Lightning Strikes Twice at Rapidan Dam

JIM HERBERT, P.E., VICE PRESIDENT/SENIOR CIVIL ENGINEER, BARR ENGINEERING CO.; AND JOE HJERPE, P.E., SENIOR CIVIL ENGINEER, BARR ENGINEERING CO.; TOM MACDONALD, VICE PRESIDENT/SENIOR WATER RESOURCES ENGINEER, BARR ENGINEERING CO. RYAN THILGES, P.E., COUNTY ENGINEER/PUBLIC WORKS DIRECTOR, BLUE EARTH COUNTY

ABSTRACT

The Rapidan Dam, located in Blue Earth County, Minnesota, was constructed in 1910. Since 2002, the dam has faced some significant structural challenges, primarily due to severe flooding and subsequent erosion. A February 2002 inspection revealed critical structural instability, including a deep scour hole under the dam, prompting immediate stabilization efforts, including rock fill and concrete placement. These measures temporarily reduced the risk of failure; however, the dam encountered another severe incident in June 2024 when historic rainfall led to catastrophic flooding. The deluge caused debris accumulation and a failure of the west abutment, resulting in notable riverbank erosion, property destruction, and power outages. This event underscored the vulnerabilities of the dam, which are magnified by severe weather patterns and debris management challenges. Barr, along with county, state, and federal agencies, is coordinating to assess the damage and risks, and plan for the dam's removal and subsequent property restoration.

I. RAPIDAN DAM

The Rapidan Dam is in Blue Earth County in south central Minnesota on the Blue Earth River, approximately 10 miles south of Mankato, Minnesota (Figure 1).

Figure 1 Location of Rapidan Dam in southwest Minnesota

The dam was built in 1910 by Consumers Power Company (predecessor to Xcel Energy) to produce hydroelectricity and serves a 2,430 square mile watershed. Blue Earth County (County) took ownership of the dam and reservoir lands following the 1965 flood that damaged the hydropower operations. Hydropower generation was redeveloped in the mid-80's by a private developer in conjunction with the County. The 87 ft. high Ambursen buttress dam consists of a west (left) abutment and core wall, a 54 ft. concrete non-overflow section, a 92 ft. powerhouse with integral intakes, a 180 ft. gated spillway section with five Tainter gates, a 72 ft. spillway section that formerly included timber needle gates, a 58 ft. non-overflow section, and an east (right) abutment (Figure 2).

Figure 4 Rapidan Dam (Photo Credit: Barr Engineering Co.)

II. 2002 INSPECTION AND EMERGENCY REPAIRS

Have you ever inspected a dam and wanted to make a quick exit? This was the case for Barr Engineering Co. (Barr) engineers in February 2002, when an inspection of the Rapidan Dam revealed severe structural issues, including a large scour hole under the dam's buttresses measuring more than 18 ft. deep and extending more than 30 ft. upstream of the dam's toe (Figure 3). Intense spring flow conditions led to the failure of the downstream apron, causing erosion of the underlying soft sandstone bedrock and compromising the structural integrity of the dam. This discovery indicated that the dam was on the brink of failure, with its buttresses cantilevered over open water instead of resting on bedrock. Immediate action was necessary to prevent a catastrophic collapse, especially with spring rains approaching. The inspection was limited due to safety concerns, but stability analyses confirmed the dam's precarious state.

Figure 3 **Voids in concrete base that should be founded on bedrock (Photo Credit: Barr Engineering Co.)**

III. 2019 FLOODING AND DAMAGE

Spring flooding in 2019 damaged the downstream apron, the Tainter gates, and the powerhouse, and power generation was halted. The damaged Tainter gates were not operational and were placed in the fully open position. In the winter of 2019-2020, a large ice jam downstream of the dam caused the tailwater to rise and flood the powerhouse up to 14.7 ft. above the operating floor, damaging the turbines and their electrical controls (Figure 4). The dam has not produced power since 2019. The County was in the process of surrendering its FERC exemption when the 2024 breach occurred.

Figure 4 **Comparison: Downstream ice buildup (left), January 18, 2020 (note white signs on powerhouse for scale of ice dam height) vs. normal tail water (right) [Photo Credit: Blue Earth County (left), Barr Engineering Co. (right)]**

IV. 2024 FLOOD AND WEST ABUTMENT BREACH

Despite emergency repair efforts in 2002 and subsequent projects, the Rapidan Dam encountered another significant challenge in June 2024 due to severe flooding (Figure 5). Historic rainfall caused the Blue Earth River to swell, and debris accumulation at the gates led to water surging over the dam, leading to a complete failure of its west abutment. This failure resulted in riverbank erosion, the collapse of a nearby home, damage to the dam and powerhouse, and the destruction of an Xcel Energy substation, causing outages for approximately 600 households.

Figure 5 **Rapidan Dam west abutment breached following June 2024 historic rain (Photo Credit: Blue Earth County Sheriff's Office)**

The floodwater peaked at 34,800 cubic feet per second, making it the second-largest flood in the dam's history. Despite the severity, no mass evacuations were necessary or ordered, although a nearby bridge and campground were closed as a precaution. Authorities, including those from the MN Department of Natural Resources – Dam Safety, the Minnesota Department of Transportation, the U.S. Army Corps of Engineers, and the Federal Energy Regulatory Commission, were on-site to assess the damage and ongoing risks.

V. WHAT HAPPENED?

The failure of the Rapidan Dam's west abutment was primarily caused by a combination of factors. Recent bouts of heavy rain significantly increased the flow of the Blue Earth River, which collected trees, logs, and woody debris along the Blue Earth River floodplain. This debris accumulated on the front face of the dam and on the Co. Road 9 bridge piers located upstream of the dam. Anecdotally, it appears that a mass of woody debris broke free from the bridge piers, adding to the debris along the dam and partially blocking the gate bays, despite all five gates being fully open. The gate capacity was significantly reduced, causing the reservoir elevation to increase until water began flowing over the dam and west abutment area, breaching the west abutment and eroding the downstream slope. This increased water flow led to rapid erosion around the dam's abutment, undermining its structural integrity. When the west abutment failed, a portion of the sediment accumulated behind the dam was released downstream, exacerbating the erosion and impacting the channel. Figure 6 shows several dryer years and lower flows that may have contributed to an increased load of woody debris along the Blue Earth River floodplain, prior to the June 2024 event. Typically, much of the debris would have been periodically swept downstream during precipitation events throughout the year.

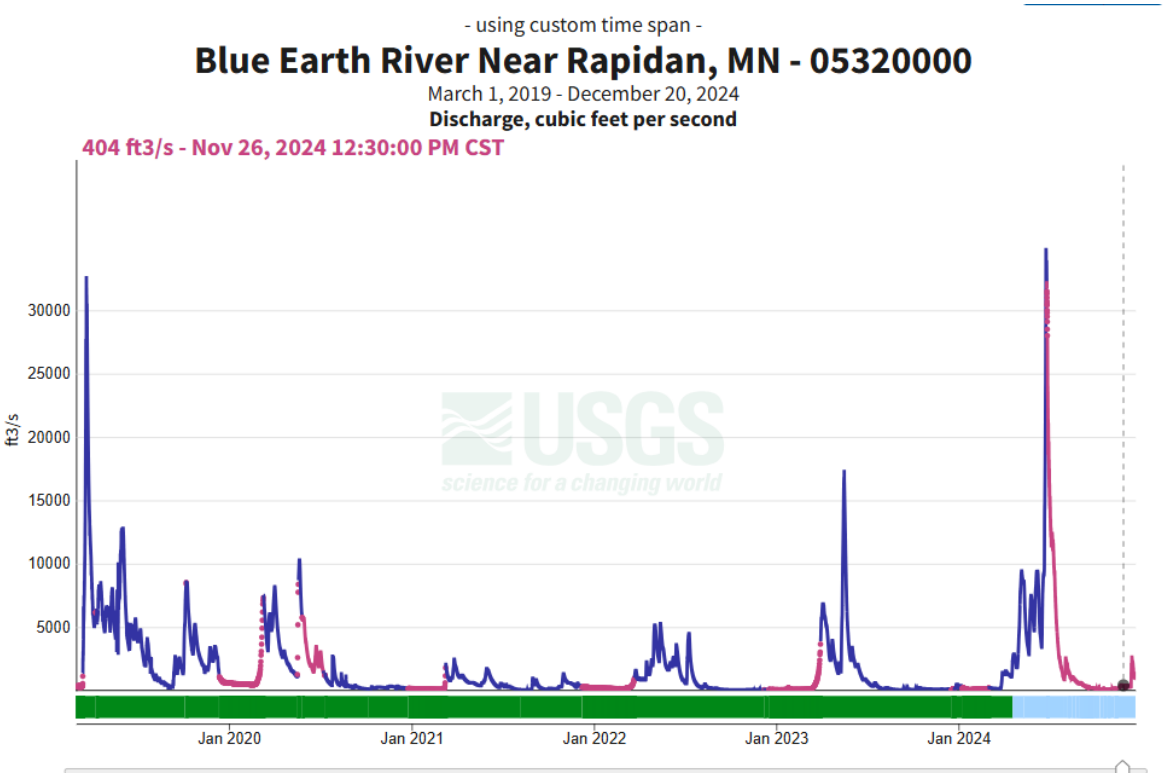

Figure 7 USGS Gage Data from March 2019 through December 2024

VI. EMERGENCY RESPONSE AND REPAIR EFFORTS

The Rapidan Dam became a focal point of public attention during the flood event and following the breach of its west abutment. As debris accumulated and flows increased, the County enacted several measures to protect public safety. The home and pie shop/store immediately to the west of the dam were evacuated. Fencing was erected around the area to keep the public away. The County contacted the contractor they typically use for debris removal; however, their equipment was at another site several hours away. Other contractors were contacted, but none would put their personnel or equipment on the structure due to safety concerns.

The County worked with various state and federal agencies to implement their Emergency Action Plan several days before the breach. The County determined that due to the high tailwater, if a failure of the dam occurred abruptly, water levels would not rise to a significant enough level to affect downstream bridges or overtop levees in Mankato, MN. Ultimately, the west abutment failed, and the adjacent home was swept downstream. The second adjacent building (pie shop/store) was acquired and removed by the County post-failure, to ensure it didn't wash downstream and add an additional hazard. No injuries or fatalities occurred.

In addition to the damage to the dam, a bridge immediately upstream underwent significant damage. The piers were undermined, and the bridge was found to be irreparably damaged and then demolished. A separate project to replace the bridge is ongoing.

VII. KEY TECHNICAL CHALLENGES AND SOLUTIONS

Barr was retained to design the removal of the dam and the associated channel. The design efforts faced several technical challenges, including coordination with the design consultant for the bridge replacement project 150 ft. upstream. Due to separate funding sources, the bridge replacement and dam removal projects are understood to be on different design timelines. Because of this, the dam removal will likely occur after the new bridge construction is complete. This will result in two design cases for the channel scour protection – an interim case where the dam is still in place and flows are restricted. Then, after dam removal, the channel will be designed to accommodate the new bridge piers. The bridge team would prefer minimizing cut to improve the construction of the piers, which means raising the channel profile as much as feasible. This will result in the river channel being constructed on engineered fill consisting of riprap, filters, and boulders.

Additionally, the area features highly erodible St. Peter sandstone bedrock. Because of the rock erodibility, the bedrock is subject to scour and can't be relied upon for channel armoring.

The HEC-RAS 2D model was used to determine channel velocities and provide the basis for the channel design through the updated channel reach. Velocities up to approximately 14 fps and shear stresses up to 12 psf were modeled upstream of the new bridge where the channel narrows during the 100-year flood. At the pinch point adjacent to the existing dam, the 2D model predicted velocities exceeding 30 fps and shear stresses exceeding 9 psf, respectively. As a result of the proposed design, these 100-year velocity and shear stress values are predicted to be reduced to approximately 13 fps and 4 psf, respectively. The proposed project includes grading approximately 6,600 linear feet of the Blue Earth River, extending approximately 4,500 ft upstream and 2,100 ft downstream of the existing dam. Large riprap is expected to protect the channel, intermixed with smaller riprap and filter aggregate to minimize void space. Benches have been included in the proposed design along some channel reaches to allow for additional flow capacity and improved floodplain connectivity during high flow events. Rock boulder vanes will also be included to provide additional stability for the constructed channel bed material. Large woody debris will be incorporated as feasible to enhance aquatic organism habitat throughout the constructed reach, while adding stability against lateral adjustment of the river channel.

In addition to the channel design, a geotechnical investigation was performed to support the reconstruction of the failed west downstream slope. County property has been swept away, and access through County property to a downstream camping area is no longer available. In order to reach the camping area, one must traverse private property. The dam removal project will include restoration of a portion of the private property and County property lost to provide access to the County-owned land downstream. It is expected that park features will be included along the west bank with water access.

VIII. CONCLUSION

The Rapidan Dam removal project design is ongoing, but various challenges have been identified. A successful project will require interdisciplinary coordination between design teams from multiple consultants. Numerous federal and state agencies are involved in the project permitting and funding, which adds additional wrinkles for the design team to navigate.

AUTHOR BIOGRAPHIES:

Jim Herbert, P.E., Vice President/Senior Civil Engineer, Barr Engineering Co.

4300 MarketPointe Drive, Minneapolis, MN 55435, JHerbert@barr.com

Jim Herbert, P.E., is a vice president and a senior civil engineer at Barr Engineering Co. In his more than 40 years of experience, he has specialized in water resource management and civil engineering, particularly in dam and tunnel services and construction administration. Jim began working on the Rapidan Dam in the late 1990s, helping Blue Earth County evaluate long-term plans for the dam and removal versus repair options. In 2002, he played a crucial role in performing emergency repairs and stabilizing the dam after severe undermining was caused by erosion of the sandstone bedrock. Jim earned his Bachelor of Science in Civil Engineering from the University of North Dakota.

Joe Hjerpe, P.E., Senior Civil Engineer, Barr Engineering Co.

4300 MarketPointe Drive, Minneapolis, MN 55435, JHjerpe@barr.com

Joe Hjerpe, P.E., is a senior civil engineer at Barr Engineering, Co. He has been with Barr for over 10 years, starting as an intern in 2014. Since then, Joe has worked on designs for numerous dam removal and spillway replacement projects. He also has experience with cutoff wall design and construction support for dams and levees. Joe graduated from the University of Wisconsin–Madison, earning a civil and environmental engineering degree with an emphasis in construction engineering management.

Tom MacDonald, Vice President/Senior Water Resources Engineer, Barr Engineering Co.

325 South Lake Avenue, Duluth, MN 55802 TMacDonald@barr.com

Ryan Thilges, P.E., County Engineer/Public Works Director, Blue Earth County

35 Map Drive, PO Box 3083, Mankato MN, Ryan.Thilges@blueearthcountymn.gov