Michigan Dam Incident Response Review

An Analysis of the 2020 Edenville and Sanford Dam Failure Response

April 2022

FEMA

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(Cover photo source: MSP 2022)

Contents

Tables and Figures

Acronyms

ADA	Americans with Disabilities Act
ASDSO	Association of State Dam Safety Officials
CEII	Critical Energy Infrastructure Information
COVID-19	coronavirus disease 2019
DEM	digital elevation model
DIRR	Dam Incident Response Review
DSS-WISE	Decision Support System for Water Infrastructure Security
DHHS	Health and Human Services
DNR	Department of Natural Resources
DOT	Department of Transportation
DSP	Dam Safety Program
DTMB	Michigan Department of Technology, Management and Budget
EAP	emergency action plan
EGLE	Environment, Great Lakes, and Energy
EM	emergency manager
EMHSD	Emergency Management and Homeland Security Division
EOC	emergency operations center
EOP	emergency operations plan
EPA	U.S. Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FERC	Federal Energy Regulatory Commission
FLTF	Four Lakes Task Force
GIS	geographic information system

HEC-RAS	Hydrologic Engineering Center's River Analysis System
ISAA	Information Sharing Access Agreement
LiDAR	light detection and ranging
MCTV	Midland Community Television
MDOT	Michigan Department of Transportation
MI	Michigan
MSP	Michigan State Police
NASA	National Aeronautics and Space Administration
NDSP	National Dam Safety Program
NIC	National Integration Center
NWS	National Weather Service
PBS	Public Broadcasting Service
PCII	protected critical infrastructure information
PDA	Preliminary Damage Assessment
PII	personally identifiable information
PIO	Public Information Officer
PMF	probable maximum flood
POD	point of distribution
PPE	personal protective equipment
US	United States
USACE	U.S. Army Corps of Engineers
VOAD	Voluntary Organizations Active in Disasters
WEA	Wireless Emergency Alert
WFO	Weather Forecast Office

Executive Summary

On the evening of May 19, 2020, following several days of heavy rain, the Edenville Dam, located one mile north of Edenville, Michigan, failed. The resulting release of water subsequently caused the Sandford Dam, located a few miles downstream, also to fail.

The record-breaking flooding caused by these dam failures caused widespread damage and destruction to buildings, homes, roads, utility infrastructure, and natural resources. More than 4,000 structures across the region were reportedly impacted by the floodwaters, with estimated losses of roughly $245 million. Fortunately, approximately 11,000 residents successfully evacuated the area with no serious injuries or loss of life reported.

This Dam Incident Response Review examines the causes for these dam failures and identifies the actions taken by the dam owners and emergency managers as the situation developed. Examining this event highlights the causes behind these dam failures, but also provides key insights and lessons for other jurisdictions with dams. The cascading impact of the Edenville dam failure causing the Sanford dam failure shows the dependencies within a water management system and the importance of collaborating across watershed areas.

Specific findings and recommendations from this review include:

Risk is increasing and dam safety should be considered on a watershed scale.

As the climate has warmed, rainfall extremes have intensified, causing the risk and severity of watershed-scale flooding to increase in many parts of the United States. The effects of localized extreme rainfall can saturate a watershed area and cause heighted risks for the inter-related system of dams. Coupled with the increasing age of dams across the country, it is important to examine dam risk across watershed areas.

Relationships and collaborative planning before an incident greatly impact effective communication, coordination, and response during an emergency incident.

Strong working relationships established during non-emergency times help build confidence and trust between the individuals, agencies, organizations involved in emergency response efforts. Strong relationships also promote efficient and effective communication and coordination during a rapidly developing incident.

Exercises provide a valuable opportunity to test plans, to confirm roles and responsibilities, and to identify areas for improvement.

Exercises build preparedness by providing a low-risk environment to validate plans, procedures, and capabilities. Exercises in areas with dams is particularly critical to clarify responsibilities between dam owners and the downstream communities in the event of a dam failure. Exercises can also help

identify resource requirements and areas for improvement for evacuation, alert and warning notifications to vulnerable populations and other operational priorities.

Data analysis is critical for planning and for impactful post-event analysis.

Consistent, quality data are key to any analytical analyses. The better the data, the better the results and outcomes. Data is needed before an event to enhance community analysis, inundation modeling, and capability assessments. After an incident it is important for agencies involved in data collection activities to work together to collect data in an appropriate and efficient manner to reduce duplicative efforts and preserve the "freshness" of perishable information.

Open communications with the community are essential to explain risk and to create more effective alerts and warnings for evacuations and shelter-in-place guidance.

Educating community stakeholders businesses, community organizations serving underserved populations, and the public about potential risk will help to increase compliance with instructions to evacuate or to shelter-in-place.

1. Introduction

This Michigan (MI) Dam Incident Response Review (DIRR) focuses on the characterization and documentation of incident response related to the Edenville and Sanford Dam failures that occurred in May 2020. The goal of this review is to better understand the events leading up to the incident, the response and recovery efforts, and the impacts of this dam incident to highlight best practices and lessons learned. This MI DIRR of the Edenville and Sanford dams was funded by the Federal Emergency Management Agency (FEMA) National Dam Safety Program (NDSP), with support from the Agency's National Integration Center (NIC).

Benefits of conducting a DIRR include:

1. Support for community efforts to build back better and stronger after a dam-related incident.
2. Gain Insights to improve FEMA's prevention, mitigation, response, and recovery policies, procedures, guidance, operations, best practices, and grants related to dams and dam safety.
3. Gather and assess real-world data to enhance modeling, dam criteria or standards, or other resources.
4. Better understanding of impacts to the built environment with implications for effective mitigation.
5. Document of best practices and lessons learned as technical assistance for other dams.
6. Coordinate and collaborate with partners from federal, state, local, tribal, and territorial government, along with private sector, research organizations, non-profits, industry, academia, and others.

The *Edenville and Sanford Dams: Incident Response Review* provides an overview of Argonne National Laboratory's research findings related to the Edenville and Sanford Dam failures, including why and how the dams failed, the magnitude and extent of impacts, how the dam emergency was handled, and who played what roles during the incident and response. In addition, this review documents the best practices, lessons learned, challenges, and areas of improvement identified during and after these dam incidents.

To support the information and findings in this report, the MI DIRR team performed extensive open-source research, analyzed available data sets, and interviewed more 20 individuals representing 10 different agencies and organizations, including:

- American Red Cross
- FEMA Region V
- Four Lakes Task Force (FLTF)
- Gladwin County
- Michigan Department of Environment, Great Lakes, and Energy (EGLE)
- Michigan Department of Health and Human Services (DHHS)
- Michigan State Police (MSP)
- Midland County
- National Weather Service (NWS)
- U.S. Army Corps of Engineers (USACE)

Table 1 provides additional details on each agency's roles and responsibilities during and after the Edenville and Sanford dam failures.

Table 1: Overview of the Roles and Responsibilities Related to the Dam Failures and Associated Response of the Agencies Interviewed

Agency	*Roles and Responsibilities Related to the Dam Failures and Associated Response*
American Red Cross	Sheltering
FEMA Region V	Situational monitoring; federal support (e.g., damage assessments); and voluntary agency activity coordination
Four Lakes Task Force (FLTF)	Consultation and technical support (as Delegated Authority on behalf of Midland and Gladwin counties)
Gladwin County	Emergency management coordination and incident response
Michigan Department of Environment, Great Lakes, and Energy (EGLE)	Emergency management; situational monitoring; oversight of response actions; and federal/state/tribal/local agency coordination
Michigan Department of Health and Human Services (DHHS)	Multi-agency coordination for health-related issues and assistance requests
Michigan State Police (MSP)	Onsite situational monitoring; incident coordination and response (link between the county emergency operations center [EOC] and state EOC); state resource request coordination; and damage assessment and recovery support
Midland County	Emergency management coordination and incident response
National Weather Service (NWS)	Issued flood warnings; provided regular updates and reports on current and developing weather and river stage forecasts
U.S. Army Corps of Engineers (USACE)	Technical support; field data collection; and rapid inundation modeling and mapping

2. Why and How the Dams Failed

2.1. Incident Overview

A stalled low-pressure system over the southern Great Lakes region brought record rainfall to southeast Michigan over a three-day period from the morning of May 17, 2020 and continuing through the morning of May 19. Historic flooding occurred along several rivers across the region, including the Cedar, Tobacco, and Tittabawassee rivers in Gladwin and Midland counties. The excessive rainfall, in combination with a decade-long history of maintenance and compliance issues, led to the catastrophic failure of the Edenville Dam on the evening of May 19. The resulting flood wave caused the subsequent failure of the Sanford Dam, just northwest of the City of Midland. The record-breaking flooding resulted in widespread damage and destruction to buildings, homes, roads, utility infrastructure, and natural resources (e.g., forest and lake ecosystems). Approximately 11,000 residents were successfully evacuated with no serious injuries or loss of life reported. More than 4,000 structures across the region were reportedly impacted by the floodwaters, with estimated losses of roughly $245 million (Galvin 2020), which is on the same order as FEMA's preliminary damage estimates of more than $250 million (EGLE 2020).

2.2. Dams Overview

The dams of interest in this study are located in the lower peninsula of Michigan—specifically, within Gladwin and Midland counties, as illustrated in Figure 1. The Edenville Dam (Wixom Lake) and Sanford Dam (Sanford Lake) are part of a series of four consecutive dams along the Tittabawassee River (identified with red flags) that also includes the Secord Dam (Secord Lake) and Smallwood Dam (Smallwood Lake). At the time of the incidents, Boyce Hydro Power, LLC (Boyce Hydro), located in Nevada, owned and operated all four dams. Gladwin County and the City of Beaverton locally own and operate two other area dams, the Chappel Dam (Wiggins Lake) and Beaverton Dam (Ross Lake) upstream on the Cedar and Tobacco rivers, respectively.

Originally built in the early 1900s (c. 1912–1925), all six dams were constructed primarily for hydropower generation, not flood control purposes (FLTF 2020a), although their presence does help control the downstream flow along these river systems, into the city of Midland, and eventually the Saginaw River. Over the years, the lakes and ecosystems created by these dams have become a naturalized part of the environment and have created significant economic, recreational, and social benefits to the local communities and the state (FLTF 2020c).

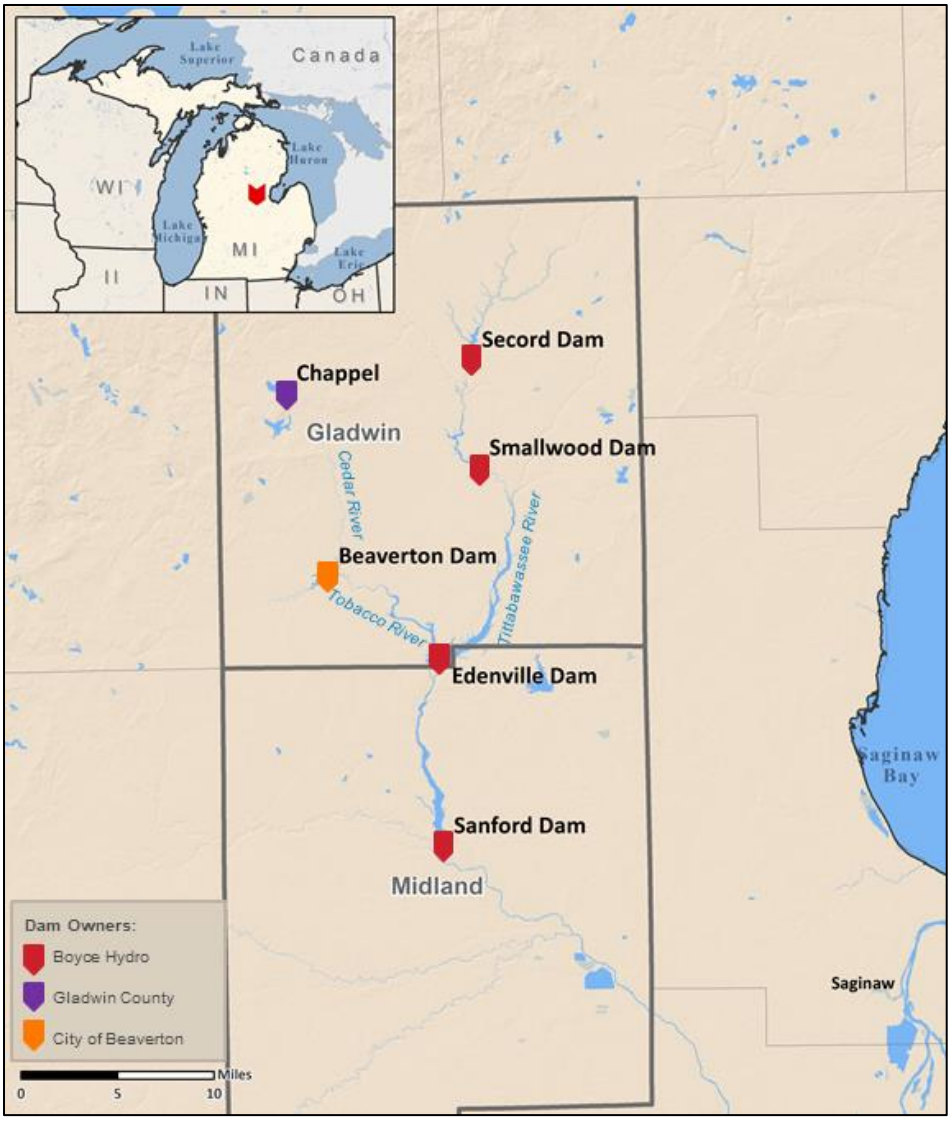

Figure 1: Six dams of interest along the Tittabawassee, Cedar, and Tobacco rivers located in Gladwin and Midland counties

The Edenville and Sanford dams (figures 2 and 3, respectively) are both earthen embankment dams with concrete ogee spillways equipped with Tainter gates.[1] The Edenville Dam is located on the county border between Midland and Gladwin counties and was constructed in two sections: one embankment/gate-controlled spillway across the Tittabawassee River and another across the Tobacco River. The powerhouse is located on the Tittabawassee River side of the dam. Prior to failure, the Edenville Dam was 54 feet high and about 6,600 feet in length at its crest (TRC Engineers Michigan, Inc. 2020). Wixom Lake was approximately 2,300 acres (40,000 acre-feet) at

[1] An ogee spillway has a control weir with an S-shaped curved downstream face that is designed on the basis of the principle of a projectile. Tainter gates, named after the engineer who invented them, are a type of radial arm floodgate used throughout the world in dams and canal locks to control water flow.

normal summer elevation. The Sanford Dam is located 10 miles south, downstream from Edenville on the Tittabawassee River. It consisted of four major components: the left embankment, powerhouse, gate-controlled spillway, and the right embankment with an additional fuse plug spillway. Prior to its failure, the Sanford Dam was 36 feet high and approximately 1,580 feet long (Spicer Group, Inc. 2019). At normal summer elevation, impounded water formed the approximately 1,500-acre (15,000 acre-feet) Sanford Lake.

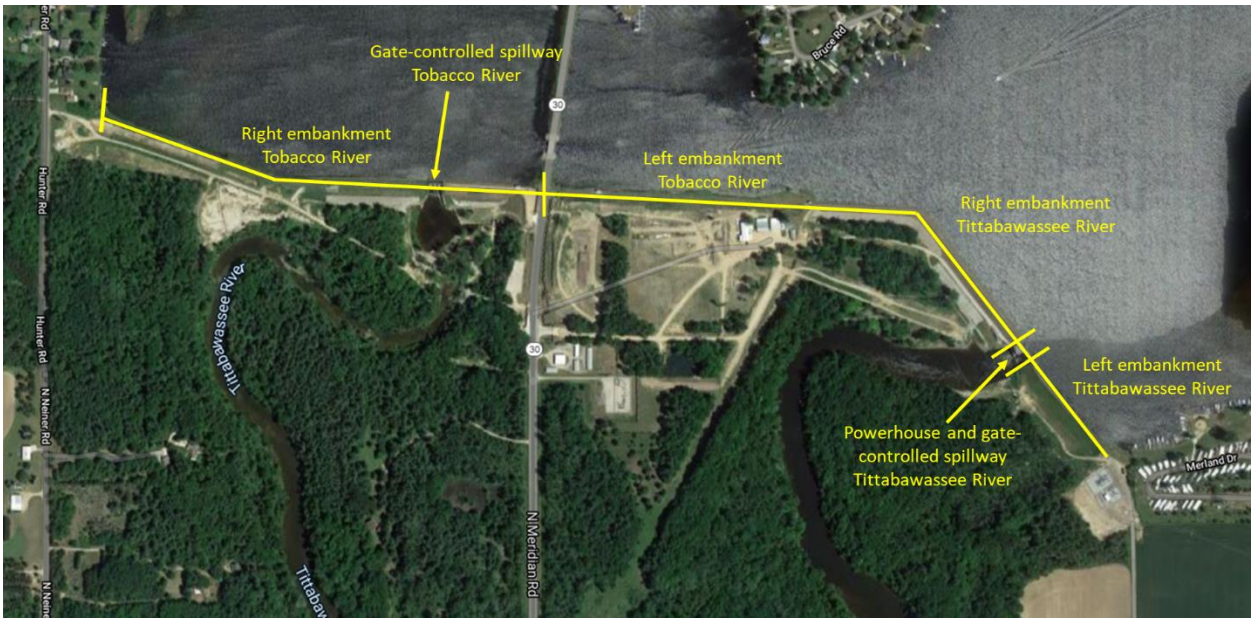

Figure 2: Main sections of Edenville Dam *(left to right, looking downstream)*

Figure 3: Main sections of Sanford Dam *(left to right, looking downstream)*

In June 2017, Boyce Hydro received a Federal Energy Regulatory Commission (FERC) compliance order for long-standing failure to make necessary capital improvements to address management and safety concerns at Edenville Dam. By September 2018, FERC officially revoked Boyce Hydro's hydroelectric generating license for continuing failure to address ongoing non-compliance. Following the revocation of the facility's FERC license, jurisdiction and regulatory authority for the Edenville Dam transferred to Michigan's Department of Environment, Great Lakes, and Energy (EGLE) Dam Safety Program (DSP). By May 2019, the Midland County Circuit Court named the Four Lakes Task Force (FLTF), a nonprofit, volunteer, community-led organization, as the Delegated Authority for the four dams—Edenville, Sanford, Secord, and Smallwood—and their respective lakes; Wixom, Sanford, Secord, and Smallwood. The FLTF would acquire the dams and lakes from Boyce Hydro, then repair and operate them on behalf of Midland and Gladwin counties (FLTF 2021a).

In December 2019, using funds from Midland and Gladwin counties and assessments on residents, the FLTF entered into a purchase agreement with Boyce Hydro to acquire the dams. The first installment was scheduled for June 2020, but after the flood and subsequent dam failures in May, the acquisition was put on temporary hold and Boyce Hydro subsequently declared bankruptcy (FLTF 2020c). In December 2020, a judge for the U.S. Bankruptcy Court for the Eastern District of Michigan granted a motion to allow FLTF to acquire title to all four Boyce Hydro dam properties through condemnation, also known as *eminent domain* (FLTF 2020b). The official transfer of property occurred in January 2021. The FLTF has officially formed an Operations Transition Team to manage the safe transfer of the asset and is moving forward with studies and planning to stabilize and rebuild the infrastructure required to restore Wixom and Sanford lakes (FLTF 2021b).

2.3. Incident Timeline

2.3.1. RECORD RAINFALL AND HISTORIC FLOODING

Beginning a few days before the dam incidents, on the morning of Sunday, May 17, 2020, and continuing into the morning hours of Tuesday, May 19, 2020, a stalled low-pressure system and frontal boundary across the southern Great Lakes region brought record rainfall to southeast Michigan. Figure 4 illustrates a static shot of a weather map from the early evening on May 17, with the black box highlighting Gladwin and Midland counties, where the dams are located.

Widespread rainfall totals of 5-8 inches (characterized as having an annual exceedance probability of 0.5 percent[2]) led to significant flooding of several of the region's rivers and historic flooding along the Tittabawassee River. Figure 5 illustrates the total rainfall experienced across the region. The NWS issued multiple flood warnings for the affected counties. High water closed roads and bridges; traffic signals were down due to area power outages. To protect the integrity of the dams' infrastructure, all six dams along the Tittabawassee, Cedar, and Tobacco River system were running

[2] An annual exceedance probability of 0.5 percent means a rain event of this size has a 1 in 200 chance of occurring in a given year.

with gates wide open and actively trying to lower water levels in their impounded lakes. In addition to river flows, excess surface runoff generally flows north to south downstream towards the Edenville and Sanford dams, exacerbating the flooding situation.

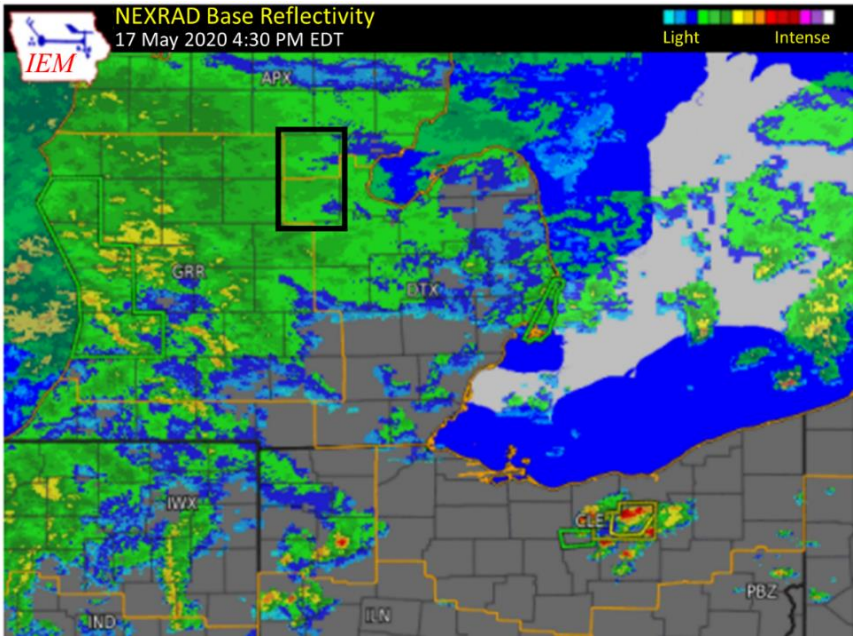

Figure 4: Static shot of weather map from the early evening on May 17, 2020; black box indicates location of Gladwin and Midland counties (NWS 2020a)

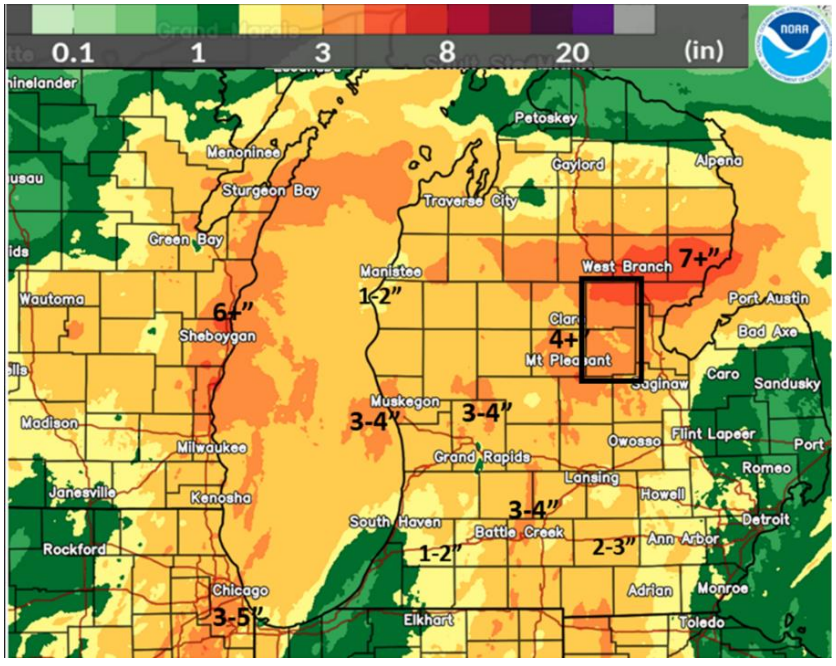

Figure 5: Total rainfall, May 17-May 19, 2020; black box indicates location of Gladwin and Midland counties (NWS 2020c)

The Gladwin and Midland County Emergency Managers (EM) were in regular contact during this time, providing updates on flooding and potential issues occurring at the area's dams. The EMs were also in frequent contact with the various local dam operators. The NWS local Weather Forecast Offices (WFOs) also provided the EMs regular updates on current and developing weather and river stage forecasts (Boyer 2020, North 2020).

2.3.2. THE EVOLVING SITUATION AT THE DAMS

On the evening of Monday, May 18, 2020, concern in Gladwin County centered around the Chappel Dam on the Cedar River and Smallwood Dam on the Tittabawassee River. The Chappel Dam was near overtopping and experiencing some erosion issues because of high flow conditions and water lapping over the side of the dam near the old powerhouse, which was no longer producing energy. Fortunately, the dam operators, who were onsite with the dam engineer and emergency responders (i.e., Gladwin County EM and Sheriff), were able to stabilize the dam using backfill (e.g., gravel and sand), mitigate the issue, and prevent failure (North 2020, Trumble 2020). At the Smallwood Dam (Figure 6), the auxiliary spillway activated as designed, but significant erosion was occurring at multiple locations due to high flow conditions, water escaping through the powerhouse structure, and turbulent eddy currents in the tail water area of the dam (North 2020, Trumble 2020). As with Chappel Dam, dam operators were able to successfully mitigate some of the damage and prevent failure.

Figure 6: Smallwood Dam erosion and emergency spillway activation during the May 2020 flood event (Jacuzzibusguy 2020)

In Midland County, the EM was in phone communication with the onsite operators at Edenville Dam. Around 9:00 pm on the night of May 18, dam operators conveyed uncertainty regarding the state of the dam and how the situation might develop overnight, which left the Midland County EM with major

concerns over the dam's potential for failure due to overtopping. As a result of this call, and after consideration of the time of day and availability of resources[3], the Midland County EM and a consensus of county officials decided to issue an immediate and preemptive evacuation order[4] (before official activation of the EAP) around midnight. The order included residents living along Sanford and Wixom lakes and the communities of Edenville, Jerome, and Sanford—the first three communities downstream that would be impacted within 1–5 hours in the event of the Edenville Dam failing. Following the county's *Dam Failure Response Plan* and starting in the areas at highest risk, the fire department and sheriff's office performed door-to-door notifications as a follow-up to the emergency alerts. Shelters were set up at a local middle and high school.

At around 12:30 am on Tuesday, May 19, 2020, the dam operators initiated the emergency action plan (EAP) for all four Boyce Hydro dams and began the formal process for Boyce Hydro to notify local agencies and officials of a dam-related incident. Interestingly, Boyce Hydro did not directly notify the state DSP officials from EGLE of these evolving conditions at the dams at this time, even though they are listed on the EAP call-out notification tree. Instead, the onsite Edenville Dam operators directly notified them later the next morning around 9:00 am (DeVaun 2020, Trumble 2020). The Gladwin and Midland county EMs were already fully aware of the situation by the time the EAP was activated. They had been in regular communication with the dam operators by phone in the days leading up to the dam emergency.

In the early hours of May 19, Boyce Hydro onsite dam operators along Tittabawassee River identified that flooding and high-water levels were becoming a problem and raised the condition level at the dams to Condition B—"potentially serious condition developing"—indicating the potential for dam failure. Around 3:30 am, the Smallwood Dam sounded its warning siren because the lake water had reached a level that was concerning (North 2020). Significant flooding around the Smallwood Dam led Gladwin County to issue evacuations for the impacted area. Fortunately, Smallwood Dam never breached. As for the Edenville and Sanford Dams, the dams' gates were fully open and the spillways overwhelmed, such that overtopping was still a concern (Boyer 2020). Figure 7 shows the Edenville Dam Tittabawassee River spillway discharging floodwaters at full capacity prior to the dam's failure.

Throughout the morning and into the afternoon of May 19, concern grew steadily at Edenville Dam as a combination of factors added to its instability. Although the rain had stopped, the two dams of the Cedar and Tobacco River system and the four dams of the Tittabawassee River system continued large-volume, full capacity spillway releases of runoff water, which was stored in their reservoirs. The resulting high flows led to extensive flooding in the watershed upstream of Edenville Dam. Wixom Lake's water levels had risen to within about two feet of cresting the dam. Thus, the main concern during this time was that the dam would overtop and fail as water levels in the lake continued to rise (Trumble 2020). The Tittabawassee River side of the dam near full capacity prior to the dam's failure

[3] Section "*4.2.2 Preemptive Evacuation"* provides additional details on time of day and availability of resources considerations.

[4] Section "*4.2.1 Clear Consistent Messaging"* provides additional details on public communication and messaging.

is also shown if Figure 7. However, the dam was experiencing multiple other issues as well. Wave action due to high winds was causing erosion along the upstream face of the Tittabawassee River side of the dam. Adjacent to the Tobacco River spillway on the downstream side of the dam, additional erosion was occurring because of discharge splashing up and over the wing walls, along with weep-hole seepage within the retaining walls. Increased seepage was also observed from the toe drains, which were not properly daylighted (i.e., open to allow water flow), along with some sluffing along the toe drain ditches (DeVaun 2020, Trumble 2020).

Figure 7: Tittabawassee River side embankments near capacity and fully open spillway gates on May 19, before the dam's failure (PBS 2020)

EGLE DSP officials, along with an earth moving contactor and dam engineer representing the FLTF, were onsite at Edenville monitoring the situation, assessing conditions, and advising the dam operators as they made decisions to help mitigate the issues occurring at the dam (DeVaun 2020, Trumble 2020). Mitigation measures, including the installation of turbidity curtains, use of geofabrics, and placement of sandbags, were applied at the time due to potential stability concerns related to the saturated embankment. Onsite officials and personnel were considering the option of a controlled breach if lake levels continued to rise. A controlled breach near the left abutment, where water depths were shallower and the grade was flatter, would increase the discharge released downstream and prevent the overtopping and potential failure of the dam at its deepest part. There was a large excavator on the site, but onsite officials and personnel decided to delay this action for a few hours and monitor developments (DeVaun 2020).

Neither the Nevada-based dam owner nor a Boyce Hydro dam engineer or consultant were present onsite during the emergency, although EGLE DSP officials were in phone contact with the owner.

EGLE DSP officials were also in direct contact with multiple other local, state, and federal agencies, including the owners of Chappel and Beaverton dams, FERC, state EMs (at the state EOC), and the Gladwin and Midland County EMs. They were checking-in on what people knew, providing updates from the field, inquiring about flooding and flow conditions, and making sure people had what they needed to make critical decisions.

2.3.3. THE DAMS FAIL

On the evening of Tuesday, May 19, 2020, around 5:40 pm the Edenville Dam failed when a section of the dam started sloughing, which rapidly progressed to slope failure along the eastern Tittabawassee River portion structure's embankment wall (EGLE 2020). The exact cause(s) of the Edenville Dam failure is still under independent investigation by a team of qualified individuals (outside of FERC, EGLE, and Boyce Hydro) with expertise in the various disciplines of dam safety engineering (EGLE 2020). However, Figure 8 illustrates the progression of the breach along the Tittabawassee River embankment immediately after it began. A small stream of water overtopping the dam appears to have caused sloughing on the downstream face of the embankment. The sloughing eventually led to slope failure, likely caused by the instability of the embankment rather than erosion of the crest. This is supported by the observation that the breach discharge, after the failure of the downstream slope, initially remained small because it was controlled by the higher upstream slope crest. The increased muddy flow that followed was due to the increased erosion and subsequent failure of the upstream face of the embankment.

The breach sent an uncontrolled release of water down the already flooded Tittabawassee River toward Sanford Lake and the Sanford Dam. Upon notification of the failure, the Midland County EM fully activated its EOC. Midland County Central Dispatch Authority[5] (referred to as Central Dispatch) immediately issued repeat evacuation notices for the three communities initially evacuated (Edenville, Jerome, and Sanford) along with additional notices to four other communities (Lincoln, Homer, City of Midland, and Midland Township) further downstream. The NWS also sent out a flash flood warning.

County officials closed additional roads and bridges were closed, and more emergency shelters were opened throughout the area. Emergency managers and first responders deployed a team north of the breach to monitor for distressed kayakers or boaters (North 2020). Emergency vehicles drove down streets with lights, sirens, and air horns making public evacuations announcements in the jurisdictions immediately downstream. Public safety officials began to close roads and perform door-to-door notifications in the communities farther downstream, which had more time to evacuate (North 2020, Boyer 2020).

[5] Midland County Central Dispatch Authority (or Central Dispatch) is a consolidated emergency services answering point and 9-1-1 call center, responsible for handling law enforcement, fire, and medical requests for the City of Midland and Midland County.

Figure 8: Progression of Edenville Dam breach along the Tittabawassee River embankment as it began, 20-second time-lapse *(from top to bottom)* (Coleman 2020)

Within the next few hours, the floodwaters reached Sanford Dam. Until that point, the dam was not at immediate risk or concern of failure, although it was operating with fully open flood gates. However, the flood wave coming downstream from the Edenville Dam was more than Sanford Dam was capable of handling and eventual failure was expected: an assumption included in the Boyce Hydro dams' EAP.

The design of the Sanford Dam embankment included a "fuse-plug spillway" section, which consisted of a concrete weir overtopped by an embankment designed to wash away in high flood conditions. It was assumed that, once the embankment failed, the underlying concrete weir would serve as an auxiliary spillway to increase the discharge released downstream and thereby prevent the overtopping of the dam and potential subsequent failure. At around 7:45 pm, the fuse plug began to wash out, but the rate of water level rise was so fast that the dam overtopped the earthen embankment before the washout process was complete (Figure 9). The overtopping of Sanford Dam sent floodwaters further downstream through Sanford and toward the cities of Midland and Saginaw, where the Tittabawassee River joins the Saginaw River and ultimately outlets to Saginaw Bay. In the end, the entire right embankment with fuse plug eroded down; the spillway, powerhouse, and left embankment largely remained intact.

Figure 9: Sanford Dam overtopping on May 19, 2020 (CFI Media 2020)

2.3.4. POST-FAILURE

Governor Gretchen Whitmer issued an emergency declaration for Midland County late on Tuesday, May 19, 2020 (adding Arenac, Gladwin, and Saginaw counties on May 22). The governor also held a press conference around 10:00 pm during which she urged downstream residents to evacuate, even though Michigan was under a COVID-19 (coronavirus disease 2019) stay-at-home order. President Trump followed on May 21 with his approval of an emergency declaration for areas throughout mid-

Michigan hit with catastrophic flooding. These two declarations helped ensure federal aid availability for impacted areas. The Michigan State Police (MSP), National Guard, and American Red Cross, along with several Michigan state departments (e.g., EGLE, Health and Human Services [MDHHS]; Transportation [MDOT]; Technology, Management and Budget [DTMB]), provided support, resources, and additional assistance during the ongoing response and recovery efforts. EGLE DSP continued to provide technical expertise and field support related to ongoing safety and stability issues at the remaining portions of the Edenville Dam (i.e., Tobacco River side earthen embankment) and Sanford Dam, as well as the dams upstream. EGLE, in coordination with the Department of Natural Resources, also deployed teams to assess the extent of damages to environmental resources and aquatic species in and around the Wixom and Sanford Lake impoundment areas.

The successful evacuation of approximately 11,000 people in Midland and Gladwin counties prevented any significant injury or loss of life. However, the flooding across the region led to the complete destruction of numerous structures and extensive damage to both public and private property. Floodwaters also washed out several bridges and roadways, including multiple sections of M-30, a state trunk-line highway that runs north to south through Gladwin and Midland counties, and caused the temporary closure of hundreds of other roads and bridges until the waters receded and inspections could be completed. Figure 10 provides a before-and-after image of the Curtis Road bridge, located just a half-mile south of the Edenville Dam on the Tittabawassee. The “after” image was taken May 21 before floodwaters fully receded. In addition, nearly 5,500 customers in Midland County and 2,900 customers in Gladwin County were left without electric power (Lascari 2020). Power outages also affected numerous traffic signals.

Figure 10: Curtis Road Bridge: Aerial imagery before and after the Edenville dam failure *(left,* May 2019, *and right,* May 21, 2020) (Wilkinson/Maxor 2020)

Around 6:30 am on Wednesday, May 20, 2020, floodwaters caused the failure of the Poseyville Road dike. The resulting flood inundated a small business and residential area located in Midland Charter Township, just south of the City of Midland, and required local officials to issue additional emergency notifications and evacuation orders.

The Tittabawassee River, which normally runs at around 12-14 feet during this time of year, was predicted to crest at 38 feet in Midland on the evening of May 20. However, by midday, the river

crested slightly lower at 35.05 feet, still shattering the previous record of 33.94 feet set in 1986, by more than a foot. Figure 11 illustrates the measured and predicted levels of the Tittabawassee River at Midland before and after reaching peak height (NWS 2020b). The cumulative effects of the rain event (with a 0.5 percent annual exceedance probability) and subsequent dam failures has been categorized as a having a historical 0.2 percent annual exceedance probability.[6] Figures 12 and 13 show before-and-after images of the Edenville and Sanford dams, respectively.

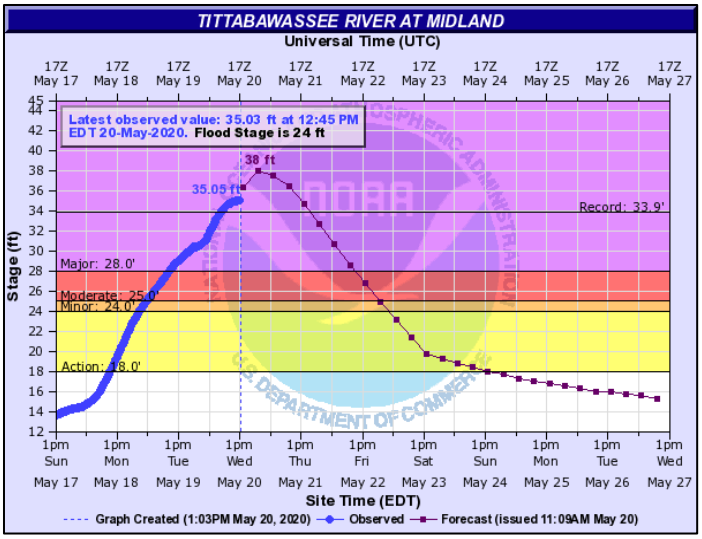

Figure 11: Measured and predicted Tittabawassee River levels at Midland before and after reaching peak height (NWS 2020b)

Once the river had crested and the flows began to recede, the four upstream dams were able to begin closing their gates and stem the flow downstream. However, the downstream flooding was slow to recede and safety concerns at the area's dams lingered for several days because of the large volumes of water that remained behind the four upstream dams—Secord, Smallwood, Chappel, and Beaverton. Fortunately, none of these dams failed. The eventual drawdown of water, ordered by FERC to allow appropriate inspection and necessary repairs, alleviated failure concerns at those dams.

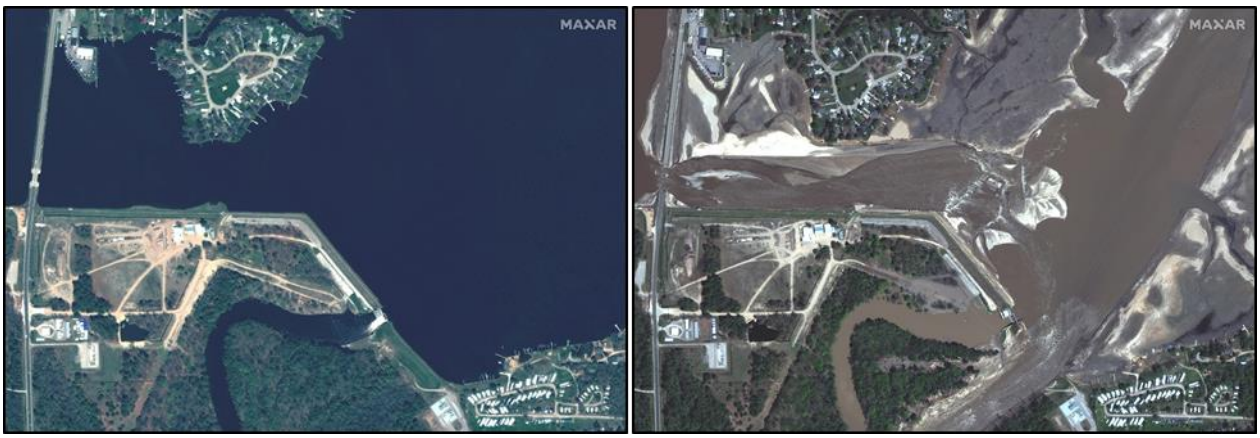

Figure 12: Edenville Dam: Aerial imagery before and after the dam failure *(left,* May 2019, and *right,* May 21, 2020) (Wilkinson/Maxor 2020)

[6] An annual exceedance probability of 0.2 percent means a flood event of this size has a 1 in 500 chance of occurring in a given year.

Figure 13: Sanford Dam: Aerial imagery before and after the dam failure *(left,* May 2019, *and right,* May 21, 2020) (Wilkinson/Maxar 2020)

Figure 14: NASA Landsat satellite image of sediment flowing into Saginaw Bay at Bay City a few days after the dam failures (Skilling 2020)

Subsequent downstream flooding also occurred in Saginaw County, where the Tittabawassee River joins the Saginaw River. Floodwaters also contributed to rising waters along the Cass River and led to a dike breach on Birch Run Creek on May 21, 2020. Residents of Spaulding Township were urged to evacuate (Simpson-Mersha 2020). Sediment-loaded floodwaters made their way approximately 60 miles downstream from Sanford Dam and into the Saginaw Bay at Bay City. Figure 14 shows a National Aeronautics and Space Administration (NASA) Landsat satellite image of the Saginaw Bay at Bay City on Thursday, May 21, 2020.

By the morning of Friday, May 22, some evacuees started to return to their homes, as conditions permitted. All evacuees remaining in congregate shelters (e.g., open floor plans and shared sleeping,

eating, and bathroom arrangements) were moved to non-congregate shelters (e.g., hotels) by Sunday, May 24. Reported barriers to individuals leaving non-congregate shelters included availability of affordable housing, pending insurance processes; home cleanup and repair needs, pending inspections and contract work; and specific access and functional needs requirements (Moran-Gardner 2020b).

On June 12, 2020, the State EOC concluded incident response operations and transitioned to recovery activities. A Federal Stafford Act major disaster declaration was issued on July 9, 2020. Recovery efforts, including dam stabilization, erosion prevention, damage assessments, extensive debris removal, infrastructure repairs, home repairs, and environmental monitoring, continued for months after the incidents and into 2021.

2.4. Reasons for the Dam Failures

The reasons for the Edenville and Sanford dam failures are a complicated combination of many factors. Although the exact cause(s) of the dam failures will not be fully known or understood until a full independent forensic investigation of the failures is complete, many of the underlying issues are evident. Multiple litigations are ongoing between Boyce Hydro, EGLE, and FERC over responsibility for the dam failures.

First licensed by FERC in 1998 and acquired by Boyce Hydro in 2006, the Edenville Dam had more than a decade-long history of compliance issues related to known deficiencies and Boyce Hydro's failure to adequately address them. The extensive list of needed repairs and improvements included issues with spillway capacity that eventually led to the revocation of Edenville's FERC license in September 2018. Compounded by the heavy rain and resulting flooding, the 96-year-old dam was stressed beyond its limit and ultimately breached. The smaller Sanford Dam subsequently failed as a direct result of the flood wave that came downstream from the Edenville Dam, which caused the level of the impounded lake to rapidly rise and overtop the dam, leading to its successive failure.

The complicated regulatory oversight history of Edenville Dam is also reported as a contributing factor to the dam's failure. In Michigan, FERC has sole regulatory authority over all hydropower dams and state statutes do not create duplicative oversight. Thus, if a hydropower dam loses its FERC license (as was the case of Edenville Dam), regulatory authority transfers to the state (i.e., EGLE DSP). However, because duplicative authority does not exist, EGLE DSP did not possess much documentation on the dam and lacked vital knowledge of the dam's regulatory history and past engineering assessments (EGLE 2020). In addition, EGLE DSP faced information-sharing difficulties that inhibited the transition of regularity authority, since much of FERC's data and records (e.g., past inspection reports, historical files, technical analysis) are protected from public dissemination due to federal infrastructure laws (i.e., protected critical infrastructure information [PCII] or critical energy infrastructure information [CEII]) (Trumble 2020). Consequently, EGLE DSP had to reinspect and reassess the dam and recreate its compliance history, which resulted in a steep learning curve to understand how the Edenville Dam met state regulatory requirements (which differ slightly from

federal requirements for high hazard potential dams) (Trumble 2020).[7] It was not until late 2019 that EGLE DSP was finally able to determine, based on preliminary analysis, that the dam did not comply with state regulatory requirements either, at which point they began working with Boyce Hydro and the FLTF to address the dam safety issues and needed upgrades (Trumble 2020). The final comprehensive engineering analysis (which EGLE DSP needed to confirm its initial conclusions, adequately address concerns, defensibly enforce regulations, and hold Boyce Hydro accountable) was ongoing at the time of the dam failures.

Another cited issue underlying the Edenville and Sanford dam failures is related to the fact that the state of Michigan has not sufficiently invested in safety of its dams for many decades (ASDSO 2020). According to a report published by an Association of State Dam Safety Officials (ASDSO) Peer Review Team in September 2020, this lack of investment led to the accumulation of dam safety needs as the state's dams aged (often well beyond their originally intended design life). In addition, even though existing staff are fully qualified and dedicated, the EGLE DSP is extremely understaffed (ASDSO 2020). At the time of the dam failure, there were only two full-time dam safety engineers, with some administrative support, to oversee roughly 1,100 dams. This makes it difficult for the DSP to perform their mission as mandated by the legislation, rules, and best practice. Moreover, the rigorous enforcement of dam safety violations has also been lacking for decades in Michigan, which, in the case of Edenville, has exposed the downstream areas to the consequences of dam failure (ASDSO 2020).

3. Magnitude and Extent of Impacts

The cascading failures of the Edenville and Sanford dams, in combination with widespread heavy rain and historic flooding, impacted more than 4,000 homes and businesses across the region, with estimated losses of roughly $245 million (Galvin 2020). Approximately 1,000 of these structures were severely damaged or destroyed; the remaining 1,500 buildings experienced minor flood damage (NWS 2020b). Damage to natural resources from the flood was also extensive, including harm to lakes' ecosystems, fish, wildlife, and wetlands. In addition, although numerous human lives were disrupted and approximately 11,000 people were evacuated, no serious injuries or loss of life were reported. The observed inundation extent of the flooding is presented in Figure 15. Data does not include flood depth and were available only for Midland County and part of Saginaw County. This data covers the area south of the Edenville Dam to the confluence of Tittabawassee and Saginaw

[7] Although many FERC dam safety requirements are similar to those of EGLE DSP, one major difference exists. FERC requires that high hazard potential dams be able to safely convey the full probable maximum flood (PMF), whereas Michigan (under Part 315 of The Natural Resources and Environmental Protection Act, 1994) requires that high hazard potential dams over 40 feet high be able to safely convey only one-half PMF. Prior to revocation of the FERC license, it was well documented by FERC that the Edenville Dam could not pass full PMF flows. However, there was no analysis available on the dam's ability to pass the one-half PMF flows (EGLE 2020).

Rivers. Observed data were not available for flooding extent from the confluence of the Tittabawassee and Saginaw rivers to Saginaw Bay, which runs through Saginaw and Bay counties.

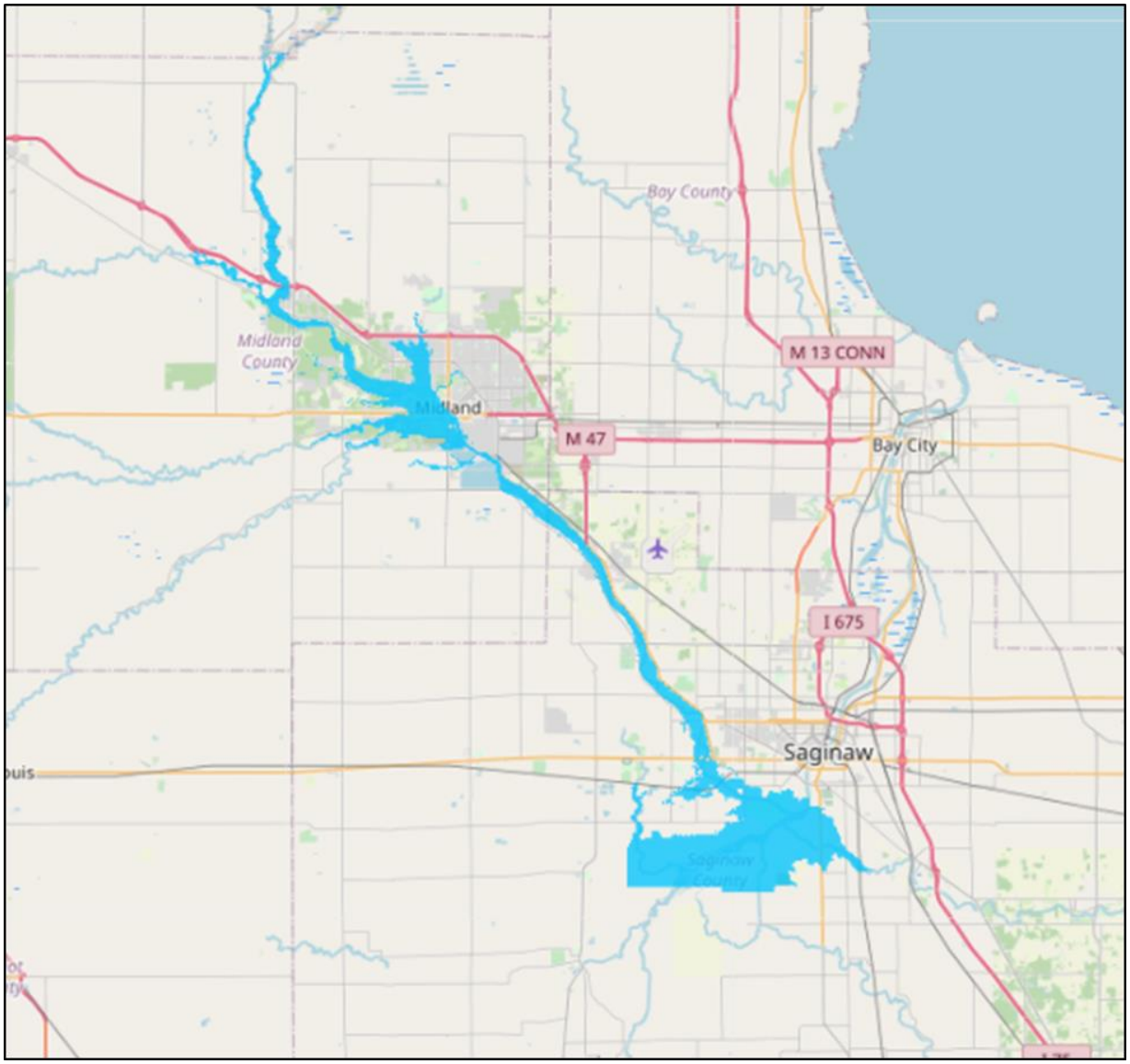

Figure 15: Observed inundation extents for Midland and Saginaw counties after the May 2020 dam failure and flooding incidents (Midland County 2020a)

Figure 16 presents the full downstream extent of the flooding, along with maximum flood depth, as simulated by Decision Support System for Water Infrastructure Security (DSS-WISE) Lite.[8]

[8] DSS-WISE Lite is a web-based tool that offers automated two-dimensional dam-break analysis and post-processing of human consequences. It was especially designed to assist dam safety officials to perform rapid and reliable two-

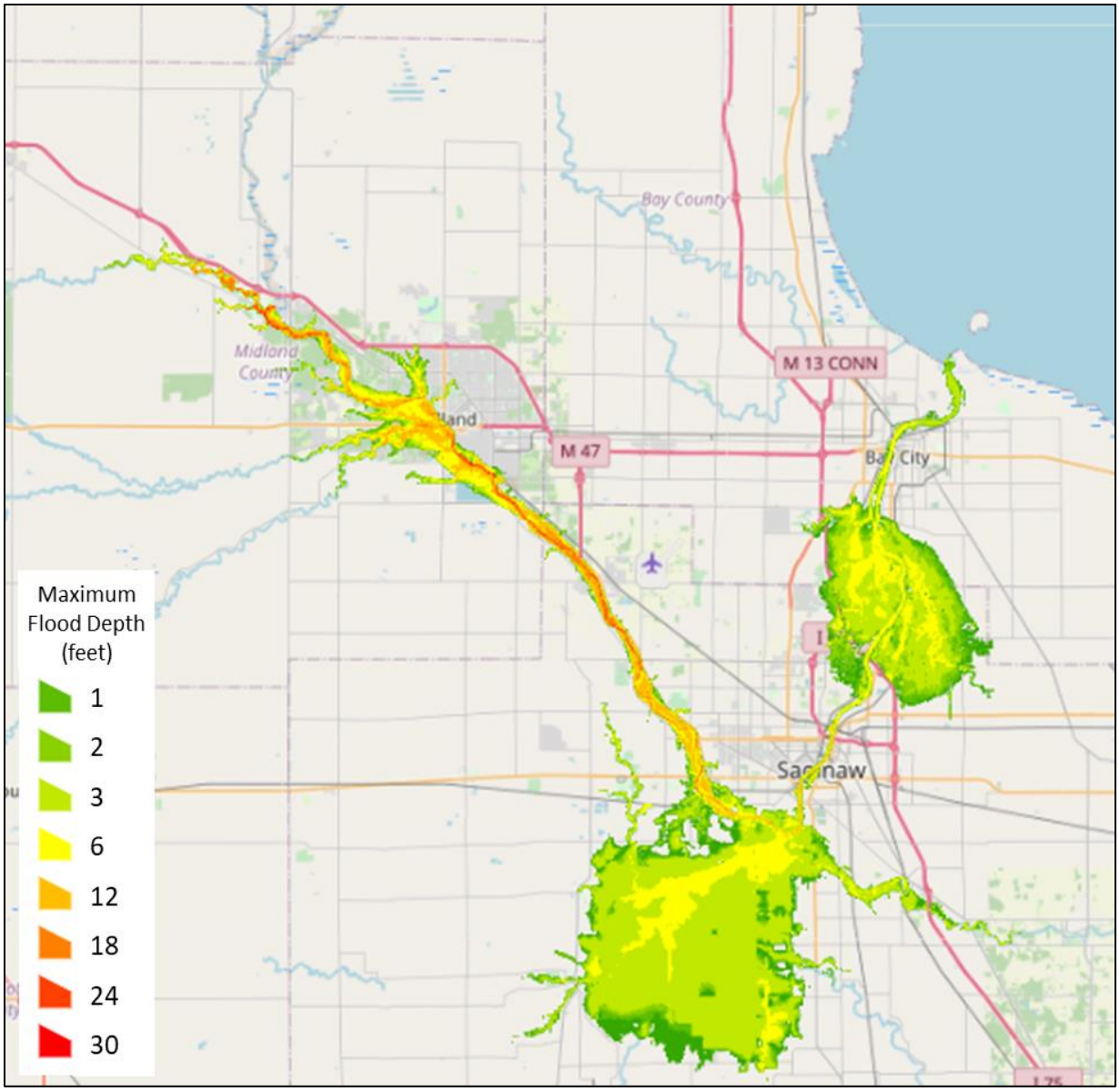

Figure 16: Maximum flood depth (in feet) as simulated by DSS-WISE Lite for the May 2020 dam failure and flooding incidents

dimensional dam-breach simulations for preparedness phase. Using an extremely fast computational engine makes DSS-WISE Lite also an ideal tool for real-time emergency simulations for emergency response planning during real-life dam safety incidents. DSS-WISE Lite has been adopted by FEMA, its stakeholder agencies, and more than 40 states.

3.1. Conditions at the Failed Dams and Emptied Lakes

3.1.1. EDENVILLE DAM AND WIXOM LAKE

Following the May 2020 dam failure, water levels in Wixom Lake were significantly lower, as compared with normal conditions. The shoreline has been replaced with hundreds of feet of sediment and a drop-off where the water's edge had been located. Because of the breach location, the Tobacco River side of Wixom Lake was only partially emptied. On the Tittabawassee River side, the old riverbed under the emptied lake was clearly visible. Figure 17 shows satellite imagery of Wixom Lake on May 25, 2020, after floodwaters receded. Flow coming from the Tobacco River was being diverted to the Tittabawassee River, initially through the area where the M-30 bridge was washed out (see the Transportations Infrastructure and Access Issues section for more details on the M-30 bridge). The combined flows of the Tittabawassee and Tobacco rivers cut a new channel within the failed section of the Edenville Dam embankment.

Figure 17: Satellite imagery of Wixom Lake after floodwaters receded (May 25, 2020) (Google Earth 2021)

Figure 18 highlights the footprint of the failed section of the Edenville Dam. The crest line and the outline of the failed section are shown in yellow to provide a better appreciation of the extent of the failure. The width of the breached section is estimated around 480 feet, extending from the left side of the spillway on the Tittabawassee River to the left abutment where the switchyard is located. Figure 18 also shows the approximate footprint of an estimated 220-foot section of the failed M-30 bridge deck.

Per the request of EGLE, Boyce Hydro contracted a professional engineering firm to perform an inspection and visual assessment of the Edenville Dam to determine if immediate action should be taken on the remaining sections of the dam to mitigate risk to public safety, natural resources, and public transportation (TRC Engineers Michigan, Inc. 2020). The inspection was conducted on June 10, 2020, approximately three weeks after the dam failure and flooding incidents. Figure 2 provides an illustration of the various dam components assessed.

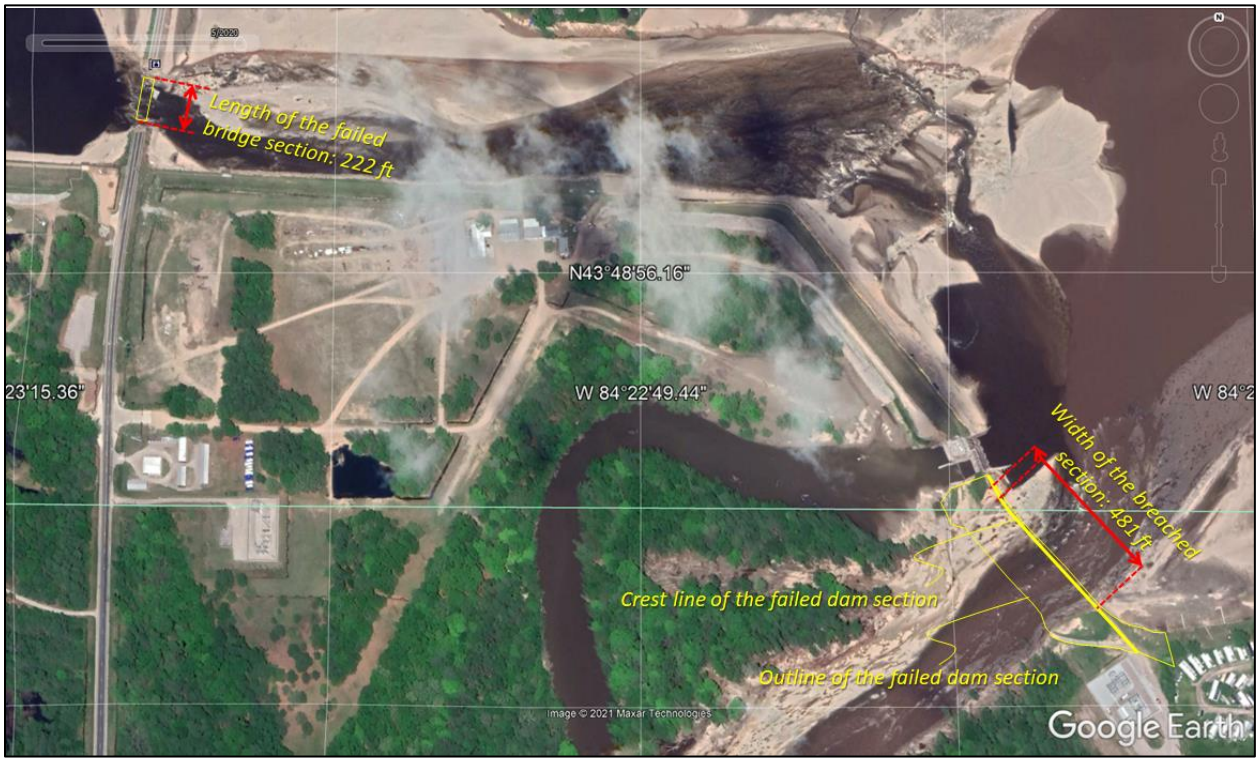

Figure 18: Aerial imagery of Edenville Dam after floodwaters receded (May 25, 2020) (Google Earth 2021)

As expected, a majority of the Tittabawassee River section of the left (easternmost) earthen embankment no longer existed, since the breach occurred in this section of the dam. The small sections remaining on either end of this area were assessed as unsatisfactory because their structural integrity had been compromised. The right embankment of the Tittabawassee River section was still generally intact, although the upstream slope was rated in poor condition.[9] It

[9] Condition terms were based on the expert judgment of an inspector at the time of the inspection to describe the physical condition of a component based on visual observations, and are not intended to provide an overall assessment of safety based on engineering analyses and studies. Satisfactory conditions indicate the component is "expected to fulfill intended function." Fair condition is defined as "expected to fulfill intended function, but maintenance is recommended." Poor condition is defined as "may not fulfill intended function; maintenance or repairs are necessary." Unsatisfactory conditions

appeared that a portion of the toe had been eroded along a majority of this section. In addition, tension cracks had developed at the crest of slope and the riprap seemed to have eroded, both likely a consequence of wave action during the flooding incident prior to the breach. The downstream slope was considered to be in satisfactory condition.

On the Tobacco River side, the downstream slope of the left embankment looked to be in fair condition, with some localized sloughing and wet spots present on the downstream slope. Sediment had also accumulated in toe drain ditches. The condition of the upstream slope, on the other hand, was deemed unsatisfactory. A large section of that slope had been severely eroded and tension cracks had developed at the crest of dam over a majority of the length of section. This section of embankment was identified at high risk to public safety because its structural integrity may end up compromised as the embankment continues to erode. As such, inspectors recommended immediate action to protect against further erosion of this section. On the right (westernmost) embankment of the Tobacco River side, a majority of the upstream and downstream slopes appeared to be in fair to satisfactory condition. On the downstream side, inspectors saw no apparent signs of significant slope movement, seeps, tension cracks, or rills. The upstream slope showed no signs of major erosion, other than some areas where wave action had reduced the effectiveness of the riprap.

The powerhouse and the Tittabawassee and Tobacco River spillway structures all appeared to be largely intact and structurally stable. However, their condition was generally considered fair to poor due to some signs of deterioration, erosion, and cracking in parts.

3.1.2. SANFORD DAM AND SANFORD LAKE

Similar to Wixom Lake, without the dam structures to impound the water, Sanford Lake has essentially drained, and the shoreline replaced with hundreds of feet of sediment. Figure 19 shows satellite imagery of Sanford Lake before (June 10, 2018) and after (May 25, 2020) the dam failures and the floodwaters receded. Down the entire length of the after image, the old, pre-dam riverbed is visibly evident.

Figure 20 highlights the footprint of the failed Sanford Dam. Water flowing down from the Tittabawassee River runs over the washed-out portion of what used to be the right earthen embankment. The crest line and the outline of the failed section are shown in yellow to provide a better appreciation of the extent of the failure. The width of the breached section has been estimated at around 890 feet, extending from the right side of the still intact concrete spillway. The remnants of the fuse plug spillway, concrete side walls, and slab, which could not be carried away by the flow, are also visible in the image. Figure 20 also shows the significant accumulation of debris build-up behind main spillway. Figure 3 provides an illustration of the various dam components assessed.

indicate the component “is not expected to fulfill intended function; repair, replacement, or modification is necessary.” (TRC Engineers Michigan, Inc. 2020)

Figure 19: Satellite imagery of Sanford Lake before and after the Edenville and Sanford dam failures *(left,* June 10, 2018, *and right,* May 25, 2020) (Google Earth 2021)

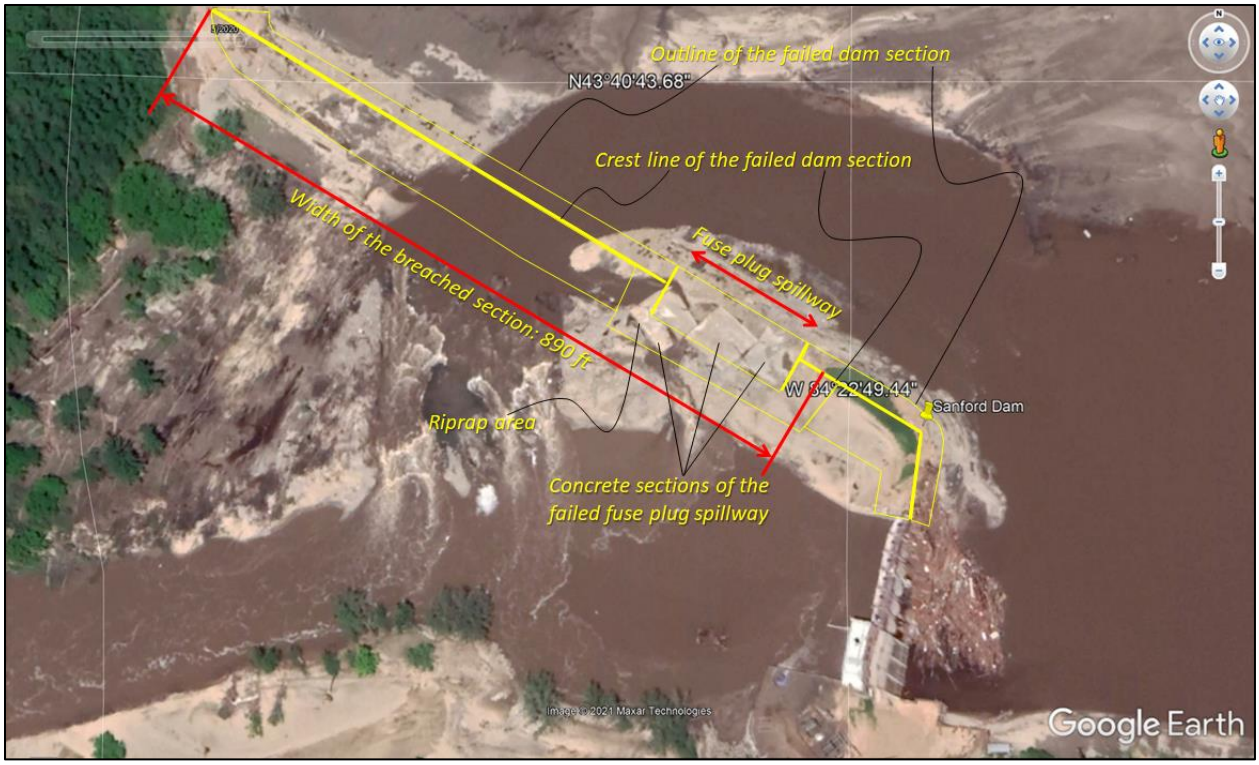

Figure 20: Aerial imagery of Sanford Dam after floodwaters receded (May 25, 2020) (Google Earth 2021)

3.2. Transportations Infrastructure and Access Issues

Even before the dam failures, the historic rains led to the temporary closure of more than 100 roads across the region that were rendered impassable by the widespread flooding (Dolinar 2020, North 2020). Following the dam failures, nearly 30 bridges and roadways required extensive inspections and numerous repairs prior to reopening to the public (MDOT 2020a). The extent of road damages varied from scour damage to complete structural failure. Closures of local roadways and bridges greatly increased commuting times and negatively impacted response times for emergency services. The Michigan Department of Transportation (MDOT) posted regular road updates on their website and sent out numerous media releases on the status of the area's roads and bridges (Eickholt 2020). In total, Michigan received more than $25 million in Federal Highway Administration (FHWA) Emergency Relief (ER) funds, coordinated by MDOT, for flood damage to the central part of the state in fiscal year 2020 (FHWA 2020).

Major bridges directly damaged by the dam failures included M-30 over the Tobacco River, M-30 over the Tittabawassee River, Curtis Road, and US-10 over Sanford Lake (EGLE 2020). Of key significance are the two M-30 bridges. A roughly 220-foot section of the approximately 1,250-foot two lane Tobacco River Bridge, located in Gladwin County just north of the Edenville Dam in Wixom Lake, completely collapsed and washed out during the flood. The Tittabawassee River Bridge, an approximately 300-foot, two- lane bridge in Midland County just south of the Edenville Dam,

sustained extensive damage to the piers and bridge approach. Figure 21 illustrates the locations of, and the damages sustained by the two M-30 bridges.

The damage to the two M-30 bridges, in conjunction with the closure of two other bridges (Highwood Road and Estey Road) that crossed the Tittabawassee River between Smallwood and Edenville Dams, created considerable access issues in the area surrounding Wixom Lake. The absence of these bridges created a peninsula north of Edenville Dam between the Tobacco and Tittabawassee rivers, which isolated several homes and businesses in Tobacco and Billings townships. Residents and first responders faced a 45-minute detour north around the lake because they could not cross the Tittabawassee River directly north or south of Edenville Dam (Eickholt 2020, North 2020). In response, Midland County positioned 25,000-gallon water tanks throughout the area to cut down the response time for vital firefighting and first responder activities (Eickholt 2020, Boyer 2020).

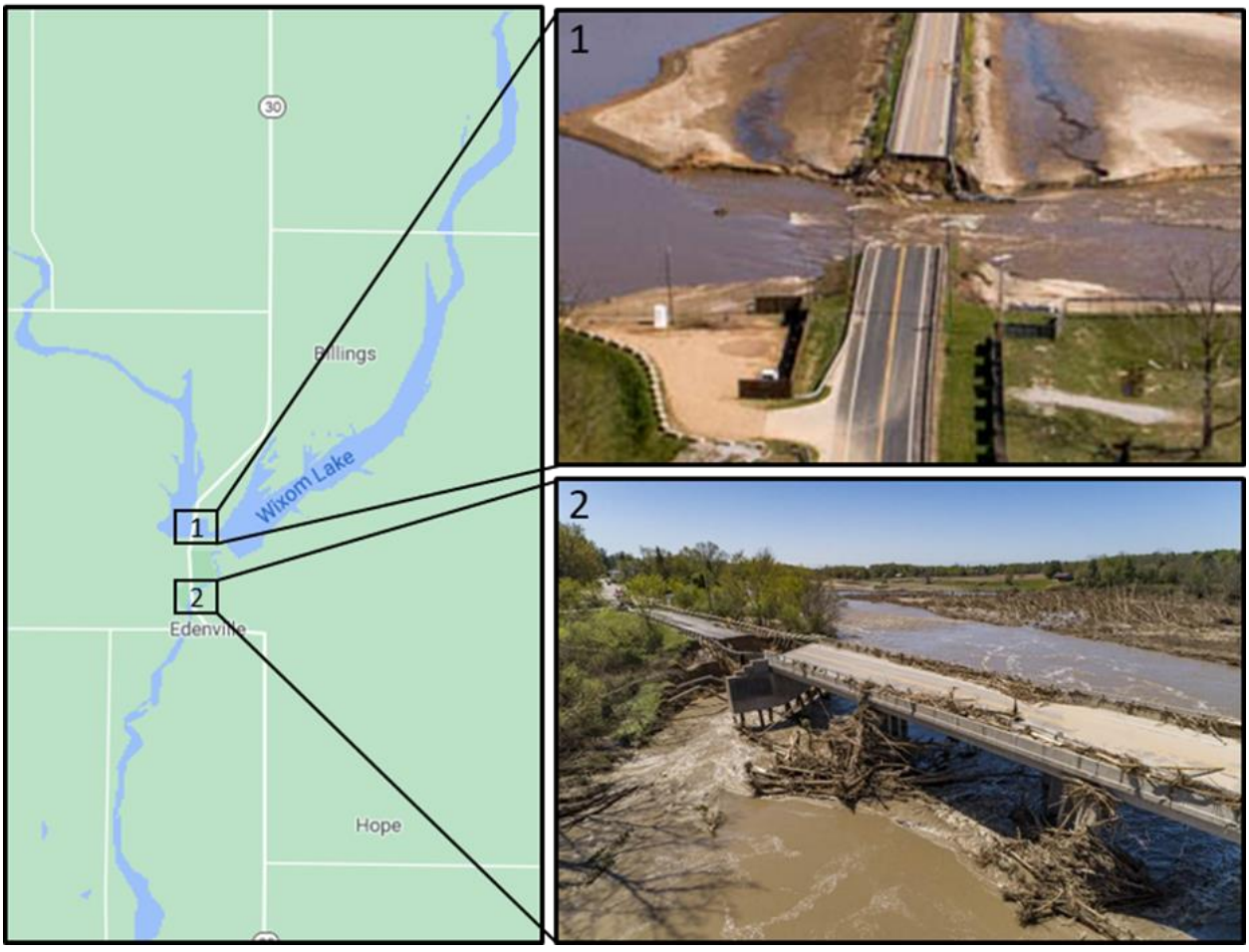

Figure 21: M-30 bridges over the Tobacco River (Box 1) and Tittabawassee River (Box 2) following the Edenville Dam failure (MDOT 2020b, 2021)

3.3. Drinking Water and Wells

A major unexpected consequence of the dam failures was drinking water loss at hundreds of private residential wells. In the weeks following the dam failure and flooding incidents, initial estimates indicated about 330 wells were impacted; however, this number rose to nearly 600 by the fall (Galvin 2020, North 2020). There are multiple reasons why wells experience problems after a major flood incident, such as operational concerns (e.g., pump issues or clogging with silt), damage by debris, and potential contamination. However, the situation affecting about a third of the wells in Gladwin Country is uniquely linked to the change in Lake Wixom's water level (Eickholt 2020, Schafer 2020a).

The high groundwater table that existed in the Lake Wixom area prior to the dam failures had been created artificially by the dam and man-made lake. As a result, many of the wells in the area were able to be hand-dug more than 80 years ago at depths of less than 30 feet (Eickholt 2020). The owners of these shallow wells were essentially drawing water straight from the lake through the ground. After the dams failed and Lake Wixom drained, the groundwater table fell and the shallow wells had no water source left to draw from, so they dried up. Pressure losses were also reported in Gladwin County along the Tittabawassee River due to dropping water levels, which affected fire hydrants that drafted directly from the river (Barker 2020, Galvin 2020).

EGLE is working with the local health department to investigate the extent of the problem, map out the dry wells, and identify the new location of the groundwater table. Experts do not anticipate the groundwater returning to previous pre-dam failure levels until the dams are replaced and reservoirs refilled (Schafer 2020a). Thus, if a well dried up or lost pressure because it was dug too shallow, the only solution is for an owner to replace it with a deeper well. Initial interim solutions included providing bottled water to residents for drinking purposes and offering information on water disinfection and sampling for bacteria (Eickholt 2020, Schafer 2020a).

Other drinking water issues related to the dam failures and historic flooding include potential contamination risk to local community source water supplies. Numerous boil water advisories were issued for the area. EGLE worked with affected communities to ensure adequate measures are taken to protect water supplies and test drinking water (Eickholt 2020, Assendelft 2020). Damage to water mains and other water infrastructure also occurred, but systems were quickly repaired and brought back online within only a few days.

3.4. Wastewater Infrastructure

As expected, floodwaters inundated the area's wastewater systems, which are a combination of sanitary and combined sewers. Officials estimated that the system was taking in about three to four times its normal daily inflow (Eickholt 2020). Impacts generally included overcapacity issues that led to sewer overflows and backups, but no loss of wastewater treatment capabilities was reported in either Gladwin or Midland County (North 2020, Eickholt 2020).

In the City of Gladwin, flooding along the Cedar River (below the Chappel Dam) came within a few feet of knocking out the electrical systems for the sewage treatment plant (North 2020). Fortunately, the plant never lost power and remained functional throughout the historic rain event.

The City of Midland was forced to shut down five pump stations, including its Valley Street station that services the largest area of the city, including the MidMichigan Medical Center (Schafer 2020b). Fortunately, the Wastewater Department had participated the previous year in a dam failure tabletop exercise and had a plan. That plan, along with flood mapping, helped wastewater supervisors identify exactly which five (of the 43 total) pump stations would be under water. Wastewater Department staff worked to keep the five identified pump stations running as long as possible before shutting them down just before inundation by floodwaters. Within 48 hours, all pump stations were dewatered, cleaned, repaired, and working again, at least partially, restoring service to both residents and the medical center. Wastewater officials reported that, if the pump stations had not been shut off, damage repair and restoration would have taken weeks rather than days (Schafer 2020b).

Residual impacts to the area's wastewater system include silt in the pipes and debris blocking drains and ditches.

3.5. Healthcare Facilities

The MidMichigan Medical Center, located in the City of Midland, continued operation throughout the May 2020 dam failure and flooding incidents. During the first 24 hours, general services were paused and scaled back to "life- or limb-threatening situations" only and the emergency department accepted only local ambulances (Schafer 2020c). However, the main hospital facility never closed or was evacuated, although a number of patients were discharged early or moved to non-impacted areas of the hospital (Gamble 2020). In addition, a few select patients (i.e., all COVID-19 positive patients and two expectant mothers) were transferred to other regional hospitals, some at the request of their physicians (Schafer 2020c). Most of the area's other medical services, clinics, and offices operated by MidMichigan Health (e.g., urgent cares, physicians' offices, rehabilitation sites, and home care and home medical equipment supply) were closed due to flooding.

During the emergency, hospital officials worked alongside local agencies, closely monitored the evolving situation, sandbagged around the hospital, and followed their Flood Preparedness Plan. Previous experience with a major flood incident in 1986 led to multiple safety and resiliency improvements to the hospital's facilities, including a floodwall and generators installed above the flood plain (MidMichigan Health 2020). Although the floodwater did inundate some buildings on the Medical Center campus (e.g., emergency medical services building, urgent care, and Sturgeon Creek building), the main hospital remained fully protected by the floodwall. However, the main hospital did experience sewer backups measuring 9 feet on the lower level and multiple power outages, including in one intensive care unit, the cafeteria, and the kitchen. A temporary outdoor kitchen was set up in the parking lot and local food trucks came in to feed onsite employees each day (Schafer 2020c).

3.6. Dow Chemical Plant

Dow Chemical Corporation's (Dow) corporate headquarters and a major chemical manufacturing plant are located in the City of Midland. Although Dow has its own emergency planning, it is also a part of every county emergency plan because of the potential for chemical contamination during a flood incident or other emergency. Thus, Dow is greatly involved in all countywide emergency planning activities and is represented at the Midland Country EOC, when activated.

In the days prior to the dam failures, primary concern and discussion involved the potential for catastrophic flooding at Dow's chemical plant situated along the Tittabawassee River. Initial predictions estimated that the river would crest at 38-feet, which could put up to 15 feet of water at the Dow plant. As water levels in the Tittabawassee River began to rise on May 19, 2020, Dow activated its local EOC and crisis management system even before the upstream dams failed. Working closely with the U.S. Environmental Protection Agency (EPA) and U.S. National Guard, Dow planned for the worst-case scenario and stabilized its Midland plant by shutting down the entire complex (Schafer 2020d). In addition to shutting down all operating units, the company moved onsite railcars and loaded trailers to higher ground or off-site. Only essential staff remained onsite.

By the time the river crested at about 35 feet, the Dow plant had experienced some inundation (Figure 22), but much of the impact was successfully mitigated. Many reports focused on floodwaters that mixed with an onsite pond. Fortunately, Dow responded that the pond was filled with saltwater used for ground water remediation (not waste) and posed no public safety concerns (Schafer 2020d). There were no reported chemical or product releases.

Figure 22: Dow Chemical facility along the Tittabawassee River on May 20, 2020 (Jeffery and Miller/Elconin 2020)

EGLE continues to work the EPA and Dow to evaluate the effect of flooding on its Midland site, along with previously remediated areas on the Tittabawassee River, Saginaw River, and Saginaw Bay Superfund site (Assendelft 2020).

3.7. Other Impacted Buildings and Local Landmarks

3.7.1. NORTHWOOD UNIVERSITY

At Northwood University, a small private university in Midland along the Tittabawassee River, several buildings and most of the student athletic facilities (indoor and outdoor) were inundated by floodwaters ranging from six inches to eight feet deep (Kozlowski 2020, Petzold 2020). Figure 23 illustrates the location and extent of flooding at Northwood University. The entire AstroTurf surface of the football field, which appears to be untouched on higher ground (Figure 24), was actually floating on top of the floodwaters, nearly five feet above the ground (L. Thompson 2020). Initial damage estimates were around $10 million, including $4.2 million in damages to the athletic facilities (Petzold 2020).

Upon notification of the imminent flood, the University's Core Crisis Team activated, working to minimize the impact of the flooding by moving critical documents onto higher floors, fully evacuating the campus, and shutting down the power (Kozlowski 2020, L. Thompson 2020). Fortunately, because of COVID-19 and the cancellation of in-person classes in Michigan, only 25 international students, who were not able to return home because of the pandemic, still lived on campus (Petzold 2020).

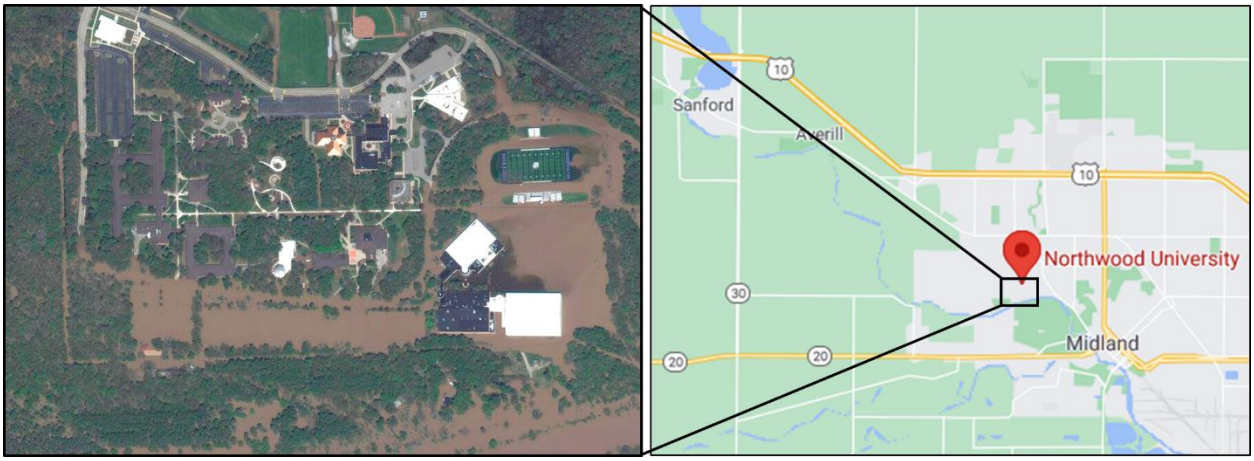

Figure 23: Flooding at Northwood University in Midland, Michigan
(Maxar 2020, Google Maps 2021)

Figure 24: Student athletic facilities on Northwood University campus following May 2020 dam failure and flooding incidents (PBS 2020)

3.7.2. MIDLAND PUBLIC LIBRARY

The Grace A. Dow Memorial Library, Midland's public library, sustained major water damage from flooding. The mechanical rooms on the lowest level were submerged, affecting climate control systems (Livingston 2020). Approximately four to six inches inundated the lower level that houses Midland Community Television (MCTV), book collections, 120 years of historical editions of the *Midland Daily News,* and other artifacts. Prior to the dam failures, volunteers and employees worked to save about $2 million worth of library materials from the lower levels by moving them to higher ground and sandbagging the doorway (Jordan 2020, Livingston 2020,). As a result, very little was lost.

3.7.3. SENIOR LIVING COMMUNITY

The Riverside Place Senior Living Community, one of Midland's two senior living communities, is located along the Tittabawassee River. The lower level of the facility was completely inundated. The first floor also sustained extreme flood damage throughout (Jordan 2020). All residents and staff were forced to evacuate. More than 50 seniors, some who had been quarantined in their apartments for months due to the coronavirus, were relocated with staff to the Midland High School community shelter; most others went to stay with either family or friends (Morford 2020).

3.7.4. MUSEUMS, HISTORICAL SITES, AND CULTURAL CENTERS

The Sanford Centennial Museum, managed by the Sanford Historical Society, is located along the Tittabawassee River just downstream of Sanford Dam. The museum houses an extensive local history collection, including nine authentically restored and furnished historic buildings. A number of those buildings were flooded with six inches to a few feet of water, damaging the structure, destroying contents, and leaving behind a thick layer of mud and debris (Moran 2020).

The Midland Center for the Arts consists of an auditorium, theater, lecture hall, art studios, rehearsal rooms, museum of science and art, and exhibit areas. The Center is also home to the Midland County Historical Society and museums at Heritage Park, which include historic homes, galleries, archives, library, and research facilities located along the bank of the Tittabawassee River. The main center building lost its main power switch and sustained major water damage. Flooding also damaged a number of other buildings, facilities, and artifacts across the campus. Floodwater depth ranged from six inches to five feet, damaging about 20-25 percent of the artifacts (Moran 2020). The Center estimates flood cleanup and repairs at $8-10 million (Kamana 2020).

Floodwaters destroyed the Fieros Forever car museum (Figure 25) in downtown Sanford. The 3,000-square-foot building housed an automotive shop and Fiero museum, which featured 30 Pontiac Fieros including kit cars, a pace car, and super duty engines. When floodwaters receded, the cars were found spread across the once-flooded downtown area.

Figure 25: Fieros Forever car museum in downtown Sanford (Hunter/Mears 2020)

3.7.5. MIDLAND COUNTY COURTHOUSE

The Midland County Courthouse in downtown Midland was flooded with about 18 inches of water on its lowest level, as illustrated in Figure 26. Fortunately, no official records or court documents were

damaged in the flooding, although the courthouse temporarily lost power and had its air handler system submerged. The elevators were destroyed and needed replacement. The District Court was able to remain open and resume normal operations; however, until the elevators could be replaced, there was no public access to the Probate or Circuit Court levels of the courthouse. Temporary courtrooms were set up in an adjacent building for jury trials and hearings that required in-person attendance. All other court sessions were conducted virtually (i.e., Zoom) or were adjourned to a later date, as per COVID-19 protocols (Midland Daily News 2020).

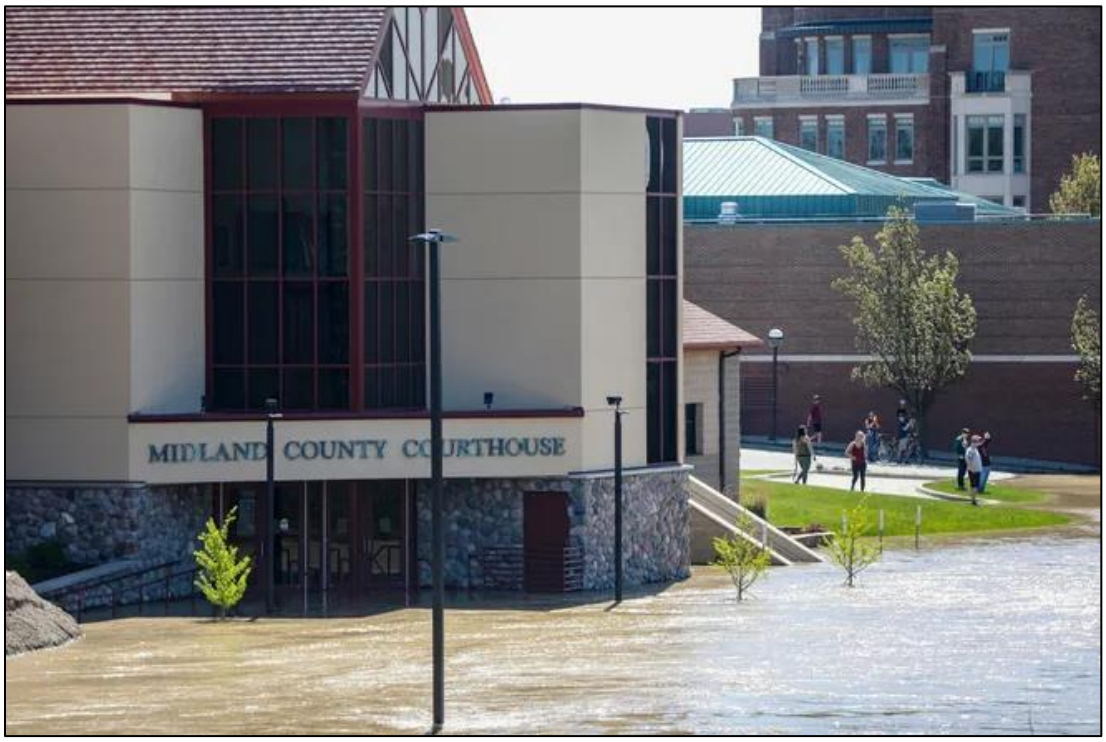

Figure 26: Midland County Courthouse in downtown Midland following the May 2020 dam failure and flooding incidents (Witsil 2020)

3.7.6. OTHER IMPACTED BUILDINGS AND FACILITIES

Extensive flooding across the region impacted numerous homes, public facilities and parks, government buildings, schools, police and fire stations, medical services and offices, places of worship, stores, restaurants, gas stations, and other businesses. In Gladwin County, north of the Edenville Dam, flooding primarily affected homes and businesses along the rivers due to the 200-year rainfall event. Figure 27 illustrates a flooded gas station north of the Edenville Dam on the west bank of the Tittabawassee River. Flooding in areas south of the Edenville and Sanford dams extended from Midland County through Saginaw and Bay counties and was significantly worse. The flood resulting from the combination of the dam failures and the 200-year rainfall event has been categorized as an historic 500-year flood event.

Downtown Sanford is located along the Tittabawassee River just south of the Sandford Dam. The small village, which spans only a few blocks, was completely submerged (Figure 28). The downtown

area included a hardware store (Figure 29), a grocery store, a bank, and a post office (**Error! Reference source not found.**), along with a couple of restaurants and a few other small businesses.

Figure 27: Flooded Wixom Lake Gas & Launch located along the west bank of the Tittabawassee River (Witsil 2020)

Figure 28: Downtown Sanford, just south of the Sanford Dam, after the dam failures (MSP 2022)

Figure 29: Hardware store in downtown Sanford (PBS 2020)

Figure 30: Sanford post office (Jackson 2020)

In the City of Midland, floodwaters affected numerous homes, stores, restaurants, churches, schools, government buildings, public parks, recreational facilities, historic landmarks, museums, and other businesses. Figure 31 offers a street-level view of the flood height at the circular pavilion of the Midland Area Farmers Market along the eastern bank of the Tittabawassee River. Figure 32 features before-and-after images of downtown Midland during the May 2020 dam failure and flooding incidents.

Portions of the Currie Golf Course, owned by the City and privately managed by Billy Casper Golf, were submerged in up to 10 feet of water, including the clubhouse and restaurant. Once the water receded, several inches of sediment and debris covered fairways and greens and needed to be removed (Altvater 2020).

Figure 31: Midland Area Farmers Market circular pavilion following May 2020 dam failure and flooding incidents (Jeffery and Miller/Proctor 2020)

Figure 32: Downtown Midland before and after the dam failures *(top,* July 2012; *bottom,* May 2020) (Campbell/Schrier 2012, S. Thompson 2020)

3.8. Dow Superfund Site

Past waste disposal practices by Dow at its Midland plant resulted in hazardous material contamination both on- and off-site. Dioxins and other toxic compounds settled in river sediments, along riverbanks, and on floodplain areas downstream of the Midland plant. The contaminated area, which extends over 50 miles through the Tittabawassee and Saginaw rivers and into Saginaw Bay, is classified as a multi-segment federal Superfund site. Cleanup activities began in 2007 and are ongoing in a number a segments (EPA 2007, 2021).

After the dam failures, EGLE worked with the EPA and Dow to collect sediment samples and monitor impacts. Their goals are to evaluate how flooding affected the previously remediated areas and how the hazardous materials (i.e., dioxins) potentially may have been redistributed to areas outside the Superfund site segments (EGLE 2020, EPA 2021).

3.9. Natural Resources

Following the Edenville Dam failure, EGLE and the Michigan Department of Natural Resources (DNR) deployed teams on and along the area's river and lake bottomlands to assess the extent of environmental resource damages. The teams collected data on and assessed the extent of high-water flooding across the affected areas, stream stability, erosion issues, impact to wetlands, habitat loss, and mussel and fish population impacts. This effort was performed to identify areas of erosion that could impact private property, collect data vital to bridge and road repairs, and gather evidence that could be used in potential future enforcement actions (EGLE 2020). Results of the assessments have yet to be published publicly.

3.10. Debris and Debris Management

The historic flooding, combined with the failures of Edenville and Sanford dams, caused major destruction and washed large amounts of sediment and debris downstream. Debris consisted of smashed and damaged boats, kayaks, canoes, jet skis, lawn furniture, and propane tanks, in addition to pieces of houses, sheds, and docks, and numerous washed-out trees and tree branches.

After the floodwaters receded, debris and destruction littered the streets and other inundated areas (Figure 33). Debris was left piled up behind remaining structures at the Sanford Dam (Figure 34), on bridges (Figure 35), and against bridge pilings (Figure 21, Box 2). Large additional waste and garbage (Figure 36) was generated by home and business owners doing cleanup and repair activities.

Flood debris is often contaminated by floodwaters filled with numerous pathogens, chemicals, and sewage. County and city officials have helped residents with cleanup efforts by facilitating landfill access and frequent garbage and large-item collections. A temporary state exception (through July 1, 2020) also allowed debris to cross county lines to help speed up cleanup efforts throughout the affected area (Murdock 2020).

Extensive debris removal continued for months after the May 2020 incidents. Officials estimated that more than one million pounds of debris has been removed from Sanford (Kanerva 2020). In Midland, more than 110,000 cubic yards of debris was reportedly collected during their cleanup. This is triple the amount that ordinarily is sent to the landfill in a year (PBS 2020).

Removal of the debris behind the Sanford Dam did not begin until late October 2020. Its removal was critical to beginning the initial engineering work to stabilize the dam. The FLTF funded the debris removal using state and federal grant money and volunteers helped sort through the material. Property owners were asked to submit claims if they thought they owned anything found in the debris. All unclaimed debris was sent to a landfill (Ellison 2020).

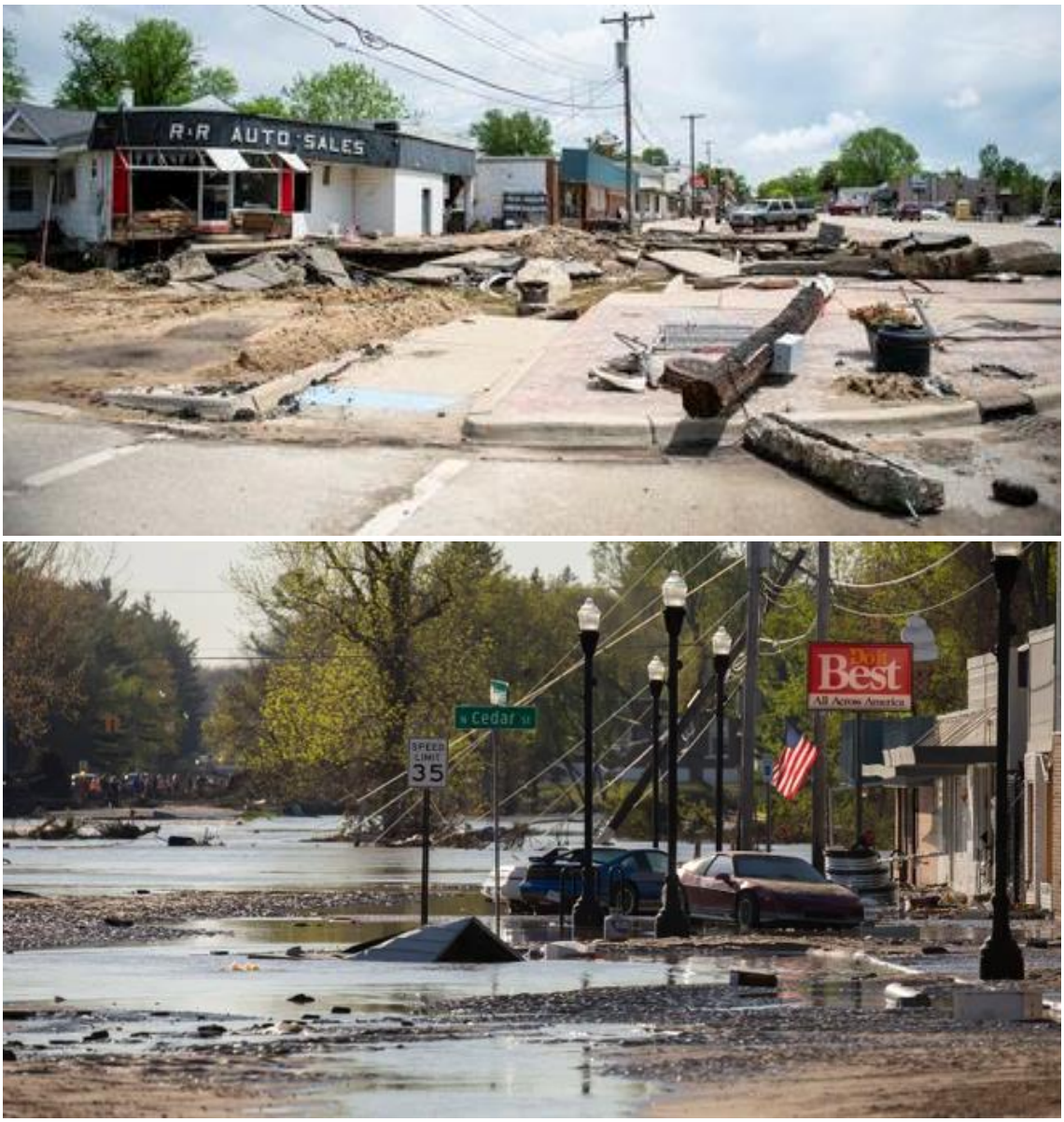

Figure 33: Debris and destruction littered the streets in downtown Sanford after floodwaters receded (Boomer 2020, Witsil 2020)

Figure 34: Debris pile remaining behind Sanford Dam (MSP 2022)

Figure 35: Debris and sediment left on Curtis Road Bridge after floodwaters receded (May 2020) (Johnson/May 2020)

Figure 36: Large quantities of waste and garbage generated by home and business owners from cleanup and repairs activities (PBS 2020)

4. Best Practices and Lessons Learned

4.1. Importance of Relationships

4.1.1. EMERGENCY MANAGEMENT COORDINATION

The successful incident response and evacuation of more than 11,000 residents is due in large part to the extensive coordination and communication established by the local EMs, in conjunction with dam operators, prior to the incidents of May 2020. EMs in Gladwin and Midland counties understood how the regional hydrology and existence of the dams connected their counties. As a result, the EMs created and maintained a strong working relationship that facilitating ongoing communication during the incident, supported situational awareness, and built trust. They also established processes that enabled both agencies to prepare themselves, their teams, and their communities to respond to an emergency incident.

Working from the strong pre-existing relationship, EMs in Midland and Gladwin counties stayed in regular touch with each other by phone in the days leading up to the dam emergency and throughout the evolving incidents. They also connected regularly with local partner agencies and stakeholders, including the onsite dam operators, first responders, EGLE, NWS WFOs, and Dow, to share information and maintain situational awareness. Strong relationships established during non-emergency times helped build confidence and trust, enabling EMs to coordinate and communicate more effectively during an incident.

In a rapidly developing incident, internal and interagency communications are also critical. Within their respective agencies, both counties' EMs also developed internal processes to share information and improve situational awareness. Interagency communications helped coordinate efforts between EM employees and staff in other departments and agencies, who also shared a role in emergency response. Strong established local relationships, based on active exercising and a shared history, helped people know and understand their roles (e.g., lead or support) and specific responsibilities.

Many of the communication methods used during the incident response were informal—such as text-messaging groups, phone calls, and in-person conversations—but were nonetheless very effective and could be activated quickly when needed. The trust established within and between the local agencies enabled candid conversations about the issues, challenges, and potential solutions. The ongoing response to COVID-19 that generated a heightened level of internal and interagency communications, including regular email updates and video teleconferencing with various stakeholders (e.g., elected officials, township supervisors, city managers, public safety officials, and community partners), was already occurring at both EM agencies. These exchanges simply scaled up once the chance for significant flooding and potential dam failure was evident.

4.1.2. DAM OWNERS VERSUS DAM OPERATORS

At the time of the incident, Boyce Hydro owned and operated all four of the dams along the Tittabawassee River. This presented a unique situation in Michigan because the dam owner was physically located in Nevada and communicated only infrequently with county EMs. As a result, nearly all interactions were with the local dam operators, who were responsible for daily operations and traveled between the four dams. Fortunately, the EMs successfully built and developed a strong working relationship with the dam operators, communicating and engaging with them on a regular basis. From the EMs' perspective, a good relationship with the onsite operators was critical to getting the information needed to make informed decisions, because they are the ones with the greatest knowledge and understanding of the dams.

The EAP for the four Boyce Hydro dams included a formal process for notifying local agencies of an incident involving the dam. Operators were first to notify Boyce Hydro owners, who subsequently called Central Dispatch in Midland County. Central Dispatch then directly contacted the county EMs. However, because of their established relationship, the dam operators enacted an informal communication process that included regular updates via frequent, direct phone calls with both Gladwin and Midland County EMs throughout the incidents of May 2020. These critical phone communications are what led Midland County to preemptively issue the initial evacuation order for communities immediately downstream of Edenville Dam.

4.2. Communication and Messaging

4.2.1. CLEAR CONSISTENT MESSAGING

When it came to public communications, such as alert and warning notifications, each county had specific processes for creating, reviewing, approving, and disseminating the alert and warning messages. These were preexisting, documented processes for emergency communication that the counties simply enacted once the incident occurred.

In Gladwin County, the EM was solely responsible for the release of public alerts and warnings. The EM handled the creation, review, and dissemination of information, primarily via Nixle (an opt-in alerting system). The Chairman of the Board of Commissioners authorized the EM to take the actions he felt necessary. As such, the Gladwin County messaging primarily focused on getting to higher ground immediately (i.e., "seeking shelter" in Figure 37). The Gladwin County EM did not advise people to evacuate to a designated shelter because he did not want people to needlessly risk their safety during the COVID-19 pandemic by driving at night on already flooded roads.

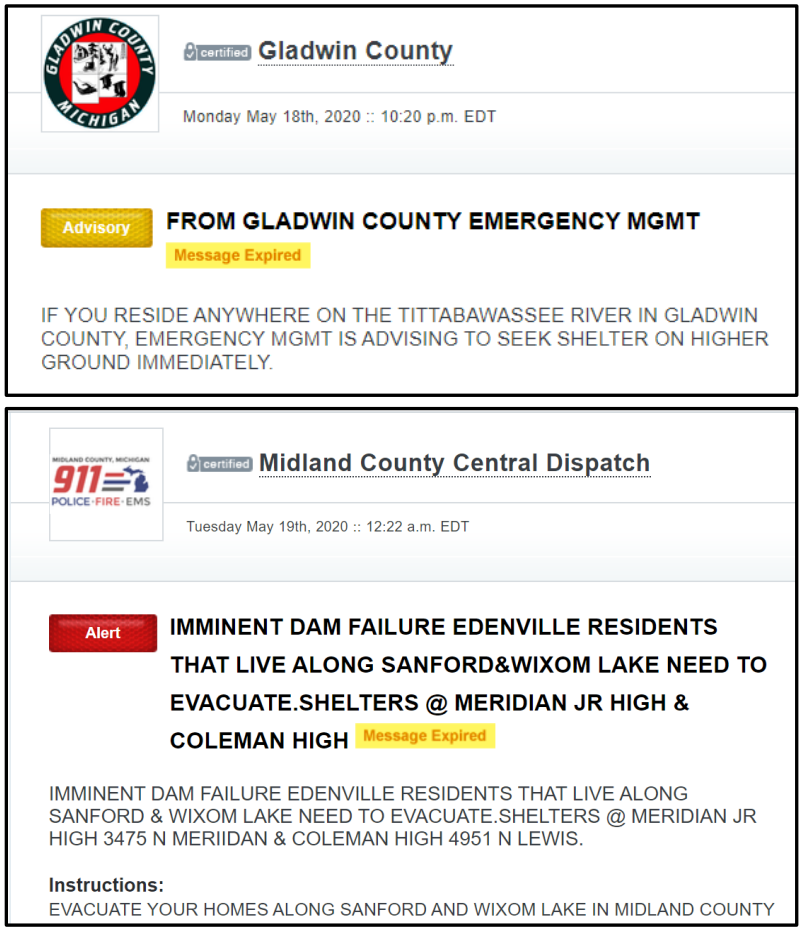

Figure 37: Sample Nixle messages issued by Gladwin and Midland counties during the May 2020 flooding and dam failure events (Gladwin County 2020, Midland County Central Dispatch Authority 2020)

Midland County had a collaborative and coordinated response to messaging. The EM proposed issuing the initial evacuation order for the communities immediately downstream of the Edenville Dam during a prescheduled Midland City Council Meeting COVID-19 update session. The recommendation received unified support from county officials and the messaging process began. Midland County followed a formal, preplanned process for sharing information that was coordinated between the director of Central Dispatch, County EM, and Public Information Officers (PIOs) present in the EOC. This process helped ensure that Midland County was the main source of incident-specific information and that messaging was consistent, accurate, and verified before public release.

Midland County officials first provided information to those who needed it in a timely manner for coordination efforts and response activities, such as EOC representative groups, first responders, elected officials, and key community stakeholders (e.g., Dow, MidMichigan Medical Center, Northwood University). Central Dispatch in Midland County issued alert and warning messages countywide to the public for immediate action. No targeted messaging was done; all recipients received the same information. Messages about the flooding, road closures, dam failure, evacuation and shelters were issued to the public via numerous channels, including Wireless Emergency Alerts (WEAs), Nixle, and the NWS. Because the situation was rapidly changing and life safety was the top priority, Midland County officials shared information with the public as soon as it was received and verified internally. That meant that, rather than receiving one or two posts each day, residents saw from five to more than 30 "real-time" status updates per day on the evolving incidents.

Pre-scripted messages for a dam emergency or dam failure did not exist; although the county had discussed creating them for inclusion in their Dam Failure Response Plan, such messages had not been formalized. Central Dispatch in Midland County led the creation and dissemination of alert and warning messages because, due to their day-to-day work handling emergency calls, they understood how the public would receive and interpret such messages. Messaging was timely, brief, and contained clear instructions about the protective actions the residents needed to take (as illustrated in Figure 37). Alerts and messages also included clear visuals, like geographic information system (GIS) based inundation maps, images and video of actual flooding, and standardized "emergency evacuation" or "flood warning" graphics (as depicted in Figure 38). The addition of clear and appropriate visuals can help support the written message content and provide helpful context to the information.

News and formal press releases were then sent to local and regional media for wider distribution, published publicly on the county's website, and posted to various social media (e.g., Twitter and Facebook). Media amplification of agency messages allowed information to reach a broader audience. Posting a consistent message across multiple platforms and channels, which were well used and understood in the community, also helped assure that the county maintained control over information release and that information was widely seen and shared. Social media was also used to address rumors, clear confusion, and correct misinformation. In their communications and postings, PIOs directed the public to county information sources and requested that the media and other agencies share the county's messaging and social media content. In many cases, rather than creating new posts, POIs edited existing posts with new information to help safeguard against the

inadvertent sharing of “old” or outdated information. The Central Dispatch center was also set up to field questions and offer needed assistance.

This systemic and collaborative approach to communication helped manage messaging, maintain consistency, and establish the County EM as the primary source for verified, trusted incident-specific information.

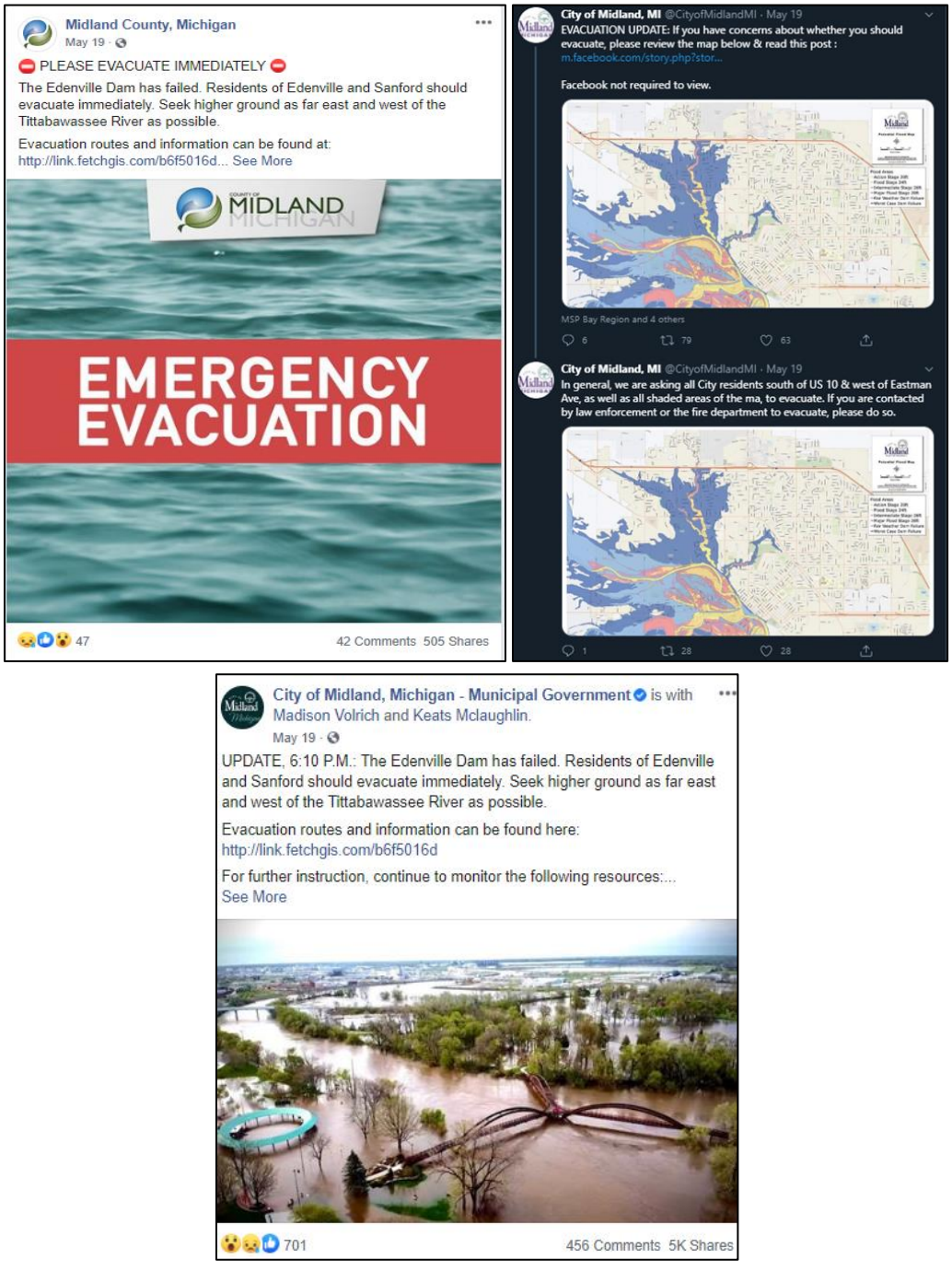

Figure 38: Alerts and messages included clear and appropriate visuals (City of Midland 2020a,b, Midland County 2020b)

4.2.2. PREEMPTIVE EVACUATION

Emergencies rarely happen at a convenient time. During the May 2020 incident, even without a dam breach, the Midland County EM and a consensus of county officials decided to recommend an evacuation of the communities immediately downstream from Edenville Dam (Boyer 2020). The three communities within the impact area would be inundated with water within five hours, or less, of the dam's failure.

Officials considered many factors when making this preemptive, protective action decision. First and foremost was the time of day. Initial concerns about the dam culminated on the evening of May 18, when the dam operator communicated clear uncertainty about the how conditions at the dam might change or progress overnight, especially as lake levels continued to rise. The strong relationship between the dam operator and the EM allowed for the transparency and trust needed to make appropriate decisions. With so much unknown and many unanswered questions, the EM believed it was safer and more effective to take action in advance of an anticipated risk, versus responding to an emergency incident (Boyer 2020).

At that point of the day, most residents were home and near their phones, computers, and/or televisions to receive the evacuation message. If the dam breached overnight, it would have been very challenging to safely evacuate people, assuming there was even time to warn them, and many residents would likely be stranded and need rescuing. Officials did not want people waking up to flooded houses and vehicles, potentially panicking because they had no way to easily leave or safely get out (Boyer 2020). Moreover, for those that were able to evacuate, Midland Country's rural location would pose additional public safety concerns related to the flooding. At night in rural areas, it is nearly impossible to distinguish between dark, dry roads and dark, water-covered roads.

Another important factor was the availability of emergency responders, who were largely volunteers and had full-time day jobs (Boyer 2020). In the evening and nighttime hours, it is generally easier for these individuals to support the response effort and help conduct door-to-door notifications. A preemptive order also allowed for the extra time needed to call in and coordinate these first responder volunteers.

4.3. Preparedness and Understanding Risk

4.3.1. DAM FAILURE EXERCISE

In the fall of 2019, Boyce Hydro sponsored a semi-functional exercise designed to test the EAP for all four of their dams at once to meet FERC licensing requirements. The dam operators had all the functional parts, while local stakeholders participated as a tabletop exercise. Over 100 people, who would be involved in response efforts across Gladwin and Midland counties, participated.

Knowledge of the region's topography and understanding that any dam failure incident could affect both counties, the EMs and local stakeholders focused on coordination across multiple jurisdictions. This included what, when, and where resources might be needed and how to best deploy their limited supplies. The exercise also played a significant role in clarifying plans and communications

procedures and making sure each group knew and understood their various roles during a dam failure emergency. Even though many issues and details remained unresolved, the discussions that occurred at the county level during the exercise led to the creation of the Midland County Dam Failure Response Plan (Boyer 2020).

Although the exercise scenario involved a failure at only Smallwood Dam, and not the catastrophic scenario that unfolded in May 2020 flooding and dam failures, the tabletop exercise highlighted important dam owner/operator limitations and underscored the transfer of responsibility once the dams failed (Boyer 2020). Up to the point of failure, dam operators were responsible for managing operations to mitigate downstream risks. However, once a failure occurs, the responsibility for notifying and protecting the community falls entirely to local and county agencies. This realization of assumed responsibility by county EMs, local stakeholders, and elected officials helped facilitate the fast and unified response seen during the subsequent emergency.

4.3.2. COMMUNITY AWARENESS

Another factor contributing to the successful emergency response and evacuation was Gladwin and Midland counties' recent experience with significant flooding. In June 2017, thunderstorms brought heavy rains that caused widespread flooding and extensive damage to both public and private property across the area. The Tittabawassee River in Midland crested at 32.15 feet during the 2017 flooding incident, about three inches lower than the 2020 river crest of 35.05 feet. This incident provided EMs and first responders with valuable experience and practice responding to a flooding emergency. Officials knew what areas and roadways would be at greatest risk to potential flooding and who might be most affected. Because flooding was a known hazard, officials had a plan.

The 2017 floods also raised community awareness of local flood risk. The recent nature of the incident may have contributed to the likelihood that residents were more willing to take action without delay, since they had a clear memory of the potential dangers and what could happen. Residents took the emergency seriously, listened to alerts and warnings, and reacted appropriately.

Additionally, the communities near the dams were aware of the potential for dam failure. Following the revocation of Edenville Dam's FERC license, media stories and community conversations questioned the safety and reliability of the dam(s) and whether they were being properly maintained. A key area of focus was the dams' aging infrastructure and dam owners' inability to remedy ongoing safety and compliance issues. In response, a group of community volunteers formed the FLTF, which works and engages with public officials to administer and oversee the maintenance and safe operations of the four Tittabawassee River dams, improve certainty on restoration time and costs, and ensure long-term viability of the lakes for the community and future generations (FLTF 2021a).

Interestingly, Gladwin and Midland County EMs indicated that some community members did not consider multiple hazards occurring simultaneously and how the resulting impacts might go beyond their historical understanding. Instead, these residents considered the risk of a dam failure and the risk of riverine flooding from extreme precipitation as separate incidents (Boyer 2020, North 2020).

4.4. Operating in a COVID-19 Environment

4.4.1. EMERGENCY MANAGEMENT RESPONSE

The ongoing global pandemic presented numerous challenges to EMs before, during, and after the incidents of May 2020. Remarkably, operating in a COVID-19 environment also presented a few unexpected benefits.

In the months prior, COVID-19 response activities occupied much of the EMs' attention. This left little time to focus on other things, such as planning and training activities, which otherwise might have been conducted. For example, the Gladwin County EM, who had been in the position only for a few months, had planned for an EOC activation drill but never got the chance to execute one. In Midland County, the EM and Central Dispatch director had intended to draft pre-scripted messages for inclusion in their Dam Failure Response Plan, but these were not completed.

During the emergency, COVID-19 considerations had to be dealt with in real time but did not seem to hinder response. Dealing with the ongoing COVID-19 response efforts, the State and County EOCs were already activated to some extent, so they merely needed to pivot and scale-up to deal with the evolving dam incidents. Because of stay-at-home orders, officials and EMs were accustomed to virtual meetings, briefings, and updates. In fact, the Midland County EM piggybacked onto a prescheduled COVID-19 update call with a meeting of the Midland City Council to update them on the situation and get approval for the initial evacuation. The EOCs were also accustomed and able to continue operating at a reduced in-person staffing level until absolutely necessary after the Edenville Dam failure. The MSP were also proactive on the issue of personal protective equipment (PPE) and quickly supplied anything EOC staff, field personnel, and shelter workers needed. (Eickholt 2020).

Additional benefits of the dam failures occurring in a COVID-19 environment include the fact that most people were at home to receive the messaging, schools were shut down, and the seasonal visitor population was very low because the parks and lakes were closed to recreation. All county facilities and buildings were closed to both the media and the public, which made it easier to manage the ongoing situation. In addition, many staff who would have otherwise been out of town, including the Midland County EM, were instead available to support the response efforts because most personal vacations had been canceled due to COVID-19 travel restrictions (Boyer 2020).

Post-failure, COVID-19 concerns primarily involved issues related to evacuation and sheltering, as detailed in the next section. There were also many unknowns surrounding the potential long-term consequences and lingering effects of the displacement of more than 11,000 people during a pandemic.

4.4.2. EVACUATION AND SHELTERING DURING A PANDEMIC

In the early morning hours of May 19, 2020, and in the midst of a global pandemic, officials warned residents to evacuate their homes amid life-threatening dangers due to the imminent dam failure of the Edenville Dam. Additional evacuation notices were issued the following day after the Edenville

Dam breached and in anticipation of the Sanford Dam failure. Many people were able to stay with family or friends, but some were forced to find refuge in shelters.

The COVID-19 environment added a level of complexity to the situation, requiring extra thought and precautions. Maintaining public health guidelines and restrictions in the shelters was one of the biggest challenges. At that time, FEMA had not published any official guidance around emergency sheltering in a pandemic environment, although a number of draft plans were circulating. The closest documents available were the Centers for Disease Control and Prevention recommendations on how to operate a homeless shelter and the American Red Cross COVID-19 sheltering guidance contained in their national level concept of operations (Lasher 2020, Morford 2020). Shelters did their best to follow these recommendations, but it was difficult. Formal community sheltering plans did not exist at the local level; many shelter managers had no training and there was little time to prepare (Boyer 2020). For example, the manager of the Midland High School shelter (pictured in Figure 39) was the high- school principal because he had the keys and could turn on the lights. Fortunately, there do not appear to be any documented cases of COVID-19 linked to sheltering operations.

Figure 39: Emergency congregate shelter setup in the Midland High School gymnasium (PBS 2020)

In the affected areas, it takes several hours for the Michigan Region of the American Red Cross to activate and mobilize a shelter—time that residents did not have (Boyer 2020). Therefore, counties worked with local health department offices to mobilize and immediately open shelters at local schools, churches, and community centers. While not optimal, all initial shelters were congregate, with open floor plans and shared sleeping, eating, and bathroom arrangements. The American Red Cross shelters were set up following Americans with Disabilities Act (ADA) standards (e.g., 110 square feet per person, head-to-toe configuration for cots) that allowed for extra space (Morford 2020). Evacuees were screened upon arrival and provided with the recommended protective

equipment; volunteers wiped down surfaces regularly. Officials advised individuals in the shelters to wear masks, socially distance, wash hands, and use hand sanitizer to help mitigate contracting or spreading the virus. A number of people chose to stay outside the shelter's parking lot in their cars, only entering to get resources and information (Lasher 2020, North 2020).

The Michigan Region of the American Red Cross worked closely with the state and FEMA Region 5 to continually assess and understand sheltering requirements. In total, 25 shelters were opened across the region for people needing temporary emergency lodging due to flooding (American Red Cross 2020). At its peak, Midland County had six congregate shelters open: two operated by the American Red Cross and four community-run, sheltering an estimated 300 individuals. Within 5 days after the incidents, the American Red Cross and impacted communities worked together to gradually move all congregate shelter residents into non-congregate settings (i.e., hotels). Local voluntary agencies collaborated with corporate sponsors (i.e., Dow) to create nine open points of distribution (PODs) throughout the impacted area. These PODs were critical in providing water, food, personal care items, cleaning supplies, and laundry vouchers for affected individuals (Moran-Gardner 2020b).

Another COVID-19 challenge for shelters related to staffing. Due to pandemic-related restrictions, many Voluntary Organizations Active in Disasters (VOAD) agencies experienced limitations and modifications to their traditional response operations. In general, older individuals with "time freedom" make up much of the VOAD second responder workforce that shelters depend on (Boyer 2020, Moran-Gardner 2020a). Being part of a COVID-19 vulnerable or at-risk population, many of these older individuals were generally less willing or available to support in-person staffing needs. COVID restrictions also limited travel for out-of-area volunteers. Thus, disaster response agencies found it difficult to secure volunteers for sheltering and other in-person response and recovery activities.

5. Challenges and Areas of Improvement

5.1. Data Sharing

Throughout the MI DIRR project, there were several challenges associated with data sharing, including general inability or unwillingness to share, delays in releasing data, missing or incomplete datasets, and size constraints.

One of the data-sharing obstacles related to concerns associated with the sharing of personally identifiable information (PII) data and related privacy considerations. This was particularly the case regarding the use of the Preliminary Damage Assessments (PDA) conducted by FEMA Region 5 and the MSP. FEMA has strict procedures regarding the protection of PII data.

Another data-sharing issue related to obtaining the EAP for the four Boyce Hydro dams. Multiple agencies, including EGLE and Midland County, said they had the EAPs in hand. However, no one was willing to share because of confidentiality (i.e., PCII or CEII). The MI DIRR team was advised to

request the EAP directly from the dam owner. However, because of ongoing litigation and liability concerns related to the dam failures, the MI DIRR team never obtained the EAP document.

The Midland County EM GIS Department was willing to share the information and data it had available, including actual inundations extents, LiDAR (light detection and ranging) data, digital elevation models (DEMs) before and after the flooding, and high-resolution aerial photography. The USACE was also open to sharing their data after receiving the necessary internal approval. USACE files included breach survey data, along with input and output data from the Hydrologic Engineering Center's River Analysis System (HEC-RAS) model. However, in general, these types of data files tend to be very large, which makes data sharing much more difficult. Furthermore, many organizations have advanced security protocols and firewalls that limit file transfer options. Solutions for sharing the large format files included sending a secure flash drive to Midland County GIS and using USACE's secure access file exchange, DoD SAFE. Although successful in the end, the entire process took time and extra coordination. In addition, file structures and indexing differed across agencies, so it took additional time to sort through and catalogue the data received.

5.2. Data Collection

A major issue with the multiple datasets used in the MI DIRR analysis was inconsistent quality and varying resolutions, depending on the type of file. This was primarily due to the fact that different agencies and organizations collected the data using countless different technologies and techniques based on their individual data-collection guideline, capabilities, and experience. As a result, some databases had missing fields or incomplete records, as was the case with the observed inundation extent. Shapefiles and aerial photography also had different resolutions, which complicated comparison and analysis.

Timeliness of data collection is also key, as much of the data needs for analysis are considered time-sensitive and highly perishable, such that it loses its initial value over time. Observed flood extent was one of these key datasets, for which the MI DIRR team received only partial data. High-water marks was another critical dataset. Unfortunately, these measurements were only partially collected and never received by the MI DIRR team. Following the May 2020 dam failure and flooding incidents, Midland County EM submitted a request to the USACE to have high-water marks document. However, for whatever reason, this assessment did not occur and eventually too much time had passed to guarantee any degree of data certainty (Boyer 2020; Eickholt 2020). The high-water mark information that was collected, in the form of geotagged images of structures and damage, were stripped from the files received by the MI DIRR team.

6. Findings and Recommendations

Key findings from the Edenville and Sanford dam failures provide valuable insights and important recommendations for other communities, with special considerations for stronger collaboration between emergency managers and dam owners/dam operators.

Risk is increasing and dam safety should be considered on a watershed scale.

As the climate has warmed, rainfall extremes have intensified, causing the risk and severity of watershed-scale flooding to increase in many parts of the United States. The effects of localized extreme rainfall can saturate a watershed area and cause heighted risks for the inter-related system of dams. Coupled with the increasing age of dams across the country, it is important to examine dam risk across watershed areas.

Findings from Edenville/Sanford Dam Failures:

The historic regional rainfall experience in Michigan in May 2020 was a key factor in the Edenville and Sanford dam failures. The six dams along the Cedar, Tobacco, and Tittabawassee rivers in Gladwin and Midland counties exist in series along river systems. As seen in the events in Michigan, one dam failure can be transmitted downstream causing additional dams to fail. In some areas, different entities own, operate, and regulate the various dams within a watershed, which can complicate preparedness and mitigation planning and can also create challenges for effective response.

Recommendations for Jurisdictions with Dams:

- Conduct analysis of the watershed, including groundwater, rivers, and streams, and the water management system, including dams, gauges, and reservoirs. Examine dependencies within the water management system, including upstream and downstream effects for each dam.

- Build relationships of all parties with a role in watershed management. Watersheds will often cross jurisdictional boundaries, including state boundaries, and dams within a watershed area can have different owners, EAPs, and protocols.

Relationships and collaborative planning before an incident greatly impact effective communication, coordination, and response during an emergency incident.

Strong working relationships established during non-emergency times help build confidence and trust between the individuals, agencies, organizations involved in emergency response efforts. Strong relationships also promote efficient and effective communication and coordination during a rapidly developing incident.

Findings from Edenville/Sanford Dam Failures:

In the case of the May 2020 dam failure and flooding incidents, communication and coordination by the Boyce Hydro dam owner was greatly lacking. Prior to the incidents, the dam owner had a very poor relationship with both state regulators and county EMs, likely due in large part to the long history of maintenance and compliance issues. In addition, the dam owner resided out of state (i.e., Nevada), which made communications with their Michigan community partners more challenging.

During the evolving incidents, when the dam operators initiated the EAP and the formal notification process began, state EGLE DSP officials never received direct notification from the Boyce Hydro dam owner (as specified in the EAP call-out notification tree). Instead, it was the onsite operators who directly notified them hours later. The EMs also received dam-related information directly from the operators, not the dam owners.

On the other hand, communication and coordination on the part of the county EMs was very strong. Their well-established and sustained relationships with each other, state and local officials, and onsite dam operators greatly increased their situational awareness and real-time knowledge in the days leading up to and throughout the May 2020 incidents. As a result, they were able to do their jobs more effectively and efficiently. They also connected regularly with local partner agencies and stakeholders and established trust with the community. This led residents to take the incidents seriously, listen to emergency alerts and warnings, and react appropriately, resulting in a highly successful evacuation with no major injury or loss of life.

Recommendations for Jurisdictions with Dams:

- Establish ongoing working relationships between emergency managers and dam owners/dam operators. Have emergency managers tour dam facilities and have dam owners/operators tour emergency operations centers.

- Share and coordinate Emergency Operations Plans and Emergency Action Plans. Crosswalk roles and responsibilities, especially for communications and notifications. Negotiate issues related to sharing EAPs for privately held dams, to include signing non-disclosure agreements, if necessary.

- Explain any ownership complexities (e.g., the Edenville and Sanford dams were owned by Boyce Hydro Power, LLC, located in Nevada, some dams are owned by homeowner's associations) and share compliance requirements.

- Develop outreach strategies to key stakeholders, including private sector representatives; community planners; nonprofit partners; academics, and other individuals and organizations with information or a role in dam-related emergencies.

- Jointly review long-term floodplain planning programs, such as the National Flood Insurance Program's (NFIP) Special Flood Hazard Areas (SFHA) and Community Rating System (CRS) to better understand and take actions for incentives and credits.

- Collaborate on hazard mitigation plans, floodplain management plans, business continuity plans, and Threat and Hazard Identification and Risk Assessments (THIRA).

Exercises provide a valuable opportunity to test plans, to confirm roles and responsibilities, and to identify areas for improvement.

Exercises build preparedness by providing a low-risk environment to validate plans, procedures, and capabilities. Exercises in areas with dams is particularly critical to clarify responsibilities between dam owners and the downstream communities in the event of a dam failure. Exercises can also help identify resource requirements and areas for improvement for evacuation, alert and warning notifications to vulnerable populations and other operational priorities.

Findings from Edenville/Sanford Dam Failures:

Exercises conducted in advance of the 2020 dam failures were a contributing factor to the coordinated and effective response activities.

Because the City of Midland had participated in a tabletop exercise the year before the 2020 dam failures, they had developed a plan that helped wastewater supervisors identify the stations that would be under water. This exercise and planning discussion helped the City manage the shutdown of five pump stations during the dam failures.

Similarly, Boyce Hydro sponsored an exercise to test its EAP to meet FERC licensing requirements in 2019. With over 100 people participating, the exercise focused on coordinating across multiple jurisdictions, including identifying resources, managing limited supplies, clarifying communications procedures, and response roles.

Even though exercises scenarios may not anticipate the specific circumstances of real-world events, exercises and post-exercise discussions helped to clarify the responsibilities of the dam operators and the local and county agencies. The tabletop exercise highlighted important dam owner/operator limitations and underscored that responsibility for the event would transfer to county EMs, local stakeholders, and elected officials once the dams failed. The clarity gained through these exercises was instrumental in the unified response to the Edenville and Sanford dam failures.

Recommendations for Jurisdictions with Dams:

- Establish regular exercise schedules, including FERC exercise requirements, and include critical stakeholders across the jurisdiction.
- Ensure exercise design is realistic and meaningful, tests critical roles and responsibilities, highlights major decision points, and provides a comprehensive assessment of how EOPs and EAPs are integrated. Review EAP threat level determinations and how these inform triggers for emergency management phased operations.
- Conduct thorough exercise reviews to identify actionable items to improve plans, clarify roles and responsibilities, and enhance relationships amongst stakeholders.

Data analysis is critical for planning and for impactful post-event analysis.

Consistent, quality data are key to any analytical analyses. The better the data, the better the results and outcomes. Data is needed before an event to enhance community analysis, inundation modeling, and capability assessments. After an incident it is important for agencies involved in data collection activities to work together to collect data in an appropriate and efficient manner to reduce duplicative efforts and preserve the "freshness" of perishable information.

Findings from Edenville/Sanford Dam Failures:

While some data on inundation modeling was likely used for the dam incident exercises conducted in 2019, the DIRR did not obtain any specifics on pre-incident modeling. Regarding data collection following the Edenville and Sanford dam failures, there were numerous challenges with collecting data about the incidents, including general inability or unwillingness to share, delays in releasing data, missing or incomplete datasets. Capturing and sharing timely data was also problematic. For example, the DIRR team was not able to collect even basic information about the flooding consequences from the dam failures such as observed flood extent and high-water marks.

Recommendations for Jurisdictions with Dams:

- Improve modeling and analysis of dam failure scenarios—including how to coordinate with State representatives to use the Decision Support System for Water Infrastructural Security Web (DSS-WISE) to understand likely consequences of dam emergencies and how to integrate the results into future planning or situational awareness products.
- Use the Resilience Analysis and Planning Tool (RAPT) to understand the attributes of at-risk populations and infrastructure in the inundation areas.
- Incorporate data analysis of dam-related emergencies in new or revised plans and assessments, such as emergency operations plans, emergency action plans, hazard mitigation plans, floodplain management plans, business continuity plans, and Threat and Hazard Identification and Risk Assessments (THIRA).
- When possible, create standardized guidelines and practices for data collection during an event. Determine in advance what data will be important and who will be responsible for collecting the data, especially when data inputs needed for comprehensive analysis are captured by multiple organizations and agencies.
- Develop data-sharing agreements in advance to avoid assumptions, issues, or misconceptions associated with the data's intended use.
- Analyze the impacts of the built environment to potential damage from dam emergencies; develop cost/benefit analysis for effective mitigation and investment strategies.

Open communications with the community are essential to explain risk and to create more effective alerts and warnings for evacuations and shelter-in-place guidance.

Educating community stakeholders businesses, community organizations serving underserved populations, and the public about potential risk will help to increase compliance with instructions to evacuate or to shelter-in-place.

Findings from Edenville/Sanford Dam Failures:

While the DIRR team did not have information on community outreach efforts to explain risk from a potential breach or failure of the local dams before the 2020 incident, this review of the response highlights key decisions made to evacuate 11,000 residents out of harm's way.

When dam failure at the Edenville dam was deemed possible, the Midland County EM, in consultation with county officials, issued a preemptive evacuation order to the downstream communities that would be impacted. When the breach occurred, Midland County Central Dispatch Authority immediately issued repeat evacuation notices.

In addition, the fire department and sheriff's office performed door-to-door notifications as a follow-up to the emergency alerts and drove emergency vehicles down streets with lights, sirens, and air horns making public evacuations announcements. The county also set up shelters at a local middle and high schools.

Recommendations for Jurisdictions with Dams:

- Develop risk communications strategies to inform the community about risk from dam emergencies using inundation modeling and analysis of community demographics. When individuals understand and believe their risk, they are more likely to prepare and more likely to take protective actions when needed.

- Create pre-scripted messages and outreach strategies based on social science research to increase compliance with alerts and warnings.[10] Map potential delays in issuing messages and include clear protocols, roles, and responsibilities in EOPs and EAPs. Test alerts and warnings platforms and messages as part of exercises.

- Ensure alerts and warnings and outreach strategies address language issues, access and functional needs, time of day, tendencies to engage in milling (the desire to corroborate risk and protective action guidance), concerns for children and pets, concerns during concurrent public health emergencies, and hesitancies around evacuating.

[10] A Guide to Public Alerts and Warnings for Dam and Levee Emergencies (nfrmp.us)

- Develop comprehensive, zoned, dam incident evacuation / shelter-in-place plans based on full- and non-breach inundation maps, GIS data, community demographics, and all risk types.

7. Conclusion

According to the American Society of Civil Engineers 2021 Report Card for America's Infrastructure, the number of high-hazard potential dams has more than doubled over the last 20 years, as development steadily encroaches on once-rural dams and reservoirs. A high-hazard rating indicates that if dam failure were to occur, the resulting consequences would likely be a direct loss of human life and extensive property damage. This Report Card also states that "officials estimate the number of deficient high-hazard-potential dams now exceeds 2,300."[11]

The Edenville and Sanford dams were classified as high hazard dams before the May 2020 failures. This event underscores that when even relatively unassuming dams fail, there can be a massive impact to the community. In a single 24-hour period, more than 4,000 structures across the region were damaged, with estimated losses of roughly $245 million.

While it is important to invest in maintenance, compliance, and mitigation for dams across the country, the events of May 19, 2020 also demonstrate the importance of investing in collaborative planning, exercises, data analysis, communicating with the public, and using watershed areas to plan across jurisdictional boundaries. Supporting local officials, emergency managers, dam owners/operators, and community members through technical assistance to build resilience for dam emergencies is an equally valuable investment to save lives.

[11] Dam Infrastructure | ASCE's 2021 Infrastructure Report Card

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