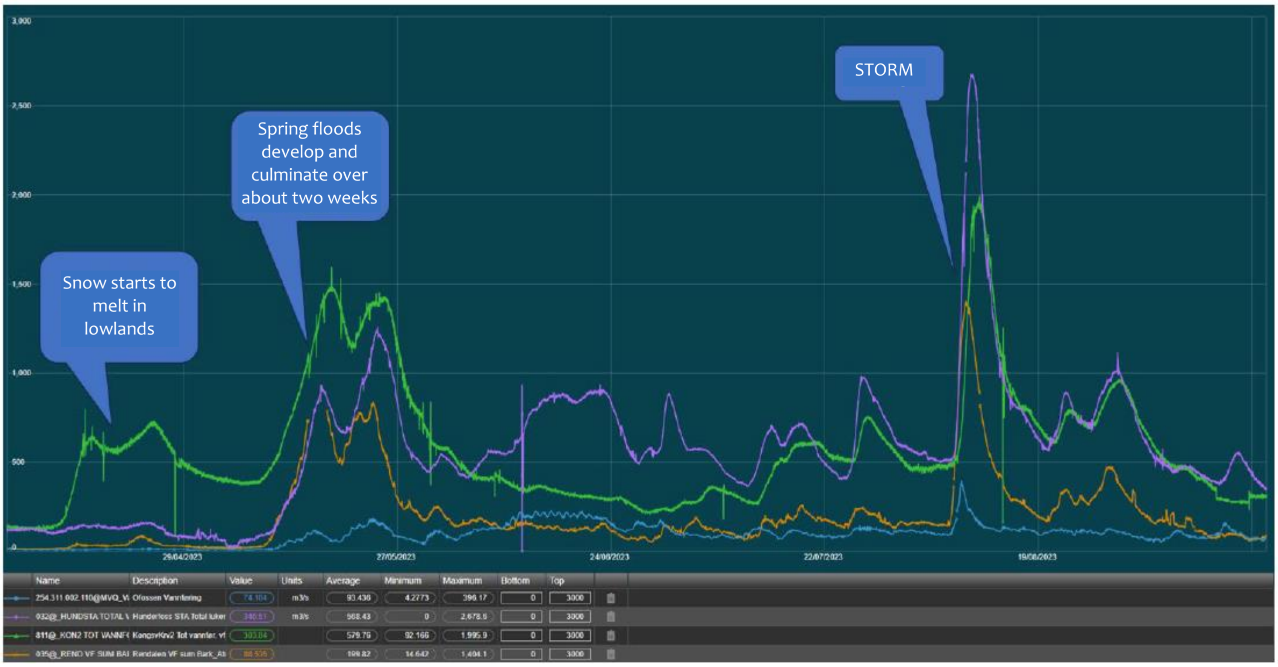


Figure 10: Comparison of spring flood 2023 and Storm Hans (rate of flow at four selected monitoring stations)

Figure 10 shows that both the strength and intensity of Storm Hans surpassed a normal flood situation that the organisation is used to handling. The sudden and rapid development of Storm Hans is particularly worth noting. During a typical spring flood, the rate of flow rises by up to 80 m^3 per hour, while during Storm Hans, the rate of flow rose by 150 m^3 per hour.

5.3 Photos of the incident

Selected photos from and after the incident are presented below.

Photo 9: Braskereidfoss Power Station, morning of 09/08/2023 (Source HEV)

Photo 10: Overtopping of the floodgates at 12:24
(Photo: Håkon Skogmo/Source NVE)

Photo 11: Power plants and gated dam at 12:16 (Photo: Police/Source NVE)

Photo 12: Overtopping of road bridge, embankment dam and gated dam at 15:31 (Photo: Police/Source NVE)

Photo 13: After the failure of the embankment dam at 17:04 (Photo: Police/Source NVE)

Photo 14: Remains of the embankment dam after dam failure (photo: DNV)

Photo 15: Gatehouse in pillar, with submerged machinery.
The photo was taken after most of the water had been drained.
Water can still be seen at the bottom of the gatehouse (Photo: DNV)

Photo 16: Generator 1 submerged. The photo was taken after most of the water had been pumped out.
At the top of the photo you can see the line where the water reached at its peak,
marked with a red arrow (Photo DNV)

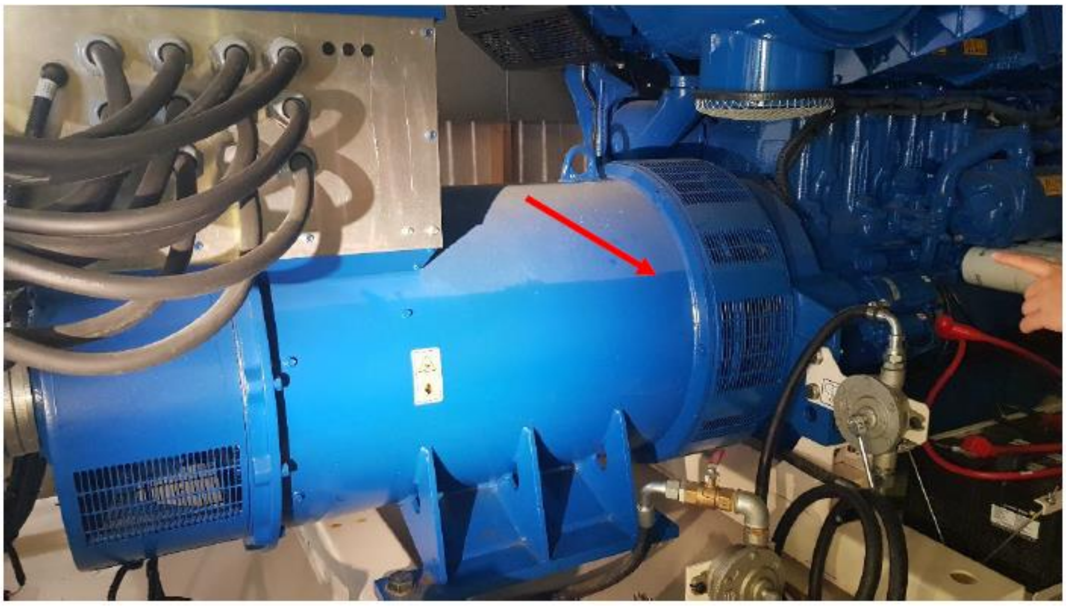


Photo 17: Submerged emergency generator. The line near the top of the generator cover shows where the water reached at its peak, marked with a red arrow (Photo DNV)

5.4 Graphical presentation of gate manoeuvres and water levels

A starting point for understanding the course of events is a graphical presentation taken from the web application Aveva PI Vision.

The graphic in Figure 11 on the following page shows both the movements of the five gates during the period and changes in the stormwater level at Braskereidfoss during the period 07/08/2023 from 18:00 to 09/08/2023 at 10:00. The Y-axis shows the percentage opening of the gates and the water level in metres above sea level.

- The blue line shows the movements of Gate 1, the timber gate.
- The yellow line shows the movements of Gate 2, the bottom gate.
- The purple, turquoise and red lines show the movements of Gates 3, 4, and 5, respectively, the three floodgates.
- The light brown line shows the level of stormwater.

	Name	Description	Value	Units	Average	Minimum	Maximum	Bottom	Top
	OpMon.Posisjon luker.808.314.001|Opening Gate 1|Relativ opening		0	%	15.155	0	92.195	0	100
	OpMon.Posisjon luker.808.314.001|Opening Gate 2|Relativ opening		0	%	46.693	0	99.756	0	100
	OpMon.Posisjon luker.808.314.001|Opening Gate 3|Relativ opening		0	%	8.1258	0	19.438	0	100
	OpMon.Posisjon luker.808.314.001|Opening Gate 4|Relativ opening		0	%	6.0054	0	17.61	0	100
	OpMon.Posisjon luker.808.314.001|Opening Gate 5|Relativ opening		0	%	6.4412	0	22.151	0	100
	808.312.001.110@MVL_Mag1Ms1_Vst1:(moh)	Braskereid VAN Vannstand 1	163.06		163.45	160.53	165.11	162	165.5

Figure 11: Diagram showing Braskereidfoss gate openings (%) and surface water level (metres above sea level) during the period 07/08/2023 from 18:00 to 09/08/2023 at 10:00

Up to around 23:30 on 08/08/2023, it is clear that the bottom gate, which was set to automatic, was constantly fine-tuning the water level such that it was at HRWL (163.20 metres above sea level). The three floodgates were being operated from the operations centre and were being opened gradually as the rate of flow rose. Every time one of the floodgates was opened a bit, you can see that the bottom gate was adjusted downwards slightly. The timber gate was closed during this period.

Operational staff at Braskereidfoss were in contact with the operations centre at around midnight. They put the bottom gate in manual and fully opened both it and the timber gate. This created some disturbances in the water level, but the water level dropped somewhat. At the same time, they adjusted the setpoint for HRWL down to 163.00 metres above sea level.

Before leaving Braskereidfoss, they set the bottom gate back to automatic. However, it quickly returned to full opening due to the rising water level. From around 23:45, no further changes were made to the positions of the floodgates. The water level therefore rises steadily throughout the night.

At around 05:20, the water level reaches 164.76 metres above sea level, and it looks like the water level has stopped rising at this time. However, this is because the water was overflowing the measurement tank, and the measurements themselves level off even though the reservoir's water level continued to rise. The drop in water level just after 07:00 was not genuine.

At about 06:00, it looks like all of the gates were closing. It is assumed that the station had been flooded from this point onwards, and it is natural to assume that water had penetrated both the cabinets and the components belonging to the operational control systems and electrical components. Therefore, from this point onwards, the signals from the station are not considered reliable. When the water level dropped and the floodgates became visible, it turned out that the gates were still in similar positions to the ones they were put in late in the evening of 08/08/2023, about 15-20% opening.

5.5 Course of events

In the following, the course of events is presented as a timeline, where each individual sub-event or sub-activity is separated out as a separate line. Table 4 has four columns.

- Timing: Can be specific time/date or a period of time.
- Actor: Can be a role, company, power station, system, operations centre, etc.
- Event: Can be an actively executed activity or an incident
- Remarks: Can be DNV's comments on the event, experience or statements of a less factual nature, excerpts from reports or similar.

The timeline starts in 1978 when Braskereidfoss was established and includes relevant events or activities of a more historical nature that have been of relevance for the investigation. For the days surrounding the event itself, 07/08/2023 - 09/08/2023, the timeline is substantially more detailed. The emergency response activities following the incident were not part of the investigation and are therefore only described briefly in the timeline.

Table 4: Timeline for the Braskereidfoss incident

Timing	Actor	Event	Remarks
History and development			
1978	HEV	The run-of-the-river Braskereidfoss Power Station, which dams the Glomma River, commenced production in 1978.	The original owner was Hedmark Energi AS. The ownership and ownership structure have changed several times in the period up to today; Braskereidfoss is now owned and operated by Hafslund Eco Vannkraft. This report does not address the ownership structure.
1991	HEV	Establishment of the operations centre at [redacted]	The number of power stations operated from Lillehammer will rise in the coming decades, [redacted]

Timing	Actor	Event	Comments
1992	NVE Supervision and Contingency Planning (NVE-T)/ Vassdragsre Gulantens Forening (VR)/ Nybro-Bjerck	Report “Project Dam Safety: Functional safety of floodgates” /3/. The report deals with dams in general, although Braskereidfoss is used as a case in a separate sub-report. The report primarily deals with the technical functional safety of the station’s main components, although to a certain extent it also deals with organisational and human factors.	The report concluded that the overall functional safety of the gates at Braskereidfoss is good. The report’s conclusion also points out the following weaknesses: - If a failure occurs at the facility that causes the water level to rise, it is crucial that staff attend within a relatively short space of time. - Typical human error is not a factor that has been particularly emphasised in this analysis, but it can reduce functional safety. One example of human error could be, for example, forgetting to reconnect the automatic control system after it has been disconnected to manually operate the floodgates. Omissions can occur during general servicing such as forgetting to refill emergency generators with petrol, etc. - The analysis also shows that when the water level in the dam overtops the dam pillars between the floodgates at contour line 165, it is very likely that there will be no chance of raising the three floodgates. The water will then flow down into the gatehouses and destroy the electric motors for the raising mechanisms. (…) The top pillar at contour line 165 will therefore be decisive for taking measures to open the floodgates. Recommended actions in the report include: - Consider emergency raising mechanisms for the floodgates (not implemented). - More reliable water level measurement (implemented) and raising the water level measuring tube in the pillar for Floodgate 5 (not implemented) - Ensure signal transmission between floodgate and the operations centre (implemented). - Signal transmission to the at home duty officer in the event of a high rate of flow (changed system since 1992) - Increase gatehouse drainage capacity (not implemented) - Routing of all power cables under the road bridge as a risk (implemented). - Establish connection for emergency generators (implemented). - A gap between the top buttress dam and bridge should be sealed to avoid the power station being flooded (not implemented). Remarks: Several of the measures from 1992 that were not implemented may have had an impact on the extent of the damage 09/08/1992. However, the investigation did not reveal what assessments have been made in relation to the recommendations.
1995	Eastern Norway/HEV	The extreme Flood Vesleofsen hit Eastern Norway in June 1995.	In this extreme flood, there was one fatality, 7,000 people were evacuated and damage worth NOK 1.8 billion was sustained. The rate of flow at Elverum/Braskereidfoss was approx. 3300 m^3/s. This incident was referred to in several of the interviews as one of the biggest flood situations at Braskereidfoss.

2004/2005	HEV	The duty arrangement with an at home duty officer for Braskereidfoss was discontinued.	Up until this point, there had been permanent duty arrangements involving at home duty officers for Braskereidfoss (and other facilities). These duty arrangements meant that the duty officer was notified by pager, and later by a text message being sent to their mobile phone, when an alarm went off at the facility. This ceased from 2004/2005, when staffing at the operations centre was also changed to round-the-clock staffing.

Timing	Actor	Event	Comments
2016	HEV	Braskereidfoss was expanded with a new power plant, Braskereidfoss 2 (new building and generator: an 18 MW Kaplan turbine). Total annual production at the station thus increased by 40 GWh, to 170 GWh/year.	[redacted]
03/04/2017	HEV	Signal 'WATER LEVEL HIGH' is removed on 03/04/2017 and the signal 'WATER LEVEL ABNORMAL' added 04/04/2017	[redacted]
2017		A risk and vulnerability analysis (RVA) was conducted in 2017. The analysis was based on the methodology from the following two references: 1. NVE: "NVE Guidance for risk and vulnerability analyses for the power supply." (consultation edition, 05/03/2010) 2. Energy Norway: "Guide for comprehensive risk management for the power industry"	In this analysis, Risk 311.1 Damaging Flooding was categorised as 1E (unlikely (less than once every 25 years), disastrous consequences). Compensatory measures described as contributing to risk mitigation included: 1. The bottom gate having battery backup and opening automatically at HRWL+40 cm. When it opens automatically at high water level, the gate is operated by battery 2. Multiple floodgates that can be operated if one floodgate fails: One timber gate m^3/s One bottom gate 270 m^3/s (the one operated by battery) Three floodgates at 800 m^3/s
02/05/2018	Sweco Norway AS	Report "Braskereidfoss Dam – Reassessment 2016" /2/ The report was sent to NVE for approval on 09/05/2018. The response from NVE was first sent to HEV on 03/01/2023. See separate description of activity on this date.	The reassessment report concludes, among other things, that: - Both the gated dam and the buttress dam will be overtopped at dimensioning flood water levels (...) The embankment dam will be vulnerable to heavy erosion from overtopping in the event of a flood disaster. <u>Gates</u> - The gates are well maintained and followed up, and no factors concerning the floodgates were identified that require immediate action. <u>Supervision</u> - The periodic supervision of the dam is satisfactory. Risk assessments, general supervision and reassessments should also be conducted in line with the Dam Safety Regulation. <u>Instrumentation</u> - It is stated that the dam has instrumentation that includes a water level gauge and that the water level is measured continuously. The requirement for continuous measurement of the water level at the dam has been addressed. **Three nonconformities from the Dam Safety Regulation were identified, with associated recommendations:**

			Gated dam

Timing	Actor	Event	Comments
			- At dimensioning flood water level (DFWL), gate pillars are overtopped at 0.80 m and 1.03 m DFWL, respectively, with and without bottom gate capacity. Section 5-12 of the Dam Safety Regulation requires that the top of the dam must at least be at the level of the dimensioning flood water level. The dam does not satisfy the requirements for the necessary freeboard. Section 5-8 requires dams to have floodgates with sufficient capacity to divert dimensioning drainage floods at dimensioning flood water levels. The requirement for flood diversion capacity is thus not satisfied. - Recommended measures: Measures should be taken to avoid overtopping the gated dam at DFWL. It was recommended that stability calculations be carried out for pillars and thresholds in connection with the preparation of a technical plan. Buttress dam - The buttress dam is topped at DFWL and preparations have not been made for overflowing behind the dam (same regulatory requirements as for the gated dam). - Recommended measures: Measures should be taken to avoid overtopping of the buttress dam at DFWL. It was recommended that stability calculations be carried out in connection with the preparation of a technical plan. Embankment dam - The moraine core is overtopped by 0.9 m at DFWL. The dam does not satisfy the freeboard top seal requirements. Based on observations from the inspection, the dam does not satisfy the requirements for the required stone size for slope protection in line with NVE's guidelines. The Glomma River carries large amounts of water and floods last for some time. The dam will thus be subject to severe erosion at an overtopping of 1.8 m at PMF (1.5 x Q1000) and 3.16 at Q1000 including gate failure. The assessment, therefore, is that the dam will not withstand overtopping in the event of an accident situation. - Recommended measures: The embankment dam should be cleared of vegetation. The recommendation is to reinforce the embankment dam in accordance with the applicable Regulations and guidelines. It was recommended that stability calculations be carried out in connection with the preparation of a technical plan. Remarks: No plans were implemented or actions taken in relation to these recommendations from HEV.
October 2018	HEV	Flood Ottaf	Highlighted by HEV as one of the most extensive floods in recent years and suggested as a basis for comparisons with Storm Hans in relation to the workload at the operations centre.
19/10/2019	NVE	Braskereidfoss is downgraded from consequence class 2 to consequence class 1 following an application from HEV (15/02/2018)	The original basis for recommending that the facility be categorised as consequence class 2 was a failure wave map showing that one to three homes in the centre of Våler would be impacted in the event of the dam failing. Access to better map data in the form of laser data for terrain heights provided a basis for a reassessment of

			the number of homes that would be impacted downstream from the facility, and this showed that no homes would be impacted if Braskereidfoss Dam failed. Additionally, the rate of flow following a failure would be comparable to the initial rate of flow when the floodgates are opened.

Timing	Actor	Event	Comments
25/03/2022	HEV	Last annual inspection at Braskereidfoss (Dated 25/03/2022, it was in practice conducted over an extended period)	Conclusion: "In general for all floodgates: Lacks instructions for gate operation and wiring diagrams for electricity. Should be available in all gatehouses. Emergency procedure for gate operation will be produced. Pillars: no development of cracks. Bridge beams and systems: OK. Gate bearings OK. No deformation of gates. All floodgates have an electric shaft – not converted for frequency control. Possible problem with spare parts. Check the possibility of changing motors between gates. Gatehouse OK, power OK." No findings were made concerning the functionality of the floodgates.
22/05/2022	HEV	The RVA for Braskereidfoss from 2017 was updated to include the changes that had been implemented and the vulnerabilities that had been identified. Previous risk factors were included, and new ones were added. A risk assessment was carried out based on the requirements of the Energy Emergency Preparedness Regulation, the Dam Safety Regulation and HSE legislation.	Damaging flooding is one of the scenarios in the analysis that has the most serious consequences. The scenario is described as follows: "This incident involves situations and conditions that for one reason or another cause flooding. These could be along the watercourse upstream or downstream from a power station or water penetration into a station. The analysis involves drainage capacity and penetration from white water." Possible causes: - Malfunctions in gate function - Heavy rainfall and rapid melting in spring The following barriers are listed in relation to this risk: - Floodgate 2 has battery backup and opens automatically at HRWL+40 cm. When it opens automatically at high water level, the gate is operated by battery - Multiple gates that can be operated if one gate fails: A timber gate 90 m3/s, a bottom gate 270 m3/s (the one operated by battery), and three x 750 m3/s floodgates - Flood Response Plan - Malfunction of Flood Diversion Devices Response Plan - Training - Do not run the dam down quickly. Risk of landslide in relation to railway. - Gate clearance - New water level regulator in 2013 - More reliable station supply: - Significantly improved after Braskereidfoss came in at 132 kV Mjøsringen. - New emergency generator with full capacity for gates - Inspection of riverbed The risk is accepted with the aforementioned measures.
03/01/2023	NVE	Letter to HEV "Dam Braskereidfoss, Våler Municipality.	The reassessment report is approved by the NVE four

		Approval of reassessment report – decision with conditions"	and a half years after being submitted. The following decisions are made: "Decision – Approval with conditions Pursuant to Section 7-5 of the Regulations relating to Safety at Watercourse Facilities (Dam Safety Regulation), the reassessment report for Braskereidfoss Dam is approved contingent on proposed measures for closing the nonconformities identified in the reassessment and associated progress plan are submitted. The deadline for submission is 01/03/2023."

Timing	Actor	Event	Comments
			No response was provided by HEV, there was only an inspection with NVE and a briefing on the situation for an NVE case officer in the spring of 2023.
30/01/2023	HEV	The RVA for the operations centre in Lillehammer from 2021 was updated. Existing risks were reassessed, and new risks were identified and further assessed. A risk assessment was carried out based on the requirements of the Energy Emergency Preparedness Regulation, the Dam Safety Regulation and HSE legislation.	The analysis describes the barriers established for the various risk scenarios. A vulnerability assessment was conducted for each scenario. The scenarios that are relevant for extreme weather events such as Storm Hans are listed below. They were all classified as green, i.e. *"Risk accepted as low, without further measures"*, without further mitigation. [redacted]
April/May 2023	HEV	Test operation of all floodgates at Braskereidfoss conducted as part of Preventive Maintenance (PM 24813). 27/04/2023: Test operation of Floodgates 4 and 5 11/05/2023: Test operation of Floodgate 3	Successful testing of floodgates completed. Description of procedure: During the floodgate testing, there was one man on the bridge and one in each gatehouse. The man on the bridge checks that the gate moves straight in its guides. When opened, the jet of water is distributed equally across the entire gate, and that the jet of water is cut off equally across the gate. The man in the eastern gatehouse listens for noises in the machinery and control cabinets in his gatehouse and operates the gate. The man in the western gatehouse listens for noises.
May 2023	HEV	Annual spring flood	Flood situation highlighted by HEV as a basis for comparisons with Storm Hans in relation to the workload at the operations centre.
July/August 2023	HEV	Storm Hans is forecast for the end of July, with heavy rainfall forecast for the coming weeks. Hafslund monitors the alerts from NVE and calculates daily forecasts for its watercourses. Operations and watercourses are followed up on a daily basis at the morning meetings in Lillehammer.	

Timing	Actor	Event	Comments
07/08/2023			
10:00	Strategic emergency managemen t team	First meeting of the strategic emergency management team for Storm Hans. The preparedness level for Innlandet County, including the Glomma River, is raised to level 3 'elevated preparedness' on the same morning at 07:00 at the morning meeting. This was based on warnings from NVE, as well as its own forecasts.	Operational staff and operators informed about the elevated preparedness. Two further daily status meetings are scheduled (10:00 and 15:00) All areas are reviewed. [redacted]
15:00	Operational emergency managemen t team	First meeting of the operational emergency management team for Storm Hans.	All areas are reviewed. Response assurance from the end of the working day to the start of the next day (this is later extended beyond 09/08/2023). Emails sent out from the emergency response manager concerning who is on duty. The forecast for the Glomma River near Elverum is 1500 m3/s. The focus is on other areas that are considered more vulnerable. [redacted]
15:00	Strategic emergency managemen t team	Status meeting for the strategic emergency management team.	The meeting minutes contain the comment that "The weather appears to have shifted in a more westerly trajectory."
15:00	Operations centre	The operator at the operations centre starts a 16-hour shift (15:00-07:00). Due to the high level of activity, the operator, in consultation with the head of the operations centre, uses on-call arrangements [redacted]	
07/08/2023-09/08/2023	Operations centre	[redacted]	[redacted]
08/08/2023			
07:00	Operations centre	[redacted]	[redacted]
08:00	Operational emergency managemen t team	Status meeting	From the minutes of the meeting: "Looks like there's decent control still in all areas except Roppa. Risk of crews not getting out." [redacted]
10:00	Strategic emergency managemen t team	Status meeting	From the minutes of the meeting: "The weather seems to have taken a more southern/western trajectory. Showers were expected, but it appears to be more in the form of area precipitation. The models are not optimal in this situation. Precipitation is forecast throughout the day and into tomorrow." "Rapidly rising rate of flow in the Glomma River. Forecast 1500 at Elverum. Continued rainfall to come." Capacity at the operations centre is not mentioned in the meeting minutes.
12:00	Operational emergency managemen t team	Status meeting	From the minutes of the meeting: "Østerdalen South NN response The Glomma River is rising.

Timing	Actor	Event	Comments
			Possible need to staff the Elverum power stations throughout the evening." "Focus: Ensure good risk assessments." [redacted]
15:00	Operations centre	[redacted]	[redacted]
15:30	Strategic emergency management team	Status meeting	From the minutes of the meeting: "The Glomma River: (...) 1500 at Elverum could be reached tonight. The flood peak could be at 2000." [redacted]
Approx. 16:45	Operations centre	[redacted]	[redacted]
Approx. 20:00	Operations centre	The operations centre contacts the maintenance manager and says that it is registering a bit of a "turbulent dam" at Braskereidfoss. The suggestion is to resolve this by opening the timber gate.	
20:50 - 22:50	Operations centre	[redacted]	[redacted]
Approx. 23:00-00:40	Operational staff	Evening shift operational staff arrive at Braskereidfoss at approx. 23:00. They observe high water levels and take several measures to regulate the water level.	Operational emergency management team/operations management team has organised a 'roaming watch' at the three Elverum stations: Strandfossen, Skjefstadfoss and Braskereidfoss. Two people (operational staff from maintenance) travel between the facilities to check on them and carry out necessary tasks, typically clearing gates.
Approx. 23:30	Operational staff	As agreed with the operations centre, the timber gate is opened 100%. Water level regulation (bottom hatch) is set to manual from the station prior to operation of the timber gate, from Auto (A) to Hand (H). A signal is sent to Floodgate 5 to slightly increase its aperture in order to compensate for fluctuations during opening. The timber gate was opened and was fully open (100%) at 23:29. The setpoint for HRWL adjusts downwards by 20 cm to 163.00. The water level drops slightly. To get the water level back up, they reduce Floodgate 5's aperture by one interval back down. The bottom gate is then put returned to Auto (A).	A - Auto = automatic H - Hand = manually, both from operations centre and locally at station

Timing	Actor	Event	Comments
00:00	Braskereidfoss	Gate statuses at around midnight: Floodgate 3 is in manual with an opening of 1.46 m. Floodgate 4 is in manual with an opening of 1.44 m. Floodgate 5 is in manual with an opening of 1.53 m. The bottom hatch is set to auto. The timber gate is open	
09/08/2023			
00:13	Operations centre	[redacted]	[redacted]
Approx. 00:40	Operational staff or	Operational staff are in contact with the operations centre by telephone. - They report that the timber gate is open and that the bottom gate has been returned to automatic. - They warn that an open timber gate can cause fluctuations before the level in the dam stabilises. - They report that they are moving on to Skjefstadfoss. They leave Braskereidfoss at approx. 00:40.	There is some uncertainty about what information was exchanged by telephone before operational staff left the station and what was understood. When the call ended, both operational staff and the operator at the operations centre were left certain that Braskereidfoss was under control. At the operations centre, one of the operators may have misunderstood the message from operational staff and thought that they were leaving people at the station.
Approx. 00:40 - 06:30	Braskereidfoss	During this period no one was on site at Braskereidfoss. The following is the situation when the evening shift leaving Braskereidfoss: - The timber gate is at full opening. - The bottom gate is in auto and reaches full opening at approx. 00:40 (approx. 270 m3/s) - Floodgates 3, 4 and 5 are in manual and all are at approx. 20% opening. The water level rises throughout the night.	No attempt is made to open the floodgates during this period of time.
00:01 - 02:04	Operations centre	[redacted]	[redacted]
Approx. 02:00	Braskereidfoss	The water level reaches 163.20 metres above sea level, which is defined as the highest regulated water level (HRWL).	
02:01 - 02:10	Operations centre	[redacted] [redacted]	[redacted] [redacted]

Timing	Actor	Event	Comments
02:04	Operations centre	[redacted]	[redacted]
02:10 - 02:18	Operations centre	[redacted]	[redacted]
Approx. 05:20	Braskereidfoss	The water level reaches 164.7 metres above sea level.	At this point, it overflows the measurement tank, and level measurements flatten out as the water level in the reservoir continues to rise.
Approx. 05:30	Braskereidfoss	The water level reaches 165 metres above sea level.	At about this point, the water is assumed to have overflowed the pillars of the gated dam and started to flow into the gatehouses where the floodgates' motors are located. The water also overflows the buttress dam and starts to penetrate the plants.
06:12	Operations centre	[redacted]	[redacted]
06:17	Operations centre	[redacted]	[redacted]
06:17	Braskereidfoss	Generator 1 goes to automatic stop at 'Pump tank level critically high'	After this point in time, it is assumed that the station had been flooded, and it is natural to assume that water had penetrated both the cabinets and the components belonging to the control systems and electrical components. Therefore, from this point onwards, the signals from the station are not considered reliable. The generator shutting down results in the loss of water diversion through the turbine and thus escalates the rise in the level of water in the dam.
06:18	Operations centre	[redacted]	[redacted]

Timing	Actor	Event	Comments
Approx. 06.30		Signals and measurement values are no longer reliable after the plant had been flooded. The timing will vary for the different types of measurements. 06:30 is an approximate time stamp.	This is assumed, based on the graphs and data history for this morning, to be the time when measurement values can no longer be assumed to be reliable. All notifications, error signals and measurement values after 06:17 must be considered unreliable because Braskereidfoss 1 was under water at this time. Braskereidfoss 2 was underwater at 06:40
06:30	Operations centre	[redacted]	[redacted]
06:40	Braskereidfoss	Generator 2 shuts down.	Disconnection after switch drop of 22kv. Probably due to electrical failure as a result of water penetrating the plant. Plant without voltage. The generator shutting down results in the loss of water diversion through the turbine and thus escalates the rise in the level of water in the dam. Total loss of approx. 470 m3/s as a result of the two turbines shutting down. The altitude at which the planet should be located was discussed during the design of BF2. The original plan was changed by raising the altitude of the plant by 0.5 metres compared with the original floor plan. It thus sits 50 cm higher up than plant 1 and this is why the power supply at plant 2 was interrupted sometime after BF1.
06:40	Braskereidfoss	Emergency generator starts 230 V supply.	
Approx. 06:45	Operational staff	Operational staff arrive at Braskereidfoss. The water overflows the dam and across the car park between Braskereidfoss 1 and Braskereidfoss 2. They go onto the dam and can see that the gatehouses for Floodgates 3, 4 and 5 are underwater. It is therefore irresponsible or impossible to enter the gatehouses to try to operate the floodgates locally. They report this up the line to the operating organisation. They blocked off the road on both sides of the river. They call the operations centre and ask them to open the floodgates. They have no access to the control room in the Braskereidfoss 2 building from which it is also possible to operate the floodgates. They therefore contact operational staff from Elvia and ask them to come to the site with keys.	Roof contour line of the gatehouses is at 163.03 metres above sea level.
06:52	Operations centre	[redacted]	[redacted]
06:56	Operational staff	Operational staff are advised that they cannot operate the floodgates from the operations centre.	

Timing	Actor	Event	Comments
07:04	Operations centre	[redacted]	[redacted]
07:02-07:11		[redacted]	The signal 'Water level measurement critically high' is sent to the operations centre at water level 161.00 and at 165.00, i.e. either 220 cm lower or 180 cm higher than HRWL (163.20). 165.00 corresponds to the level of the top of the pillars of the gated dam. This signal will thus not be sent until overtopping is actually happening and will not serve as a real warning to the operators at the operations centre. Operators at the operations centre understand that the 'Water level measurement critically high' signal should be triggered shortly after level 5, which for Braskereidfoss is set at 163.25.
07:16	Elvia	Operational staff from Eliva arrive at Braskereidfoss [redacted]	HEV and Elvia work together on supply and grid accessibility. [redacted]
07:18 - 07:36	Operational staff	Operational staff have gained access to Elvia's control room and are attempting to operate the floodgates from there. Floodgate 3 is started and operated towards opening from 1.77 metres with "long open signals", from opening of 1.77 metres to opening of approx. 2.20 metres. It stops at 07:36. A visual estimate, using the level of the roof of the gatehouse, estimates that Floodgate 3 has an opening of 2.20 metres.	There is a cable fire in the 22KV installation and smoke develops in the control room. Operational staff must at some point temporarily stop operating the gates and exit the control room to put on smoke diving equipment. Floodgate 3's opening is increased by approx. 40 cm in relation to the gate opening values on the control screen. The position measurement was estimated visually on site and was not based on measurements from position sensors since these had been submerged by this point in time.
09:05	Braskereidfoss	The supply from the 220V emergency generator fails.	[redacted] The building that houses the emergency generator has been penetrated by water. It can be seen that the water level has reached about halfway up the generator itself.
09/08/2023 – incidents and actions other the final attempt to open the floodgates (not part of the investigation)			
Morning - afternoon	HEV	Flooding of the entire Braskereidfoss facility continues throughout the day. In the morning, HEV contacts the emergency services, which help secure the area, evacuate residents (10-15 households), etc. The police suggest attempting to blow up the dam. The Norwegian Armed Forces arrive on site. The suggestion concerning blowing a hole in the dam is rejected. A decision is made to wait and see how the situation develops and allow the water to erode away the embankment dam.	Because the power plants have lost their power supply and the floodgates are locked in a partially open position, the overflow over the floodgates and the station area increases. The focus shifts to full preparedness and monitoring the status of the dam.
Approx. 16:30	Braskereidfoss	The embankment dam collapses as a result of overtopping. 1 The water level quickly drops and the rate of flow past Braskereidfoss normalises.	Reference is made to activity date 02/05/2018 Report "Braskereidfoss Dam - Reassessment 2016": "(…)The assessment, therefore, is that the dam will not withstand overtopping in the event of an accident situation."

5.6 Information flow in the operational control system

In connection with the investigation, DNV was given an event log from SCADA, a signal log from the local SCADA [redacted] and a command log covering the relevant period for the incident. These logs were viewed in relation to each other and relevant events compared and analysed. The lists have also been analysed against screenshots from Aveva PI.

Table 5 shows trigger limits for alarms and limit alerts of relevance to the incident.

SCADA uses the following signal categories:

- Level 0: Signals that should be recorded and reported on the first working day.
- Level 1: Signals that should be handled by the operations centre on its own initiative.
- Level 2: Signals that should be handled by the operations centre in consultation with on-call personnel.
- Level 3: Signals that should be handled by on-call personnel and that require immediate call-out/error correction.

The categories apply to each individual power station, but are not standardised throughout the company. Project managers, in collaboration with suppliers, are responsible for establishing data lists for parameters and notifications that should be included in SCADA during development or upgrades. In the event of significant changes, the operations centre should be informed of the changes made by the various parameters in the system.

Table 5 Overview of relevant signals, limit alerts and alarms

Element	Type	Triggering factor	Signal category	Colour	Acoustic alarm	Comments
GR3HIGH	Limit alert	Gate 2 rate of flow > 260 m3/s		White	Yes	
GR4HIGH	Limit alert	Gate 2 rate of flow > 265 m3/s		White	Yes	
GR5HIGH	Limit alert	Gate 2 rate of flow > 270 m3/s		White	Yes	
WATER LEVEL ABNORMAL	Signal	Water level ≥ 163.30	Level 1	Yellow	Yes	
GR3HIGH	Limit alert	Water level 1 ≥ 163.22		White	Yes	
GR4HIGH	Limit alert	Water level 1 ≥ 163.23		White	Yes	
GR5HIGH	Limit alert	Water level 1 > 163.25		White	Yes	
GR5HIGH	Limit alert	Water level 2 ≥ 163.27		White	Yes	
GR5HIGH	Limit alert	Water level 3 ≥ 163.28		White	Yes	
WATER LEVEL MEASUREMENT CRITICAL	Signal	Water level ≥ 165.00	-	-	Yes	Some uncertainty about the exact trigger value.
TURBINE REGULATOR Ind.2	Signal	Water level 3 ≥ 163.30	Level 2	Red	Yes	Some uncertainty about the exact trigger value.
GR3HIGH	Limit alert	Pump tank 1 > 1.05 m		White	Yes	
GR4HIGH	Limit alert	Pump tank 1 > 1.20 m		White	Yes	
GR5HIGH	Limit alert	Pump tank 1 > 1.22 m		White	Yes	
GR4HIGH	Limit alert	Pump tank 2 > 1.05 m		White	Yes	

GR5HIGH	Limit alert	Pump tank 2 > 1.33 m		White	Yes	
PUMP TANK LEVEL	Signal	Pump tank > 1.3 m	Level 2	Red	Yes	Some uncertainty about the exact trigger value.
PUMP TANK LEVEL CRITICALLY HIGH	Signal	Pump tank > 2 m	Level 2	Red	Yes	There is some uncertainty about the exact trigger value.

The screenshots from Aveva PI were compared with the alarm and event lists from SCADA [redacted] The signal log, event log and command log provide a comprehensive picture of which commands were sent from the operations centre that night and how the operational control system responded to the commands. The logs also contain operational notifications from automated processes at the power station, but are considered less relevant for gate control.

The signals sent to and from the power station up to Braskereid 1 shutting down at 06:17 are considered reliable. It is assumed that the power plant had been flooded and that water had penetrated control systems and electrical components after this, and the cause of certain alarms and whether they were caused by short circuits is not known with certainty. DNV used signal lists and alarm logs to understand the expected functionality of the operational control system. No position has been taken regarding the design of the individual alarm's function and relevance in relation to the outcome of the incident.

Table 6 provides a summary of the most relevant alarms, commands and limit values. The alarm texts are abbreviated, but informative for the operator. 'SETPREG' is, for example, an abbreviation for the setpoint control of gates. [**NB: The alarm texts in this translation have been translated where possible to make them easier to read and understand - please see the original Norwegian report for the original alarm texts in Norwegian.**] Comments on the table are provided in the subsequent sections.

Table 6 Excerpts of alarms, commands and limit values

No:	Date:	Time:	Description:				
1	08/08/2023	20:49:01	Braskere.2 GEN1	Active effect setp	Ordered value 5.50 MW	M	
2	08/08/2023	21:39:09	Braskereidf	Gate 5 rate of flow setp	Ordered value 250.00 m3/s	M	
3	08/08/2023	21:39:09	Braskereid FEL	SETPREG GATE 5	SIGNAL		
4	08/08/2023	21:39:49	Braskereid FEL	SETPREG GATE 5	*ONGOING		
5	08/08/2023	21:45:19	Braskereidf	Gate 4 RATE OF FLOW SETP	Ordered value 250.00 m3/s	M	
6	08/08/2023	21:45:19	Braskereid FEL	SETPREG GATE 4	SIGNAL		
7	08/08/2023	21:46:04	Braskereid WATER REG	WATER LEVEL ABNORMAL	SIGNAL		1
8	08/08/2023	21:46:05	Braskereid FEL	SETPREG GATE 4	*ONGOING		
9	08/08/2023	22:02:36	Braskereid WATER REG	WATER LEVEL ABNORMAL	Normal		
10	08/08/2023	22:38:05	Braskereidf	Gate 3 RATE OF FLOW SETP	Ordered value 250.00 m3/s	M	
11	08/08/2023	22:38:05	Braskereid FEL	SETPREG GATE 3	SIGNAL		
12	08/08/2023	23:38:44	Braskereid FEL	SETPREG GATE 3	*ONGOING		
13	08/08/2023	22:48:40	Braskereid WATER REG	WATER LEVEL ABNORMAL	SIGNAL		1
14	08/08/2023	22:48:41	Braskereid WATER REG	WATER LEVEL ABNORMAL	Normal		
15	08/08/2023	22:48:42	Braskereid WATER REG	WATER LEVEL ABNORMAL	SIGNAL		1
16	08/08/2023	22:55:21	Braskereid WATER REG	WATER LEVEL ABNORMAL	Normal		
17	08/08/2023	22:55:24	Braskereid FEL	SETPREG GATE 5	SIGNAL		
18	08/08/2023	22:55:24	Braskereidf	Gate 5 rate of flow setp	Ordered value 300.00 m3/s	M	
19	08/08/2023	22:56:10	Braskereid FEL	SETPREG GATE 5	*ONGOING		
20	08/08/2023	23:08:13	Braskereid GATE 2	WATER LEVEL REGULATION	OFF		
21	08/08/2023	23:08:14	Braskereid FEL	SETPREG GATE 2	*ONGOING		
22	08/08/2023	23:08:53	Braskereid WATER REG	WATER LEVEL ABNORMAL	SIGNAL		1
23	08/08/2023	23:14:15	Braskereid WATER	FLOODGATE 1	*CLOSED		
24	08/08/2023	23:29:22	Braskereid GATE 2	WATER LEVEL REGULATION	ON		
25	08/08/2023	23:29:22	Braskereid FEL	SETPREG GATE 2	SIGNAL		
		23:30:00	Timber gate fully opened				
26	08/08/2023	23:32:15	Braskereid GATE 2	WATER LEVEL REGULATION	OFF		
27	08/08/2023	23:32:16	Braskereid FEL	SETPREG GATE 2	*ONGOING		

28	08/08/2023	23:35:36	Braskereid GATE 2	WATER LEVEL REGULATION	ON			
29	08/08/2023	23:35:36	Braskereid FEL	SETPREG GATE 2	SIGNAL			
30	08/08/2023	23:55:58	Braskere.2 TB1	ELECTRONIC LIMIT	PRESENT			
31	08/08/2023	23:57:10	Braskere.2 TB1	ELECTRONIC LIMIT	*PRESENT			
32	08/08/2023	23:58:11	Braskere.2 TB1	ELECTRONIC LIMIT	PRESENT			
33	09/08/2023	00:01:44	Braskereid WATER REG	WATER LEVEL ABNORMAL	SIGNAL			1
34	09/08/2023	00:04:33	Braskere.2 TB1	ELECTRONIC LIMIT	*PRESENT			
35	09/08/2023	00:11:17	Braskereid WATER	Gate 2 rate of flow set	Upper warning check OFF			L
36	09/08/2023	00:13:22	Braskereid WATER	Gate 2 rate of flow	Alarm processing blocked ON			M
37	09/08/2023	00:13:22	Braskereid WATER	Gate 2 rate of flow	Blocking expiration time: 09/08/2023 07:00			M
38	09/08/2023	00:18:39	Braskere.2 TB1	ELECTRONIC LIMIT	PRESENT			
39	09/08/2023	00:19:30	Braskere.2 TB1	ELECTRONIC LIMIT	*PRESENT			
40	09/08/2023	00:20:53	Braskere.2 TB1	ELECTRONIC LIMIT	PRESENT			
41	09/08/2023	00:22:54	Braskere.2 TB1	ELECTRONIC LIMIT	*PRESENT			
42	09/08/2023	00:24:13	Braskere.2 TB1	ELECTRONIC LIMIT	PRESENT			
43	09/08/2023	00:24:13	Braskere.2 TB1	ELECTRONIC LIMIT	*PRESENT			
44	09/08/2023	00:27:23	Braskereid WATER REG	WATER LEVEL ABNORMAL	Normal			
		00:40:00	Staff leave the power station					
45	09/08/2023	00:45:19	Braskere.2 TB1	ELECTRONIC LIMIT	PRESENT			
46	09/08/2023	00:46:15	Braskere.2 TB1	ELECTRONIC LIMIT	*PRESENT			
47	09/08/2023	00:47:18	Braskere.2 TB1	ELECTRONIC LIMIT	PRESENT			
48	09/08/2023	00:51:25	Braskereid WATER REG	WATER LEVEL ABNORMAL	SIGNAL			1
49	09/08/2023	01:10:49	Braskere.2 TB1	ELECTRONIC LIMIT	*PRESENT			
50	09/08/2023	01:14:05	Braskere.2 TB1	ELECTRONIC LIMIT	PRESENT			
51	09/08/2023	01:32:21	Braskereid WATER REG	WATER LEVEL ABNORMAL	Normal			
52	09/08/2023	01:32:22	Braskereid WATER REG	WATER LEVEL ABNORMAL	SIGNAL			1
53	09/08/2023	01:32:23	Braskereid WATER REG	WATER LEVEL ABNORMAL	Normal			
54	09/08/2023	01:38:26	Braskere.2 TB1	ELECTRONIC LIMIT	*PRESENT			
55	09/08/2023	02:01:30	Braskereid WATER	Water level 1	Into the GR3HIGH zone	163.22 masl	value:	163.22
56	09/08/2023	02:02:38	Braskereid WATER	Water level 1	Into the GR4HIGH zone	163.23 masl	value:	163.23
57	09/08/2023	02:04:40	Braskereid WATER REG	WATER LEVEL ABNORMAL	SIGNAL			1
58	09/08/2023	02:06:08	Braskereid WATER	Water level 1	Into the GR5HIGH zone	163.25 masl	value:	163.25
59	09/08/2023	02:06:18	Braskereid WATER	Water level 2	Into the GR5HIGH zone	163.27 masl	value:	163.27
60	09/08/2023	02:06:51	Braskere.2 TB1	ELECTRONIC LIMIT	PRESENT			
61	09/08/2023	02:07:31	Braskere.2 TB1	ELECTRONIC LIMIT	*PRESENT			
62	09/08/2023	02:08:31	Braskere.2 TB1	ELECTRONIC LIMIT	PRESENT			
63	09/08/2023	02:09:37	Braskereid WATER	Water level 3	Into the GR5HIGH zone	163.28 masl	value:	163.28
64	09/08/2023	02:09:53	Braskere.2 TB1	ELECTRONIC LIMIT	*PRESENT			
65	09/08/2023	02:10:03	Braskere.1 TB1	TURBINE REGULATOR Ind.2	SIGNAL			2
66	09/08/2023	02:16:47	Braskere.1 TB1	TURBINE REGULATOR Ind.2	Normal			
67	09/08/2023	02:18:21	Braskere.1 TB1	TURBINE REGULATOR Ind.2	SIGNAL			2
68	09/08/2023	02:59:36	Braskere.1 B1FEL	PUMP TANK 2 Ind.1	OPERATION			
69	09/08/2023	03:07:46	Braskere.1 B1FEL	PUMP TANK 2 Ind.1	*OPERATION			
70	09/08/2023	06:11:22	Braskere.1 B1FEL	PUMP TANK 2 Ind.1	OPERATION			
71	09/08/2023	06:11:44	Braskere.1 B1FEL	Pump tank level 1	Into the GR3HIGH zone	1.05 m	value:	1.06
72	09/08/2023	06:11:48	Braskere.1 B1FEL	Pump tank level 2	Into the GR4HIGH zone	1.05 m	value:	1.05
73	09/08/2023	06:12:31	Braskere.1 B1FEL	PUMP TANK LEVEL	SIGNAL		2	
74	09/08/2023	06:12:31	Braskere.1 B1FEL	BILGE PUMP 1 Ind.1	OPERATION			

75	09/08/2023	06:12:32	Braskere.1 B1FEL	Pump tank level 1	Into the GR4HIGH zone	1.20 m	value:	1.20
76	09/08/2023	06:13:38	Braskere.1 B1FEL	Pump tank level 1	Into the GR5HIGH zone	1.33 m	value:	1.35
77	09/08/2023	06:13:38	Braskere.1 B1FEL	Pump tank level 2	Into the GR5HIGH zone	1.33 m	value:	1.34
78	09/08/2023	06:17:07	Braskere.1 B1FEL	PUMP TANK LEVEL CRITICALLY HIGH	SIGNAL			2
79	**09/08/2023**	**06:17:07**	**Braskere.1 GEN1**	**STOP RELAY**	**STOP**			
		06:18:00	The operations centre calls power station staff					
80	**09/08/2023**	**06:19:08**	**Braskere.1 GEN1**	**INTAKE GATE IND.2**	**CLOSED**			
81	**09/08/2023**	**06:23:56**	**Braskereid WATER**	**FLOODGATE 4**	**CLOSED**			

82	09/08/2023	06:23:59	Braskere.2 VAN	FLOODGATE 4 REMOTE CTRL	OFF	
83	09/08/2023	06:28:05	Braskereid WATER	FLOODGATE 5	CLOSED	
84	09/08/2023	06:32:26	Braskereid WATER	FLOODGATE 1	CLOSED	
85	09/08/2023	06:35:51	Braskere.2 VAN	FLOODGATE 5 REMOTE CTRL	OFF	
86	09/08/2023	06:42:06	Braskereid WATER	FLOODGATE 3	CLOSED	
87	09/08/2023	06:42:06	Braskereid WATER	BOTTOM GATE 2	CLOSED	
88	09.08 2023	06:42:20	Braskere 2 B2NG1 DIESEL GEN RUNNING		SIGNAL	2
89	09/08/2023	06:42:23	Braskere.2 GEN1 INTAKE GATE OPEN		OPEN	
90	09/08/2023	06:42:38	Braskere.2 GEN1 STOP RELAY		STOP	
		06:45:00	Staff arrive at the power station			
		06:51:00	Arriving staff call the operations centre			
91	09/08/2023	06:48:06	Braskere.2 GEN1 INTAKE GATE OPEN		*OPEN	
92	09/08/2023	06:51:51	Braskereidf	Gate 5 rate of flow setp	Ordered value 600.00 m3/s	M
93	09/08/2023	06:51:56	Braskereidf	Gate 4 RATE OF FLOW SETP	Ordered value 600.00 m3/s	M
94	09/08/2023	06:52:06	Braskereidf	Gate 3 RATE OF FLOW SETP	Ordered value 600.00 m3/s	M
95	09/08/2023	06:52:06	Braskereid FEL	SETPREG GATE 3	SIGNAL	
96	09/08/2023	06:52:10	Braskere 2 GEN1	INTAKE GATE CLOSED	CLOSED	
97	09/08/2023	06:54:40	Braskereidf	Gate 3 RATE OF FLOW SETP	Ordered value 400.00 m3/s	M
98	09/08/2023	06:55:06	Braskereid FEL	SETPREG GATE 3	*ONGOING	
99	09/08/2023	06:55:23	Braskereidf	Gate 4 RATE OF FLOW SETP	Ordered value 400.00 m3/s	M
100	09/08/2023	06:55:40	Braskereidf	Gate 4 RATE OF FLOW SETP	Ordered value 500.00 m3/s	M
101	09/08/2023	06:56:04	Braskereidf	Gate 3 RATE OF FLOW SETP	Ordered value 500.00 m3/s	M
102	09/08/2023	06:56:04	Braskereid FEL	SETPREG GATE 3	SIGNAL	
103	09/08/2023	06:57:39	Braskereidf	Gate 3 RATE OF FLOW SETP	Ordered value 400.00 m3/s	M
104	09/08/2023	06:59:04	Braskereid FEL	SETPREG GATE 3	*ONGOING	
105	09/08/2023	07:00:00	Braskereid WATER	Gate 2 rate of flow	Alarm processing blocked OFF	
106	09/08/2023	07:02:01	Braskereid WATER REG WATER LEVEL MEASUREMENT CRITICAL		SIGNAL	2
107	09/08/2023	07:04:30	Braskereidf	Gate 3 RATE OF FLOW SETP	Ordered value 500.00 m3/s	M
108	09/08/2023	07:04:30	Braskereid FEL	SETPREG GATE 3	SIGNAL	
109	09/08/2023	07:05:35	Braskereidf	Gate 3 RATE OF FLOW SETP	Ordered value 450.00 m3/s	M
110	09/08/2023	07:06:15	Braskereidf	Gate 3 RATE OF FLOW SETP	Ordered value 400.00 m3/s	M
111	09/08/2023	07:07:00	Braskereidf	Gate 5 rate of flow setp	Ordered value 550.00 m3/s	M
112	09/08/2023	07:11:58	Braskereid WATER REG WATER LEVEL MEASUREMENT CRITICAL		Normal	
113	09/08/2023	07:11:58	Braskereid WATER REG	WATER LEVEL MEASUREMENT CRITICAL	SIGNAL	2
114	09/08/2023	07:25:50	Braskere.2 22B2T1 E		OUT command	M
115	09/08/2023	07:25:59	Braskere.2 22B2T1 S		OUT command	M
116	09/08/2023	07:27:20	Braskere.2 22B2T1 S		OUT command	M
117	09/08/2023	07:38:19	Braskere.2 VAN FLOODGATE 3 REMOTE CTRL		OFF	

5.6.1. Command log from the operations centre

DNV was sent a command log describing, and giving the times for, all commands sent from the operations centre [redacted] The log runs from 06/08/2023 to 10/08/2023, but only the relevant period from 08/08/2023 to 09/08/2023 was systematically reviewed. [redacted]

[redacted]

At Braskereidfoss, Gate 5 and Gate 4 were operated on the evening of 08/08/2023 at 21:39 and 21:45, respectively. Later, Gate 3 and gate 5 were operated at 22:38 and 22:55. Just past midnight at 00:13, alarms are blocked for rate of flow limit values for Gate 2, ‘Alarm processing blocked on, Gate 2 rate of flow’. Limit alerts warning of the rate of flow through Gate 2 were then blocked until 07:00 the following morning. The signal log in Table 6 confirms that alarm processing for Gate 2 would be automatically reactivated at 07:00 on 09/08/2023. In the command log from the operations centre, the alarm blocker is the last recorded command for Braskereidfoss before the power station stops the following morning. It is assumed that the operations centre has not executed any commands and that the operational control system and communication lines have worked.

Figure 12: Screenshot of Gate 2 limit values

Alarm blocking the rate of flow in Gate 2 was an important action that was taken by the operations centre. The alarm log shows that there were almost 20 limit alerts regarding the rate of flow in Gate 2 just before about 00:13, when the alarm blocking occurs. At that time it is clear that the rate of flow is approaching maximum capacity.

5.6.2. The operations centre's signal and alarm logs

It is important to distinguish between signals and alarms sent from the power station, and limit alerts set locally at the operations centre. Limit alerts are always presented as white on the operator's alarm log at the operations centre. During the night, multiple 'B2 electronically limited' alarms were sent by the power station, which DNV is told is an alarm that signals that the Braskereidfoss 2 turbine is running at maximum capacity and that an automatic electronic limit has been activated to protect it from overloading.

Multiple 'Water level abnormal' alarms were sent in the evening and night before the incident. This is a level 1 alarm and is displayed in yellow on the alarm log of the operators at the operations centre. This alarm does not say whether the water level is abnormally high or low, but is intended to notify the operator that the water level is deviating from normal. Local SCADA uses the alarm text 'Stormwater level abnormal', while SCADA uses the alarm text 'Water level abnormal'. Water level abnormal is triggered when at least one of the three water level measurements is outside the set limits. This alarm was recorded in the operational control system four times during the night at 00:01, 00:51, 01:32 and 02:04. At 02:10 and 02:18 the alarm 'B1 Turbine regulator alert' was triggered. This alarm was sent twice by the power station, warning that the operational status was deviating from normal.

Just before Braskereidfoss 1 stopped in the morning at 06:12, there was an alarm from the power station that ‘Pump tank high level’, followed by ‘Pump tank level critically high’ at 06:17. At this point, it is assumed that the pump tank has been flooded.

From this point onwards, how the signals should be interpreted is somewhat uncertain since the power station is believed to have been flooded. It is assumed that the electrical components belonging to the operational control system have been exposed to water. It is also clear that a slew of alarms were triggered after Braskereidfoss 1 stopped, which is also to be expected when a live installation is exposed to water. These alarms have not been systematically reviewed, although we have nevertheless emphasised looking at the signals associated with the gates since these may be of relevance with respect to when the gates were no longer available for operation. DNV was also provided with a signal log from the local SCADA [redacted] confirming that there were staff at the power station. The signal log from local SCADA was compared with the SCADA event log to recognise concurrent events and which commands were executed from the operations centre or local control room.

5.6.3 Gate operations

DNV was also given access to selected screenshots from the course of events. Figures 13 and 14 show the gate positions during the period covered by the course of events, from 16:00 on 08/08/2023 to 09:00 on 09/08/2023.

Figure 13: Gate positions as a percentage for the period 08/08/2023 at 16:00 to 09/08/2023 at 10:00

Figure 14: Gate positions indicated in metres for the period 08/08/2023 at 16:00 to 09/08/2023 at 10:00

Timber gate, Gate 1: The timber gate is represented by the blue graph and was opened 100% at approx. 23:30. As the graph confirms, this gate remained constantly open throughout the night. As a consequence of the timber gate being opened, the event log shows that the situation at the dam was turbulent and that the bottom gate was regulating to reduce fluctuations in the water level.

Bottom gate, Gate 2: Regulation was set to Manual locally prior to opening the timber gate, and the operations centre is notified of this. It was put back to Auto once the timber gate was fully open. The effect of the regulation gate's maximum capacity of 270 m^3/s is regarded as limited in relation to regulating large volumes of water. Based on Aveva PI data, it is clear that the bottom gate reaches maximum volume between midnight and 01:00, and remains at maximum capacity throughout the night. As mentioned, locally there were three limit alerts regarding the bottom gate. These do not trigger any alarms at the operations centre, as limit alerts were blocked.

The floodgates, Gates 3, 4 and 5: Both of the graphs taken from Aveva PI and the command log show that Gates 4 and 5 setpoint were regulated and ordered to 250m^3/s just before 22:00 on the evening of 08/08/2023. Gate 4 can be seen on the green graph, while Gate 5 can be seen on the red graph. Just before 23:00, Gate 3 was also ordered to 250m^3/s, which can be seen on the purple graph in the screenshot from Aveva PI. At 22:55, Gate 5 was again ordered to an opening equivalent to 300m^3/s. After this point in time and until the morning, no attempts were made to regulate the floodgates (or the bottom gate).

If one moves forward to the morning of 09/08/2023, there were signals in the alarm list indicating that the gates are closed and 'Remote control of signal OFF'. As early as 06:23, there was a signal that Gate 4 was closed, at 06:28 there was a signal that Gate 5 was closed and at 06:42 there was a closed signal on the last floodgate, Gate 3. At the stated times, there were on site observers who could see that this was not true and that the gates were not closed. It must therefore be assumed that this is when the monitoring and operational control system were lost, as the screenshot from Aveva PI may also indicate. It is impossible to determine from data logs and graphs obtained from the operational control system whether the gates were operated after this.

The floodgates can be remotely controlled from the operations centre, locally controlled from the control room and locally controlled from the gatehouses themselves. All three locations have a switch that enables you to manually change the control mode from remote control to local control. The operational control system received signals that remote control was switched off at 06:23 for Gate 4 and 06:35 for Gate 5. It is therefore reasonable to assume that it was not possible to operate these gates remotely from the operations centre after this.

Gate 3, on the other hand, did not send a remote signal control until 07:38. From the alarm logs, it is clear that attempts were made to send commands to all floodgates from 06:51 until remote control of Gate 3 was lost. Subsequent visual observations show that the signals sent to Gate 3 during this time did actually increase the aperture in Gate 3.

5.6.4 Evaluation of information flow in the operational control system

After a systematic review of the alarm lists, command and event logs, it is clear that the course of events corresponds with the timeline, observations and the conducted interviews. It is also possible to show that the operations centre received alarms and alerts from the power station throughout the night to which it was unable to respond. Limit alerts for water level high and water level abnormal were also overlooked. The alarm blocking for water level Gate 2 at 00:13 meant that limit alerts did not reach the Operations Operator. The last recorded gate operation was carried out at 22:55 on Tuesday, 08/08/2023, and an attempt was made to operate them again at 06:51 on Wednesday, 09/08/2023. There are no indications that attempts were made to operate the gates between these two times. All of the indications are that the system functioned normally, and initiating further technical investigations is not considered necessary.

6. ROOT CAUSE ANALYSIS

6.1 Immediate causes

Immediate causes describe the direct causes of the incident, such as technical errors or deficiencies, or operational errors or inactions.

6.1.1. Lack of attention to the danger from rising stormwater levels

The immediate cause of the floodgates at Braskereidfoss not being opened when the water level rose was a lack of awareness of the danger from the rising level of surface water. Braskereidfoss Power Station is not manned and is normally monitored and controlled from the operations centre in Lillehammer. Several alarms were triggered during the night warning that the water level was rising, but the operators at the operations centre were not aware of these alarms.

Nor were there any operational staff present at Braskereidfoss on the night who could have observed the rising water level and activated the floodgates locally. Thus, no one was aware of the situation that was developing, where the water level was rising and eventually overflowed the dam. Therefore, no one attempted to activate the floodgates between approx. 00:40 and 06:30.

It has been concluded that the event was not caused by any faults or failures in technical systems.

6.2 Basic causes

The basic causes may explain the lack of attention to the fact that the water level exceeded the HRWL and that no attempt was made to activate the floodgates. No single cause of the incident can be pointed to. There were several basic reasons for why the situation was not noticed. These can be attributed to human, technical and organisational factors, and not least the interplay between these. The basic causes that have been identified are described in the following section.

6.2.1. Vulnerability in the barrier function 'open floodgates'

In the event of a high rate of flow or damaging flooding, there is only one barrier at Braskereidfoss to prevent flooding. That barrier is the floodgates. The barrier function can be referred to as 'open floodgates'. This function relies on technical, organisational and operational barrier elements.

Examples of the technical barrier elements for floodgates are: power supply, electric motors/driving gear, PLS, water level meter, SCADA, etc.

An important organisational barrier element is having sufficient operators working at the operations centre and these having the necessary expertise and training.

As far as operational barrier elements are concerned, these will be ensuring that the operator at the operations centre, or person on site at the station, performs an action that activates the gates. Braskereidfoss is normally unmanned, which was also the case on the night of 09/08/2023, from approx. 00:40.

The facility is not fitted with any form of automatic emergency regulator that steps in if no operational action is taken and triggers the floodgates at high water levels.

In order for the barrier function ‘open floodgates’ to work, they were reliant on one single operational barrier element: the operator at the operations centre who activates the floodgates. Since this operational barrier element was not performed on the night of the flood, there were no other barrier elements that could activate the barrier function, either technical or operational.

An automatic emergency regulator would have been a technical barrier element that could have triggered the barrier function ‘open floodgates’ at a specified water level if the operational barrier element did not work.

In this context, it does not matter whether the operator has several different options for monitoring the water level and several types of alerts (limit values and cameras). Nor, in this context, does it matter whether the floodgates are equipped with back-up solutions if normal power supply is interrupted (alternative power network, emergency generator, etc.).

Until around 2004/2005, there was an on-call system for Braskereidfoss (and other facilities), where at home duty officers were notified on pagers, and later mobile phones, when alarms went off at the facility. The operations centre was not staffed round the clock at this time. Without making comparisons with the current system, it may have been a strength to ensure that information was sent directly to staff who could handle the situation in the field, without the information first having to be received and processed by the operator at the operations centre.

6.2.2 Vulnerabilities at the operations centre

[redacted]

[redacted]

The operations centre is part of the operational emergency management team in Hafslund Eco Vannkraft's Emergency Preparedness Plan (section 3.3.2). However, there are no emergency preparedness instructions for the operations centre that specify how it should organise itself or what types of notifications, alerts, signals, etc. should be prioritised in an emergency situation.

[redacted]

The operations centre is included in emergency preparedness exercises carried out at the facilities. However, no emergency response exercises specifically targeted at the operations centre are conducted where training is carried out based on scenarios involving more serious incidents at multiple facilities and where operators are challenged by more demanding situations. There are no exercises that test parallel crisis management for multiple facilities, which is what happens in relation to the operations centre when extreme weather events are ongoing. In these circumstances, multiple facilities experience heavy loads at the same time, where the prioritisation and criticality assessments of which facilities to prioritise can be a challenge for the operator.

[redacted]

There is also a historical perspective on the vulnerability of the operations centre.

The operations centre was established in 1991, when [redacted] facilities started to be managed from the operations centre. Today, the number of facilities operated from the operations centre has increased to [redacted]. However, it is still [redacted] that must operate all facilities or dams. As the facilities were built at different times, their technology and monitoring capabilities differ greatly. The facilities have varying degrees of standardisation, which ultimately increases the demands on operators. In the interviews, each facility was described as having its own ‘personality’ and it was said that they must be operated based on individual factors.

Although it is not possible to simply compare the work situation at the operations centre in 1991 with today's situation, the increase in the number of facilities may nevertheless have increased vulnerabilities at the operations centre and contributed to its inability to handle the incident as expected. [redacted] facilities, although during Storm Hans it turned out that the number of facilities was too large to manage, even by [redacted]. This is dealt with further in the next section.

6.2.3 Extraordinarily large workload at the operations centre

The operations centre’s workload was extraordinarily high during Storm Hans, including on the night of 09/08/2023. While the Glomma River has experienced higher rates of flow on previous occasions, when these are viewed in isolation, the total geographical river drainage basin and the rapid development and impact of the extreme weather event were significantly greater than what those involved had experienced previously.

The operators at the operations centre were in telephone contact with operational staff on site at Braskereidfoss at around midnight. Given that the water level was rising, it was agreed to open the timber gate. The bottom gate was also set to manual before the timber gate was opened manually. As intended, this resulted in the water level dropping. The bottom gate was then set back to automatic before the operational staff left Braskereidfoss to continue on to Skjefstadfoss. At that time, the water level had been regulated such that it was somewhat lower, and both the operational staff and operators have said that they perceived Braskereidfoss to be “under control” at that time.

During the night, several critical situations on other watercourses and dams were managed from the operations centre and these took up a lot of the operators’ attention. There were especially some situations at [redacted] that took a lot of time and attention. The number of system notifications, alarms, telephone calls and commands was significantly higher than in normal situations, and also when compared with previous emergency situations, which had been concentrated in smaller areas. Figure 15 shows the number of stations with alarms per hour from 02/08/2023 to 10/08/2023.

[redacted]

On the night of the incident, the number of facilities sending alarms was generally between 10 and 15 per hour; significantly more than in normal situations.

In the period between 02:00 and 02:18, there were several warnings at the operations centre about rising water levels at Braskereidfoss. There were three limit alerts that the HRWL had been exceeded and two alerts about the turbine regulator, ref. Table 5. However, none of these alerts were caught and acted upon by the operators, as one would expect in a normal situation.

The operations centre is equipped with audiovisual alarms (acoustic signals and blinking lights on the ceiling) which are triggered by alarm notifications. In a normal situation, where the number of alarms is low, these should draw the attention of the operator to events that need to be handled. Figure 16 shows the number of alarms per hour from 02/08/2023 to 10/08/2023.

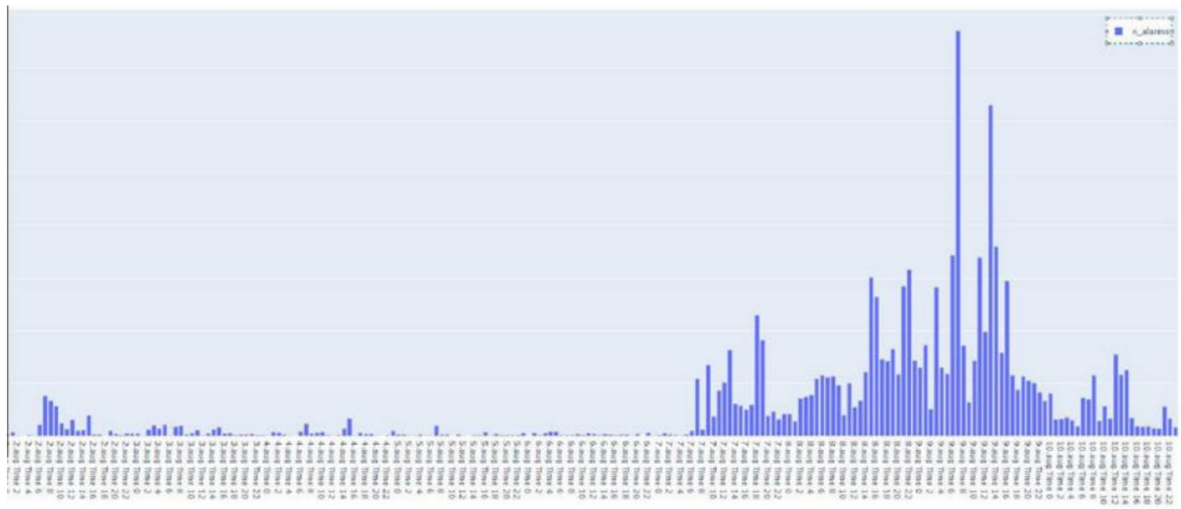


Figure 16: Number of acoustic alarms at the operations centre from 02/08/2023 to 10/08/2023 (total limit alerts and alarms/signals, minus blocked alarms)

From 00:00 to 06:00, the total was closer [redacted] alarms at the operations centre. Between 02:00 and 03:00 there were around [redacted] alarms in the operations centre. It must be assumed that this created a very high level of stress and that it was difficult to get an overview of and act on all alarms.

In the 30-minute period from 02:00-02:30, seven telephone calls to/from the operations centre were registered, with a total duration of approx. 17 minutes. It is natural to assume that the telephone calls took attention away from the limit alerts and alarms.

The assessment is that the situational picture for the operators was unclear on the night of 09/08/2023 and that it was difficult to gain an overview of incoming information and act on all relevant alarms. The operators described the experience as chaotic, with a stream of incoming notifications and more or less continuous alarms.

The incident 'Forecasted storms' was covered in the RVA for the operations centre (Risk 10), which asked the question "What if we have not taken preventive measures before a forecasted storm?" Under the heading 'Comments on consequences', it says that "One can get caught up in operational management and realise too late that one has to mobilise more broadly. We can fall behind in dealing with a situation, and it may take longer than necessary before we get a situation under control. Things can develop into something more serious than necessary." Reports from the operators indicate that this is how the situation at the operations centre developed on the night of the incident.

6.2.4. Work-related fatigue among operators at the operations centre

The Civil Aviation Authority Norway provides a good definition of fatigue. It defines fatigue as:

"A physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload that can impair a crew member's alertness and ability to safely operate an aircraft or perform safety-related duties." /7/

While this definition is aimed at aviation, it is applicable to other types of operational personnel, such as the operators of the operations centre.

[redacted]

As demonstrated in the previous section, the workload at the operations centre was abnormally high on both 08/08/2023 and 09/08/2023. In combination with long shifts and little sleep, it is assumed that the operators experienced a degree of physical fatigue and reduced mental capacity, which in turn can lead to a higher risk of miscalculations and mistakes. More or less continuous audiovisual alarms may have had a counterproductive effect and acted as an additional stress factor for operators.

The incident 'Not fit for work' has been dealt with in the RVA for the operations centre (Risk 11). The comments on probability/status states that "The operations centre has good collegiality and a high threshold when it comes to throwing in the towel due to illness. You know that another colleague will have to take the shift if you can't turn up. We've probably had cases where you're in the grey area in terms of whether you're fit to be at work." In the comments on consequences, it states that there is a "Greater chance of misjudgements, incorrect operation, etc." Reports from the operators indicate that these are the circumstances that prevailed on the night of the incident.

The current shift system has not been imposed by the employer, rather it was promoted by employees. In 2008, an agreement was signed between the trade unions, whereby the system, which includes 16.25 hour shifts, was accepted pursuant to the Working Environment Act. The agreement states that one of the conditions for entering into the agreement was that "The workload on the longest of shifts will be compensated for by opportunities to rest. Night work (00:00-06:00) is assumed to be passive in nature. The workload over time must be assessed on an ongoing basis with regard to adverse physical or mental effects."

Night shifts have been described as normally calm. However, the nights of both 08/08/2023 and 09/08/2023 were very hectic for the operators. Especially for the operator who was on duty for 16 hours both nights, but also for the operator who was on duty for 16 hours on the night of the incident alone, it is assumed that the workload and stress levels contributed to mental and physical fatigue that adversely affected performance.

6.2.5 Vulnerabilities in the operational control system's user interface at the operations centre

Ideally, the user interface at the operations centre should be designed to provide operators with a good overview of the situation and control of the power stations at all times. Such continuous monitoring also makes it possible to handle incidents in an emergency situation. [redacted]

A large amount of information is communicated from the operational control system to the operations centre, and as mentioned earlier, the degree of standardisation between the [redacted] facilities varies. This is due to both the different designs and ages of the facilities. [redacted] This results in, according to descriptions from operators in Lillehammer, a manageable amount of information. In normal operation, a best practice approach is taken to monitoring and managing the information flow.

In emergency situations such as Storm Hans, the amount of information can be perceived as overwhelming by the operators. Figures 15 and 16 show this increased activity. Reference is made to section 6.2.3 Extraordinarily heavy workload at the operations centre. How the information on the screen is managed and prioritised at any given time depends to some extent on individual practices. Here, continuous alarms that remain on during a shift change in an emergency situation can be perceived as stressful and highly exhausting.

Specific aspects of the user interface for Braskereidfoss may also have affected the situational awareness. [redacted] Limited options for filtering incoming signals in the form of signal prioritisation based on criticality were reported. The various facilities send alerts based on the setup of their alarm signals, [redacted]

Several of the dams have the 'Water level high' alert set as an indication that the situation at a facility must be assessed. For Braskereidfoss, the text of this alert was changed from 'Water level high' (removed 03/04/2017) to 'Water level abnormal' (added 04/04/2017) after the upgrade in 2017. No justification has been found for this change and we were unable to confirm whether it had been communicated to operators. This abnormal state alert indicates whether the water level in the dam is within the normal range as it is defined. If a 'Water level abnormal' alert is notified, it indicates that the signal is outside this interval, although it does not distinguish between water level low or water level high. The alert is combined as 'Water level abnormal'.

Prior to the upgrade, there was also a 'Critically high water level' signal, which was displayed as a red signal at the operations centre. This was described as being absent to begin with at an early stage of the investigation in interviews. Furthermore, it was found that the alert in the event of 'Water level critical' is first sent at 165 metres above sea level, i.e. at the same level as the top of the pillars and gatehouses, and thereby does not function as an effective warning to the operations centre.

Table 7 shows when 'Water level abnormal' was triggered on the night of 09/08/2023. It is assumed that using the historical forecast of 'Water level high' would have provided a clearer indication of the development of the water level at Braskereidfoss during this period. 'Water level abnormal' can result in waves or other swells. It does not provide information on whether the abnormal water level is high or low.

Table 7 Examples of 'Water level abnormal' alerts

09/08/2023 00:01:44	BRASKEREIDFOSS	Braskereid WATER REG	WATER LEVEL ABNORMAL	SIGNAL	1
09/08/2023 00:27:23	BRASKEREIDFOSS	Braskereid WATER REG	WATER LEVEL ABNORMAL	Normal	
09/08/2023 00:51:25	BRASKEREIDFOSS	Braskereid WATER REG	WATER LEVEL ABNORMAL	SIGNAL	1
09/08/2023 01:32:21	BRASKEREIDFOSS	Braskereid WATER REG	WATER LEVEL ABNORMAL	Normal	
09/08/2023 01:32:22	BRASKEREIDFOSS	Braskereid WATER REG	WATER LEVEL ABNORMAL	SIGNAL	1
09/08/2023 01:32:23	BRASKEREIDFOSS	Braskereid WATER REG	WATER LEVEL ABNORMAL	Normal	
09/08/2023 02:04:40	BRASKEREIDFOSS	Braskereid WATER REG	WATER LEVEL ABNORMAL	SIGNAL	1
09/08/2023 07:09:02	BRASKEREIDFOSS	Braskereid WATER REG	WATER LEVEL ABNORMAL	Normal	

A limited number of dams can be viewed on the screen at the same time. Here, the normal practice is to prioritise a selection of power stations that are regarded as needing visual monitoring the most, based on past experience of what needs monitoring the most. Braskereidfoss was not included in the group of power stations that are monitored continuously.

[redacted]

[redacted] Other parameters such as location, range and clarity also are mentioned as factors that affect the quality of video surveillance.[redacted]

The limit values for water level are divided into five levels, although only the top three of these levels are defined as limit values and result in limit alerts in SCADA: GR3HIGH, GR4HIGH and GR5HIGH are set at 163.22, 163.23 and 163.25, respectively. These appear as white notifications on SCADA's user interface screens. The limit alerts activate the acoustic signal after 30 seconds.

6.2.6 Inadequate risk and situational awareness in relation to extreme weather events

Storm Hans was a predicted event for Region Innlandet, with heavy precipitation forecast. Hafslund Eco Vannkraft took steps to prepare for the event. On 07/08/2023, a decision was made to trigger 'elevated preparedness' at 10:00. Both the strategic emergency management team and operational emergency management team for Innlandet held two daily emergency preparedness meetings that included reviews of the situations in areas/at dams.

The emergency preparedness plan for Braskereidfoss in the event of damaging flooding states that "For a rate of flow of 1800 m3/s, the dam (/power station) must be manned unless otherwise specifically agreed with the emergency management team. Establish communication with the emergency management team. Damaging flooding can occur with rates of flow above 2500m^3."

The forecast was for below this level, although it was estimated that the rate of flow could reach as high as 2000 m^3/s on 09/08/2023. The assessment was that the expected rate of flow of up to 2000 m^3/s was considered well within the limits of what could be handled. This was based on experience from previous situations with similar and larger rates of flow and Braskereidfoss's diversion capacity of around 3500 plus around 450 in total from the two turbines. An expected rate of flow at this level is rare but not abnormal.

Meeting minutes from the emergency meetings on 08/08/2023 state that: "The Glomma River: (...) 1500 m^3/s at Elverum will be reached at night. The flood peak could be at 2000." and "The Glomma River is rising. Possible need to staff the Elverum power stations throughout the evening (…). Focus: Ensure good risk assessments."

A mobile on-call watch (also called a 'roaming watch') was organised for the three Elverum stations on the evening of 08/08/2023. This meant that operational staff were at Braskereidfoss around midnight, before moving on to the next plant. A permanent watch at Braskereidfoss was not considered necessary. Naturally, the staffing situation was also taken into account. The operating organisation has limited staff and at the same time as the staff were expected to see a heavy workload in the next few days. When the operational staff left Braskereidfoss and moved on to Skjefstadfoss at around 00:40, the rate of flow was around 1600 m^3/s and rising. This is shown in the figure below.

Figure 17: Rate of flow in the Glomma River near Elverum 07/08/2023 to 09/08/2023 (Source: NVE, Sildre)

The assessment and decisions regarding night staffing at Braskereidfoss seemed sensible at the time they were made. However, one assumption on which this was based is that the operations centre was functioning as expected and had the capacity to monitor the situation, and would react quickly and call out the staff again if the need arose. Generally, it appears that the focus was not on the operations centre in the emergency preparations. No discussion or decisions regarding operator capacity at the operations centre were logged in meeting minutes on either 07/08/2023 or 08/08/2923. It appears that there may have been an underlying perception that the operations centre had the necessary capacity and could follow up all facilities in a flood situation.

The incident 'Forecasted storms' was covered in the RVA for the operations centre (Risk 10), which asked the question "What if we have not taken preventive measures before a forecasted storm?" The existing barriers mentioned are: Forecasts, Training Plan (including emergency preparedness exercises), Emergency Preparedness Plan and Procedures. A comment on the risks states: "Uncertainty about the weather. If it is much worse than reported."

Seen in isolation, it can be assumed that the situation and rate of flow at Braskereidfoss could and should have been handled relatively problem-free. However, in retrospect, it is clear that the overall scope and consequences of the extreme weather were underestimated.

6.2.7 Technical vulnerabilities in the design of Braskereidfoss

It has been concluded that the dam failure at Braskereidfoss was not due to faulty floodgates.

However, several vulnerabilities have been identified in the design of the Braskereidfoss facility. Several of these were pointed out in the Dam Safety Project in 1992, along with recommendations on risk mitigation measures. These vulnerabilities did not contribute to the floodgates not being opened as normal as the water level rose on the night of 09/08/2023. However, had these factors been remedied in line with the recommendations, it cannot be ruled out that the extent of the damage might have been limited.

Reference is made to Appendix A *Braskereidfoss Power Station: Investigation – system failure and dam failure* (Multiconsult) for a more detailed description of technical vulnerabilities.

In connection with Project Dam Safety and assessment of the functional safety of floodgates, a report was prepared in 1992 in which the gates at Braskereidfoss were used as an example. This report addressed various factors that could have a bearing on manoeuvring safety and conducted analyses surrounding manoeuvring safety. The report was produced by Nybro-Bjerck AS on behalf of the Norwegian Water Resources and Energy Directorate (NVE) and the Water System Management Association (VR)

The conclusion at that time was that the overall functional safety of the gates at Braskereidfoss was good.

No significant technical changes have been made to the design or function of the floodgates since this report, including in terms of equipment for manoeuvring the gates.

Various critical situations were considered, and Chapter 6.1(d) and (e) looks at a situation where some of the floodgates do not open: d) Only the bottom gate and sector gate open, and e) No gates open.

In the case of situation d), where none of the three floodgates open, it was pointed out that the water level would rise rapidly and overtop the buttress dam (top contour line 165) in a relatively short space of time. This would in turn result in water penetrating the power station, with the subsequent generator shutdown.

In the event of a flood reaching contour line 164.4, water would flow in and over the float pipe for measuring water levels in the gatehouse on the western pillar, Gate 5. The gatehouses have limited drainage and there is a high probability that this gate will be put out of operation due to water flowing over electric motors and position sensors.

The measuring tube in the pillar for Gate 5 is the same one as in 1992, and this machine room will be flooded at water level contour line 164.4. Thus, this floodgate is will most likely be put out of action. This situation has not been remedied since then. However, a water level of contour line 164.4 is a significant rise in flooding, equivalent to 1.2 metres above the HRWL.

So will the machine rooms for Gates 4 and 3 as the pillars will be topped at water level contour line 165.0. Water will then flow into the machine rooms through the personnel access hatches at the top. This can also happen at a lower water level than contour line 165 if the floodgates are left with an opening of 1.5-2 metres and at the same time the gate shields are overtopped. In these circumstances, build up in front of the gates may cause water to flow into the pillars at an even lower water level than contour line 165.

The report pointed out that independent emergency raising mechanisms, that can open the gates independently of the current raising system, have not been installed on the gates.

Braskereidfoss Power Station is equipped with its own permanently installed 800 kVA emergency generator, which automatically starts in the event of a power outage or other interruption to the facility’s power supply The emergency generator is physically located in a separate room adjacent to the power plant building for the new Braskereidfoss power plant generator 2 from 2016.

The generator feeds the 230 V busbar at Braskereidfoss 2, via switchgear and over to the busbar for Braskereidfoss 1. This continues via the cable arrangement under the bridge out to the floodgates on the dam.

In addition, there is a 110 V battery system with a 5 kVA inverter that can feed into the supply for the gates. The battery capacity is stated to be 350 Ah, but it is uncertain how far this capacity will go when it comes to being able to raise the gates.

The generator has been installed on the floor at contour line 161.0. When the water overflowed the buttress dam (contour line 165.0) and eventually penetrated the power station, the generator room was also partially filled with water.

6.3 Assessment of other possible contributing causes

In addition to the causes described in the preceding section, an assessment was made of whether other causes may have contributed to the floodgates not being opened.

6.3.1 Technical failure of floodgates or operational control system

An assessment has been made of whether the reason why the floodgates were not opened was due to faults or failures in technical systems.

There is nothing to indicate a technical failure in the floodgates or in the operational control system. The information and documentation available indicate that they worked until the facility was flooded. The floodgates had been maintained and tested in accordance with the plans and supervision procedures. All communication between Braskereidfoss and the operations centre through SCADA had functioned as normal.

This is a unanimous assessment by Hafslund Eco Vannkraft, DNV and Multiconsult.

6.3.2 Incorrect operation of floodgates

The gates are controlled manually from the operations centre (remotely) or the power station (locally) when manual control (H) has been determined to be best for Braskereidfoss. Manual control is intended to prevent the same degree of wear and tear on equipment that automatic control could have caused in the event of frequent regulation. The gates are currently not connected in parallel, meaning that they are opened in stages in series in order to avoid the differences in gate openings being too large.

The gates were subjected to both local and remote control in the 12 hours prior to the incident. No indications were found that the gates were operated incorrectly.

6.3.3 Lack of expertise or experience

Most of the on-duty operators at the operations centre and operational staff in the field on night shifts have done their jobs for a long time. They are well acquainted with best practice for the scope of work for which they are responsible. From a technical perspective, they appear to have a full overview of the systems and control mechanisms installed at Braskereidfoss. However, no more in-depth assessment has been made of the expertise of the staff at the operations centre.

No indications were found that a lack of expertise or experience with the operational control system or floodgates contributed to the incident.

The factors related to inadequate emergency preparedness incident training and exercises are described in Chapter 6.2.2.

6.3.4 Inadequate, incorrect or late reaction when the incident was discovered

The frequency of alerts and alarms was very high in the last six hours before the power station was flooded. The operators pointed out that the incident could have been avoided had they responded to, and acted on, earlier alarms. This factor has already been identified as a cause.

By the operations centre clock, the incident was detected by operators due to a critically high pump tank level signal at 06:17. They contacted operational staff at 06:18 and asked them to go to Braskereidfoss. In the meantime, attempts were being made to open the gates from the operations centre. Operational staff arrived at Braskereidfoss at approx. 06:45. They saw that the gatehouses were flooded and inaccessible. Opening the gates from the gatehouses was therefore impossible. The control room was not accessible due to the development of fire and smoke. [redacted] Braskereidfoss 2 has a computer connected to common local control that can be used to control the floodgates. However, operational staff did not have access to this control room and therefore contacted personnel from [redacted] who arrived with keys at approx. 07:16. Attempts were then made to open the gates from the control room locally. Attempts were made to operate the gates until 07:36, when they ceased responding.

A review of the timeline and actions taken suggest that the incident could not have been avoided at the time it was discovered.

7 CONCLUSION/SUMMARY

DNV's investigation identified immediate and basic causes behind why the floodgates at Braskereidfoss Dam were not opened as the rate of flow in the Glomma River was increasing during the night of Wednesday, 09/08/2023 and eventually resulted in the overtopping of the dam.

The immediate cause of the floodgates at Braskereidfoss not being opened when the water level rose was a lack of awareness of the danger from the rising level of surface water. Braskereidfoss Power Station is not manned, and is normally monitored and controlled from the operations centre in Lillehammer. Several alarms were triggered during the night warning that the water level was rising, but the operators at the operations centre were not aware of these alarms.

Nor were there any operational staff present at Braskereidfoss on the night who could have observed the rising water level and activated the floodgates locally.

It has been concluded that the incident was not caused by any faults or failures in technical systems.

There were several basic reasons why the situation was not noticed. These can be attributed to human, technical and organisational factors, and not least the interplay between these.

The basic causes that have been identified are (summarised in short form):

- **Vulnerabilities in the barrier function 'open floodgates':** Only one barrier function can prevent Braskereidfoss being overflowed in the event of a high rate of flow: 'open floodgates'. This barrier function in turn relies on a single operational barrier element, which is the 'operator operations centre' who has to activate the gates. No automatic emergency regulation, or other mechanisms, are in place that step in if no action is taken by the operational barrier element for some reason or other.
- **Vulnerabilities at the operations centre:** [redacted]
- **Extraordinarily heavy workload at the operations centre:** [redacted]
- **Work-related *fatigue* among operators at the operations centre:** [redacted]
- **Weaknesses in the operational control system's user interface at the operations centre:** [redacted]

- **<u>Inadequate risk and situational awareness in relation to extreme weather events:</u>** In the emergency preparations, the assessment was that Braskereidfoss did not require permanent staffing during the night, although operational staff were on site and checked the facility at around midnight before they moved on. One assumption on which this assessment was based is that the operations centre was functioning as expected and had the capacity to monitor the situation and would react quickly and call out staff as needed. On the night of 09/08/2023, this did not happen. The overall effects of the extreme weather event were thus underestimated.

- **<u>Technical vulnerabilities in the design of Braskereidfoss:</u>** A number of vulnerabilities have been identified in the design of the Braskereidfoss facility. Several of these were pointed out in the Dam Safety Project in 1992, which included recommendations on risk mitigation measures. Some of these vulnerabilities have been rectified since 1992, others have not. These weaknesses did not contribute to the floodgates not being opened as normal as the water level rose on the night of 09/08/2023. However, had these factors been remedied in line with the recommendations from 1992, it cannot be ruled out that the extent of the damage might have been limited. The main vulnerabilities that that have been identified are:
    - In situations where none of the three floodgates open, the water level will rise rapidly and overtop the buttress dam in a relatively short period of time. This would in turn result in water penetrating the power station, with the subsequent generator shutdown.
    - The gatehouses are vulnerable to water penetration in the event of flooding, both via the float pipe for measuring water levels and directly through man hatches. The drainage capacity of the gatehouses is limited. In the event of water penetration, the motors that operate gates can be put out of service, as happened on 09/08/2023.
    - Independent emergency raising mechanisms, that can open the gates independently of the current raising system, have not been installed on the gates.
    - Braskereidfoss Power Station is equipped with its own permanently installed emergency generator. The generator has been installed on the floor, 4 metres below the top of the buttress dam. When the water overflowed the buttress dam and eventually penetrated the power station, the generator room was also partially filled with water and the generator put out of service.

An assessment was conducted of whether other factors may have contributed to the incident, including technical failures in floodgates or operational control systems, incorrect operation of the floodgates, lack of expertise or experience, or inadequate, incorrect or late reaction when the incident was detected. Beyond what has been described, none of these factors were found to have contributed to the floodgates not being opened.

When the basic causes are viewed in context, it is possible to understand how the incident could occur. In this context, talk about ‘human error’ or ‘mistakes’ is not relevant, rather the overall system was not robust enough to deal with a scenario such as Storm Hans. The inaction that resulted in the floodgates not being opened must be viewed as a consequence of vulnerabilities in the system, and not as a cause of the incident.

All in all, Hafslund Eco Vannkraft was not prepared for the overall impact of the extreme weather event Storm Hans.

The investigation identified weaknesses in relation to human, technical and organisational factors that ought to be reviewed and improved in order to prevent similar incidents happening again.

8 RECOMMENDATIONS

A set of recommendations has been developed based on the root cause analysis. Although the recommendations are based on the experiences from the Braskereidfoss incident, the lessons learned will have some transfer value for other dams and other operations centres.

8.1 Ensuring comprehensive risk management for operations

It is recommended that Hafslund Eco Vannkraft strengthens its risk management processes in order to be better equipped to meet future situations involving extreme weather events. Risk management should be carried out at an overarching level, such that the operations function is viewed as a whole with regard to the resilience of human, technical and organisational factors. The risk of the operations centre not acting on alarms and opening floodgates or alerting operational staff was not assessed in any of the RVAs provided. The risks associated with potential changes in the occurrence and nature of extreme weather events should also be included.

Barrier management should be included as a key element in risk management, where barrier functions are mapped and systematically assessed to ensure a sufficient degree of resilience. A number of existing barriers for Braskereidfoss were mentioned in the documentation received, and during the investigation in general. Forecasts, training, procedures, etc., which are currently listed as barriers, are not in themselves barriers. They are factors that impact performance. Other barriers that it is assumed would work in an emergency situation at Braskereidfoss do not appear to be effective in practice and have never been tested, such as emergency generators or opening floodgates using hand cranks or mobile cranes.

In 2017, the Petroleum Safety Authority Norway published “Principles for barrier management in the petroleum industry, Barrier memo 2017” in which it presents a good presentation of the components of good barrier management. This can be used as good guidance for all types of activities. It describes all the components that must be in place to put a good management mechanism in place. These include barriers, technical, organisational and operational barrier elements, performance impacting factors and degradation factors. A good tool for achieving barrier management in general activities or a power station is the ‘bow tie’ method, see Figure 18. Using this involves mapping the barrier functions that are in place for an accident incident, both probability-reducing and impact mitigating.

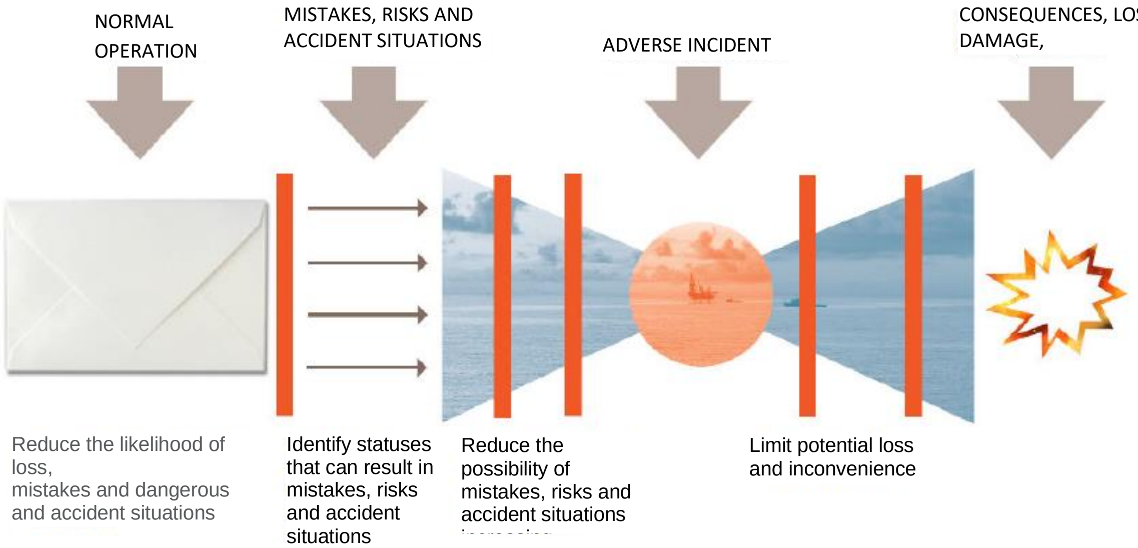


Figure 18: Traditional barrier diagram with functions (illustrated in red) for handling mistakes, risks and accident situations outside normal operation

It is important to note that all barriers and barrier elements must be verified in order for them to be considered functional in an emergency. Today, many technical barrier elements are verified through inspections and testing, although no written procedure has been submitted for how the floodgates should be tested. Several of the operational barrier elements mentioned in the documentation and interviews have never been tested in practice. This applies, for example, to raising floodgates using hand cranks or mobile cranes. This type of barrier element can typically be verified through testing and exercises.

Change management should also be included as a key element of risk management so that technical, organisational and operational changes are systematically documented. One example is the gradual increase from [redacted] facilities operated from the operations centre, which has apparently not resulted in the necessary changes in the capacity of the operations centre or how it operates.

It is important to include operational staff in both risk assessments and the preparation of measures.

Risk assessments related to specific emergency situations should also be strengthened. In the wake of Storm Hans, it seems clear that the total impact was underestimated. Permanent staffing of Braskereidfoss during the days the extreme weather event lasted could have averted the incident. This should be learned from and consideration given to whether the threshold for staffing should be lowered in relation to the current criteria.

8.2 Make the 'open floodgates' barrier function more resilient at Braskereidfoss

The investigation has revealed vulnerabilities in the barrier function 'open floodgates' for Braskereidfoss. This barrier function is currently dependent on a single operational barrier element to be effective. which is that [redacted] the operations centre manually activates the floodgates. This weakness was a decisive factor in allowing the 09/08/2023 incident to happen.

An automatic emergency regulator should be installed that will step in if the operations centre fails to act and activate the floodgates if the water level exceeds the highest regulated water level (HRWL).

Another potential measure that should be considered is that 'Critically high water level' warnings should be sent directly to the operational staff on duty to ensure that there are at least two independent barrier elements that can take action and open the floodgates.

Other recommendations for making the barrier function more resilient are described in more detail in the following sections.

8.3 Make the operations centre more resilient in relation to emergency situations

The investigation identified several vulnerabilities at the operations centre that had an impact during the incident on 09/08/2023.

[redacted]

The user interface is reviewed in Chapter 8.5.

[redacted]

One method that can be used to conduct a comprehensive assessment of the operations centre, including user interfaces, is Crisis Intervention and Operability Analysis (CRIOP). This has been produced by SINTEF /6/.

8.4 Review the operation centre's shift arrangements

[redacted]

8.5 Improve the operations control system's user interface at the operations centre

[redacted]

8.6 Staffing of the facility in a flood situation

As previously mentioned, staffing, training and exercises for the operations centre should be strengthened. However, the same also applies for operational staff in the field.

Reference is made to Appendix A Braskereidfoss power station: Investigation – system failure and dam failure (Multiconsult). From Chapter 7.4 Facility staffing:

The function of segment gates of this design (floodgates) is to open in case of flooding and not be overtopped, i.e. where water flows over the gates. In case of overtopping, the lifting force needed will increase significantly as a result of the water load on the large horizontal plate beams downstream of the gate shield.

It is therefore very important for emergency preparedness and staffing to be in place in a critical flood situation. If one of the floodgates does not respond to an open command from the remote control point, the gates must be operated locally, either from the power station or from the machine rooms in the pillars.

During the incident that led to the dam failure, staff were on site at the facility until after midnight on the night of 09/08/2023. While water levels continued to rise, a decision was made at this time to leave the facility. The staff stated that they believed that the water level was under control and being followed up by the operations centre.

It is worth noting that the gated dam at Braskereidfoss is “vulnerable or sensitive” in the sense that, if one or more of the floodgates cannot be opened, the available window of time for installing backup solutions or remedying faults is short. If the emergency generator does not start as intended, the fault must be remedied. If the fault cannot be remedied, a backup generator must be put in place and connected. This takes time. Ultimately, the gates can be raised by connecting a portable drill to the shaft of the motors and ensuring coordinated manual operation. Braskereidfoss had not been prepared for such a solution.

The current instructions (Doc. 808.3.3 Eidsiva) state that the power station/dam facility at Braskereidfoss must be staffed at a rate of flow of 1800 m^3/s.

Our recommendation is that the facility should be staffed earlier, i.e. also in the case of smaller floods than this. Staff should be on site on a full-time basis during intense floods, while inspection rounds may be sufficient in the case of seasonal floods (snow melt/spring floods), which normally develop over a longer period of time.

We also recommend that high water level alerts be sent directly to the operational staff who are part of the on-call system for the individual facility.

From Chapter 3.4 Flood characteristics:

In the largest watercourses in Norway, the typical seasonal floods such as spring floods in connection with snow melting will normally be the largest. (...) In recent years, several torrential rain floods have been experienced, and these floods tend to develop much faster. Even with a peak rate of flow lower than the largest floods, the flood during Storm Hans peaked after just a few hours.

While we have better forecasts/prognoses now than before, in practice this means that one has less time to take action if equipment fails in flood situations. This means that emergency preparedness procedures designed for slower flood processes may not be sufficient in the event of ‘torrential rain’ floods.

8.7 Technical recommendations for Braskereidfoss

It has been concluded that the dam failure at Braskereidfoss was not due to a technical fault in relation to the floodgates. Nevertheless, several vulnerabilities have been identified in relation to the design of the facility that led to the floodgates being put out of operation at an earlier point in time than might have been the case had these situations been remedied.

Reference is made to Appendix *A SUBREPORT: Braskereidfoss Power Station – Investigation, system failure and dam failure (Multiconsult) for a more detailed description of technical factors and* recommendations.

In summary, the following technical risk mitigation measures are recommended:

- Install hydraulically actuated raising mechanisms on the floodgates at Braskereidfoss.
- Establish a system that opens the floodgates automatically in the event of flooding.

- Install emergency raising mechanisms on the floodgates.
- Portable drill connected to existing machinery as a backup solution.
- Measures for preventing the overtopping of the buttress dam.
- Measures for better preventing the power plants and gatehouses flooding.

9 ABBREVIATIONS AND DEFINITIONS

Table 8 Abbreviations and definitions

Abbreviation	Definition
Aveva PI Vision	A self-service dashboard for context-driven viewing, on-the-fly analysis and sharing Aveva PI system data securely – accessible anywhere on any device.
Barriers	Measures intended either to identify situations that may lead to mistakes, risks and accident situations, prevent a specific course of events occurring or developing, influence a course of events in an intended direction or limit damage and/or loss. /5/
Barrier element	Technical, operational or organisational measure or solution included in the realisation of a barrier function. /5/
Barrier function	The task or role of a barrier. /5/
Barrier management	Coordinated activities intended to establish and maintain barriers so that they can fulfil their function at all times. /5/
Dam Safety Regulation	Regulations relating to Safety at Watercourse Facilities (Dam Safety Regulation), FOR-2009-12-18-1600, Ministry of Petroleum and Energy
DFWL	Dimensioning flood water level
Fatigue	Civil Aviation Authority Norway's definition: Fatigue is defined as a physiological state of reduced mental or physical performance capability resulting from sleep loss or extended wakefulness, circadian phase, or workload that can impair a crew member's alertness and ability to safely operate an aircraft or perform safety-related duties. /7/
PM	Preventive maintenance
HEV	Hafslund Eco Vannkraft
HRWL	Highest regulated water level
IGSS	A SCADA system used to monitor and control industrial processes. [redacted]
Consequence class	All watercourse systems must be classified as one of five consequence classes. Facilities that in the event of failure or malfunction may pose a risk of harm to people, the environment or property, must be classified in consequence classes 1 to 4. Consequence class 4 is used for facilities with the greatest impacts. Facilities with negligible impacts are classified in consequence class 0.

CM	Corrective maintenance
LRWL	Lowest regulated water level

[redacted]

NVE	The Norwegian Water Resources and Energy Directorate
PLS	Programmable logic controller
RVA	Risk and vulnerability analysis
SCADA	SCADA stands for Supervisory Control And Data Acquisition, and is an operational control system with software and hardware elements that enables companies to: - Control industrial processes locally or in remote locations - Monitor, collect and process real-time data - Interact directly with devices such as sensors, valves, pumps, motors, etc. via human-machine interface (HMI) software - Record events in a log file SCADA has been installed and integrated at Hafslund Eco Vannkraft as a basis for the controlled operation of the power stations.

10 DOCUMENTATION

Documentation received from Hafslund Eco Vannkraft in connection with the investigation.

#	Documents	Type
1	Emergency preparedness limits for watercourse incidents	Procedure
2	Emergency Preparedness Plan, Hafslund Eco Vannkraft, rev. 8	Procedure
3	Procedure for gate operation	Procedure
4	Sweco Reassessment report for Braskereidfoss Dam (including appendices)	Document
5	RVA Lillehammer operations centre	Document
6	Braskereidfoss/BK2 RVA analysis 2017, updated 2022	Document
7	Monitoring plan BF Dam	Document
8	Alarm logs	Logs/screenshots
9	Event lists	Logs/screenshots
10	Course of events from Aveva PI	Logs/screenshots
11	Signal lists BF takeover 2017	Technical basis
12	Signal categorisation	Technical basis
13	Indikering-mplinget-setpunkt	Technical basis
14	Maintenance history	Technical basis
15	General description of facility and system	Technical basis
16	Various key emails containing necessary information	Memo
17	Warnings and forecasts	Memo
18	Operational records	Memo
19	Calling in of staff and response assurance during Storm Hans	Memo
20	Screenshot Aveva PI	Memo
21	Data from SCADA	Memo
22	Meeting minutes and logs during Storm Hans	Memo
23	Telephone logs	Memo

11 REFERENCES

/1/ Regulations relating to Safety at Watercourse Facilities (Dam Safety Regulation), FOR-2009-12-18-1600, Ministry of Petroleum and Energy

/2/ Braskereidfoss Dam – Reassessment 2016, Sweco, 02/05/2018

/3/ Report "Project Dam Safety, Report no. 6, Functional safety of floodgates, Nybro-Bjerck, NVE Supervision and Emergency Preparedness Department (NVE-T), Water System Management Association (VR), May 1992

/4/ Occupational health comments on working hours, Compass Topic no. 1, 2020, Norwegian Labour Inspection Authority

/5/ Principles for barrier management in the petroleum industry, Barrier memo 2017, Petroleum Safety Authority Norway

/6/ CRIOP (Crisis Intervention and Operability analysis) – A scenario based risk analysis of control centres, SINTEF

/7/ National Aviation Safety Plan, Civil Aviation Authority Norway

APPENDIX A

SUBREPORT: Braskereidfoss Power Station – Investigation, system failure and dam failure (Multiconsult)

REPORT

Braskereidfoss Power Station

CLIENT

DNV AS

SUBJECT

Investigation – system failure and dam failure

DATE/REVISION: 16/11/2023 /

DOCUMENT CODE: 10254061-01-RiMask-RAP-001 Braskereidfoss Power Station – Investigation – Rev. 02

Multiconsult

Braskereidfoss during Storm Hans. Photo: Innlandet Police.

Multiconsult

REPORT

PROJECT	**Braskereidfoss Power Station**	DOCUMENT CODE	10254061-01-RiMask-RAP-001 Braskereidfoss Power Station – Investigation. Rev. 02
SUBJECT	Investigation	ACCESS	Restricted
CLIENT	**DNV AS**	PROJECT MANAGER	Kurt Benonisen
CONTACT	Christian Stage	PREPARED BY	Kurt Benonisen
COORDINATES	Zone: East: North:	RESPONSIBLE UNIT	10234051 Hydropower Mid

SUMMARY

During the extreme weather event Storm Hans in August 2023, the rate of flow in the middle reaches of the Glomma River rose very quickly and developed into a significant flood in a short period of time. While the rate of flow and simultaneous management of the facilities in the area were at their most intense, operational factors resulted in the floodgates not being opened enough and in as timely a fashion as specified in the station's procedures. When the floodgates were not opened like they should have been, the water level at Braskereidfoss rose rapidly during the night of 09/08/2023.

The floodgates were subsequently put out of action by water flowing over the top of the pillars and into the machine rooms and thus submerging the machinery and electrical motors that operate the gate works.

The failure of the dam at Braskereidfoss was not due to faulty floodgates.

Rapidly rising flooding during the night between 08/08/2023 and 09/08/2023 resulted in the gates being overtopped and the raising mechanisms being submerged when staff arrived at the station on the morning of 09/08/2023. By that time, it was no longer possible to open the dam's three large segment gates and the flood rose to above the crest of the embankment dam, at contour line 166.7 metres above sea level. The embankment dam failed at about 16:30 in the afternoon.

Recommended risk mitigation measures are:

- Install hydraulically actuated raising mechanisms on the floodgates at Braskereidfoss.
- Establish a system that opens the floodgates automatically in the event of flooding.
- Alerts for operational staff and staffing of facilities at critically high water levels.
- Install emergency raising mechanisms on the floodgates.
- Portable drill connected to existing machinery as a backup solution.
- Measures for preventing the overtopping of the buttress dam.
- Measures for better securing the power station and gatehouses from submersion.
- 'Live' emergency preparedness exercises in which the operations centre and operational staff participate.

Multiconsult

02	16/11/2023	Updated after some comments from HEV	Kurt Benonisen	Vegar Tviberg	Kurt Benonisen
01	06/11/2023	Updated after meeting with DNV and HEV	Kurt Benonisen	Vegar Tviberg	Kurt Benonisen
00	24/10/2023	To customer for comment	Kurt Benonisen	Vegar Tviberg	Daniel Melkersen
REV.	DATE	DESCRIPTION	PREPARED BY	VERIFIED BY	APPROVED BY

Hafslund Eco believes that this information is not sensitive because the dam is categorised in consequence class 1.

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1 Background

In connection with the extreme weather event Storm Hans at the beginning of August 2023, Braskereidfoss Power Station on the Glomma River was flooded. The dam's floodgates were not opened enough when the water level was rising, which eventually led to the gate machinery also being submerged and the floodgates thereby being put out of operation. Thereafter, the water level continued to rise rapidly, and the embankment dam was overtopped and failed on the afternoon of 09/08/2023.

Braskereidfoss Power Station is owned and operated by Hafslund Eco Vannkraft AS (HEV). Based on the incident, HEV launched an investigation to determine its causes and learn lessons. HEV engaged DNV to assist with this work on finding causal relationships. DNV in turn engaged Multiconsult to take part in this work, particularly in relation to the technical aspects surrounding the function and manoeuvring of gates. Multiconsult contributed NVE certified technical advisers in all classes for discipline III to this investigation.

Pursuant to Section 7-11 of the Dam Safety Regulation (DSF), HEV was also responsible for submitting a report to NVE on what happened and how the accident or incident was handled. Such a report should be submitted to NVE within 3 months of the date of an accident.

2 Aims and purpose of the investigation

The purpose of the investigation was to find out why the dam's floodgates were not opened as normal as the Glomma River's rate of flow rose during the night of 09/08/2023.

The investigation's terms of reference were:

- Document the course of events.
- Identify the immediate and basic causes of relevance to the event, including human, technical and organisational factors, as well as the interplay between these.
- Identify recommendations in order to prevent similar events happening again.

The objective of the investigation is to learn from the event and improve dam-related safety.

The failure of the embankment dam was not part of this investigation.

3 Dam and flood diversion

Braskereidfoss Dam is a concrete gated dam with an adjoining embankment dam along its western section. On the eastern side, the gated dam transitions to the intake structure for the power station ending with an adjoining buttress dam.

The gated dam is about 80 metres long and has a maximum height of 14 metres. The top of the gated dam is at contour line 165.0 (the pillars) and the roadway is at contour line 166.70.

The embankment dam has a length of about 220 metres and a maximum height of 20 metres. The buttress dam is about 32 metres long and has a maximum height of 14 metres.

The intake pool has regulatory limits with an HRWL at contour line 163.2 and an LRWL at 162.2 metres above sea level.

The dam at Braskereidfoss was completed in 1978. The dam was built to exploit a fall of approx. 9.5 metres on this section of the Glomma River. The first Kaplan turbine was put into production in the same year, with an absorption capacity of approx. 270 m3/s and an output of approx. 22 MW. In 2015, the power station was expanded with a new power plant with a Kaplan turbine to the east of the old one, with an output of approx. 18 MW, and a maximum absorption capacity of approx. 200 m3/s. The total maximum absorption capacity through both generators is therefore approx. 470 m3/s at HRWL.

The floodgates consist of three larger segment gates with apertures of 20.0 x 8.0 metres. In addition, there is also a sector gate (timber gate) with an aperture of 8.0 x 4.0 metres. There is also a bottom gate (segment gate) installed under the sector gate with an aperture of 8.0 x 2.8 metres. This segment gate helps regulate the water level if a generator fails or the rate of flow in the river exceeds the capacity of the generators. In front of the bottom gate there are guides for a separate revision gate (8.0 x 6.0 metres), which is common for both the float race and discharge race.

The gates are numbered as follows:

Sector gate: Gate 1: W x H = 8 x 4 m

Bottom gate, Gate 2: W x H = 8 x 2.8 m

Segment hatches: Gate 3-5: W x H = 20 x 8 m

Gates 1 and 3 to 5 all have a freeboard of 20 cm above the HRWL, such that the top gate is at contour line 163.4 when these gates are in the closed position.

Numbering of gates according to the control system. Illustration photo: SWECO (does not match reassessment and inspection reports)

A total of four pillars house the gates and account for a combined 14.4 metres of the dam's width.

The pillars have a width of 3.6 metres, a length of up to approx. 28 metres and a maximum height of approx. 14.0 metres.
The pillars have a bracing girder design to facilitate revision barriers. Inside the pillars, with access from the top of the pillar, there is a gatehouse or machine room for the gates' works.

The gated dam starts at the western pillar. In addition to being a gate pillar, the western pillar serves as a retaining wall for the embankment dam. The eastern pillar also has a common function since it lies between a floodgate on the western side and a gated timber race on the eastern side. The timber race ends at the intake for Braskereidfoss 1.

3.1 Classification

A decision by the Norwegian Water Resources and Energy Directorate (NVE) in October 2015 classified the dam as being in failure consequence class 2. Following a new assessment, the dam was classified down to consequence class 1 in a decision by NVE dated 09/10/2019, which is also its current consequence class.

3.2 Flood calculations

Flood calculations were carried out by Norconsult AS with its last revision on 15/06/2017. The flood calculations were approved by NVE in a letter dated 09/10/2019. These flood calculations, with their associated flood values, were produced for a consequence class 2 dam. For a consequence class 2 dam, the dimensioning rate of flow is set as Q_{1000}. Q_{1000} results in a dimensioning flood water level equal to 165.8 metres above sea level. This value was calculated without gate failure and blockages in the gate races.

In order to satisfy the conditions set by NVE for approving the flood calculations, Sweco performed a new waterline calculation to demonstrate the effects of tail water or lower edge of the bridge and gates at PMF. This was done in 2021, ref. /4/. In this memo (Table 1), Sweco calculated Q_{500} as being a rate of flow of almost exactly 3573 m^3/s and a dimensioning flood water level at contour line 164.61 metres above sea level with all gates in operation.

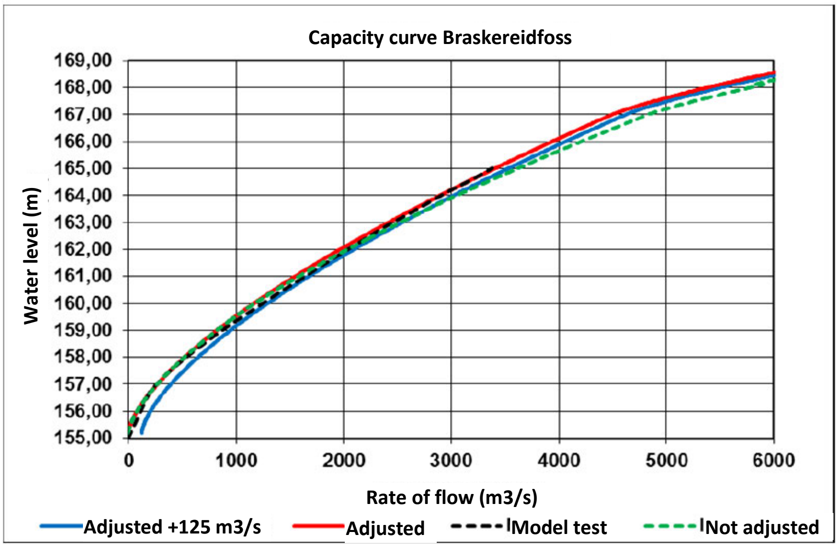
With one of the floodgates out of operation and the bottom gate closed, the water level was estimated to be 168.12 metres above sea level (Table 3 in Sweco's memo). The bottom gate is normally used for water level regulation, and opens when the rate of flow exceeds the capacity of the generators.

	Rate of flow (m^3/s)	Water level without gate failure	Water level Bottom gate closed, other gates open	Water level With gate failure 1 floodgate bottom gate closed
DFWL Q_{500}	Approx. 3500	164.6	165.3	168.1

All heights specified in NN1954 (the Norwegian height datum reference point)

3.3 Diversion capacities (rounded off values)

Gate no.	**Gate type**	**Capacity at HRWL contour line 163.2 [m^3/s]**	**Capacity at contour line 164.6 [m^3/s]**
1	Sector	90	150
2	Segment	270	300
3-5 inclusive	Segment	2250	3000



Diversion capacity curve for Braskereidfoss

Braskereidfoss Power Station during spring flood, May 2013. Rate of flow approx. 2100 m3/s.

Photo: Eidsiva Vannkraft AS

3.4 Flood characteristics

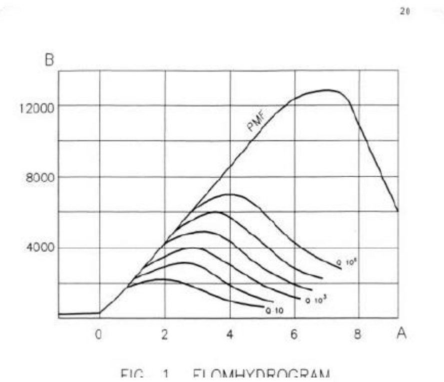


FIG. 1 FLOOD

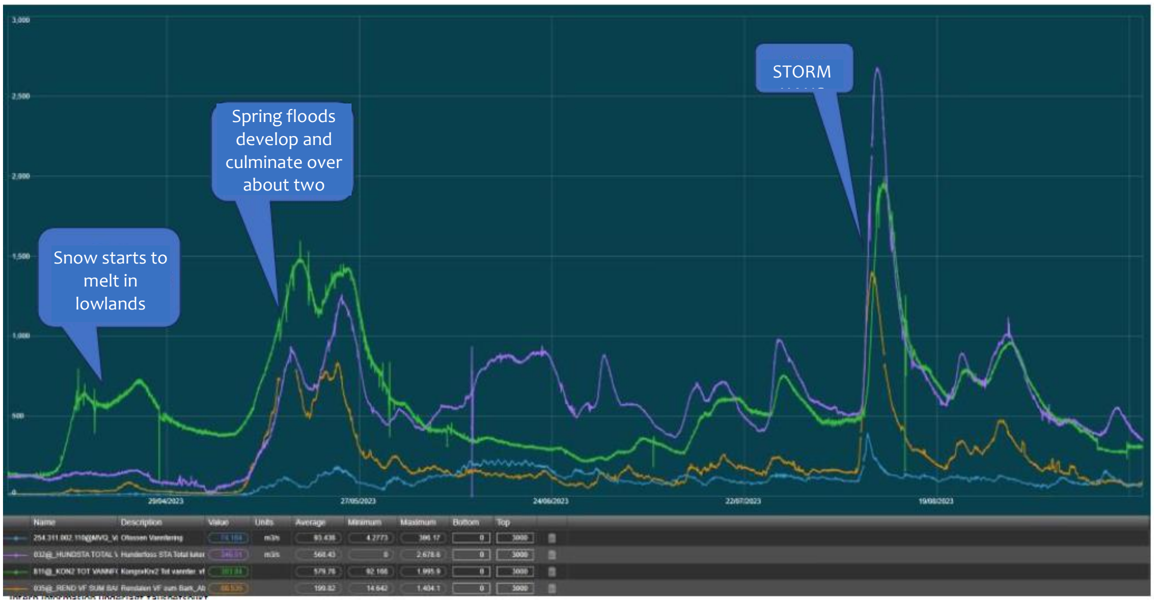
A- Time (24 hours)
B. Rate of flow (m^3/s)

Table 5 Return period for the maximum value of inflow flood		
Return period year	Rate of flow Q m^3/s	Maximum rate of flow change Q/T m^3/s per hour
10	2200	80
10^2	3100	80
10^3	4000	80
10^4	5000	100
10^5	6000	100
10^6	7000	100
PMF	13200	100

The flood hydrograph and flood values for Braskereidfoss shown in the diagram and table above are from calculations carried out in connection with the dam safety project from 1992, ref. /3/. The values also correspond well with the flood values used in the design and dimensioning of dams and gates.

In the largest watercourses in Norway, the typical seasonal floods such as spring floods in connection with snow melting will normally be the largest. A spring flood with a return period of 1000 years (Q1000) will, based on the hydrograph, not peak for 3-4 days. In recent years, several torrential rain floods have been experienced, and these floods tend to develop much faster. Even with a peak rate of flow lower than the largest floods, the flood during Storm Hans peaked (at approx. 1800 m^3/s) after just a few hours.

While we have better forecasts/prognoses now than before, in practice this means that one has less time to take action if equipment fails in flood situations. This means that emergency preparedness procedures designed for slower flood processes may not be sufficient in the event of ‘torrential rain’ floods.



Typical spring flooding in 2023 compared with flooding associated with Storm Hans in 2023. Lines show the course of events in the Glomma River and the Gudbrandsdalslågen River. Screenshot: HEV

4 Reassessment

The most recent reassessment of the Braskereidfoss Dam was carried out by SWECO in the period 2016-2017, with a report dated 02/05/2018.

The reassessment was based on a consequence class 2 dam. The report concludes that the gated dam and buttress dam will be overtopped by dimensioning flooding. The embankment dam does not satisfy the freeboard requirements for preventing overflow based on the dimensioning water level for consequence class 2.

The gates were found to be in good condition, and no factors were identified that required immediate action.

NB:

Calculations are available for the gate bodies of Floodgates 3-5. The conclusion was that their strength and safety were sufficient. The segment gate’ lifting capacity was not checked in the same way as was done for the bottom gate.

4.1 “Project dam safety – functional safety of floodgates” - Risk assessment Braskereidfoss - report February 1992

In connection with Project Dam Safety and assessment of the functional safety of floodgates, a report was prepared in 1992 in which the gates at Braskereidfoss were used as an example. This report addressed various factors that could have a bearing on manoeuvring safety and conducted analyses surrounding manoeuvring safety. The report was produced by Nybro-Bjerck AS on behalf of the Norwegian Water Resources and Energy Directorate (NVE) and the Water System Management Association (VR)

The conclusion at that time was that the overall functional safety of the gates at Braskereidfoss was good.

No significant technical changes have been made to the design or function of the floodgates since this report, including in terms of equipment for manoeuvring the gates.

The biggest technical vulnerability pointed out at this time was the automatic control and warning system that alerts operators in the event of faults. The fact that the power supply to the gates is routed together with cables under the road bridge was also pointed out as a vulnerability.

The report emphasises that getting staffing on site at the facility within a short period of time had a major impact on the overall functional safety of the hatches.

At that time, the plan was to have staff at the station round the clock in the event of forecasted flooding.

Various critical situations were considered, and Chapter 6.1(d) and (e) looks at a situation where some of the floodgates do not open: d) Only the bottom gate and sector gate open, and e) No gates open.

- In the case of situation d), where none of the three floodgates open, it was pointed out that the water level would rise rapidly and overtop the buttress dam (top contour line 165) in a relatively short space of time. This would in turn result in water penetrating the power station, with the subsequent generator shutdown.
- In the event of a flood reaching contour line 164.4, water would flow in and over the float pipe for measuring water levels in the gatehouse on the western pillar, Gate 5. The gatehouses have limited drainage and there is a high probability that this gate will be put out of operation due to water flowing over electric motors and position sensors.

NB: Today, there are two Kaplan turbine generators at Braskereidfoss with a total absorption capacity of approx. 470 m3/s at full operation. This means that the interval between gate failure to overtopping of the buttress dam will be somewhat longer than stated in the said report from 1992.

The cable system under the bridge has also been secured. An additional system for water level measurement has also been installed, beyond what was the case in 1992.

The control and warning system has been improved significantly since 1992, including with redundant signal transmissions for water level and gate position.

The operations centre has also been staffed round the clock since 2003/2004, which it was not in 1992.

Meanwhile, the measuring tube in the pillar for Gate 5 is the same one as before, and this machine room will be flooded at water level contour line 164.4. Thus, this floodgate is will most likely be put out of action. This situation has not been remedied since then. However, a water level of contour line 164.4 is a significant rise in flooding, equivalent to 1.2 metres above the HRWL.

So will the machine rooms for Gates 4 and 3 as the pillars will be topped at water level contour line 165.0. Water will then flow into the machine rooms through the personnel access hatches at the top. This can also happen at a lower water level than contour line 165 if the floodgates are left with an opening of 1.5-2 metres and at the same time the gate shields were overtopped. In these circumstances, build up in front of the gates may cause water to flow into the pillars at an even lower water level than contour line 165.

The most important thing to take away from the analysis from 1992 is the situation concerning preparedness in a flood situation and manoeuvring of the gates.

5 Floodgates and regulation gates

Description	Segment gates 3 pcs	Sector gate	Bottom gate – segment
Main dimensions W x H	20 x 8.2 m (incl. 0.2 m freeboard)	8 x 4.2 m (incl. freeboard)	8 x 2.8 m
Supplier:	Kværner Brug AS	Kværner Brug AS	Kværner Brug AS
Gate threshold:	Contour line 155.2	Contour line 159.4	Contour line 149.4
HRWL:	Contour line 163.2	Contour line 163.2	Contour line 163.2
Upper edge gate at top	Contour line 162.95	-	Contour line 152.2
Floor gatehouse:	Contour line 162.4	-	-
Characteristic pressure:	8 mVs	4 mVs	13.8 mVs
Drainage capacity per gate: at contour line 164.7	Approx. 1000 m^3/s	Approx. 150 m^3/s	Approx. 300 m^3/s
Raising mechanism:	Chain pull-up 2 x 40 metric tons	Chain 2 x 40 metric tons	Hydraulic 52 metric tons
Gate body:	Not torsion-proof	Shell	Shell
Control:	Locally from gatehouse, power station and remote	Locally from gatehouse, power station and remote	Auto for generator, local and remote
Emergency raising mechanism:	No	-	No
Emergency generator:	Yes – diesel generator	Yes	Yes

5.1 Status

Maintenance/rehabilitation

- September 2000: The sector gate was rehabilitated incl. blower cleaning and painting
- June - October 2010: The segment gates were rehabilitated incl. blower cleaning and painting
- August 2013 - January 2014: The bottom gate was rehabilitated including blower cleaning and painting
- Bearing friction measurements carried out, Norconsult: Bottom gate and segment gates in 1988, acceptable level Events at the gates.
- June 2000: Gate works, Gate 4, both sides, disassembled, overhauled and reassembled
- March 2003: Driving motor for Gate 4, eastern side, burned and replaced.
- Spring 2010: Gate 4 Fault in time relay for stepping of resistance for driving motors. Relay replaced.
- December 2013: Changed coupling between motors, Gate 5

In the interviews of operational staff during the investigation in the autumn of 2023, they state that the gates at Braskereidfoss have worked well over the years, with few faults errors.

In recent years, there have been some individual incidents involving couplings between motors that have broken and been replaced. The chains were lubricated regularly. The gates are tested annually.

5.2 Inspections and maintenance

The dam and gates are inspected on a regular annual basis and changes or measures are reported from year to year. The dam and gates are reported to be well looked after and subject to a satisfactory inspection regime for this type of facility.

No reports were submitted from main inspections or special inspections of the dam.

The station was reassessed in a report prepared by Sweco in 2018. Earlier, a reassessment report had been prepared by Norconsult in 2003.

The inspection report dated 25/03/2022 states the following:

1. There are no instructions for operating the gates and electrical wiring diagrams. Should be available in all gatehouses.
2. There is no emergency procedure for operating gates, one should be produced.
3. All floodgates have an electric shaft – not converted for frequency control.

Points 1 and 2 were remedied in 2022. The conversion to frequency control has not been carried out.

5.3 Manoeuvring – operation

5.3.1 Control and floodgates machinery

Floodgates 3-5 are operated with setpoints up to the desired opening as a percentage or rate of flow in m^3/s. Control is performed from the operations centre or from the PC panel in the power station. The floodgates can also be operated from the indicator board in each gatehouse/machine room in the pillars, albeit then without a setpoint.

As previously mentioned, the floodgates are segment gates with two-sided chain raising driven by electric motors via gears. The gates are not torsion-proof structures, and different chain speeds could cause jamming in the guides due to deformations.

The raising mechanisms have a stated capacity of 40 metric tons per chain, or 80 metric tons in total. The gates were delivered by Kværner Brug in 1978. At that time, the same requirement for overcapacity in the raising mechanism that applies today did not apply. Today, the requirement is that it should be possible to open such gates from a closed position even with overtopping of the gate shield. The raising mechanism must be designed with a minimum overcapacity of 30% at the dimensioning flood water level (DFWL) and from the closed position.

When these gates were constructed, it was common to dimension the gate body to withstand flood water levels in a closed position without it breaking up, while raising mechanisms were usually dimensioned based on the assumption that gates would be opened before water overflowed. Raising mechanisms were dimensioned based on the weight of the gate and the friction in bearings and gaskets, often with 10% added for various uncertainties.

The water load on a segment gate has a radial effect against the shield and this force is transmitted onwards to the gate bearing. The actual weight of the water therefore does not affect the raising mechanism, as in the case of a sector gate or folding gate.

When the plate girders and gate struts are 'filled' with water, this results in a significant additional load on the raising mechanism.

Photo: DNV

Here the water level is at the height of the roadway/dam crest at approx. contour line 166.5 metres above sea level.

An overtopping of the floodgates as in the August flood will result in significant overloading of the raising mechanisms, especially the chains and gears. A thorough examination of their condition after such overloading is therefore very important.

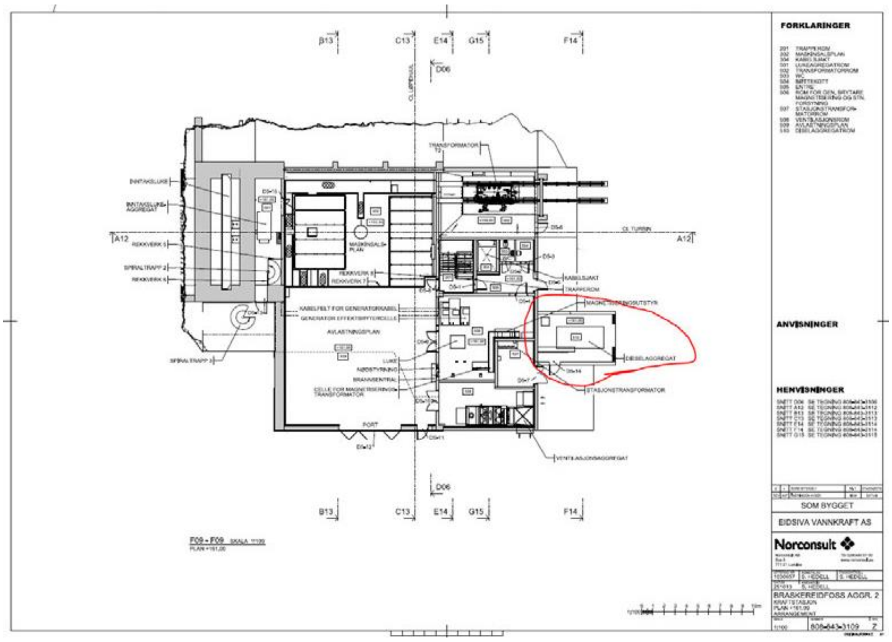
Each plate girder has a surface area of about 32 m^2. The combined value for both girders is more than 60 m^2, and with a water load of, for example, 1 metre on average, this gives an additional total load of more than 50 metric tons on the floodgate's raising mechanism. The nominal lifting capacity of the raising mechanism is 80 metric tons.

5.3.2 800 kVA emergency generator

Braskereidfoss Power Station is equipped with its own permanently installed emergency generator, which automatically starts in the event of a power outage or other interruption to the facility's power supply
The emergency generator is physically located in a separate room adjacent to the power plant building for the new Braskereidfoss power plant generator 2 from 2016.

The generator feeds the 230 V busbar at Braskereidfoss 2, via switchgear and over to the busbar for Braskereidfoss 1. This continues via the cable arrangement under the bridge out to the floodgates on the dam.

In addition, there is a 110 V battery system with a 5 kVA inverter that can feed into the supply for the gates. The battery capacity is stated to be 350 Ah, but it is uncertain how far this capacity will go when it comes to being able to raise the gates.



Drawing showing the location of the emergency generator at the station for generator 2 – the new Braskereidfoss.

The generator has been installed on the floor at contour line 161.0. When the water overflowed the buttress dam (contour line 165.0) and eventually penetrated the power station, the generator room was also partially filled with water.

Photos show that the water rose to a level corresponding to slightly above the middle of the generator.

Water level, generator set – emergency power system. Photo: DNV

According to staff at the station, the emergency generator was operational until approx. 09:05 on 09/08/2023.

We were not told that the cable duct to the floodgates was damaged during the incident.

The generator failed because it was submerged. However, the gatehouses/machine rooms in the pillars had already been flooded and put out of service before this.

5.3.3 Manual operation

Each raising mechanism has a crank connection for manually raising the floodgates. However, this operation requires considerable effort on the part of staff to raise the gates. The 1992 report, ref. /3/, estimates that it would take six men about 4 hours to crank the gate up. Three men on each side of the gate to maintain the tempo.

Our recommendation is to acquire powerful drills that can be connected directly to the gears instead of using manual hand cranking. One on each side of the gates. In addition, there should be clear position marking on the chain to avoid skewed raising and jamming in the guides when operating them. Coordination must be done through communication over means of communication.

5.3.4 Raising mechanism machinery – chain works

<u>Limitations</u>

A non-torsion-proof segment gate requires the gate to be raised equally on both sides to avoid deformation and jamming in the guides. The works for the floodgates are therefore equipped with a synchronous motor that ensures that the main motors (asynchronous) are run at equal speed during manoeuvring. Between the motors and chain gears, there is first a worm gear and then a planetary gear that provides exchange from motor to chain. There is a band brake with an actuator between the motors, which is applied when the gate is not moving. As soon as the motors start, the brake is released.
If the gate is stuck in ice or by other blockages, the motors will start and contribute torque until the coupling between the motors breaks. The coupling normally functions as a fracture protection mechanism to prevent the gears or chain being damaged as a result of overloading. If the coupling does not break, the gear teeth can break and the chain be stretched or otherwise damaged.

Chain works – floodgates. Photo: DNV

Over time, it may prove difficult to obtain spare parts for this type of machinery, such as actuators for brakes, motors, etc. The facility owner has considered replacing the synchronous motors and converting the controller to frequency control. Before this is done, however, it is very important to have in-depth knowledge about the gates and the limitations and properties of the entire raising mechanism, so that one does not introduce more risk elements and sources of error than one already has.

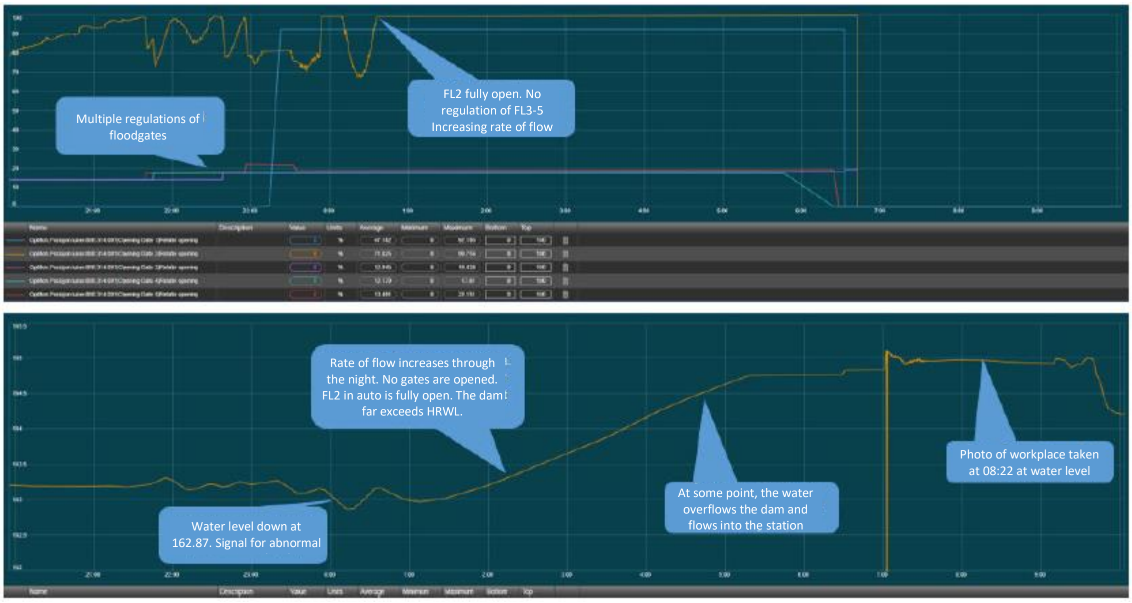
6 Course of events in connection with overtopping of the dam and dam failure

Reference is made to DNV – report 2023-4089 – doc.no. 2010341, for a more detailed description of the incident and course of events. This report focuses on the technical aspects surrounding the gated dam in connection with the incident, its vulnerabilities and suggested improvements.

6.1 Flood rising and actions

Gate openings 07/08/2023 16:00 – 09/08/2023 10:00

Gate openings and water level 08/08/2023 20:00 – 09/08/2023 10:00



Screenshot from HEV.

6.2 Failure of gate manoeuvring

- During the evening of Tuesday, 08/08/2023, the rate of flow in the Glomma River increases and the absorption capacity of the generators is exceeded, i.e. the rate of flow exceeds approx. 400-450 m3/s. The bottom gate is in Auto, and opens to keep the water level in the range of HRWL, contour line 163.2. The bottom gate has a nominal capacity of approx. 200 m^3/s.

- Floodgates 3-5 were operated from the operations centre and locally throughout the evening until about 23:30. The gates were then set to an opening of 18-20% corresponding to 1.6-1.7 metres from the sill, or an estimated diversion capacity of approx. 250-300 m^3/s. After this point in time, the floodgates were not manoeuvred from the operations centre. The bottom gate is fully open throughout the night.
- From around 01:30, the water level rises rapidly from HRWL up to about 164.7 at 05:00 in the morning. The gates were overtopped and water flowed into the gatehouses/machine rooms putting the floodgates out of action.
- At about 06:00, the water rises above the buttress dam at contour line 165.0 and the plants fill up fairly quickly with water and are submerged/put out of action.

6.3 Causes

- We refer you here to the description and root cause analysis, chapter 6 of the investigation report from DNV.
- When the gates were placed in position 1.6-1.7 m above the threshold, it means that the tops of the gates were almost flush with the dam pillars at contour line 165.0. The front wave that occurs in front of the segment gates will quickly rise to 20-30 cm above the top of the gate, and this will guide water into the pillars. Given that the personnel access hatches in the pillars were not watertight, the water flowed down into the machine rooms/gatehouses, and these were quickly flooded since they did not have sufficient drainage to divert this amount of inflowing water. This is consistent with the fact that the water level measurement at the pillars was also put out of action during this period of time.
- The machine room in the right gate pillar for Gate 5 has a measuring tube with the top of the tube at contour line 164.4. When this is overtopped, the machine room will be flooded in addition to water flowing in through personnel access hatches at the top.
- The machine room on the left pillar of Gate 3 has better drainage than the other gate pillars, and therefore this machinery was operational for somewhat longer than the others.

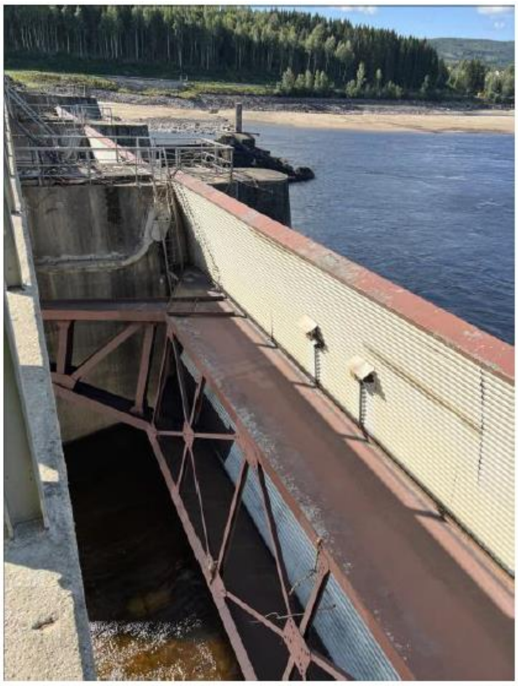
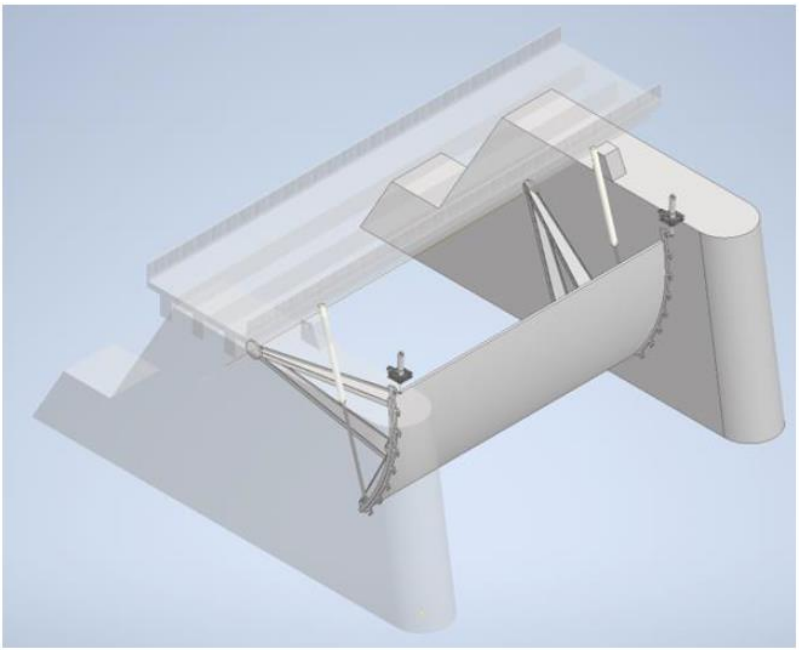


Photo showing the gate positions as they were during the flood. The tops of the gates are flush with the pillars. Photo: DNV.

7 Lessons learned and proposed measures

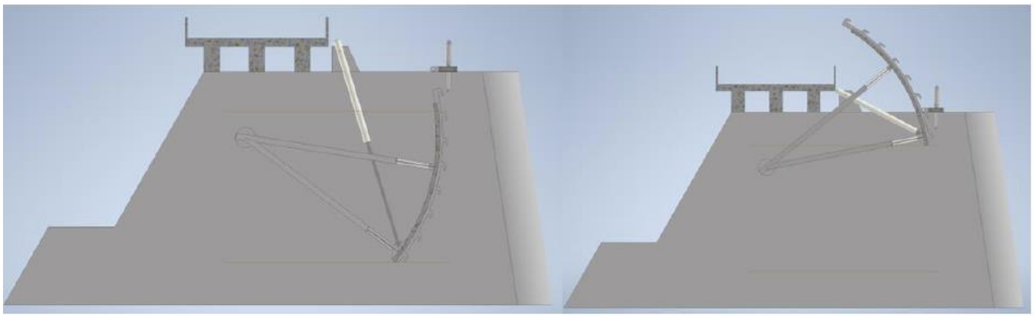
7.1 Hydraulic raising mechanism

Hydraulic single-acting cylinders instead of chain raising mechanisms on existing floodgates will require the addition of a cylinder mounting pillar, and careful checks need to be made in relation to space vis-à-vis the road bridge across the dam. Our preliminary assessment based on the model shows that there should be sufficient space without coming into conflict with the road bridge.



Model of Braskereidfoss floodgate showed hydraulic raising mechanisms, as well as emergency raising mechanisms. Multiconsult

Hydraulic cylinders are also vulnerable in the event of overtopping and water above the gates if they are not shielded. This can be solved with screens on the top of the gate blades that would control the flow of water somewhat in the event of overtopping. However, segment gates such as floodgates of this type should, preferably, not be overtopped. Nevertheless, a new hydraulic raising mechanism could be dimensioned to withstand a certain amount of overtopping, if the gate body otherwise allows it.



Gate, W x H = 20 x 8.0 metres in closed and open positions with placement of cylinders on the pillar. Multiconsult

We consider the use of chains in combination with a horizontally placed cylinder under the road bridge as one solution, although the transfer of forces towards the gears and axle journal quickly becomes so great that these would have to be reinforced. We therefore do not recommend such a variant. The forces acting in the pillar would also be a challenge.

7.2 Automatic opening of floodgates

A system should be established for automatically opening the gates in the event of a flood. The floodgates have freeboards of 20 cm above the HRWL. If the first 10 cm is used for water level regulation with a generator/and bottom gates, the floodgates could start opening from approx. 15 cm above HRWL and then follow the water level with approx. 5-10 cm freeboard when this increases. However, an automatic system should not be installed on large floodgates where there is a two-sided chain raising mechanism and electric shaft on the raising mechanism. The wear and tear on chains and gears may quickly become so great that the risk of errors and skewed raising will increase substantially over time. We therefore recommend that the floodgates be converted to raising mechanisms based on hydraulic cylinders and generators, one cylinder on each side of the gates (still two-sided raising mechanism). Generators can be placed in existing machine rooms after they have been made watertight to prevent the inflow of water over the pillars.

Synchronisation would take place by measuring the position in each cylinder simultaneously with redundant measurement via separate position sensors directly connected to the gate blade and via dedicated potentiometers in the machine rooms.

We also recommend that separate emergency raising mechanisms be established for each gate. A toothed rack should be mounted on the front of each gate blade and attached to the existing fastener for the raising mechanism. On top of the pillars, separate cylinders should be mounted for the stepwise raising of the gates in a situation where the main raising mechanisms are out of action.

7.3 Facility staffing

The function of segment gates of this design (floodgates) is to open in case of flooding and not be overtopped, i.e. where water flows over the gates. In case of overtopping, the lifting force needed will increase significantly as a result of the water load on the large horizontal plate beams downstream of the gate shield.

It is therefore very important for emergency preparedness and staffing to be in place in a critical flood situation. If one of the floodgates does not respond to an open command from the remote control point, the gates must be operated locally,
either from the power station or from the machine rooms in the pillars.

During the incident that led to the dam failure, staff were on site at the facility until after midnight on the night of 09/08/2023. While water levels continued to rise, a decision was made at this time to leave the facility. The staff stated that they believed that the water level was under control and being followed up by the operations centre.

It is worth noting that the gated dam at Braskereidfoss is "vulnerable or sensitive" in the sense that, if one or more of the floodgates cannot be opened, the available window of time for installing backup solutions or remedying faults is short. If the emergency generator does not start as intended, the fault must be remedied. If the fault cannot be remedied, a backup generator must be put in place and connected. This takes time. Ultimately, the gates can be raised by connecting a portable drill to the shaft of the motors and ensuring coordinated manual operation. Braskereidfoss had not been prepared for such a solution.

The current instructions (Doc. 808.3.3 Eidsiva) state that the power station/dam facility at Braskereidfoss must be staffed at a rate of flow of 1800 m^3/s.

Our recommendation is that the facility should be staffed earlier, i.e. also in the case of smaller floods than this. Staff should be on site on a full-time basis during intense floods, while inspection rounds may be sufficient in the case of seasonal floods (snow melt/spring floods), which normally develop over a longer period of time.

We also recommend that high water level alerts be sent directly to the operational staff who are part of the on-call system for the individual facility.

7.4 Existing machinery:

It is very important to conduct careful inspections of the chain and other machinery before choosing to keep these going forward. Any stretching in chains, damage or cracks in the gears, machine frame, motors, brake, attachments to gates, etc. must be carefully checked. If there is no damage to the raising mechanisms, there is nothing wrong with using these for the time being, and until any new raising mechanisms are put in place.
Some factors:

- The raising mechanism has been through the 'wars', experiencing considerable overload!
- The old machinery has worked well, but it may be difficult to obtain spare parts in the years to come.
- The machinery has been submerged, and the motors and actuators may still need to be replaced in order to get the gates operational as soon as possible.

- The gate pillars should be made watertight so that water does not flow in and fill the rooms in the event of a major flood.
- Connection using a portable drill attached to the motor shaft should be established instead of hand cranking. At the same time, establish good marking on the chain or position marking to avoid skewed raising and jamming.

Gate works and motors that have been submerged.

7.5 Hydraulic motors

Hydraulic motors instead of electric ones would be able to recover better from flooding in machine rooms. This requires that the chains and gears are OK. The generators should be placed in watertight gatehouses. The locating of common generators on the land side would result in very long tubing guides out to each pillar, which may also be vulnerable. Still, such a solution would not be recommended in combination with automatic control of the gates, as the wear on chains would still be a challenge. This is therefore not recommended.

7.6 Rebuilding the dam and ensuring flood diversion capacity.

As previously mentioned, the dam was declassified from failure consequence class 2 to consequence class 1 in 2019. The background for this included better map data and calculations showing that the wave caused by a failure of the dam would not impact any homes/residential units in the event of a dam failure.

The dimensional flood Q_{500} is now estimated by Sweco to be approx. 3500 m^3/s, with an associated dimensioning flood water level equal to contour line 164.6 metres above sea level. (All gates operational). With the bottom gate out of operation, the flood water level is calculated at contour line 165.3 metres above sea level.

The embankment dam had a top impervious core at contour line 165.3 metres above sea level and its foundations stood on silt/soil deposits, and the distances down to bedrock are large with a depth of approx. 25 metres at the deepest part. Therefore, it would be very demanding/impractical to establish a new concrete dam in the collapsed part of the current embankment dam.

Ensuring the floodgates function with hydraulic raising mechanisms and the automatic opening of gates, as well as establishing emergency raising mechanisms on the three floodgates, would address the dam's diversion capacity for the vast majority of floods moving into the facility. And without major modification, the dam will continue to be dependent on floodgates being manoeuvred, even if one or more links in the manoeuvring functions fail.

As we see it, the best solution now, in terms of the time it will take for reconstruction and functional safety, would be to rebuild the embankment dam as it was before it failed, while ensuring the floodgates function. Rebuilding the facility is also regarded as important in terms of new floods in the future, dam safety and getting the power station back in operation.

8 Conclusion/summary

During the extreme weather event Storm Hans in August 2023, the rate of flow in the middle reaches of the Glomma River rose very quickly and developed into a significant flood in a short period of time. While the rate of flow and simultaneous management of the facilities in the area were at their most intense, operational factors resulted in the floodgates not being opened enough and in as timely a fashion as specified in the station's procedures. When the floodgates were not opened like they should have been, the water level at Braskereidfoss rose rapidly during the night of 09/08/2023.

The floodgates were subsequently put out of action by water flowing over the top of the pillars and into the machine rooms and thus submerging the machinery and electrical motors that operate the gate works.

Therefore, the failure of the dam at Braskereidfoss was not due to faulty floodgates.

Rapidly rising flooding during the night between 08/08/2023 and 09/08/2023 resulted in the gates being overtopped and the raising mechanisms being submerged when staff arrived at the station on the morning of 09/08/2023. By that time, it was no longer possible to open the dam's three large segment gates and the flood rose to above the height of the buttress dam and flooded both power plants. The water then rose to above the crest of the embankment dam, at contour line 166.7 metres above sea level. The embankment dam failed at about 16:30 in the afternoon.

9 References

/1/ Investigation report Braskereidfoss – incident, DNV report no. 2023-4089
/2/ Reassessment report SWECO 2018 and appendices
/3/ Project dam safety, sub-report 6 – functional safety of floodgates – Nybro-Bjerck AS – 1992.
/4/ MEMO – Sweco 06/01/2021 – flood calculations for the mid-reaches of the Glomma River: Strandfossen, Skjefstadfoss, Braskereidfoss, Kongsvinger

APPENDIX 3 – Course of events:

DNV limited its investigation (see section 3.2 Limitations) to the morning of 09/08/2023 from 08:00. In our opinion, what happened up to then has been described in detail and covered in the investigation report. The following is an account of the course of events from when our personnel arrived on site at the facility on 09/08/2023.

For the record, we have also produced some sections that are relevant to the course of events.

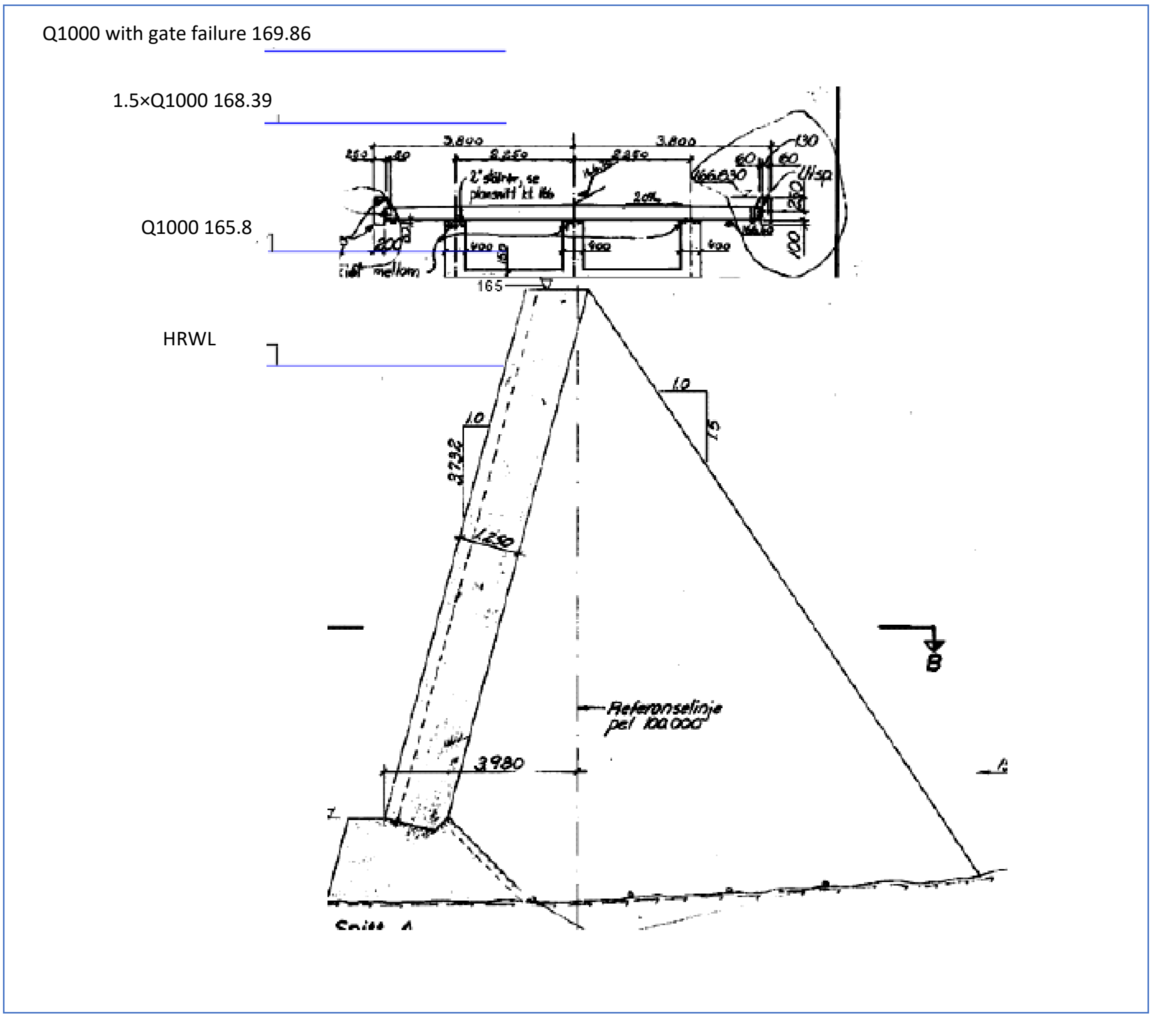


Figure 1: Typical section of gated dam with relevant contour lines

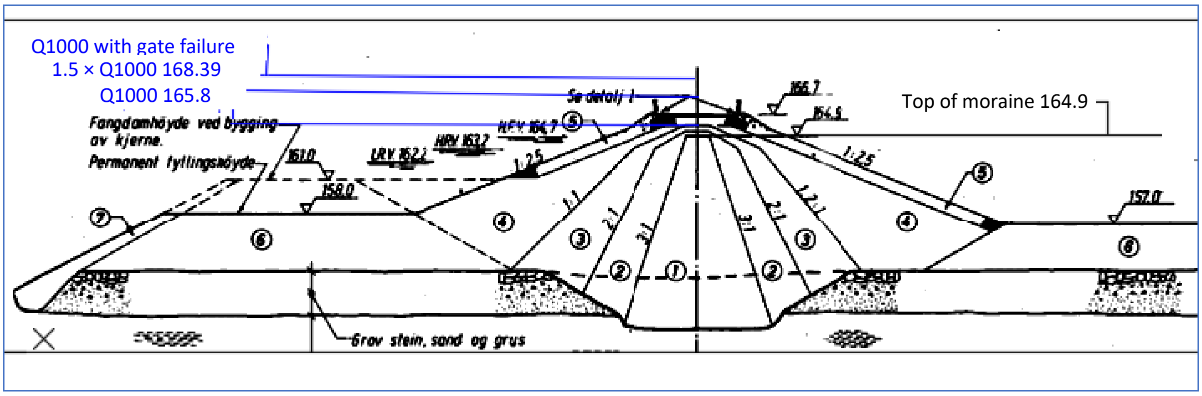


Figure 2: Typical section of embankment dam with relevant contour lines

Time	Activity	Rate of flow/water level
06:45	The emergency manager notified the Water Resources Technical Manager of an incident at Braskereidfoss, where the Water Resources Technical Manager was asked to come to the facility	Rate of flow: Approx. 1950 m3 (Elverum) Water level: Approx. 166 (estimated from photo)
07:00-07:45	The Norwegian Water Resources and Energy Directorate (NVE), represented by Edvard Listøl, was notified of the incident at the station.	
07:16	The Water Resources Technical Manager called a colleague and asked for assistance and attendance at Braskereidfoss.	
07:00-08:00	Attempted to contact the head of embankment dams at SWECO, based on responsibility for the reassessment that had been carried out. Contact not made. Claus Rikartsen at Norconsult was contacted - certified technical adviser for embankment dams. Henning Føsker, who is a technical adviser for closing and drainage mechanisms, was also notified.	
07:00-07:45	Dam failure wave calculations were retrieved by the Deputy Water Resources Technical Manager, which included a list of homes that would be vulnerable to, but still outside, the estimated failure wave.	
07:00-07:45	Contact with the contractor was established – John Galten AS. Ordered an excavator to be deployed on the western side of the dam. The intention was to be able to control a failure in case the failure develops too far to the west on the embankment dam or to use it for any urgent measures	
07:45	Arrival at the facility. The fire service arrive son site and the police have been notified but have not arrived.	
08:00	Establishment of upstream water level measurement point.	
08:30	The police arrive. Emergency response organisation is established.	

	A list of properties recommended for evacuation is given to the police. No water is overflowing the dam.	
09:00-10:00	MULTIPLE TIMES: Inspection of the embankment dam – especially the air side and for the purpose of checking softening/leaks.	
09:05	Emergency power generator stops	
09:00-10:00	New contact with contractor John Galten AS – ordered excavator for the eastern side of the dam and materials for building up above the embankment dam Overflow of the embankment dam and water into the concrete dam that is diverted westwards and into the embankment dam	
Approx. 09:30	Option of blowing a hole in the dam – the Norwegian Armed Forces are contacted via the police. First feedback from the Norwegian Armed Forces: sending a person to assess. After pressure: the Norwegian Armed Forces mobilise explosives experts – estimated arrival at approx. 12:00 Water flows over the buttress dam and into the power station	Rate of flow: Approx. 2000 m^3 (Elverum) Water level: approx. 166.3 (underside of bridge surface)
Approx. 11:10	Excavator arrives on western side. Water is starting to get onto the roadway embankment dam	Rate of flow: Approx. 2100 m^3 (Elverum) Water level: Approx. 166.7 (estimated from photo)
Approx. 11.15	The water begins to overflow the embankment dam	Rate of flow: Approx. 2100 m^3 (Elverum) Water level: Approx. 166.7 (estimated from photo)
11.30	Barriers are dismantled to avoid blockages, as well as to maximise even overflow (this was of no benefit)	Rate of flow: Approx. 2100 m^3 (Elverum) Water level:
Approx. 12:00-13:00	Laying of materials on the dam with the intention of stopping overflowing of the embankment dam. The works were quickly abandoned due to rising water levels and general safety for those working on them. Activity on the dam ended at 13:03	Rate of flow: Approx. 2100 m^3 (Elverum) Water level: Approx. 166.8 (estimated from image)

Approx. 12:00	The Norwegian Armed Forces arrive. Mobilised for quick action. Conclusion after inspection with the police: Blowing a hole in the dam would be difficult. Blowing up of gates is considered close to impossible. Explosives would have to be placed against the steel to ensure effect. Blowing up of the gate shields involves great uncertainty.	

13:00-	Activity on the dam ends. The option of blowing a hole in the buttress dam and gates is assessed Blowing a hole in the buttress dam – between the power stations – was discussed, but there was a risk of increasing the damage to the plants as a result of the blasting. Estimates are made of the effect of opening the buttress dam, effect is assessed as marginal.	Clear from the Norwegian Armed Forces: high level of uncertainty about whether blowing a hole in the dam could succeed
After 13:00	Measures were abandoned. The water level continues to rise and the overflow over the embankment dam increases.	
Approx. 15:00-15:30	Controlled blowing of a hole in the buttress dam or gate no longer relevant. Assessed first by the police and then by Hafslund Eco. The dam begins to sustain severe erosion damage. A lot of the dam's downstream support slope is eventually washed away. The moraine is staying the course well, and there is a discussion with police about blowing a hole in the embankment dams to avoid a tidal wave. This ended when it became clear that the dam was going to fail.	Rate of flow: Approx. 2180 m^3 (Elverum) Rate of flow at Elverum culminates at 06:00 on 10/08/2023 at 2240 m^3.
16:30	Failure of embankment dam	
16:30	Reservoir water level drops rapidly following failure	Measuring rod shows drop in water level 16:25 - 16:27: -10 cm 16:27 - 16:38: -34 cm

Braskereidfoss 09/08/2023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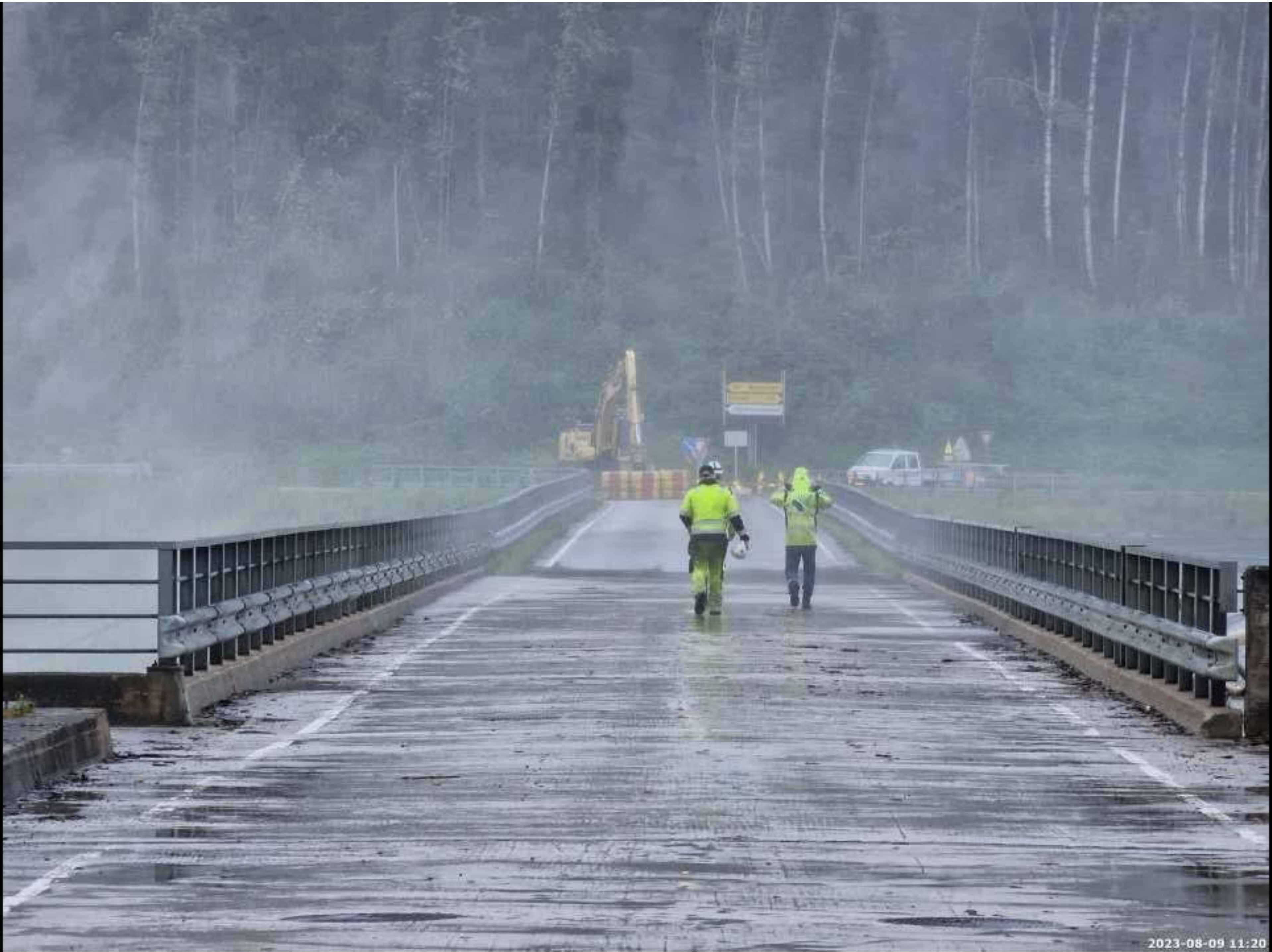
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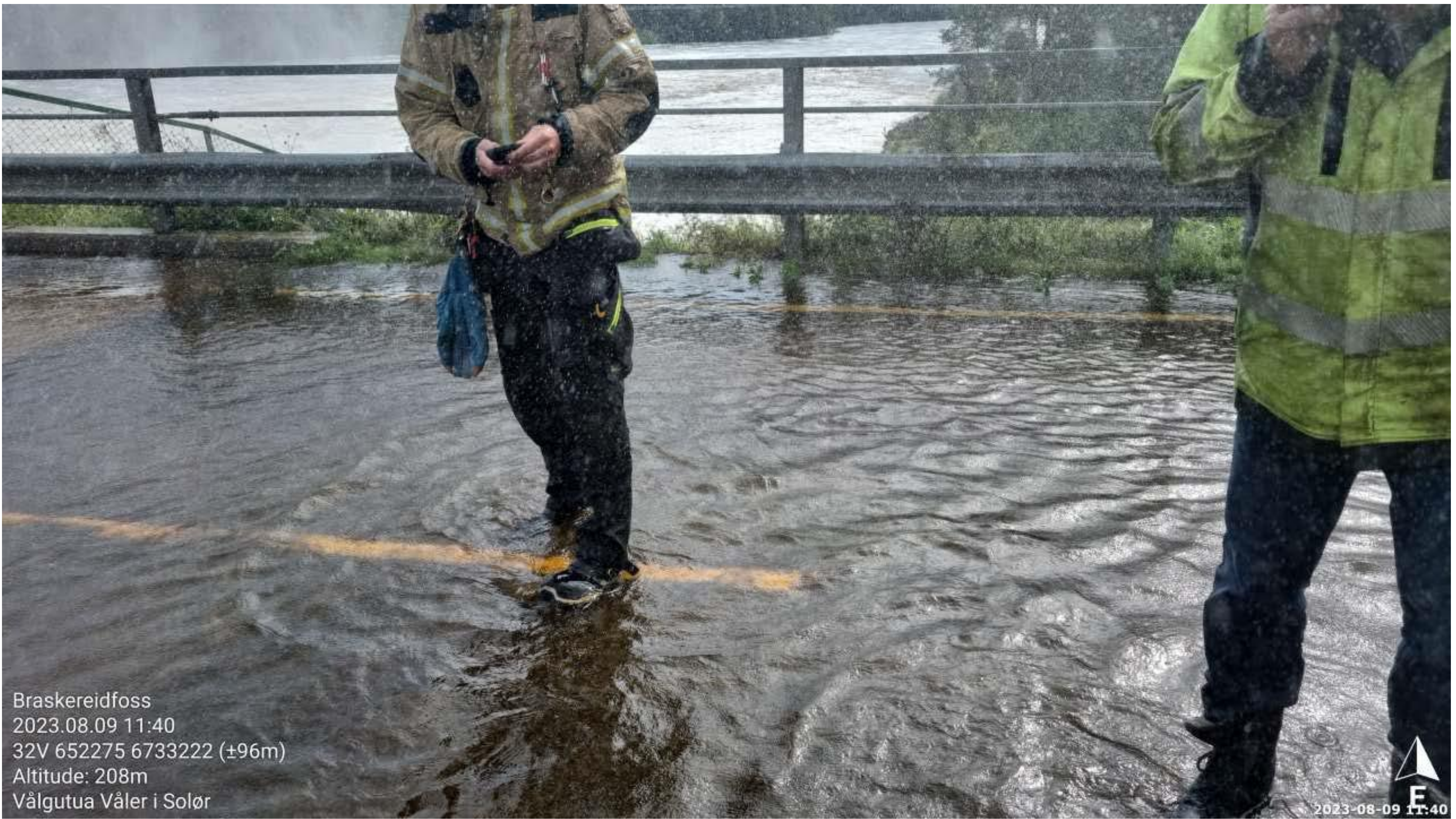
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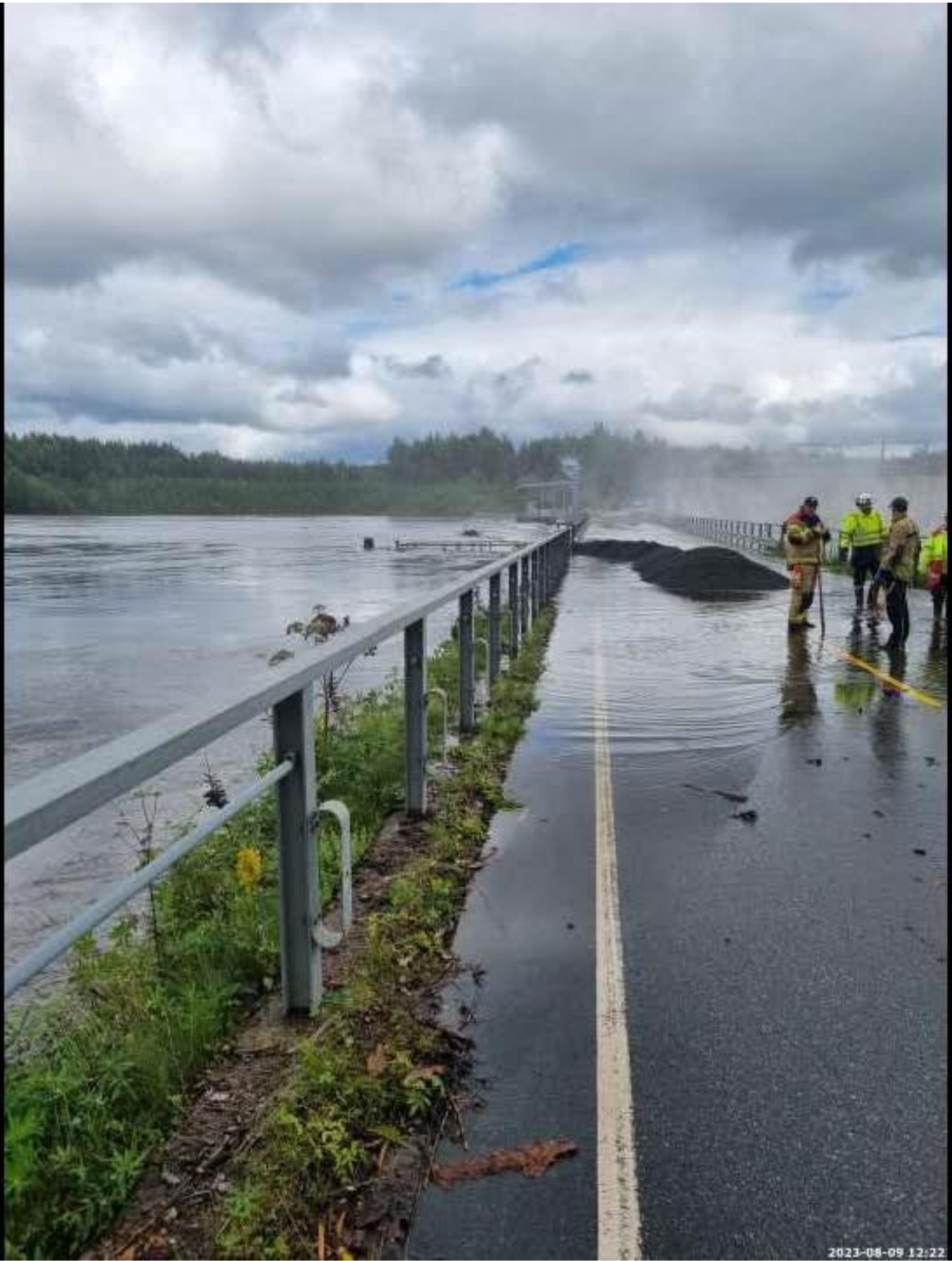
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